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**Technical  
Report**

**EWS No. 4 Well (API #05-123-44167)  
MARCH 2017 STEP RATE TESTING  
CLASS II COMMERCIAL INJECTION WELL**

EWS 4 DJ Basin LLC  
T2N, R63W, Section 18: Weld County, Colorado

April 7, 2017

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TECHNICAL REPORT  
2017 CLASS II WELL TESTING  
EWS 4 DJ Basin LLC  
EWS 4 Well (API #05-123-44167)

**TABLE OF CONTENTS**

1.0	Introduction .....	1-1
2.0	Reservoir Testing Data Collection and Analysis .....	2-1
3.0	Conclusions.....	3-1

**Figures**

Figure 1	Cartesian Plot of Bottomhole Pressure and Rate vs. Time
Figure 2	Cartesian Plot of Wellhead Pressure and Rate vs. Time
Figure 3	Analysis of Bottomhole Pressure vs. Rate and Change in Injectivity
Figure 4	EWS 4 Wellbore Diagram

**Appendices**

Appendix 1	Bottomhole Step Rate Test Raw Pressure Data (PPS Field Data Report)
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## 1.0 INTRODUCTION

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This report summarizes the March 14, 2017 reservoir testing activities performed at the EWS 4 DJ Basin LLC EWS 4 well site in Weld County, Colorado. The primary objectives included performing a step-rate test with results of the test analysis intended to satisfy the request of the Colorado Oil and Gas Conservation Commission to evaluate current conditions. The field operations included a step-rate injection test utilizing twelve 30-minute injection steps that ranged from 1.4 to 15.1 barrels per minute (bpm).

The EWS 4 Class II commercial disposal well is completed in the DJ Injection Zone including the Lyons through upper Fountain Formations. The vertical well was completed from a depth of approximately 8,564 feet to 10,188 feet KB. Injection is via a 4 ½-inch slotted liner in a 6 1/8-inch open hole. The current configuration of the well is illustrated in Figure 4.

Petrotek Engineering Corporation (Petrotek) supervised field data collection activities and evaluated the March 14, 2017 test data collected by Petroleum Pressure Surveys (PPS). The rate data and downhole pressure data are of reasonable quality and are sufficient to allow evaluation of reservoir pressure and calculation of a pressure sensitive permeability or skin threshold pressure. The test procedures, analytical methods, and results are presented in the following sections.

The data acquired indicate that the static bottomhole pressure of the comingled formation layers currently in communication to the wellbore was approximately 3,085 psia at 8,450 feet KB (8,437 feet BGL) at the time of the test. Temperature measured concurrently near the top of the injection interval prior to injection was approximately 254 degrees F. Static fluid level was found at approximately 1,258 feet KB and the static bottom hole reservoir pressure gradient measured in the well was approximately 0.366 psi/ft.

A step-rate injection test was conducted to examine short-term wellbore and reservoir behavior. During the early steps the reservoir accepts fluid with little surface pressure and with downhole pressure changes due to rate increases that may be consistent with natural fracture or radial flow in a porous media. During the step-rate test the reservoir exhibits a significant change of pressure build-up character at a bottomhole injection pressure gradient of approximately 0.466 psig/foot at the end of step 4 based on the gauge test depth of 8,437 feet BGL. When injection pressures exceeded this pressure-sensitive permeability/skin gradient threshold during the test, the reservoir began to accept significantly more injection rate with decreasing incremental pressure build-up. It is likely that naturally occurring fractures which are already open upon initial injection propagate or dilate in some portion of the injection zone during injection above this pressure threshold in conjunction with increasing rate and pressure. However, it is likely that the pressure increase observed in steps 2 and 3 is can be partially attributed to an increase in fluid viscosity, variance in low-end pump rates due to pumping equipment limitations, and wellbore clean-up.

## **2.0 RESERVOIR TESTING DATA COLLECTION AND ANALYSIS**

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### **March 2017 Pressure Transient Data Collection**

Test data were collected using pumping service company (Halliburton Energy Services) equipment to record rate and wellhead pressure. Downhole silicon memory tools set on slickline from PPS were used to record bottomhole temperature and pressure. The use of downhole gauges ensured maximum data quality and eliminated hydrostatic head changes due to variations in specific gravity along with estimates of friction loss in the tubing and surface equipment from analyses. This new well was completed in February 2017 and has not been used to inject Class II waste. A short-term constant-rate injection test was run the day before the step-rate test; the well had been in falloff monitoring for approximately 13 hours prior to the start of step-rate operations.

To conduct the reservoir testing, pumping and pressure measurement, equipment was rigged-up and pressure control equipment installed on the wellhead. Two percent KCl brine was used during testing.

After the falloff data collection period, the gauges were still at the test depth of 8,450 feet KB (8,437 feet BGL) and a stabilized static bottomhole pressure was recorded for approximately 2.5 hours. A stabilized pressure (3,085 psia) and temperature was established as baseline; a step-rate injection test was started by pumping at incrementally increasing rates. Initial injection started with approximately 13 psi of surface injection pump pressure. After 12 increasing rate steps, the test was terminated by stopping the pump and shutting in the well head with a final bottomhole injection pressure of 4,085 psia. The test data are summarized in Attachment 1 and Figure 1. Figure 4 presents the well configuration at the time of testing.

Each of the 12 injection steps were of approximate equal durations (30 minutes). It is noted that the first step continued longer than intended because it took some time for the initial variable rate to be controlled. As designed, the injection steps of approximately equal time length, but variable rate changes generate the step-like increases in pressure during the injection portion of the test. Some noise was present in the responses due to rate variations.

Based on flow rates recorded by the surface data logger, the average final injection rate step was 15.1 barrels per minute (bpm) or 634 gallons per minute (gpm). A cumulative injection volume of approximately 1,820 barrels was injected during the 6-hour step-rate injection period. A copy of the raw data collected by PPS with the field report is provided as Appendix 1.

### **General Analysis Methodology**

In addition to establishing original reservoir pressure, sufficient data were collected from the step-rate test to allow estimates of formation pressure sensitivity. Standard data

analysis techniques were utilized to review the data. Although a valid test was conducted, the step-rate test data analysis was complicated due to several factors including changing injection fluid temperature (displacement of hot formation brine followed by cooler produced brine water from the surface tanks), skin, possible wellbore clean-up, natural fractures that may be open at original reservoir pressure and a slotted screen completion into multiple-layered formations.

Plots of pressure versus rate and time functions were applied to the step-rate evaluation. A variety of graphical analyses confirmed the pressure sensitive permeability or skin factor. Plots included Cartesian graphs to evaluate the relationship of data trends. Raw data were processed and plotted using the commercially available Excel spreadsheet package. It is noted that it is unlikely that any of the data reached completely stable radial flow during any of the testing.

## **Reservoir Pressure**

Reservoir pressure was determined by obtaining a static gradient survey as the pressure transducer was run into the tubing. The well had only been shut-in for part of a day prior to this testing, so it is possible that some cross-flow was still occurring during the static monitoring period. A fluid gradient of approximately 0.430 psi/ft was measured in the tubing prior to starting the step-rate test. Static tubing fluid level was at approximately 1,258 feet KB and there was a negative wellhead pressure consistent with the gradient survey. At the test gauge depth of 8,437 feet BGL, injection zone pressure was measured as 3,085 psia (0.366 psi/ft). Figure 2 presents a plot of the wellhead pressure, bottom hole pressure and injection rate versus time.

## **Step-Rate Injection Test**

Step-rate testing is accomplished by injecting fluid at a series of increasing rates and recording the resulting injection pressures. Constant rate injection during each step and equal time period steps contribute to accurate analysis. Downhole pressure measurement is preferred to eliminate the effect of tubular friction and variable specific gravity on the data. If fluid properties, formation permeability, wellbore skin, and other formation properties remain constant during a step-rate injection test, a plot of the pressures measured at the end of each equal duration step versus rate will yield a straight line. A reduction in the slope of the pressure versus rate line typically indicates an increase in permeability or reduction in skin. In many instances this increase is attributable to opening fractures in the injection formation (Earlougher 1977).

It is well documented that the pressure required to initiate a fracture in a new completion (breakdown pressure) can often be greater than the pressure required to open pre-existing fractures in a borehole on subsequent occasions. In the case where a well is initially broken down, fluid must overcome the stresses in the immediate vicinity of the wellbore and overcome the fracture toughness of the rock to initiate the break. After this has occurred or in cases where natural fractures exist within a reservoir, pressure must only

reach a level (opening pressure) sufficient to overcome the stresses holding the rock together to open the pre-existing fracture. In naturally fractured reservoirs that have fracture transmissivity at all reservoir pressures, apparent changes may be more difficult to assign to fracture opening since fractures may be open throughout a test.

As previously noted, the raw step-rate pressure data are presented in the PPS report included as Appendix 1 of the test report. As shown by the rate and pressure data plotted in, slight rate variations occurred over each of the rate steps. Each rate step was approximately 0.5 hours, allowing classical analysis to be performed.

Figure 1 shows that a significant pressure increase is evident during each of the first three step rates. It is noted that the first step continued longer than intended because it took some time for the initial variable rate to be controlled. Steps 6 through 11 exhibit smaller relative pressure increases during each step, despite steps having significant incremental increases in injection rate. It appears that a portion of Steps 4 and 5 likely take place above a pressure sensitivity threshold. This is more clearly evident in Figure 3, which is a plot of bottom-hole injection pressure versus average rate sustained during each step. Note in this plot that the slope of the line fitted through final bottomhole pressures at the end of steps 1, 2 and 3 is substantially different than the slope obtained by fitting a curve through the final higher rate steps of the test. The slope of the line from the final steps in this test has a significantly reduced slope as compared with any slope fitted through the early test steps. All pressure is plotted for each step rate, showing the increasing pressure during each step. It is noted that the final steps exhibit a relatively smaller pressure rise during each rate step, consistent with increased permeability and/or reduced skin.

Based on the reduction in slope observed in Figure 3 and review of the pressure versus time trace illustrated in Figure 2, the pressure data appears to reach a pressure in excess of 3900 psi before deviating significantly from early behavior. During steps 4 and 5 pressure decreases and a pressure sensitive permeability or skin threshold appears to become evident in step 6. By extrapolating the early and late step lines and plotting an intersection a value of 3,750 – 3,800 psi is obtained. In this test, the pressure sensitive threshold gradient based on the Cartesian analysis method occurs in the injection zone at a pressure of approximately (3,778 psig) (gradient of 0.448 psig/ft) at a reference depth of 8,437 feet BGL. It is possible that natural fractures in the injection zone contribute to the multi-layer permeability-thickness communicating to the well at all injection rates and pressures to differing degrees throughout the test.

### 3.0 CONCLUSIONS

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The data collected during the testing were of sufficient quality to derive estimates of the current reservoir and wellbore parameters discussed in this report. Standard industry data collection and analysis procedures were followed with respect to this testing. Graphs of the data are provided that show the relationship of pressure versus time and pressure versus rate.

In summary, analysis of the data indicate that: 1) the initial reservoir pressure gradient was approximately 0.37 psi/ft prior to injection, 2) there is a pressure sensitive injectivity threshold at which naturally occurring fractures probably dilate under current wellbore conditions in the injection zone at a bottomhole pressure gradient of approximately 0.448 psig/foot, and 3) there are naturally occurring fractures in the injection zone that are likely already open with a full column of fluid in the well. During injection at pressures above a gradient of 0.448 psig/foot, it appears that the skin factor decreases and/or the permeability increases to a stimulated value as compared with trends observed at the start of the test. The injection test data showed conclusive evidence of a changing permeability or skin factor that is pressure related.

# FIGURES

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**Figure 1**  
EWS 4 DJ Basin LLC  
EWS No. 4  
March 2017 Step Rate Test

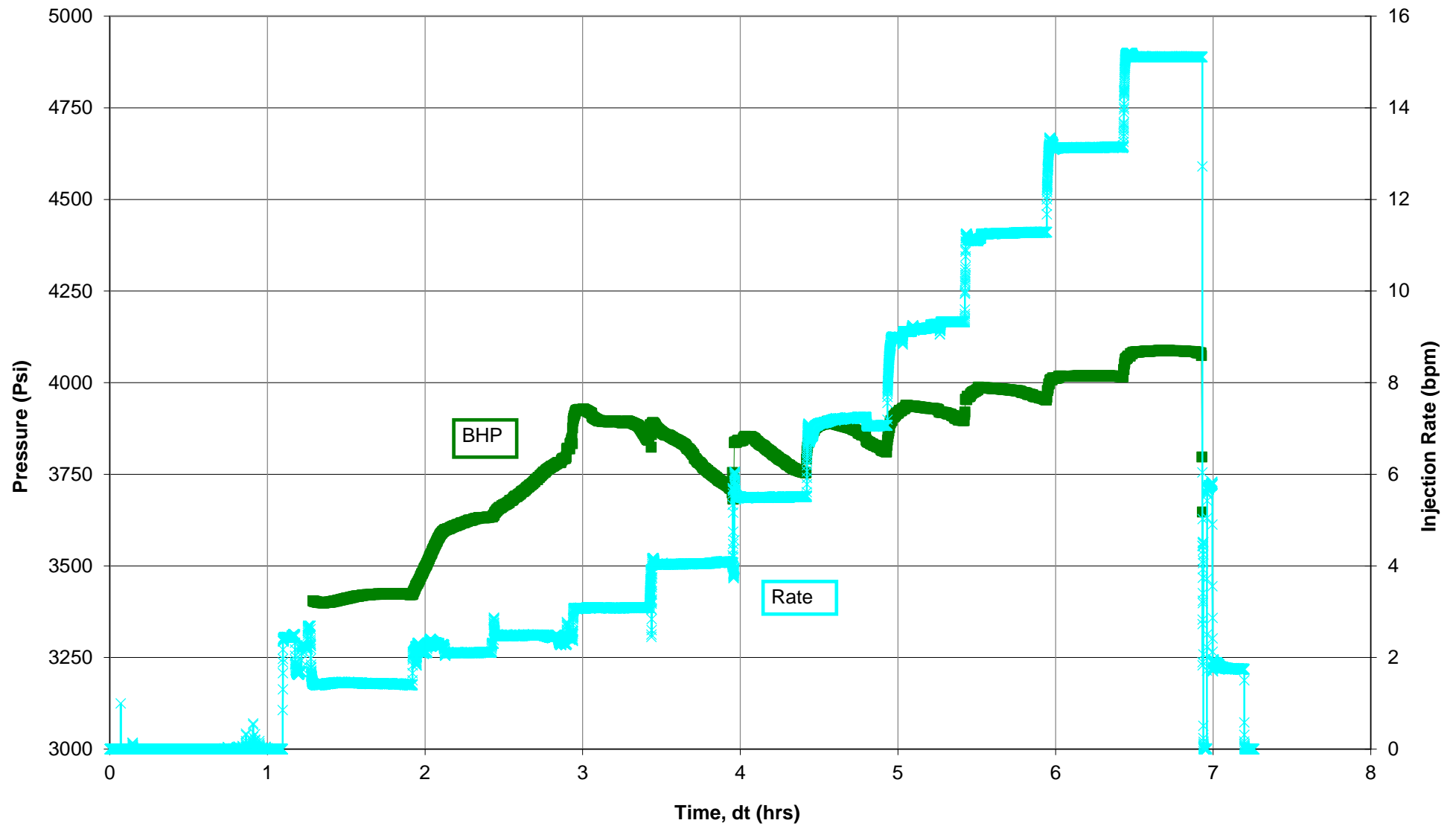
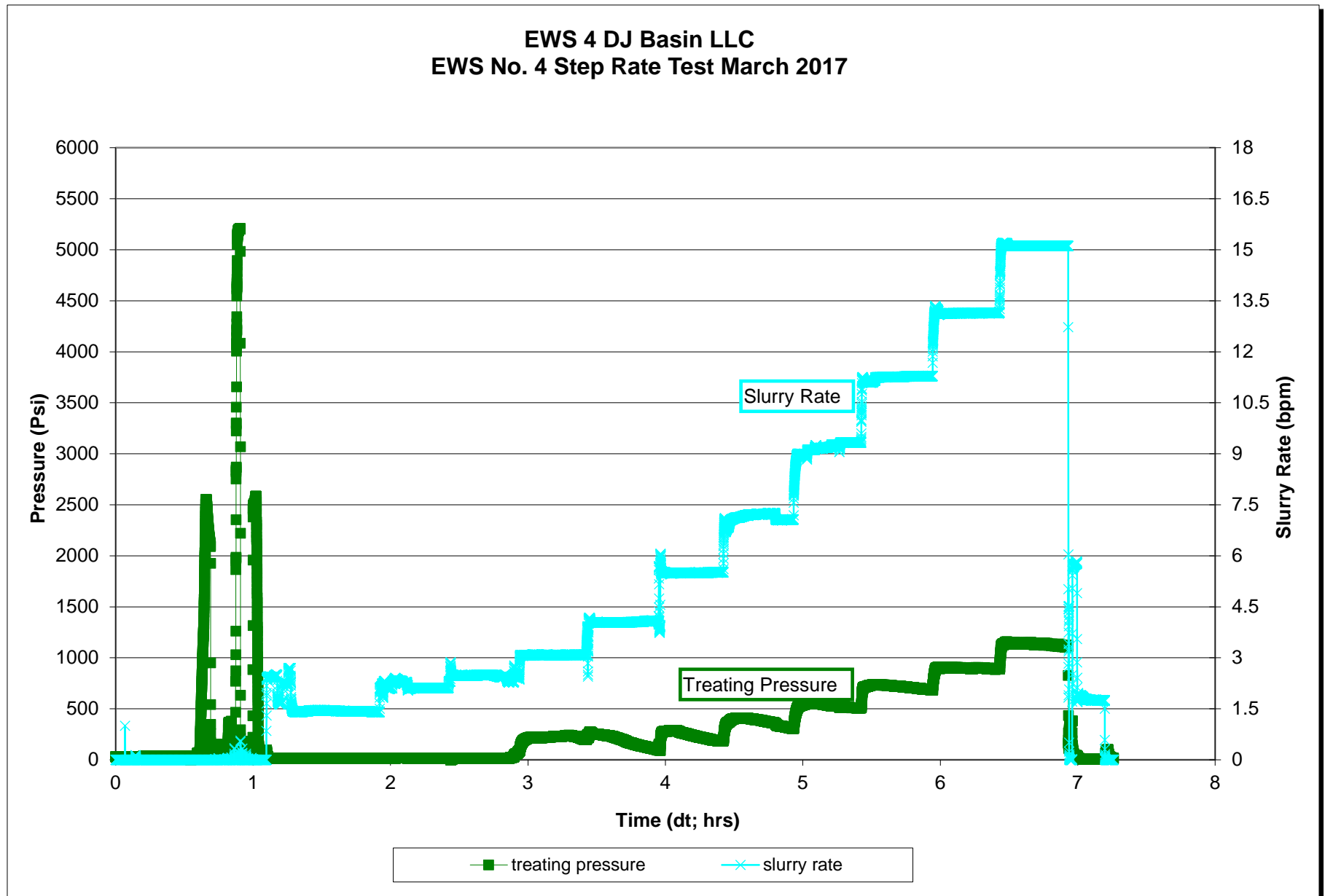
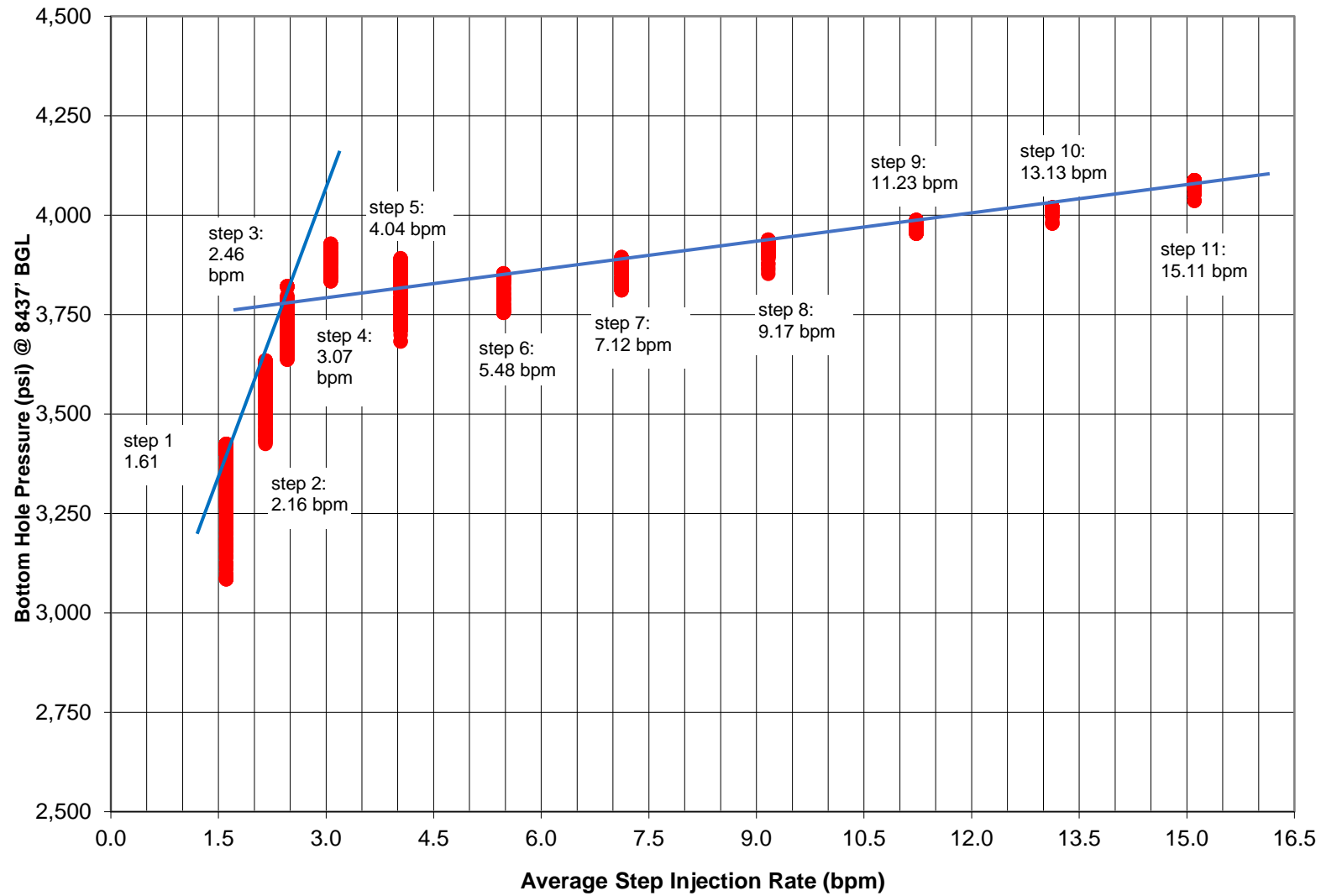
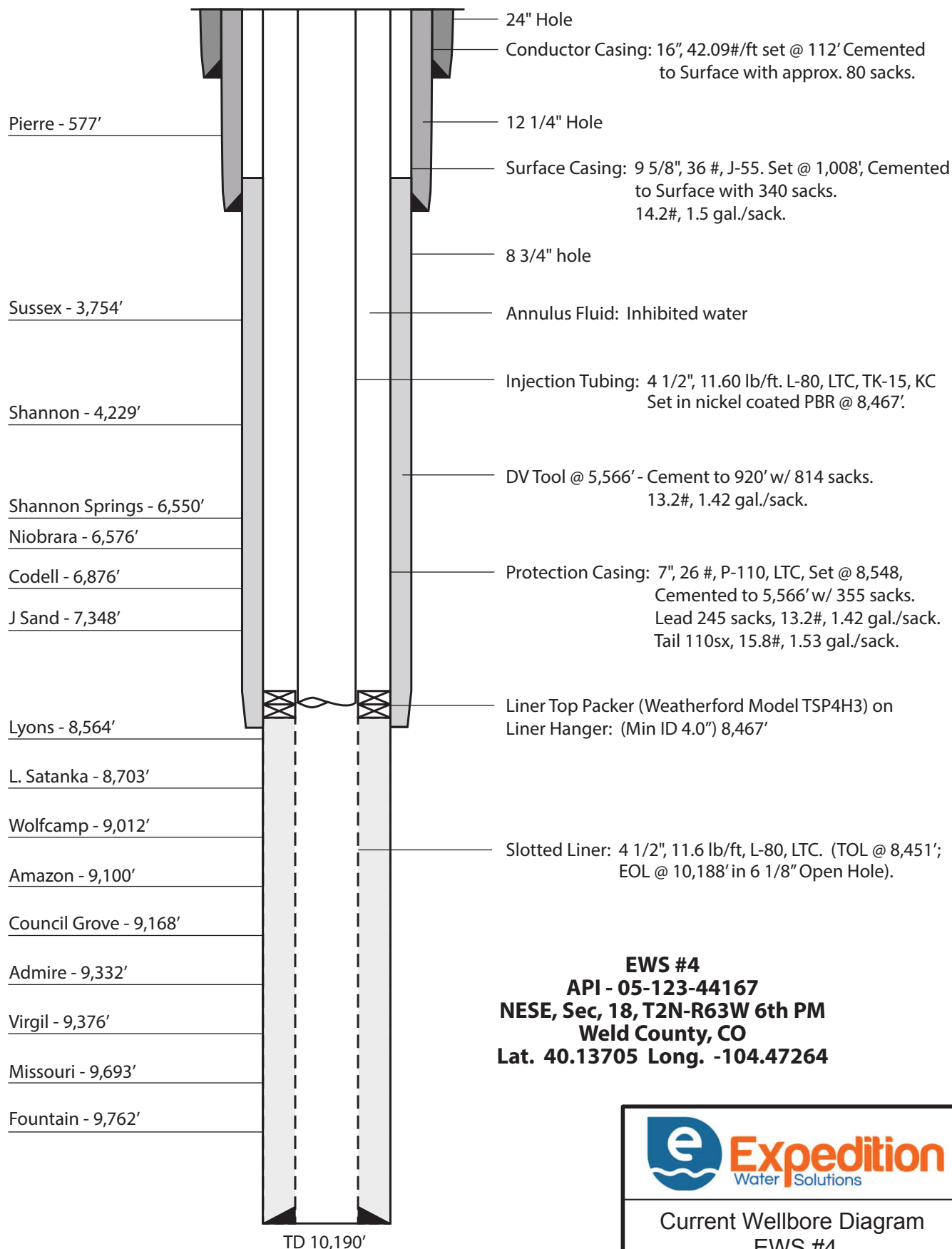


Figure 2





**Figure 3**  
EWS 4 DJ Basin LLC  
EWS No. 4  
March 2017 Step Rate Test





**EWS #4**  
**API - 05-123-44167**  
**NESE, Sec, 18, T2N-R63W 6th PM**  
**Weld County, CO**  
**Lat. 40.13705 Long. -104.47264**

Note: All depths are TVD referenced to Kelly Bushing, 13 ft. above Ground Level.

		
<p align="center"><b>Current Wellbore Diagram</b>  <b>EWS #4</b>  <b>Figure 4</b></p>		
<p align="center">2017 EWS No. 4 Drilling &amp; Completion Report</p>		
Scale: NTS	Date: 03-15-2017	
01_EWS_No4_Wellbore.ai	By: JLM	Checked: JD
		
<p align="right">5935 South Zang Street, Suite 200          Littleton, Colorado 80127 USA          303-290-9414  <a href="http://www.petrotek.com">www.petrotek.com</a></p>		

Appendix 1  
Bottomhole Step Rate Test Raw Pressure Data  
(PPS Field Data Report)

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PETROLEUM PRESSURE SURVEYS

Petroleum Pressure Surveys  
Sterling, CO 80751  
104 Juniper Dr.

*Fax:* (970) 522-5240

*Cell:* (970) 520-9359

[mkenney.pps@gmail.com](mailto:mkenney.pps@gmail.com)

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## Bottom-hole Pressure Report

COMPANY: Expedition Water Solutions Colorado, LLC  
WELL: EWS #4  
LOCATION: Weld County, Colorado  
DATE: March 12-14, 2017

**Company:** EWS Colorado, LLC

**State:** Colorado

**Well:** EWS #4

**County:** Weld

**Test Description:** Constant Rate Test/Falloff/Step-Rate Test

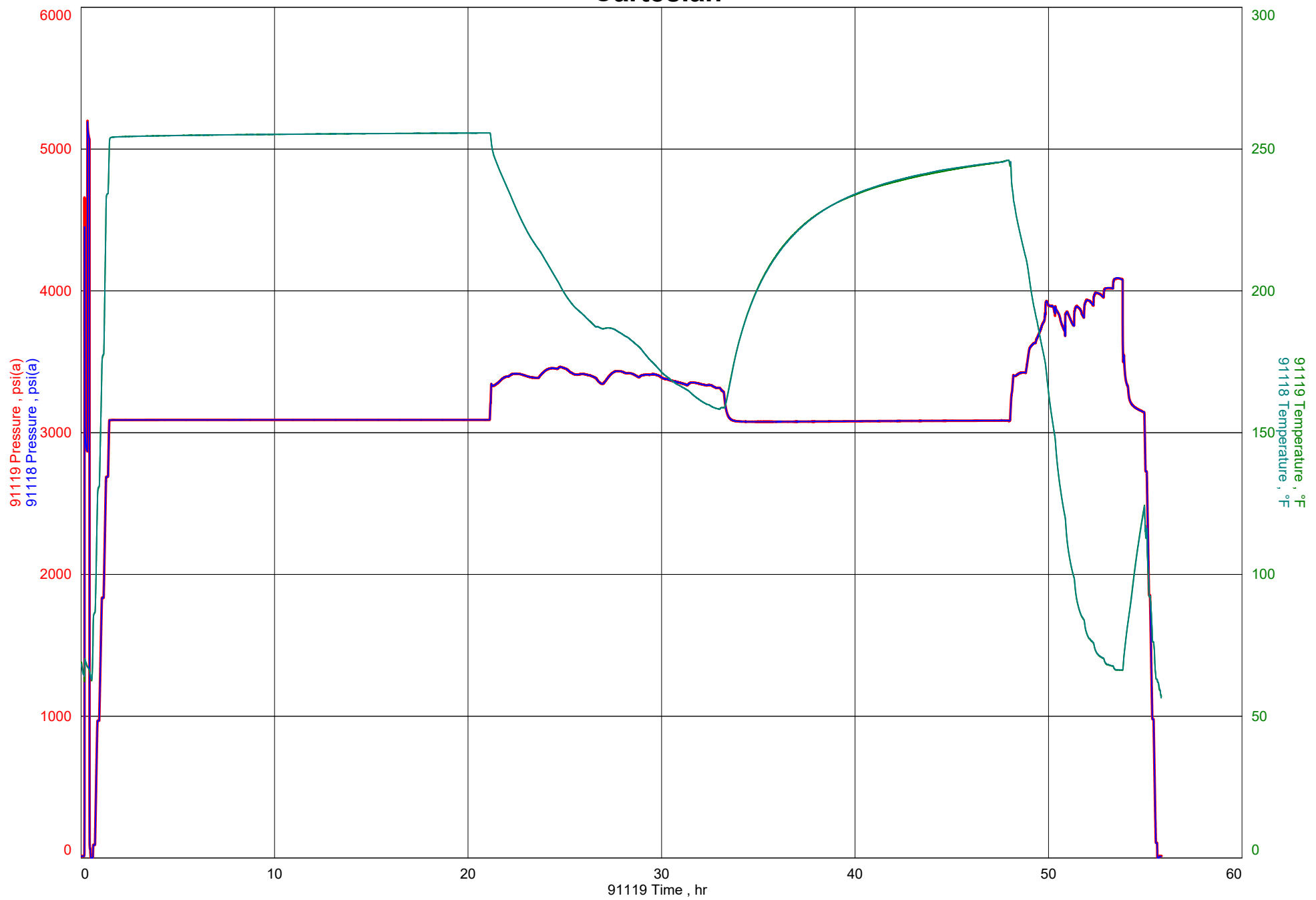
**Instrument Type:** 10K Silicon Crystal Electronic Probes

### **Procedure Chronology**

Gauges Energized	11:50 03-12-2017
Gauges in Lubricator	12:18 03-12-2017
Gauges on Bottom @ 8450' KB	13:18 03-12-2017
Start Pumping Constant Rate	08:56 03-13-2017
Well Shut In	21:03 03-13-2017
Start Pumping Step Rate	11:51 03-14-2017
Well Shut In	17:40 03-14-2017
Gauges off Bottom	18:55 03-14-2017
Gauges in Lubricator	19:34 03-14-2017

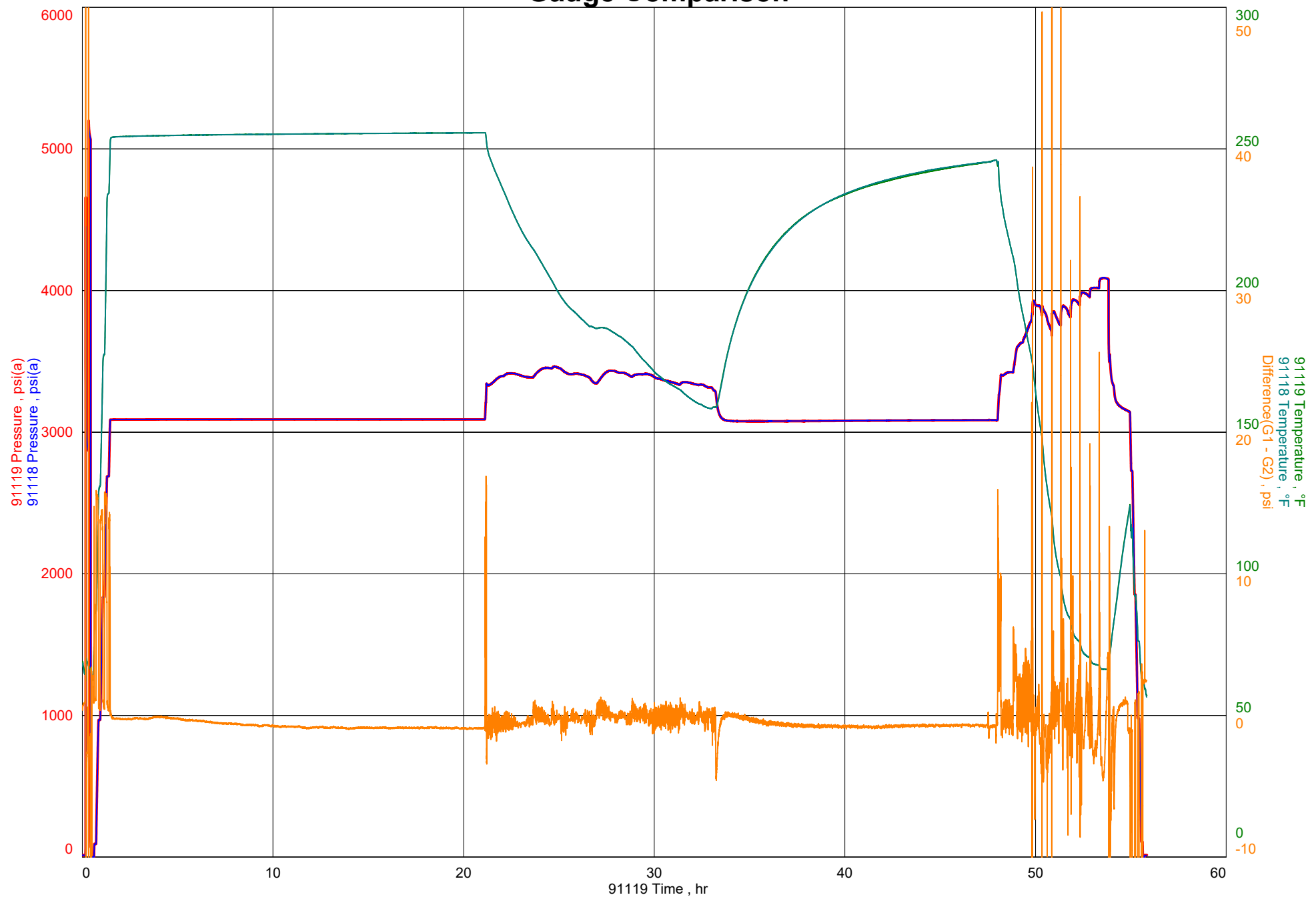
### **Pressure/Temperature Information**

Maximum Measured Pressure	5193.89 psia
Maximum Measured Reservoir Temperature	255.71 deg F





# Gauge Comparison



# RIH Gradient

Expedition Water Solutions

EWS #4

Gauge Serial Number	91119	Gauge Type	Silicon Crystal
Gauge Manufacturer	CalScan	Maximum Recorder Range	10000.00 psi
Run Depth (Log KB)	8450.00 ft	Date of Last Calibration	2016/12/21
Gauge Start Date	2017/03/12 11:50:00	Gauge Stop Date	2017/03/14 19:41:00
Date Gauge On Bottom	2017/03/12 12:18:00	Date Gauge Off Bottom	2017/03/14 18:48:00

## Test Data

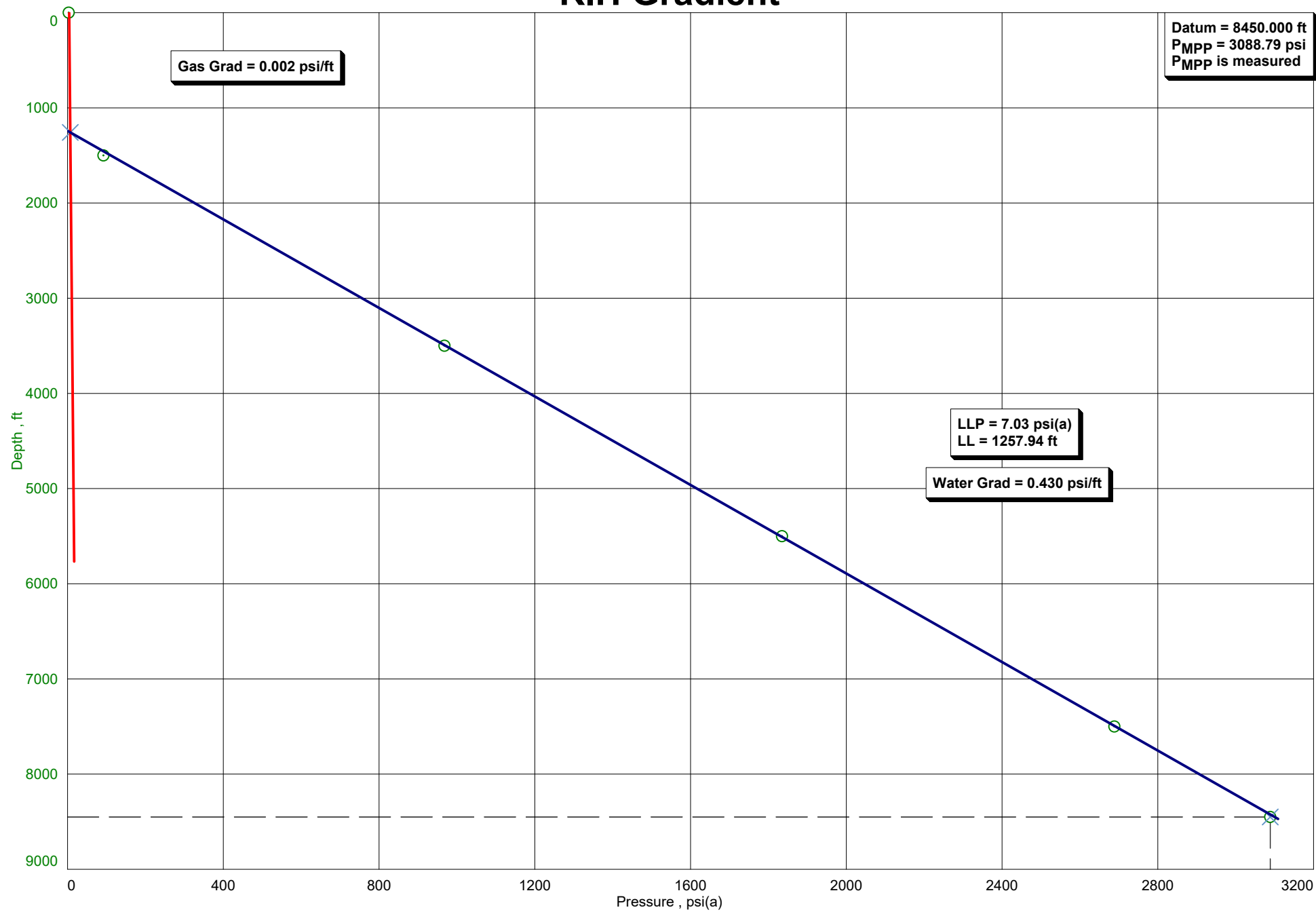
Top(TVD KB)	ft	Bottom(TVD KB)	ft
Pool Datum Depth (SS)	ft	Well Datum Depth	8450.000 ft
Tubing Pressure: Initial	0.00 psi(a)	Tubing Pressure: Final	0.00 psi(a)
Casing Pressure: Initial	48.70 psi(a)	Casing Pressure: Final	0.00 psi(a)
Start Test Date	2017/03/12	Date Well Shut-In	

Depth ft	Time hh:mm:ss	Duration min	Pressure psi(a)	Gradient psi/ft	Temp. °F	Gradient °F/ft
0.00	11:25:10		3.14		68.08	
1500.00	11:33:00	7.83	92.23	0.059	86.49	0.012
3500.00	11:46:10	13.17	968.21	0.438	130.95	0.022
5500.00	11:59:50	13.67	1835.04	0.433	177.49	0.023
7500.00	12:13:20	13.50	2688.54	0.427	234.35	0.028
8450.00	12:23:20	10.00	3088.79	0.421	254.14	0.021

## Results

Gas	0.002 psi/ft	Gas - Water Interface	1257.94 ft	7.03 psi(a)
Water	0.430 psi/ft	<b>Well Datum Depth</b>	<b>8450.00 ft</b>	<b>3088.79 psi(a)</b>

# RIH Gradient



# POOH Gradient

Expedition Water Solutions

EWS #4

Gauge Serial Number	91119	Gauge Type	Silicon Crystal
Gauge Manufacturer	CalScan	Maximum Recorder Range	10000.00 psi
Run Depth (Log KB)	8450.00 ft	Date of Last Calibration	2016/12/21
Gauge Start Date	2017/03/12 11:50:00	Gauge Stop Date	2017/03/14 19:41:00
Date Gauge On Bottom	2017/03/12 12:18:00	Date Gauge Off Bottom	2017/03/14 18:48:00

## Test Data

Top(TVD KB)	ft	Bottom(TVD KB)	ft
Pool Datum Depth (SS)	ft	Well Datum Depth	8450.000 ft
Tubing Pressure: Initial	0.00 psi(a)	Tubing Pressure: Final	0.00 psi(a)
Casing Pressure: Initial	48.70 psi(a)	Casing Pressure: Final	0.00 psi(a)
Start Test Date	2017/03/12	Date Well Shut-In	

Depth ft	Time hh:mm:ss	Duration min	Pressure psi(a)	Gradient psi/ft	Temp. °F	Gradient °F/ft
8450.00	17:46:20		3144.36		123.63	
7500.00	17:54:30	8.17	2725.78	0.441	112.94	0.011
5500.00	18:04:50	10.33	1852.72	0.437	92.38	0.010
3500.00	18:15:40	10.83	979.29	0.437	76.22	0.008
1500.00	18:26:30	10.83	106.84	0.436	62.99	0.007
0.00	18:33:30	7.00	3.37	0.069	59.36	0.002

## Results

Gas	0.001 psi/ft	Gas - Water Interface	1252.43 ft	-3.27 psi(a)
Water	0.438 psi/ft	<b>Well Datum Depth</b>	<b>8450.00 ft</b>	<b>3144.36 psi(a)</b>

# POOH Gradient

