Figure 13: East-west deviation vs. north-south deviation.

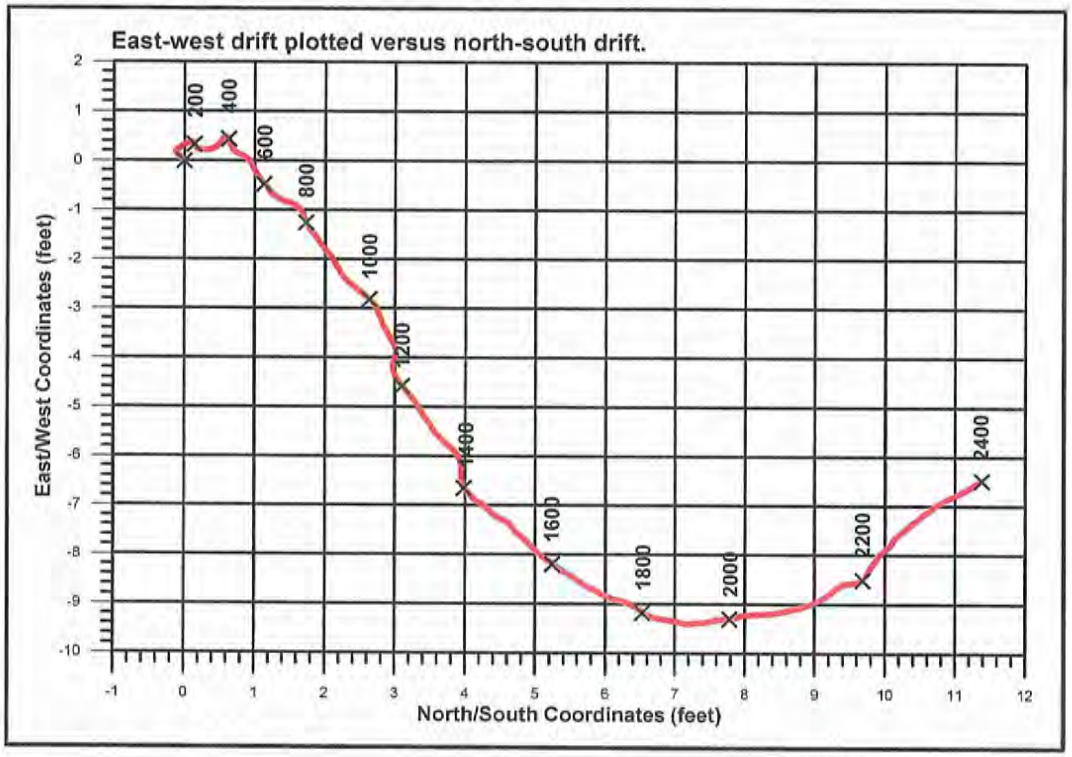


Figure 11 compares the departure from vertical in the plane of drift to a 1-degree constant departure from vertical, which is the limit of the amount of drift allowable in the specifications for the well. As shown on Figure 11, the measured drift is less than one third of the allowable drift. Figure 12 is a three-dimensional projection of the drift and deviation survey data compared to an imaginary plumb line representing a straight and plumb well. Figure 13 compares east-west drift to north-south drift and is another useful method of assessing the nature of the deviation of the well from straight and plumb.

4 ACID FRAC STIMULATION

Completed Test Well #1 was subjected to a 900-gpm constant rate yield and drawdown test beginning 3/11/2013 at 9:00 A.M. and continuing for 12 hours. The drawdown at the end of 12 hours of pumping at 900 gpm was 923.89 feet, providing a specific capacity of 0.97 gpm per foot of drawdown. The 12-hour test was considered sufficient to determine that the well required stimulation by hydraulic fracturing (fracking) with acid to achieve the target design yield of 1400 gpm.

Project specifications required hydraulic fracturing with a minimum bottom hole pressure of 1200 psi at a flow of 2800 gpm (66.7 BPM). On 3/26/2013, the well was treated with 714 BBL of 15% hydrochloric acid at bottom hole pressures in the range of 1300 to 1400 psi with flows of 50.1 to 64.3 BPM, as limited by the differential pressure rating of the packer.

Figure 14 is the Energy Services chart of surface treatment pressure, flow rates for chlorine water and acid, and horsepower applied during the acid frac stimulation. Figure 15 shows the surface treatment pressure, bottom hole pressure and the pressure in excess of the packer pressure differential rating during the acid treatment.

After acid treatment, the well was subjected to a constant rate test on 5/10/2013 at 1600 gpm for 81 hours. Drawdown at the end of 81 hours was 711.29 feet. Drawdown at 12 hours, for comparison to the pre-frac performance, was 666.33 feet providing a specific capacity of 2.40 gallons per minute per foot of drawdown, or an increase in 12-hour hydraulic performance of 2.5 times the pre-frac performance. Figure 16 shows the pre-frac and post-frac drawdown and residual drawdown at 900 and 1600-gpm, respectively.

Figure 14: Acid frac surface treatment pressure and flow rate.

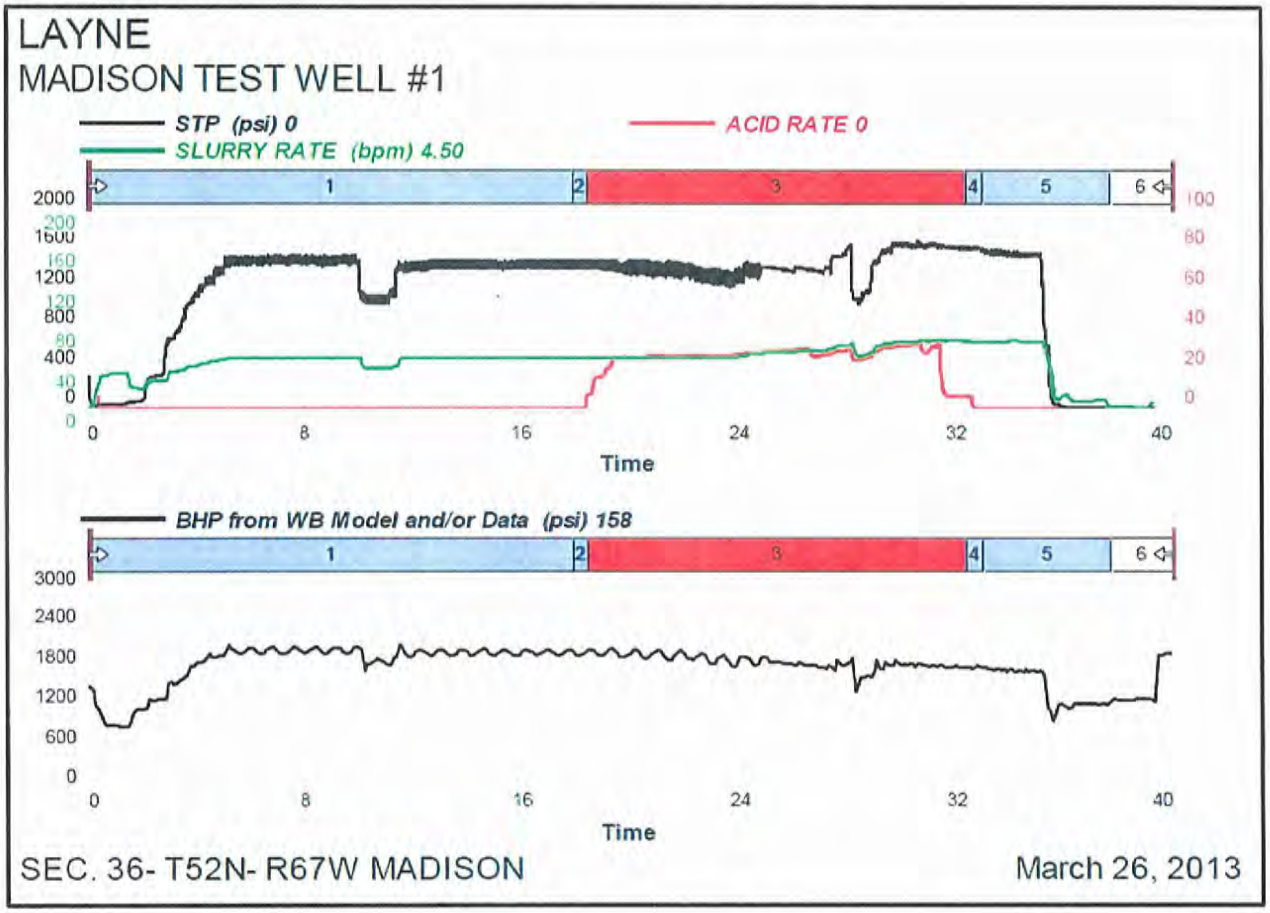


Figure 15: Bottom hole pressure (BHP) and pressure exceeding nominal packer rating.

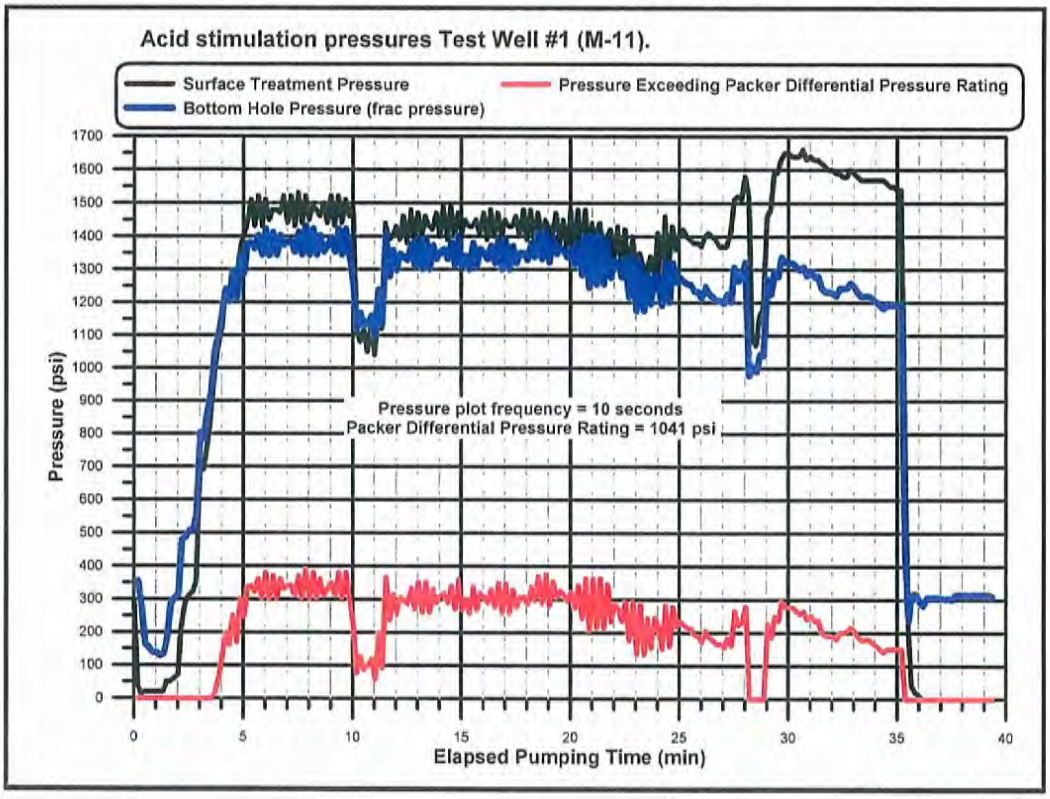
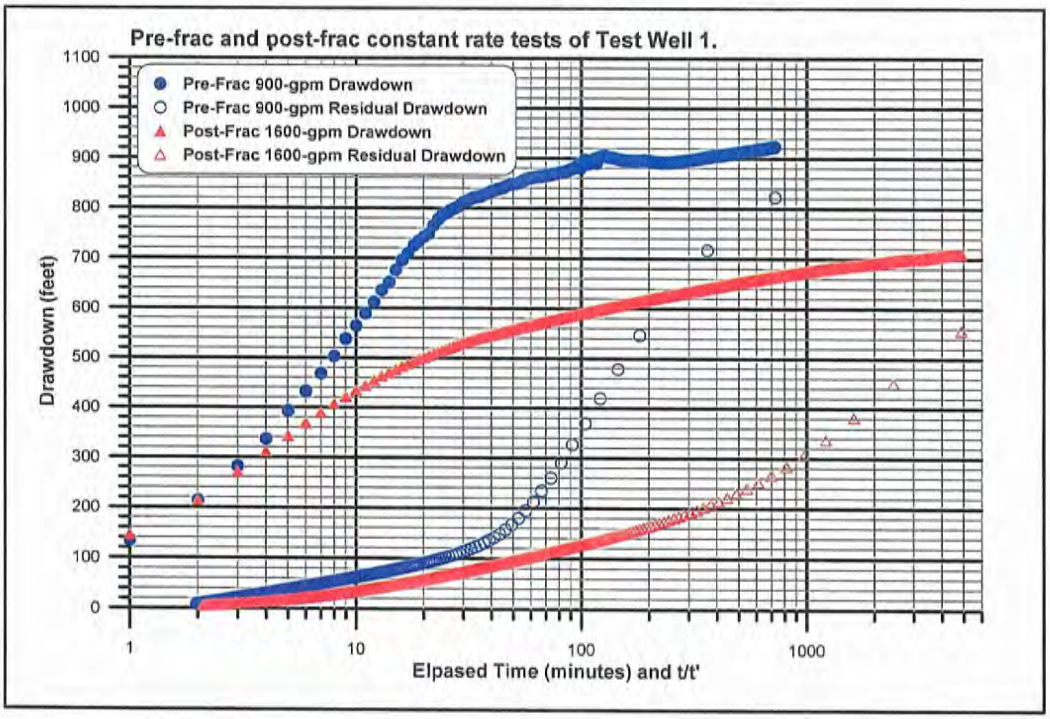


Figure 16: Comparison of pre-frac and post-frac well performance.



4.1 Acid Frac Equipment

The target for acid frac stimulation of the carbonate rock aquifer was up to 2800 gpm (66.7 BPM) at 1200 psi BHP. Individual pumper trucks can generate pressures exceeding 10,000 psi; however, at the surface treatment pressures that can be achieved at the high flow rate, a total of five pumpers were required to deliver the 66.7 BPM specified flow rate. The five pumper trucks were supported with six 400-BBL frac tanks for fresh water, four acid trucks containing 28% bulk acid, a mixing truck, a boom truck for setting high-pressure pipe, and a control truck to provide coordinated operation and control of the pumpers and ground crew. Photos 33 through 43 show frac job equipment and layout.

4.2 Packer Settings

The target bottom hole pressure (BHP) for acid stimulation was 1200 psi. A Baski inflatable packer was set in the 7-inch casing at a depth of 2390 feet BTOC. The packer differential pressure rating for the packer in 7-inch pipe was 1000 psi with the packer inflated to 1500 psi over submergence. With the static water level in the well at 727 feet BTOC, the surface packer inflation pressure required to provide 1500 psi over submergence was as follows, using clear water for inflation fluid:

1500 psi – (0.4333 psi/ft x 727 ft) = 1185 psi surface inflation pressure

The differential pressure rating of 1000 psi is 200 psi less than the target BHP treatment pressure. Baski representatives indicated the packer provided for this project had been pressure tested to 2000 psi inflation pressure. Based on this information, the packer was inflated with water to 1500 psi surface inflation pressure. With a static water level of 727 feet BTOC, 1500 psi surface inflation pressure provides the following inflation pressure over submergence (IPOS):

IPOS = 1500 psi + (0.4333 x 727) = 1815 psi over submergence

The inflation pressure of 1815 psi over submergence was safely less than the tested 2000 psi inflation pressure the packer would withstand, and provided an unknown increase in the packer differential pressure rating of 1000 psi at 1500 psi inflation pressure over submergence.

After the packer was inflated, clear water was added to the annulus between the packer tubing and the well casing so that the water level in the annulus could be monitored to ensure that the packer was sealed into the casing. Water added to the annulus decreased the depth to water BTOC from 727 to 631 feet over the packer. The increase of 96 feet of additional water above the packer increased the differential pressure rating by 41 psi, to 1041 psi plus an unknown increase in differential pressure rating due to inflation of the packer to 1815 psi over submergence instead of 1500 psi over submergence. More water was not added above the packer in order to avoid a water-hammer effect when the packer was released.

Photo 32: Packer surface inflation pressure at 1480 psi during inflation.

Photo 33: Frac equipment arriving at site.

Photo 34: New V-12 powered 2000-hp high-pressure pump.

Photo 35: Overview of frac equipment setup.

Photo 36: Frac tanks and acid trucks.

Photo 37: Mixing truck hoses to frac tanks and acid trucks

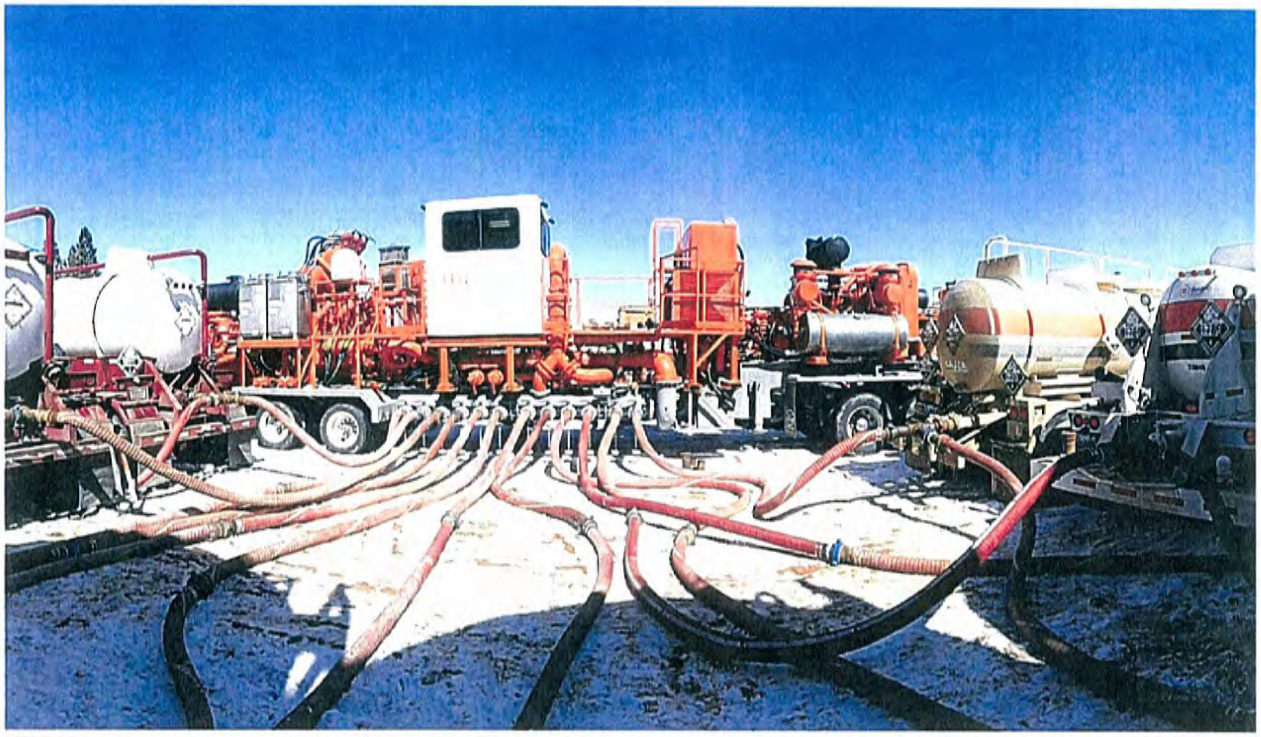


Photo 38: Ground crew connecting high pressure lines to packer tubing.

Photo 39: Well-head plumbing for frac job.

Photo 40: Pressure transducer on high-pressure line for frac job.

Photo 41: Standing by in control truck prior to acid frac stimulation.

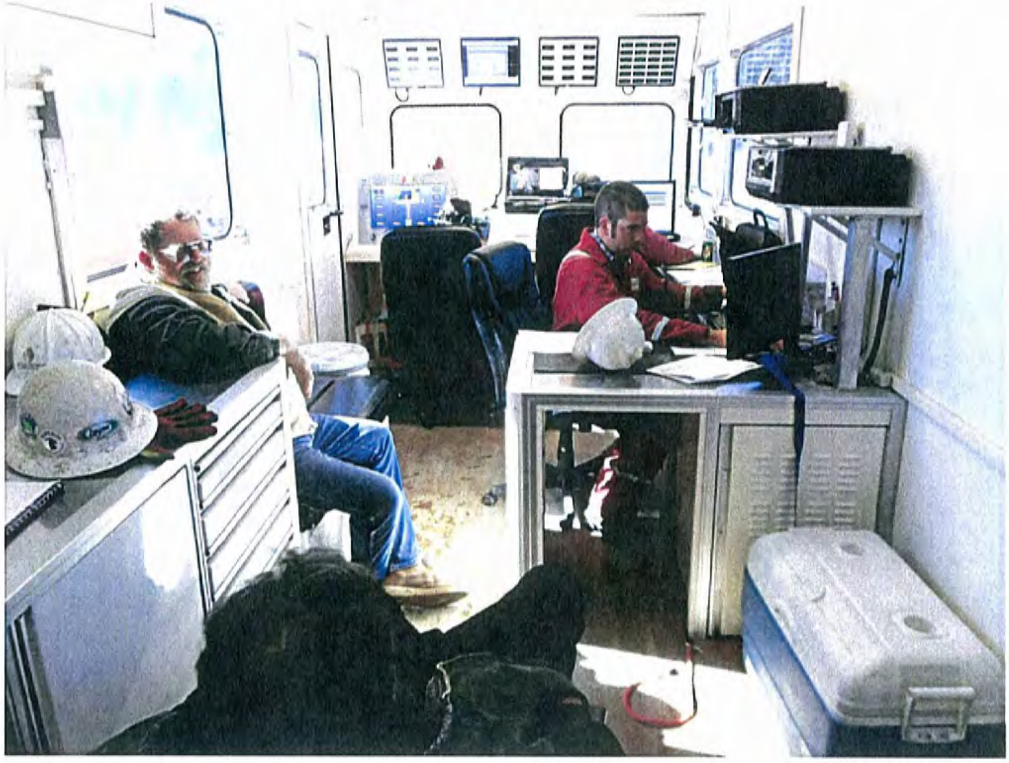


Photo 42: Operator interface with digitally controlled pumps.

Photo 43: Control truck monitor for frac job supervision; STP = 1550 psi at 66.2 BPM.

Since the differential pressure rating of the packer was not known for the increased friction on the well casing due to inflation exceeding 1500 psi over submergence, an electronic water level indicator was installed a few feet above the 631-foot water level outside the packer tubing to monitor the fluid level above the packer. If the differential pressure rating of the packer was exceeded during the frac job, the packer tubing weighed enough to prevent the packer from moving up the well; however, the excess pressure would decrease the diameter of the inflated packer and fluid would begin to move up the well above the packer. Accordingly, fluid triggering the water level indicator would show that the packer differential pressure rating had been exceeded and that the packer was leaking. A member of Layne's crew was assigned to continuously monitor the water level indicator during the high-pressure pumping. The fluid level above the packer was observed to remain stable throughout the acid frac job.

Figure 15 shows surface treatment pressure (STP) and bottom hole pressure (BHP). The difference between STP and BHP is friction loss in the tubing to the packer. The static level in the well was approximately 727 feet BTOC. If the BHP minus the packer differential pressure rating (DPR) is a positive number, that number indicates the amount of pressure applied in excess of the DPR of the packer. As shown on Figure 15, the BHP exceeded the 1041-psi DPR of the packer by 300 to nearly 400 psi during the acid fracking treatment. The pressure in excess of DPR was resisted by over-inflating the packer by 315 psi, increasing inflation from the rated 1500 psi to 1815 psi over submergence. Although the DPR of the packer at 1815 psi over

submergence is not known, the fact that it did not leak or fail indicates the unknown DPR exceeded the pressures that were applied.

4.3 Post-Acid Treatment Water Quality

Table 7 shows concentrations of selected chemical constituents in water samples collected during air rotary drilling. The samples were collected from the airlift discharge of water from the open borehole as it was drilled. Most parameters on Table 7 increase with increasing borehole depth. An exception is bicarbonate which may be sensitive to the partial pressure of CO_2 during the air lift discharge of water from the well.

Table 8: Chemistry of water samples collected during air rotary drilling.

Date: **Time:**	**2/22/2013** **8:15 A.M.**	**2/22/2013** **3:40 P.M.**	**2/23/2013** **8:25 A.M.**	**2/25/2013** **10:00 A.M.**	**2/26/2013** **2:45 A.M.**
Conditions	Air Drilling	Air Drilling	Air Drilling	Air Drilling	Air Drilling
Well Depth	2245	2472	2535	2685	2801
TDS (mg/L)	446	587	622	726	765
Conductivity. (μmhos/cm)	697	859	911	1020	1060
pH (s.u.)	10.4	8.14	8.10	8.18	8.29
Hardness as $CaCO_3$ (mg/L)	390	460	480	540	560
Ca (mg/L)	94	106	114	124	129
Mg (mg/L)	38	48	47	56	58
K (mg/L)	11	2	2	3	4
Na (mg/L)	9	4	8	14	15
Bicarbonate as HCO_3 (mg/L)	48	250	233	203	204
Carbonate as HCO_3 (mg/L)	30	ND	ND	ND	Nd
Sulfate (mg/L)	270	272	311	358	375
Chloride (mg/L)	12	5	8	13	15
Fluoride (mg/L)	1.0	1.3	1.5	2.1	2.2
Arsenic (mg/L)	ND	ND	ND	ND	ND

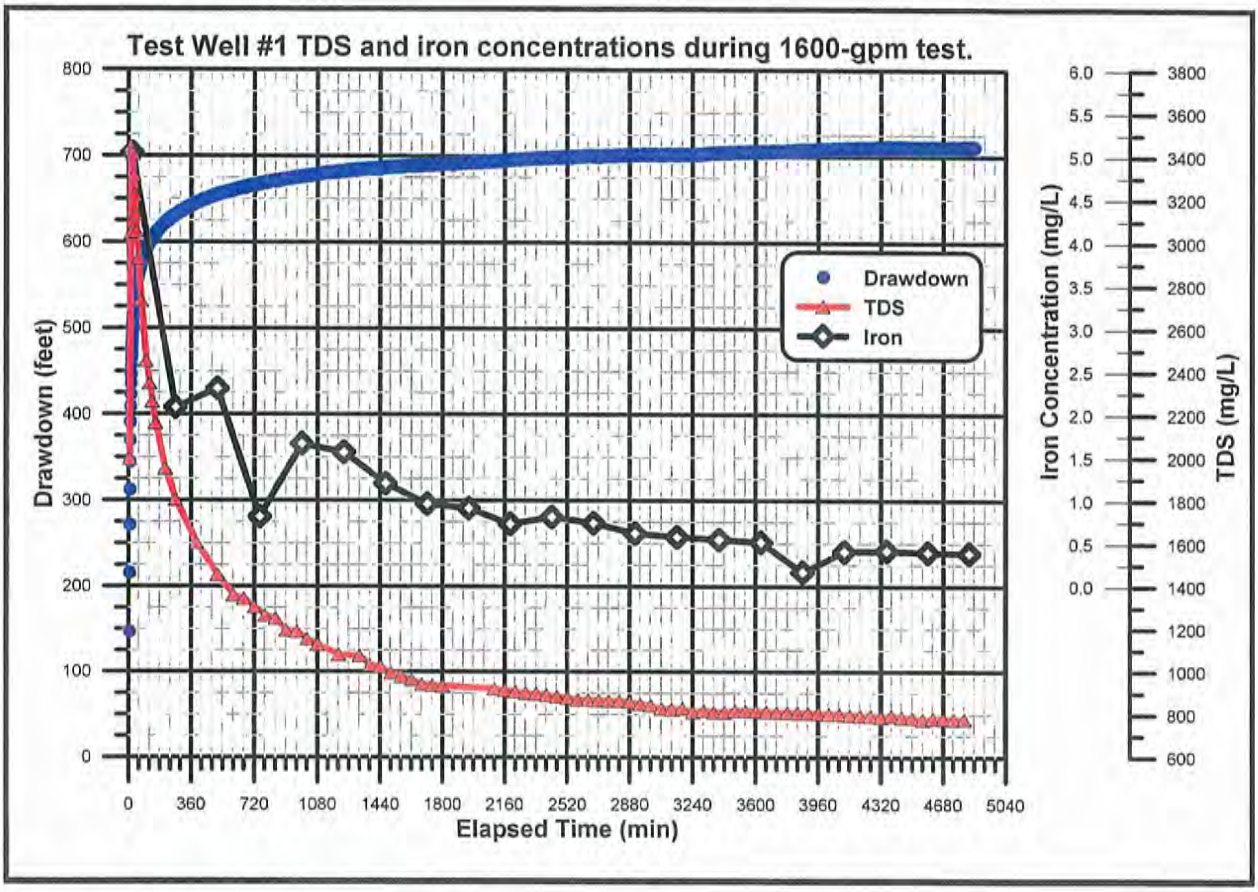
Table 8 shows the last column of Table 7 which contains the chemical parameters from a water sample collected during air rotary drilling at total well depth, plus the results from water quality samples collected after 11.5 hours of pumping at 900 gpm prior to acid stimulation of the well and one collected after 80.5 hours of pumping at 1600 gpm, after acid stimulation. The latter pumping does not include step tests and pre-test pumping of water to frac tanks immediately after the acid treatment to ensure the pH of the water was high enough to allow discharge to the land surface. The sample from the 900-gpm, pre-acid test shows parameters reasonably similar to those at the end of air rotary drilling. Parameters in the 1600-gpm, post-acid treatment test are slightly elevated, indicating that some effects remained from acid treatment of the well.

Projection of the TDS concentrations during the 81-hour test, indicated an additional 12 hours or more of pumping was required to lower the TDS to pre-acid levels. Figure 17 shows TDS concentrations versus time during the aquifer test.

Table 9: Chemistry of water samples before and after acid frac treatment.

Date: **Time:**	**2/26/2013** **2:45 A.M.**	**3/11/2013** **8:30 P.M.**	**5/13/2013** **5:00 P.M.**	**Post-Frac Tracking of Total Iron Concentration during 1600-gpm Aquifer Test**
Conditions	Air Drilling	Pre-Frac Test 11.5 hrs @ 900 gpm	Post-Frac Test 80.5 hrs @ 1600 gpm	
Well Depth	2801	2801	2801	
				5/10/13 0850 hr 5.04 mg/L
TDS (mg/L)	765	766	817	5/10/13 1300 hr 2.08 mg/L
Conductivity. (μmhos/cm)	1060	1060	1110	5/10/13 1700 hr 2.30 mg/L
pH (s.u.)	8.29	7.54	7.25	5/10/13 2100 hr 0.81 mg/L
Hardness as $CaCO_3$ (mg/L)	560	580	600	5/11/13 2100 hr 0.81 mg/L
				5/11/13 0100 hr 1.66 mg/L
Ca (mg/L)	129	135	145	5/11/13 0500 hr 1.56 mg/L
Mg (mg/L)	58	59	58	5/11/13 0900 hr 1.20 mg/L
K (mg/L)	4	4	3	5/11/13 1300 hr 0.96 mg/L
Na (mg/L)	15	15	13	5/11/13 1700 hr 0.91 mg/L
				5/11/13 2100 hr 0.73 mg/L
Bicarbonate as HCO_3 (mg/L)	204	208	220	5/12/13 0100 hr 0.81 mg/L
Carbonate as HCO_3 (mg/L)	ND	ND	ND	5/12/13 0500 hr 0.74 mg/L
Sulfate (mg/L)	375	396	390	5/12/13 0900 hr 0.62 mg/L
				5/12/13 1300 hr 0.58 mg/L
Color (c.u.)			15	
Turbidity (NTU)			3.6	5/12/13 1700 hr 0.55 mg/L
Dissolved Fe (mg/L)		0.11		5/12/13 2100 hr 0.52 mg/ L
Total Fe (mg/L)		0.63	0.39	5/13/13 0100 hr 0.17 mg/L
Dissolved Mn (mg/L)		0.011		5/13/13 0500 hr 0.41 mg/L
Total Mn (mg/L)		0.011	0.008	5/13/13 0902 hr 0.42 mg/L
				5/13/13 1300 hr 0.40 mg/L
Chloride (mg/L)	15	14	43	
Fluoride (mg/L)	2.2	2.5	2.2	
Sulfide (mg/L)		ND	ND	
N as $NO_3 + NO_2$ (mg/L)		0.18	0.20	
Arsenic (mg/L)	ND	0.005	0.002	

Figure 17: TDS concentrations during 1600-gpm post-acid treatment aquifer test.



5 YIELD AND DRAWDOWN TESTS

Test Well #1 was subjected to a pre-frac stepped rate test on 3/10/2013 and tested at 500, 650, 800 and 950 gpm. The 950-gpm step could not be sustained due to the limitations of the test pump and decreased to 878 gpm before that step was terminated after 23 minutes, as compared to 120 minutes per step for the other rates. A 900-gpm constant rate test was conducted for 12 hours on 3/11/2013 to provide additional information about aquifer response.

It was evident from the March 2013 stepped rate and constant rate tests that the well did not satisfy the design target of a 1400-gpm production well and, therefore, it was necessary to stimulate the well production with high-pressure acid-frac treatment. Stimulation of the well with high-pressure hydraulic fracturing with acid was accomplished on 3/26/3013.

After the high-pressure acid frac treatment, the well was subjected to a post-frac stepped rate test on 4/13/2013. The step test consisted of five pumping rates, each of 2-hour duration, at 1015, 1115, 1210, 1310 and 1410 gpm. The stepped rate test was followed by an 81-hour constant rate test at 1600 gpm.