Engineered Frac'd Well Flowbacks & Reservoir Evaluation

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. Pre-flowback Equipment & Setup inspection
2. “Engineered Flowback” – Optimize Rate without Damaging the FDR
3. Modeled Rates and Calculated BHPs
4. 2/3-Phase and Reservoir BBL TTA Functions
5. Fracture Dominated Region (FDR) and Matrix Properties
6. FDR Volumes and Recoverable Volumes
7. Matrix Volumes and Recoverable Volumes

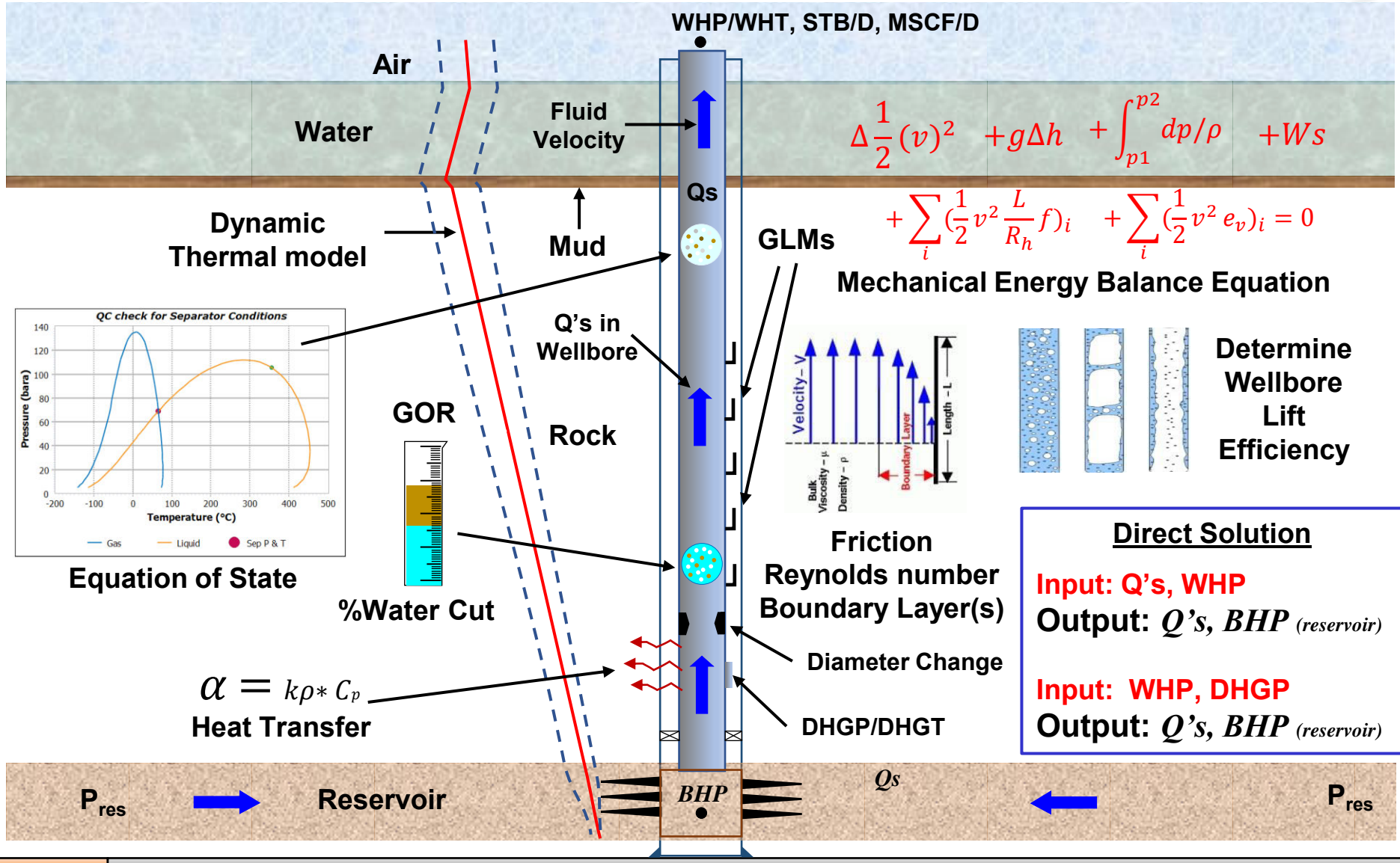
ODSI Philosophy

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. Do you very best to 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 and adjust CK appropriately
7. Only Shut-in only if you have to

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

- Developed on high-rate wells in the North & Norwegian Sea in 2017
- ODSI's Wellbore Model accounts for PVT and phase-thermal changes in the wellbore
- Applicable to frac flowbacks and multiphase flow with exceptionally good results providing **accurate BHP's**
- Once flow rates are modeled and BHP's calculated, most frac flowback data 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 (with matrix contribution)**

ODSI's Wellbore Solution, 1, 2, & 3-Phase



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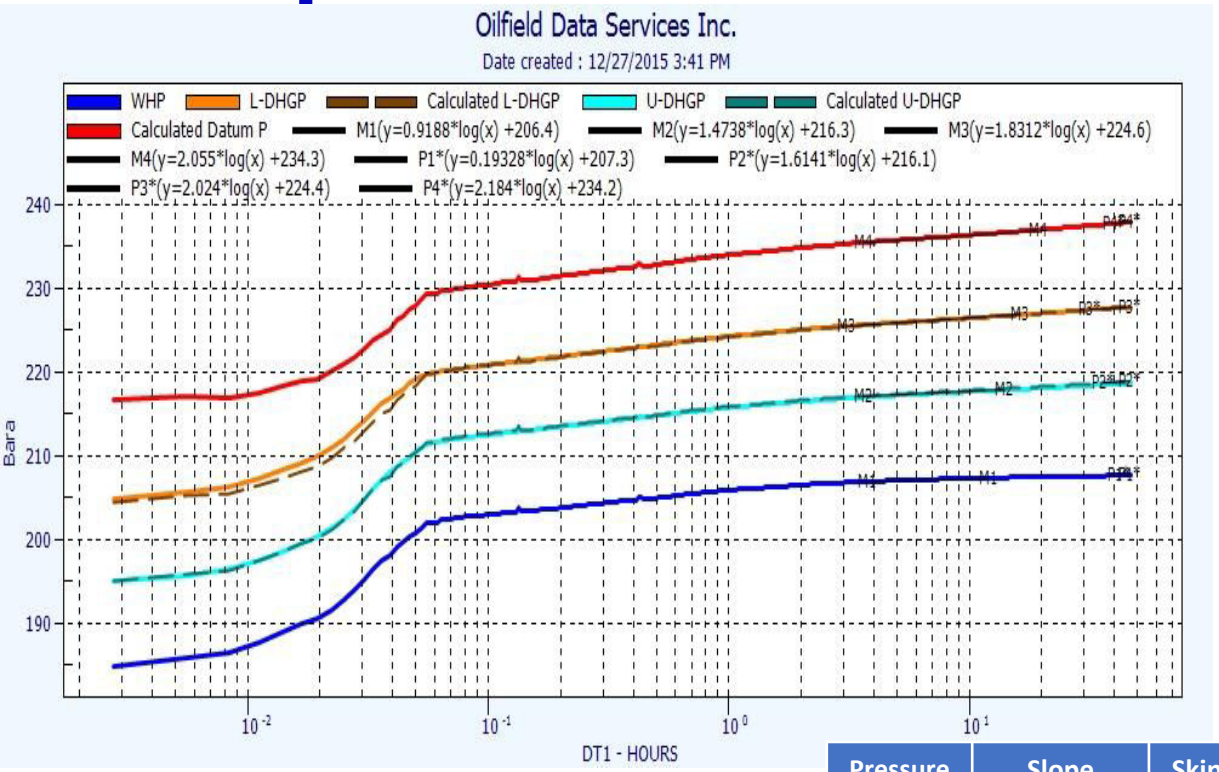
Importance of mid-completion BHP



PTA was performed on:

- WHP
- Upper DHGP
- Lower DHGP
- **Calculated BHP**

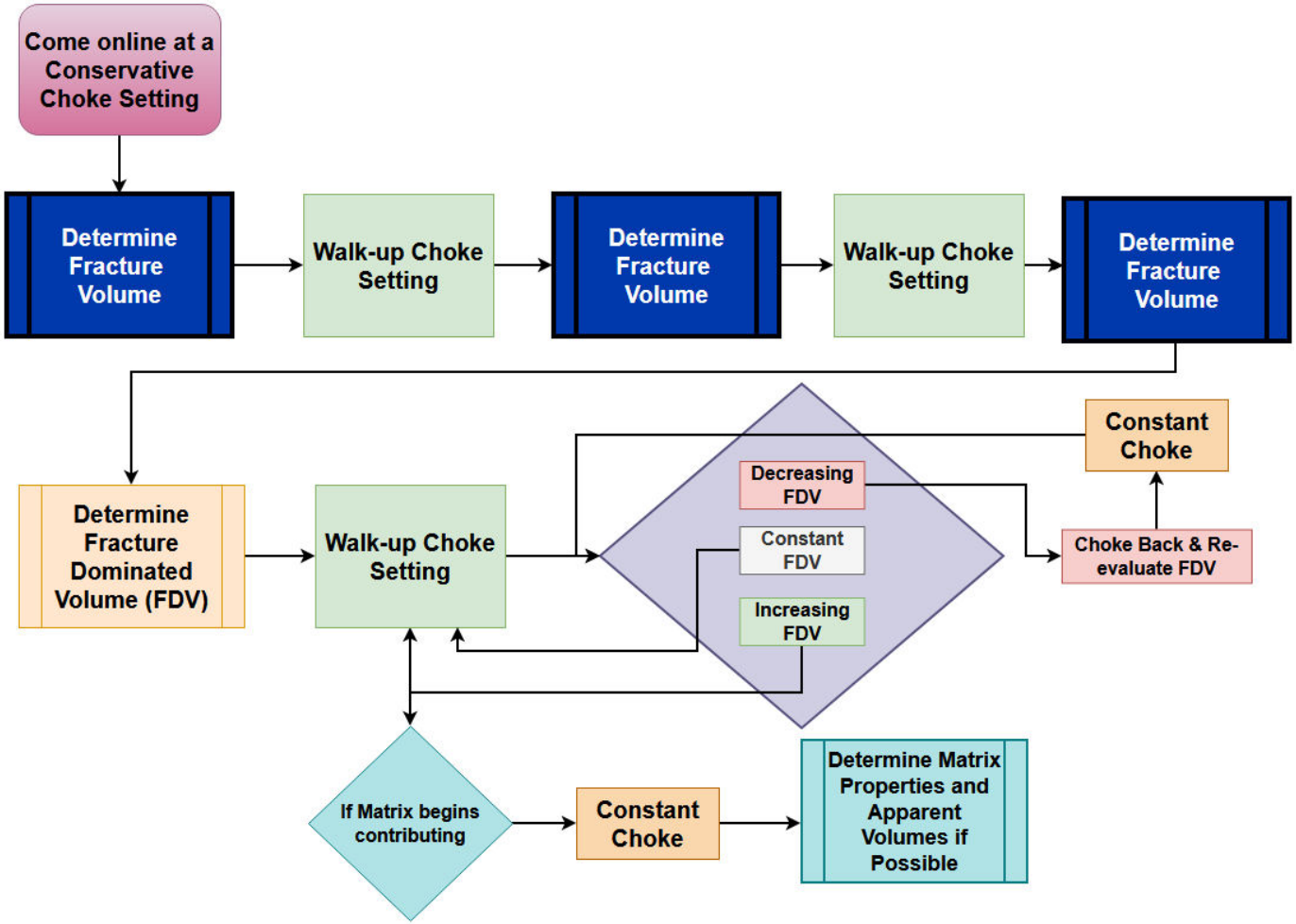
Pressure	Slope (bar/cycle)	Skin	DP Skin (bar)	Perm (md)	Kh (md-m)	P* (Bara)	ROI (m)
WHP	0.92	**20.8**	16.8	**361**	8329	**207.9**	1221
U-DHGP	1.47	**10.5**	13.4	**222**	5109	**220.9**	974
L-DHGP	1.83	**6.4**	10.3	**175**	4044	**230.5**	880
BHP	2.06	**3.6**	6.4	**154**	3541	**240.8**	837

Failure to use valid BHP for the analysis leads to overestimation of skin & perm and underestimation of reservoir pressure!

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 Conducted Properly and Safely

ODSI Workflow – Flowback Process Example



Model Rates and Calculate BHPs as frequently as possible <u>throughout the process</u>

Use BHPs and Reservoir BBL TTA to manage the test

ODSI Workflow – Flowback Example

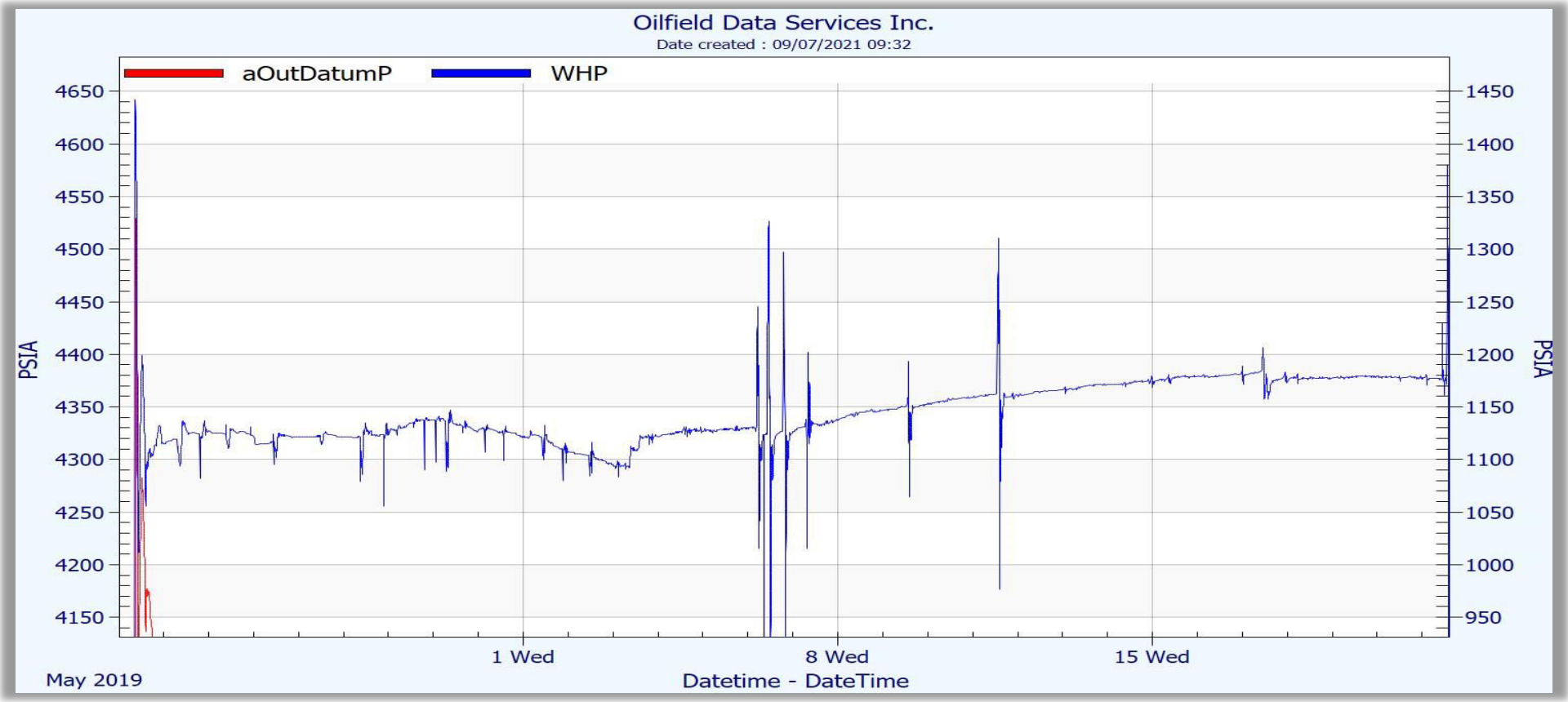
1. Bring the well online on a conservative choke (usually a 12/64”)
2. After a baseline evaluation of the frac has been achieved (typically about 2-4 hrs), increase the choke by 2/64” (to 14/64”) (~ 4 hrs)
3. Continue choke walk-up if advisable (as evaluated from the data)
4. Determine the maximum FDR choke (Until matrix contribution begins), then change the choke to that setting and flow the well for 24 HRS. (Can do a choke walk-up)
5. Choke back the well if the analysis reveals any signs of excessive stress on the proppant
6. Evaluate the drawdown/Analyze the well every 24 hours; determine if the choke can be increased (determine if the FDV is constant or increasing)
7. If the matrix begins to contribute, keep the choke constant until it can be evaluated
8. Model Rates and Calculate BHPs as frequently as possible. Use BHPs and Reservoir BBL TTA to manage the test

ODSI Workflow – Quick Flowback Analysis

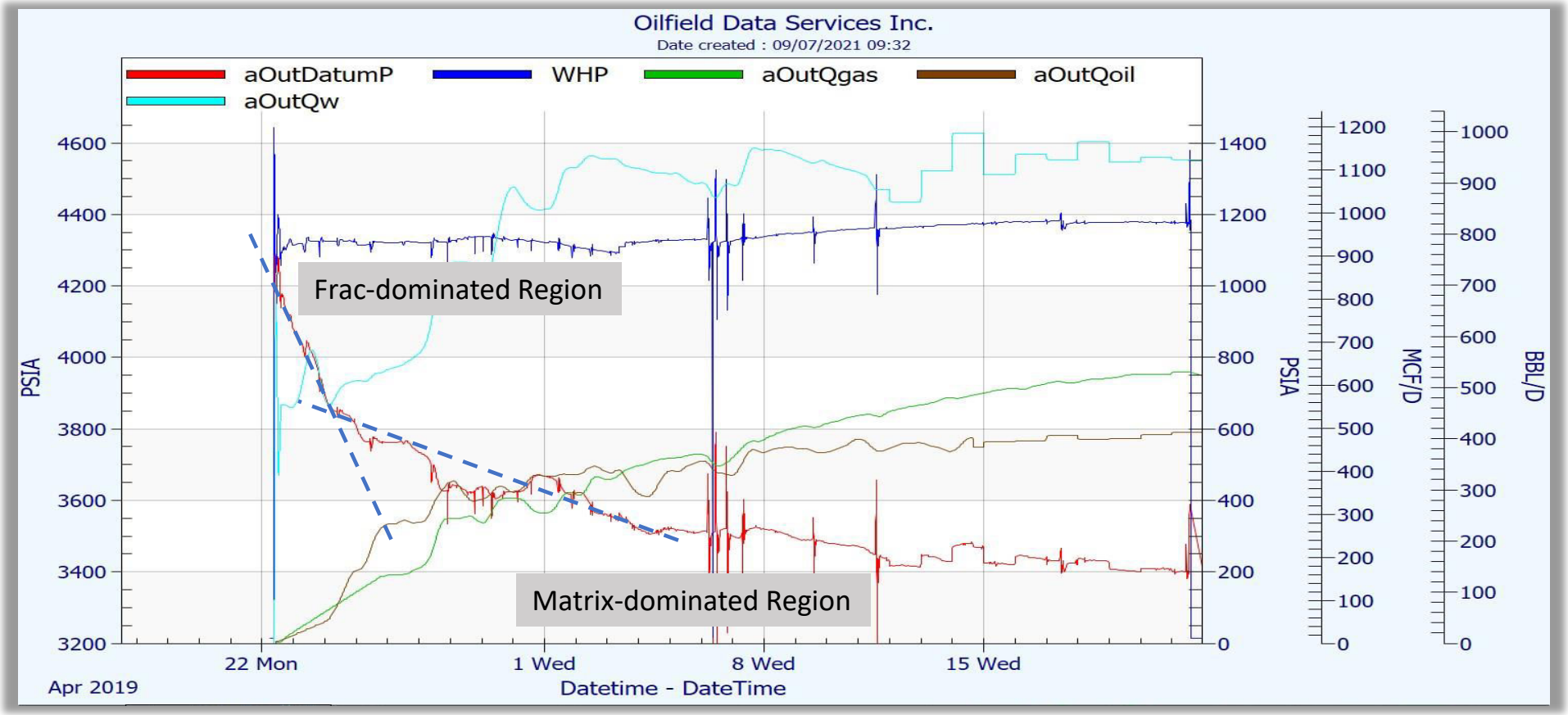
1. **USE MODELED RATE AND CALCULATED BHP**
2. Calculate TTA-RB
3. Use BHP and TTA-RB to determine the baseline decay and if the system is being stressed on subsequent choke increases
4. Err on the side of caution – you can always bump the choke later
5. Check Linear Plots if the Cartesian Plots do not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

Frac Flowback Example 1: Calculated BHP

Example 1:
3-phase Horizontal WHPs – Can Surface Data be Analyzed?

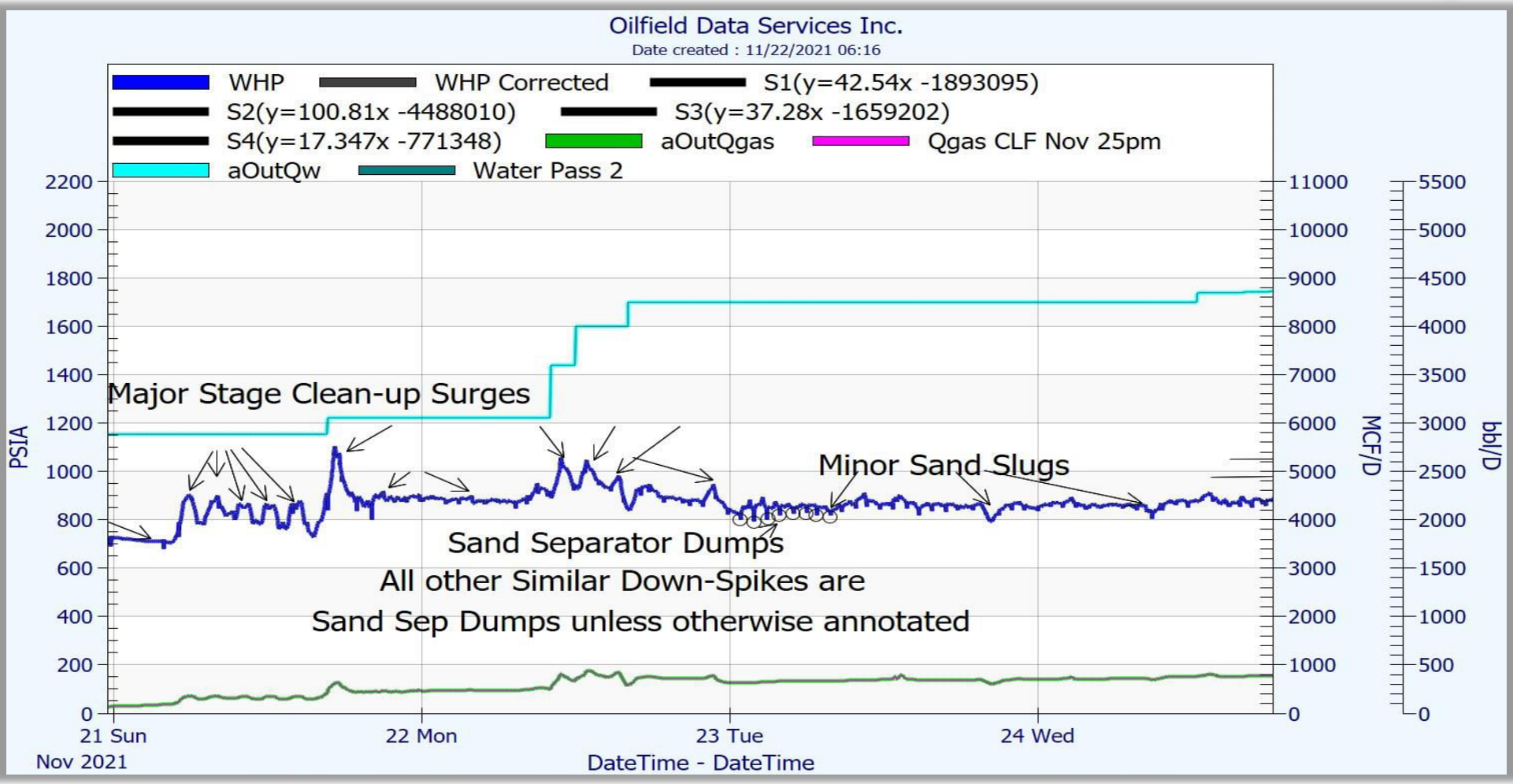


Example 1:
3-phase Horizontal Well Example:
Modeled Production Rates and Calculated BHP



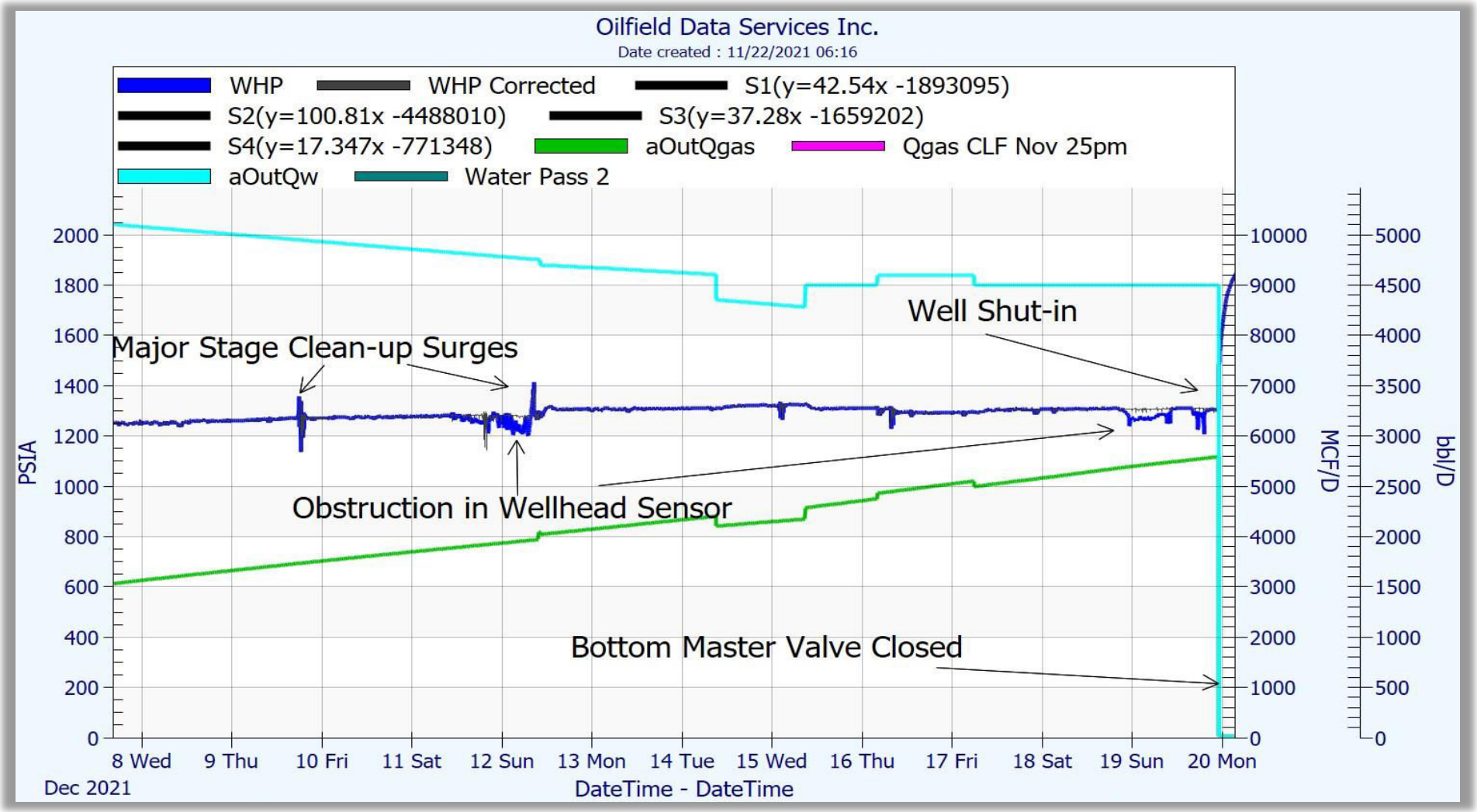
Frac Flowback
Example 2:
Analyzing WHP & BHP

Example 2: Minor & Major Frac Stage Cleanups



- Perf/stage clean-up surges are observed as spike ups in the WHP
- Longer (1-2 hrs long) dips in WHP are caused by water slugs and sand slugs

Example 2: Major Stage Cleanup Surge & Obstruction at Wellhead Sensor



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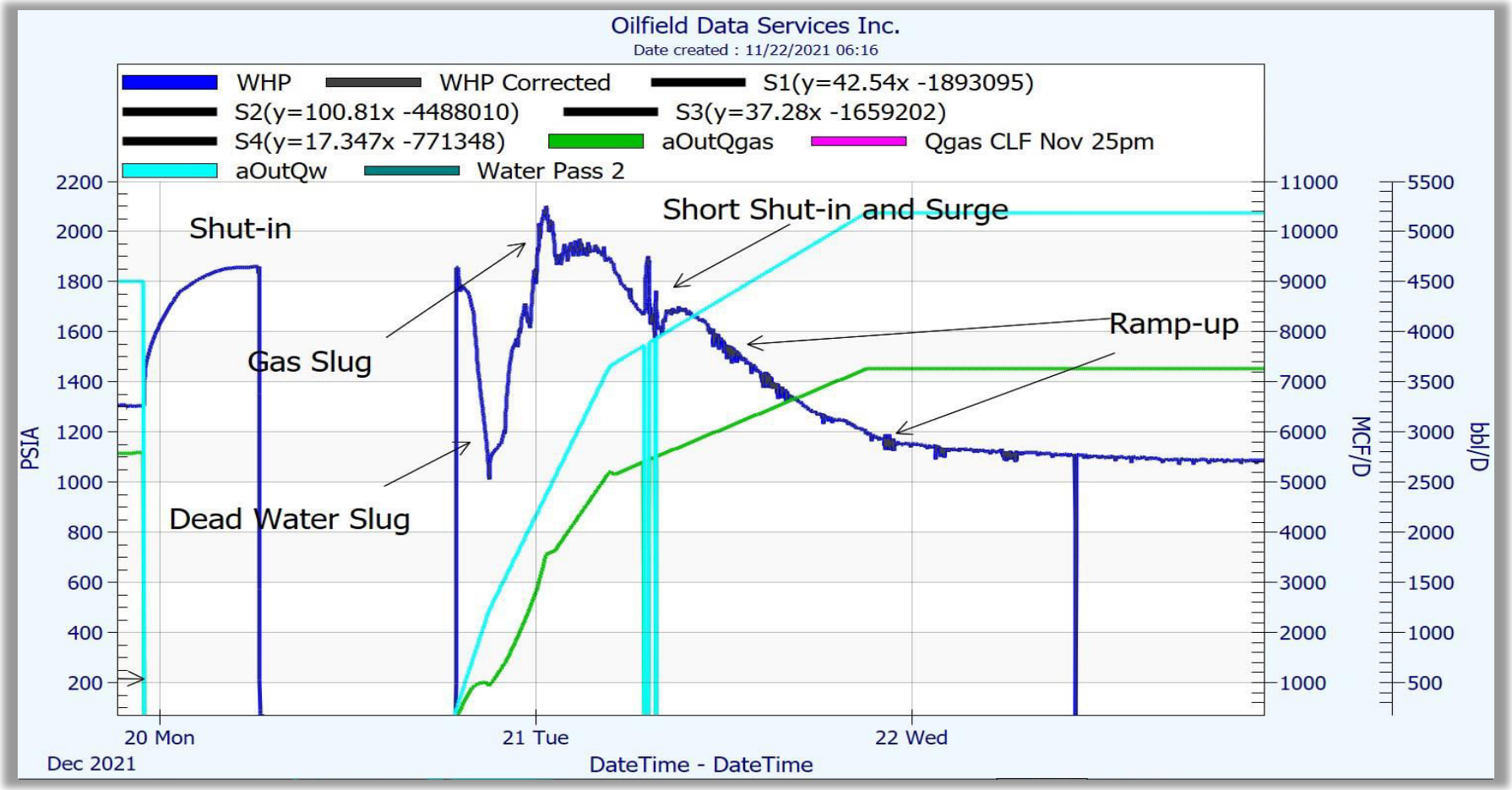
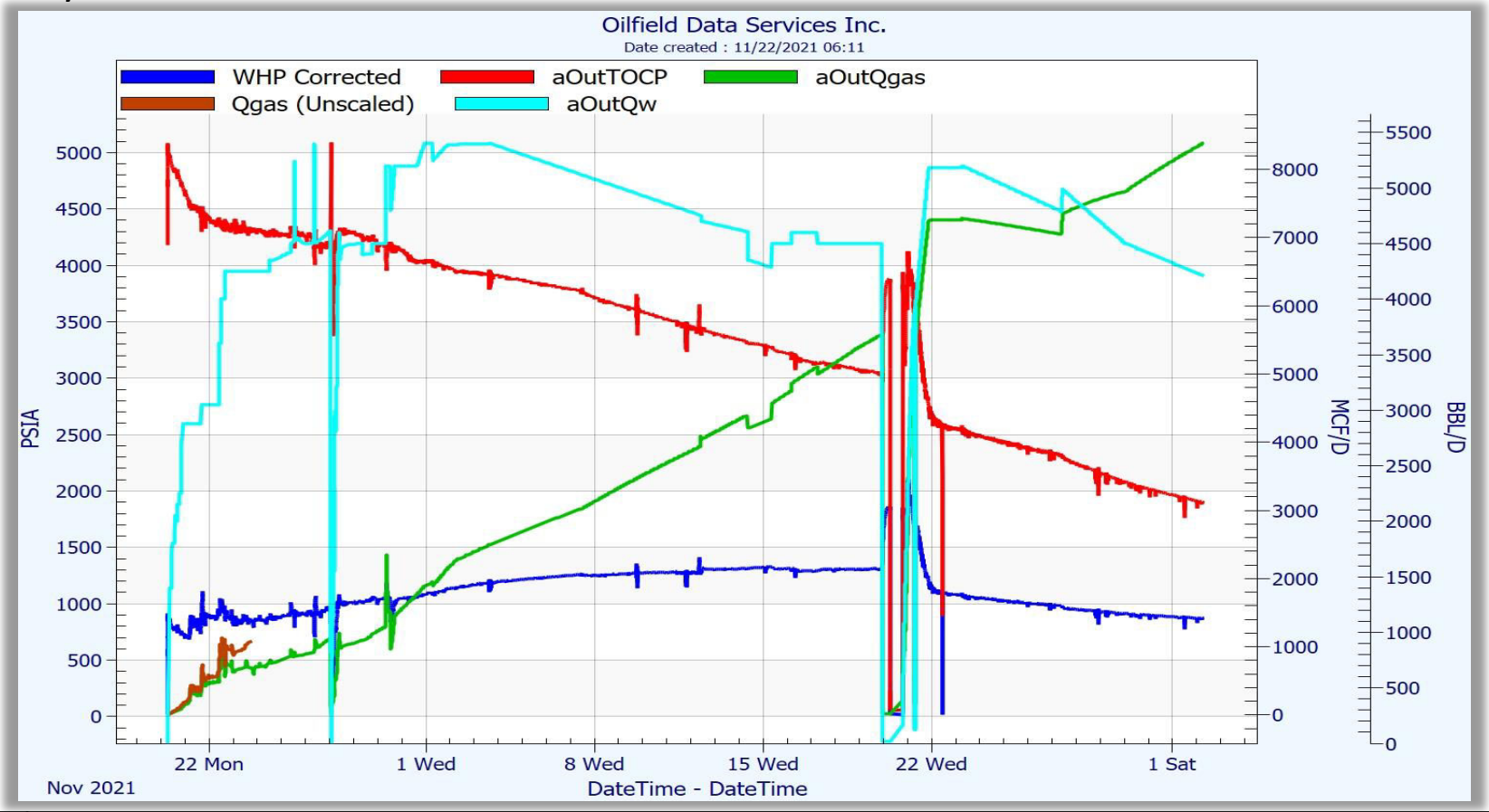
Example 2: Bringing the Well BOL after Emergency Safety Valve shut-in



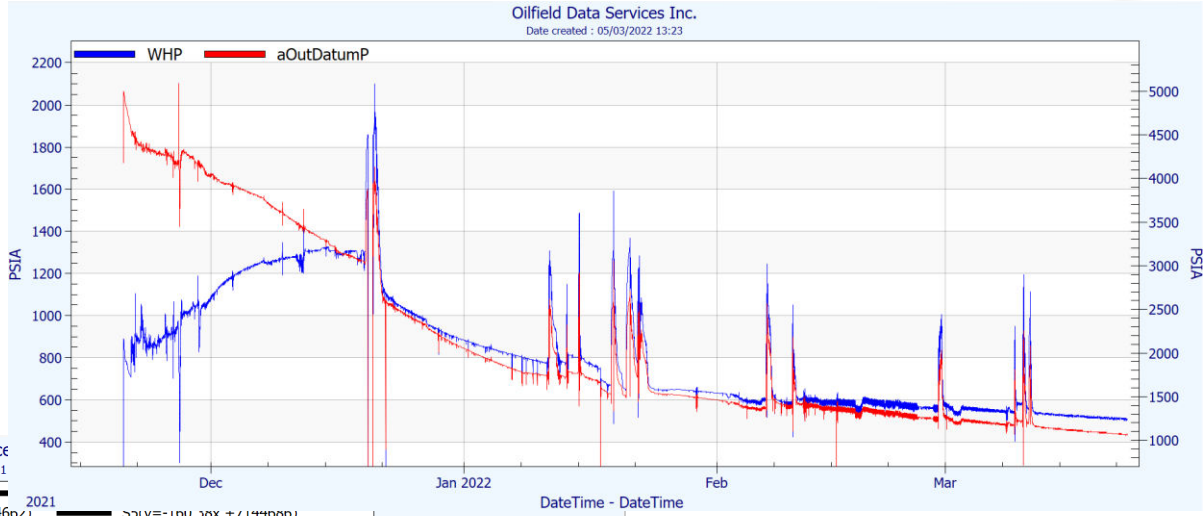
- As the well was brought back on-line, a dead water slug was observed, followed by a gas surge, before achieving proper mixing of fluids in the well bore

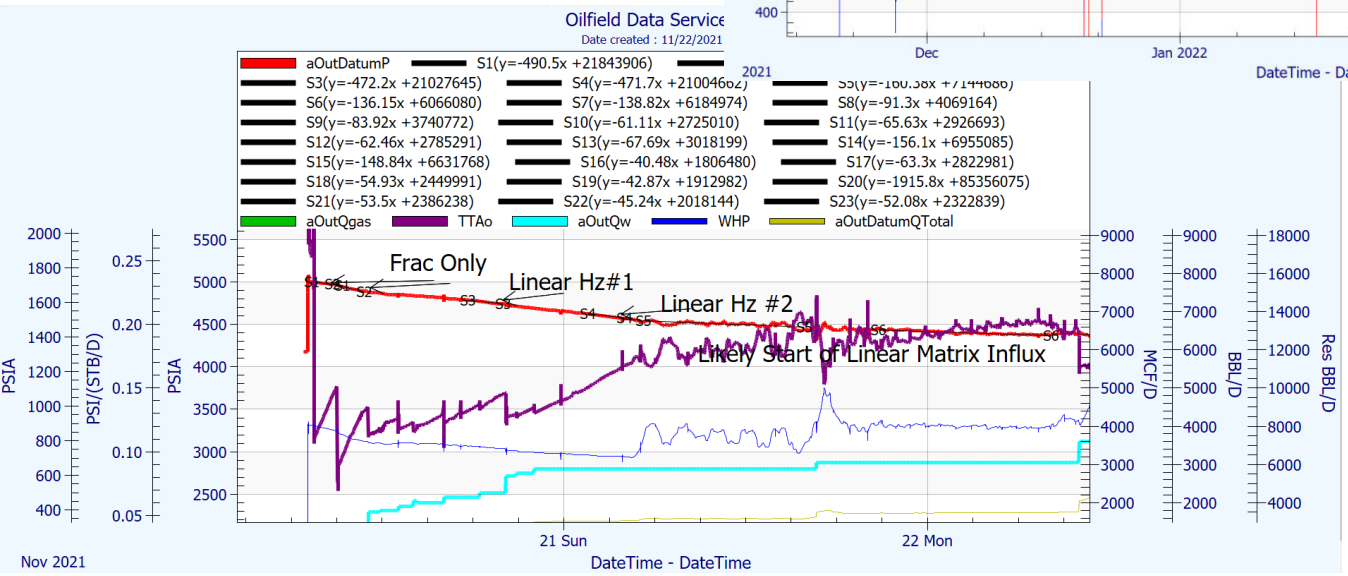
Example 2: Data Processing – BHP Conversion

- BHP conversion was performed at datum depth (heel) using WHP and Test Separator and modeled rates using ODSI's numerical solution to Mechanical Energy Balance Equation
- Failure to account for thermals and density changes in the wellbore lead to erroneous analysis and invalid reservoir volume calculations



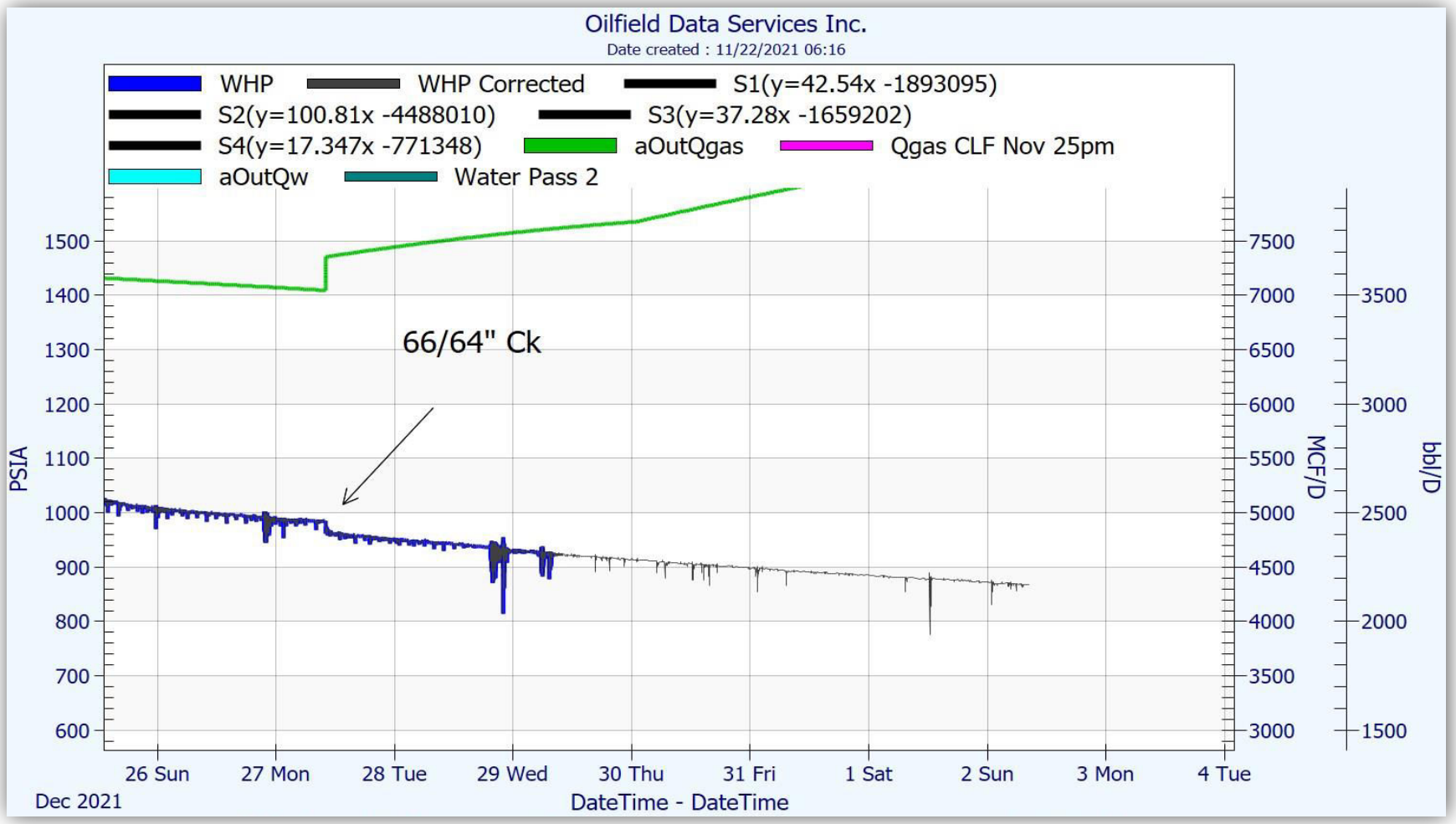
Example 2: Early Startup Data & Observed Frac Volume





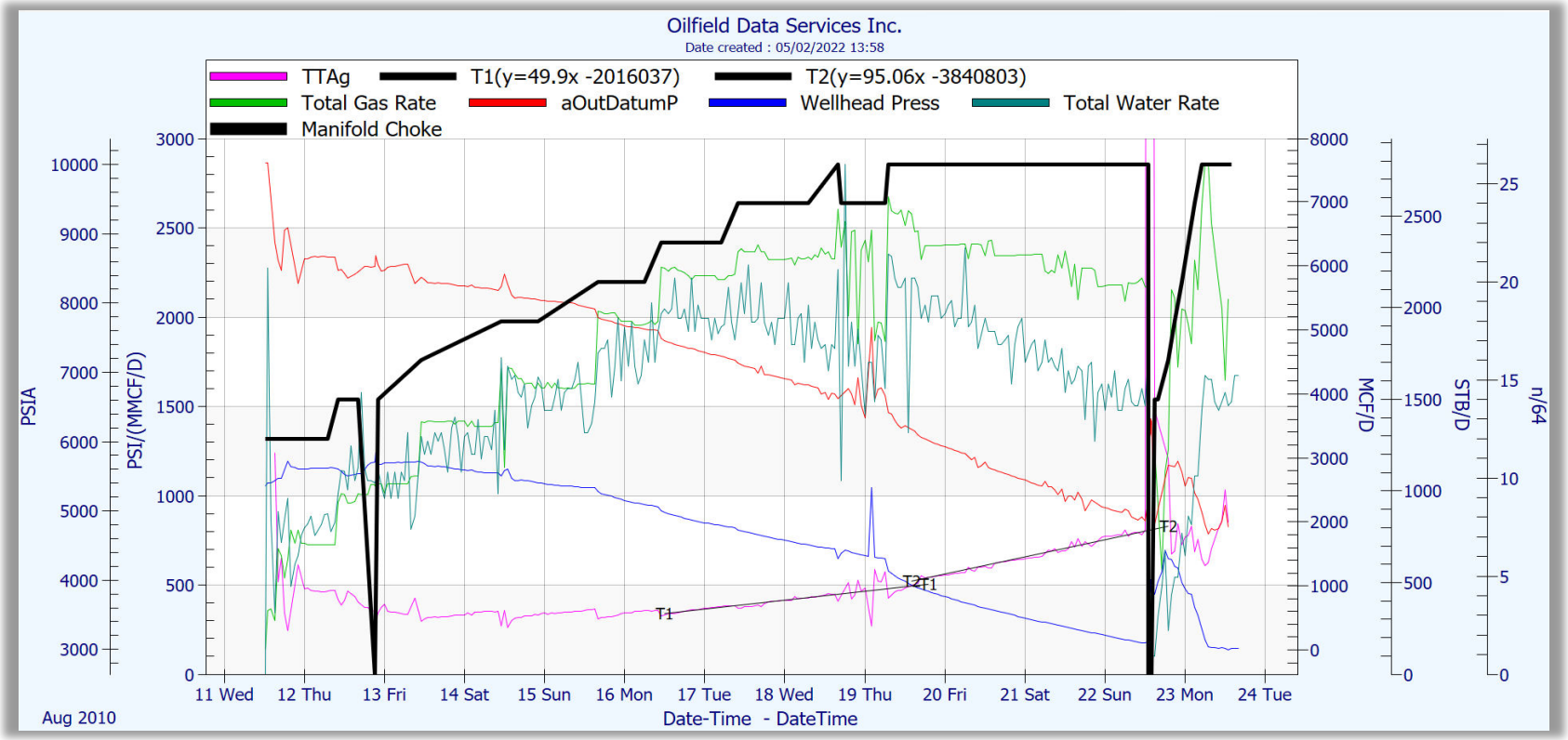
- Frac volume was observed initially (1st 3 hrs of flow)
- Linear horizontal volumes observed thereafter

Example 2: Final CK Setting



Frac Flowback
Example 3:
Evaluating Stress on the Proppant/ Fracture Dominated Region

Example 3: Frac Flowback – Excessive Drawdown/Stress on the formation

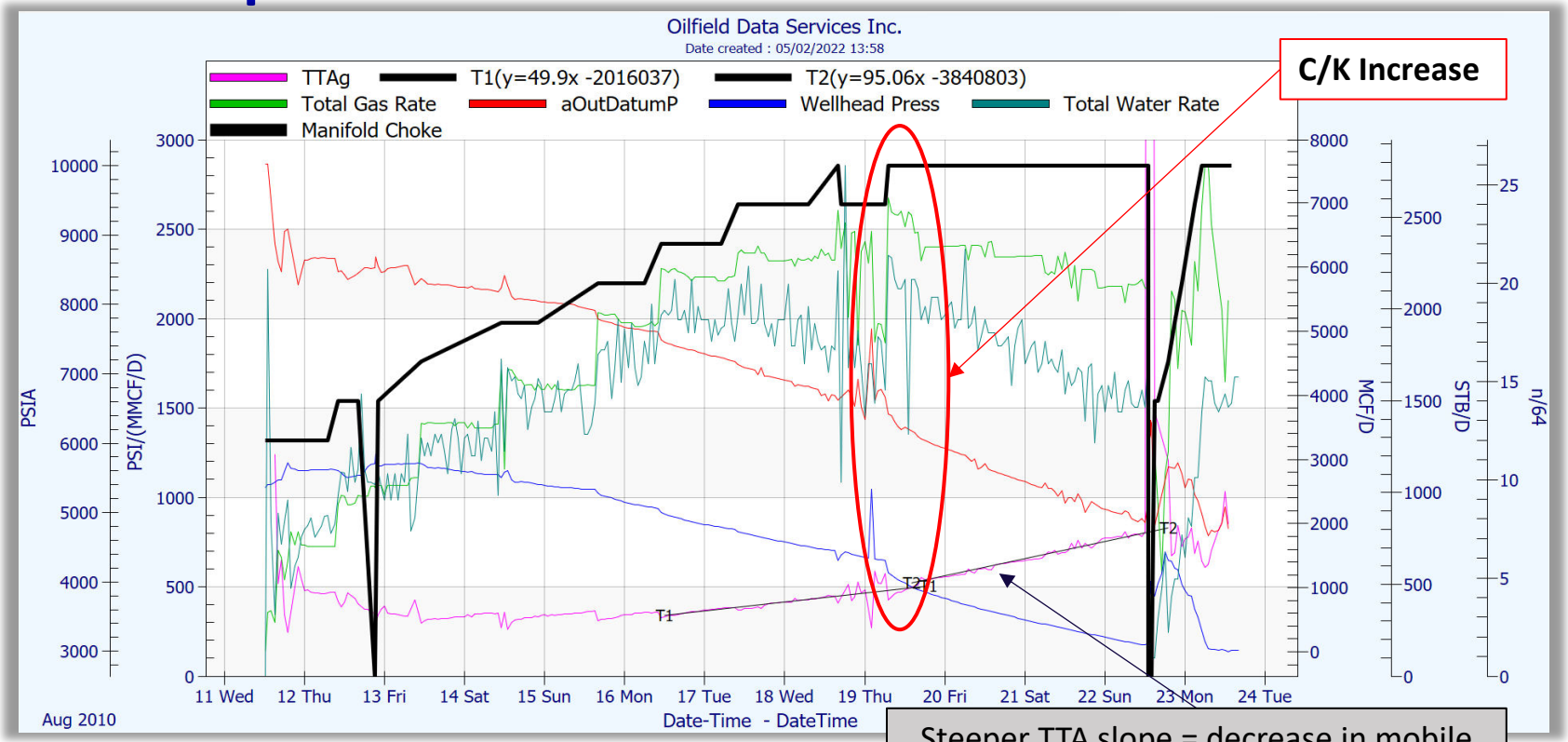


- The above is an example of historic data to identify if the formation was stressed due to excessive drawdown
- Note:

  ODSI uses the 'Thermodynamic Transient Analysis' or Relative Inverse Productivity function to quantify mobile HC volumes.

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

Example 3: Frac Flowback – Was the Formation Stressed?



Steeper TTA slope = decrease in mobile gas volumes after the CK change

- The TTA slope is a direct indicator of how much volume is moving toward the well. An increase in the slope indicates a decrease in the volume; a reduction in the slope indicates an increase in the volume.
- In this example, an increase in the choke setting resulted in stressing the formation as displayed by a reduction in mobile hydrocarbon volume from the TTA

- **Recommendation:** Choke the well back to a reduced setting and re-evaluate the mobile hydrocarbon volume

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