# Engineered Flowback & Analysis for Frack'd Wells

*Sept 2021*

***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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# ODSI Deliverables

1. “Engineered Flowback” – Optimize Rate without Damaging the FDR
2. Model Rates and Calculated BHPs
3. 2/3-Phase and Reservoir BBL TTA Functions
4. Fracture Dominated Region (FDR) and Matrix Properties
5. FDR Volumes and Recoverable Volumes
6. Matrix Volumes and Recoverable Volumes

# Issues with Multi-Staged, Multi-Phase Wells

- When does gas first enter the well bore?
- Stage/Cluster Flow Initiation (Surging)
- Differentially Pressured Intervals
- Different Formations
- Wellbore Residence Time above Top Stage
- Recognizing FDR Pseudo-Steady State
- Recognizing Matrix Flow Transition (Hybrid)
- Recognizing Matrix Hemi-Radial Flow

# ODSI Philosophy

1. Get as much information as you can (especially about the frac/FDR) before the well starts to produce hydrocarbons at the sand/frac face
2. Balance the need for DP to Clean-up the Well vs. Excessive Proppant Stress
3. Get a baseline on frac performance as soon as you can; try to get it twice
4. Model the rates properly
5. LISTEN to the Choke during the flowback. Mark down when you first hear free gas at the choke!
6. Monitor Reservoir Barrel Productivity
7. Only Shut-in if you have to

# ODSI Workflow – Prep Work

1. Build Wellbore Model
   - PVT (frac fluid and formation water), produced hydrocarbons
   - Flow Path/Piping with Estimated Friction/Roughness
   - Wellbore Thermals, Especially for Gas Wells
2. Review Frac Program and Replay Analysis
3. Determine Critical Unloading Velocities/Rates
4. Develop a Plan to Achieve the Well Test Objectives
5. Develop Residence Time Equations per phase splits
6. Establish Contingencies and Safety Constraints
7. Coordinate with Company Man and Well Testers to Ensure the Test is Properly and Safely Conducted

# ODSI Workflow – Flowback

1. Start the well out on a small choke (usually a 12/64”) (~ 4 hrs)
2. After a baseline evaluation of the frac has been achieved, increase the choke 2/64” (to 14/64”) (~ 4 hrs) – Continue choke walk-up if advisable
3. Determine which choke to go to after the initial choke settings, then change the choke to that and flow the well for 24 hrs (Can do a choke walk-up)
4. Choke back the well if the analysis reveals any signs of excessive stress on the proppant
5. Evaluate the drawdown/Analyze the well every 24 hours; determine if the choke can be increased without reducing the reservoir recovery
6. If the matrix begins to contribute, keep the choke constant until it can be evaluated
7. Model Rates and Calculate BHPs as frequently as possible. Use BHPs and Reservoir BBL TTA to manage the test

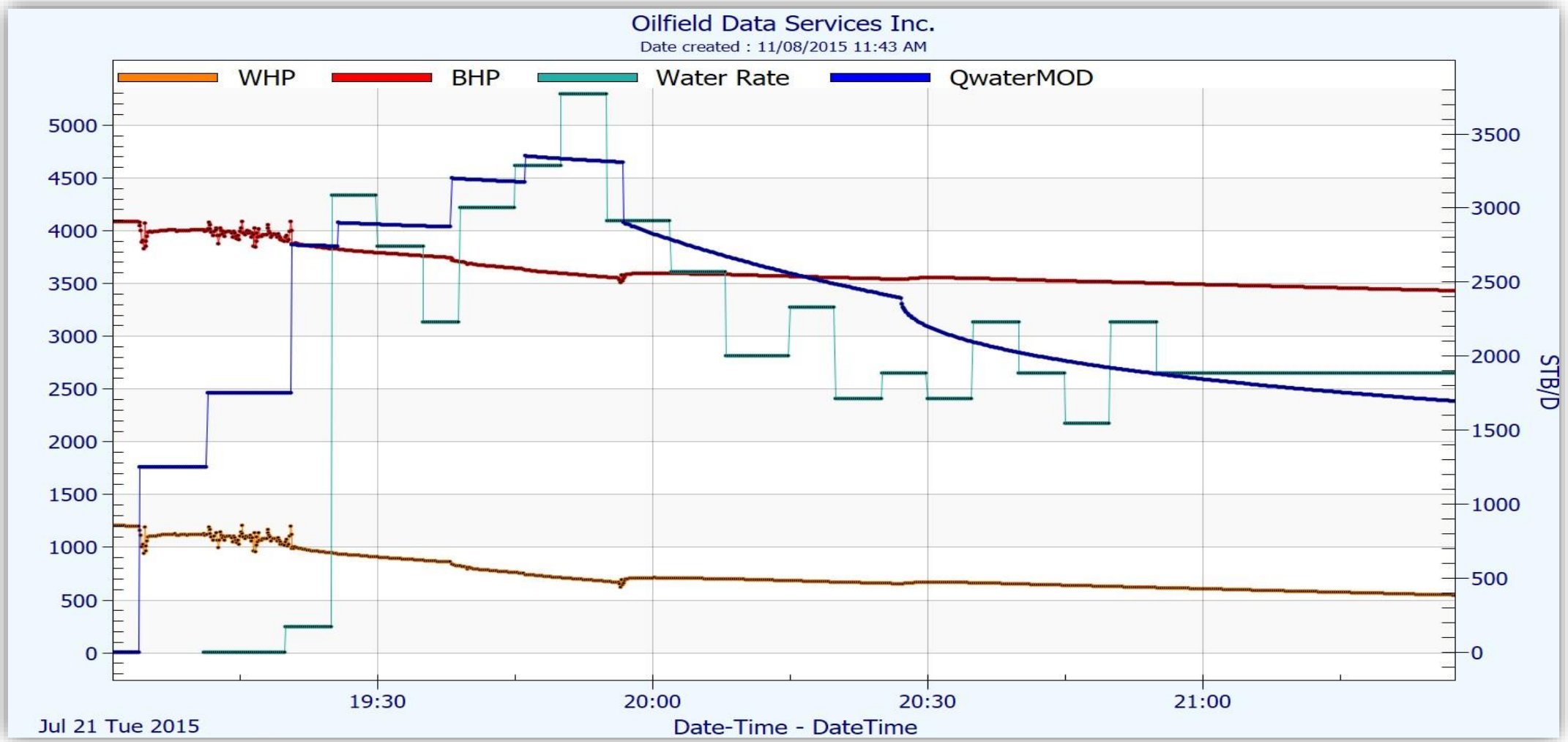
# ODSI Workflow – Quick Flowback Analysis

1. Use modeled rates and calculated BHP
2. Calculate TTA-RB
3. Use BHP and TTA-RB to determine the baseline decay and if the system is being stressed on subsequent choke increases
4. Err on the side of caution – you can always bump the choke later
5. Check Linear Plots if the Cartesian Plots do not look consistent
6. Do not try to manage the test solely on WHP once we have hydrocarbons in the well bore

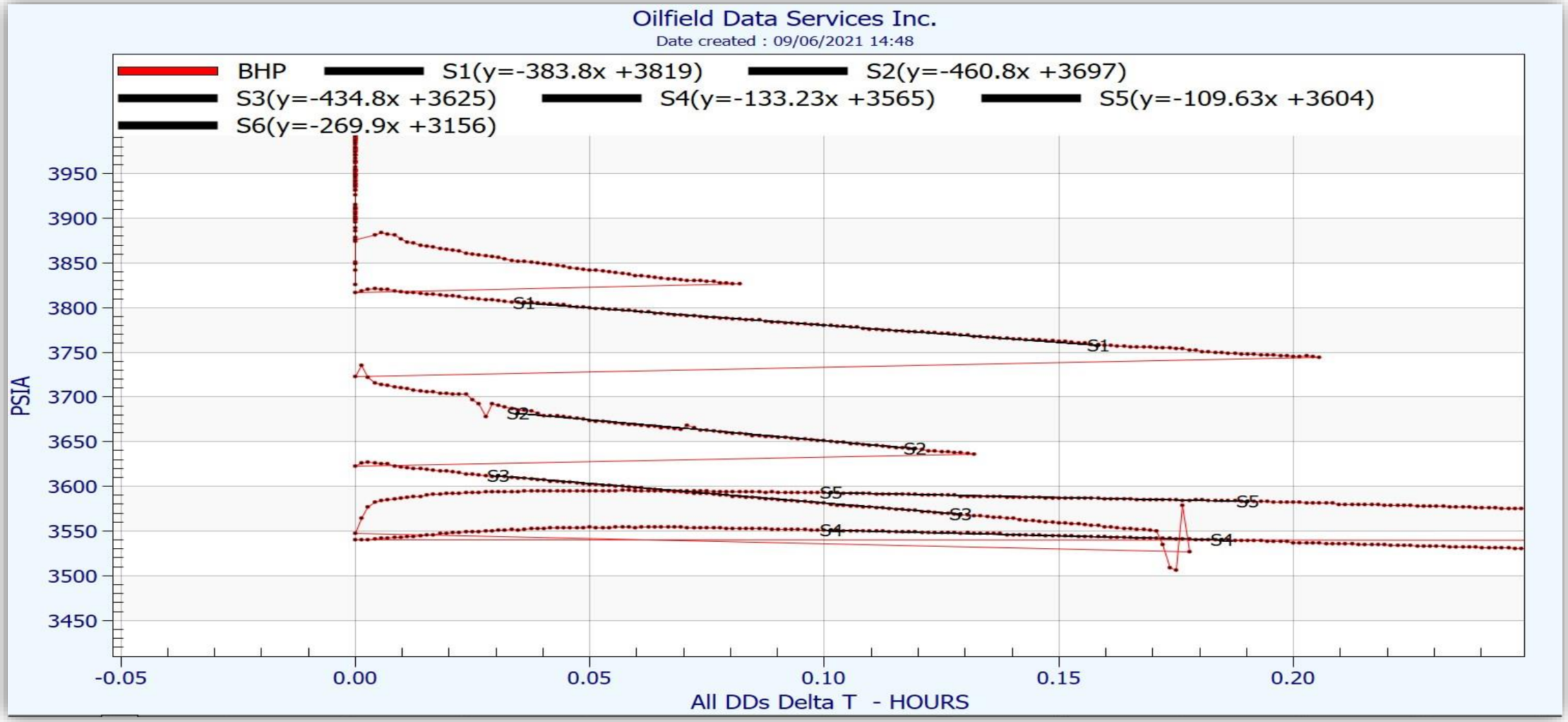
# Flowback Choke Adjustments

On-The-Fly Analysis Plots

# WHPs, BHPs and Rates – Initial Flowback – Well 3



# BHPs from Choke DTs – Well 3



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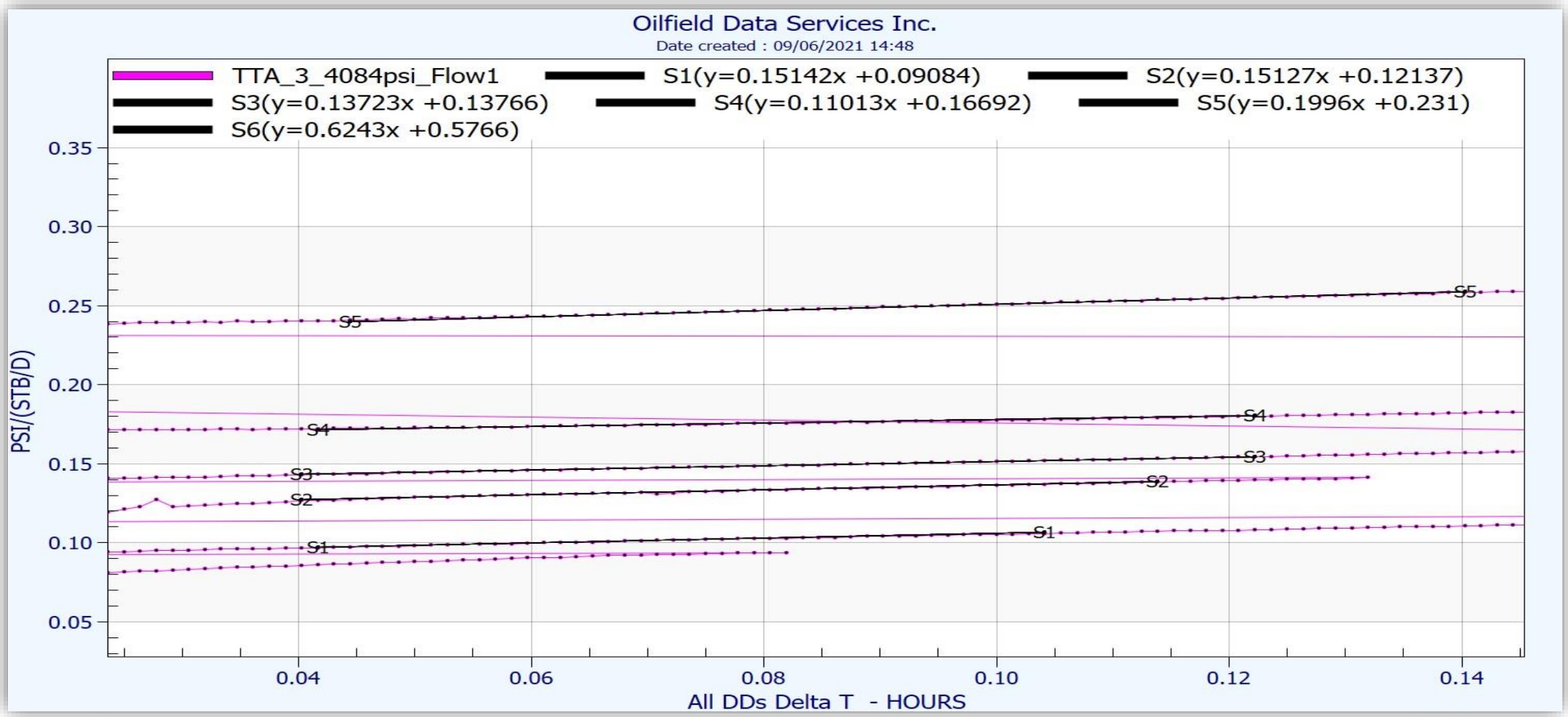
# TTA-RB with Choke DTs – Well 3



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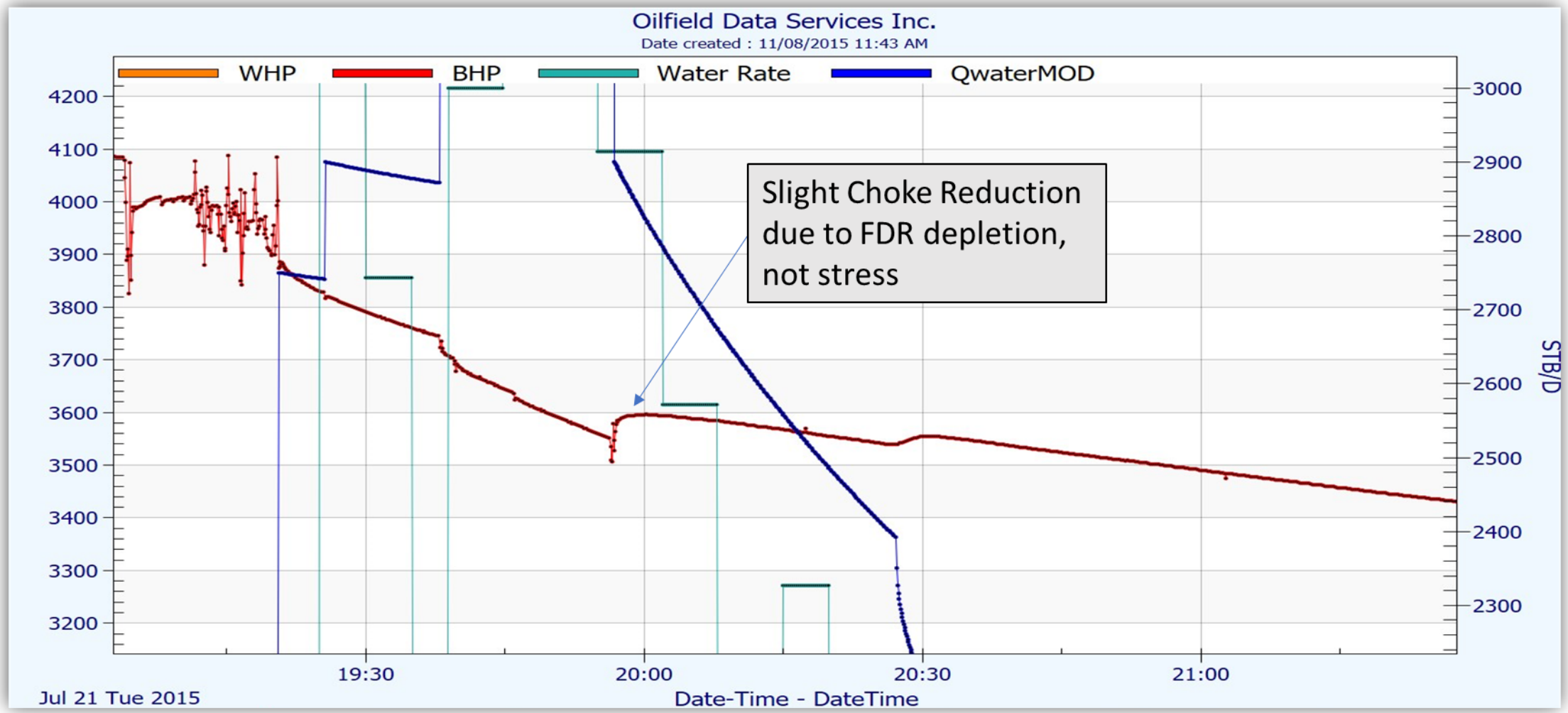
# Well 3 Flowback – BHP Zoom



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# Well 3 Flowback Management

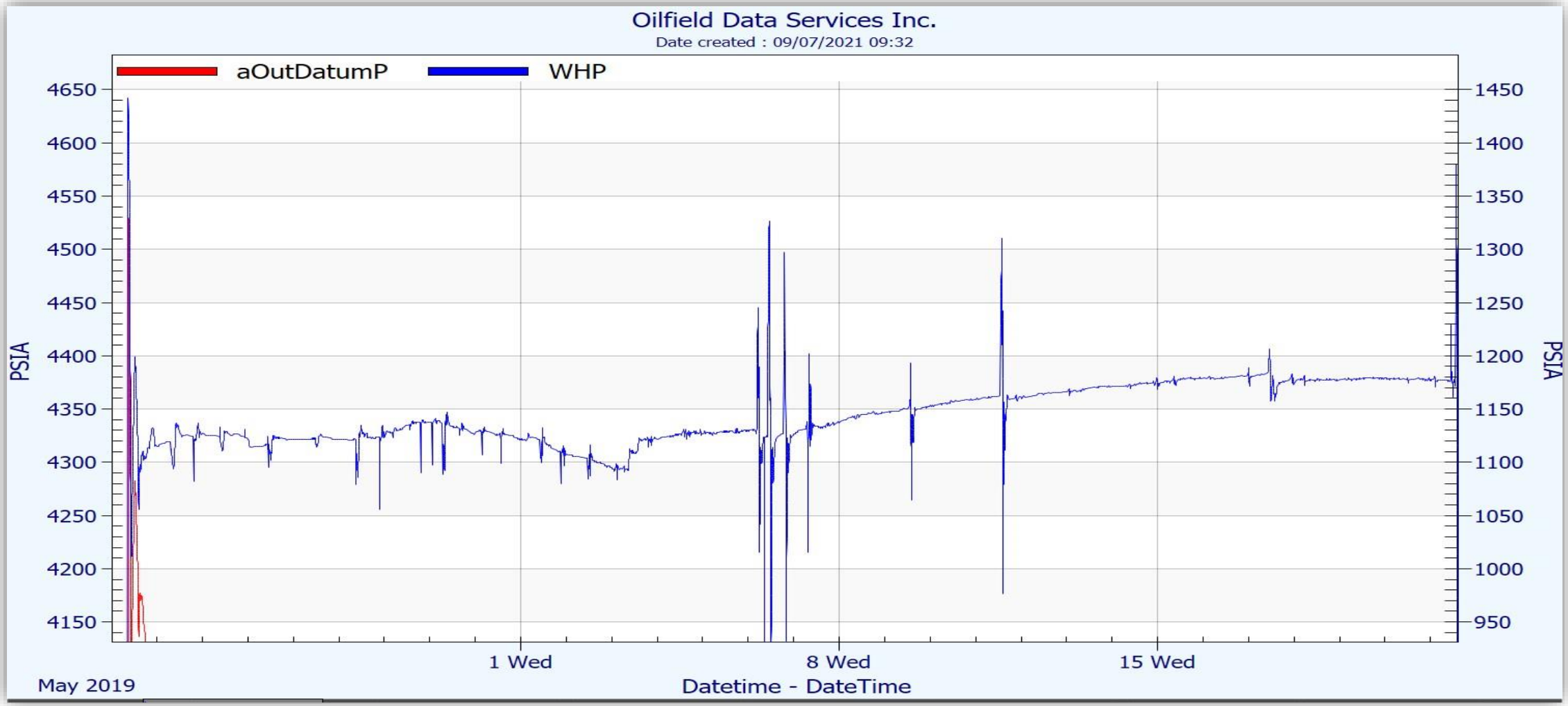
1. Good Frac Baseline
2. Stable or improving performance with time (Linear BHP/TTA Slopes)
3. Frac Region Depleting too Quickly
4. Choked Back to Gather Matrix Data, not Due to Stress
5. Gathered Enough Data to Evaluate the FDR and Matrix Potential

Note: Single Phase Liquid Throughout (Easy BHP Calculation)

# Importance of Rate Modeling and WHP-> BHP Conversion

Do Not Analyze WHP Data once Gas Enters the Well Bore!

# 3-phase Horizontal WHPs – Can Surface Data be Analyzed?



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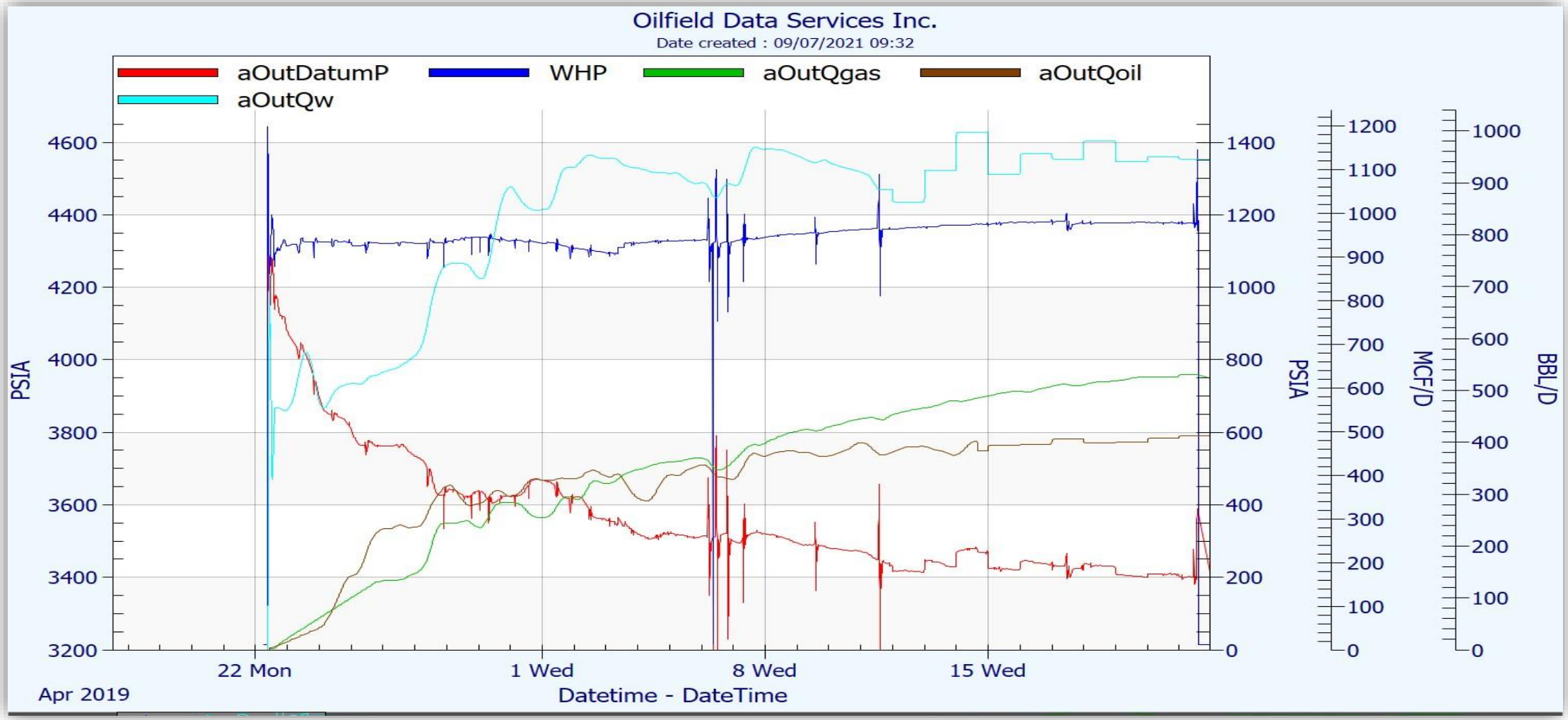
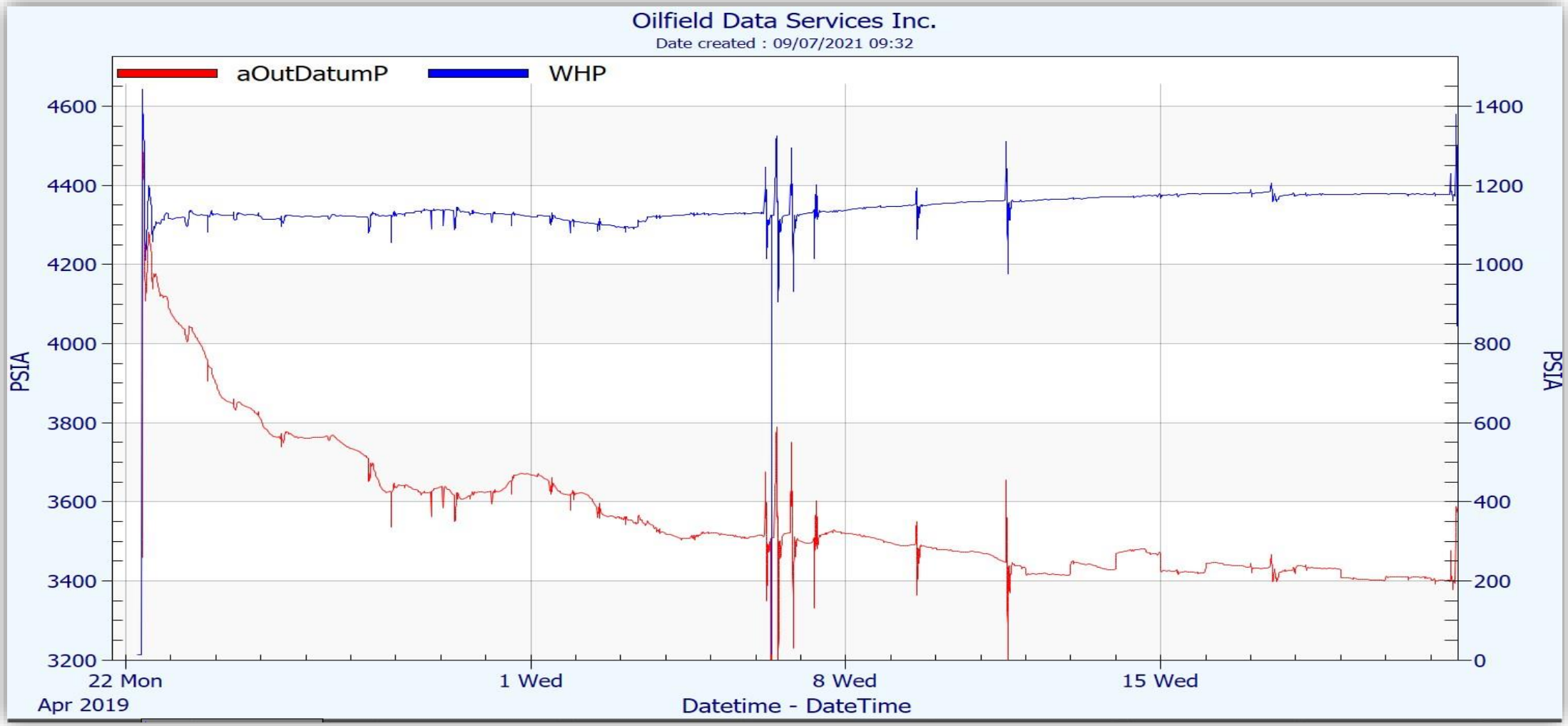
# ODSI's 3-Phase flow model (Wellbore Physics + Good PVT)

- Developed on high-rate wells in the North & Norwegian Sea in 2017
- Applied to Frac Flowbacks with shockingly good results
  - **Accurate BHPs!!!**
- With Accurate BHPs (and modeled rates), most Frac Flowbacks can be analyzed for **minimum recoverable oil and/or gas volume**
- Usually, the first 6 weeks of a well's production life can be analyzed to determine the **total likely recoverable oil and/or gas volume**

# 3-phase Horizontal WHPs – Rate Modeling and Conversion to BHP



# Comparison of Measured WHP and Calculated BHP



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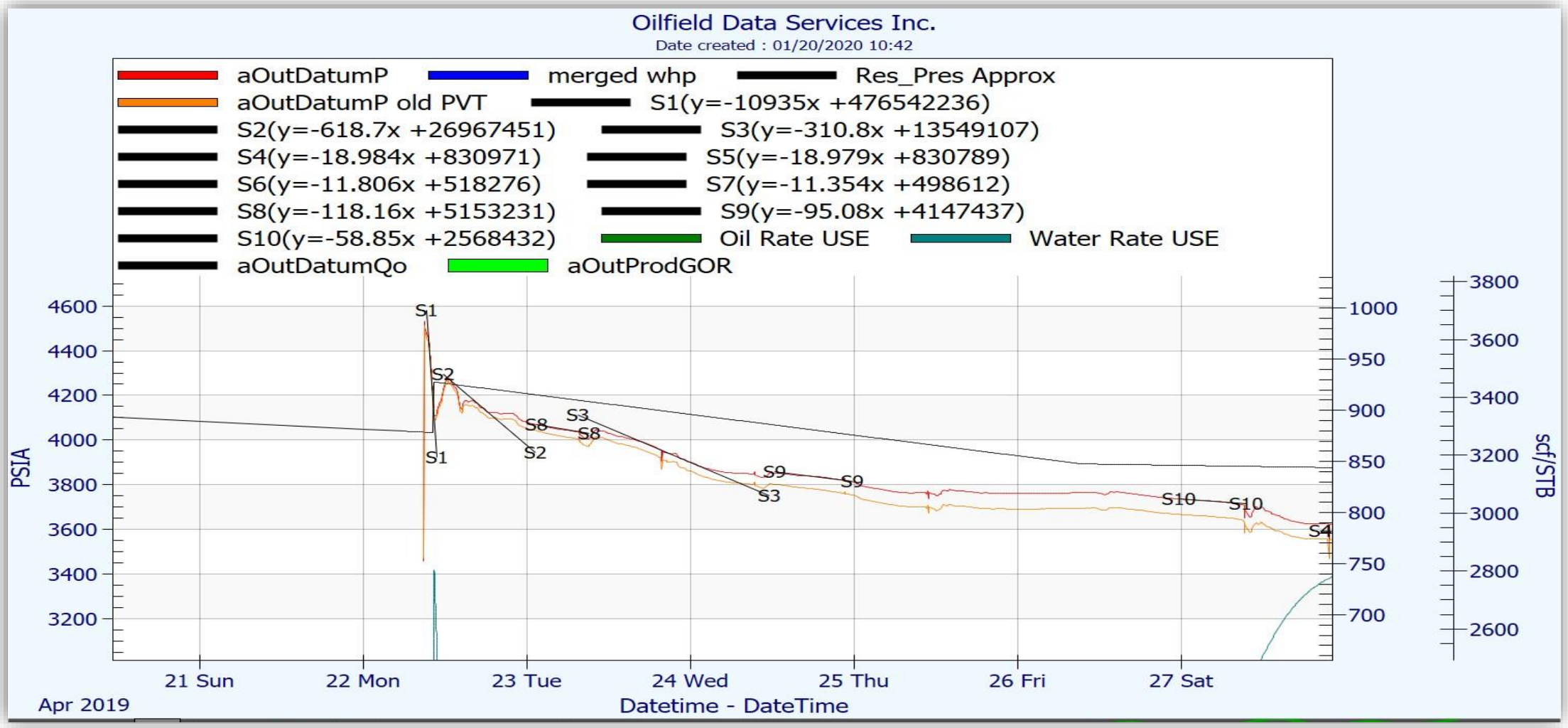
# Frac and Matrix Analysis Slopes – Finding the Signal in the Noise!



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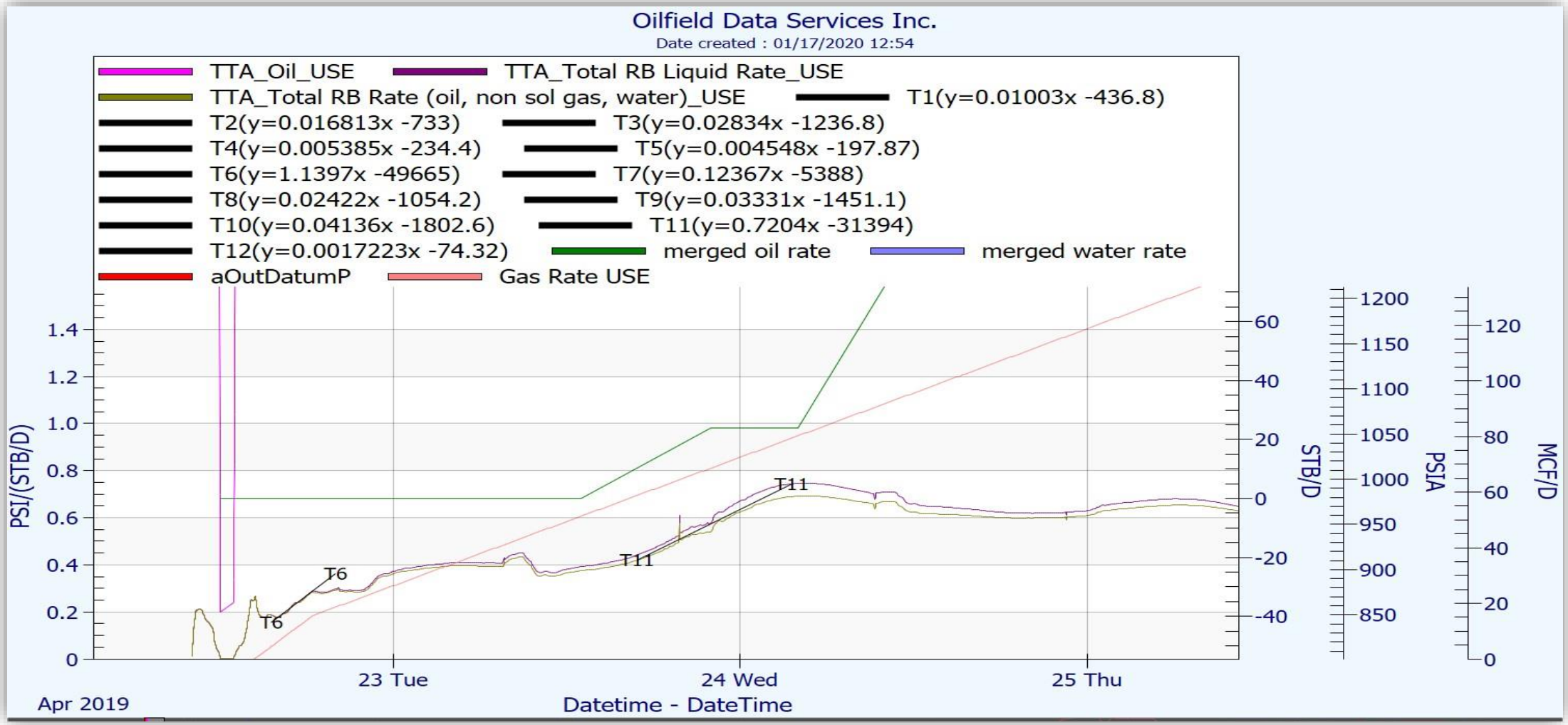
# Track TTA-RB and Find Points of Stability



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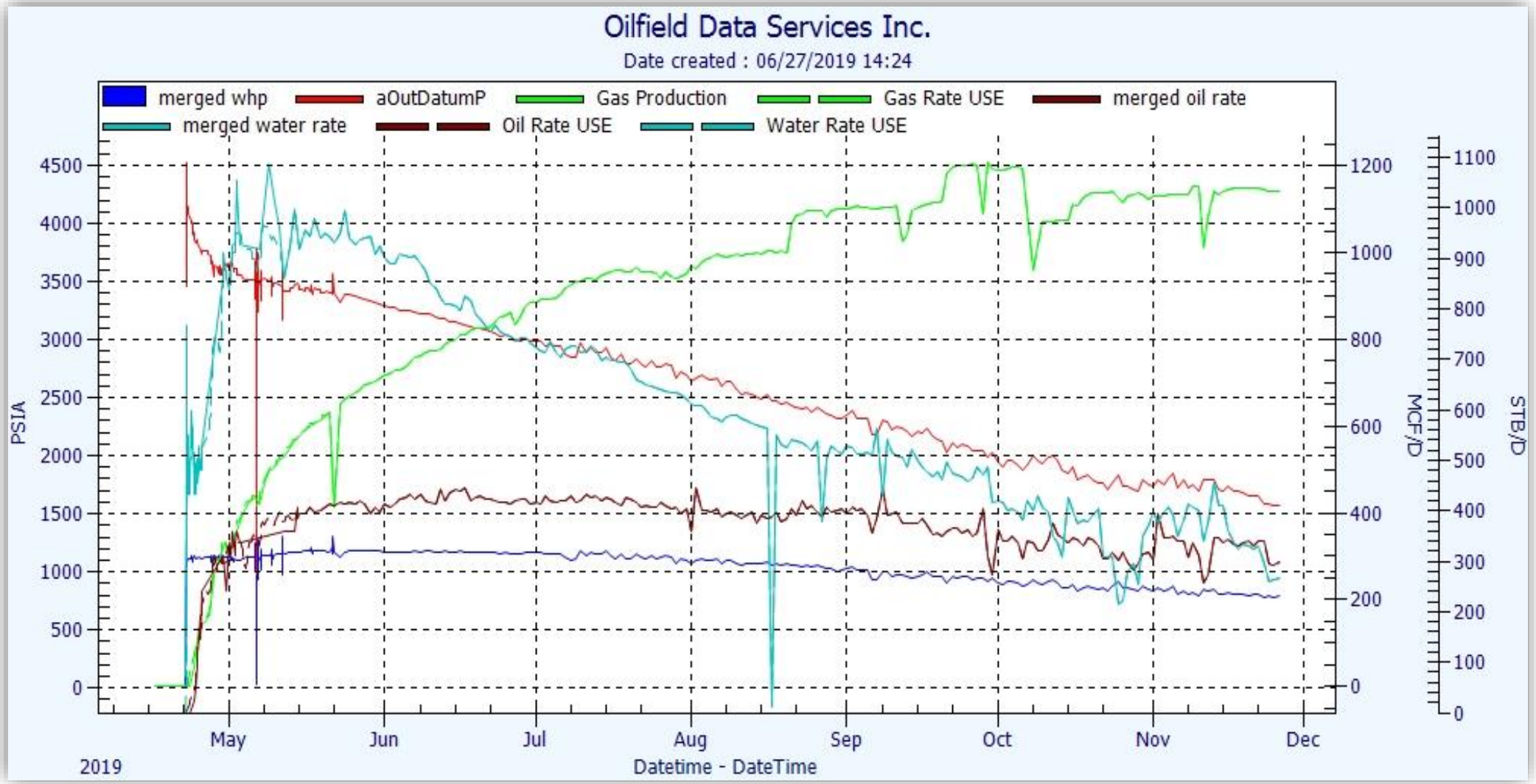
# Modeled Rates w Calc BHP at the Heel – Extended Production



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# Additional Analysis Provided by ODSI: Frac'd Well PTA



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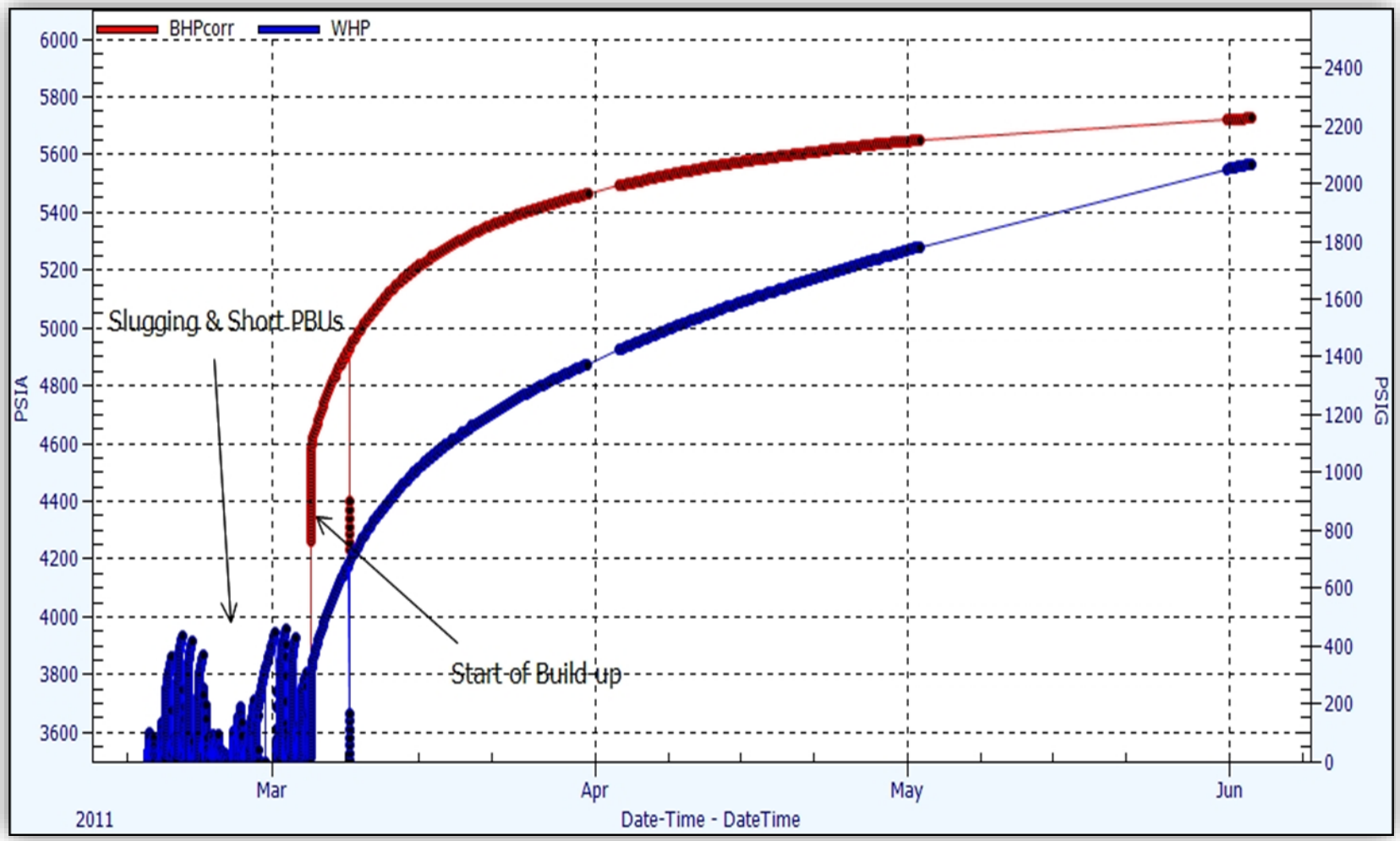
# What can the data tell you?

1. Fracture Permeability and/or Conductivity
2. Matrix Permeability
3. Effective Fracture half-length (global for multiple fracs)
4. Effective Frac-dominated Volume
5. Is there a change in the continuous fluid in the frac/matrix system (i.e. is the pad creating a water block)?
6. Observed Drainage Volume (long-term flow)

# Frack Flowback & PBU



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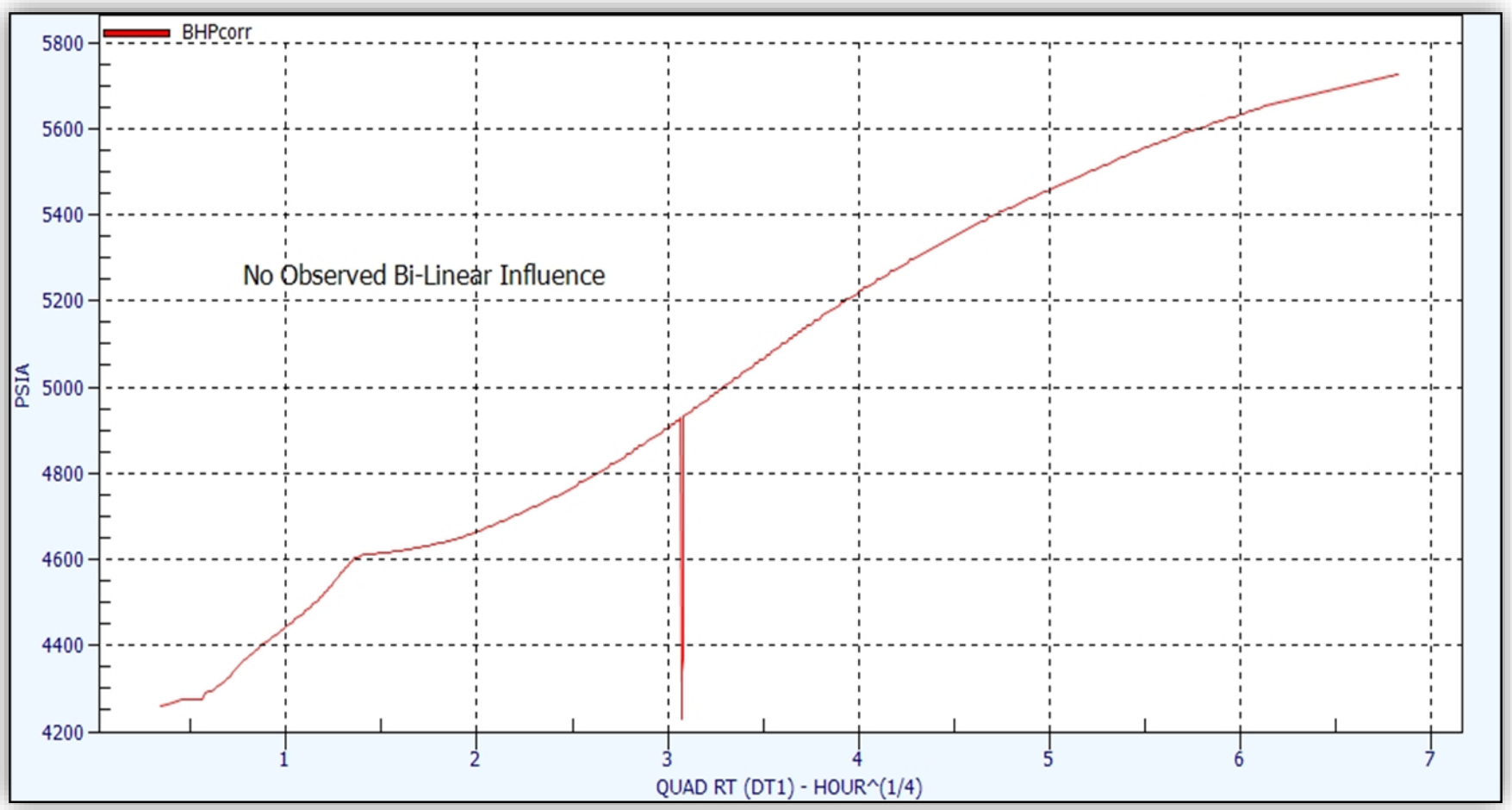
# Diagnostic Plots

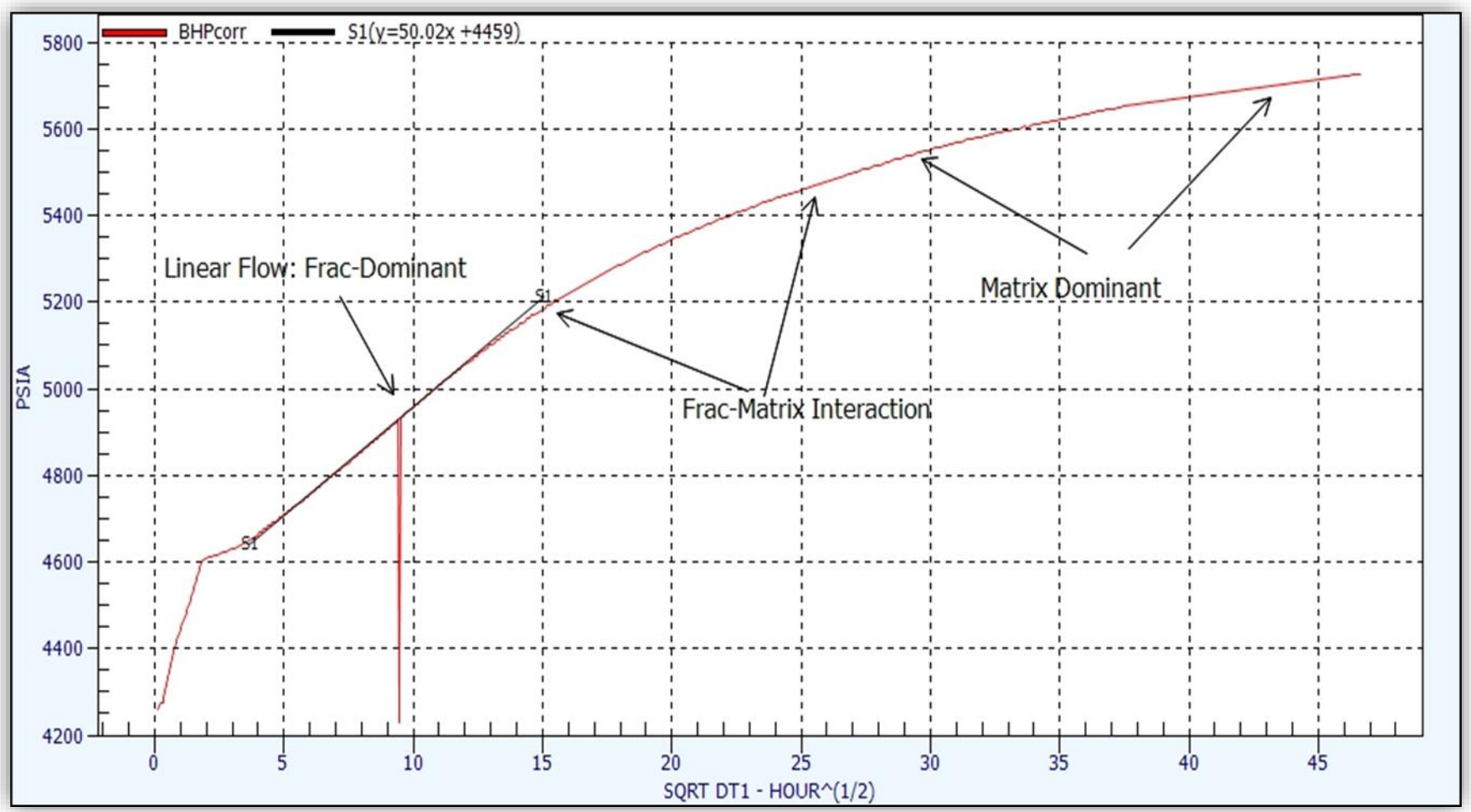
## Make Them ALL – Don't just rely on one plot

1. Cartesian plot of BHP and Rates
2. Semi-log plots of individual build-ups and drawdowns
3. Derivative plots
4. Linear Flow Plot: Square-root of delta time plots
5. Bi-linear Flow Plot: ¼-root of delta time plots

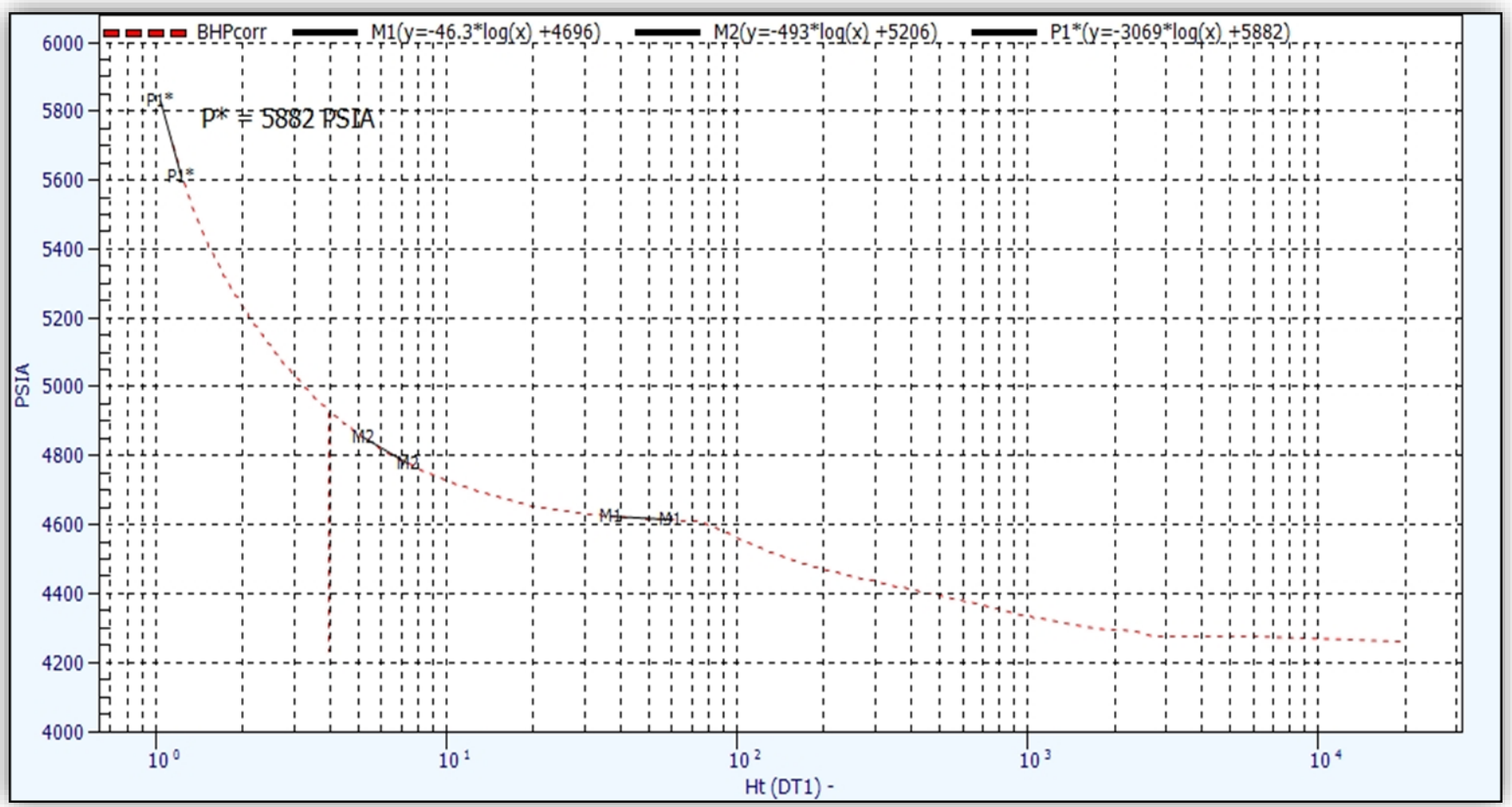
# Bi-Linear Plot of PBU



# PBU – SQRT (DT) Plot – Linear Plot



# Horner Plot - PBU



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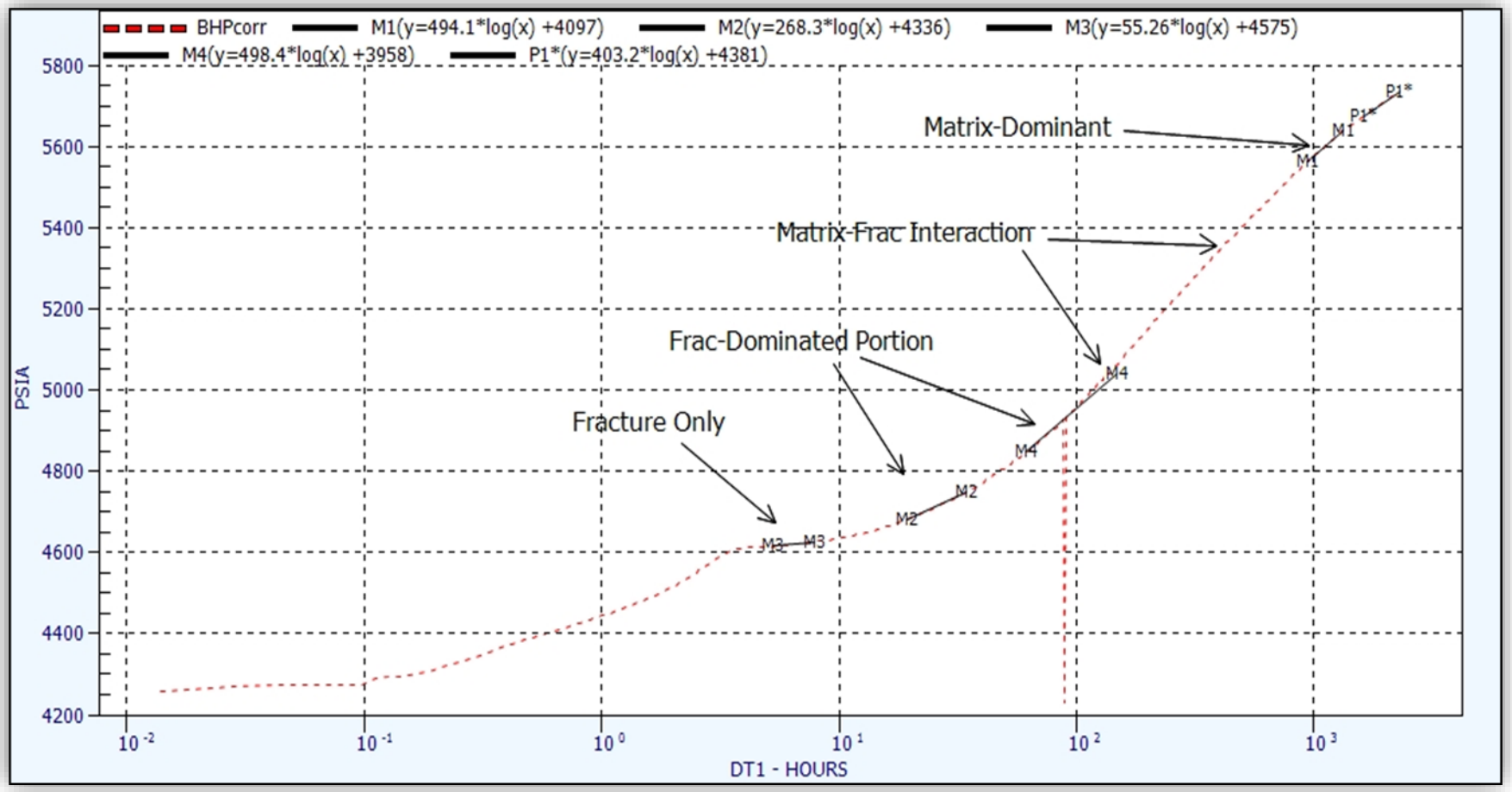
# Semi-log Plot - PBU



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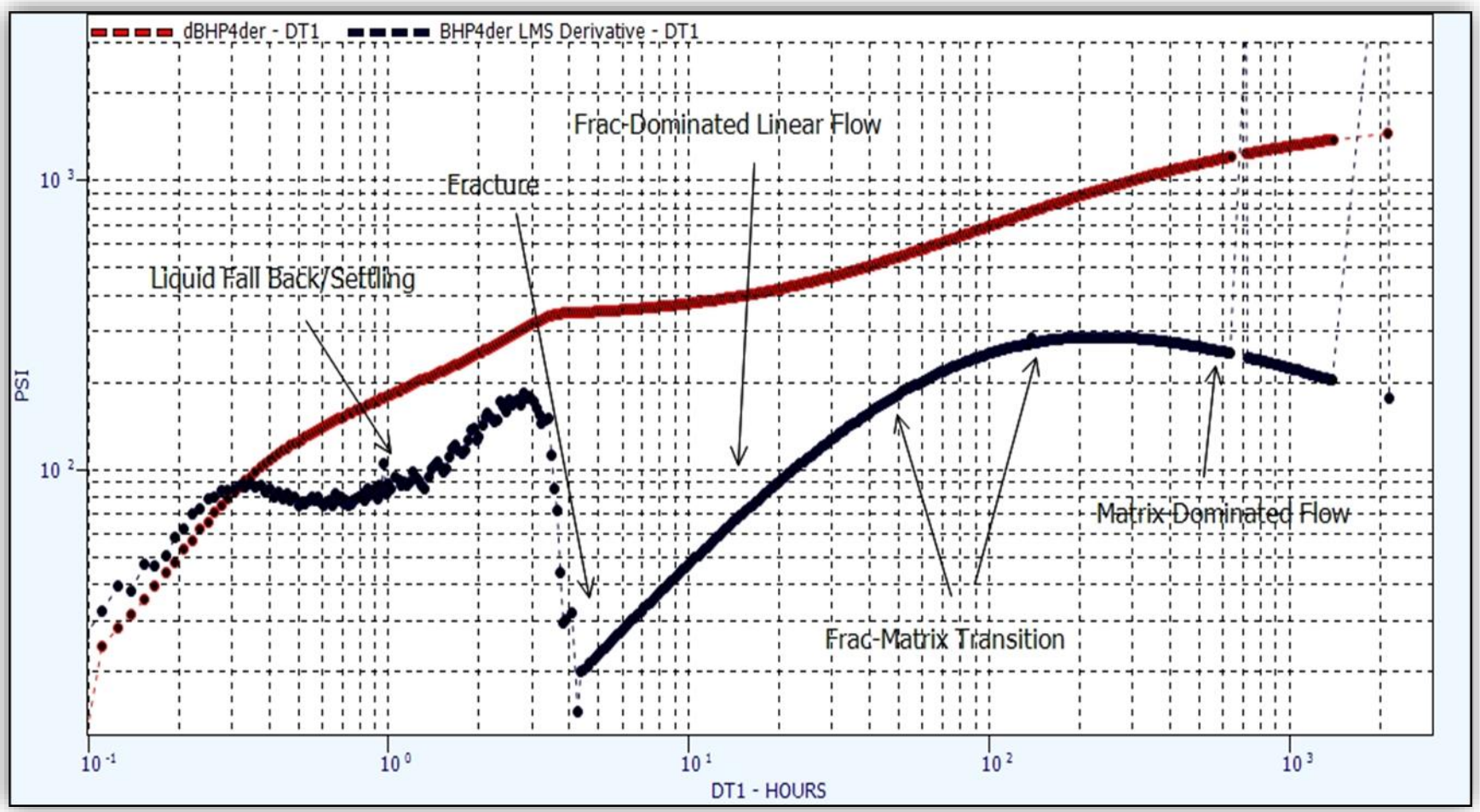
# Derivative Plot - PBU



# Well Test Analysis - Conclusions

- Fracture Perm: 1.8 md (quite bad)
- Formation Perm: 0.20 md
- Frac Extension: 250 feet from WB
- Frac Dominated Volume: 390K Res BBL
- Observed Reservoir Volume: 2.46 MM Res BBL
- Potential Recovery: 1.9 BCF of Gas

**Note: Large Water Block is Preventing Significant HC Contribution**

# Additional Analysis Provided by ODSI: Decline Analysis

# Decline Analysis - Definitions

- **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)

# The Four Flowing MBAL/EBAL Calculations

## Conventional Decline Analysis

- **Conventional SLD**: Hydraulically Connected Potential Elastic Energy, assuming infinite water drive
- **Conventional Vc**: Hydraulically Connected Potential Elastic Energy, assuming expansion/compaction drive

## TTA Decline Analysis

- **TTA-SLD**: Mobile Connected Apparent HC Volume, assuming infinite water drive
- **TTA-Vc**: Mobile Connected Apparent HC Volume, assuming expansion/compaction drive

# Connected & Mobile HC Volumes

- Observed connected and mobile volumes were evaluated from the flowback data using two methods:
  - Conventional Decline Analysis
    - Using the oil phase/rates only
  - Total Reservoir Barrel Rate Decline Analysis
    - Using total liquid rate in reservoir barrels

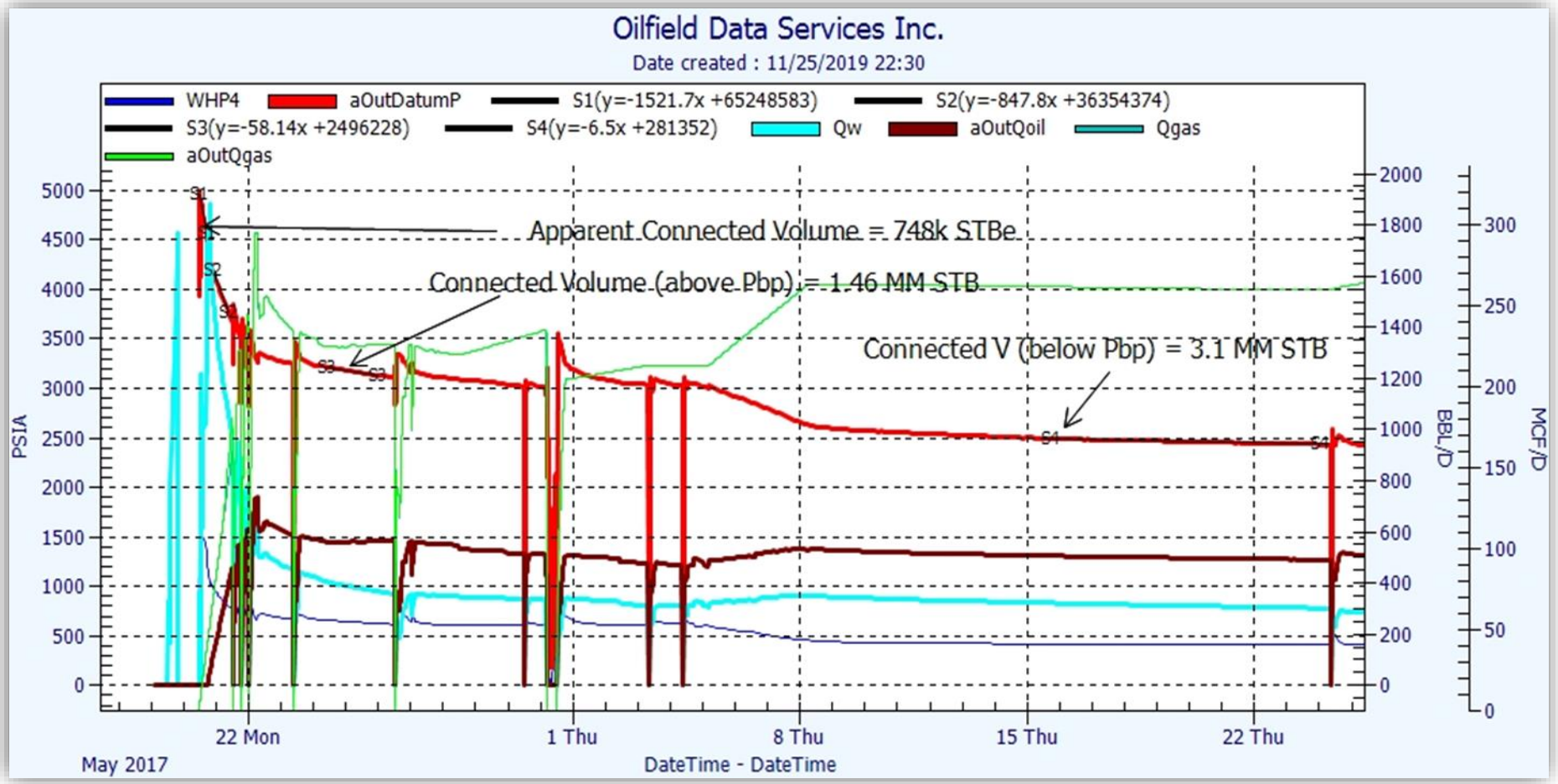
- Both methods were fairly consistent with each other and provided similar results

- Note: TTA function (relative inverse productivity) was used to evaluate observed mobile volumes

$$TTA = \frac{P_{initial} - P_{wf}}{Rate}$$

# Frac'd Horizontal Example –Connected Volumes

## (S1 = Water, S3 = Above Pbp, S4 =Below Pbp)



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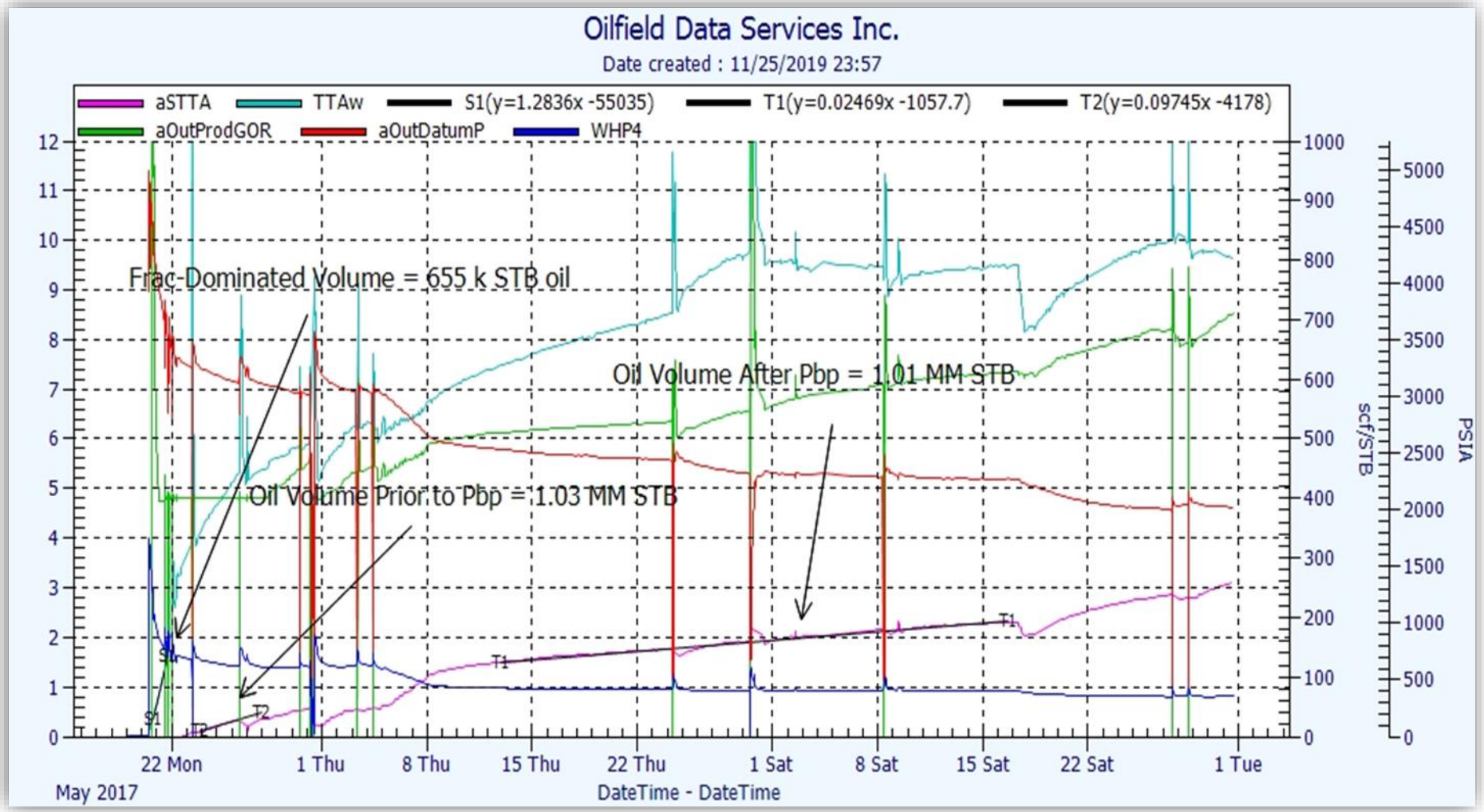
# Frac'd Horizontal Example – Mobile Volumes



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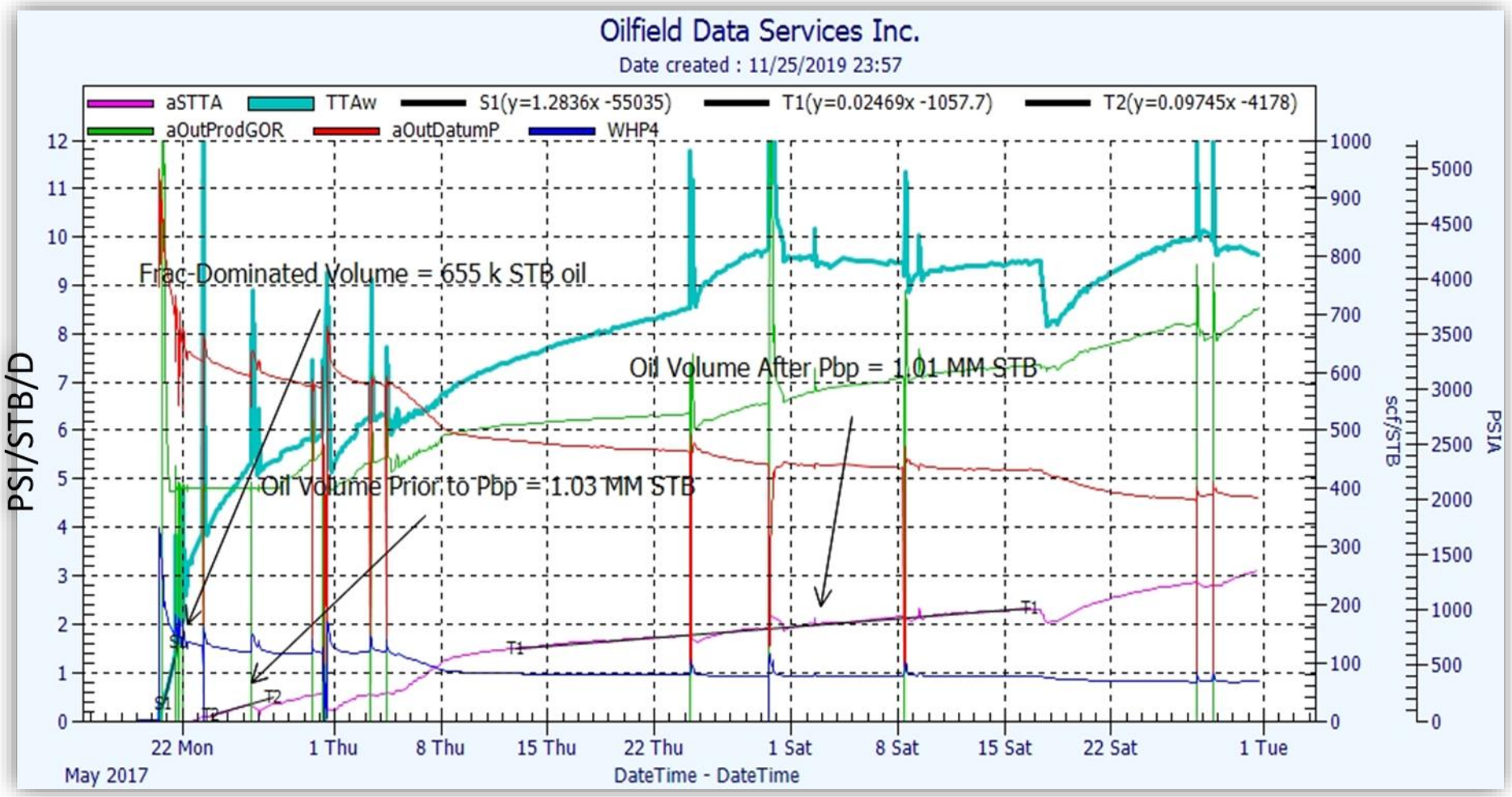
# Frac'd Horizontal Example – Mobile Frac Volume



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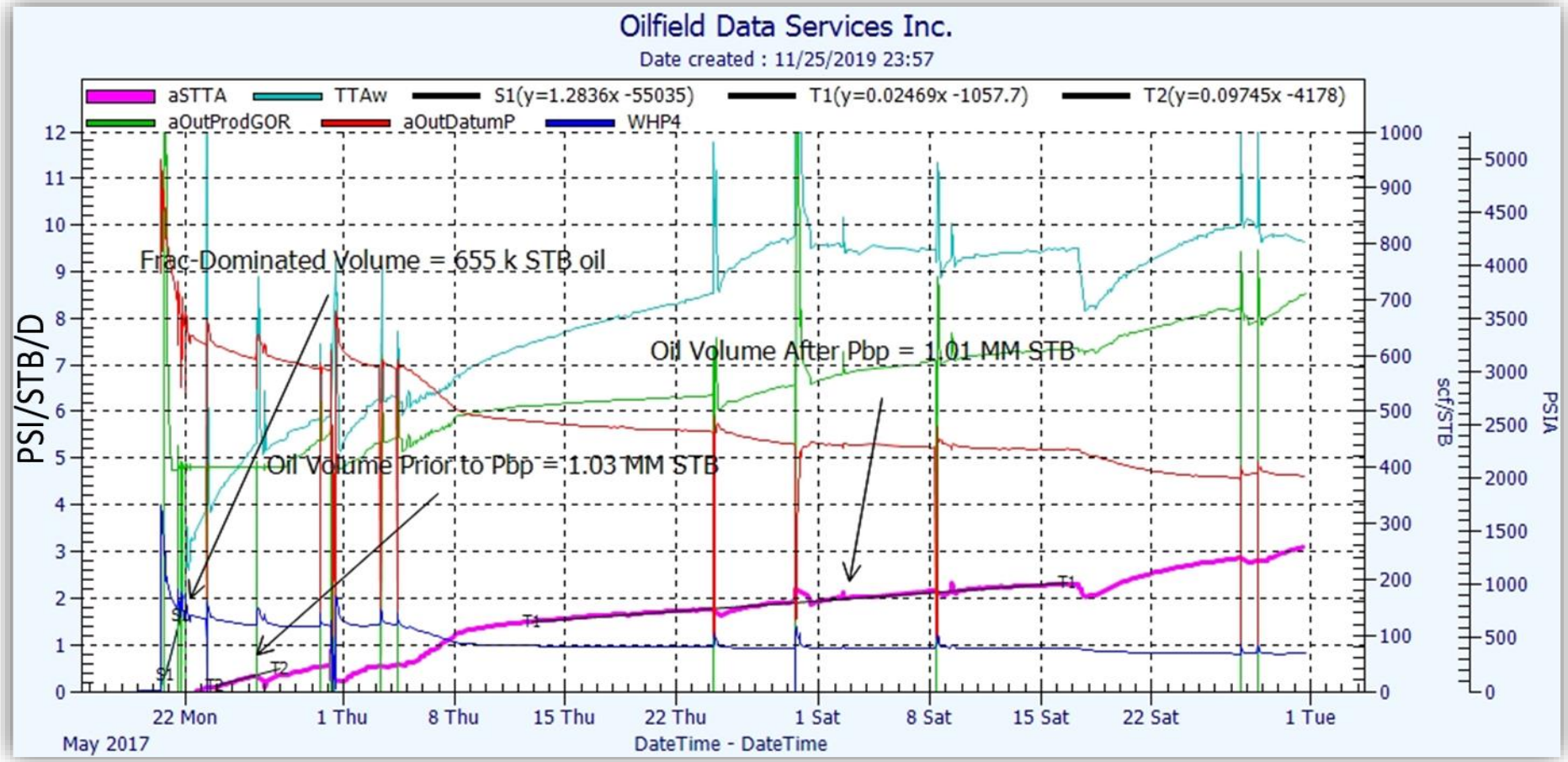
# Frac'd Horizontal Example – Mobile Oil Volumes Before & After the BHP drops below Pbp



# Frac'd Horizontal Example – Apparent Volumes

- **Connected Volumes:**
  - Frac-Dominated Volume = 748,000 STB Oil
  - Matrix + FDV (Above Pbp) = 1.46 MM STB Oil
  - Matrix + FDV (Below Pbp) = 3.10 MM STB Oil
    (solution gas drive effect)

- **Mobile Volumes:**
  - Frac-Dominated Volume = 655,000 STB Oil
  - Matrix + FDV (Above Pbp) = 1.03 MM STB Oil
  - Matrix + FDV (Below Pbp) = 1.01 MM STB Oil

Vconn Matrix + FDV (above Pbp) – Mobile FDV = 1,460,000 STB – 655,000 STB = 805,000 STB Oil

Mobile Matrix + FDV (above Pbp) – Mobile FDV = 1,030,000 STB – 655,000 STB = 375,000 STB Oil

# Frac'd Horizontal Example – Min Recoverable Volume

- Based on PVT: Recovery for Depletion = 18%
- Solution Gas Drive Boost = 3.1 MM STB/1.46 MM STB = 2.12
- No Observed Mobile Volume Decrease after BHP drops below Pbp
- Adjusted RF = 18% x 2.12 = 38.2% (of Mobile FDR)

- Based on the FDV, the proximity of the above & below Pbp Additional Volume, the PVT of the fluid and the decay of oil rate due to gas bypass, the recovery of the well can be determined
- For this well: Minimum Recoverable = (655,000)x 38.2% = 250,000 STB Oil

# Frac'd Horizontal Example – Probable Recoverable Volume

- FDR Min Recovery = 250,000 STB (add to Matrix Rec.)
- Remaining Connected Volume (total) = 805,000 STB Oil
- Remaining Mobile Volume= 337,000 MM STB Oil
- Non-Mobile (yet) Connected Volume = 468,000 STB Oil
  - Based on PVT: Recovery for Depletion = 18%
  - Solution Gas Drive Boost = 3.1 MM STB/1.46 MM STB = 2.12
  - Adjusted RF = 38.2% (of Remaining Mobile Volume)
  - No adjustment in RF for Non-Mobile Connected Volume
- Additional Recoverable Volumes:
  - Mobile: 129,000 STB Oil
  - Non-Mobile (yet): 84,000 STB Oil
  - For this well: **Probable Recoverable = 462,000 STB Oil**

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