

***Demo for  
Water Injector  
Well A***

Automated Real-Time

Well/Reservoir Evaluation Software Package

**Software Trial for  
Allocations, BHP Conversion, Auto-PTA**

Performed by Venera Zhumagulova & Chris Fair

# Executive Summary I

- No obvious reason for reduction in injectivity by analyzing the long-term Fall-offs
  - Slight increase in skin and slight increase in kh
- Near-well Auto-PTA conclusively indicated a reduction in the near-well kh and injectivity
- Difference in measured vs. calculated injection rates was a clear indication of scale build-up in the well bore
- The acid job fixed both the scale issues in the well bore and the injectivity losses in the near-well region

# Executive Summary II

- Rate Measurements compared to ODSI's d/p wellbore method can diagnose scale
- Automatic PTA saves time and provides consistency for 'apples to apples' comparisons
- Near-well kh provided the most reliable diagnostic of completion performance for this well
- After the stimulation job (Jan 2017), the measured and calculated rates matched again, indicating a cleaned well bore

# Outline

- Well Analyzer Software Features
- Well A background info
- Trial Objectives
- Data Processing
- Trial Results
  - Allocations
  - BHP
  - PTA
- Conclusions and Observations

# About Well Analyzer

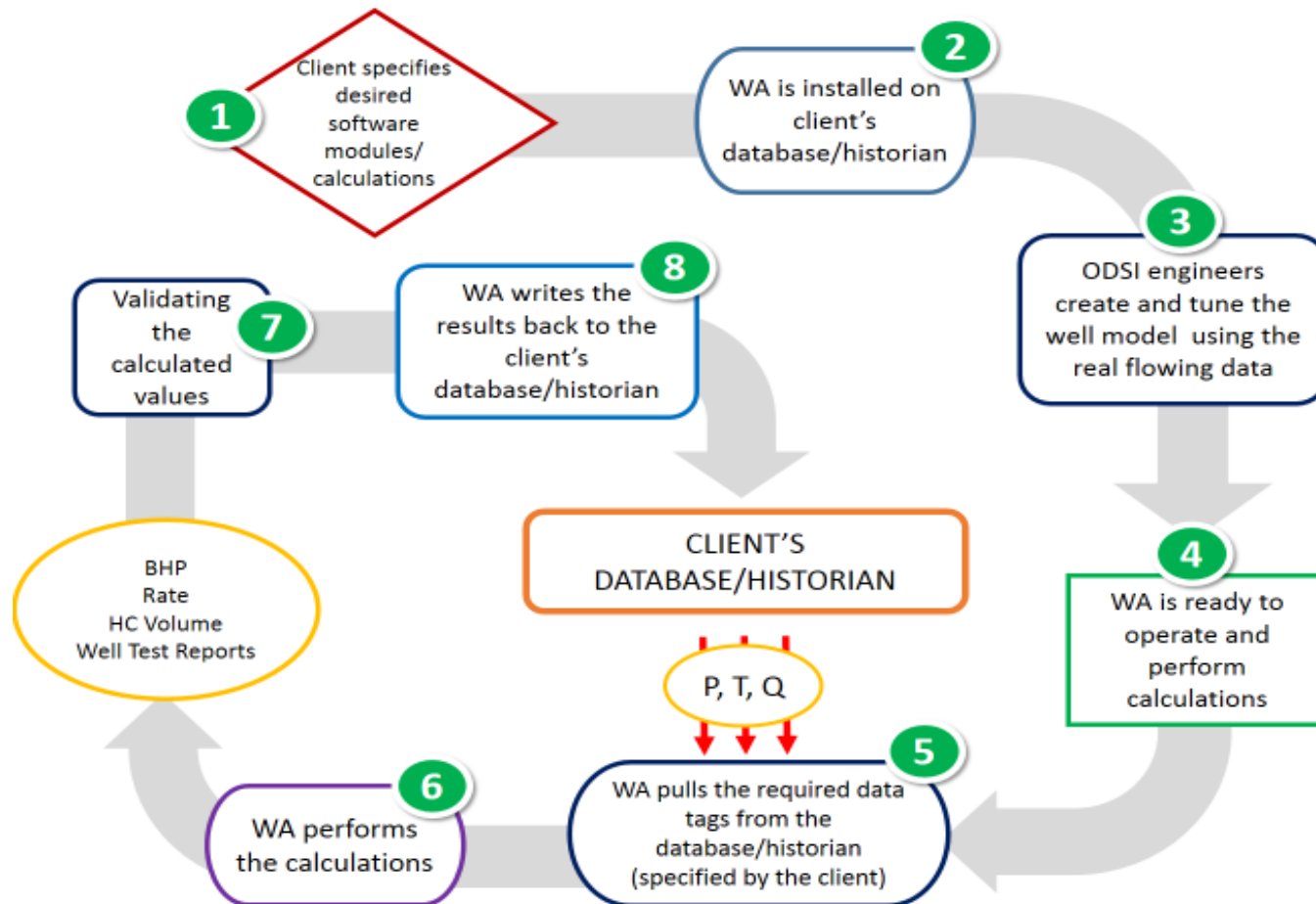
Well Analyzer is the only existing software package that is based on a direct solution to the Mechanical Energy Balance equation, which is the basis of the most VLP correlations, including:

- Cullendar & Smith
- Beggs & Brill
- Hagedorn & Brown

Well Analyzer's method uses a direct solution, hence it provides **more accurate and reliable results**

# How does it Work ?

- Works both in Real-Time and on Historic data
- Polls the required data tags from the database, performs the calculations, validates the results and writes them back to the database



# Well Analyzer Real-Time Features

- Virtual metering
  - Oil, gas and water rate calculations
  - Detects errors in allocations
- Bottomhole pressure calculation from the surface data
  - Can replace downhole pressure gauge in case it fails
- Automated Transient Interpretation of build-up & drawdown tests and injectivity & injection fall-off tests
  - Skin
  - Permeability
  - Avg.Pres/P\*

# Well Analyzer - PTA

Well Analyzer polls the data and looks for new transients. Once identified, the software analyzes them for:

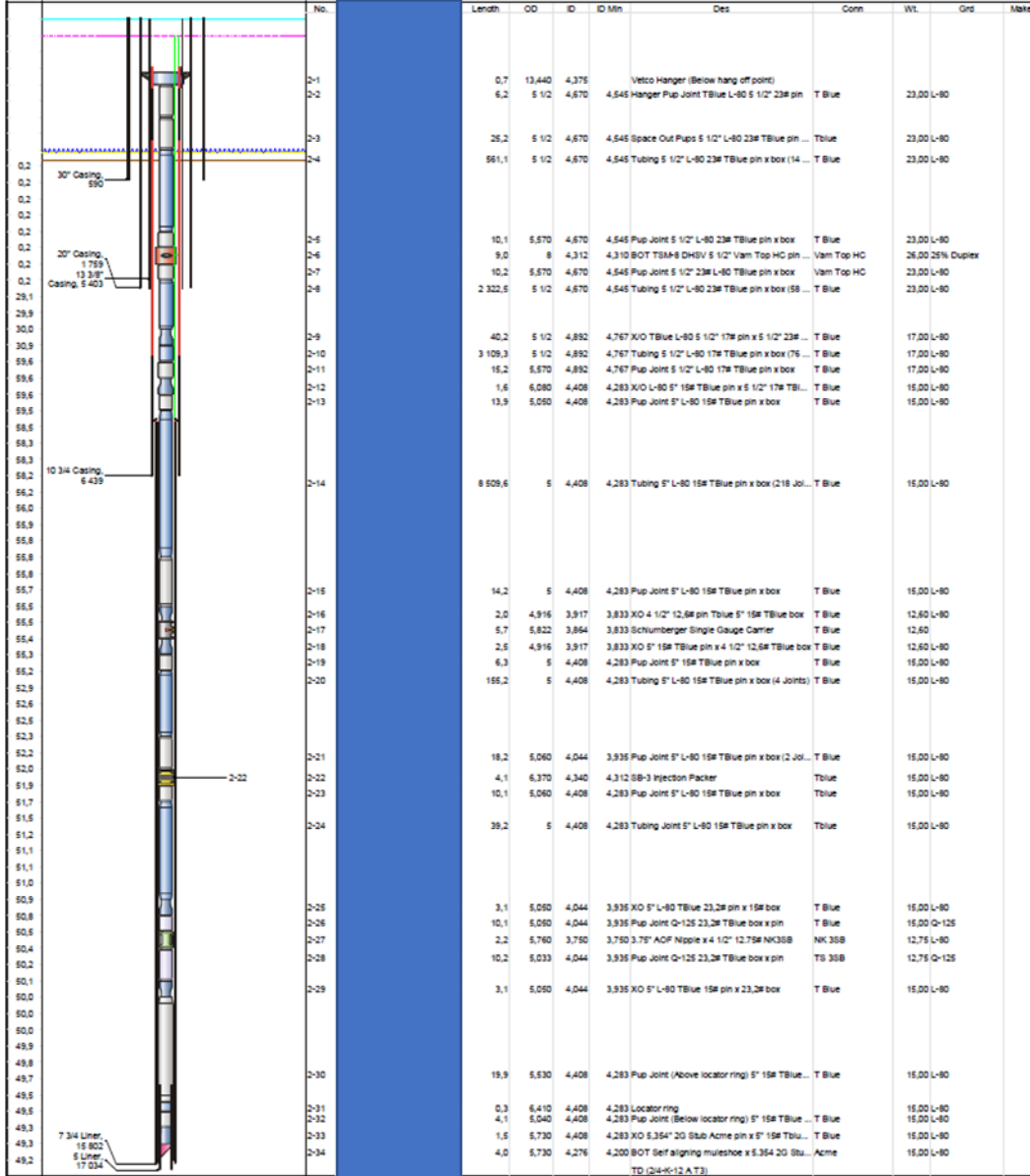
- Permeability
  - Skin
  - Pressure drop due to skin
  - Reservoir pressure
  - Productivity Index/Injectivity Index
  - Completion Efficiency
- Allows engineers to 'catch' new transients
  - Monitoring of PTA parameters and well performance (changes) with time



# Background

- 4.5 (July 2012- Feb 2017) years of production data was provided to ODSI to demonstrate software's real-time features
  - Virtual metering
  - BHP conversion
  - Auto-PTA
- The well equipped with
  - WHP
  - DHGP/DHGT
  - Water rates were being measured

# Completion Schematics



Donwhole pressure gauge @ XXX TVD

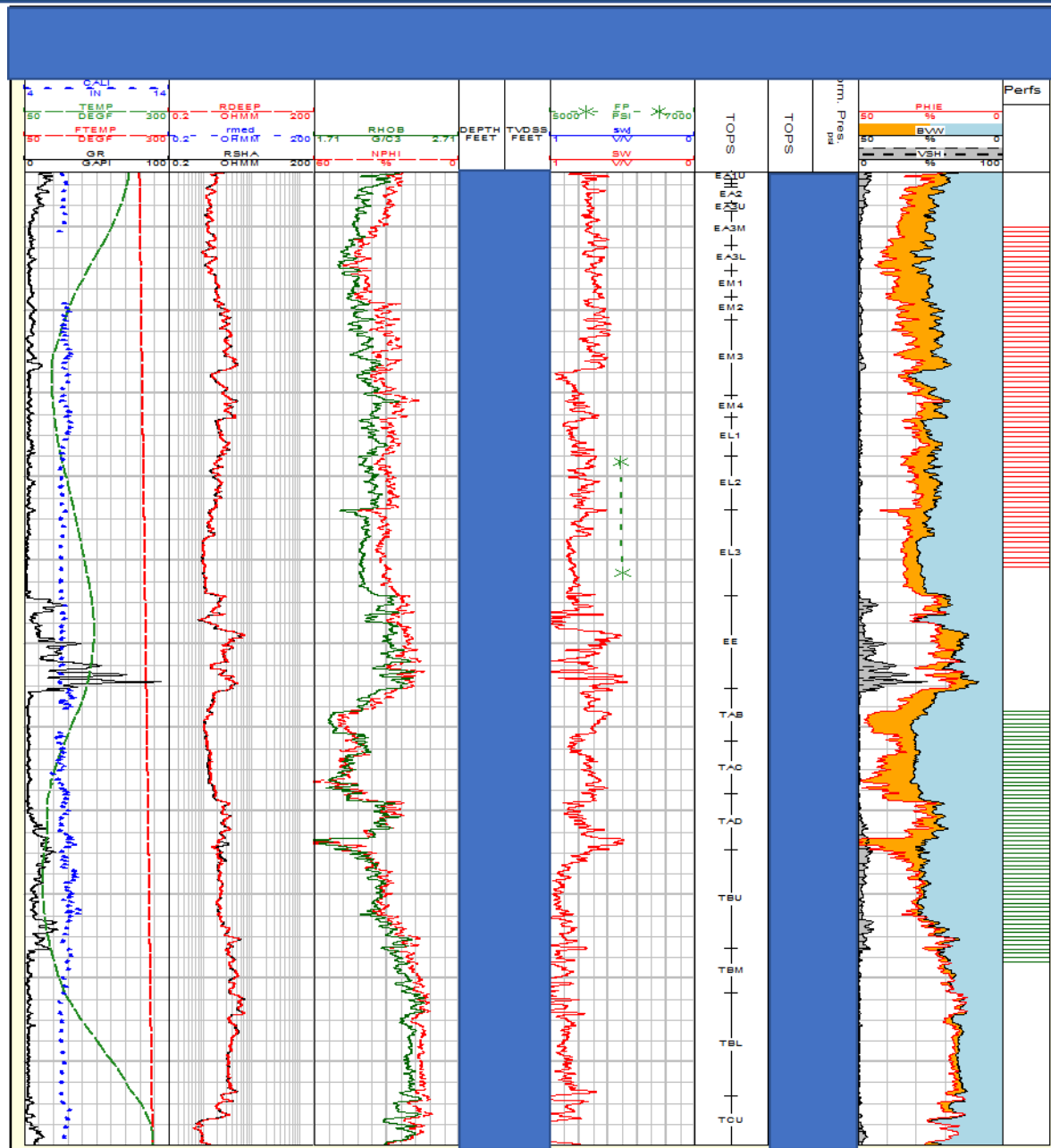


Vertical separation of 1017 ft TVD



Datum P (BHP) @ XXX TVD

# Well Logs

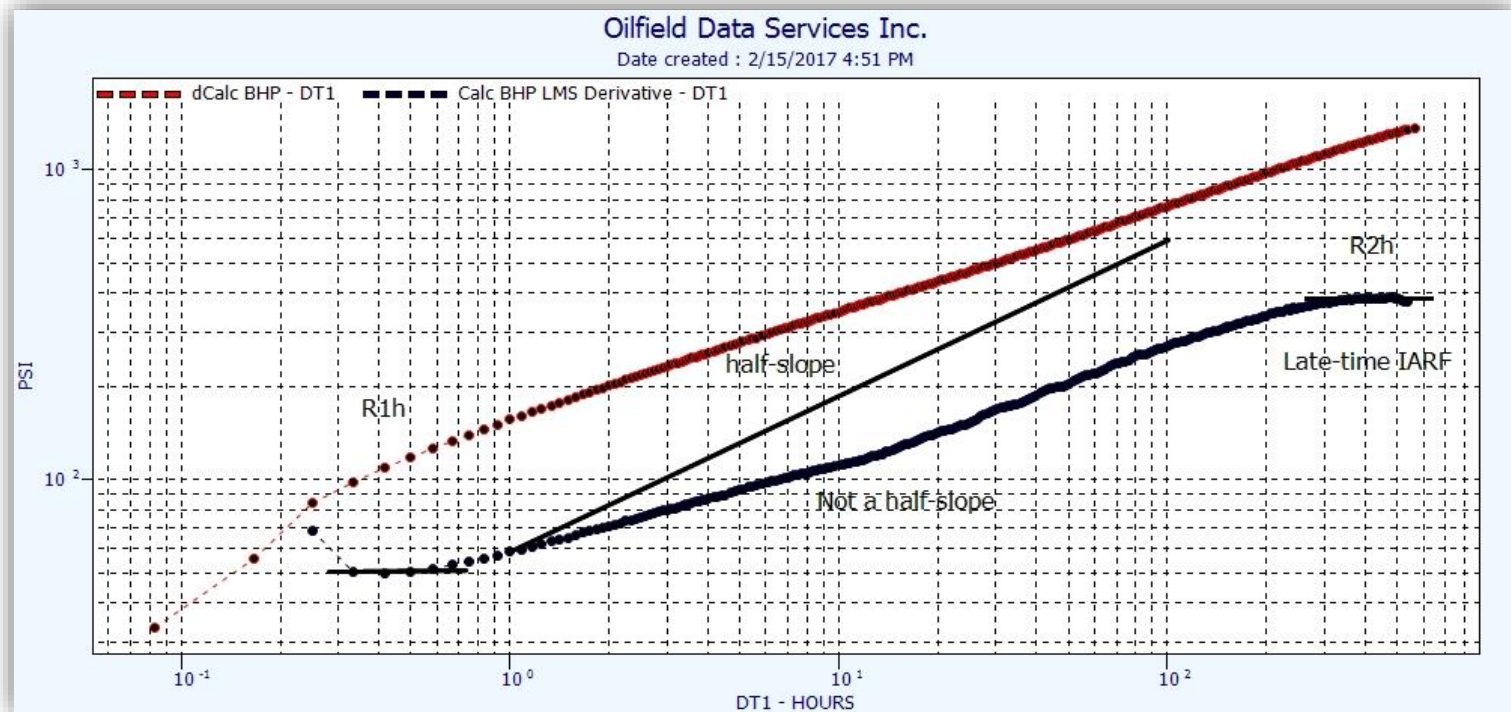


# Trial Objectives

- Build a well configuration for Well A
  - Tubing profile
  - Fine tune PVT (Water Density)
  - Well's thermal profile
- Calculate water injection rates using DP wellbore
  - DP between a tree and downhole pressure gauges
- Calculate Datum P/BHP
- Perform automated interpretation of injection fall off tests
- Provide conclusions and observations

# Trial Objectives - PTA

- From data QA/QC process, it was determined that the well had an unusual flow regime based on the derivative response, therefore, PTA was performed for both early and late time radial flow
  - Early-time IARF: 0.2 ~ 0.9 hrs
  - Late-time IARF: 300 ~ 400+ hrs



# Trial Objective – PTA

- Upon Operator's request, automated PTA was performed using both the measured and the calculated rates for the comparison purposes
- Therefore, there were a total of 4 sets of PTA results:
  - Early-time IARF with calculated rates
  - Late-time IARF with calculated rates
  
  - Early-time IARF with measured rates
  - Late-time IARF with measured rates
- (Shown on Slides 46 – 62)

# Trial Expectations

Demonstrate automated features of Well Analyzer software

- The ability to calculate the water injection rate using DP wellbore
  - Compare the results to the measured rates
- The ability to calculate Datum P/BHP
- The ability to perform auto-PTA
  - Injection Fall-off

# Trial Results



# Real-Time Inputs

The calculations (Inj. rate, BHP, auto-PTA) were performed using the following inputs:

- WHP
- DHGP/DHGT

Inputs Summary Outputs Reports

Select Input Data

WHP	WHP	PSIA
WHT	None	
DHGP	DHGP	PSIA
DHGT	DHGT	DEGC
QGas	None	
GG	None	
Yo	None	
Yw	None	
SCSSV	None	
Ext QGas	None	
Qo	None	
Qw	None	
QTotal	None	
BHP	None	

Refresh Columns

Export Inputs

Config

SamplesPerUpdate

1000

Config Ok

Load Config

Analysis Enabled

Reserves Enabled

MLTO (DEGF)

15

Legacy MLTO (not used in rate calc)

VSSV Open

Ignore invalid events

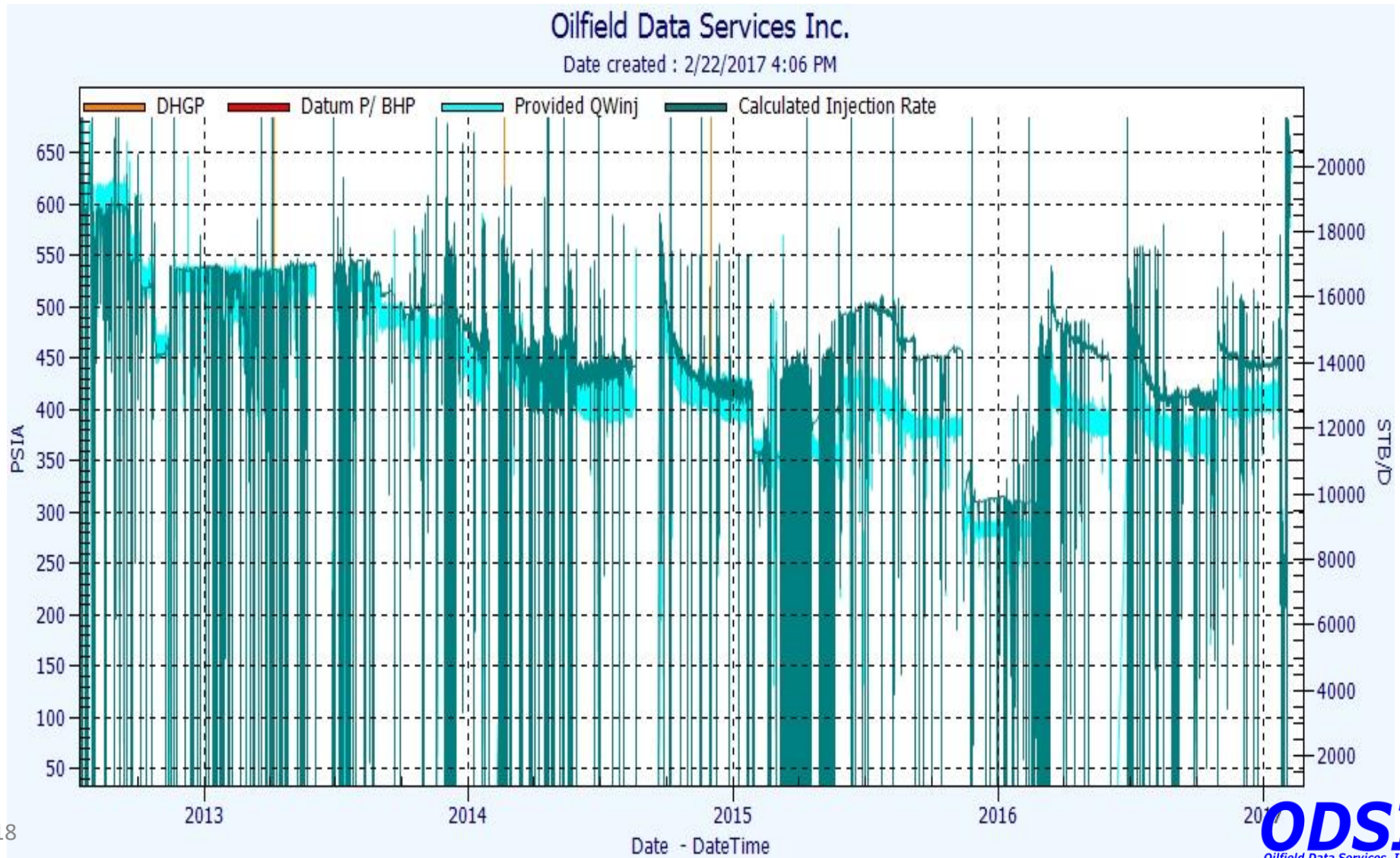
No CalcRate Smoothing

Rate Calc from Perm

Enabled

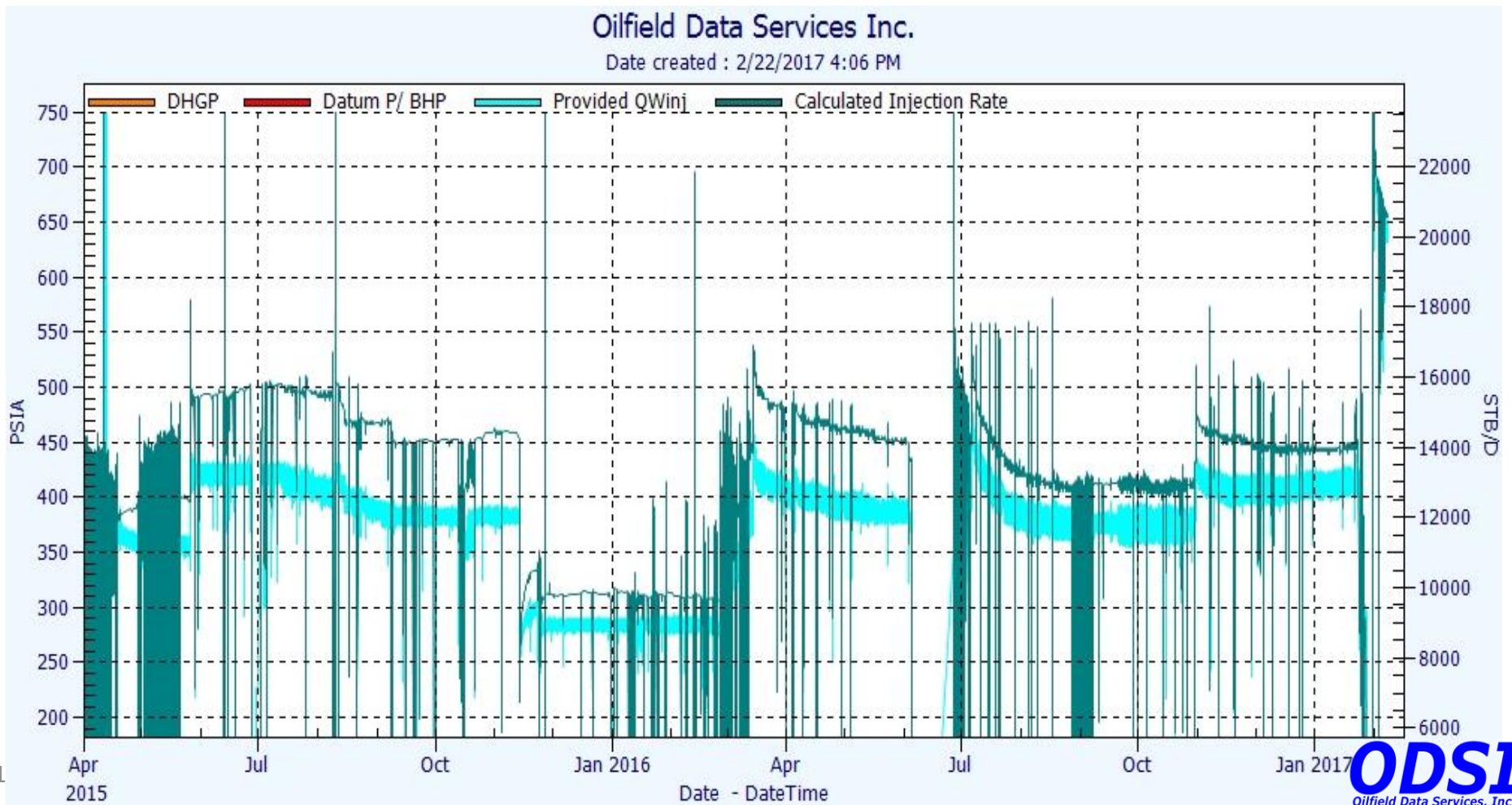
# Injection Rate Comparison

The plot shows a comparison of the calculated and measured rates



# Injection Rate Comparison

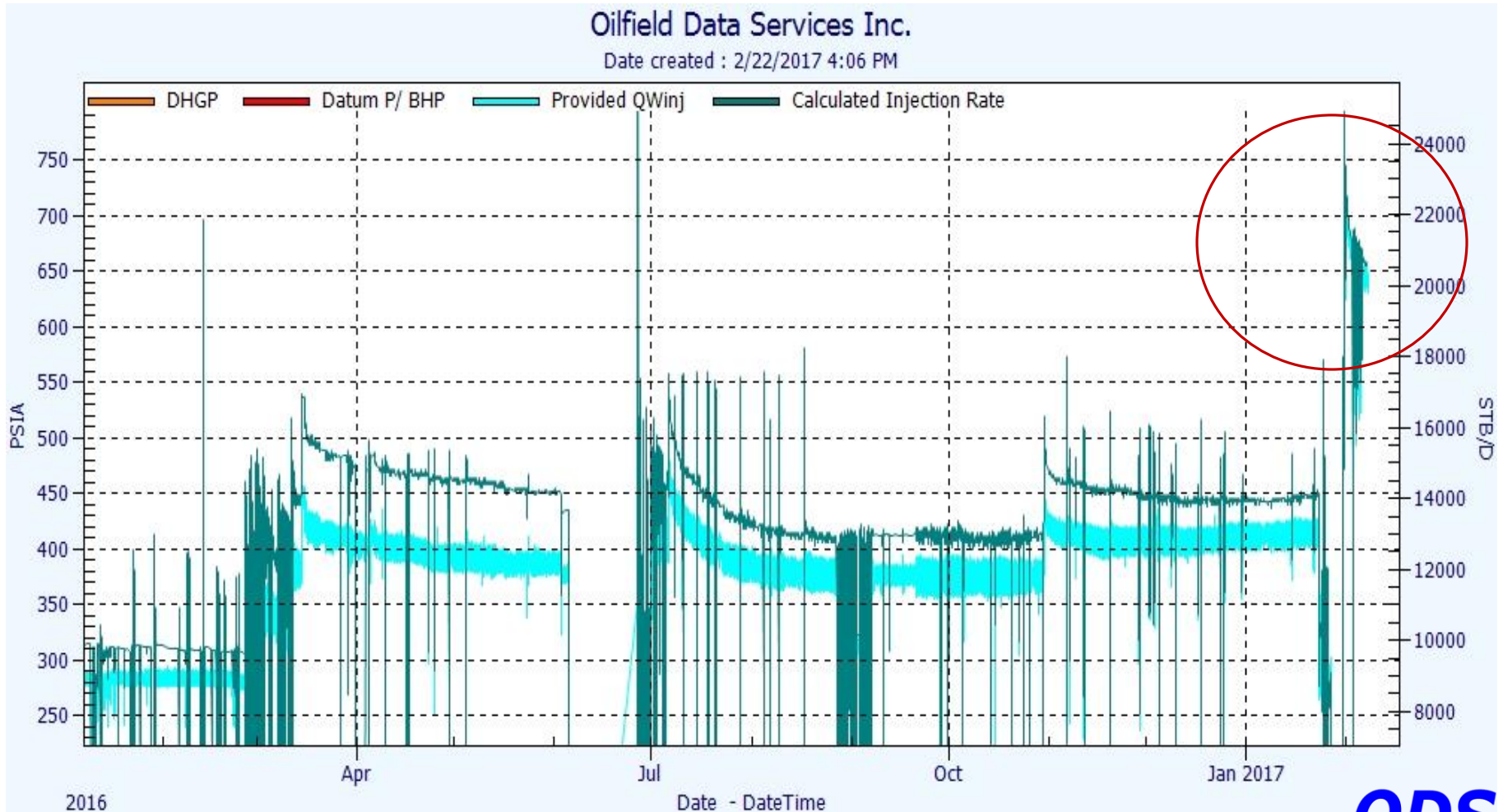
- Starting early April 2015 the measured and the calculated rates started to deviate
  - Up to 2000 STB/D difference
- After the stimulation job (late Jan 2017), the rates matched again





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# Discussion on Rate Comparison

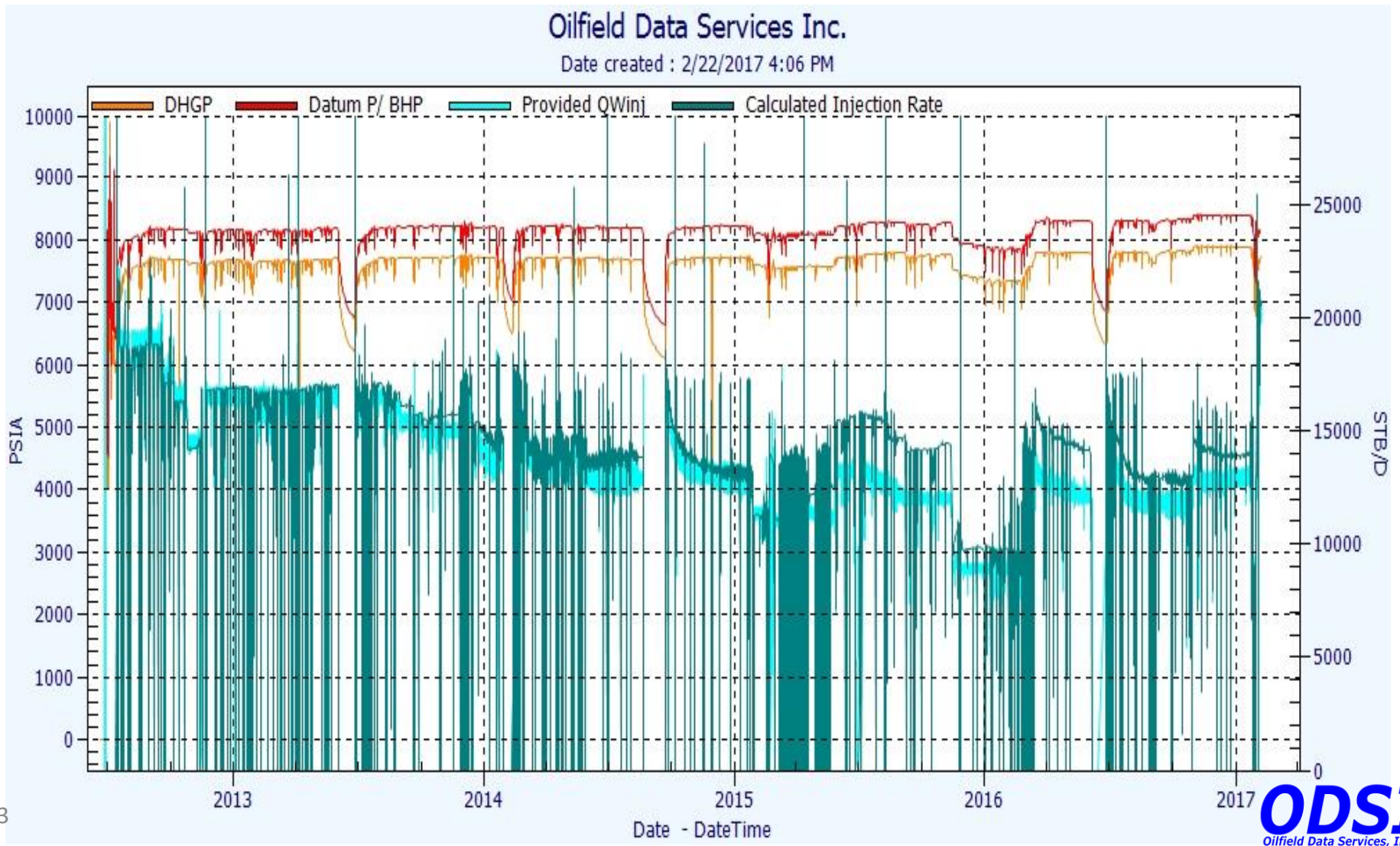
- ODSI uses a direct solution to the Mechanical Energy Balance equation for the rate calculations

$$\frac{dp}{d\rho} + \frac{v dv}{g_c} + \frac{g}{g_c} dz + \frac{2 f_f v^2 dL}{g_c D} + dW_s = 0$$

- where, head and friction are dominant components
- The difference in the measured and the calculated rates could be explained either by a heavier fluid in the wellbore (head) or additional friction
- It was more likely that the difference in rates was caused by scaling, which caused the additional friction in pipe
  - Measured & calculated rates matched again after the scale was removed with the stimulation job
- The scaling was also confirmed with PTA results
  - Decreasing kh with time
  - Decreasing II (Injectivity Index) with time

# BHP Results

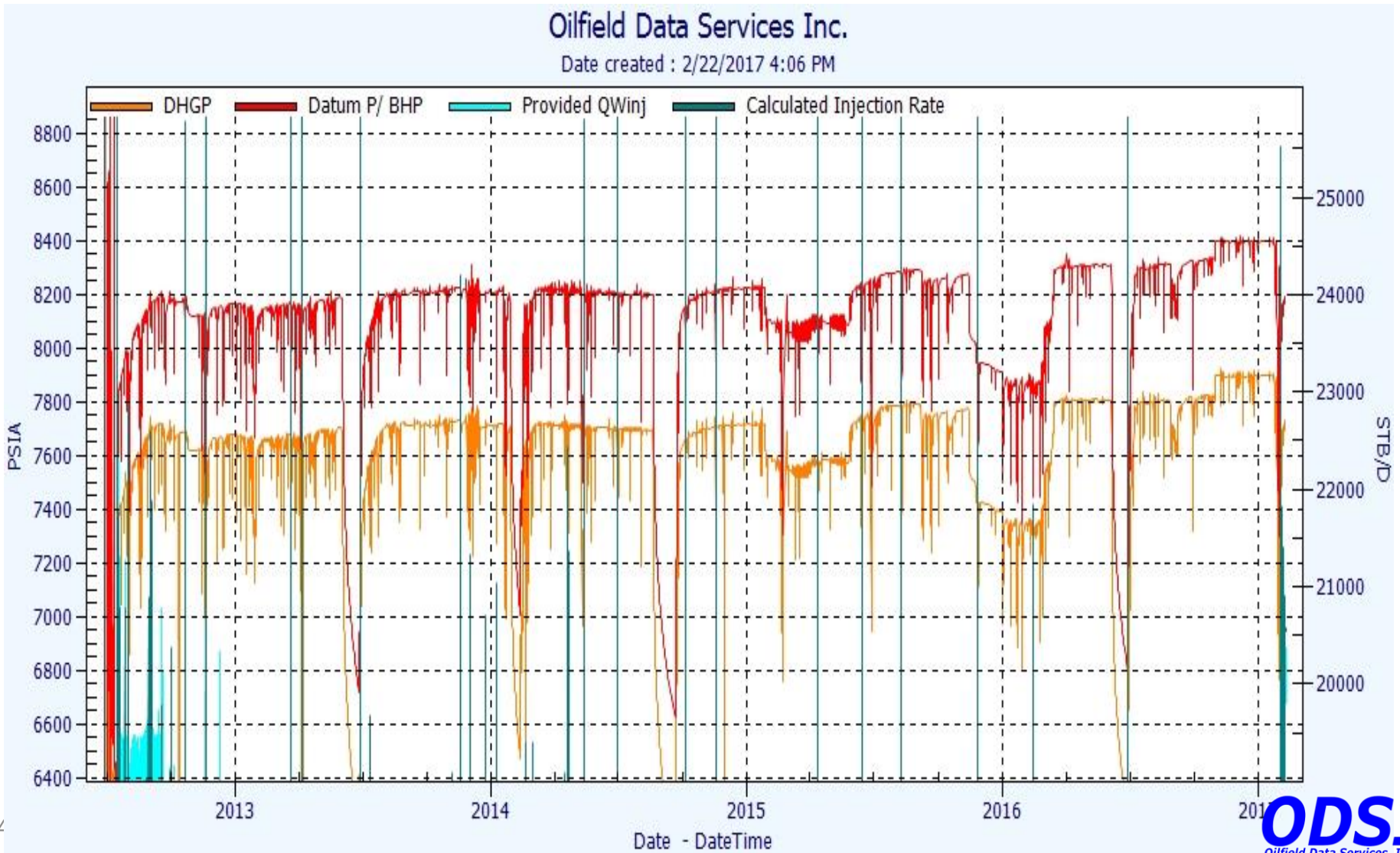
The software simultaneously calculated BHP using the DHGP and the calculated rate





# BHP Results Zoom

The software simultaneously calculated BHP using the DHGP and the calculated rate





# Auto-PTA Results

with ODSI's Calculated Rates

# Auto PTA Summary

- Auto-PTA was performed for both:
  - Early-time IARF
  - Late-time IARF

## Overall-observations:

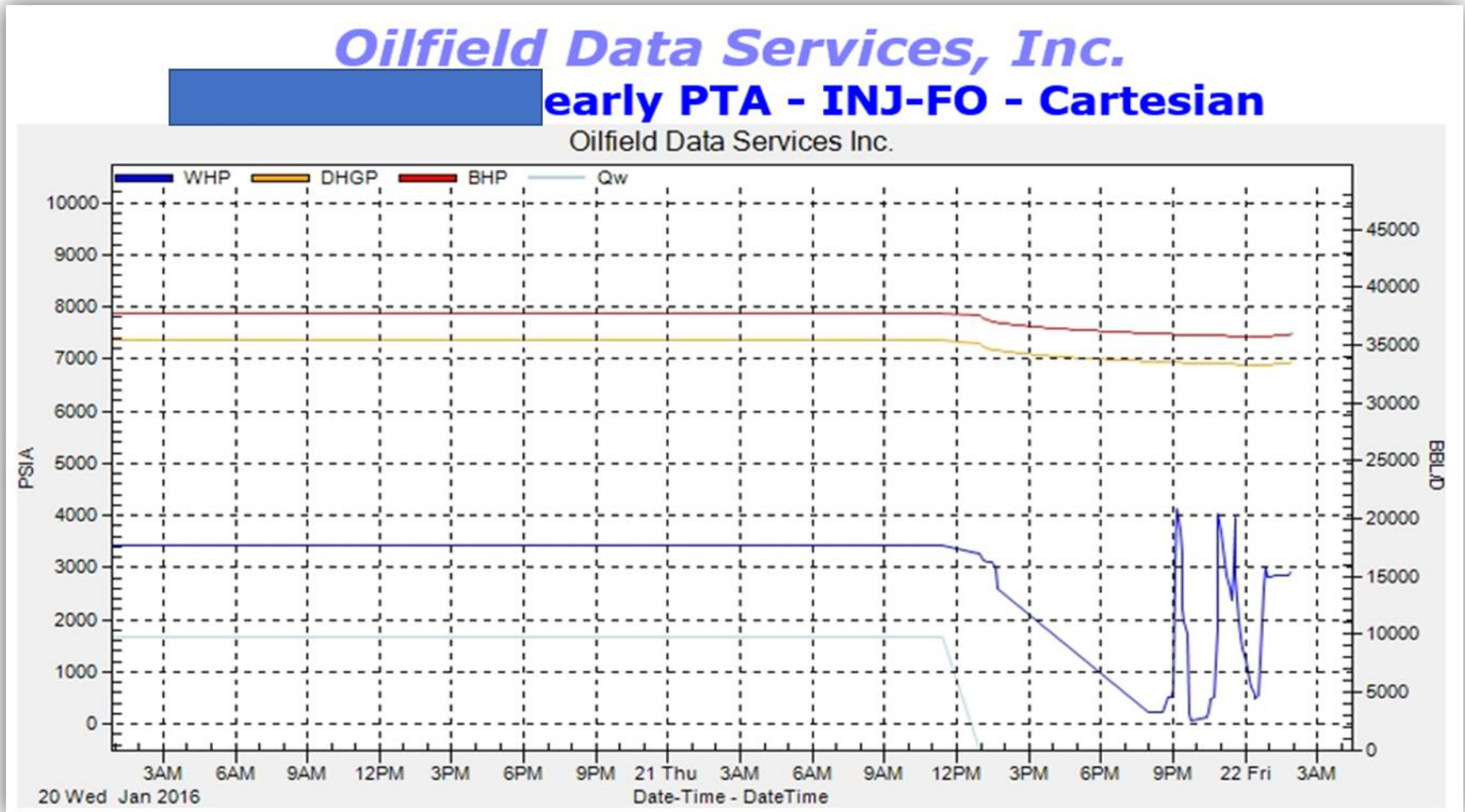
- kh was decreasing with time
  - From 16 000 md-ft ( August 2012) to 8 000 md-ft (Jan 2017) over the course of ~ 4.5 years
  - Successful re-stimulation job in late Jan 2017
  - Kh immediately increased from 8 000 md-ft to 18 337 md-ft (Feb 11, 2017 INJ fall-off test)
- Injectivity Index was gradually decreasing over the course of well's life
  - From 88 STB/psi (Aug 2012) to 47 STB/psi (Jan 2017)
  - Inj Index increased to 103 STB/psi after the stimulation job



# Auto-PTA: Example Report

## Jan 21, 2016 Inj Fall-off – Cartesian Plot

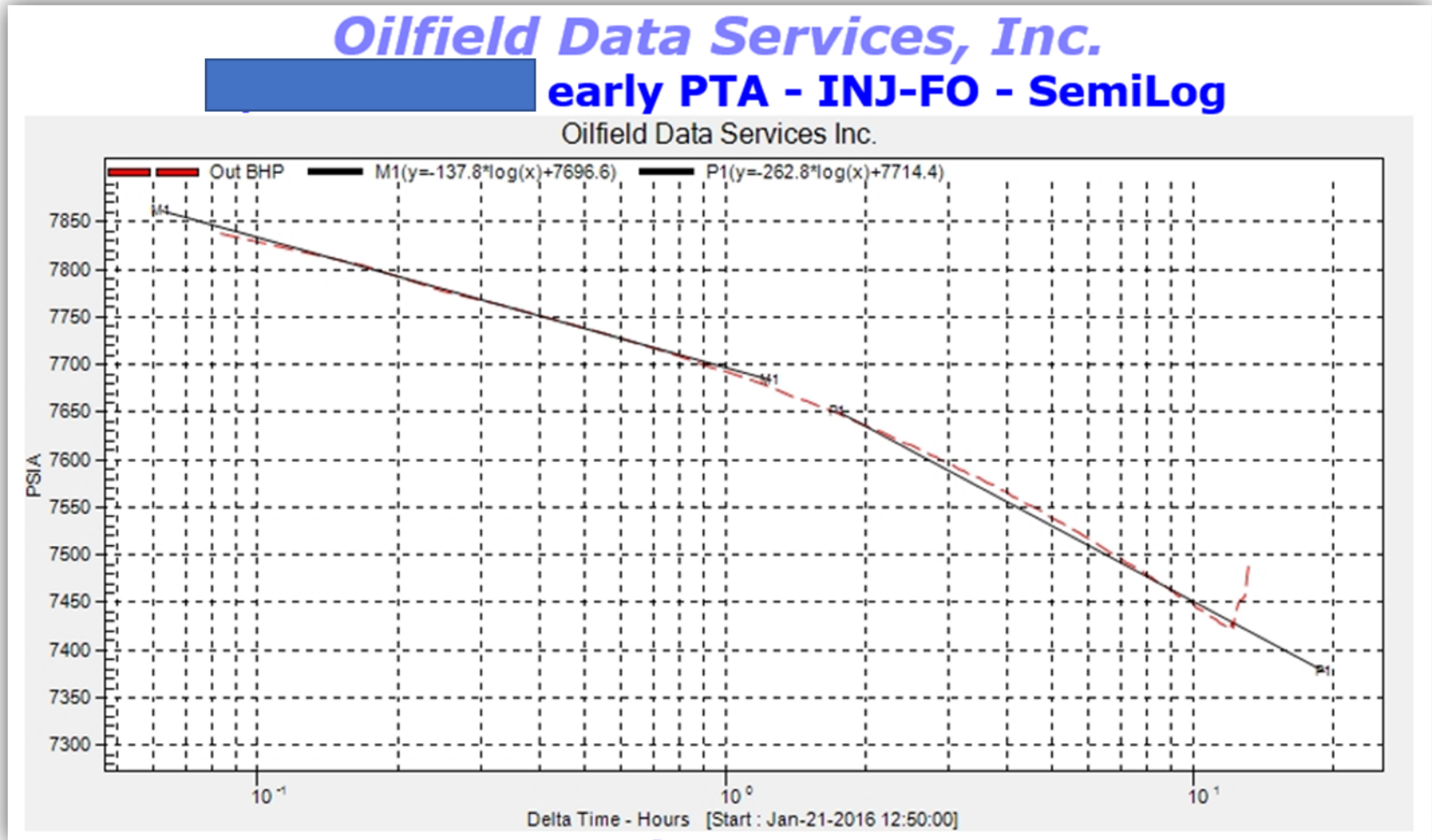
Note: This plot is a screenshot from the automatically generated PTA report



# Auto-PTA: Example Report

## Jan 21, 2016 Inj Fall-off – Semi-log Plot

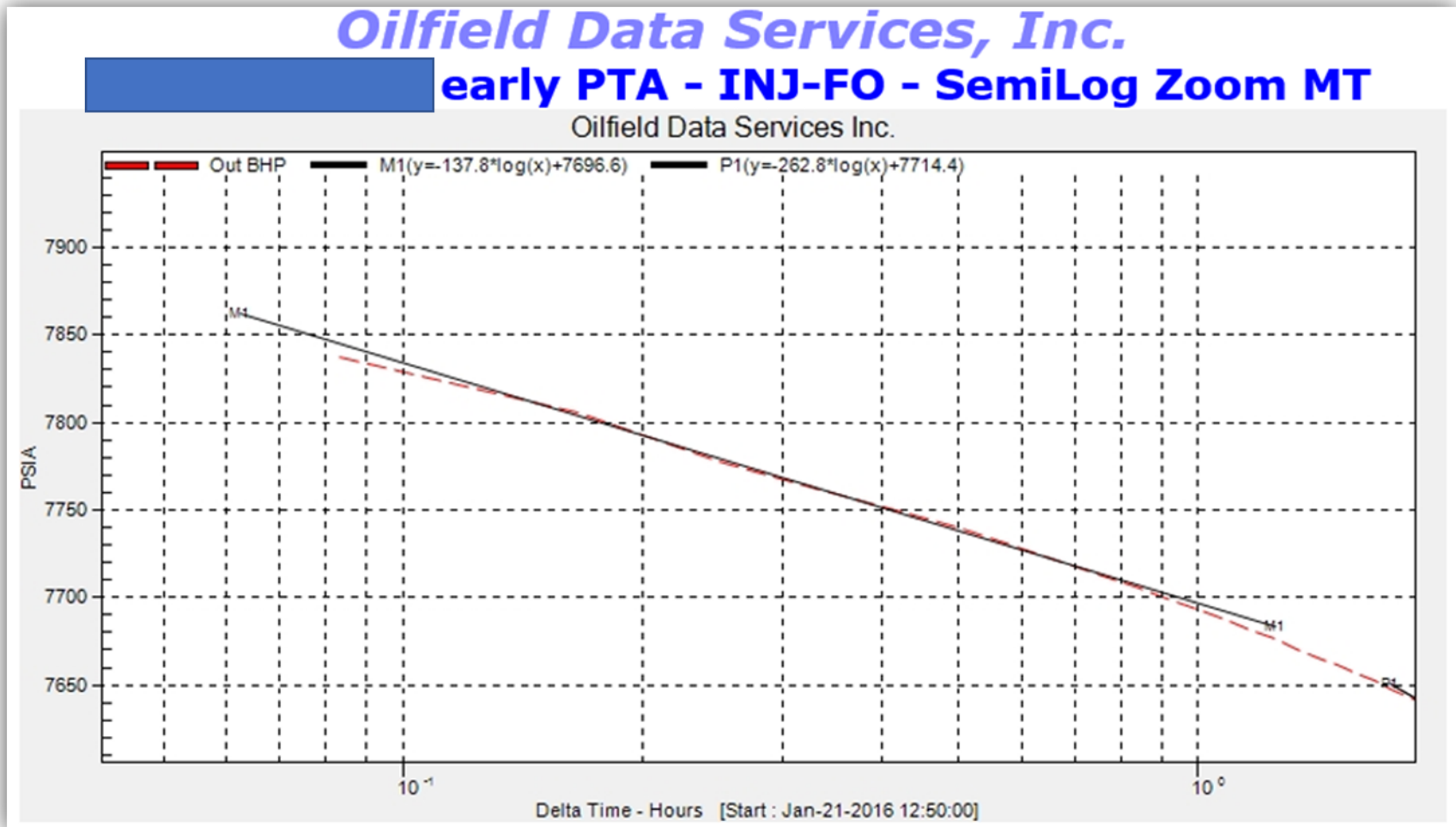
Note: This plot is a screenshot from the automatically generated PTA report



# Auto-PTA: Example Report

## Jan 21, 2016 Inj Fall-off – Sem-Log MTS Zoom Plot

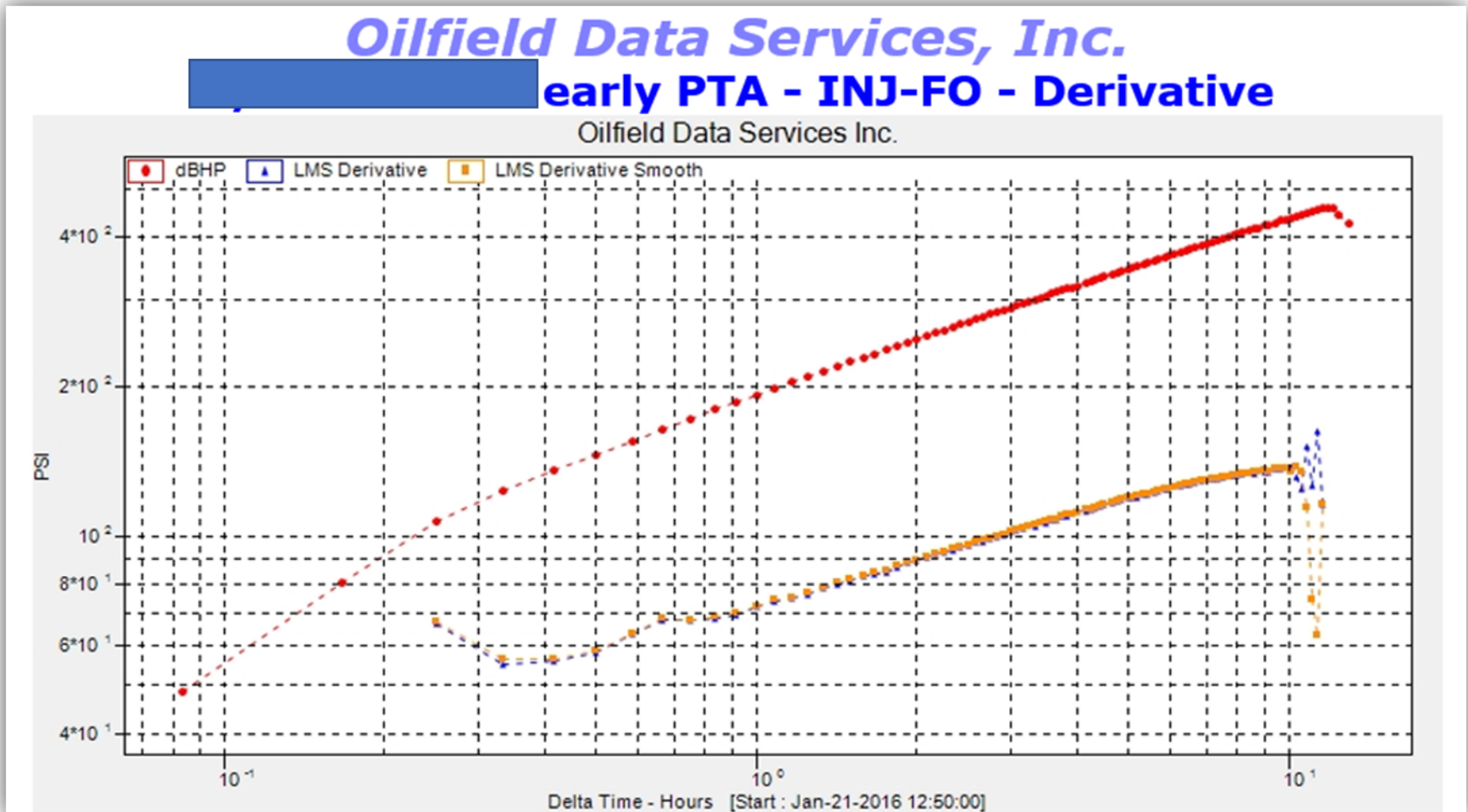
Note: This plot is a screenshot from the automatically generated PTA report



# Auto-PTA: Example Report

## Jan 21, 2016 Inj Fall-off – Derivative Plot

Note: This plot is a screenshot from the automatically generated PTA report





# Auto-PTA: Example Report

## Jan 21, 2016 Inj Fall-off – Derivative Plot

Note: This plot is a screenshot from the automatically generated PTA report  
Net Pay used = 550 ft

### *Oilfield Data Services, Inc.*

#### ANALYSIS RESULTS

INJECTION FALL OFF  
Jan/21 - 22/2016

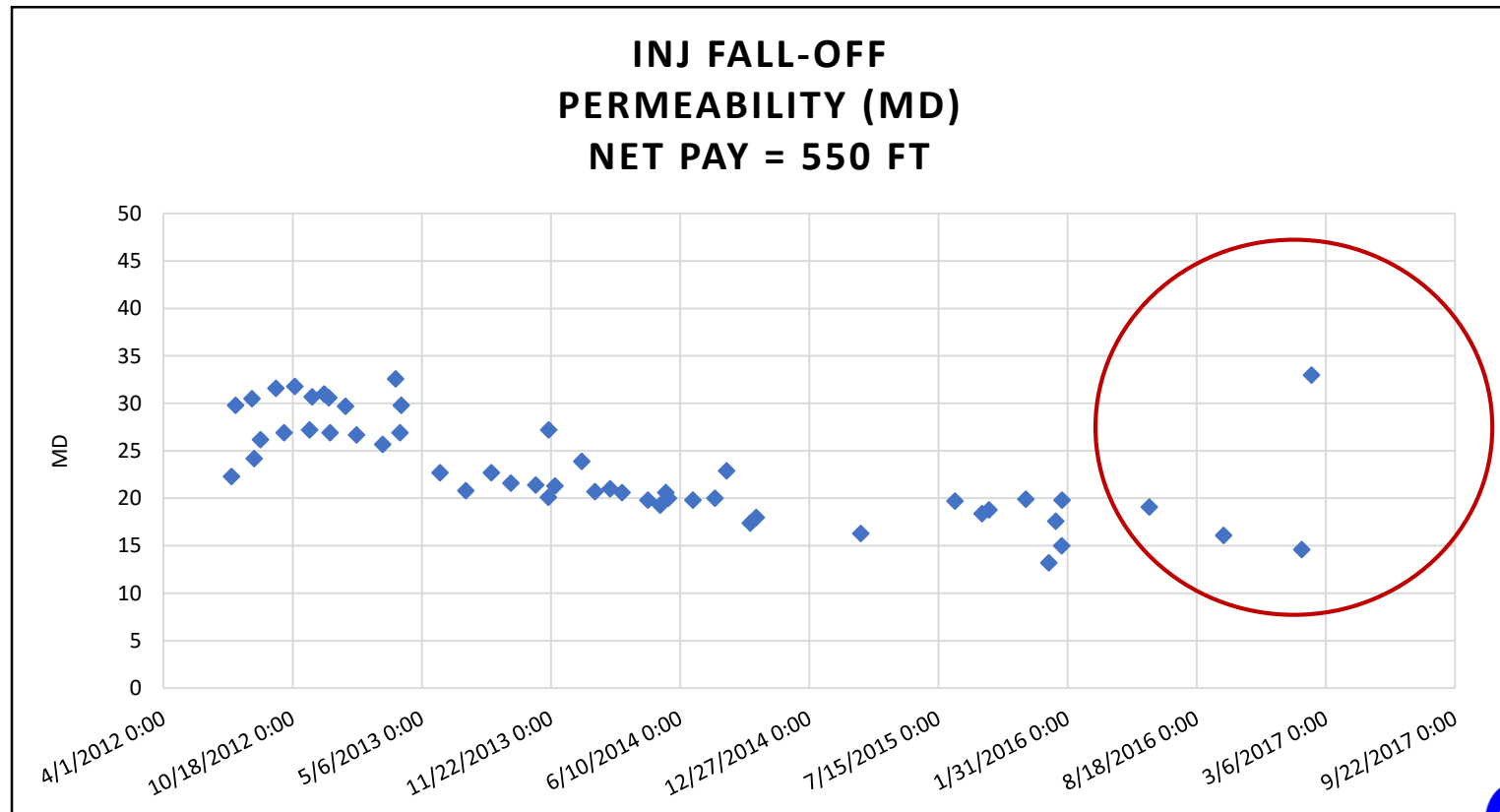
#### Calculated Reservoir & Completion Properties

SKIN	-3.1	
PRESSURE DROP DUE TO SKIN	-378	PSI
COMPLETION EFFICIENCY	300	%
PERMEABILITY	15	md
RADIAL FLOW INJECTIVITY INDEX (II)	50.9	STB/PSI
SKINLESS RADIAL FLOW II	17.0	STB/PSI
PERMEABILITY THICKNESS	8,274	md-ft
MOBILITY THICKNESS	11,819	md-ft/cp



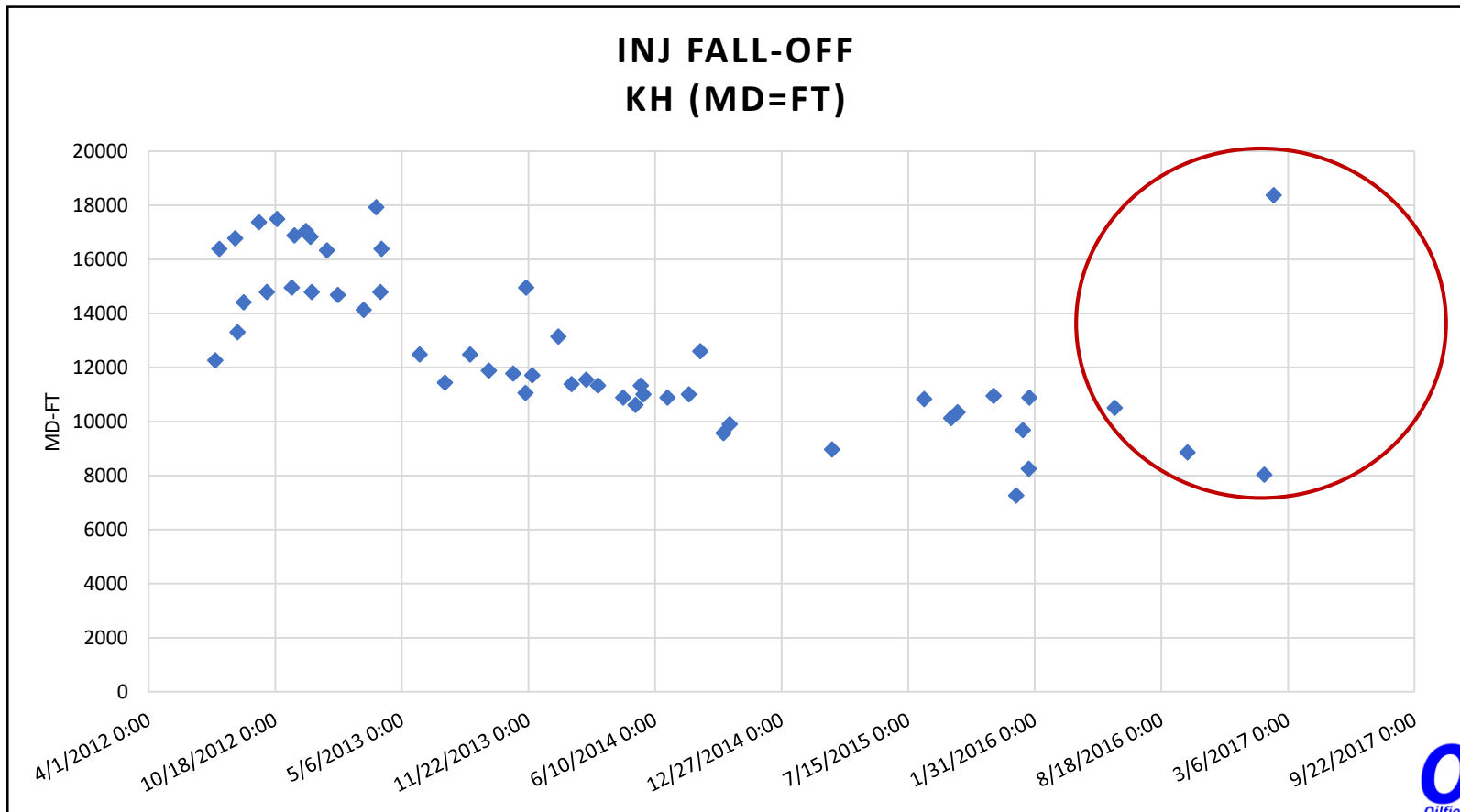
# Auto-PTA: Permeability (Early-time IARF)

- Permeability was gradually decreasing with time
  - An indication of scale build-up
- Big increase in permeability was observed from Feb 11, 2017 Fall-off test after the well was re-stimulated in late Jan 2017
  - From 14 md (Jan 27, 2017) to 32.9 md (Feb 11, 2017)
  - 135 % increase in perm



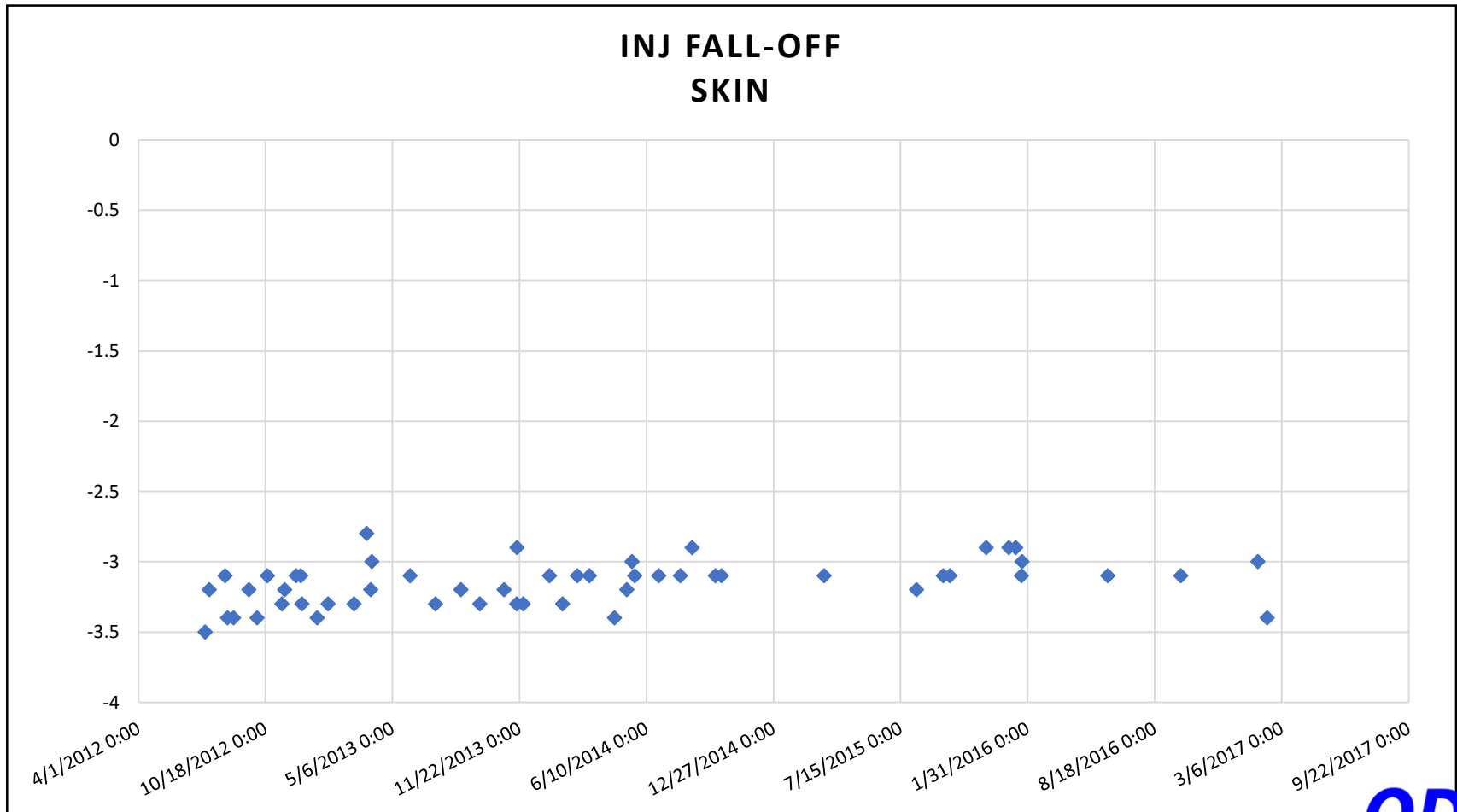
# Auto-PTA: kh (Early-time IARF)

- kh was gradually decreasing with time
  - An indication of scale build-up
- Big increase in kh was observed from Feb 11, 2017 Fall-off test after the well was re-stimulated in late Jan 2017
  - From 8 030 md-ft (Jan 27, 2017) to 18 377 md-ft (Feb 11, 2017)
  - 135 % increase in kh



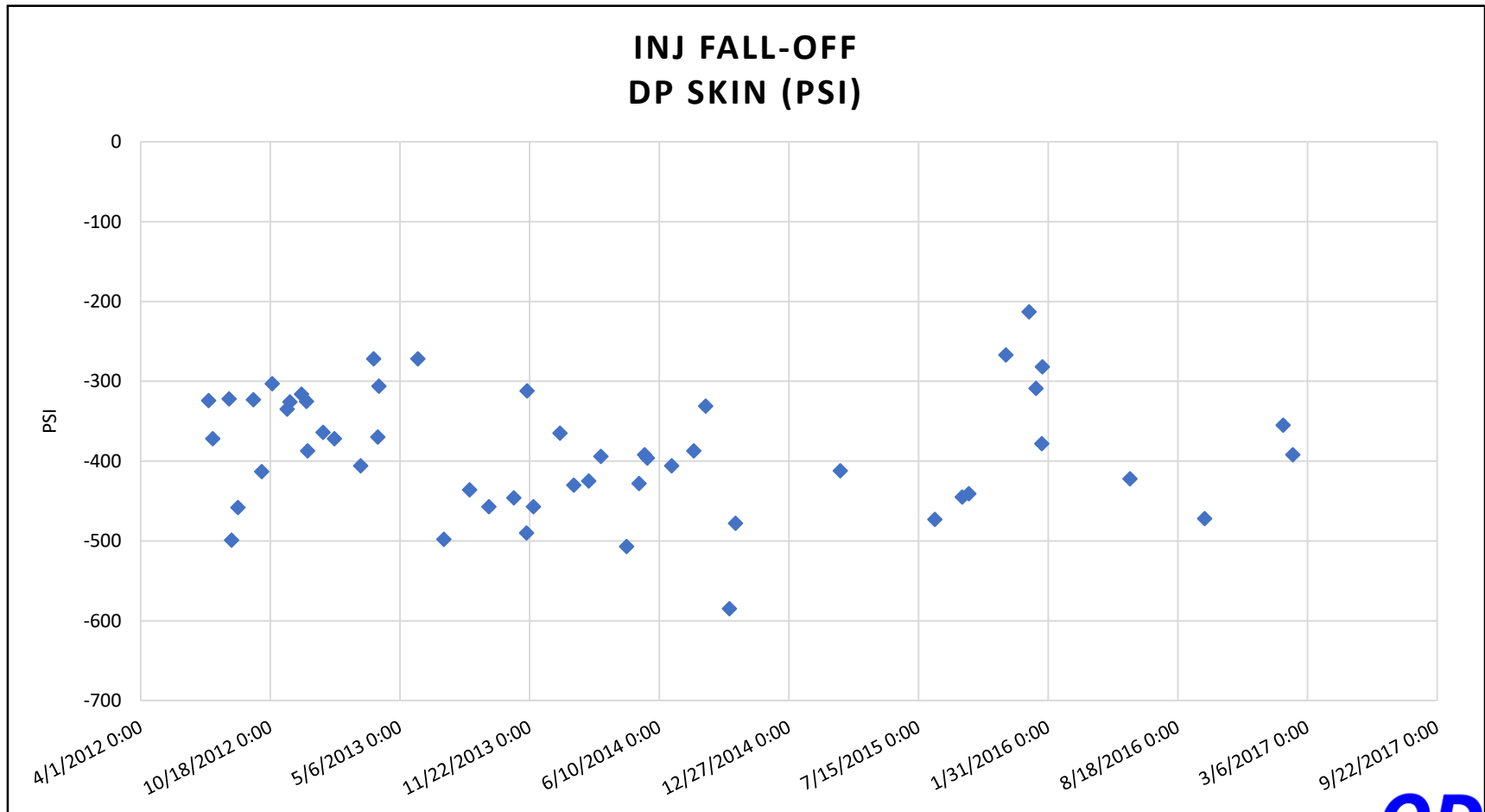
# Auto-PTA: Skin (Early-time IARF)

- Negative (stimulated) skin
- Fairly constant throughout the well's life



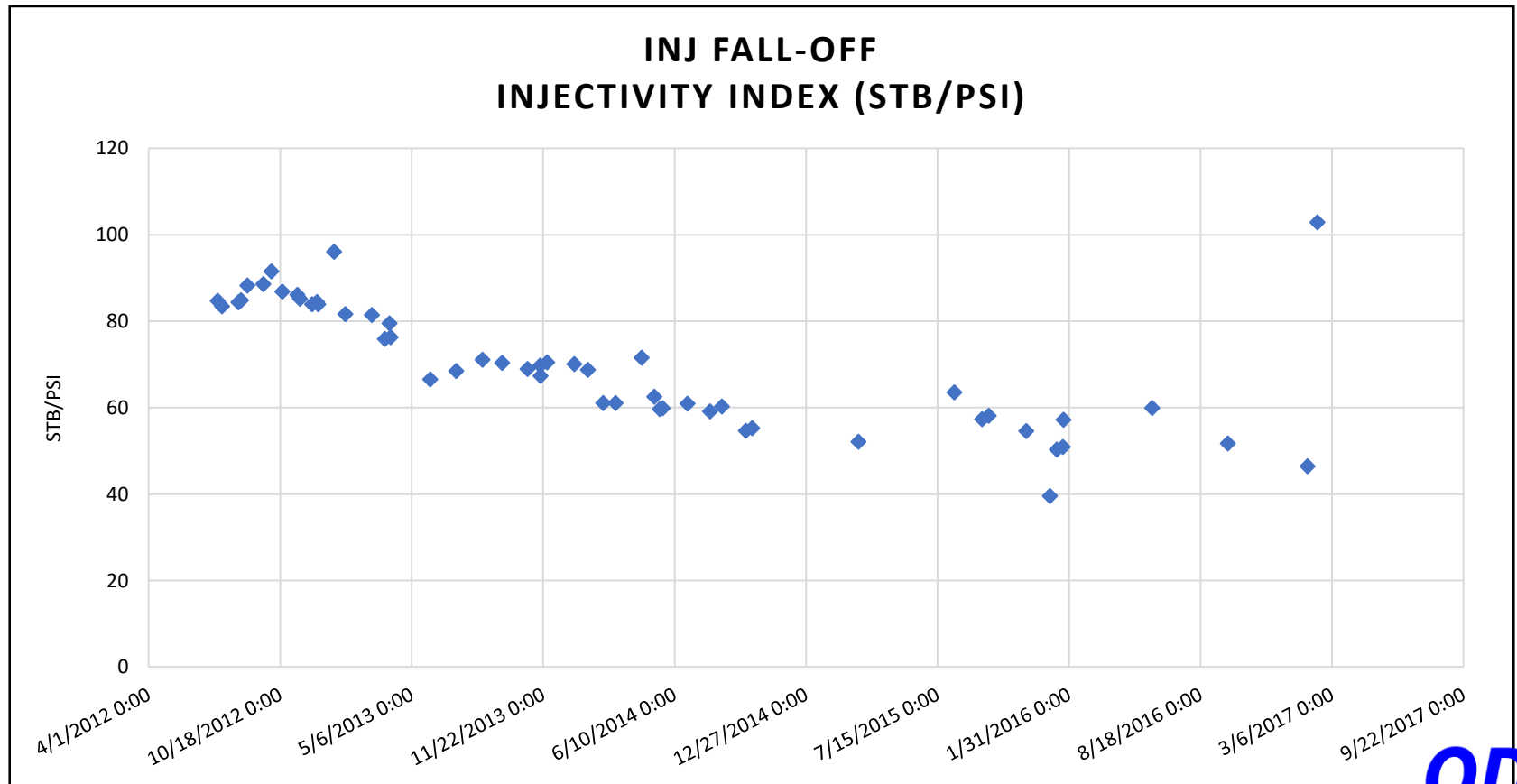
# Auto-PTA: DP Skin (Early-time IARF)

- Negative (stimulated) skin
- Fairly constant pressure drop due to skin throughout the well's life



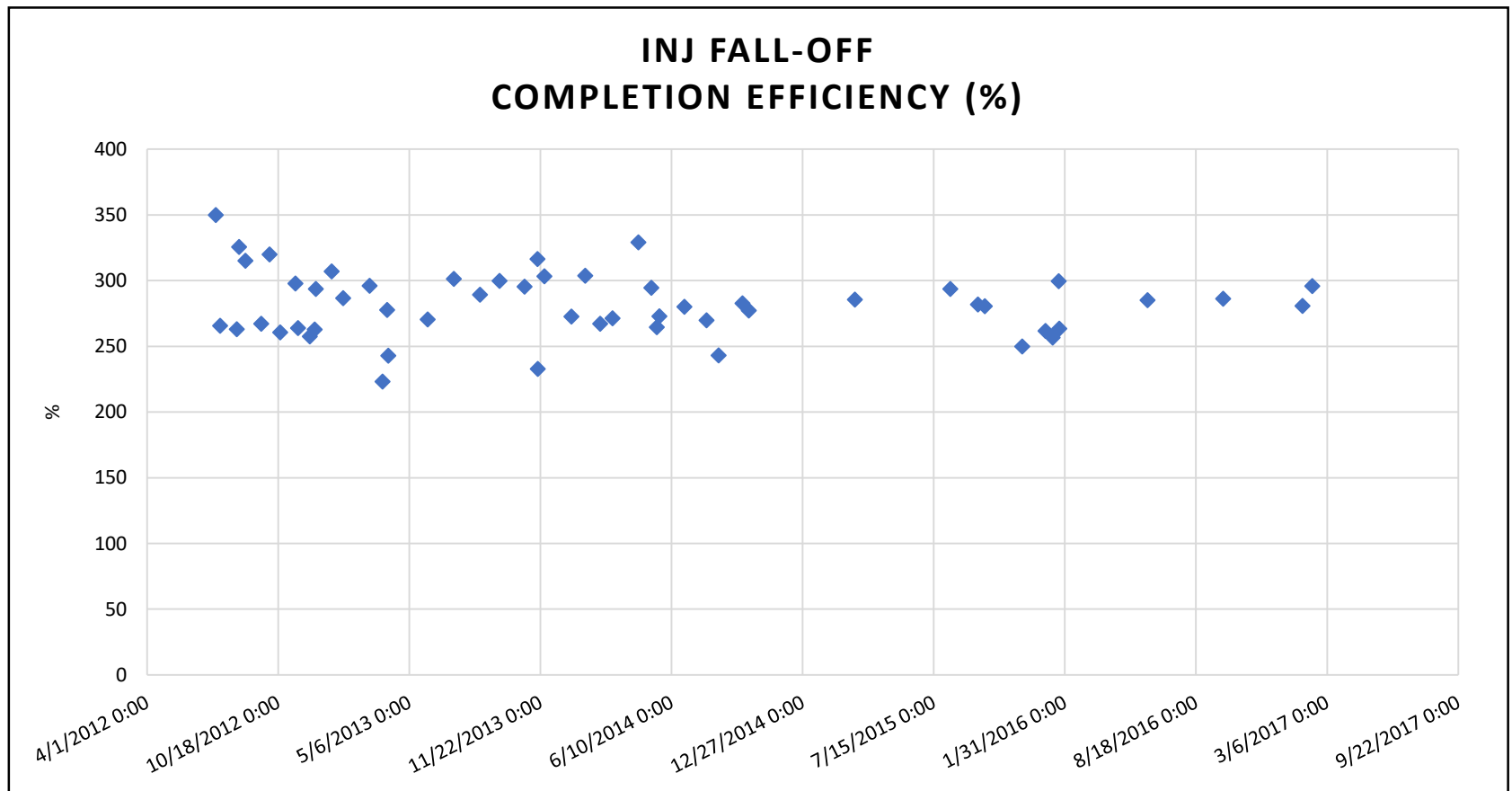
# Auto-PTA: II (Early-time IARF)

- Gradually decreasing Inj Index with time
  - From 88 STB/psi (Aug 2012) to 47 STB/psi (Jan 2017)
  - An indication of scale build-up
- Inj Index jumped from 47 STB/psi to 103 STB/psi after the re-stimulation job in late Jan 2017
  - 120 % increase



# Auto-PTA: Completion Efficiency (Early-time IARF)

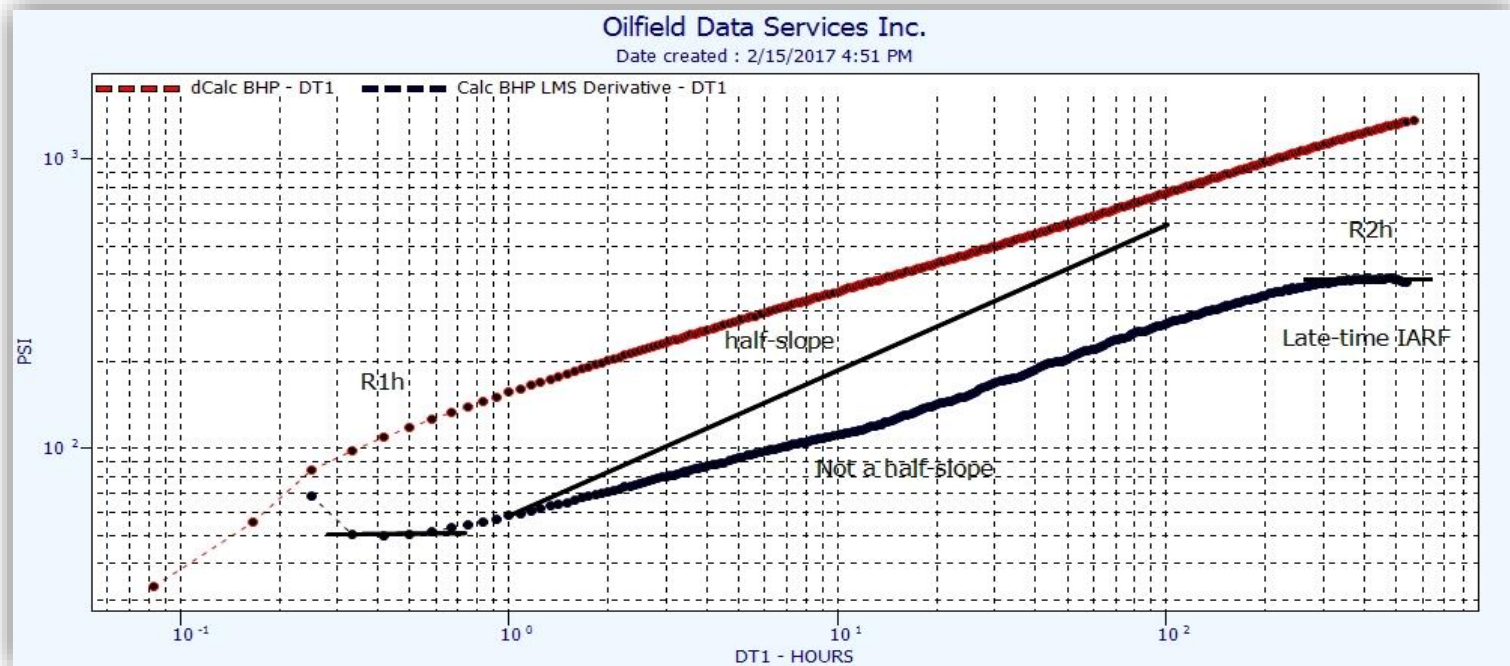
- Good Completion Efficiency
- Fairly constant throughout the production history as skin was not changing much



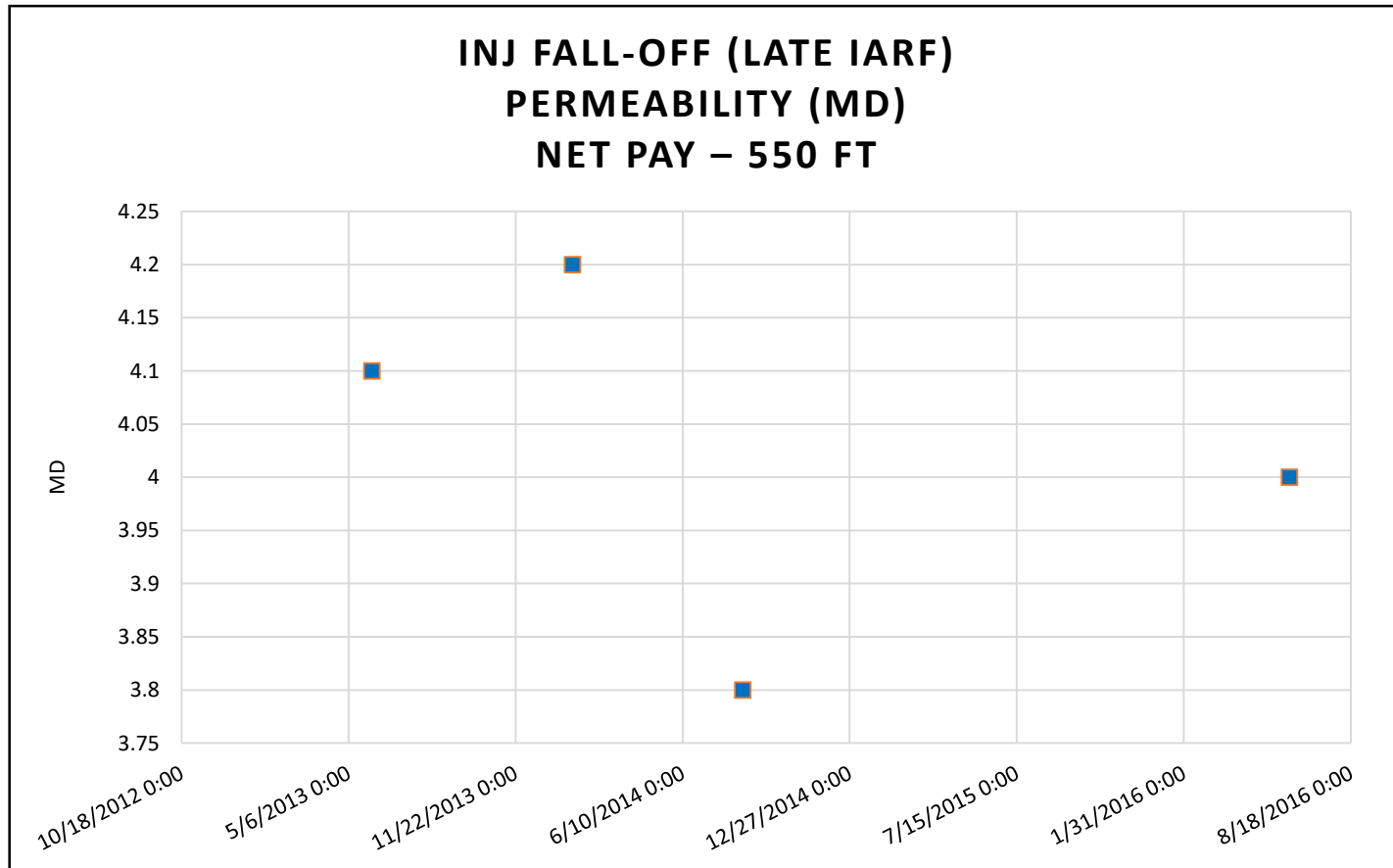
# Auto-PTA Summary Table (Late-time IARF)

Start Time	End Time	Test Length	Type	DHGPI	DHGPI	BHPi	BHPf	Qwi	Qw	Total Perm	kh	Total Skin	Total Sk	PStar	Comp Eff	PI_Water	DPs/Q
ddMMMyyyy HH:mm:ss	ddMMMyyyy HH:mm:ss	HOURS		PSIA	PSIA	PSIA	PSIA	STB/D	STB/D	md	md-ft		PSI	PSIA	%	BBL/PSI	PSI/(STB/D)
6/2/2013 23:45	6/26/2013 16:55	569.2	Fall-Off	-1	-1	8188	6720	17001	17001	4.1	2255	-5.4	-4144	6502	521.38	17.29	-0.24
1/29/2014 3:45	2/11/2014 5:05	313.3	Fall-Off	7705	6484	8205	7021	14558	14558	4.2	2310	-5.1	-3371	6653	585.42	20.96	-0.23
8/20/2014 17:50	9/22/2014 9:05	783.3	Fall-Off	7696	6082	8199	6619	13855	13855	3.8	2090	-5.1	-3468	6536	595.23	19.78	-0.25
6/5/2016 7:05	6/26/2016 22:10	519.1	Fall-Off	7780	6291	8284	6578	13623	13623	4	2200	-4.9	-3168	6618	673.11	24.65	-0.23

Late IARF was observed at around ~ 300 hrs

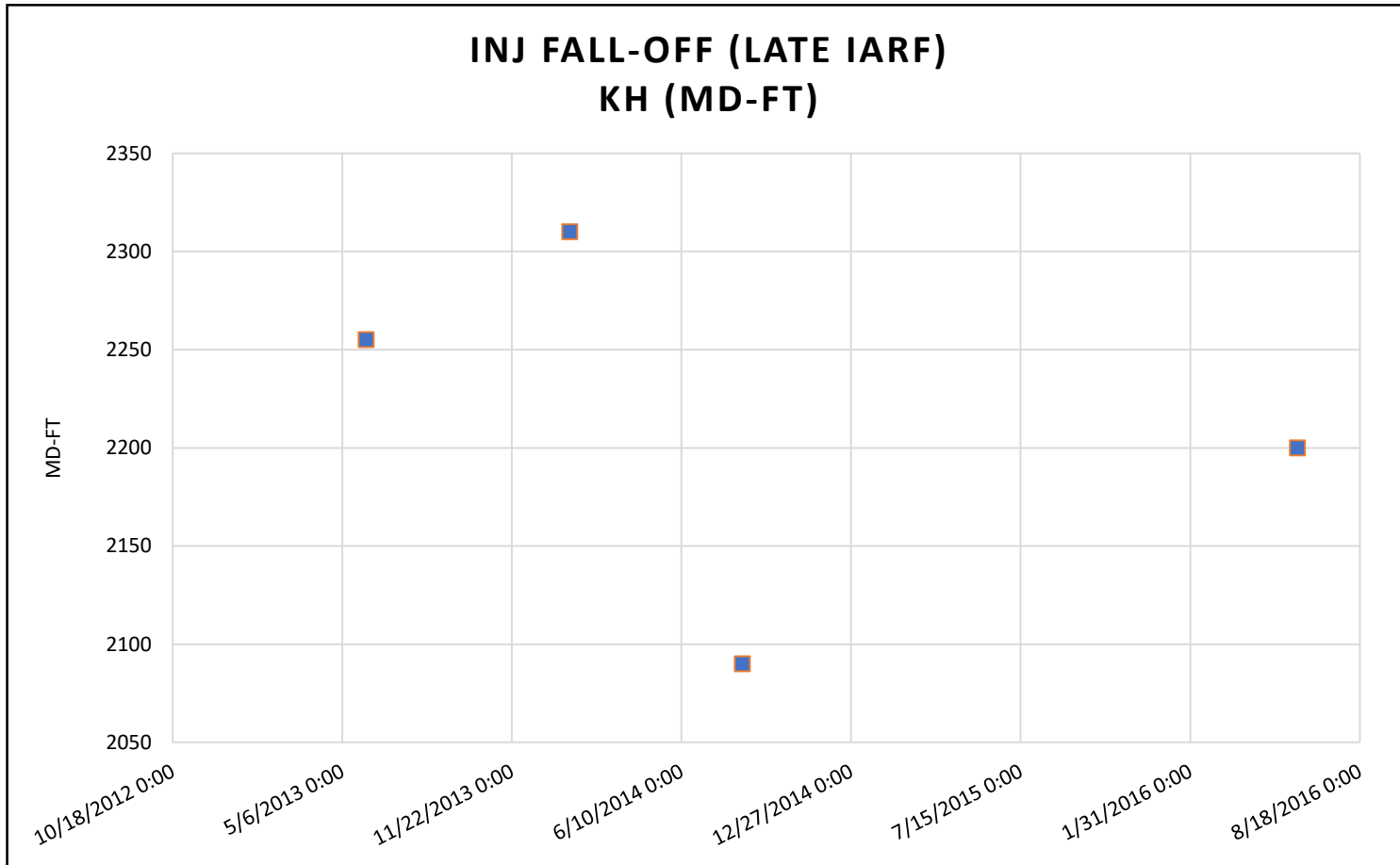


# Auto-PTA: Permeability (Late-time IARF)

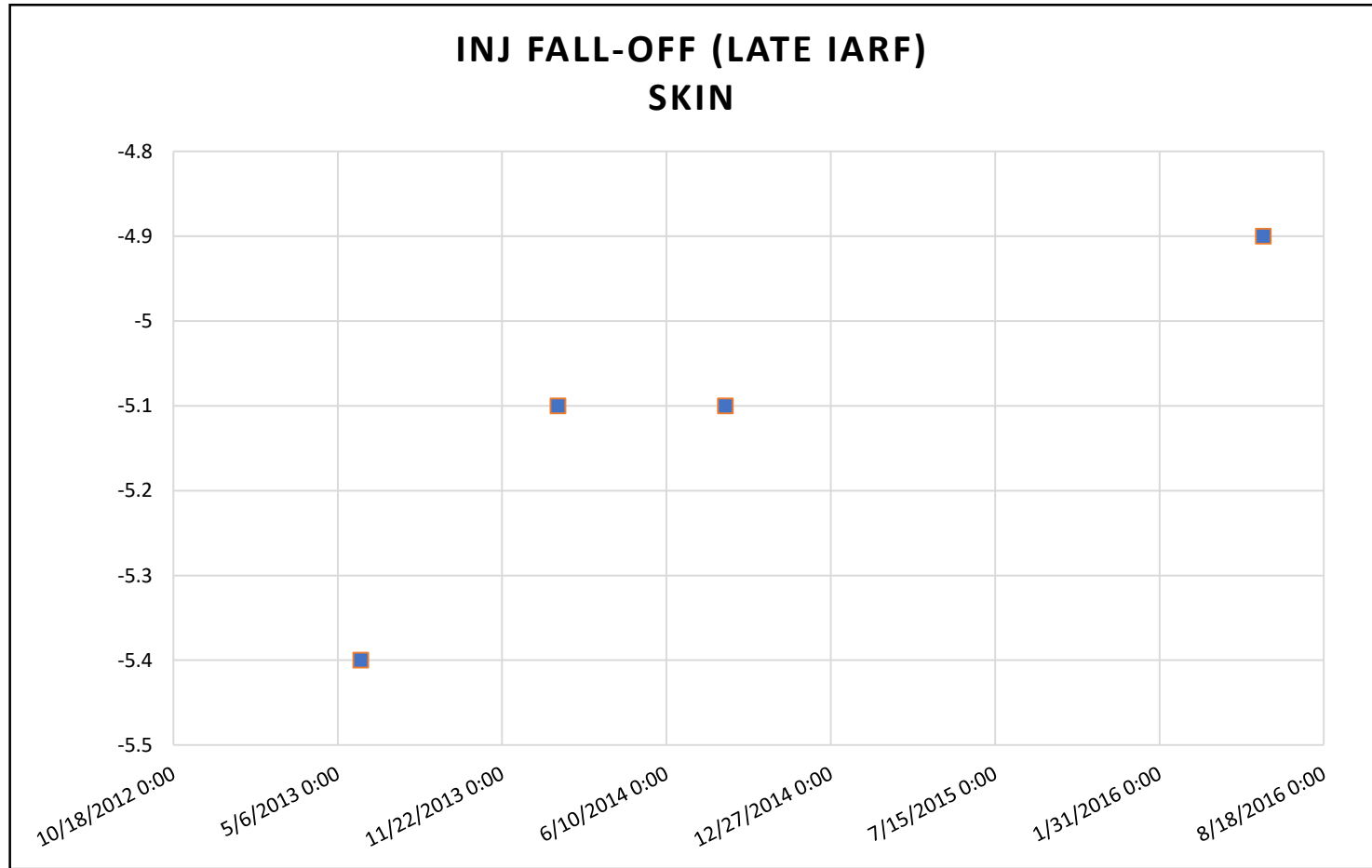




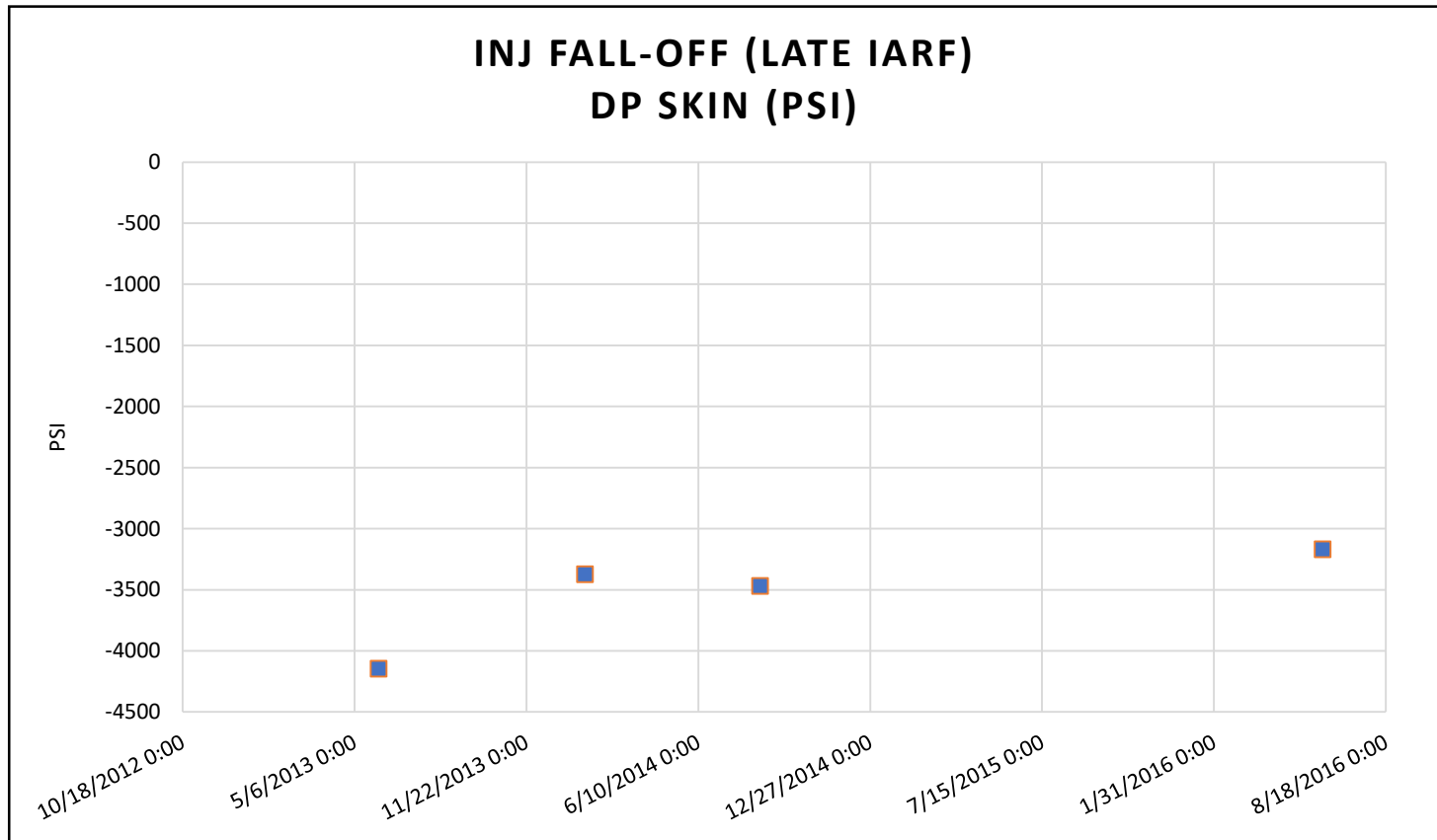
# Auto-PTA: kh (Late-time IARF)



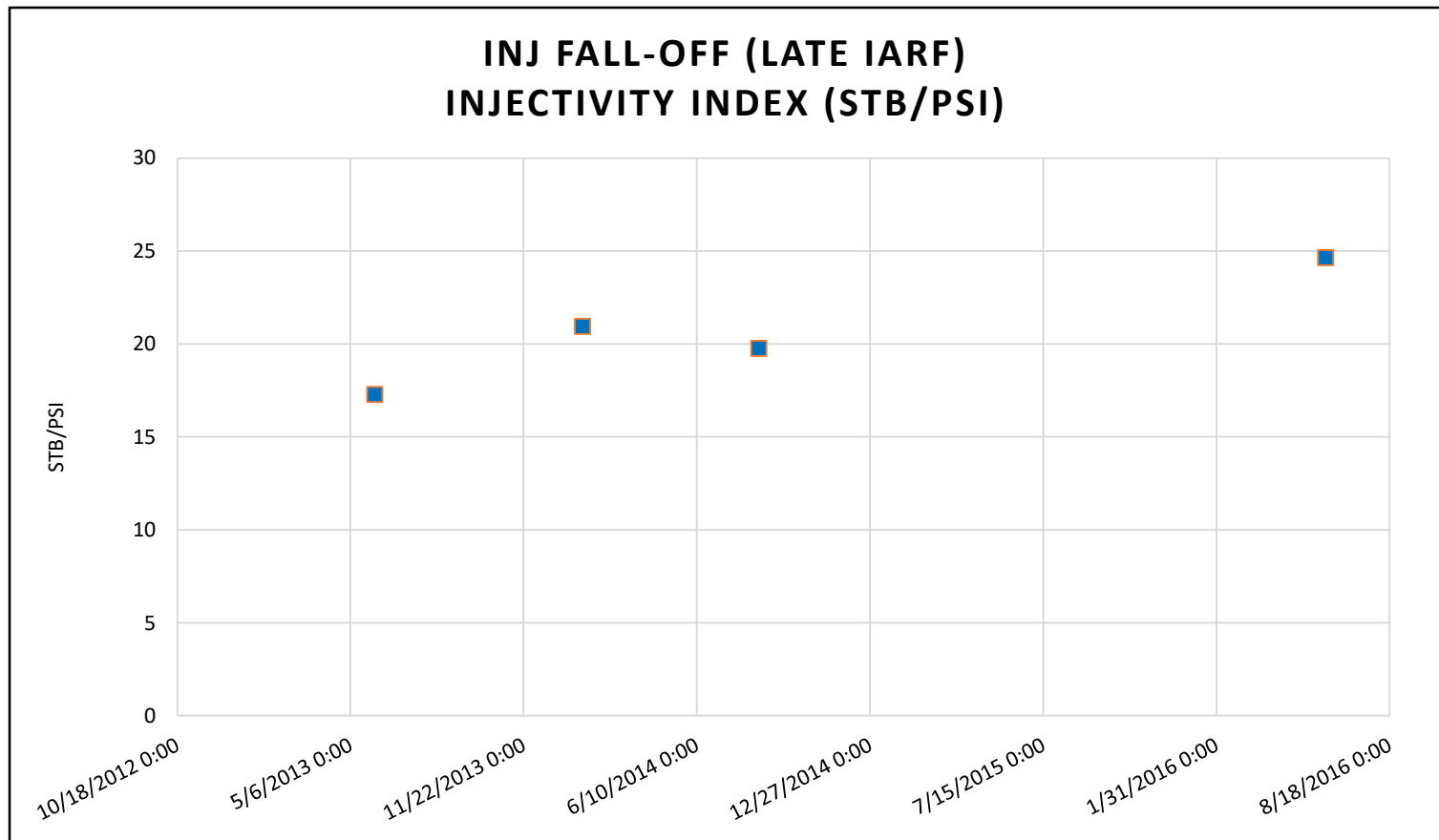
# Auto-PTA: Skin (Late-time IARF)



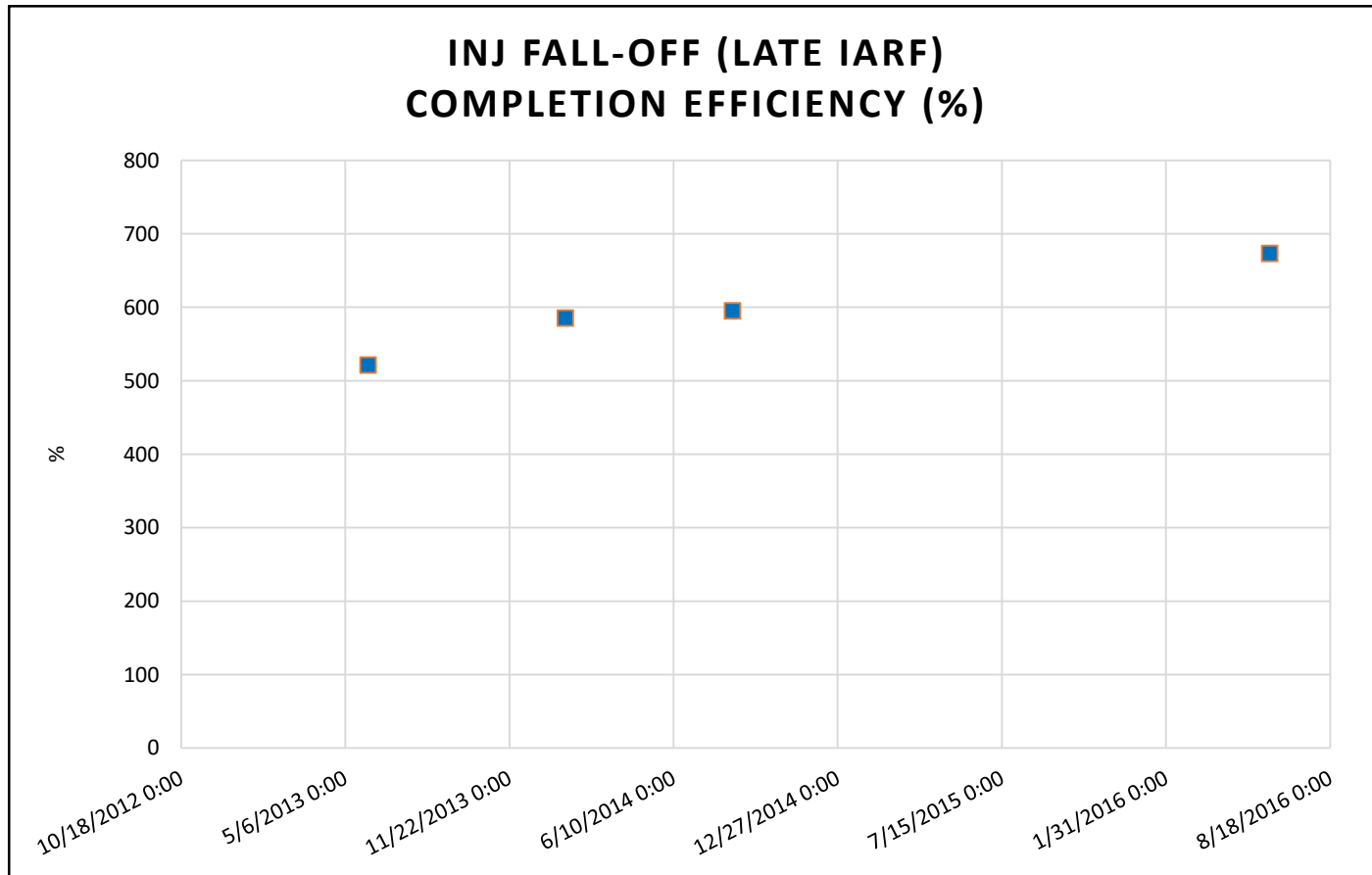
# Auto-PTA: DP Skin (Late-time IARF)



# Auto-PTA: Inj Index (Late-time IARF)



# Auto-PTA: Completion Efficiency (Late-time IARF)



# Auto-PTA Results

(Using Measured Rates)

# Auto-PTA with Measured Rates

- Upon Operator's request, automated PTA was performed using measured rates for the comparison purposes
- Similarly, PTA was done for both early and late time radial flow
- The following slides compare the results obtained from both measured and calculated rates

# PTA with Measured Rates

- Inputs for auto-PTA
  - WHP
  - DHGP/T
  - Measured Injection Rate

The screenshot displays a software interface for configuring PTA (Pressure Transient Analysis) with measured rates. The interface is divided into several sections:

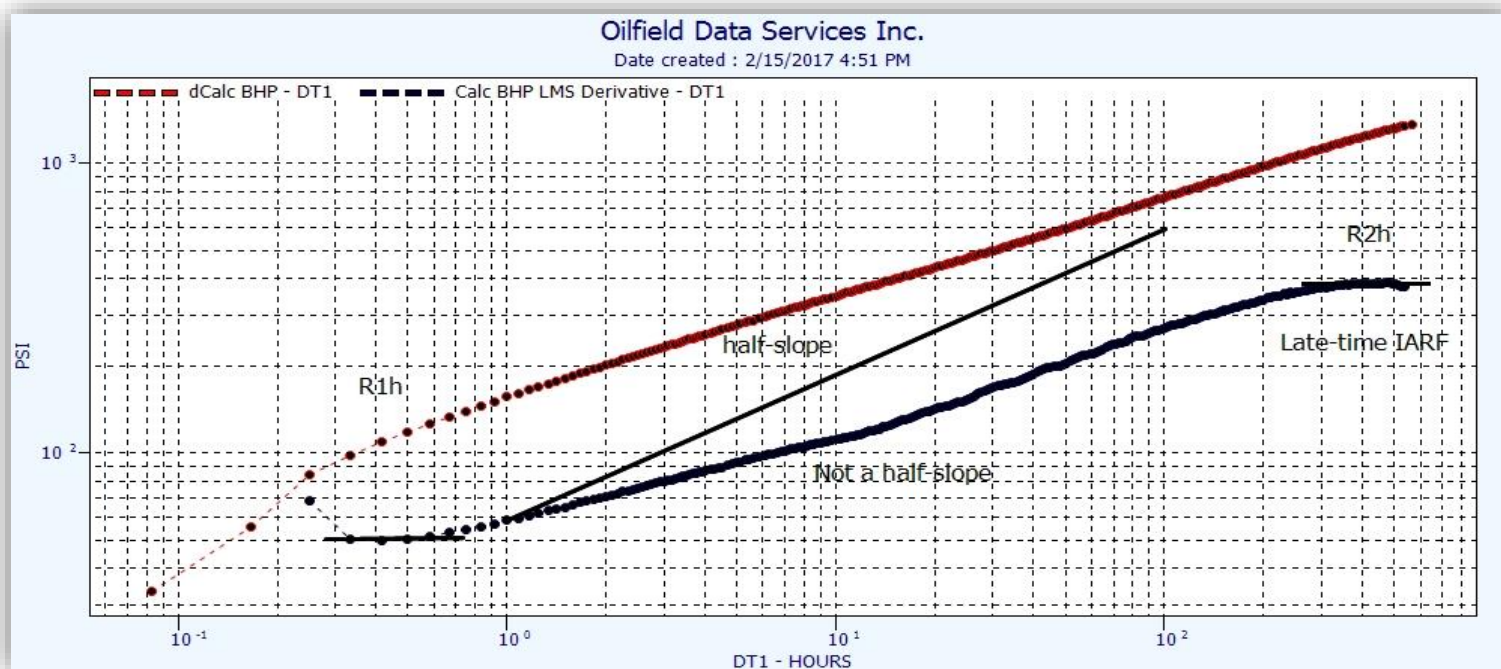
- Inputs**: A tabbed interface with 'Inputs', 'Summary', 'Outputs', and 'Reports' tabs. The 'Inputs' tab is active.
- Select Input Data**: A table of input parameters with dropdown menus for selection. Two rows are highlighted with red boxes:
  - WHP: WHP (dropdown), PSIA (unit)
  - WHT: None (dropdown)
  - DHGP: DHGP (dropdown), PSIA (unit)
  - DHGT: DHGT (dropdown), DEGC (unit)
  - QGas: None (dropdown)
  - GG: None (dropdown)
  - Yo: None (dropdown)
  - Yw: None (dropdown)
  - SCSSV: None (dropdown)
  - Ext QGas: None (dropdown)
  - Qo: None (dropdown)
  - Qw: Provided QWinj (dropdown), STB/D (unit) - This row is highlighted with a red box.
  - QTotal: None (dropdown)
  - BHP: None (dropdown)
- Config**: A section for configuring the analysis:
  - SamplesPerUpdate**: A text input field containing '100'.
  - Config Ok**: A button labeled 'Load Config'.
  - Analysis Enabled**: A checked checkbox.
  - Reserves Enabled**: An unchecked checkbox.
  - MLTO (DEGF)**: An unchecked checkbox with a text input field containing '15'.
  - Legacy MLTO (not used in rate calc)**: A red text label.
  - VSSV Open**: An unchecked checkbox.
  - Ignore invalid events**: An unchecked checkbox.
  - No CalcRate Smoothing**: An unchecked checkbox.
  - Rate Calc from Perm**: A section with an unchecked checkbox labeled 'Enabled'.
- Buttons**: 'Refresh Columns' and 'Export Inputs' buttons are located at the bottom of the 'Select Input Data' section.



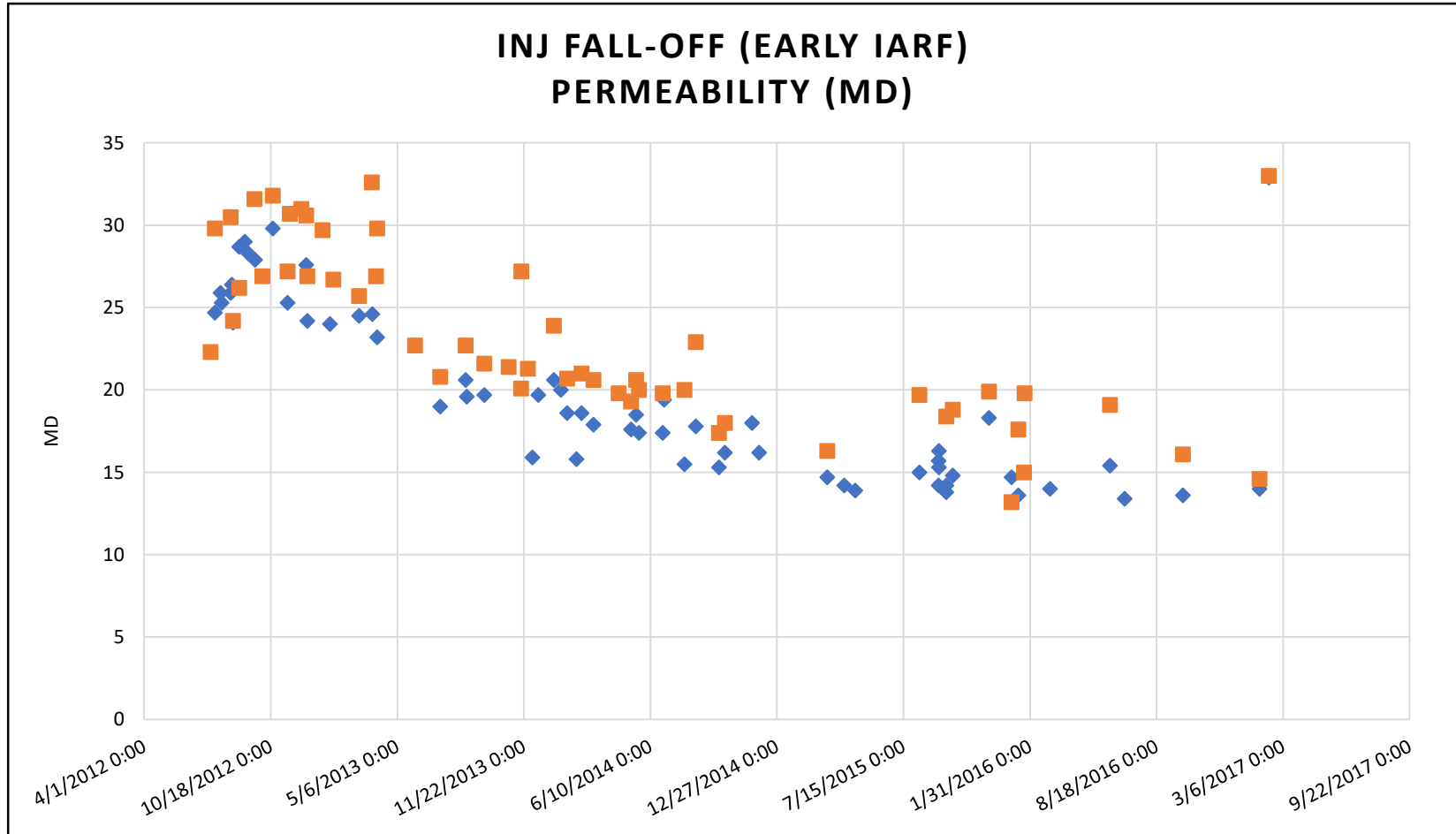


# Auto-PTA Summary Table (Late-time IARF)

Start Time	End Time	Test Length	Type	DHGPI	DHGPF	BHPi	BHPf	Qwi	Qwf	Total Perm	kh	Total Skin	P Total Sk	PStar	Comp Eff	II_Water	DPs/Q
ddMMMyyyy HH:mm:ss	ddMMMyyyy HH:mm:ss	HOURS		PSIA	PSIA	PSIA	PSIA	STB/D	STB/D	md			PSI	PSIA	%	BBL/PSI	PSI/(STB/D)
6/2/2013 22:55	6/26/2013 18:50	571.9	DD	7702	6182	8192	6719	16523	16523	4	2200	-5.3	-4140	6502	520.14	16.77	-0.25
1/29/2014 3:45	2/11/2014 21:35	329.8	DD	7709	6470	8213	7006	13744	13744	3.9	2145	-5.1	-3431	6648	573.16	18.96	-0.25
8/20/2014 17:45	9/22/2014 9:05	783.3	DD	7696	6082	8204	6619	12877	12877	3.5	1925	-5	-3439	6536	594.05	18.5	-0.27
6/5/2016 7:05	6/26/2016 2:35	499.5	DD	7780	6303	8292	6840	11801	11801	3.4	1870	-4.8	-3102	6619	674.88	21.87	-0.26

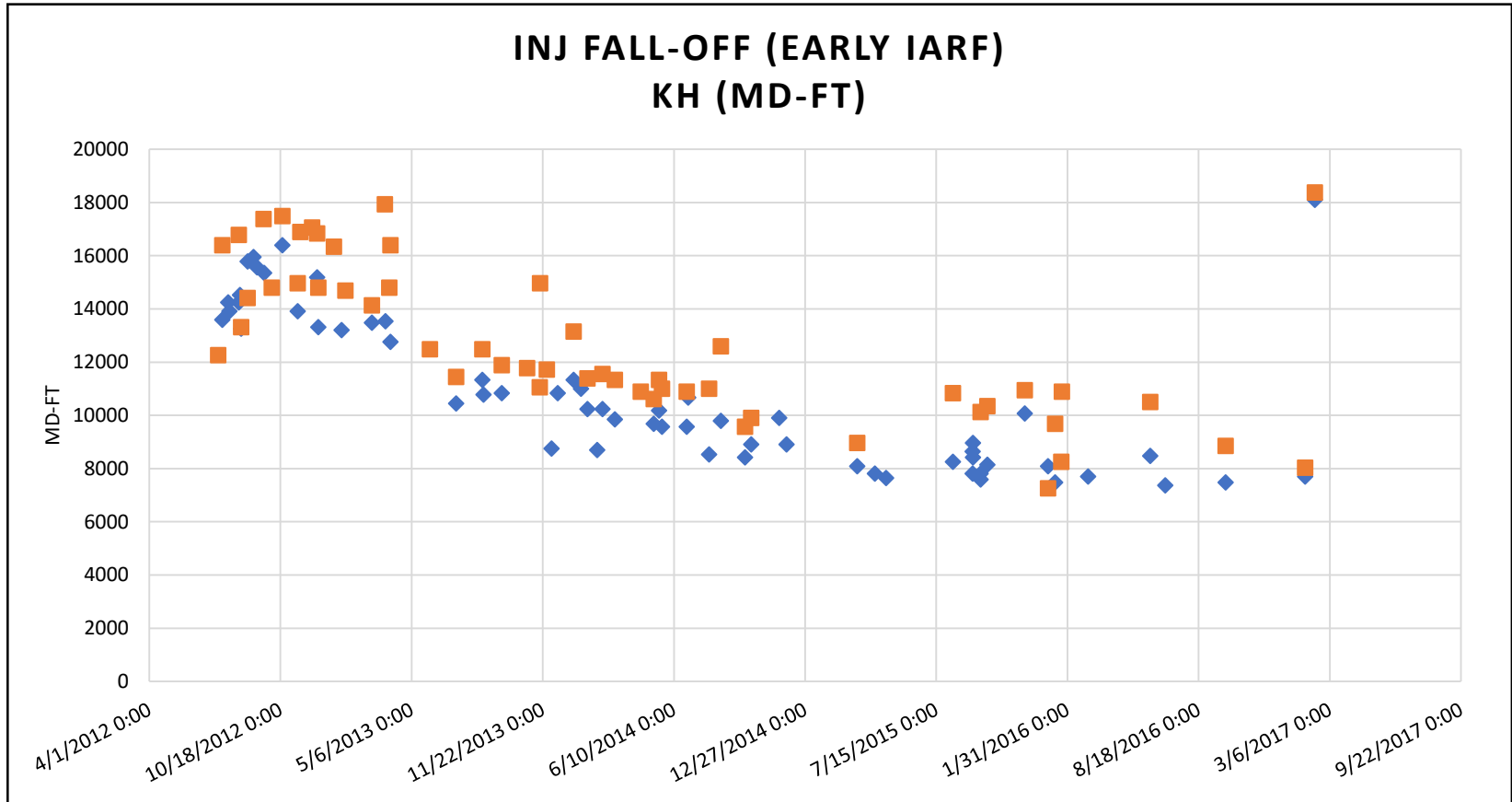


# Permeability Comparison (Early-time IARF)



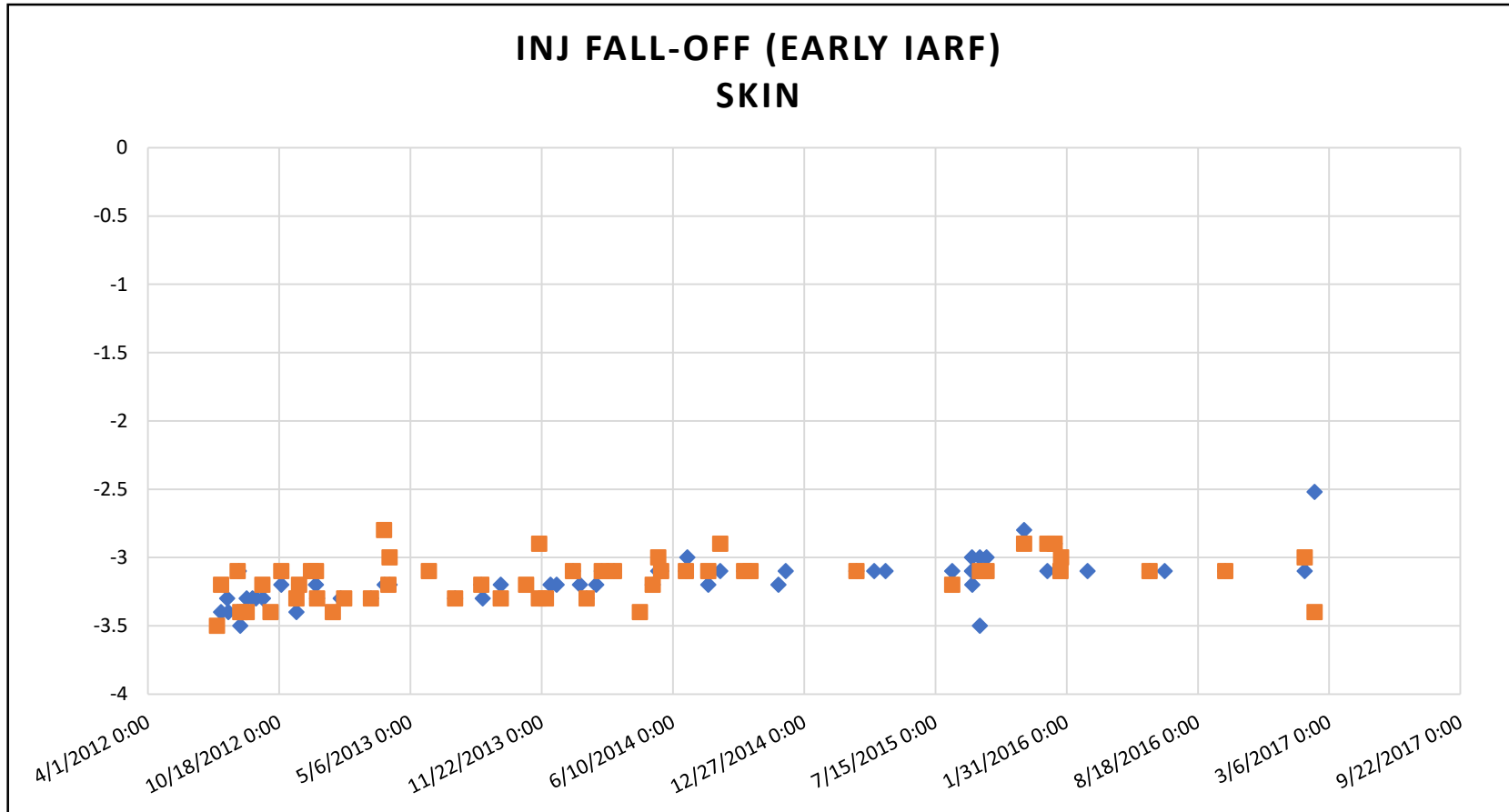
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# kh Comparison (Early-time IARF)



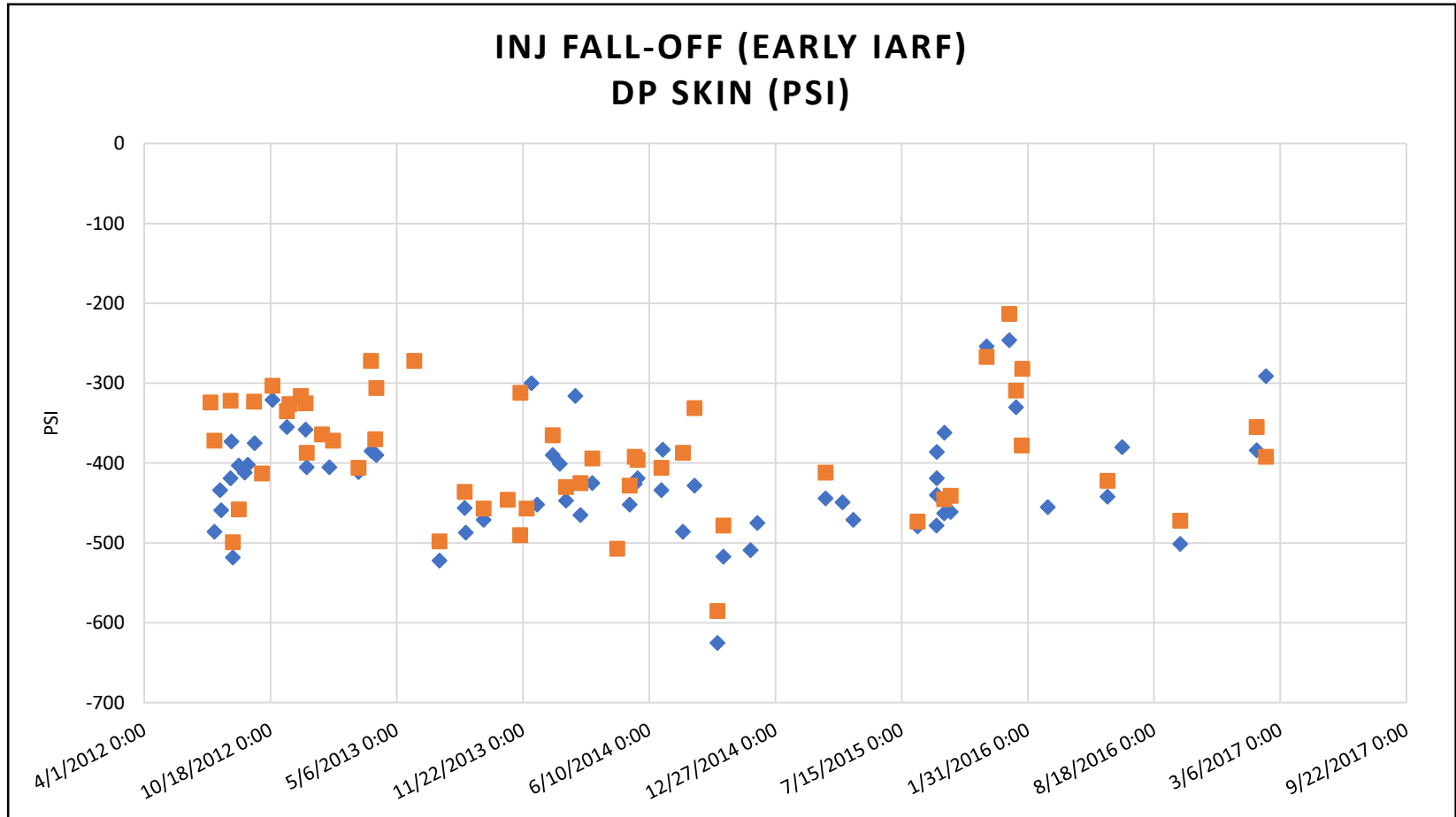
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# Skin Comparison (Early-time IARF)



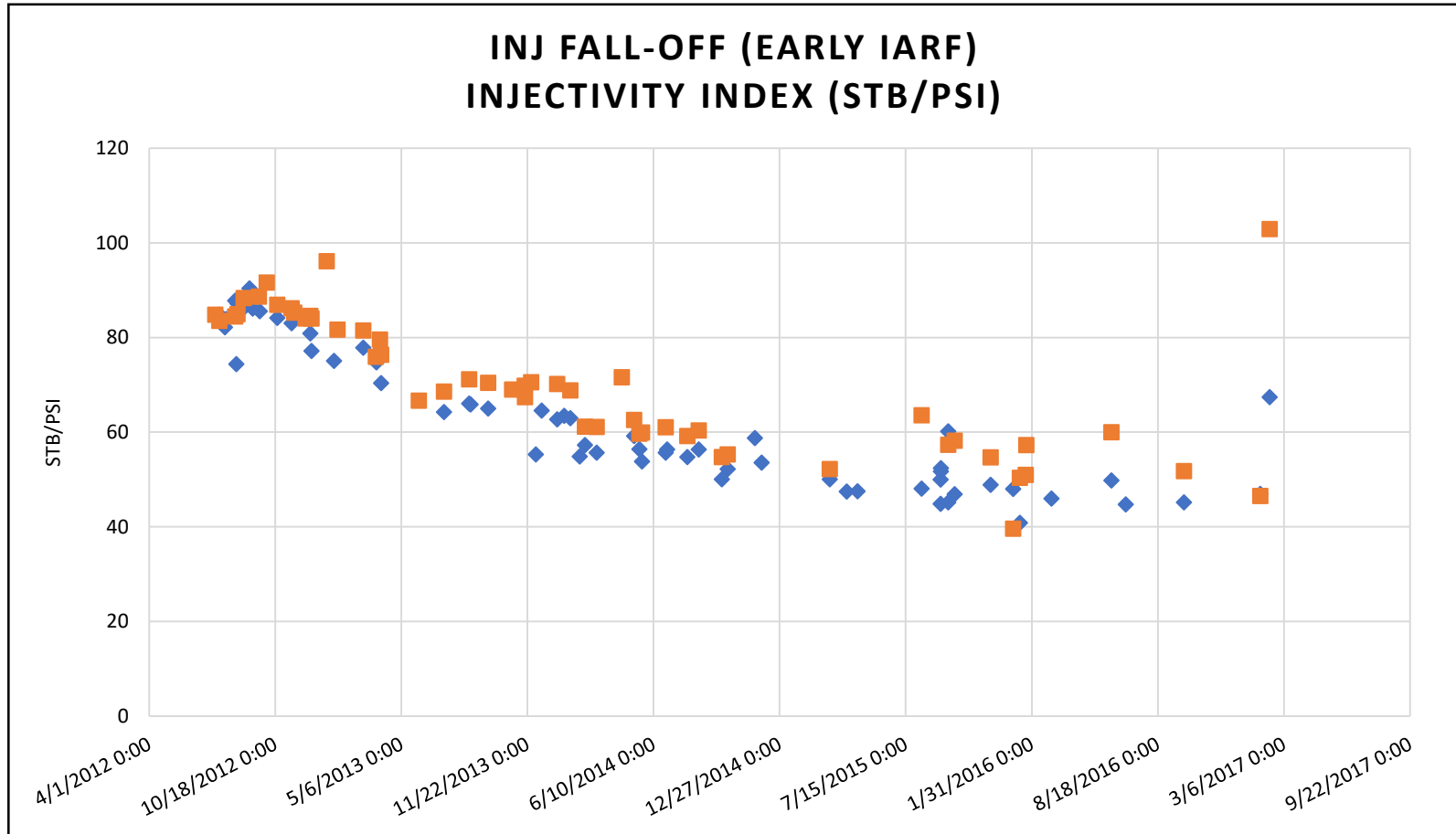
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# DP skin Comparison (Early-time IARF)



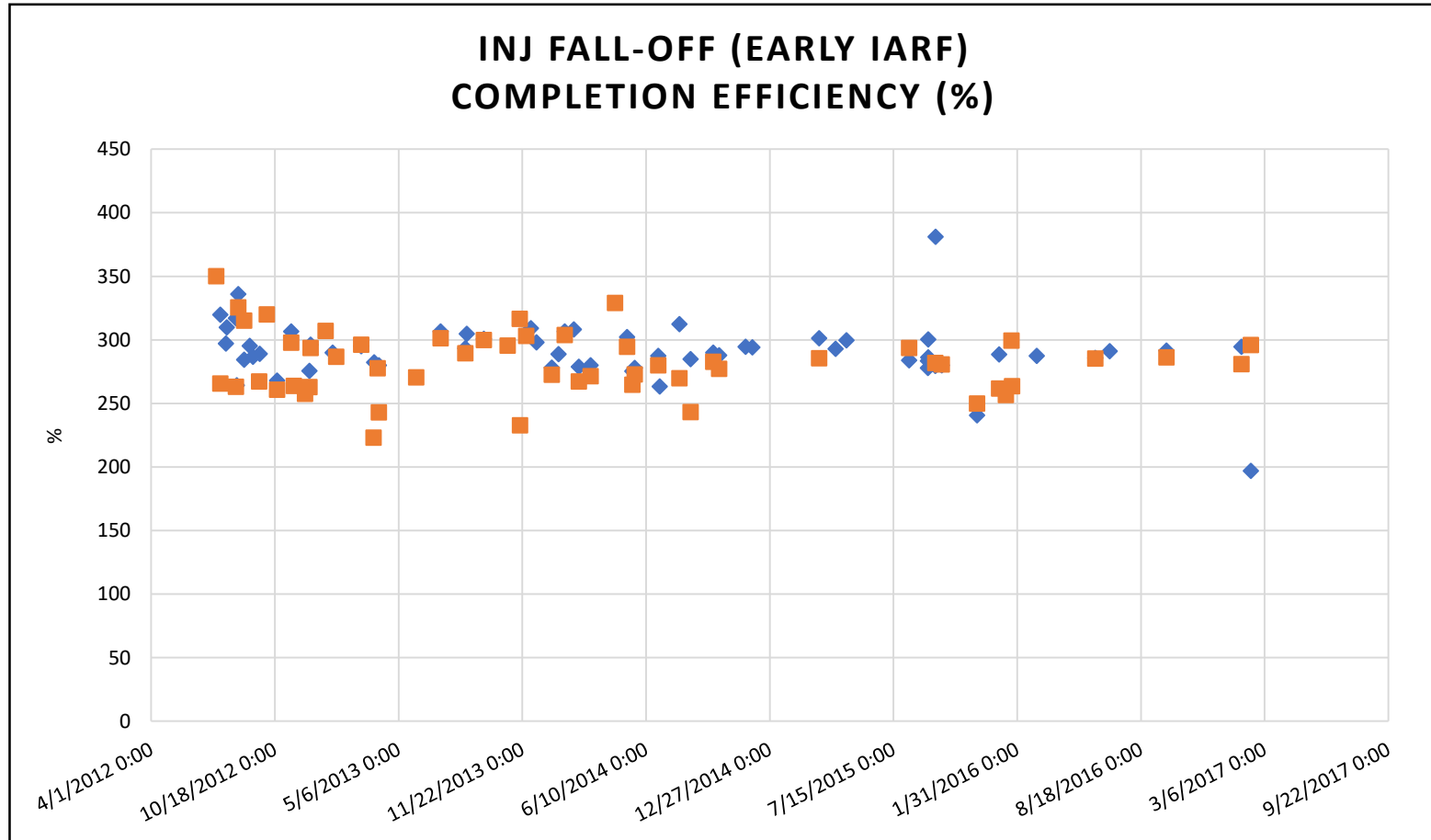
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# Inj Index Comparison (Early-time IARF)



- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

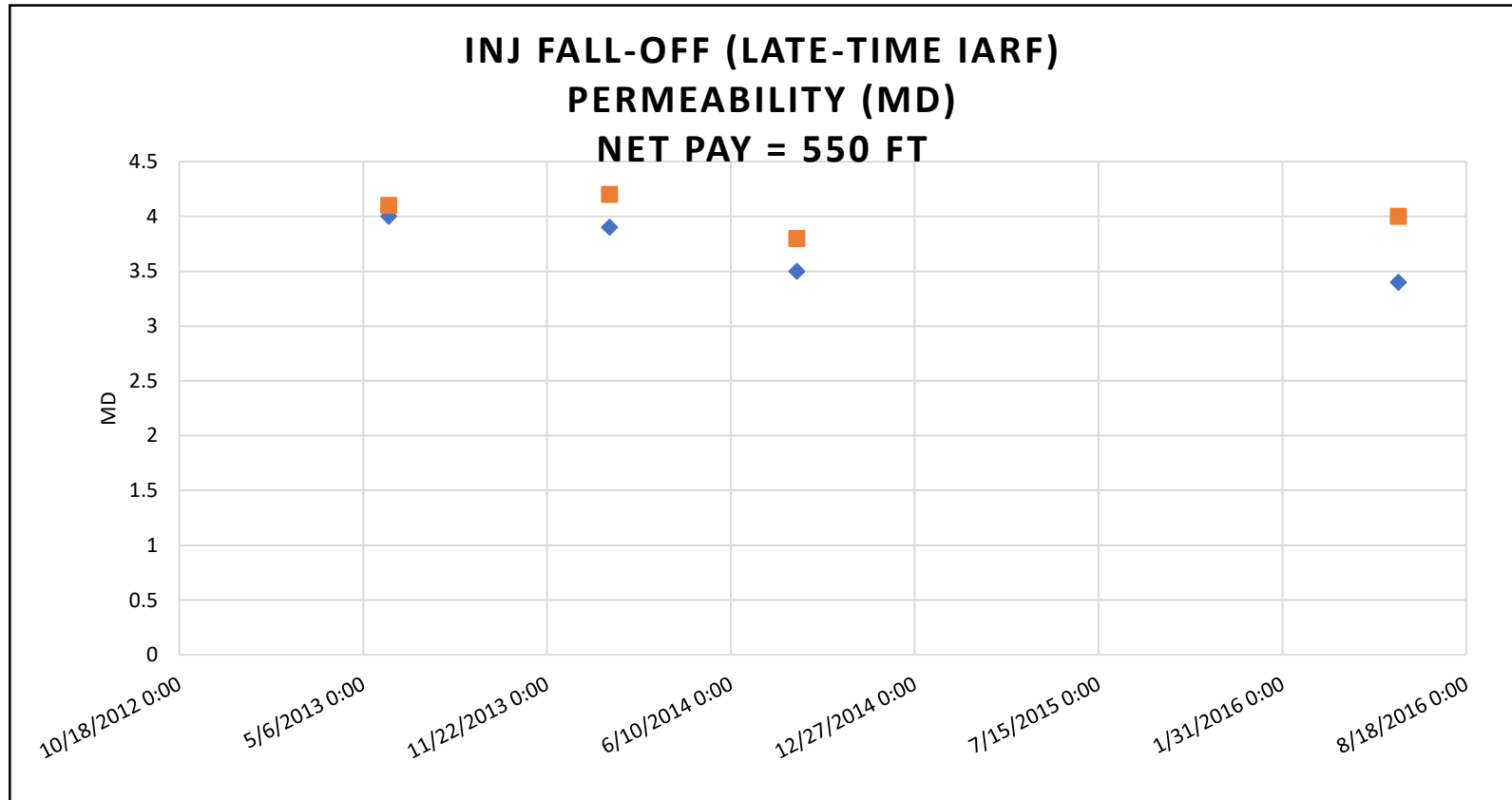
# Completion Efficiency Comparison (Early-time IARF)



- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

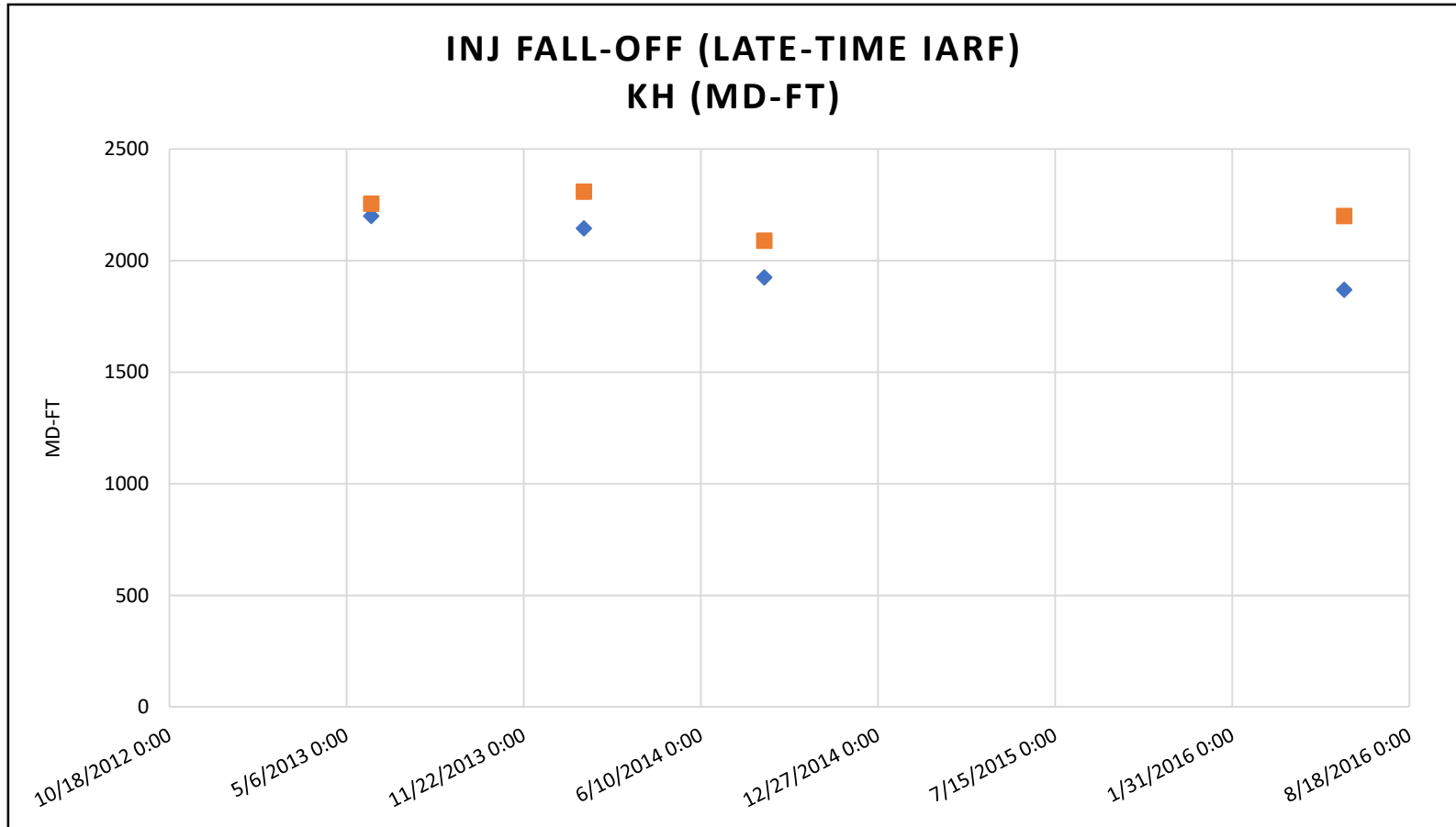


# Permeability Comparison (Late-time IARF)



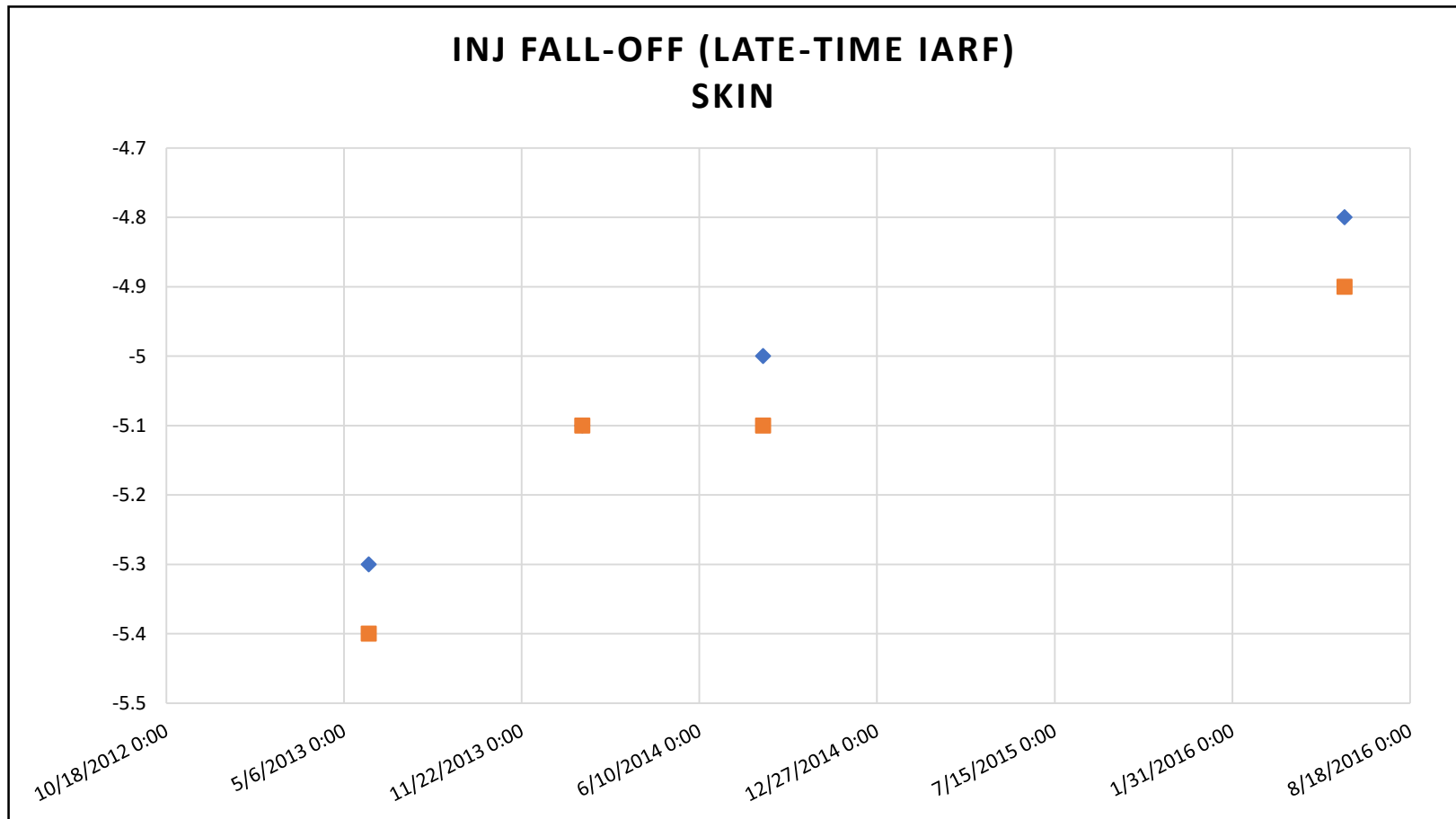
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# kh Comparison (Late-time IARF)



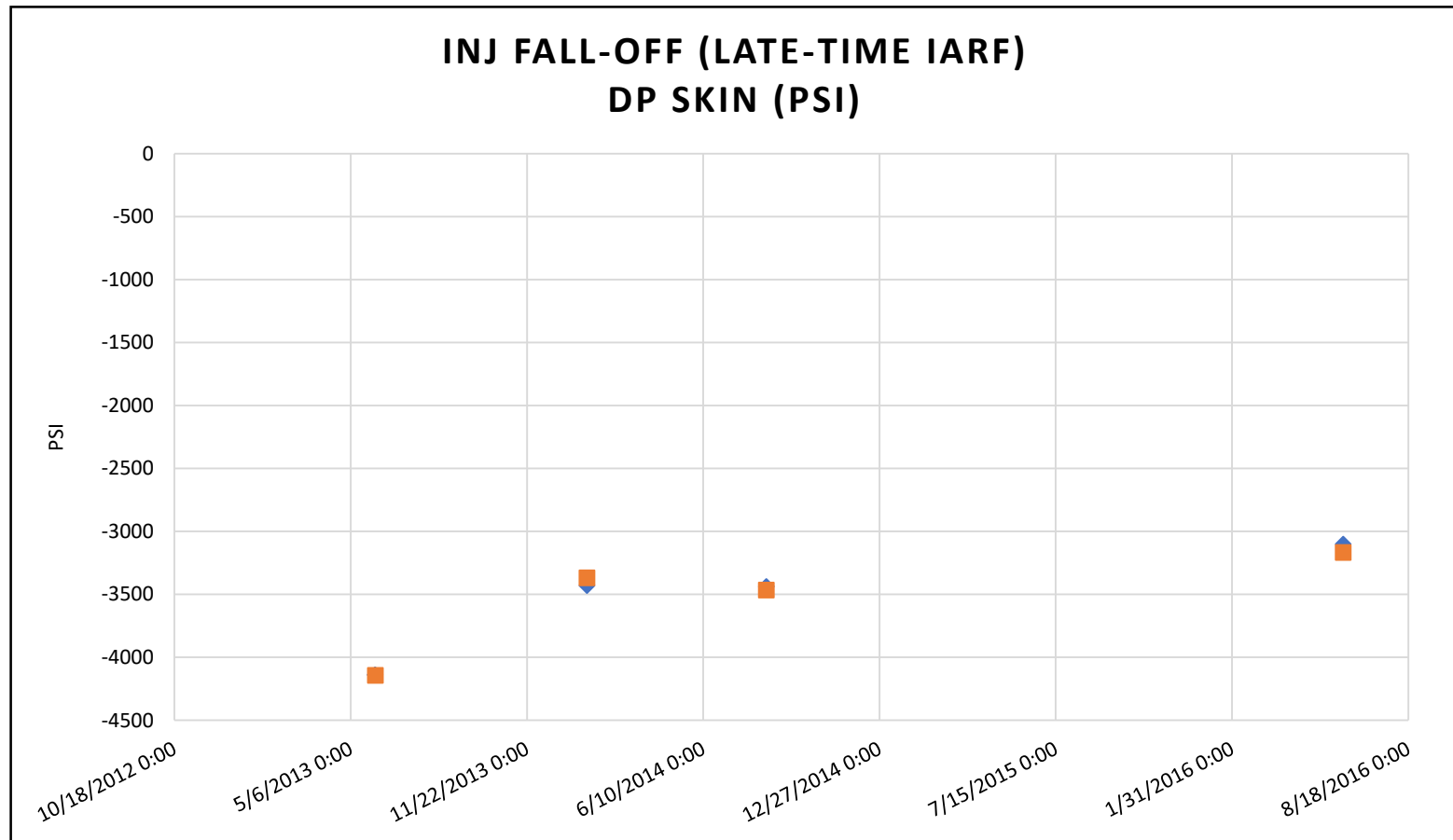
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# Skin Comparison (Late-time IARF)



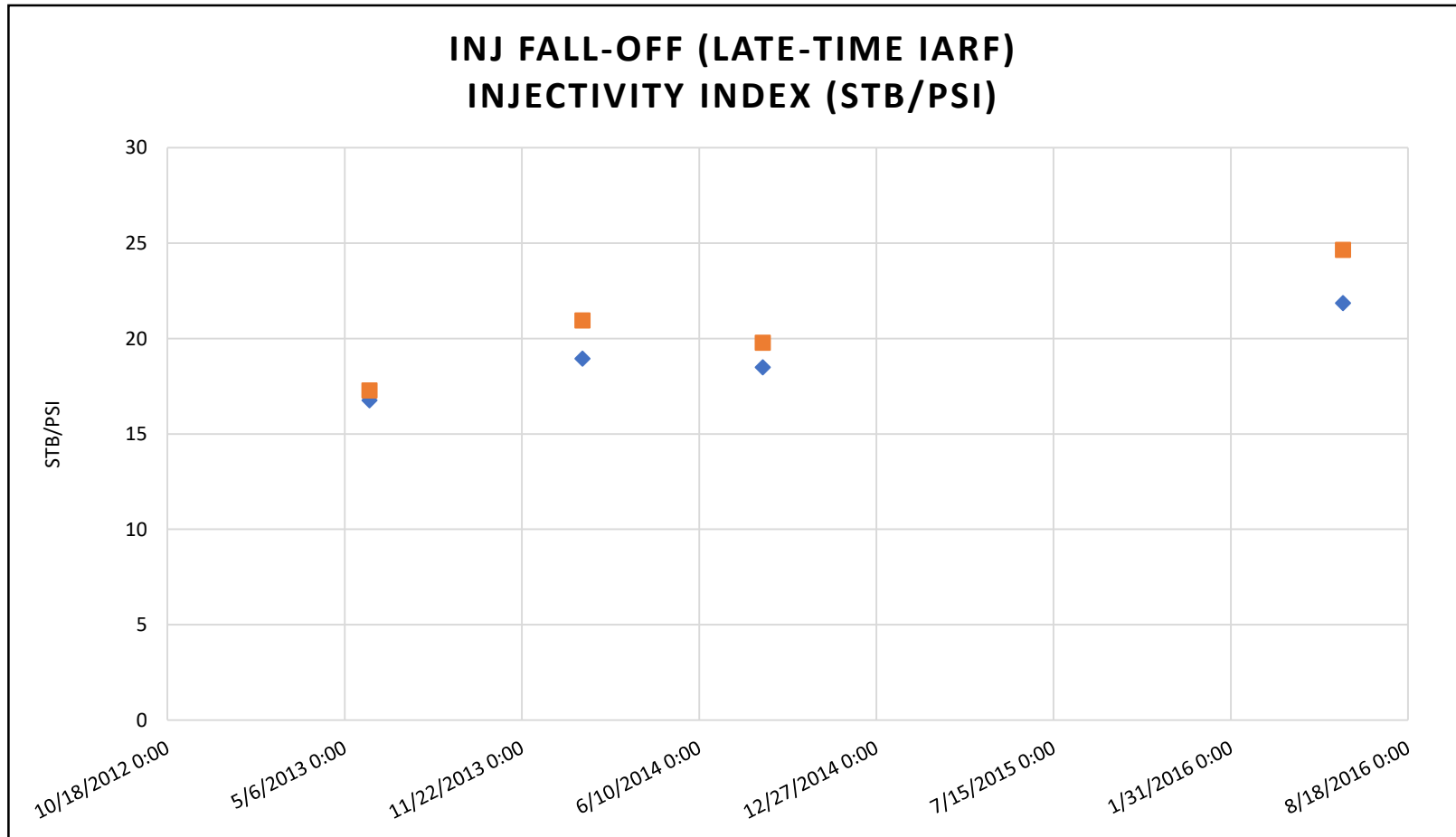
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# DP Skin Comparison (Late-time IARF)



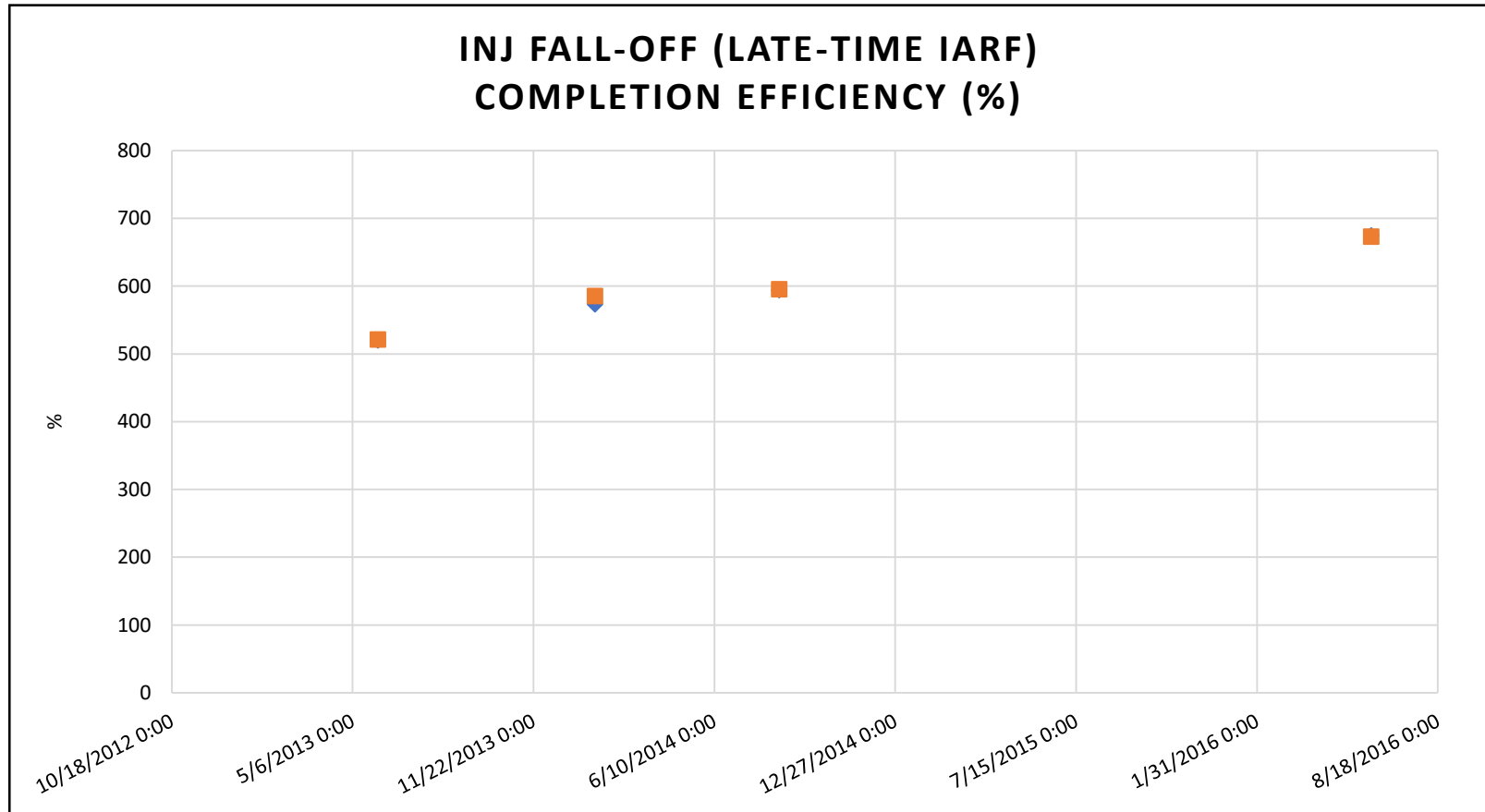
- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# Inj Index Comparison (Late-time IARF)



- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# Completion Efficiency Comparison (Late-time IARF)



- Blue – PTA results with measured rates
- Orange – PTA with calculated rates

# Feb 11, 2017 PTA Comparison Measured vs Calculated Rate

## PTA w Measured Rate

### *Oilfield Data Services, Inc.*

#### ANALYSIS RESULTS

INJECTION FALL OFF  
Feb/11 - 13/2017

#### Calculated Reservoir & Completion Properties

SKIN	-3.4	
PRESSURE DROP DUE TO SKIN	-387	PSI
COMPLETION EFFICIENCY	290	%
PERMEABILITY	33	md
RADIAL FLOW INJECTIVITY INDEX (II)	98.9	STB/PSI
SKINLESS RADIAL FLOW II	34.1	STB/PSI
PERMEABILITY THICKNESS	17,951	md-ft
MOBILITY THICKNESS	25,644	md-ft/cp

## PTA with Calculated Rate

### *Oilfield Data Services, Inc.*

#### ANALYSIS RESULTS

INJECTION FALL OFF  
Feb/11 - 13/2017

#### Calculated Reservoir & Completion Properties

SKIN	-3.4	
PRESSURE DROP DUE TO SKIN	-392	PSI
COMPLETION EFFICIENCY	296	%
PERMEABILITY	33	md
RADIAL FLOW INJECTIVITY INDEX (II)	102.9	STB/PSI
SKINLESS RADIAL FLOW II	34.8	STB/PSI
PERMEABILITY THICKNESS	18,377	md-ft
MOBILITY THICKNESS	26,253	md-ft/cp

# Conclusions I

- ODSI calculated rates matched the measured rates accurately when there was no scale in the well bore
- A deviation between measured and the calculated rates was noted during (mid-April 2015 – Late Jan 2017)
- ODSI's rate solution is independent. Any deviation from the measurement is an indication of a change in well's performance/model (PVT, friction)
- It was likely that the scale build-up caused additional friction and caused the rates to deviate
- Scale build-up was confirmed with early-time (near well) PTA results
  - Confirmed by comparing calculated rates vs. measured rates

The software helps to detect errors in Allocations and changes in well's performance!



# Conclusions II

- Scale build-up was confirmed with early-time (near well) PTA results
  - Gradually decreasing kh with time
  - From ~ 16 000 md-ft (Aug 2012) to 8 000 ( Jan 2017)
  - Re-stimulation job in late Jan 2017 removed the scale
  - Kh immediately improved to 18 337 md-ft (Feb 11, 2017)
- Gradually decreasing near-well Inj Index with time:
  - From 88 STB/psi (Aug 2012) to 47 STB/psi (Jan 2017)
  - Immediately improved to 103 STB/psi (Feb 11, 2017) after the stimulation job
- Negative and fairly constant skin with time
- High and fairly constant completion efficiency

# Well Analyzer Features

- Virtual metering
  - Oil, gas and water rate calculations
  - Detects errors in allocations
- Bottomhole pressure calculation from the surface data
  - Can replace downhole pressure gauge in case it fails
- Automated Transient Interpretation of build-up & drawdown tests and injectivity & injection fall-off tests
  - Skin
  - Permeability
  - Avg.Pres/P\*

# Why ODSI?

- Well Analyzer is not intrusive and provides fast and accurate results
- Accuracy of the technique assists in diagnosing errors in allocations
- Software-based installation only
- Low cost investment