Great West Engineering, Inc.

Water Supply Well CMRWA #2
Pumping Test Report

Central Montana Regional Water Authority

May 2017

Western Groundwater Services, LLC
6595 Bear Claw Lane
Bozeman, MT 59715
(406) 585-5947
www.westerngroundwaterservices.com

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1. INTRODUCTION

Central Montana Regional Water Authority (CMRWA) has developed water supply well CMRWA #2 at the U Bet Wellfield near Garneill (**Figure 1**). This wellfield is intended to provide a groundwater source for the Musselshell-Judith Regional Water System (MJRWS). The well was constructed into the Madison aquifer in 2012 and was tested for yield and water quality at that time with highly favorable results. CMRWA intends to develop additional wells at the U Bet Wellfield in order to meet the water system source capacity requirements.

In 2015 CMRWA was awarded a grant from the State to further evaluate water resources in Judith Basin, where the U Bet Wellfield is located. One of the activities of the grant was to conduct a substantially longer pumping test in the CMRWA #2 well than had been completed at time of construction. Data collected from the test would provide additional data to further evaluate the Madison aquifer. Testing was completed in September and October 2016. This report is presenting the analysis and results of testing.

Western Groundwater Services completed this report while working as a subconsultant to Great West Engineering, Inc. Great West Engineering, Inc. is the prime consultant to CMRWA for the MJRWS project.

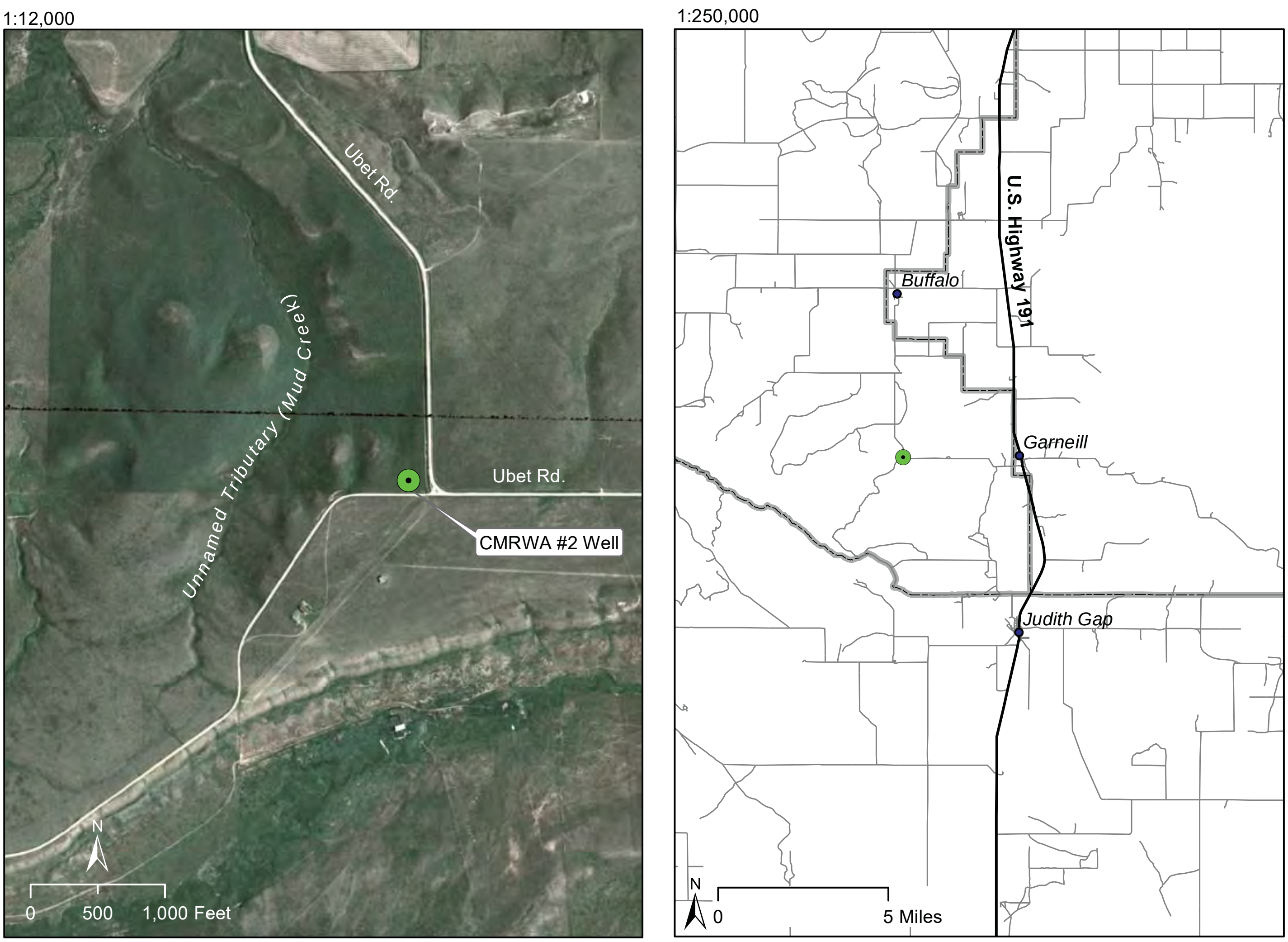

Figure 1. Location Map

2. WELL CONSTRUCTION

CMRWA #2 was equipped with a new submersible pumping system for testing.[1] A public bidding process was conducted during April 2016 to retain a contractor for the project. Boland Well Systems, Inc. of Great Falls was selected by the CMRWA Board. A schedule of values for the pumping system and contractor work to assist testing of the well is provided in **Table 1**.

Figure 2 provides the as-built log for the well construction. **Figure 3** illustrates the as-built construction for the pumping system down the well. At the surface (not shown), the 5-inch diameter column pipe is connected to a 6-inch diameter tee. A 20-foot discharge pipe extends north from the branch of the tee and terminates at a 6-inch diameter gate valve.

During pump testing, a PVC hose was coupled to a fitting immediately downstream from the gate valve and laid out 100 feet to the north fence line of the well easement area. This hose was abraded at the point of connection and leaked profusely towards the end of testing. It has been repaired since, however, to avoid this abrasion in future testing, PVC pipe and fittings could be used to extend the piped discharge to the ground. The hose could then be connected at ground level and run straight to the point of discharge.

1 A temporary pumping system furnished by the drilling contractor was used for the initial pumping test of the well.

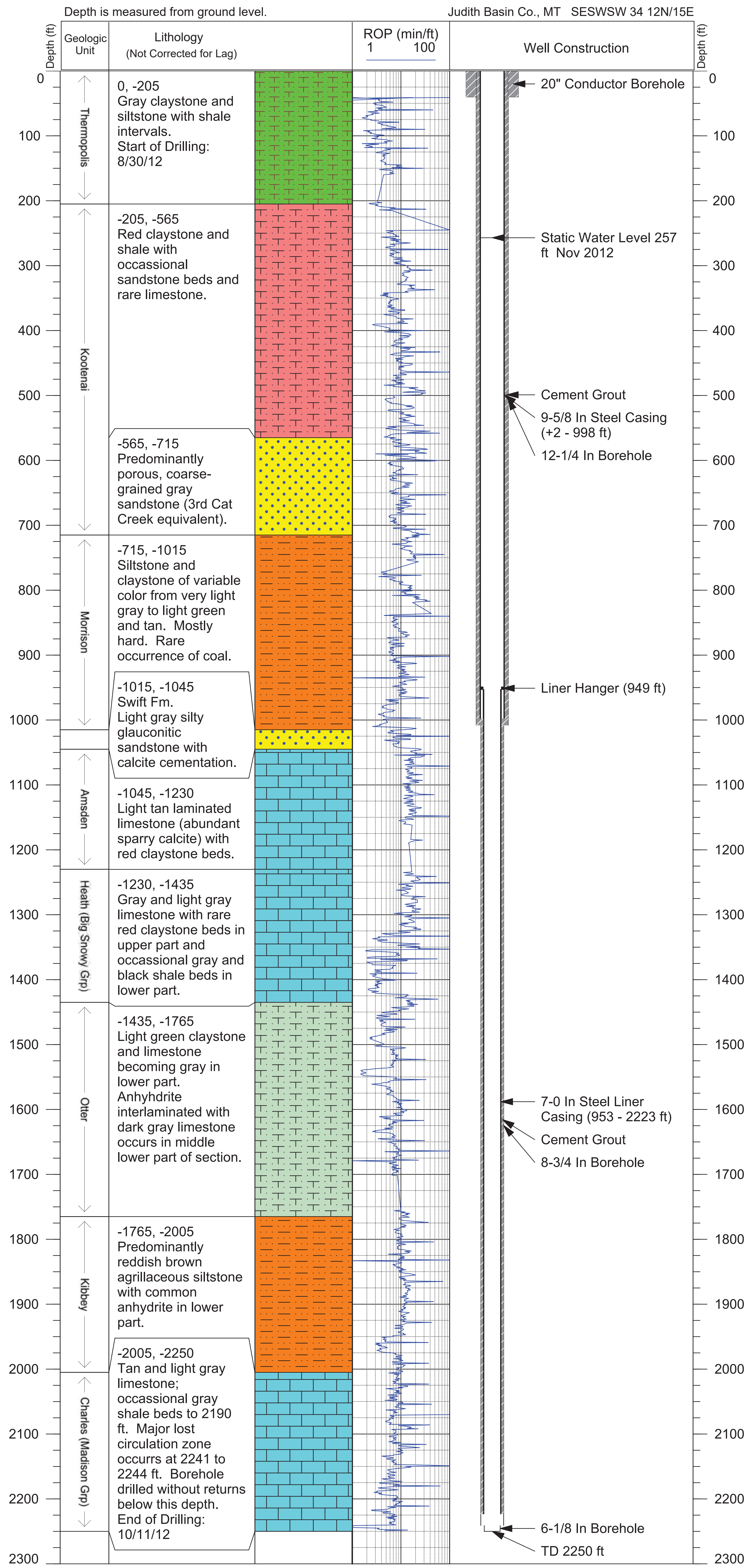

Figure 2. Well Construction Log

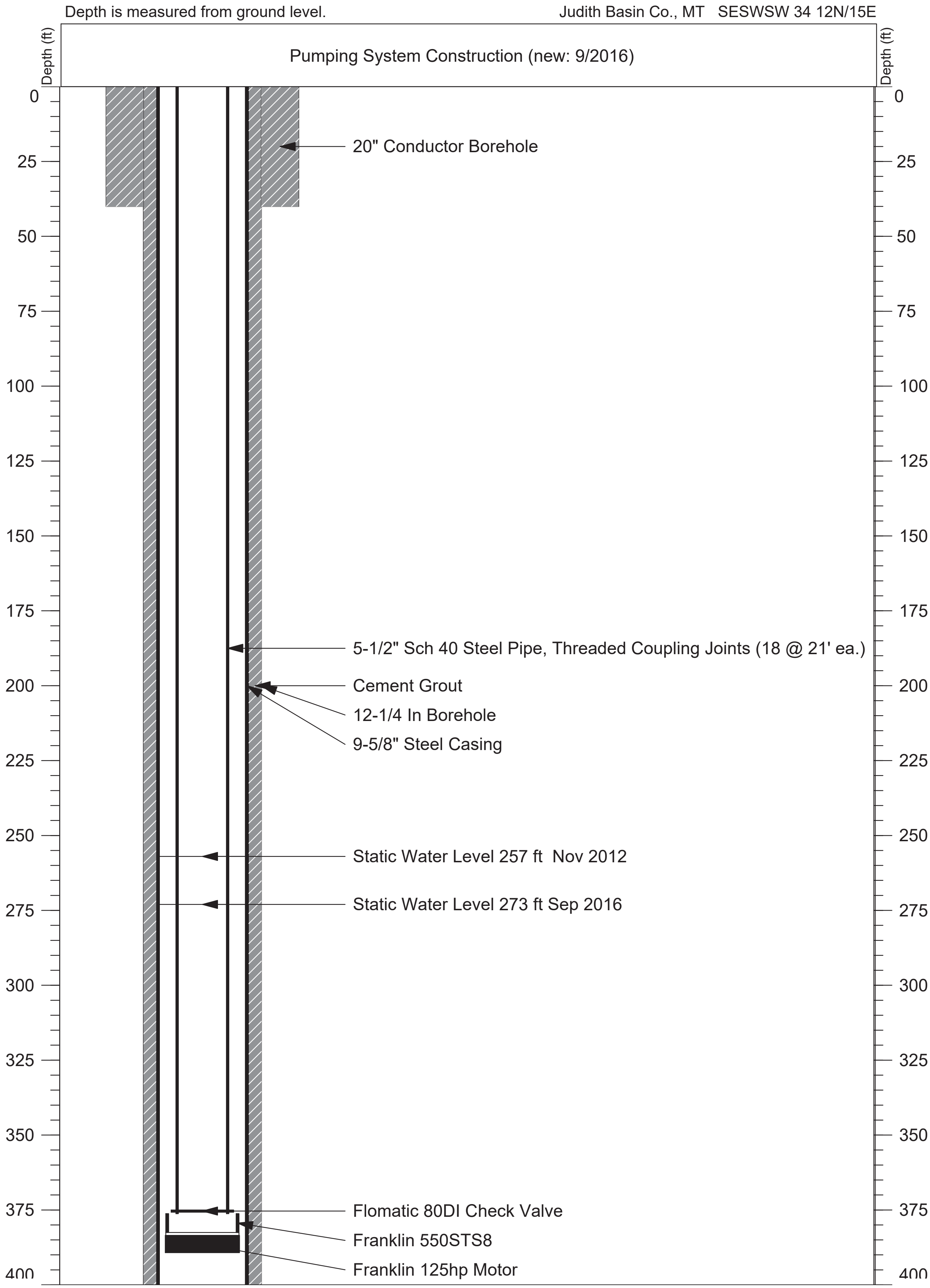

Figure 3. Pumping System As-Built

Table 1. CMRWA #2 Pumping System Schedule of Values

Pumping System	Quantity	Units	Rate	Total
Mobilization	1	LS	$ 16,000	$ 16,000
Submersible pump,125 hp motor, and check valve	1	EA	$ 27,000	$ 27,000
Soft-start pump control panel	1	EA	$ 4,000	$ 4,000
5" Sch 40 galvanized steel pipe w/couplings	375	LF	$ 14.40	$ 5,400
1" PVC Sch 80 sounding tube	1	EA	$ 270	$ 270
6" Sch 40 galvanized steel pipe, support and saddle	20	LF	$ 23.50	$ 470
6" C509 gate valve w/hand wheel	1	EA	$ 550	$ 550
Misc. 6" galvanized fittings	1	LS	$ 1,818	$ 1,818
Discharge hose, 6" lay flat	100	LF	$ 4.60	$ 460
Support plate, 1" steel, 16"x16"	1	EA	$ 700	$ 700
Subtotal				$ 56,668
Pumping Test				
Mobilization	1	LS	$ 2,500	$ 2,500
Generator rental	1	LS	$ 1,500	$ 1,500
Daily rate	20	Days	$ 900	$ 18,000
Generator fuel	6000	gal	$ 1.87	$ 11,220
Subtotal				$ 33,220
TOTAL				$ 89,888

3. PUMPING TESTS

Two tests were run to collect data that were used for evaluation of the well hydraulic performance. **Table 2** lists the times, dates and durations for testing. The step rate test is used to quantify turbulent head losses that occur for water entry into the well and flow upward to the well pump. It was also used to assess the performance of the new pumping equipment. The constant rate test is designed to estimate values for aquifer hydraulic parameters and the occurrence of boundaries.

The step rate test was run for four hours at pumping rates ranging from 381 to 631 gallons per minute (gpm). Constant rate testing was run at a rate that ranged from about 570 to 580 gpm. Constant rate testing was planned to include a 20-day continuous pumping period, however, the generator failed after 9-days. The machine was repaired and testing was restarted after 3.34 days of recovery.

Table 2. Pumping Test Schedule

Test	Start	Stop	Hours	Days
Step Rate	9/27/16 1:35 PM	9/27/16 5:35 PM	4.0	0.2
Constant Rate	9/28/16 9:15 AM	10/7/16 8:30 AM	215.3	9.0
Constant Rate	10/10/16 4:40 PM	10/20/16 1:00 PM	236.3	9.8
		TOTALS	455.6	19.0

4. DATA COLLECTION

4.1 Groundwater and Atmospheric Levels

CRMWA is monitoring groundwater levels at seven locations in Judith Basin, and atmospheric pressure at the U Bet Wellfield, and has purchased new sensors for this purpose (**Figure 4**). **Table 3** provides information on these locations and the instruments being used for monitoring. All of the instruments are pressure and temperature transducers with integral data loggers manufactured by In-Situ, Inc. of Fort Collins, CO.

Well sites were equipped with the Level TROLL 500 model. The barometric sensor model is the Level BaroTROLL. Each sensor is deployed on a communication cable that facilitates access to the data without moving the sensor. The communication cable also provides atmospheric venting and therefore instruments are reading a gage pressure. The barometric sensor located at the U Bet Wellfield is set at the CMRWA #2 wellhead above ground, and uses a non-vented cable, therefore providing a measure of absolute pressure.

The Level TROLL 500 and Level BaroTROLL sensors provide absolute measurement accuracy of pressure of ±0.1% of the sensor rating (FS) and resolution of 0.005% FS, or better—a 100 psig sensor, for example, would have absolute accuracy of 0.23 feet (ft) and resolution of 0.01 ft. Temperature accuracy is ±1ºC. For long-term monitoring, the sensors have been programmed to record measurements at 15-minute intervals. During pump testing, the sensor in the CMRWA #2 well was set to record measurements at 5-minute intervals.

Data from the CMRWA MW#1, CMRWA #1, and CMRWA #2 wells are presented in this report. The other locations will be downloaded twice per year starting in April 2017. These data will be reviewed and made publically available on the CMRWA website (centralmontanawater.com).

Table 3. Water Level Instrument Summary

Location Name	Aquifer	Sensor Rating (psig)	Date Deployed
U Bet Barometric	Atmospheric	30 (absolute)	9/19/2016
CMRWA #1	Madison	300	9/19/2016
CMRWA #2	Madison	100	9/27/2016
CMRWA MW#1	Kootenai	300	9/19/2016
Hanover Well	Madison	100	4/13/2017
Judith Gap	Kootenai	100	9/21/2016
Nicholson Ranch	Kootenai	100	9/21/2016
Peterson Ranch	Kootenai	300	9/19/2016

4.2 Discharge Rate

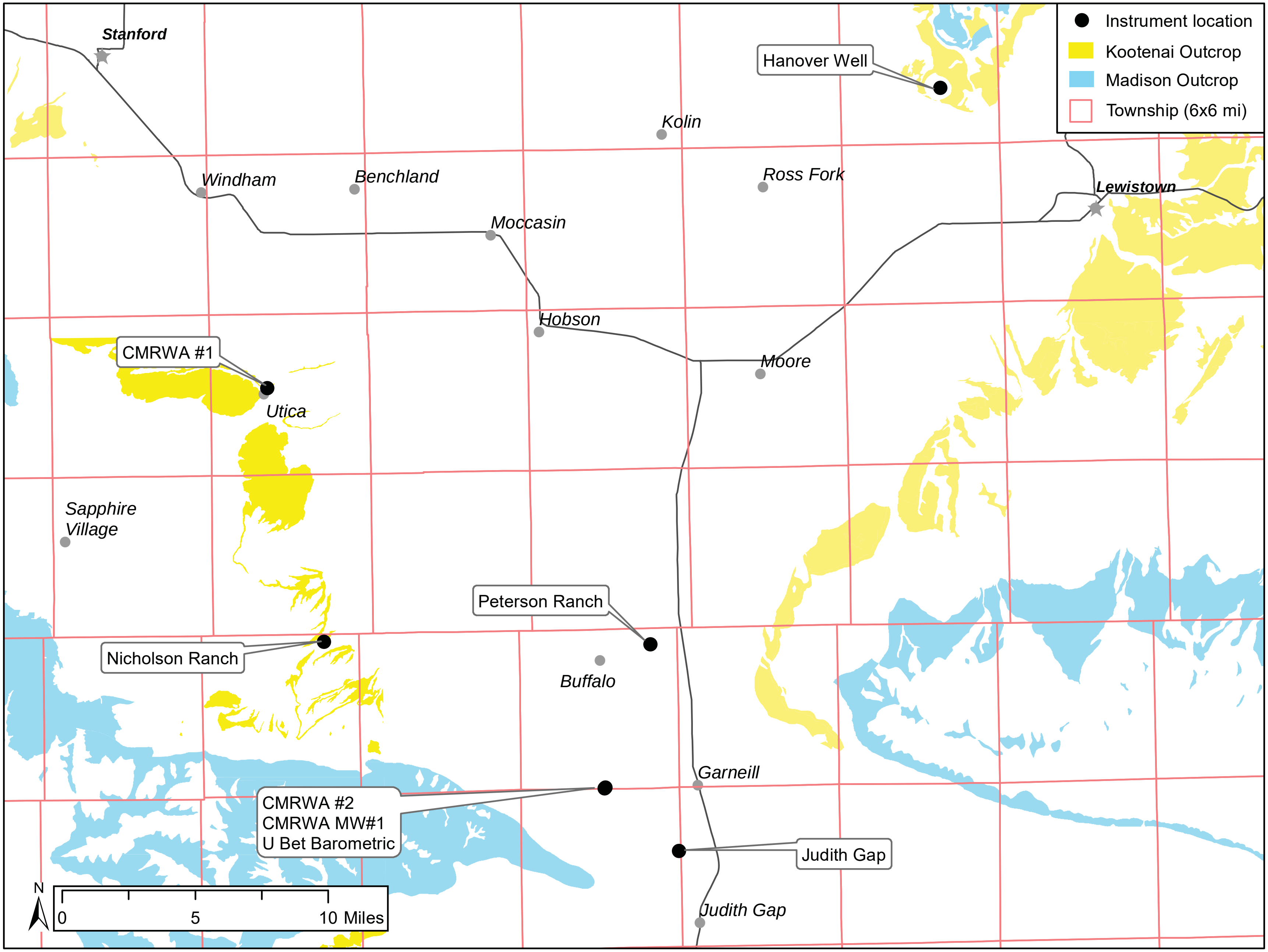

Figure 4. Monitoring Locations

Discharge rate from the CMRWA #2 well during pump testing was measured using a Controlotron 1010WP portable ultrasonic flow meter, now sold by Siemens as model SITRANS FUP1010.[2] This meter has integral data logging and accuracy of ±0.2 to 2% of reading for flow rates greater than 1 feet per second (ft/s). The meter transducers, which clamp onto the outside of the discharge pipe, were mounted in the center of a 20-ft length of 6-inch diameter schedule 40 galvanized steel pipe at the three o'clock position (looking north). The C3 Universal transducers were mounted in reflect mode as directed by the meter setup program (spacer bar offset 21) and contacted the pipe through a silcon gel (Super Lube ®), as provided by Siemens. The meter datalogger was set to record average discharge rate and total volume of discharge at 5-minute intervals. The clocks of the flow meter and water level sensors were synchronized before the start of testing.

5. STEP RATE TEST ANALYSIS

5.1 Well Analysis

A hydrograph plot of the step rate pumping test is shown on **Figure 5**. Each pumping step was 60-minutes in duration with a total test time of 240-minutes. The average discharge rates for each step were 381-, 488-, 553-, and 631-gpm. Prior to the start of testing, static water level in the well was 273 feet below ground surface (ft bgs). The pumping water level at the end of the fourth step (631 gpm) was 321 ft bgs, corresponding to 48 ft of total drawdown.

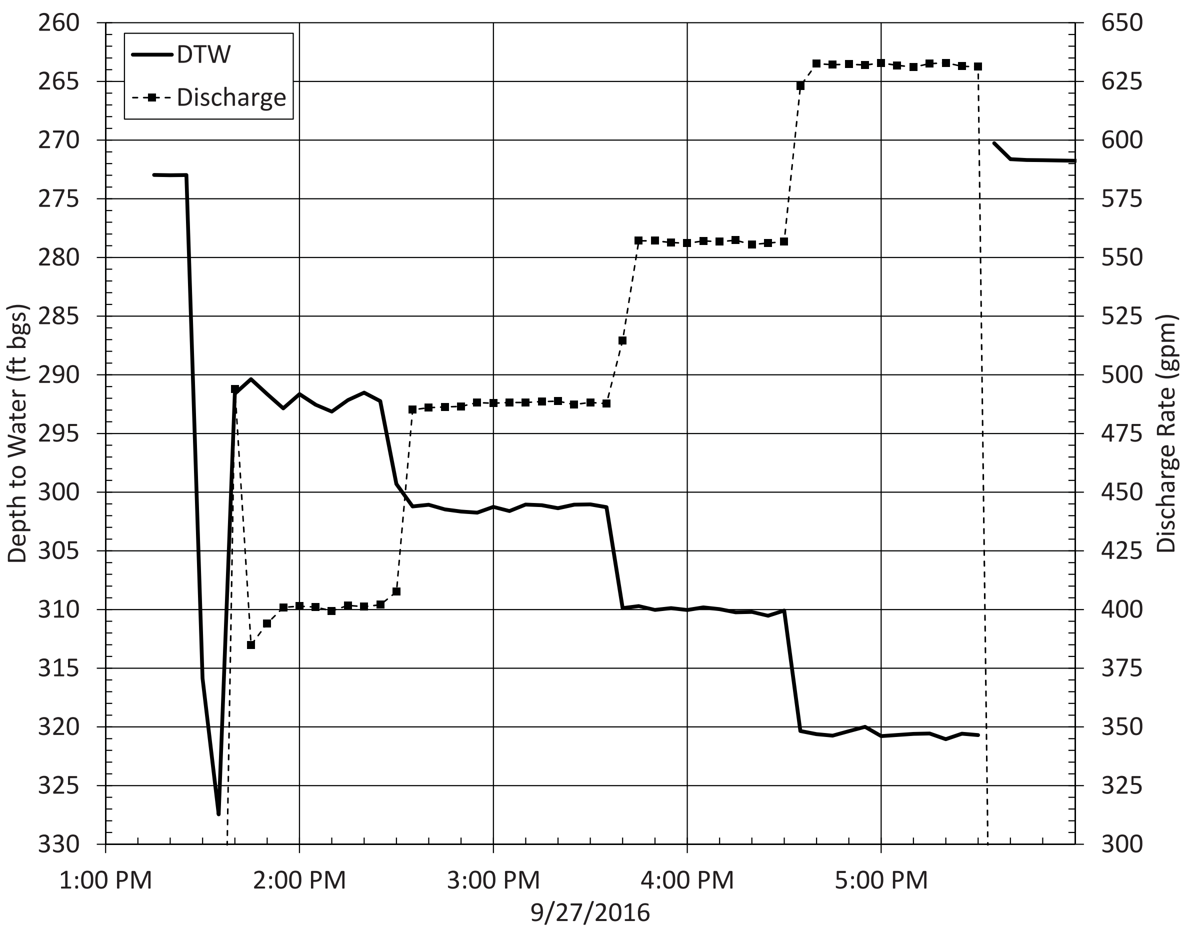

Figure 5. Step Test Hydrograph

2 Owned by Western Groundwater Services, LLC

Figure 6 shows the first step of analysis by the Hantush-Bierschenk method (Kruseman and de Ridder 1991, p. 201). Pumping water levels have been converted to drawdowns, and are analyzed for a transient response. The values of drawdown (s1 to s4) determined for each step are annotated onto the figure along with the average discharge rate for the step (Q1 to Q4). In the second step of analysis, the values for each step (e.g., s1, Q1) are plotted as points (**Figure 7)** and analyzed by regression analysis to determine total head losses. The slope of regression is the turbulent head loss coefficient (9e-5 ft/gpm^2) and the intercept is the laminar head loss coefficient (0.013 ft/gpm). The total head losses include turbulent and laminar head losses for water entry into the well borehole and for flow upward to the pump, which is set at 375 ft bgs.

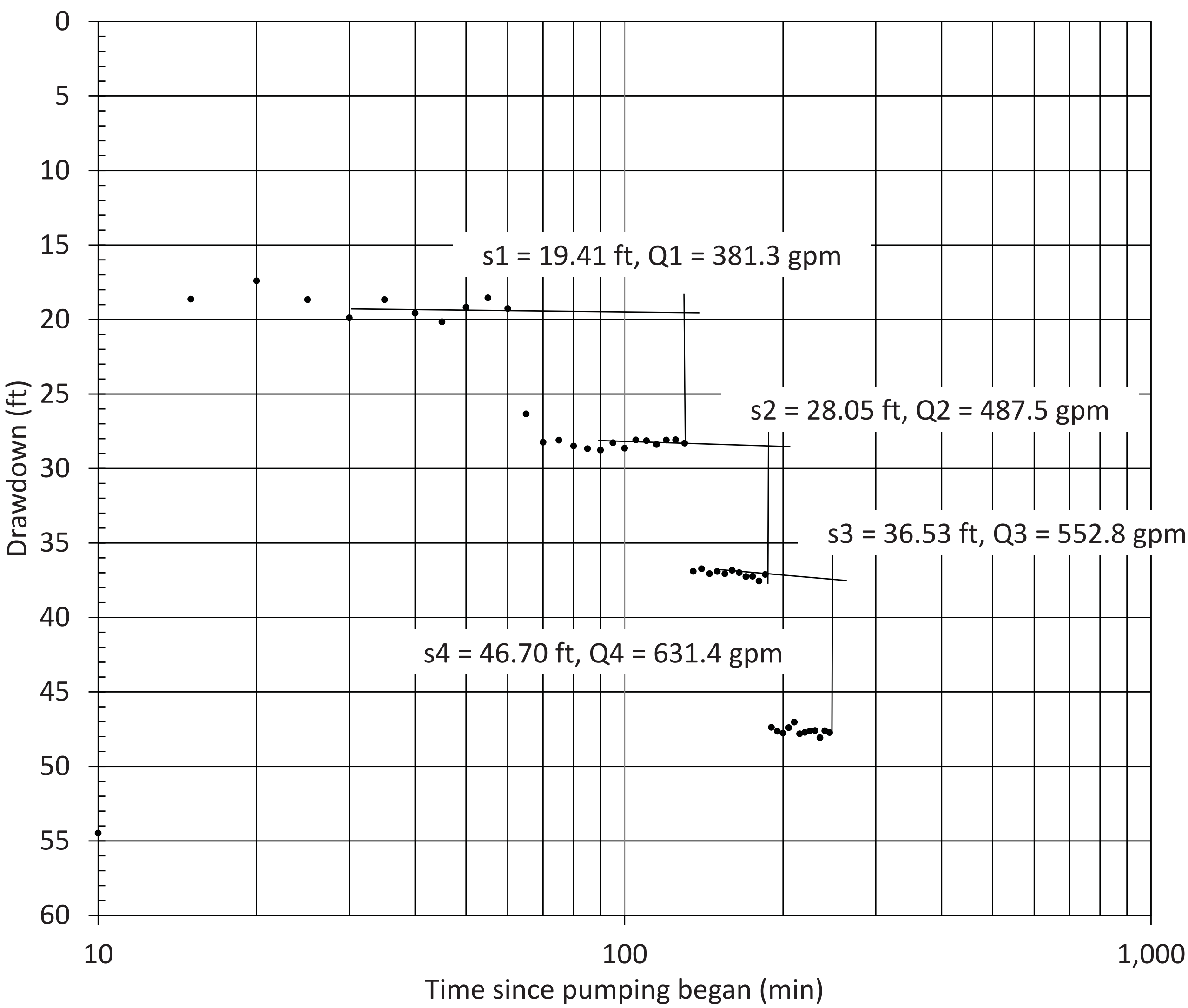

Figure 6. Step Test Drawdown

Substantial head losses occur in the well casing below the pump, particularly the 7-inch diameter liner casing. Analysis was completed to calculate this head loss and remove it from the total head loss, thereby establishing the aquifer head loss. The turbulent head loss in the casing was calculated for each flow rate of the step test by the Darcy-Weisbach equation using the iterative Colebrook formula to determine a friction factor. The analysis also used parameter values for new steel pipe (Gerhart and Gross 1985, pp. 415, 424, and 427).

The results of the same analysis from the pumping test of CMRWA #2 in 2012 are plotted for comparison. The turbulent head loss coefficients are nearly equal, but laminar head loss coefficients are greater for the 2016 test indicating an increase in aquifer drawdown. This difference may be an artifact of the analysis implementation, as the test data are generally close in value. After the well is put into service, further observation is warranted to verify these results. If connection to the aquifer is found to be degrading, a rehabilitation of the well can be performed.

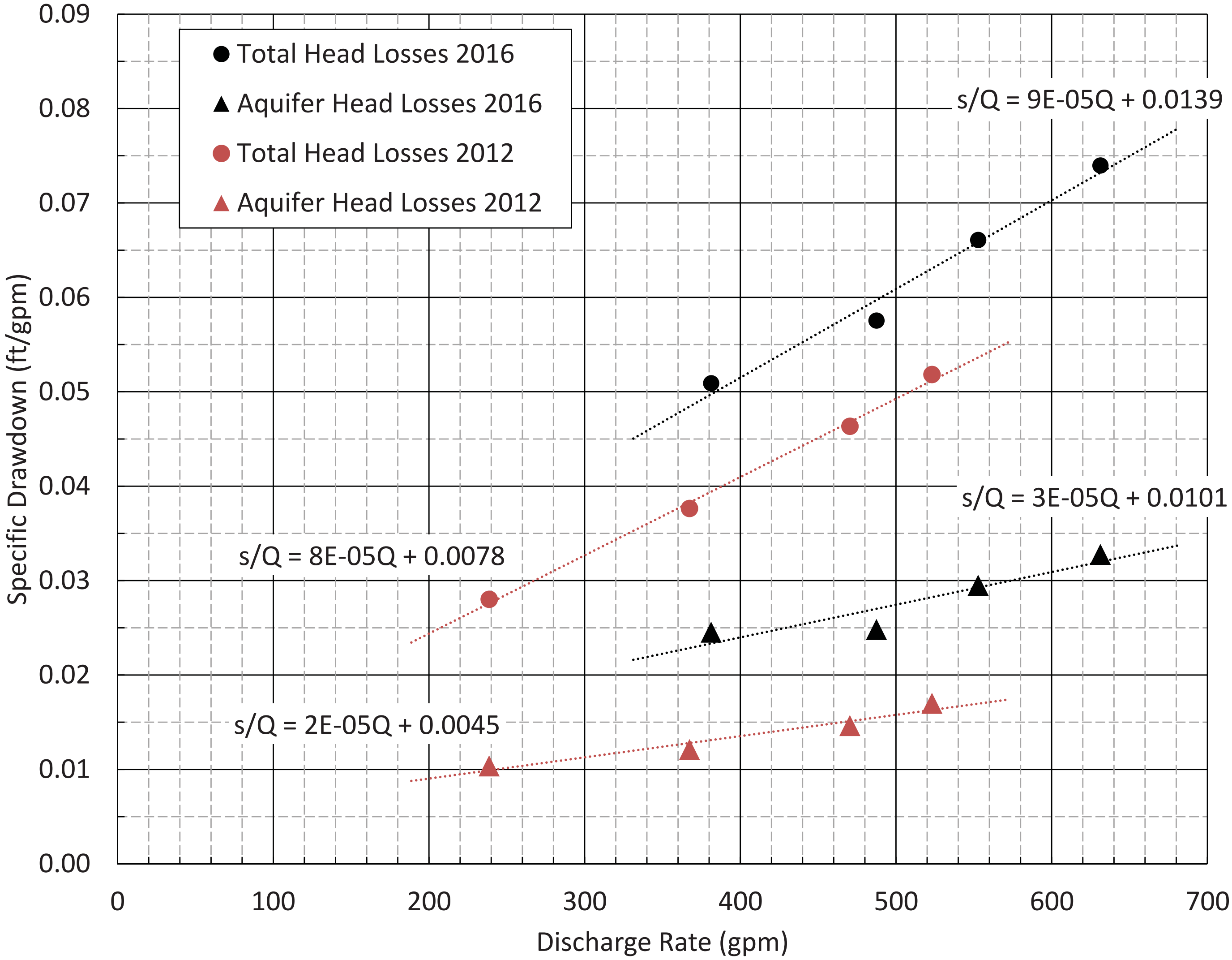

Figure 7. Step Test Regression

5.2 Pump Analysis

During the step rate test, discharge pressure at the surface was measured in order to assess pump performance. These pressure data were collected with an Ashcroft® Digital Pressure Gauge, Type D1005PS rated from 0 to 500 psig, and providing an LCD readout. This gauge has a reported accuracy of 0.5% of full scale or ±2.5 psig. The gauge was mounted in the 6-inch diameter discharge pipe, approximately 2-ft downstream from the wellhead.

Total dynamic head of the pump during testing was calculated for each step in order to compare field and manufacturer data. The terms included in the calculation were: 1) surface pressure; 2) static lift; and 3) frictional head losses. Surface pressure is directly read from the Ashcroft gauge. Static lift is the pumping water level measured to the height of the gauge. Frictional head losses were calculated using standard head loss equations and manufacturer data for the pipe and fittings between the pump and Ashcroft gauge. These included: 1) check valve (5″ dia.); 2) column pipe (5″ dia., 378 ft); 3) 6″ x 5″ bell reducer; 4) 6″ tee with branch flow; and 5) 6″ galvanized steel pipe (2 ft).

Table 4 provides the measured and estimated values, and total dynamic heads for each step. **Figure 8** shows the field points plotted adjacent to the manufacturer curve. As shown, the field test point for 381 gpm is acceptably close to the manufacturer curve, however, the deviation grows considerably at higher rates. Deviations may be related to: 1) test instrument errors (static lift, surface pressure, discharge); 2) frictional head loss calculation errors; 3) declining pump speed; and 5) poor performance of the pump. It is not clear which of these factors are influencing the results.

Based on pump affinity formulas, pump speed would have needed to have ranged from 56 to 53 Hz during the test. Of the test instruments, the flow meter has the largest error potential. However, it is rated to ±2% of reading, whereas the errors would have needed to range from 6% to 12.5%. A retest of the equipment should be performed when the well is completed and powered by line power.

Table 4. Pump Performance Field Data

Description	Field Data			
Step No.	1	2	3	4
Rate (gpm)	381	487	553	631
Static Lift (ft)	296	305	314	324
System Pressure (psig)	220	167	115	45
Head Loss (ft)	13	20	25	33
Total Pump Head (ft)	817	710	605	462

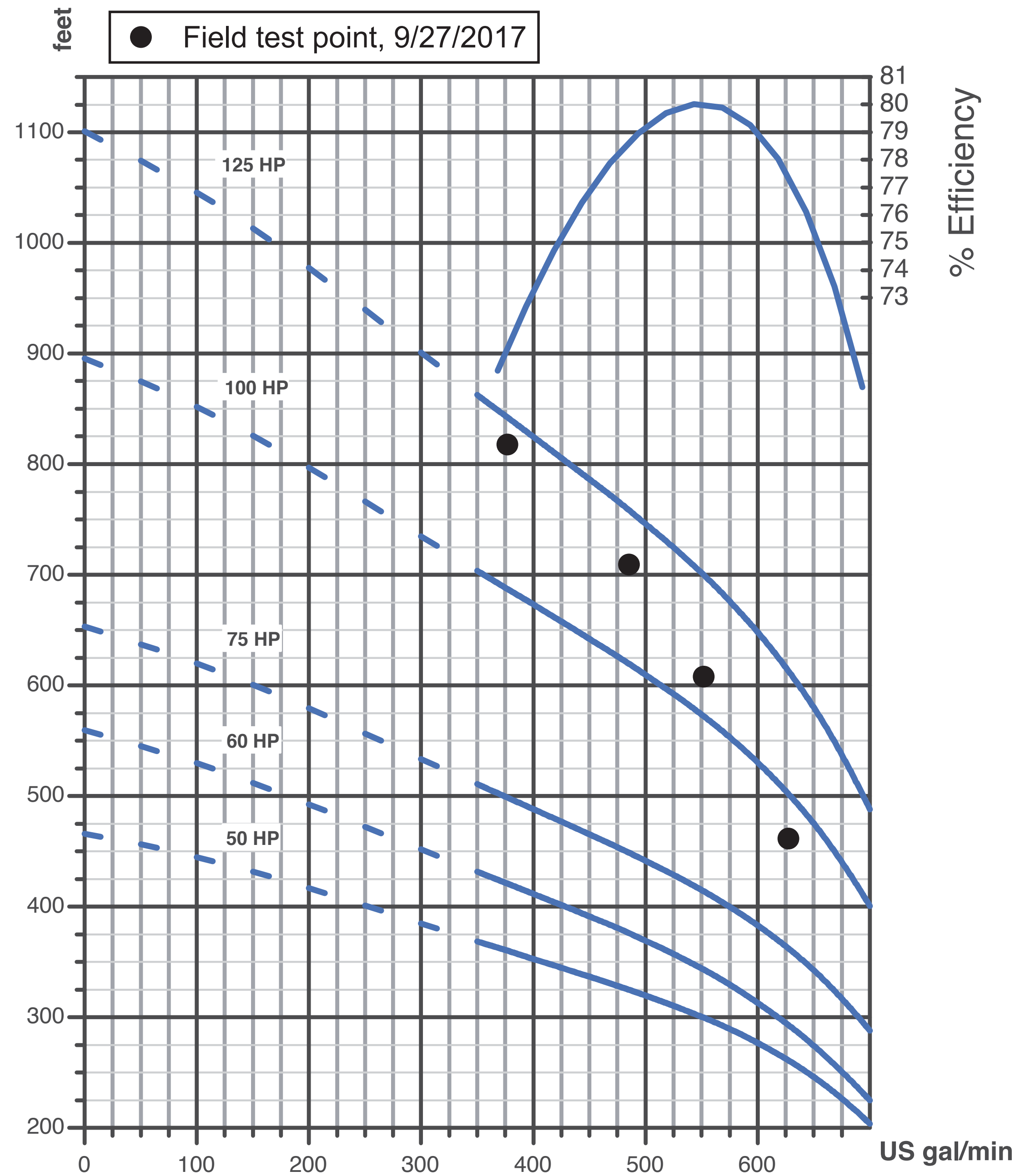

Figure 8. Pump Performance

6. CONSTANT RATE TEST ANALYSIS

6.1 Hydrograph

Static water level ahead of the start of the constant rate test was 273 ft bgs (**Figure 9**). This plot shows the well immediately recovered after the step rate test to a level greater than initial static and then slowly declined to the original static level. It appears that aquifer flow surged into the well when pumping was stopped, creating a small amount of buildup, which then declined back to the original static level.

The hydrograph for the constant rate test illustrates the pumping water levels and discharge rates through the entire test (**Figure 10**). The well water level is shown to be declining just prior to the start of pumping. The initial pumping period resulted in a pumping water level of about 310 ft bgs increasing to about 311.5 ft bgs, equating to 37 to 38.5 ft of total drawdown. For the nominal test rate of 575 gpm, specific capacity was about 15 gpm/ft.

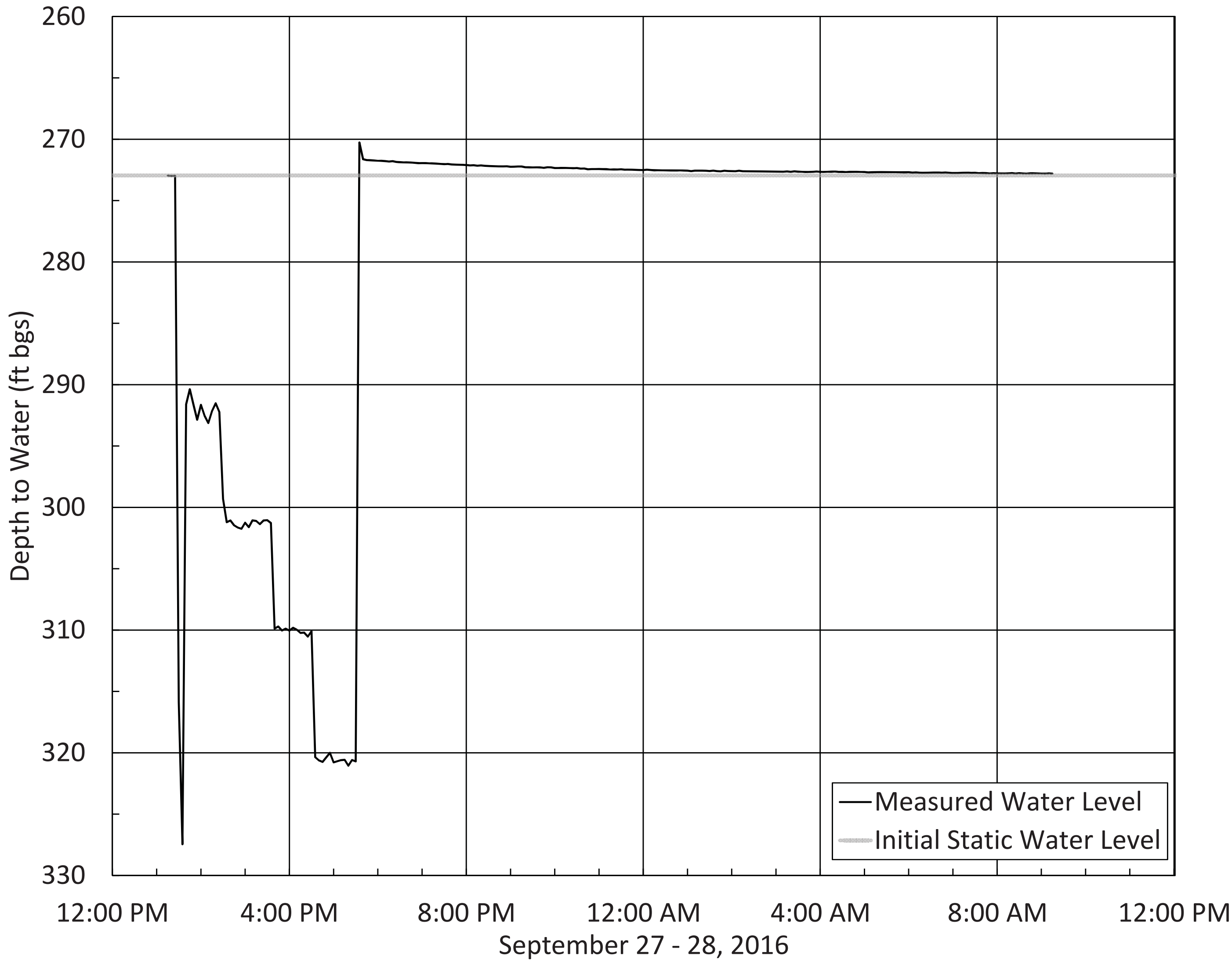

Figure 9. Pre-Test Static Water Level

Pumping water level is shown to immediately draw down and then remain essentially constant. This is true for the first pumping phase up to October 7th, and also the second pumping phase started on October 10th. This type of response is indicating that most drawdown occurs due to turbulent and linear head losses in the well and at the well bore. The aquifer drawdown appears minor thereafter.

The water levels were shown to fluctuate by approximately 1 ft, while discharge varied from 569 to 581 gpm. These fluctuations may be the result of aquifer flow surging into the well borehole and/or fluctuating power supply to the pump from the generator. They are not considered to be reflecting errors in the instruments, as both instruments show fluctuations and are independent from one another. Even with these fluctuations, discharge was within 1% of the test rate throughout the duration of testing.

The hydrograph also shows that when pumping was resumed on October 10th, drawdown was shown to increase, reaching a pumping level of 315 ft bgs and remain steady to the end of the test. It is not clear as to the cause of this difference given that the pumping rate was unchanged. It could be that the well discharge was greater than measured. This would require about 7% of error in the flow meter, which cannot be ruled out but is considered unlikely. Another possibility is that upon cessation of pumping, communication between the well and aquifer was impaired. Such a sudden downhole event also would be unlikely given the well was stressed to a much greater degree during development at time of construction.

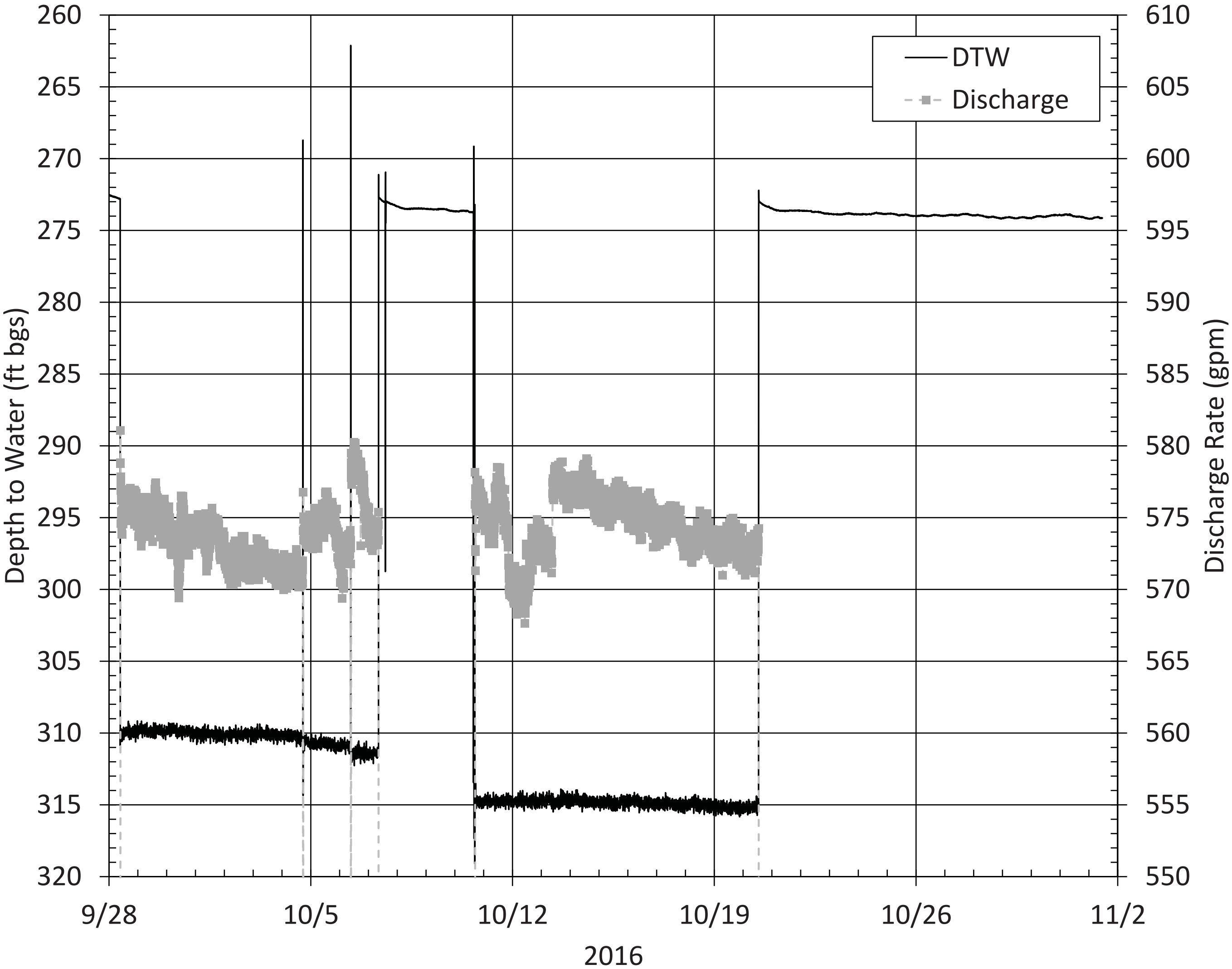

Figure 10. Constant Rate Hydrograph

Recovery water levels in the well following pumping did not fully recover to the original static level of 273 ft bgs, but appear to be stabilizing at about 274 ft bgs. This decline in static level is most likely reflecting a regional trend. Data downloaded from CMRWA #2 in April 2017 showed the declining water level to be at 288 ft bgs, and to follow a pattern that may reflect seasonality. Additional water level data from the well will be used to characterize this water level trend.

Finally, there are two periods in the discharge data that exhibit well-defined declining trends. In particular, the first part of the pumping period shows this pattern. Although the overall change in discharge is small, this trend could be important due to the very small aquifer drawdown that occurs beyond the onset of pumping. For this reason, this discharge trend was incorporated into the hydraulic analysis described in the next section.

6.2 Diagnostic Plots

Hydraulic analysis of the constant rate test data was completed using specialized software that provides numerous aquifer scenarios to be modeled and accommodates variable pumping rate tests (AQTESOLV v. 4.51, www.aqtesolv.com). Prior to analysis, turbulent head losses were subtracted from the CMRWA #2 drawdown data using the turbulent head loss coefficient from the step rate test (see above).[3] This correction is necessary because the well hydraulic models do not incorporate turbulent head losses.

Hydraulic analysis evaluated the entire data set through both periods of pumping, and many modeling iterations were completed. From this work it was found that the most satisfactory analysis could be completed on the first 6.34 days, or 9,130 minutes of testing. In order to eliminate the fluctuations that occur in these data, manual curve fitting was completed through the center of mass of the "data clouds" for both drawdown and discharge, as shown on **Figure 11** and **Figure 12**. Point data were then fit to these curves, and hydraulic analysis was completed using the point data.

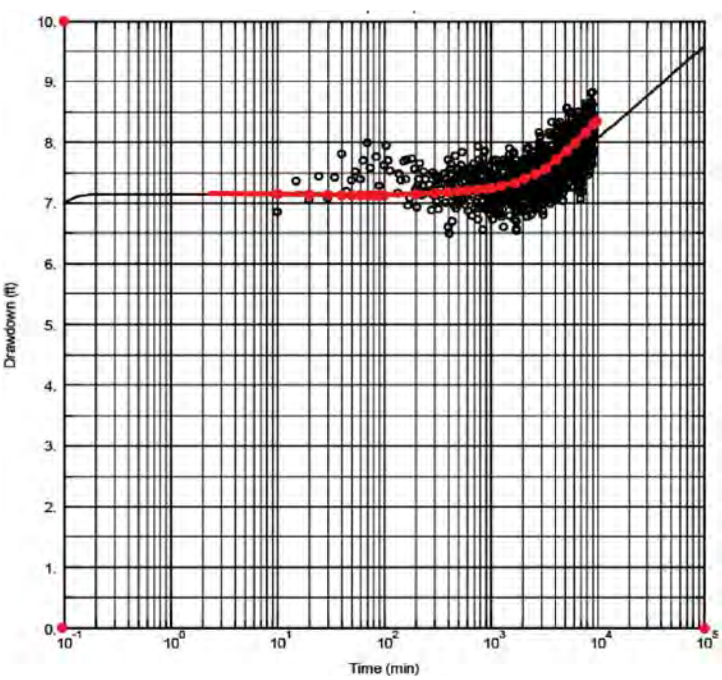

Figure 11. Drawdown Points

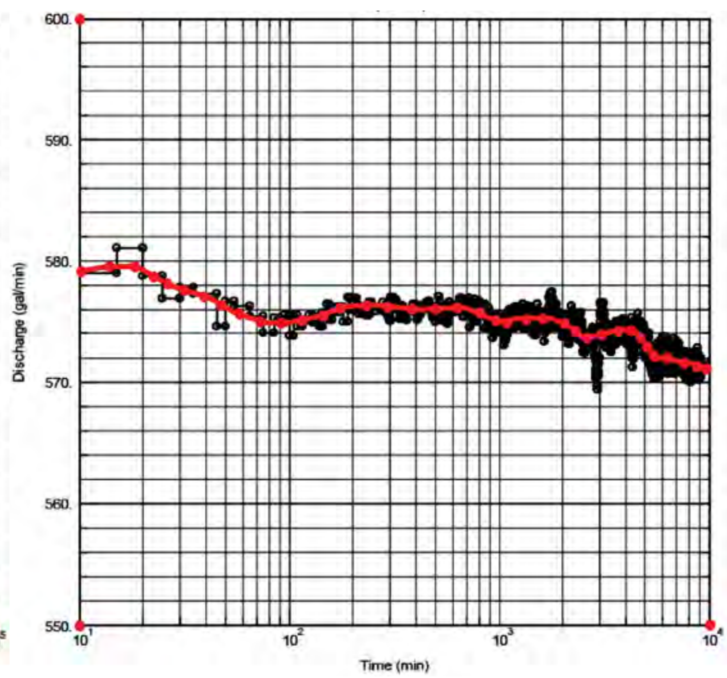

Figure 12. Discharge Points

Figure 13 shows a diagnostic plot of the drawdown data that uses logarithmic axes for both drawdown and time. The upper curve is aquifer drawdown and the lower curve is its derivative, or slope. The derivative increases continuously through the test and achieves a constant value in the last 2,000 minutes before pumping stopped. The occurrence of this constant slope is important to the test interpretation, as it indicates a less limited aquifer extent (than if the slope continued to increase). **Figure 14** is a plot of the same two curves, drawdown and derivative, but with a linear vertical axis. This plot shows the increasing drawdown more clearly. It is worth noting also that aquifer drawdown (apart from initial head losses) started at about 7.2 ft and increased only to 8.4 ft over the period of 6.34 days.

3 Turbulent head loss is given by CQ^2, where C is the turbulent head loss coefficient (9e-5 ft/gpm^2), and Q is discharge (gpm).

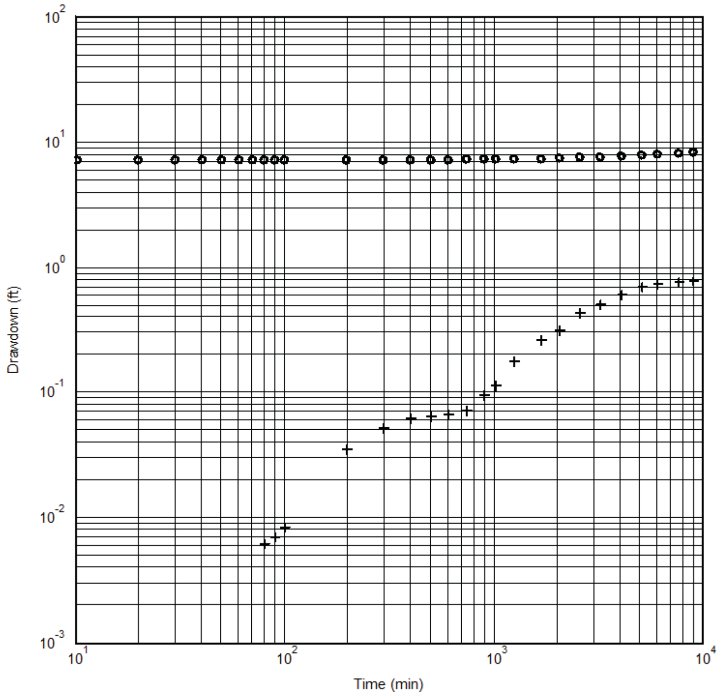

Figure 13. Log-Log Plot

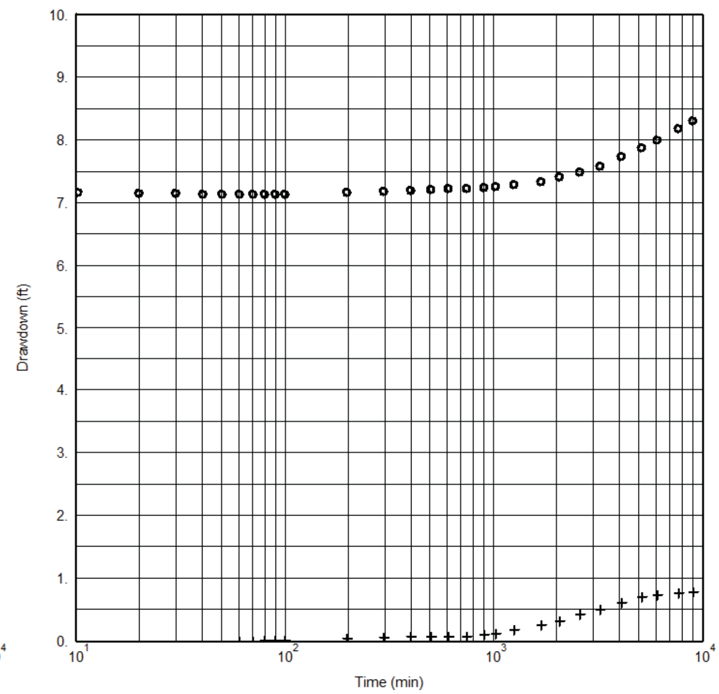

Figure 14. Semi-Log Plot

6.3 Modeling

The next step of analysis fits a well hydraulic model to the test data. Given the known conditions for the CMRWA #2 well and Madison aquifer, a fractured rock model was selected (Moench 1984). This model assumes an interconnected network of fractures that derive recharge from blocks of intact rock, referred to as matrix. The matrix has different hydraulic properties than the fractures. The fractures have high permeability and low storage, whereas the matrix has low permeability and higher storage. The matrix-fracture interface can also be modeled to have a coating, referred to as the fracture skin, that affects flow between matrix and fractures.

Three of the model input parameters were fixed for the analysis based on reasonable estimates. These included the aquifer thickness, the matrix block size, and the borehole skin factor. Aquifer thickness was set to 3 ft based on data from the borehole. With consideration of aquifer thickness, matrix block size was input as 1.5 ft (as a half-width). Borehole skin factor was set to a slightly negative value of -1.4 by adjusting the well radius to a value of 1.0 (actual radius is 0.255 ft).

Fitting of the model begins with manual adjustment of parameters to obtain a model that is near to the data points in value, but not necessarily conforming to the same trends. A numerical analysis is then run to fit the model to the test data more closely. **Figure 15** shows the model fit to the data points. The model is shown to closely match the data points of both drawdown and derivative.

In order to achieve the fit shown, two flow limiting boundaries were included in the model (**Figure 16**). The southerly boundary offset 15,000 ft from the pumping well is assumed to coincide with the up-gradient extent of the aquifer. The northerly boundary does not correspond to a known structural boundary. Other boundary configurations could likely be developed and achieve the same modeling results.

Initial model runs were made with no boundaries and then one boundary, but could not achieve a large enough slope during the late time period to match the test data. A few of the parameters were also estimated to have unrealistic values. The final model fit is visually and numerically good and the parameter

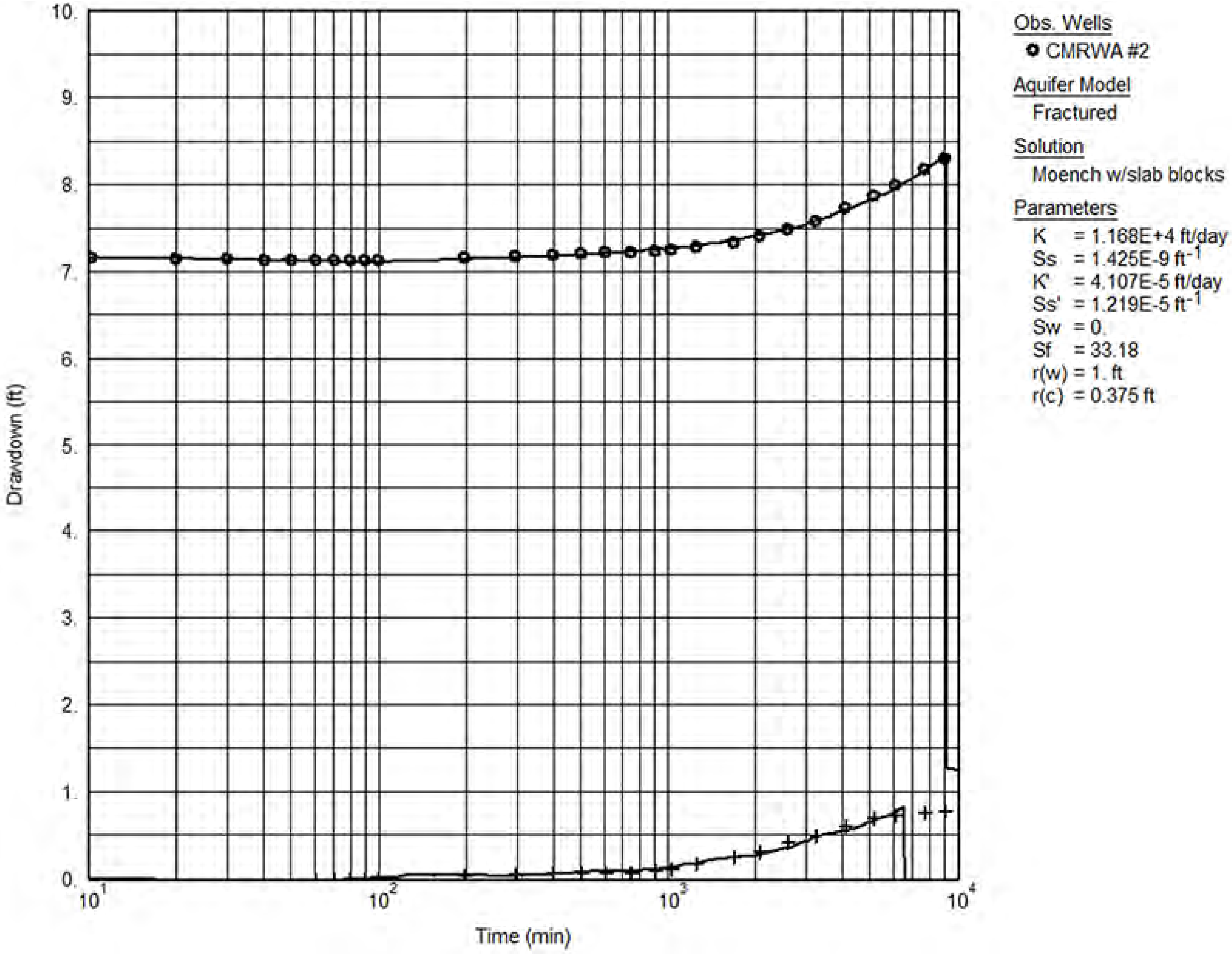

Figure 15. Model Fit

values are generally reasonable (**Table 5**). Modeled parameter values indicate that effectively all the permeability occurs in the fracture system and the matrix is extremely tight. This result is consistent with the expected behavior of the Madison aquifer.

There are likely numerous equivalent model fits that could be made to the test data. Other model fits may use different models and would likely determine different parameter values. The same model as used could be fit using different boundary offsets, aquifer thickness and matrix block thickness. For these reasons, it is necessary to obtain some parameter values from either field data or by reasonable conceptualization of the aquifer system. These ambiguities aside, it is expected that any reasonable model fits should determine high permeability for fractures and would include one or more flow limiting boundaries.

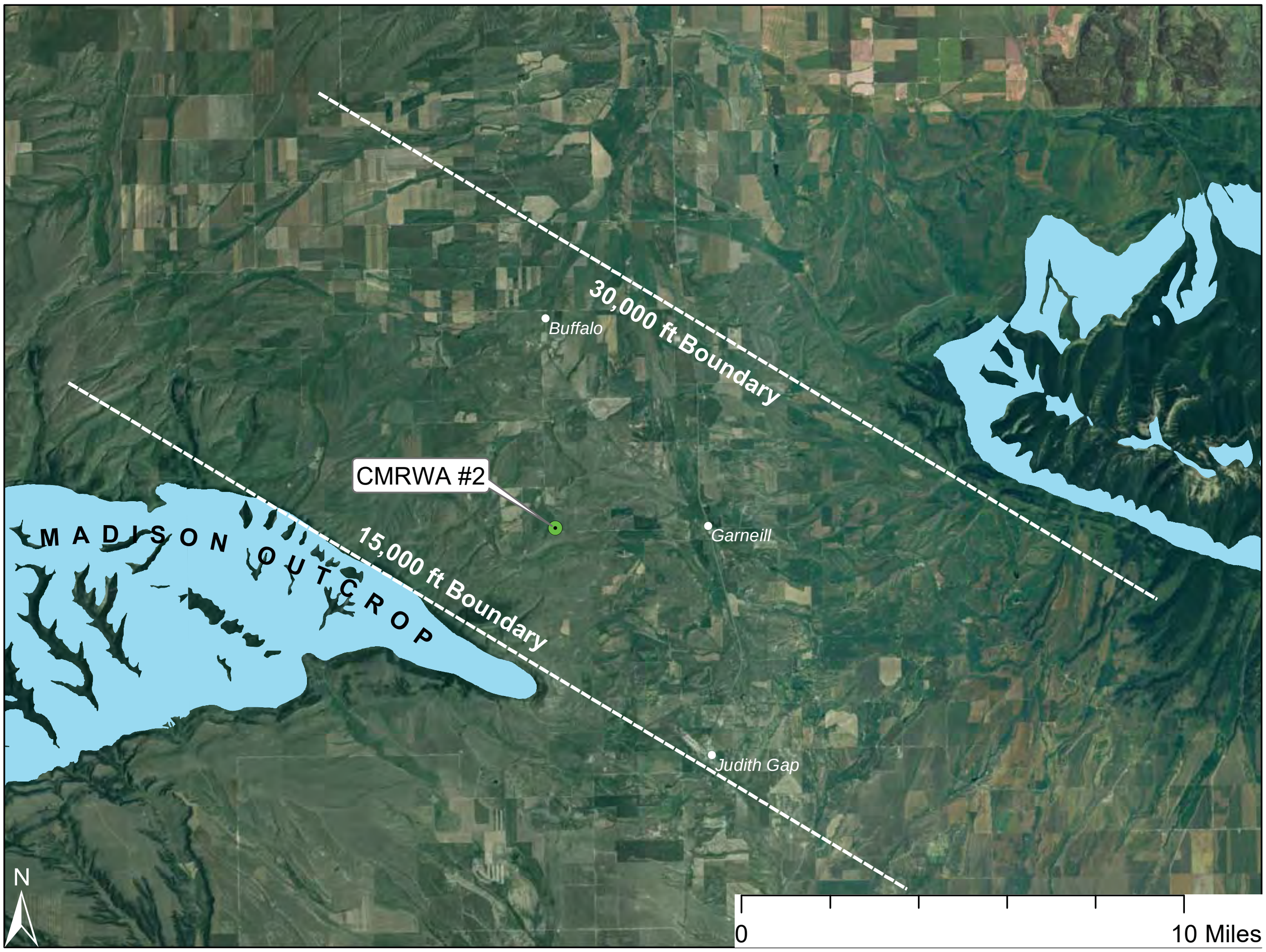

Figure 16. Model Boundaries

Table 5. Constant Rate Test Model Fit Parameters

Parameter	Value	Units	Method
Hydraulic conductivity, fractures	11,680	ft/d	Regression[A]
Transmissivity, fractures	35,000	ft^2/d	Calculated[D]
Specific storage, fractures	1.4E-09	ft^{-1}	Regression
Hydraulic conductivity, matrix	4.1E-05	ft/d	Regression
Specific storage, matrix	1.2E-05	ft^{-1}	Regression
Skin factor, fracture	33	--	Regression
Well radius, effective	1	ft	Assumed[B]
Casing radius	0.375	ft	Field data[C]
Half-width, matrix	1.5	ft	Assumed
Saturated thickness	3	ft	Field data
Thickness, fracture skin	2	mm	Assumed
Hydraulic conductivity, fracture skin	5.4E-09	ft/d	Calculated[D]

[A]Non-linear least-squares regression fit of data; [B]Value is considered reasonable assumption; [C]Measured in field or actual dimension; [D]Calculated from other estimated and assumed parameters.

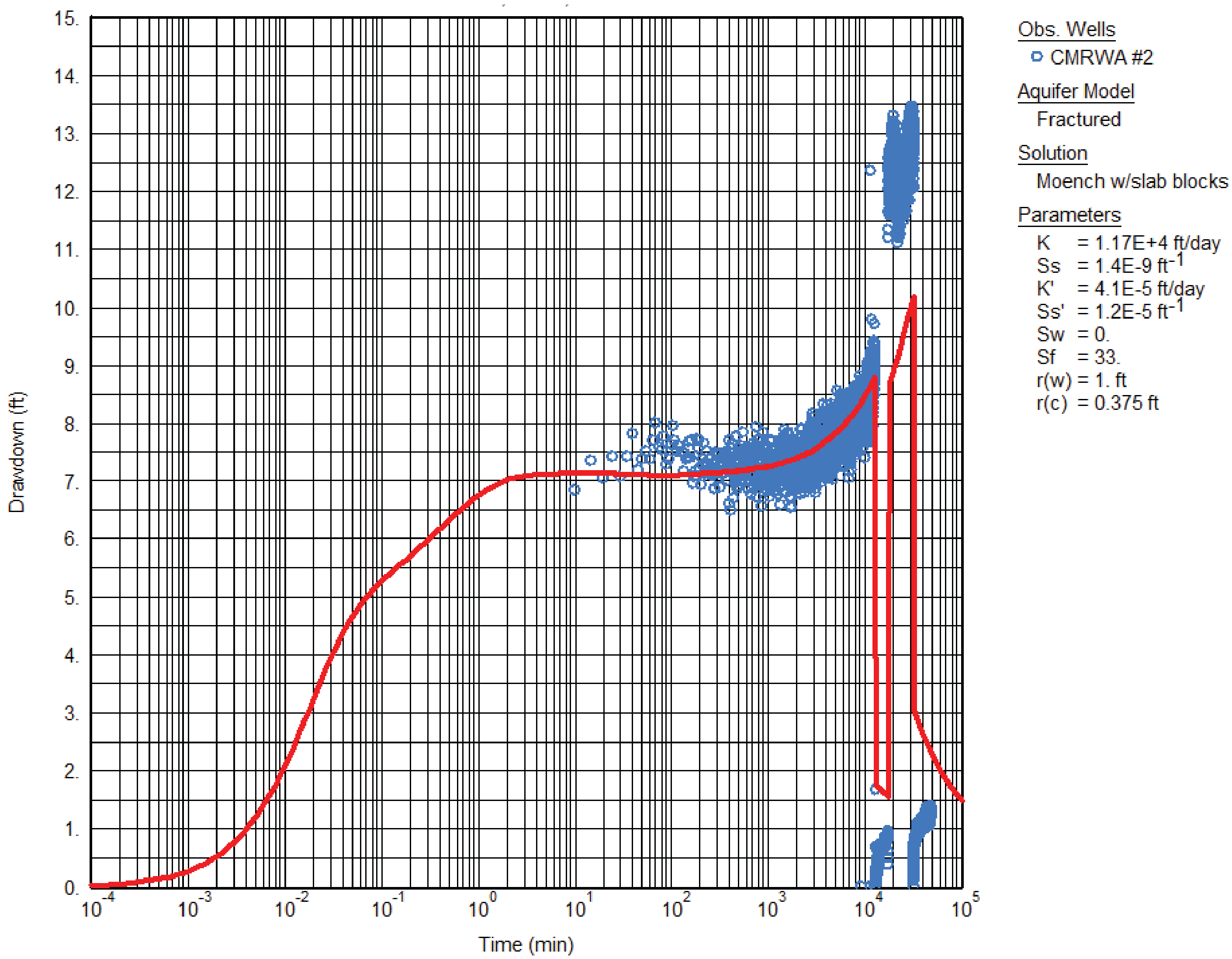

Figure 17. Late Time Model Fit

One way to further assess the quality of a hydraulic model is to apply it to data that were not directly fit. Unfortunately, this exercise shows the model to be inaccurate at matching data from the second part of the constant rate test (**Figure 17**). As discussed above, the later data exhibited greater drawdown of a couple feet that was generally not explained. Flow meter error and/or impairment of aquifer communication were two possible explanations. Adjustment of the model skin factor shows that a positive skin of 4.4 is needed to fit the late time data (**Figure 18**). Adjustment of the late time flow rate, while able to match the full data set, requires a flow of 775 gpm, which is not feasible with the installed pump and would be indicating a flow meter error of 35% (**Figure 19**). A repeat test after well completion would be useful to further assess the cause of the observed water levels.

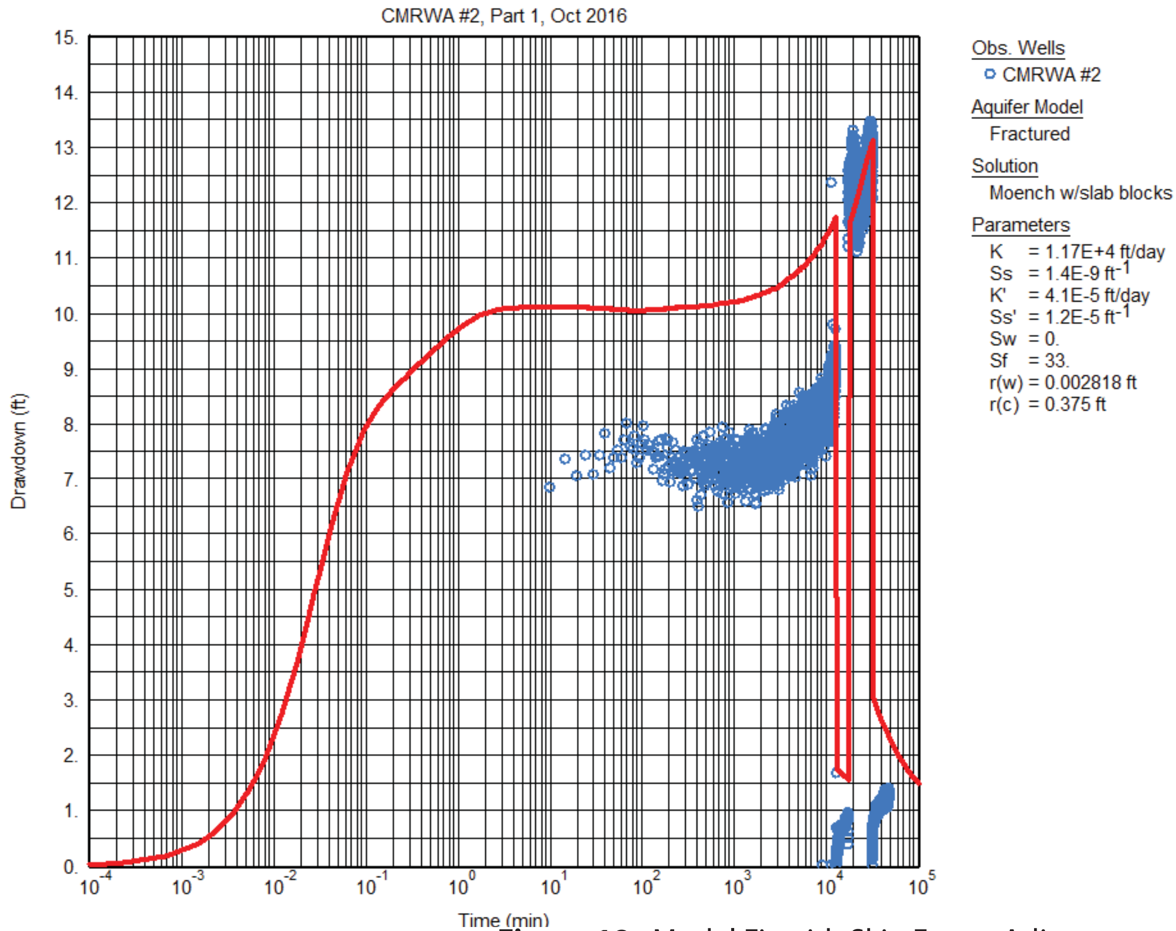

Figure 18. Model Fit with Skin Factor Adjustment

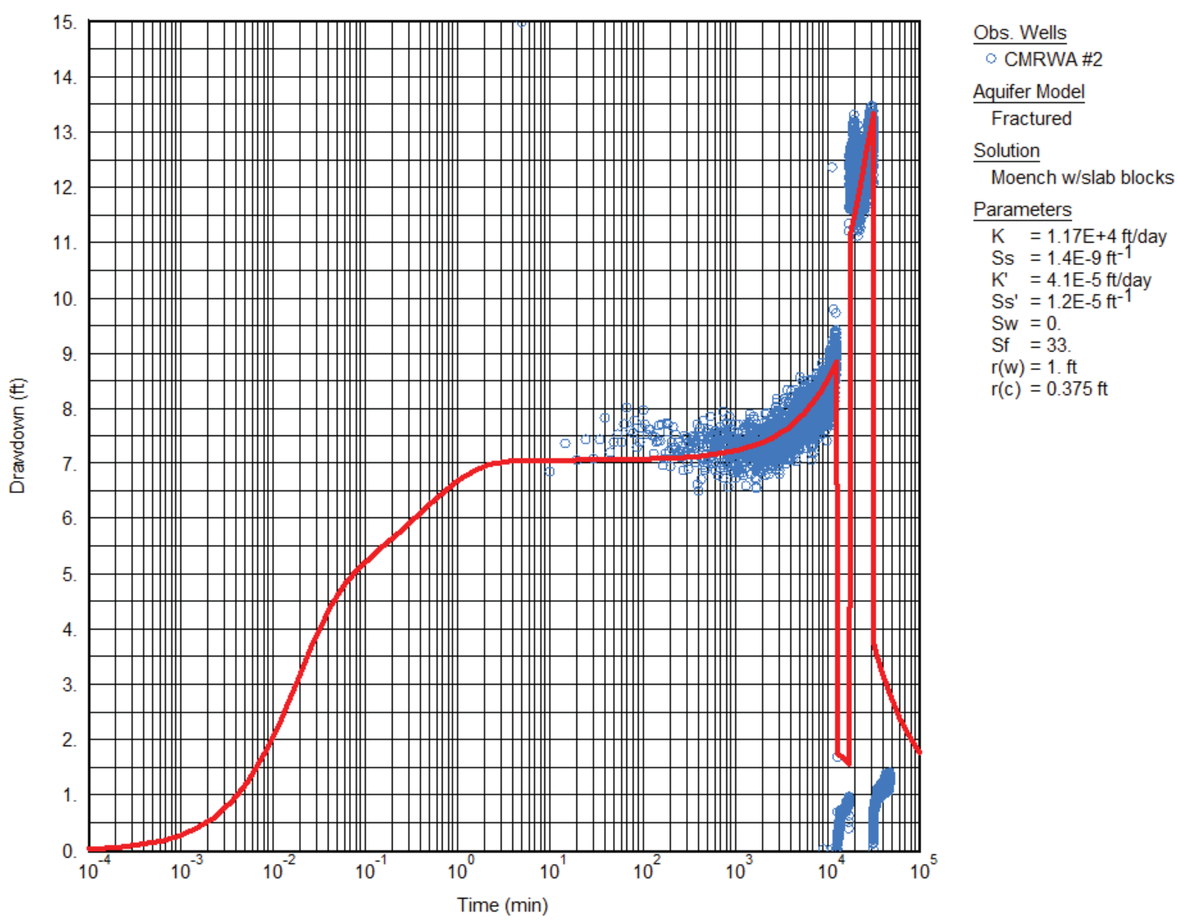

Figure 19. Model Fit with Flow Rate Adjustment

6.4 Design Rate

The testing data support a design rate of 575 gpm for the CMRWA #2 well based on a test of three or more days (DEQ Circular DEQ-1 3.2.4.1(d)(2)). If this rate were produced continuously, total annual volume would be 928 acre-feet per year (af). The pump would need to be lowered about 100 ft to produce this water.

With the current pump setting, the maximum rate from the well of 575 gpm is feasible, however, the annual volume of production is curtailed. With a target pumping water level 50 ft above the pump (325 ft bgs), the annual volume is recommended as 480 af. This volume is based on simulation of 10-years of continuous pumping, and equates to an average rate of 300 gpm. If producing at 575 gpm, this use equates to approximately 52% runtime, or a little over 12-hours per day on average. Regional trends in static water level may impact the annual volume that can be produced at the current pump setting.

6.5 Interference Drawdown

Interference drawdown was evaluated for a continuous pumping period of 180-days at the design rate of 575 gpm. The same hydraulic model as presented above was used for the analysis. Interference drawdown of 18 ft was calculated at a distance of 100 ft from the pumping well, and declined only to 17 ft at an offset distance of 1/2-mile. The cone of depression for the well is shown to be extremely flat, which is typical for highly permeable aquifers. Based on the modeling results, increasing horizontal offset may not substantially reduce the interference effects. Interference effects would be mitigated primarily by deeper pump settings. If new wells are installed into other zones that are hydraulically isolated from one another, the interference effect would not apply.

7. OBSERVATION WELL AND ATMOSPHERIC DATA

Hydrograph plots for the CMRWA #1 and CMRWA MW#1 wells show that neither of these locations responded to pumping in the CMRWA #2 well (**Figure 20** and **Figure 21**). The Madison well at Utica, CMRWA #1, exhibits a declining trend over the period of the test. The Kootenai monitoring well, CMRWA MW#1, located within 85 ft of CMRWA #2, shows an essentially constant water level through the testing period. This hydrograph shows data from a drawdown test conducted in the well when it was sampled for water quality on September 21st, however, the well had fully recovered and maintained a constant water level through the testing period of CMRWA #2, which began on September 28th.

Barometric pressure data collected during testing are intended to quantify how atmospheric pressure changes affect well water levels. When present, it can be necessary to correct pumping test and other data before analysis. At this time, atmospheric effects were determined to be negligible over the test period and no correction was warranted (**Figure 22**). Further evaluation of the relation between barometric pressure and well water level be presented in a monitoring data report later in 2017.

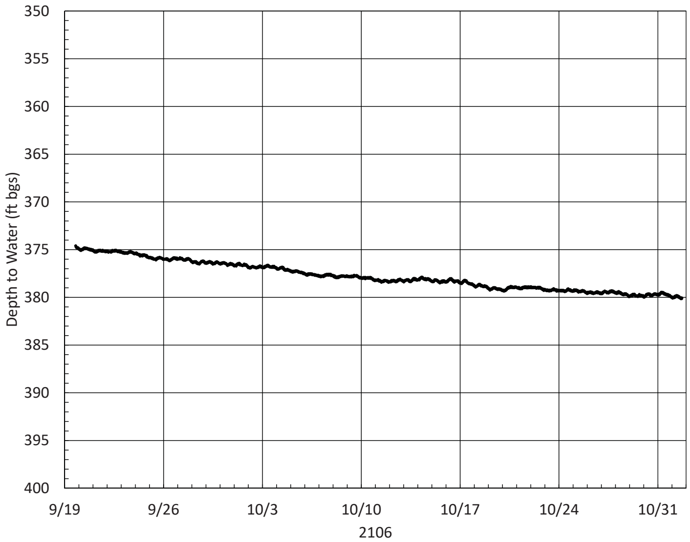

Figure 20. CMRWA #1 Hydrograph

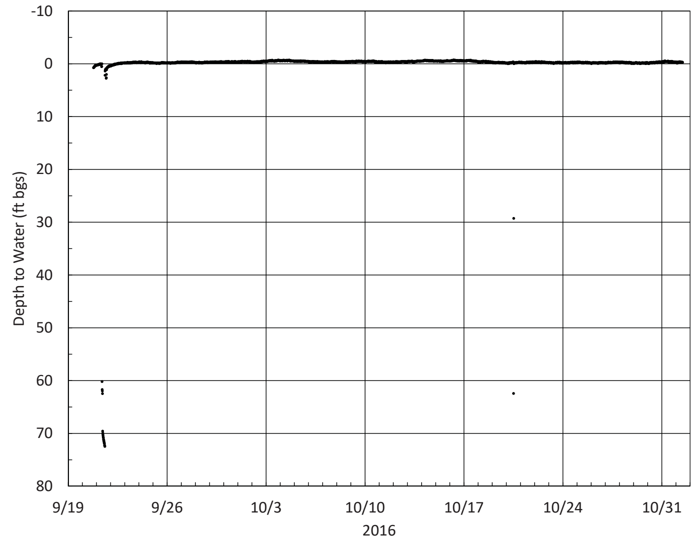

Figure 21. CMRWA MW#1 Hydrograph

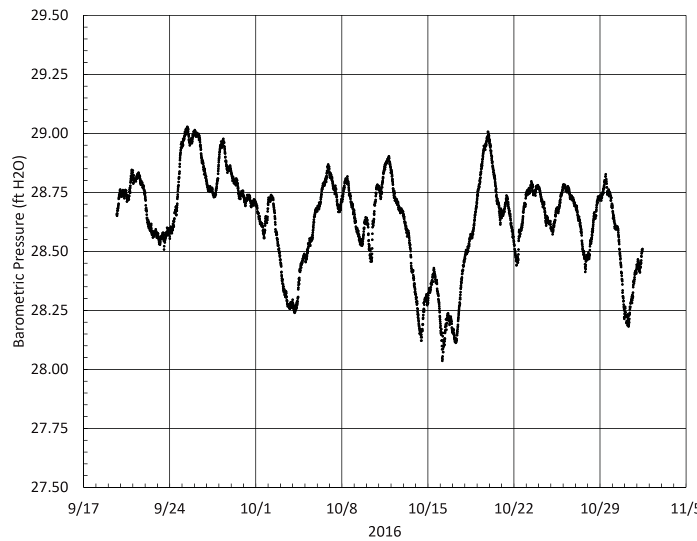

Figure 22. U Bet Barometric Plot

8. CONCLUSIONS AND RECOMMENDATIONS

- Drawdown data collected from CMRWA #2 during pumping show a trend that indicates high permeability fracture flow into the well, and enhanced drawdown caused by the occurrence of flow limiting boundaries. Two boundaries were included in the model fit to test data, one located 15,000 ft to the south, and one located 30,000 ft to the north. Other configurations could be equivalent.

- The design rate of 575 gpm for CMRWA #2 is considered an appropriate rate for operation of the well. The annual produced volume should be limited to about 480 af, although this use can be directly managed based on observed drawdown in the well. Interference drawdown in neighboring wells in the U Bet Wellfield and producing from the same zone was estimated at approximately 22 ft. Interference drawdown also would be reciprocal among multiple wells.

- Water level data from the CMRWA #1 well located at Utica and from the CMRWA MW#1 monitoring well located at the U Bet Wellfield did not respond to pumping in CMRWA #2. The CMRWA #1 well is a Madison well. Water level in this well followed a declining trend through the test period. The CMRWA MW#1 well is completed in the Kootenai aquifer (aka 3rd Cat Creek). Water level in it remained essentially constant for the duration of testing.

- The occurrence of flow limiting boundary effects should be considered when planning future wells at the U Bet Wellfield. It may be advisable to build wells that allow for deeper pump settings and to locate wells to use the available offsets. Consideration should also be given to a drilling program that would construct a new well through the entire Madison formation, even in the presence of high production fractures. In order to accomplish this drilling plan, it is most likely that air-rotary drilling would need to be used once casing was set into the Madison formation.

- Identfication of flow limiting boundaries, while undesirable for aquifer production, is inevitable as no aquifers have infinite extent. The occurrence of more than one no flow boundary is suggesting the Madison aquifer may not have broad continuity in Judith Basin. The potential for depletion of Madison aquifer springs, such as Big and Warm Springs, is considered more remote based on the results of aquifer testing.

9. REFERENCES

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