LMS/SHL/S14136

Hydrologic Testing Report Project Shoal Area: Subsurface Corrective Action Unit 447, Shoal, Nevada, Site

January 2019

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Abbreviations

AEC	U.S. Atomic Energy Commission
amsl	above mean sea level
CADD	Corrective Action Decision Document
CAP	Corrective Action Plan
CAU	Corrective Action Unit
cm/s	centimeters per second
DOE	U.S. Department of Energy
FFACO	Federal Facility Agreement and Consent Order
ft	feet
ft/d	feet per day
gpm	gallons per minute
HC	hydrologic characterization
LM	Office of Legacy Management
MV	monitoring/validation
NDEP	Nevada Division of Environmental Protection

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1.0 Introduction

This report presents the results from aquifer tests performed by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) on wells MV-4, MV-5, and HC-2d at the Project Shoal Area (Shoal) Subsurface Corrective Action Unit (CAU) 447 in Churchill County, Nevada, (now known as the Shoal, Nevada, Site). An underground nuclear test conducted at the Shoal site in 1963 resulted in residual radionuclide contamination at the detonation depth. Responsibility for environmental restoration of the Shoal site was transferred from the DOE's National Nuclear Security Administration Nevada Field Office to LM on October 1, 2006. The environmental restoration process and corrective action strategy for CAU 447 are conducted in accordance with the amended *Federal Facility Agreement and Consent Order (FFACO)* (NDEP 1996) and all applicable Nevada Division of Environmental Protection (NDEP) policies and regulations. The purpose of this report is to document the data collected during the aquifer testing of monitoring/validation (MV) wells MV-4, MV-5, and hydrologic characterization (HC) well HC-2d.

2.0 Site Location and Background

The Shoal site is south of U.S. Highway 50, approximately 30 miles southeast of Fallon, Nevada (Figure 1). The U.S. Department of Defense and the U.S. Atomic Energy Commission (AEC), a predecessor agency to DOE, jointly conducted the Shoal underground nuclear test on October 26, 1963, as part of the Vela Uniform program. The test involved detonating a 12-kiloton-yield nuclear device in granitic rock at a depth of 1211 feet (ft) (DOE 2015a). A cavity created by the test collapsed shortly after the detonation and formed a rubble chimney (Hazleton-Nuclear Science Corporation 1965). Site deactivation and postshot drilling activities began October 28, 1963. The decontamination and restoration activities were minimal, because no large areas of surface radiological contamination were found during or following the test. During cleanup, the emplacement shaft was covered with a concrete slab, and the onsite particle motion boreholes, exploratory core holes, and U.S. Bureau of Mines boreholes were plugged and abandoned. A radioactive materials survey conducted at the surface of the site in 1970 indicated that no radioactivity exceeded background for the area (AEC 1970).

2.1 Geologic and Hydrologic Setting

The Shoal site is in Gote Flat at an elevation of approximately 5250 ft above mean sea level (amsl) within the northern portion of the Sand Springs Range, which is the southern extension of the Stillwater Range, a north-northeast-trending fault block range that traverses Churchill County. The Sand Springs Range rises to an elevation of approximately 6750 ft amsl and is flanked by Fourmile Flat to the west and Fairview Valley to the east (Figure 1). The site is within an area that is part of the Cretaceous-age Sand Springs granitic batholith, which is composed of granodiorite and granite, aplite, and pegmatite dikes; andesite dikes; rhyolite dikes; and rhyolitic intrusive breccia. Internal deformation of the Sand Springs granite is largely by high-angle normal faults and fractures distributed between two dominant structural trends that strike approximately N 50^{o} W and N 30^{o} E and are vertical to steeply dipping. The most dominant of these structural feature is a shear zone that strikes N 30^{o} E and transects the eastern portion of the site (Figure 2). Several dikes of varying composition are predominantly along the same two orientations and intrude along these lines of preexisting weakness. These orthogonal-type

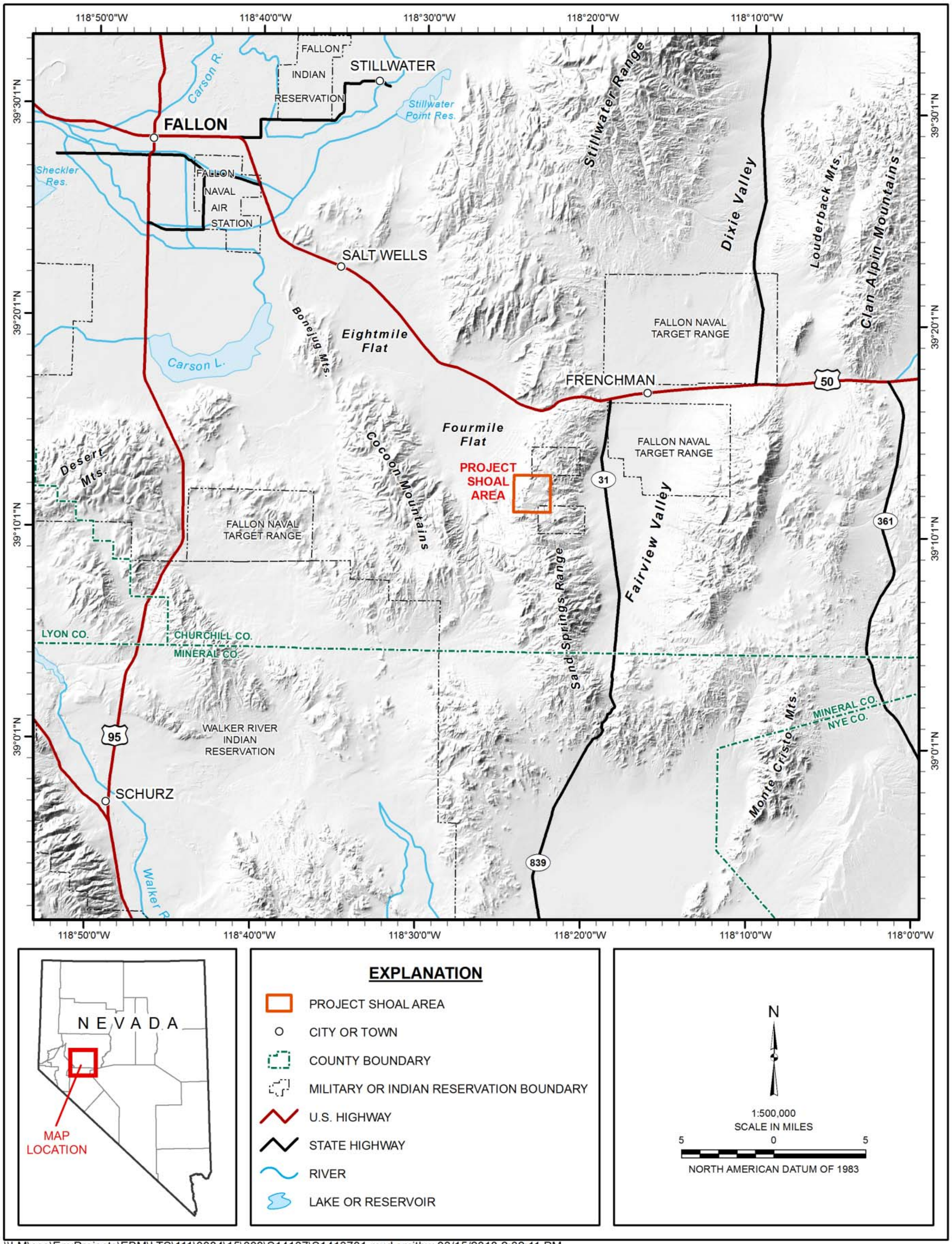

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Figure 1. Site and Surrounding Area Map, Shoal, Nevada, Site

sets of faults and fractures appeared early in the history of the Sand Springs granite and affected much of the subsequent structural and chemical evolution of this large intrusion (Nevada Bureau of Mines 1964). Figure 2 shows the site and well locations.

Groundwater is encountered beneath the site (near surface ground zero and west of the shear zone) at depths ranging from 950 to 1110 ft (4250 to 4300 ft amsl). The shear zone dips steeply to the northwest from a surface location approximately 1500 ft east of surface ground zero (Figure 2 and Figure 3) and is interpreted as a barrier to groundwater flow on the basis of disparate water levels in wells separated by the shear zone (DRI 2001). Water levels measured in wells west of the shear zone (Figure 2) have been rising approximately 1 to 3 ft per year during the time they have been monitored, beginning with the installation of the HC wells in the late 1990s. Water levels measured in site wells east of the shear zone range from 1180 to 1375 ft (about 3900 ft amsl) and have not increased, but have decreased in wells HC-5 and HC-8 (Figure 2 and Figure 3) at a rate of approximately 1 to 2 ft every 10 years (DOE 2017). Groundwater primarily flows through fractures in the low-permeability granite, with hydraulic conductivities ranging from 0.003 to 0.6 ft per day (ft/d) (DRI 2006). Recharge occurs by infiltration of precipitation on the mountain range, and regional discharge occurs in the adjacent valleys (Nevada Bureau of Mines 1964). Groundwater in Fairview Valley to the east has been used for ranching and military purposes. Figure 3 is a cross section showing the well completions, potentiometric surface, and shear zone.

2.2 Corrective Action Strategy

The original corrective action strategy for the subsurface CAU 447 included development of a site conceptual model and a numerical model to simulate groundwater flow and transport. The numerical model results were used to determine a contaminant boundary (Figure 2), which was later established as the compliance boundary for the site (NDEP 2005). These boundaries were presented in the Corrective Action Decision Document/Corrective Action Plan (CADD/CAP) with a process for validating the flow and transport model (DOE 2006). This process included the installation of three wells (MV-1, MV-2, and MV-3) in 2006 for the dual purpose of monitoring and evaluating the flow and transport model results (Figure 2). Data collected from these wells disagreed with the model predictions, which meant that elements of the site conceptual model were incorrect and the model could not be validated (Stoller 2008).

The site conceptual model is being reevaluated to address inconsistencies between the model predictions and monitoring well data. Concerns with the model stem from two observations. First, the horizontal component of groundwater flow predicted by the model was primarily toward the north–northeast, whereas horizontal gradients inferred from water levels measured in site wells do not support the modeled flow direction. Second, the model incorrectly assumed that the groundwater flow system is in a steady state; in fact, water levels west of the shear zone (Figure 2) have been rising a few feet per year since monitoring began in the late 1990s. Pursuant to the amended FFACO, LM began implementing a new corrective action strategy for the site in 2009. The new strategy was formalized through a revision to Appendix XI of the FFACO (FFACO 1996, as amended).

The new corrective action strategy was designed to enhance the monitoring well network and monitoring program at the site. It was also designed to provide new data to help reduce uncertainty associated with the site conceptual model. The enhancements are documented in

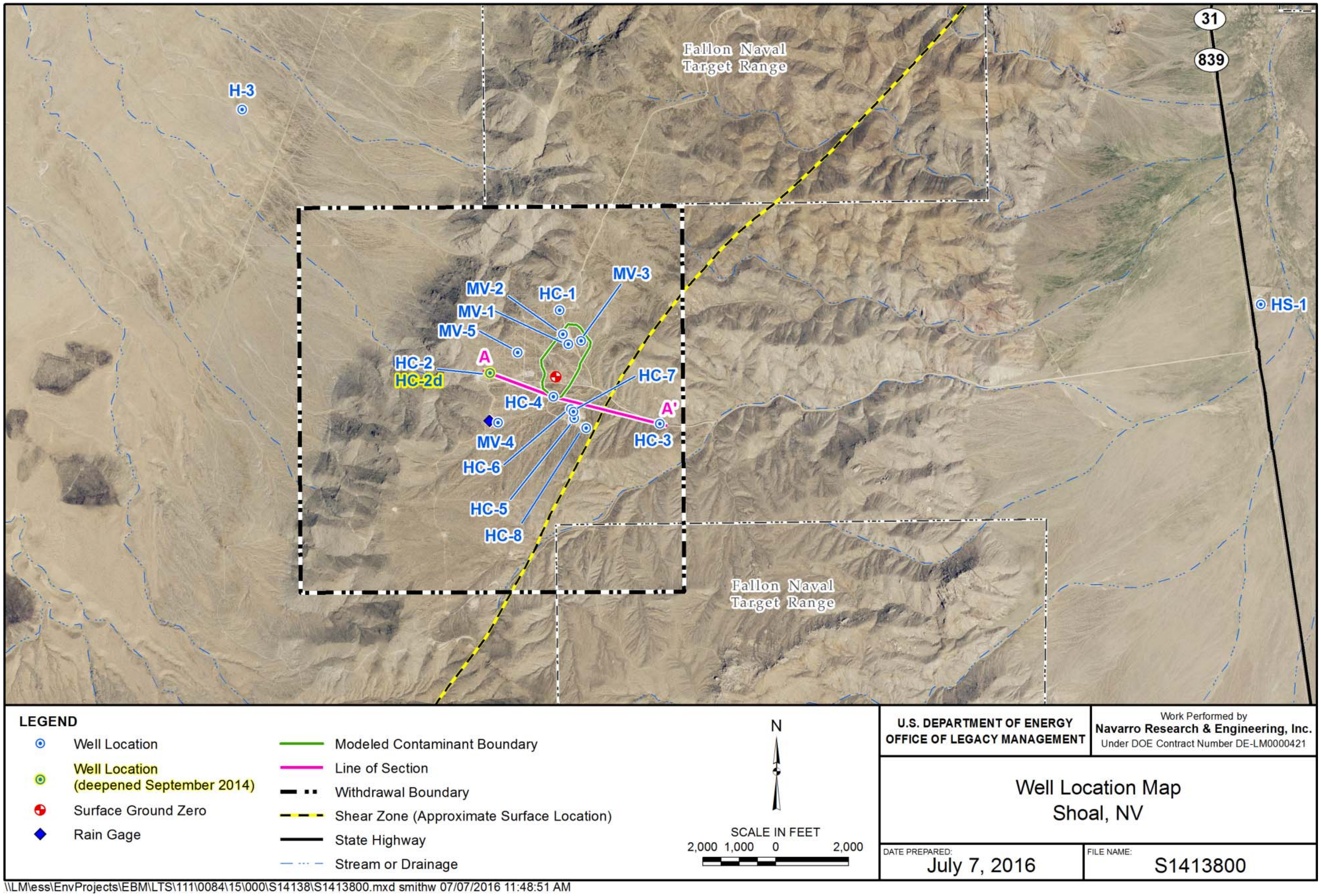

Figure 2. Site and Monitoring Well Location Map, Shoal, Nevada, Site

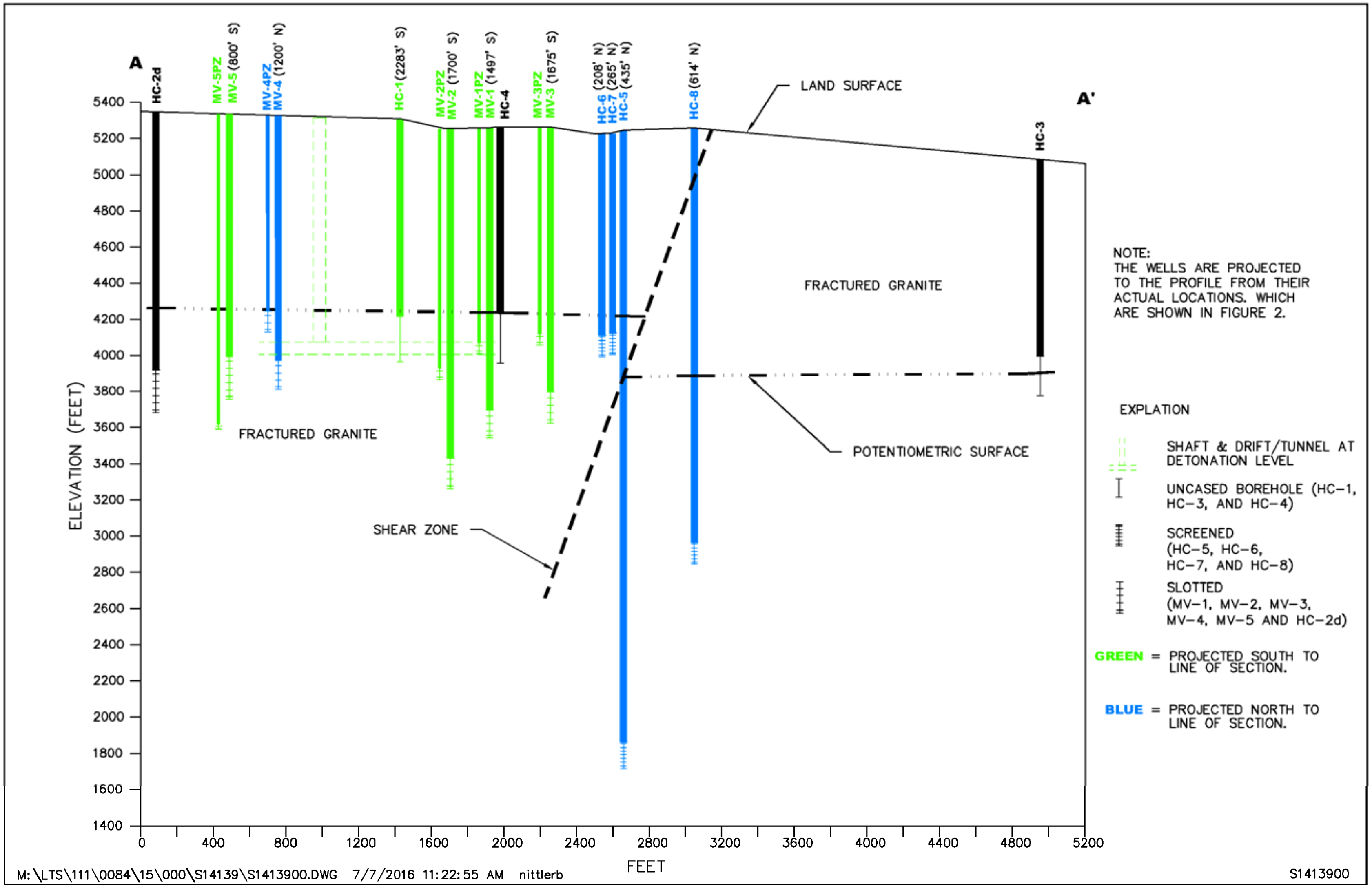

Figure 3. Cross Section A-A' Depicting Monitoring Well and Shear Zone Location, Shoal, Nevada, Site

short-term Data Acquisition Plans that were completed in 2009, 2011, and 2014 to support the CADD/CAP and provide interim guidance documents until an addendum to the CADD/CAP can be completed. The 2014 Data Acquisition Plan included the installation of wells MV-4 and MV-5 and deepening of existing well HC-2 that is now identified as HC-2d (DOE 2014). Data from these wells will be used with data from the existing monitoring well network to evaluate the adequacies of the compliance boundary and to monitor along interpreted contaminant transport pathways, as demonstrated by measured water levels.

3.0 Aquifer Testing Objectives and Activities

The objective of the aquifer tests was to obtain data that could be used to estimate the hydraulic conductivity of the water-bearing formation near wells MV-4, MV-5, and deepened well HC-2d. The *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites* (LMS/PRO/S04351) and *Fluid Management Plan, Subsurface Corrective Action, Unit 447, Shoal, Nevada, Site* (DOE 2011) were used to guide quality assurance and quality control of monitoring, sample collection, and fluid management activities. Summaries of the data collection activities, data analysis, and results are provided in the following sections.

3.1 Data Collection

The aquifer tests were performed on wells MV-4 (September 2015), HC-2d (May 2016), and MV-5 (May 2016, August 2016, and July 2017). Three separate aquifer tests were conducted on well MV-5 because of a problem with the submersible electric pump that was confirmed after the second aquifer test in August 2016. The pump was replaced in June 2017, and the final aquifer test was completed in July 2017; those data are analyzed in this report. Each aquifer test was analyzed as a single well test, which included pumping the well at a constant or near-constant rate and measuring changes in water levels during the pumping and recovery period. Other wells at the site were monitored during the test but there was no response that would make them usable as observation wells. Table 1 lists the wells and piezometers that were monitored as part of the aquifer testing, along with the screened interval elevations and water depth prior to the start of the aquifer test. Piezometers are distinguished from the wells at these locations with a “PZ”.

Table 1. Water Elevations and Screen Intervals for Wells Monitored During the Aquifer Tests

Well/ Piezometer	TOC Elevation[a] (ft amsl)	Screen Interval (ft)	TSZ Elevation[a] (ft amsl)	BSZ Elevation[a] (ft amsl)	Date/Time	Water Depth (ft)	Water Elevation[a] (ft amsl)
MV-4	5370.78	160	3969.08	3809.08	9/14/2015, 09:30	1082.75	4288.03
MV-4PZ	5370.41	120	4249.08	4129.08	9/14/2015, 09:10	1081.55	4288.86
MV-5	5318.16	240	3991.01	3751.01	7/22/2017, 13:20	1050.20	4267.96
MV-5PZ	5317.50	30	3616.01	3586.01	7/22/2017, 12:55	1049.29	4268.21
HC-2d	5343.93	240[b]	3925.15	3685.15	5/13/2016, 16:55	1105.40	4238.53

Notes:
[a] Elevations are provided in the U.S. State Plane, Zone Nevada West 2703 coordinate system, with vertical data based on the North American Vertical Datum 1929
[b] Well screen is not isolated by a filter pack or cement seal but is open to the formation for the length of the borehole.

Abbreviations:
BSZ = Bottom of screen zone
TOC = Top of casing
TSZ = Top of screen zone

Water was extracted from the wells with dedicated 5-horsepower submersible electric pumps. Well MV-4 was pumped for 22.25 hours, well HC-2d was pumped for 18 hours, and well MV-5 was pumped for 20 hours during the July 2017 aquifer test (Table 2). The flow rates were recorded in gallons per minute (gpm) during the tests and recorded every minute using a Campbell Scientific datalogger. Water levels are recorded hourly throughout the year by transducers installed in site wells. The transducers were set to record water levels more frequently in the extraction well (as frequently as 10 seconds at pump on and pump off) and nearby wells and piezometers that might be affected during each of the tests. Groundwater samples were collected for tritium analysis at the completion of each aquifer test in accordance with the Fluid Management Plan (DOE 2011) and analyzed at LM's Environmental Services Laboratory at the LM office in Grand Junction, Colorado. Tritium was not detected in any of the samples above the laboratory minimum detectable concentration, which did not exceed 400 picocuries per liter. Table 2 shows the general sequence of events.

Table 2. Aquifer Testing Sequence of Events

Well	Date	Activity
MV-4	September 14, 2015	At 13:00 Pacific Daylight Time (PDT) started pump at MV-4, flow rate 1.2 gpm
		At 13:25, flow rate at 1.0 gpm
		At 15:45, flow rate at 0.8 gpm, pulled transducer to check drawdown
	September 15, 2015	At 09:00, flow rate at 0.8 gpm, collected sample from pump discharge
		At 11:15, pump stopped unexpectedly, aquifer test completed after removing a total of 1200 gallons
MV-5	May 11, 2016	At 14:00 PDT started pump at MV-5, flow rate 0.83 gpm
	May 12, 2016	At 09:00, flow rate at 0.86 gpm
		At 09:50, pulled transducer to check drawdown in well (only a few ft)
		At 12:00, increased flow rate to 4 gpm
		At 17:00, flow rate at 4 gpm
	May 13, 2016	At 07:45, flow rate is at 3.7 gpm
		At 10:30, pulled transducer to check drawdown in well (only about 50 ft)
		At 11:01, increased flow rate to 5.5 gpm
		At 13:01, collected sample and stopped test, removed a total of 6990 gallons
HC-2d	May 13, 2016	At 17:32 PDT started pump at HC-2d, flow rate 0.8 gpm
	May 14, 2016	At 09:30, flow rate at 0.56 gpm, pulled transducer to check data
		At 11:30, collected sample and stopped test, removed a total of 650 gallons
MV-5	August 9, 2016	At 12:00 PDT started pump at MV-5, flow rate 5.5 gpm
		At 14:00, flow rate at 5 gpm
		At 10:00, pump stopped unexpectedly
	August 10, 2016	At 09:00, the pump was restarted, flow rate at 4.8 gpm
	August 11, 2016	At 08:00, flow rate at 1 gpm, concerned the pump may fail
		At 08:20, collected sample and stopped test, removed a total of 7240 gallons
MV-5	July 22, 2017	At 16:00 PDT started pump at MV-5, flow rate at 8.5 gpm
	July 23, 2017	At 08:00, flow rate at 5.6 gpm
		At 09:15, pulled transducer to check drawdown
		At 11:55, flow rate at 5.3 gpm
		At 12:00, collected sample and stopped test, removed a total of 7560 gallons

Abbreviations:
gpm = gallons per minute
PDT = Pacific Daylight Time (all times provided in PDT)

3.2 Data Analysis Method

The method used to analyze the aquifer test data was the analysis solution for fracture flow with slab blocks developed by Allen F. Moench (Moench 1984). The method is implemented in AQTESOLV for Windows, version 4.50.002. The data were analyzed as single well tests due to the anisotropy of flow at the site caused by fracture and dike orientations, along with the inability to pump a sufficient volume of water to influence other site wells. The variations in flow rates during the tests were included in the analysis (flow rates were recorded at 1 minute intervals). The analysis solution uses parameters associated with the fractures, matrix, and well (Table 3). For a single well test, different combinations of parameter values can arrive at a similar curve fit. Ranges of what are believed to be more realistic values were used to constrain the solution. The aquifer thickness was set at 200 ft for all three of the well tests for ease of comparison. In a fractured environment, only a few fractures or many fractures, including those beyond but connected to fractures in the screened interval, could dominate flow. Table 3 shows the AQTESOLV fracture solution parameters.

Table 3. AQTESOLV Fracture Solution Parameters

Symbol	Parameter
K	Hydraulic conductivity, fractures
Ss	Specific storage, fractures
K’	Hydraulic conductivity, matrix
Ss’	Specific storage, matrix
Sw	Skin factor, well
Sf	Skin factor, formation
r(w)	Radius, well bore
r(c)	Radius, casing

3.3 Results of the MV-4 Aquifer Test

Well MV-4 was pumped (September 14 to 15, 2015) for 22.25 hours at a flow rate that ranged from about 1.2 gpm initially to about 0.8 gpm for the majority of the test. The low flow rate was necessary to prevent the water level from drawing down below the pump motor and pump intake. To prevent the pump from overheating (extracted water passes by and cools the pump motor on its way to the pump intake), a flow rate of about 2 to 3 gpm is needed for pump-motor cooling. The low net flow rate out was achieved by extracting water at a higher rate (flow rate out of about 4.5 to 5 gpm) and returning a portion of the pumped water back (flow rate in) to the well (Figure 4). The depth to water measured in well MV-4 near the start of the aquifer test was 1082.75 ft (Table 1) and the top of the pump is at a depth of 1373 ft (DOE 2015b). The maximum drawdown of 215.8 ft at the end of the pumping period used 75% of the 290 ft of available water column (Figure 5). Approximately 1200 gallons of water were removed from well MV-4 during the aquifer test. A well construction diagram for well MV-4 is provided as Appendix A. Figure 4 shows the flow rates of water removed from the well, water returned to the well, and the net flow out of well MV-4. Figure 5 shows the draw down and recovery with the net flow out of well MV-4.

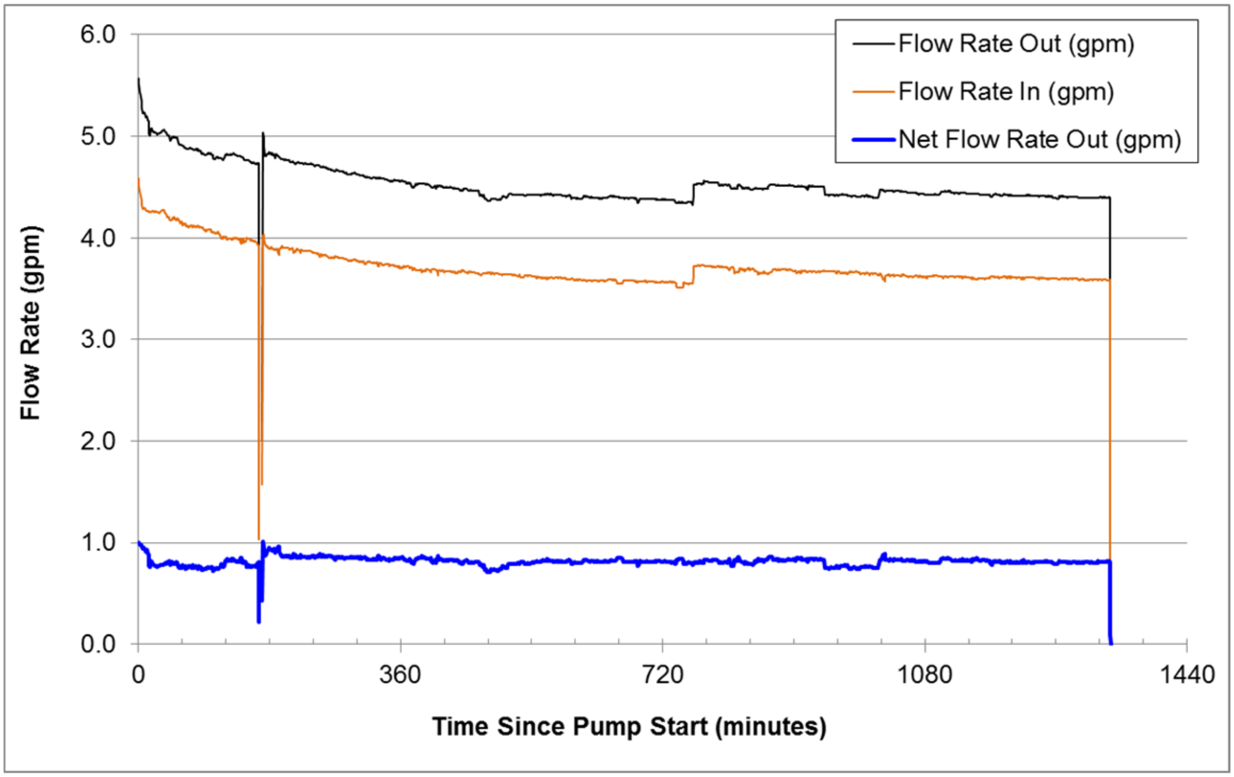

Figure 4. Flow Rates During the MV-4 Aquifer Test

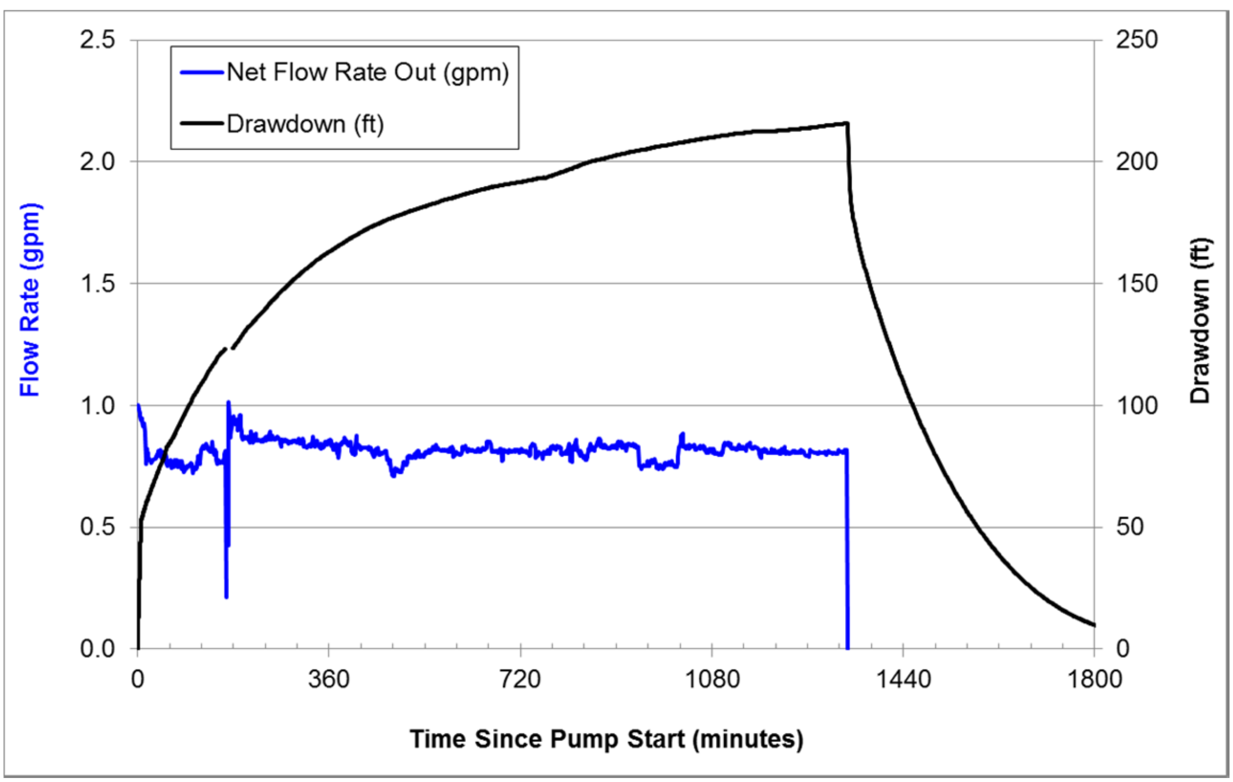

Figure 5. Drawdown and Net Flow Rate During the MV-4 Aquifer Test

Water levels in the MV-4 piezometer began decreasing about 10 hours into the aquifer test and continued to decrease for another 18 hours (maximum decrease of 0.86 ft) before the transducer records ended. A new transducer file was started at the end of the aquifer test, but the transducer and all records failed before the next download.

The data were analyzed as a single-well pumping test using the fractured model with slab blocks. Solution parameters were varied within reasonable ranges to achieve an acceptable curve match (Figure 6). More emphasis was given to later time data. The solution parameters are given in Figure 6, with the most significant being the hydraulic conductivity of the fractures (K) and matrix (K'); these are 0.0009 ft/d (1×10^{-6} centimeters per second [cm/s]) and 0.007 ft/d (8×10^{-6} cm/s), respectively. Difficulties were encountered during the drilling of well MV-4, and a bentonite-based drilling mud had to be used to stabilize the borehole (DOE 2015b). A dispersant was added to the well during the development to help break down and remove any remnant drilling mud, but it's likely the drilling mud had a negative effect on the hydraulic conductivity of the fractures. Figure 6 shows the drawdown curve match for the MV-4 aquifer test.

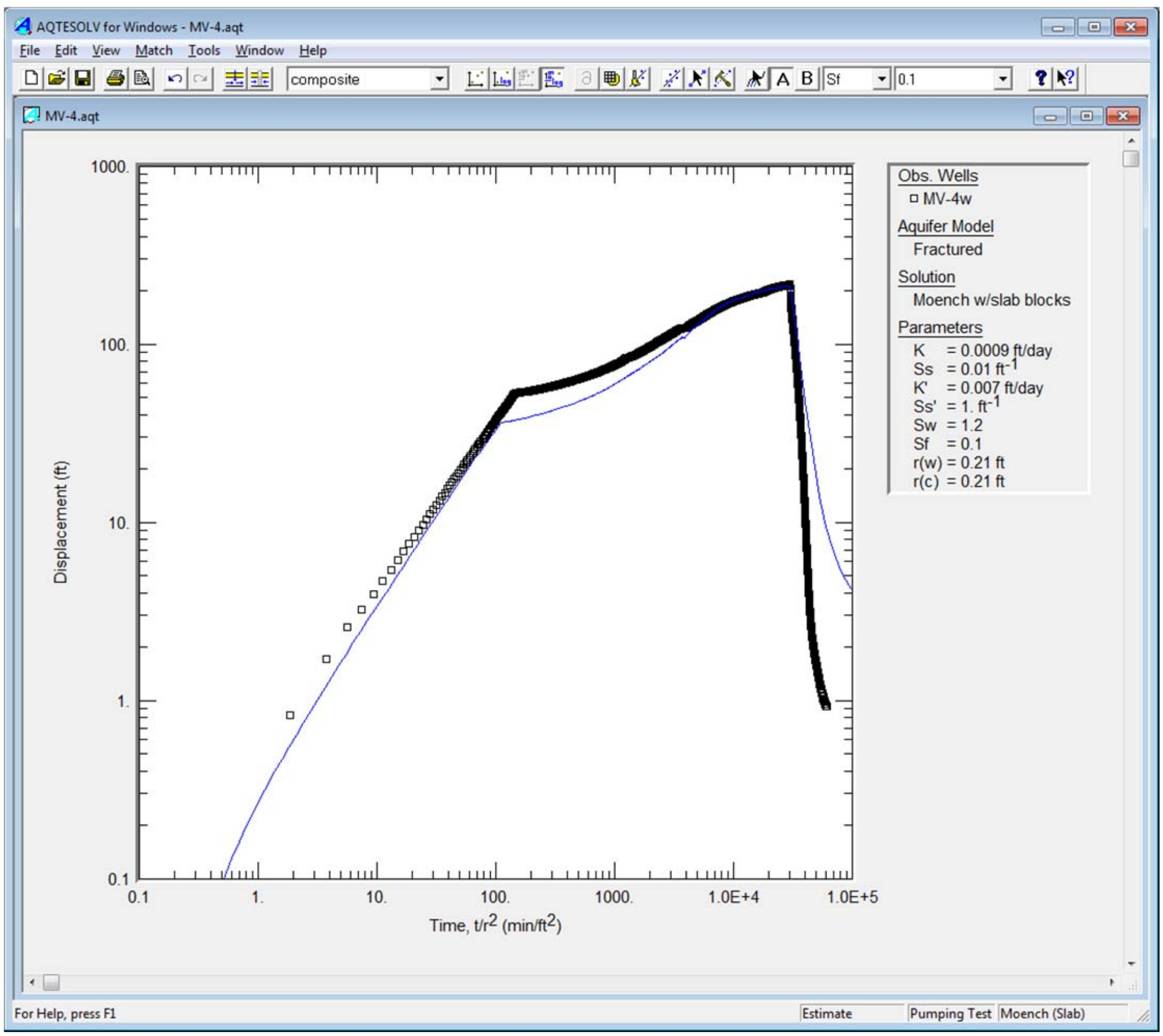

Figure 6. Curve Match (Blue Line) for the MV-4 Aquifer Test (from AQTESOLV)

3.4 Results of the HC-2d Aquifer Test

Well HC-2d was pumped (May 13 to 14, 2016) for just under 18 hours at a flow rate that began at 0.8 gpm and steadily declined to 0.54 gpm by the end of the test (Figure 7). Difficulties with the flow meter required the net flow rate to be estimated based on readings from when the flow meter was functioning; occasional bucket measurements and the totalizing flow meter were used to estimate the net flow rate. The low rate was necessary to prevent the water level from drawing down below the pump motor. To prevent the pump from overheating, a flow rate of about 2 to 3 gpm is needed for pump-motor cooling. The low net flow rate was achieved by extracting water at a higher rate (about 4 to 5 gpm) and returning a portion back to the well. The depth to water measured in well HC-2d near the start of the aquifer test was 1105.40 ft (Table 1), and the top of the pump is at a depth of 1402 ft (DOE 2015b). The maximum recorded drawdown of 198 ft occurred near the end of the pumping period when the water level dropped below the installed transducer during the last 1.5 hours (Figure 8). Approximately 650 gallons of water were removed from well HC-2d during the aquifer test. A well construction diagram for well HC-2d is provided in Appendix A. Figure 7 shows the net flow rate with estimated rate for the HC-2d aquifer test. Figure 8 shows the draw down and recovery with the net flow out of well HC-2d.

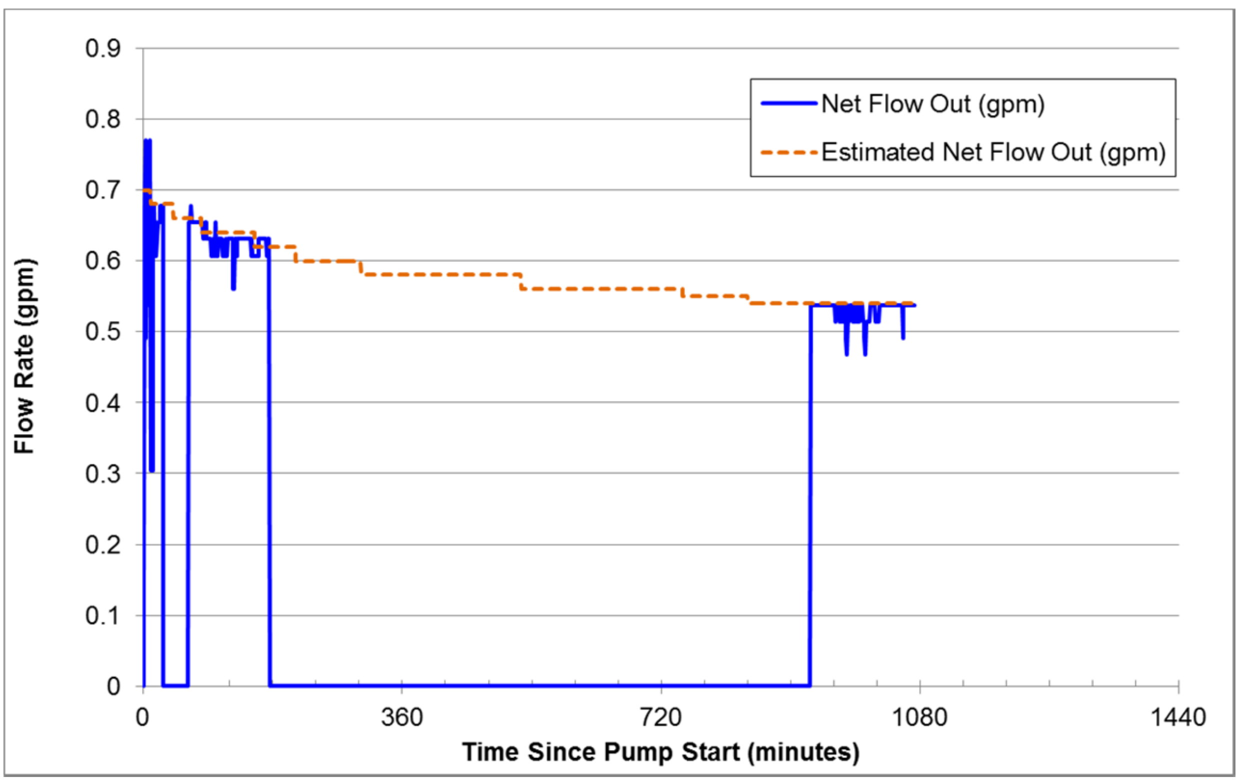

Figure 7. Flow Rates During the HC-2d Aquifer Test

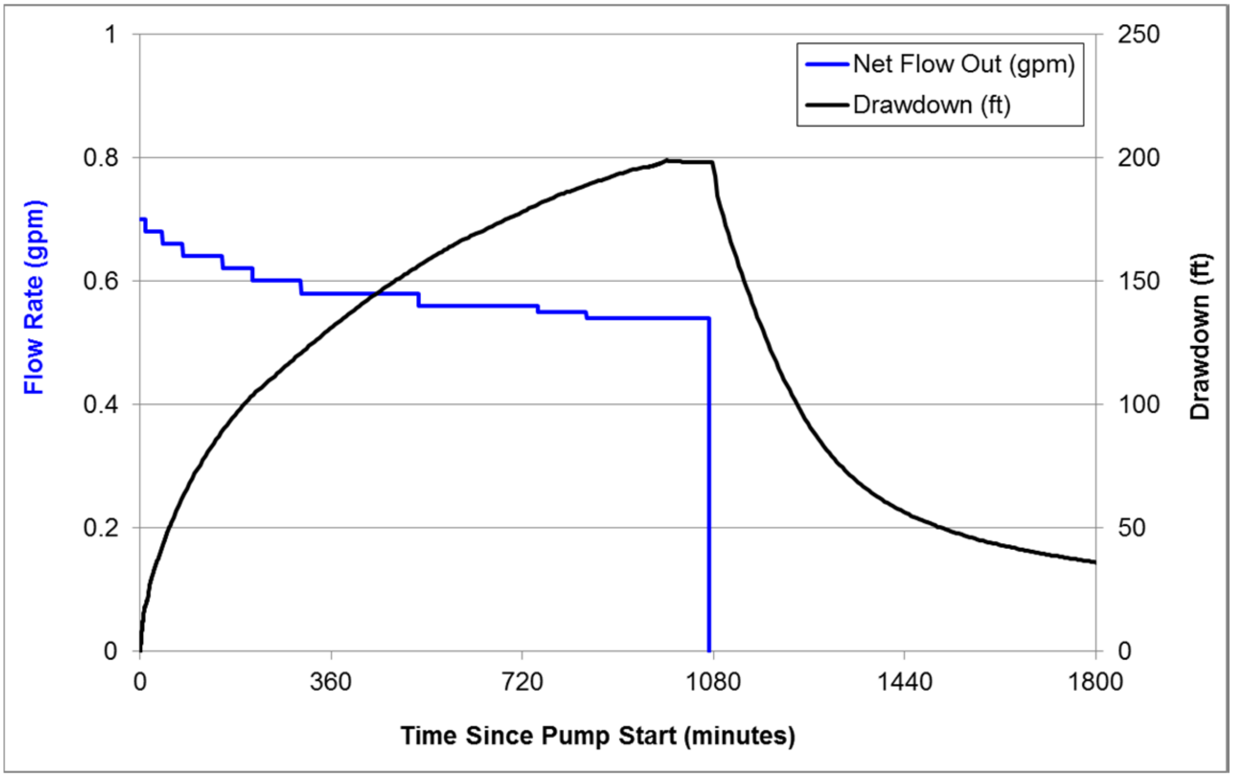

Figure 8. Drawdown and Net Flow Rate During the HC-2d Aquifer Test

The data were analyzed as a single-well pumping test using the fractured model with slab blocks. Solution parameters were varied within reasonable ranges to achieve an acceptable curve match (Figure 9), with more emphasis given to later time data. The solution parameters are given in Figure 9, with the most significant being the hydraulic conductivity of the fractures (K) and matrix (K'); these are 0.0009 ft/d (1×10^{-6} cm/s) and 0.000022 ft/d (2.5×10^{-8} cm/s), respectively. The casing in well HC-2d is open to the well bore from 100 ft to 1700 ft (total depth of the well); this includes the slotted interval (1417 to 1657 ft, 40 ft of blank), which does not have any filter pack material and is hydraulically connected to the well bore (DOE 2015b). Since this well is open to the well bore an aquifer thickness of 200 ft was used for hydraulic conductivity calculations so it would be consistent with wells MV-4 and MV-5. Figure 9 shows the drawdown curve match for the HC-2d aquifer test.

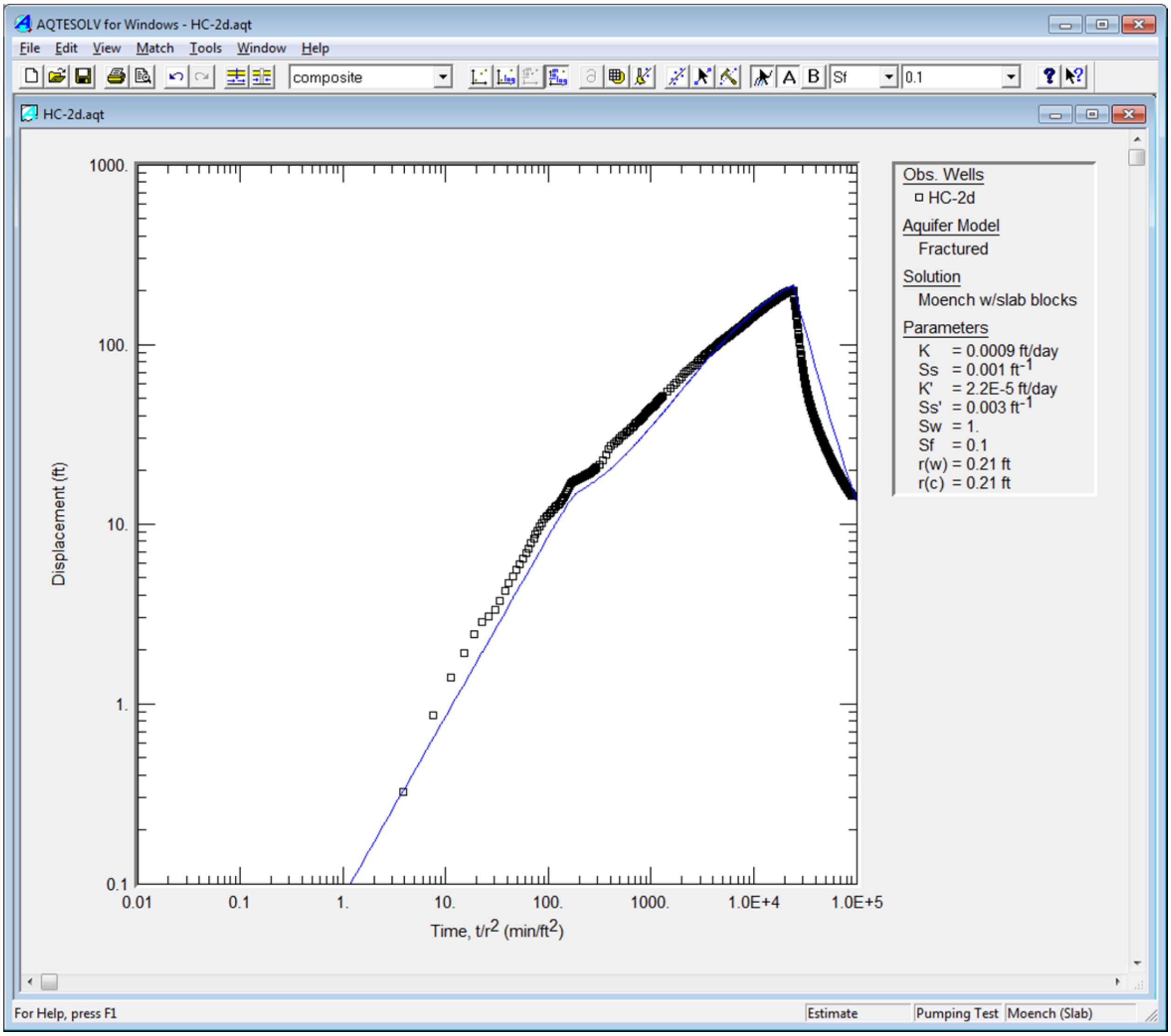

Figure 9. Curve Match (Blue Line) for the HC-2d Aquifer Test (from AQTESOLV)

3.5 Results of the MV-5 Aquifer Test

Three separate attempts were made to perform an aquifer test on well MV-5. The first attempt in May 2016 had an unusual drawdown response; water levels initially declined as expected, but later in the test they began to rise as the flow rate gradually decreased (Figure 10). Typically, flow rates decrease when drawdown in the well is large because pump efficiency decreases. The pump removes less water as water levels decline, increasing the head the pump has to work against. This decreasing flow rate is expected, water levels recovering concurrently with flow decreasing was not, suggesting trouble with the pumping system. The initial flow rate was set at 0.8 gpm, but after 22 hours of pumping and very limited drawdown, the flow rate was increased to 3.7 gpm. This increased the drawdown to about 50 ft. The flow rate was increased again to the maximum possible (about 5 gpm) late in the test to see if a future test could be conducted at the maximum flow rate. Drawdown increased to 90 ft and appeared to stabilize, indicating that the well could sustain being pumped at the maximum capacity and use less than 40% of the 240 ft of available water column. The drawdown then began decreasing in the same manner as previously after about 1 hour of pumping. The extracted water was clear with low turbidity, though the pH was more than 11. The cause of the recovering drawdown during pumping was believed at that time to be pump overheating or faulty well construction associated with cement in the well casing (causing the high pH and possible calcium carbonate precipitation). A well construction diagram for well MV-5 is provided as Appendix A. Figure 10 shows the drawdown from varying flow rates during the MV-5 aquifer test in May 2016.

A second aquifer test was conducted on well MV-5 from August 9 to August 11, 2016. The pumping period started at noon on August 9 with an initial flow rate of about 5 gpm; this held steady until the evening, when it began to decrease (a few 10ths of a gpm) and water levels began to recover (Figure 11). It was discovered the next morning that the pump had shut off unexpectedly when the motor saver tripped a few minutes after 10 p.m. Water levels had fully recovered to prepumping levels the next morning, so the test was restarted at 9 a.m., with an initial flow rate of 4.8 gpm. The flow rate steadily declined to about 2 gpm over the next 23-hours. The maximum drawdown of 61 ft was achieved an hour after restarting the test and by the end of the test drawdown had recovered to about 9 ft. The temperature of the water in the water access tube (which is strapped to the pump riser pipe) is also monitored by the transducer (located in the access tube about 10 ft above the pump) that monitors water levels in the well. The temperature increased by about 7 °C during the second test due to heating from the extracted water flowing through the pump riser pipe. It was evident that the pump was not performing properly, and the pump was shut off. An overheating pump was thought to have caused the pump motor saver to trip. Figure 11 shows the decreasing pump rate as water levels recovered and water temperatures increased during the MV-5 aquifer test in August 2016.

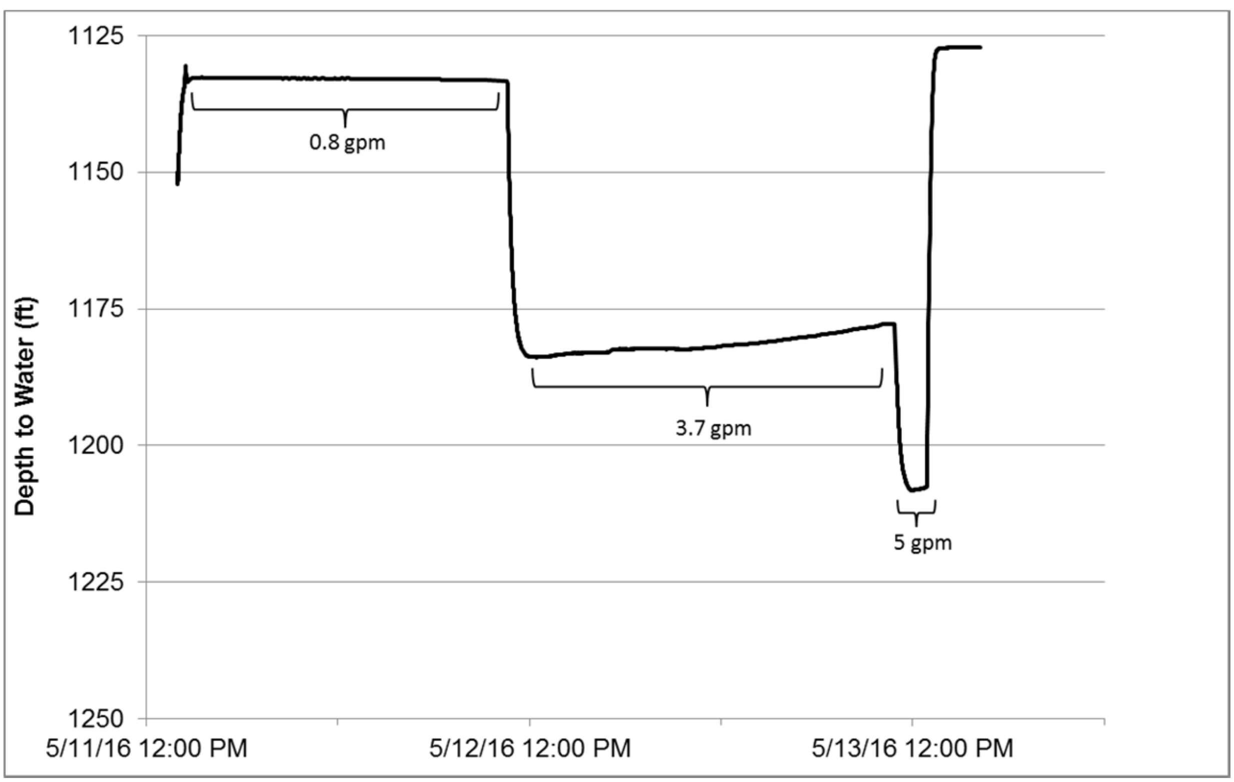

Figure 10. Initial MV-5 Aquifer Test (May 2016) Depth to Water

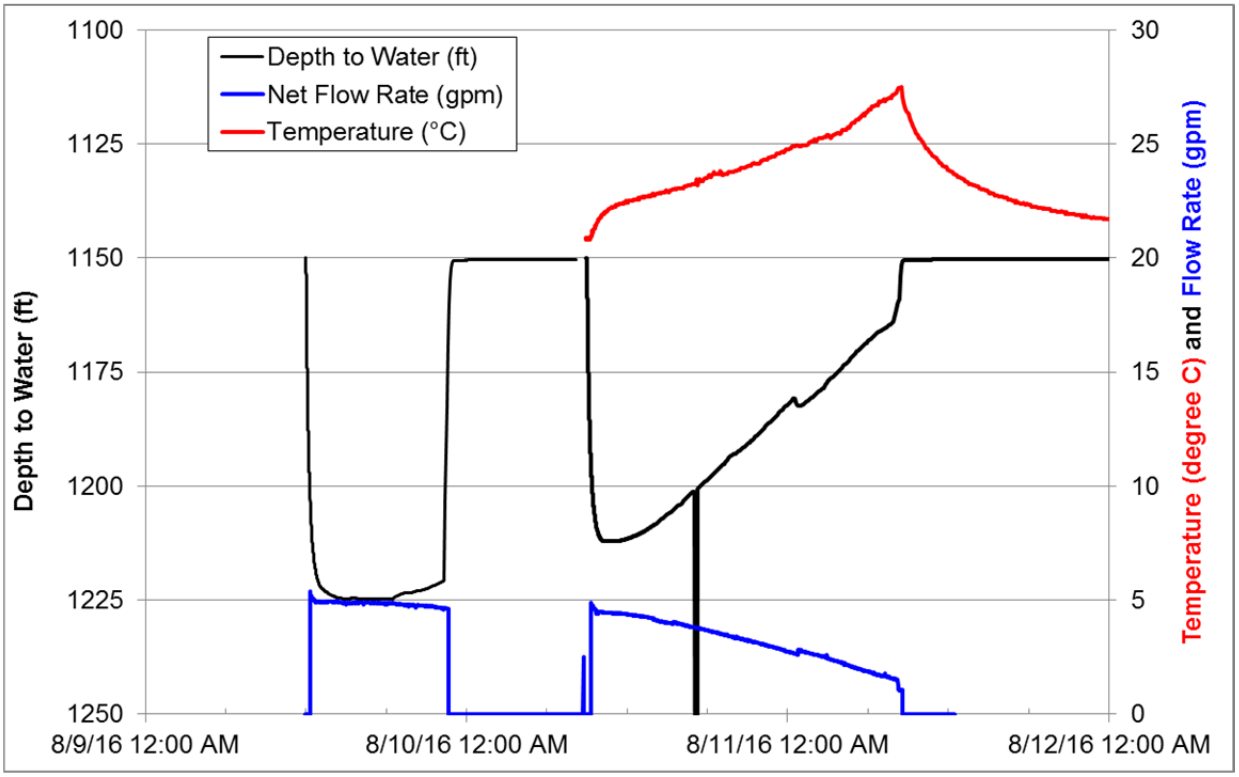

Figure 11. MV-5 Aquifer Test (August 2016) Depth to Water

The pump was pulled and replaced in late June 2017. The intake of the removed pump was coated with a calcium carbonate material (Figure 12) that effervesced with hydrochloric acid. The pump was returned to Grand Junction and taken apart. The impeller blades inside the pump were coated with the calcium carbonate material that had evidently built up during the periods of pumping and while the pump was in the well. The pump had been in the well for more than 2 years and had been used for well development and sampling without a problem. At the time, it was uncertain if the majority of the buildup occurred while the pump was operating or when the pump was idle in the well. Figure 12 shows the calcium carbonate material on the pump intake after it was removed from well MV-5 in June 2017.

Figure 12. Pump Removed from Well MV-5

The final aquifer test was performed on well MV-5 in late July 2017 (Figure 13) after the new pump was installed. Well MV-5 was pumped (July 22 to 23, 2017) for 20 hours at a rate that ranged from 8.5 gpm initially to just over 5 gpm at the end of the test (Table 2). When both the flow rate and drawdown were observed to be decreasing, pumping was stopped to prevent the buildup of calcium carbonate material and save the pump for future sampling. The depth to water measured in well MV-5 near the start of the aquifer test was 1050.20 ft (Table 1); the top of the pump is at a depth of 1306 ft (DOE 2015b). The maximum drawdown of 137 ft (water depth of 1188 ft) was reached 4 hours into the test. The depth to water had recovered to 1143 ft (45 ft of drawdown decrease) when the pump was shut off. Approximately 7560 gallons of water were removed from well MV-5 during the final aquifer test. Figure 13 shows the decreasing flow rate as water levels recovered during the MV-5 aquifer test in July 2017.

The MV-5 well and piezometer appear to be hydraulically connected, because water levels in the piezometer responded with about 1 ft of drawdown shortly after pumping started in well MV-5 (Figure 14). The top of the MV-5PZ screened interval (1700 ft deep) is 193 ft below the bottom of the MV-5 well’s screened interval (1507 ft deep). The well is filled with cement from 1507 to 1565 ft as a result of construction difficulties (DOE 2015b). Figure 14 shows the drawdown in MV-5PZ during the MV-5 aquifer test in July 2017.

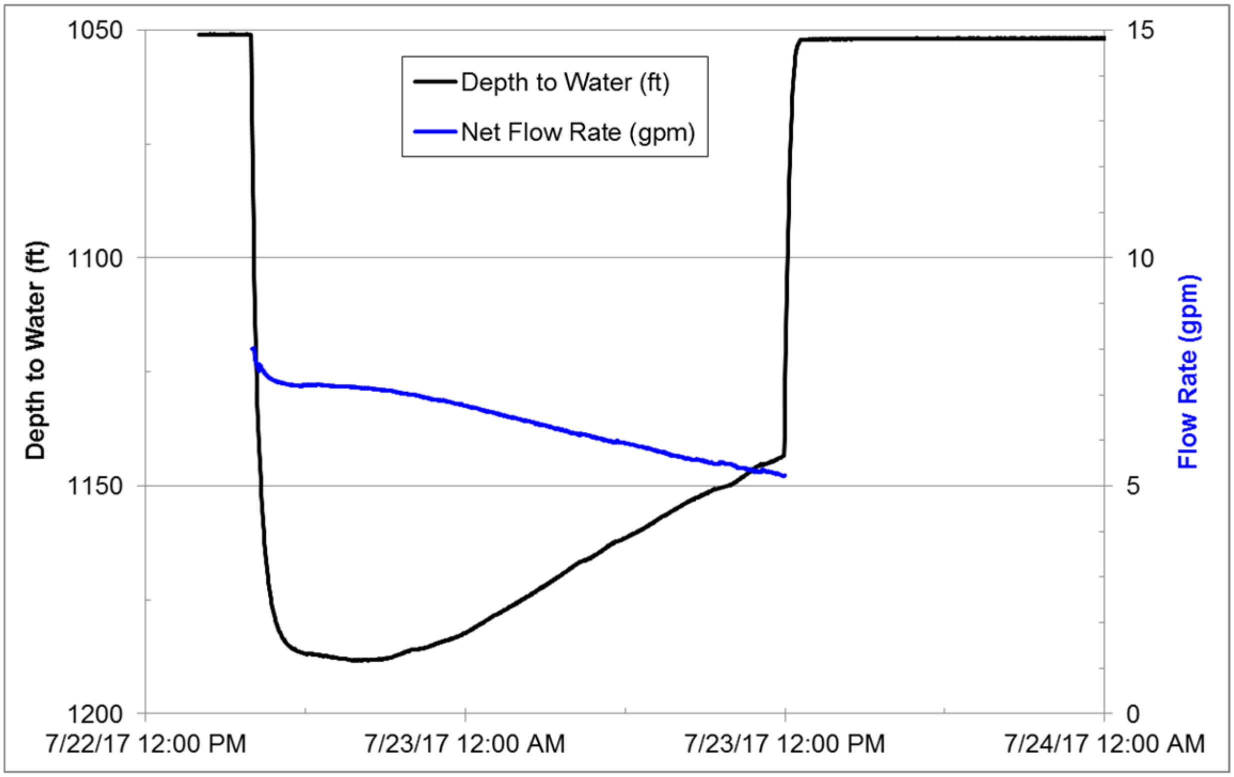

Figure 13. MV-5 Aquifer Test (July 2017) Depth to Water

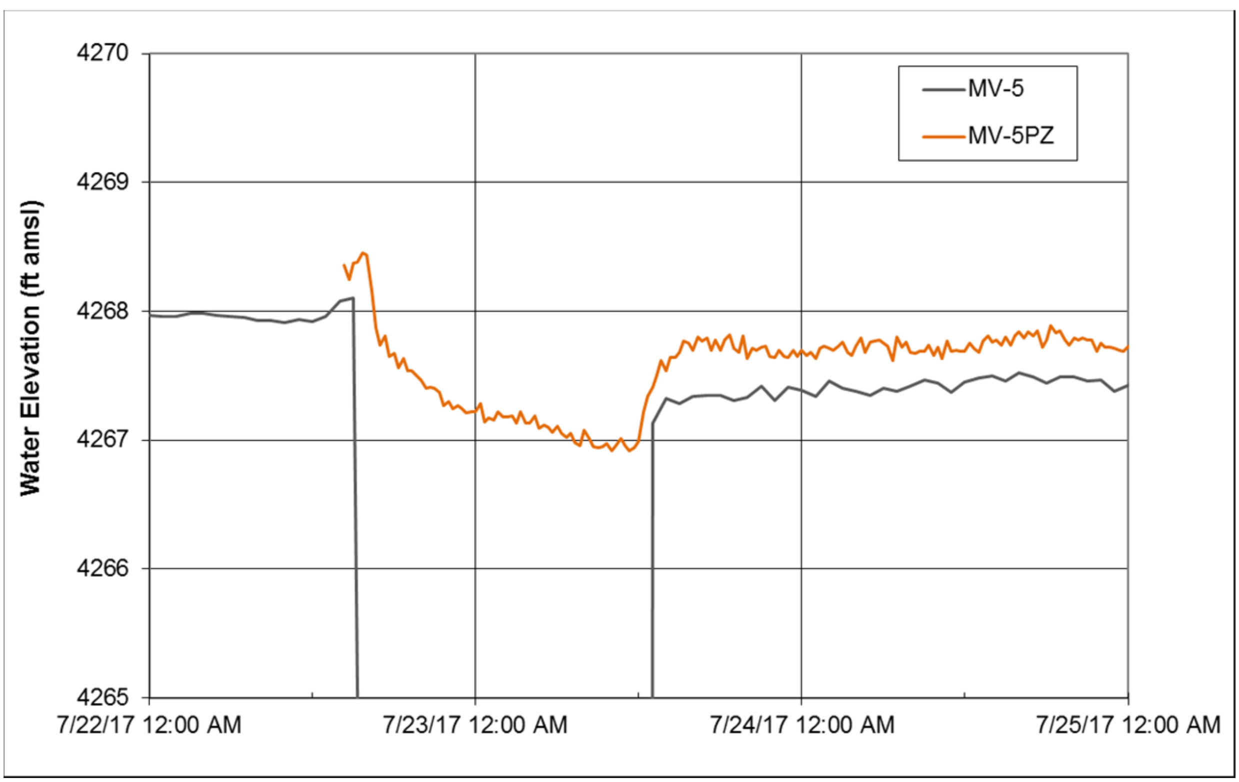

Figure 14. MV-5PZ and MV-5 Water Elevations

The data were analyzed as a single-well pumping test using the fractured model with slab blocks. Solution parameters were varied within reasonable ranges to achieve an acceptable curve match (Figure 15). More emphasis was given to later time data, though the match was good throughout the test. The ability of AQTESOLV to incorporate a variable flow rate (rates were recorded every minute) made the data from an atypical test useful. The solution parameters are given in Figure 15; the most significant are the hydraulic conductivity of the fractures (K) and matrix (K'), which are 0.29 ft/d (3×10^{-4} cm/s) and 0.00013 ft/d (1.5×10^{-7} cm/s), respectively. These results indicate that well MV-5 is one of the most productive wells at the site. Figure 15 shows the drawdown curve match for the MV-5 aquifer test.

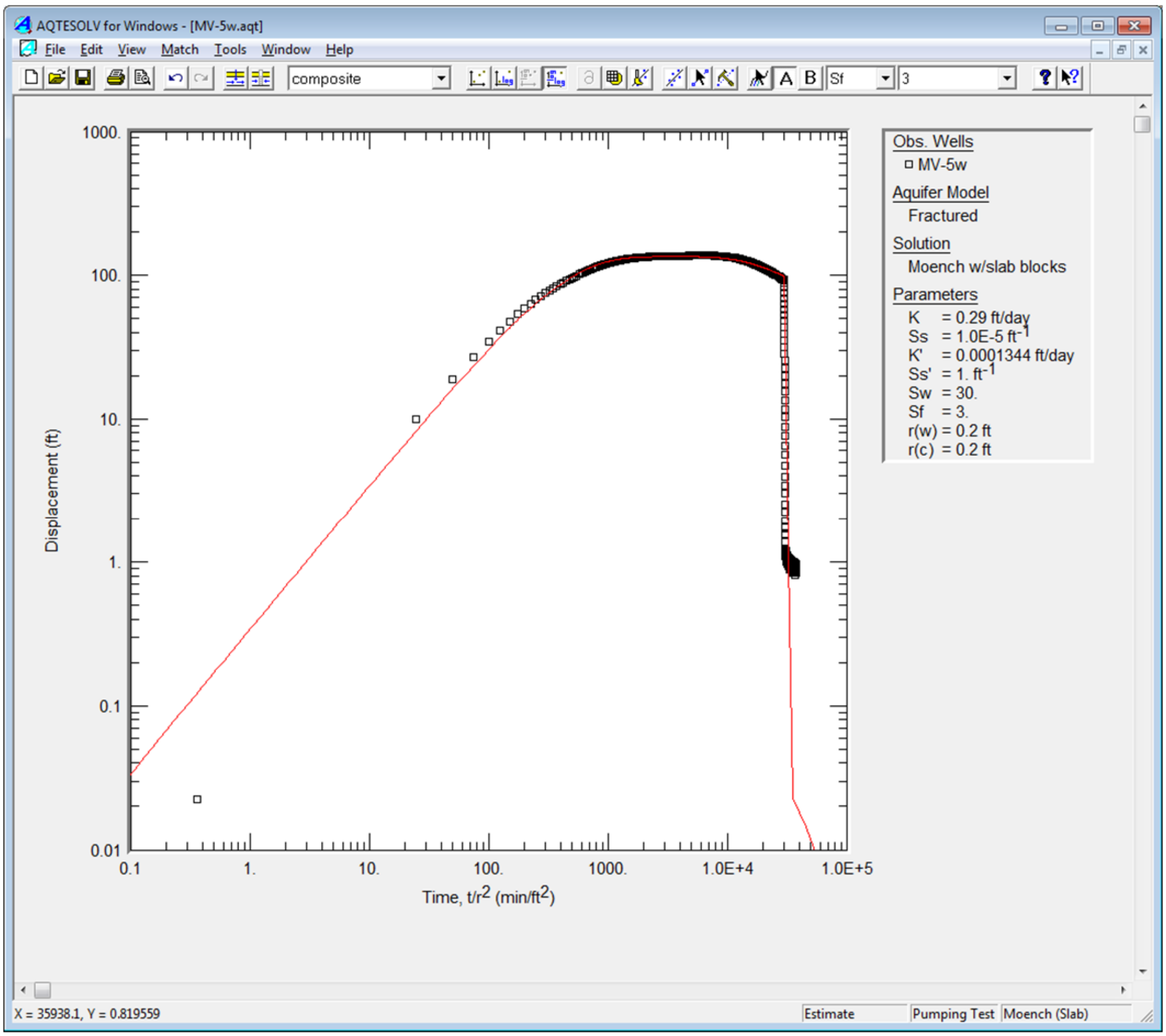

Figure 15. Curve Match (Red Line) for the MV-5 Aquifer Test (from AQTESOLV)

4.0 Summary and Conclusions

Analyses of the MV-4, MV-5, and HC-2d aquifer test data indicate a fairly wide range (2 to 3 orders of magnitude) of fracture hydraulic conductivity, from about 0.3 ft/d in MV-5 to about 0.001 ft/d in MV-4 and HC-2d. Wide-ranging results are expected for a heterogeneous fractured environment like the Shoal site. In addition to the uncertainties associated with single-well aquifer tests in fractured environments, each of the three wells posed its own challenges for testing. The flow rates for MV-4 and HC-2d were so low that a portion of the pumped water had to be returned to the well to cool the pump. Well MV-5 was much more productive than MV-4 and HC-2d, but the pump intake and impellers accumulated calcium carbonate material while pumping, reducing both flow and drawdown during the tests. Despite the challenges, good curve matches were achieved using the fractured rock with slab blocks solution (Moench 1984). These new data were also consistent with hydraulic conductivity data obtained from previous aquifer tests on other wells at the site. The wide ranging results plotted with the expected range for hydraulic conductivities for a fractured igneous rock formation (Figure 16), show that the hydraulic conductivities at the Shoal site are at the low range of what would be expected from a typical fractured rock formation, as defined by Allan Freeze and John Cherry in *Groundwater* (Freeze and Cherry 1979). This would be expected given the depth to water ranges from about 950 to 1350 ft below ground surface at the site. Figure 16 shows the hydraulic conductivities obtained from past and recent aquifer tests at the site with the expected range of hydraulic conductivities for a fractured igneous rock formation.

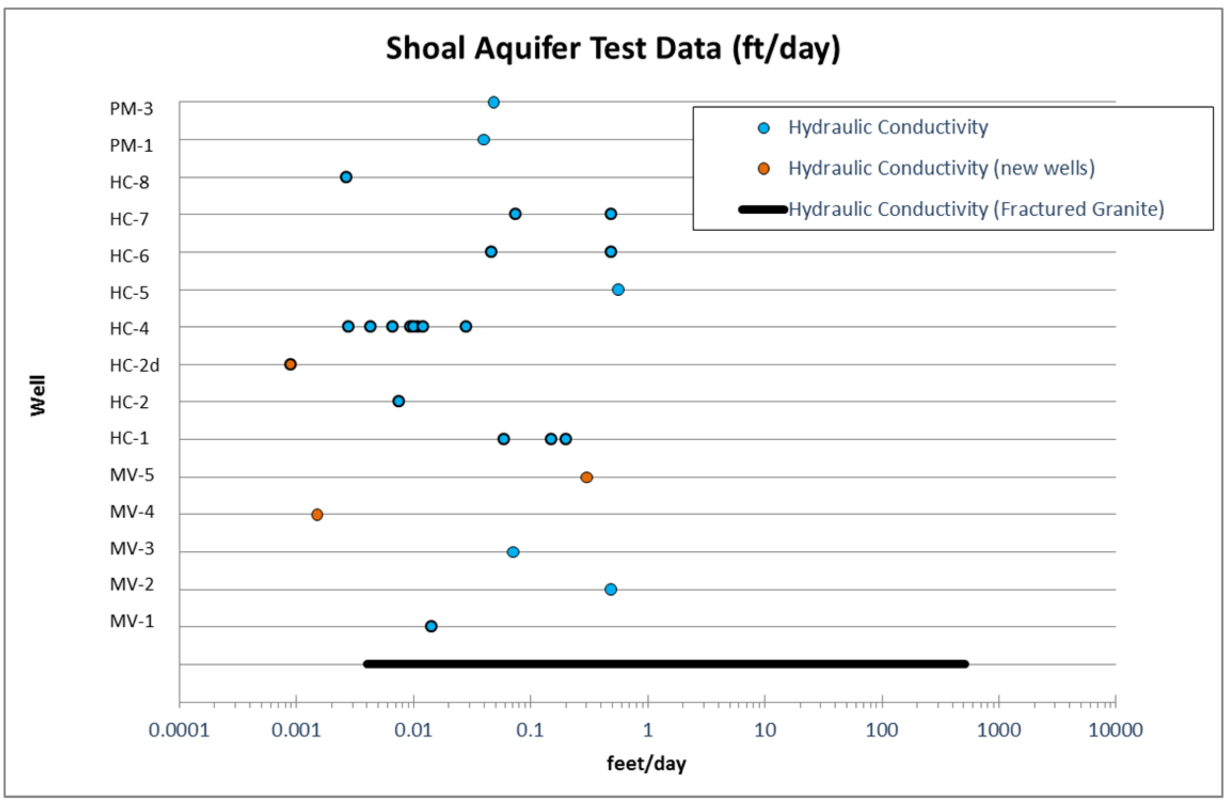

Figure 16. Summary of Aquifer Test Data

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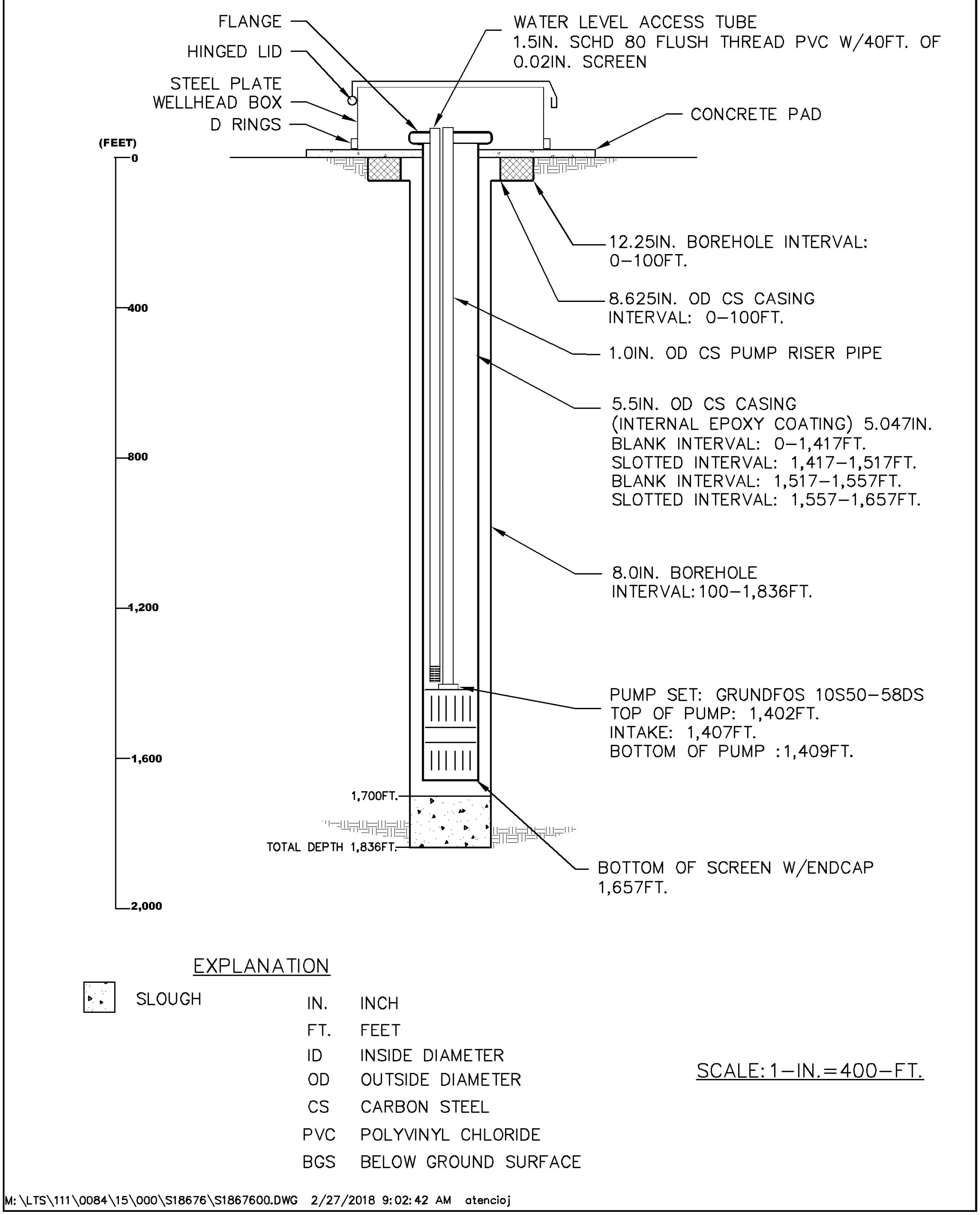
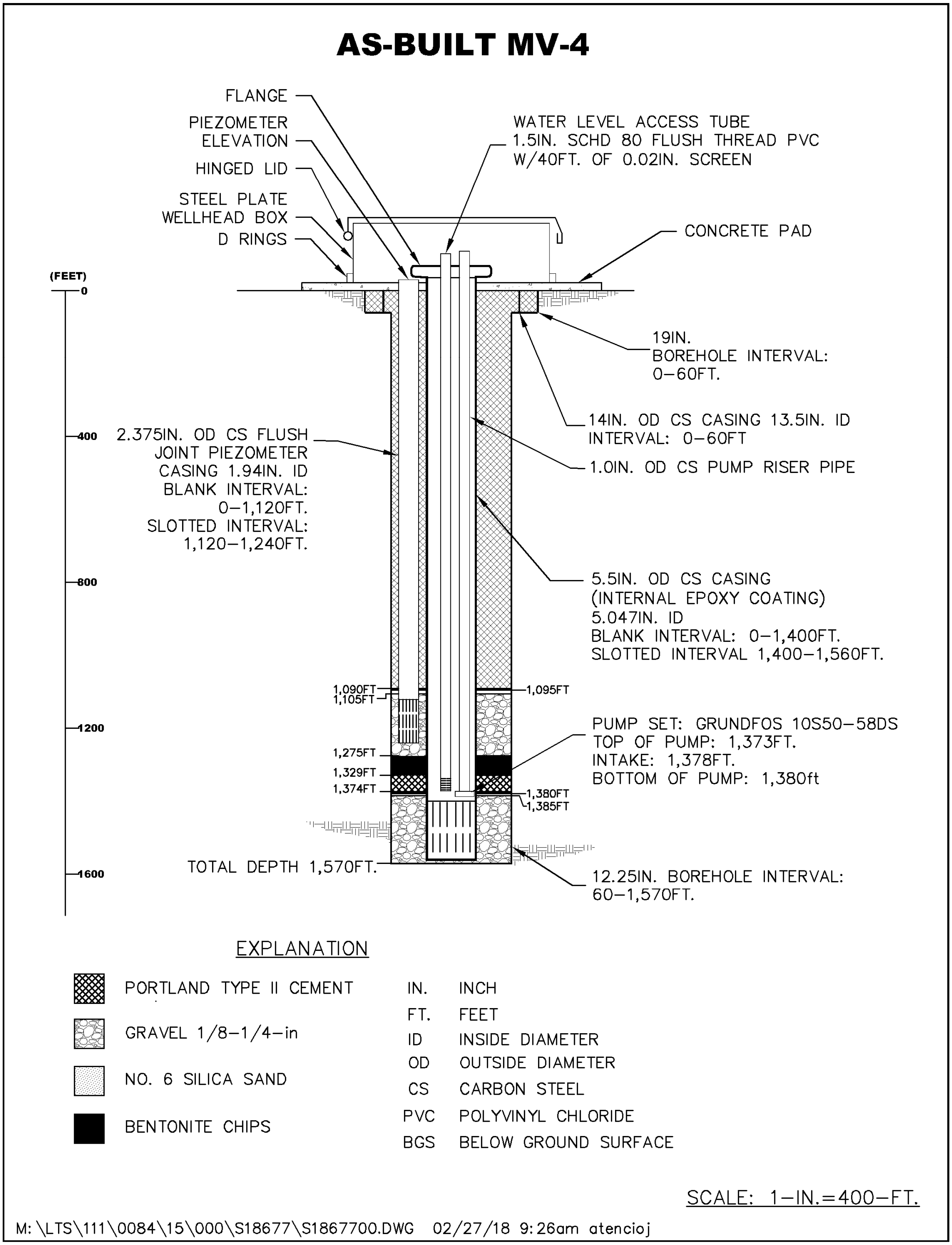
Appendix A

Well Construction Diagrams (MV-4, HC-2d, and MV-5)

AS-BUILT HC-2d




AS-BUILT MV-4
FLANGE
PIEZOMETER ELEVATION
HINGED LID
STEEL PLATE WELLHEAD BOX
D RINGS
WATER LEVEL ACCESS TUBE 1.5IN. SCHD 80 FLUSH THREAD PVC W/40FT. OF 0.02IN. SCREEN
CONCRETE PAD
(FEET)
0
400
800
1200
1600
19IN. BOREHOLE INTERVAL: 0-60FT.
14IN. OD CS CASING 13.5IN. ID INTERVAL: 0-60FT
2.375IN. OD CS FLUSH JOINT PIEZOMETER CASING 1.94IN. ID BLANK INTERVAL: 0-1,120FT. SLOTTED INTERVAL: 1,120-1,240FT.
1.0IN. OD CS PUMP RISER PIPE
5.5IN. OD CS CASING (INTERNAL EPOXY COATING) 5.047IN. ID BLANK INTERVAL: 0-1,400FT. SLOTTED INTERVAL 1,400-1,560FT.
1,090FT
1,105FT
1,095FT
PUMP SET: GRUNDFOS 10S50-58DS TOP OF PUMP: 1,373FT. INTAKE: 1,378FT. BOTTOM OF PUMP: 1,380ft
1,275FT
1,329FT
1,374FT
1,380FT
1,385FT
TOTAL DEPTH 1,570FT.
12.25IN. BOREHOLE INTERVAL: 60-1,570FT.
EXPLANATION
PORTLAND TYPE II CEMENT
GRAVEL 1/8-1/4-in
NO. 6 SILICA SAND
BENTONITE CHIPS
IN. INCH
FT. FEET
ID INSIDE DIAMETER
OD OUTSIDE DIAMETER
CS CARBON STEEL
PVC POLYVINYL CHLORIDE
BGS BELOW GROUND SURFACE
SCALE: 1-IN.=400-FT.
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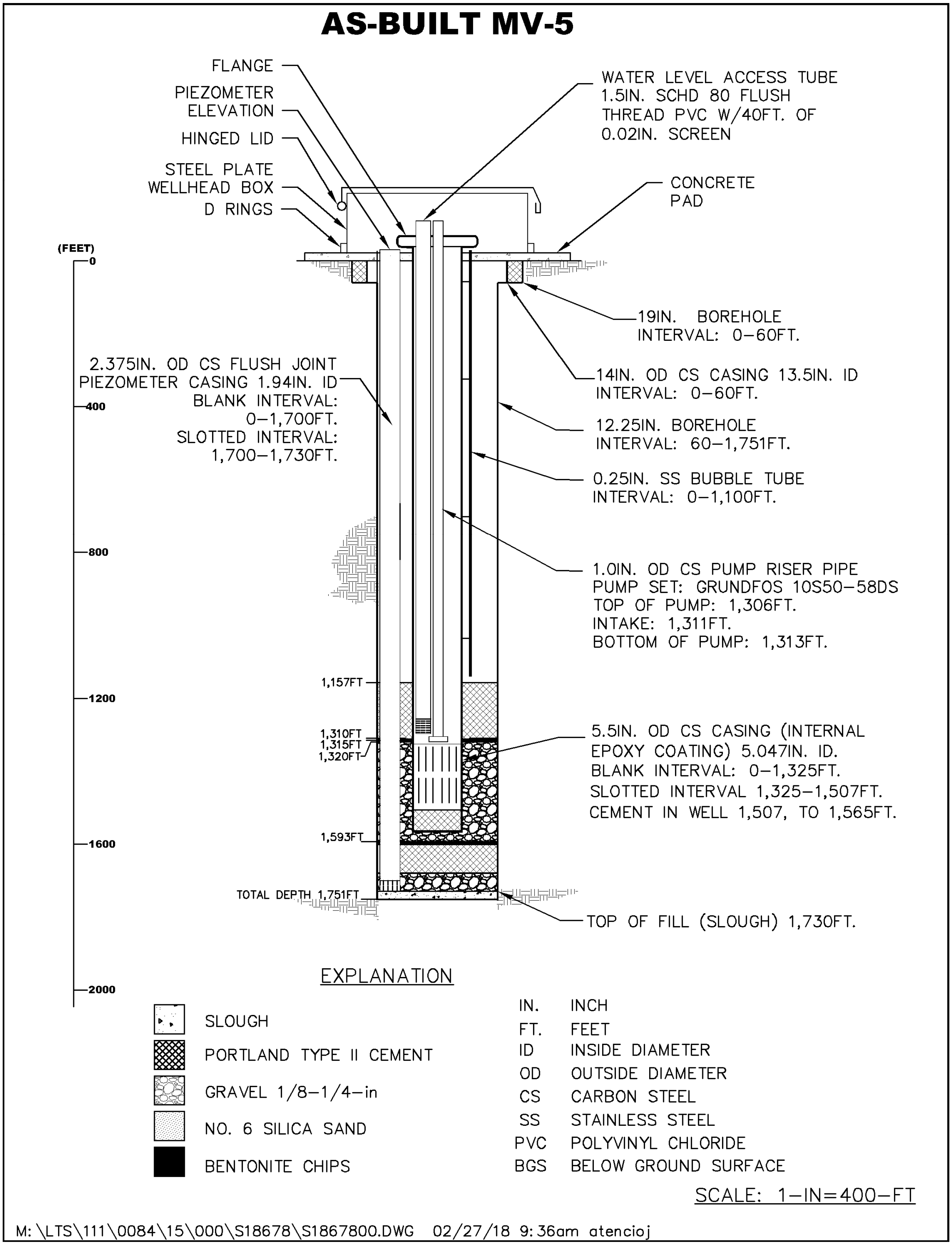
AS-BUILT MV-5
FLANGE
PIEZOMETER ELEVATION
HINGED LID
STEEL PLATE WELLHEAD BOX
D RINGS
WATER LEVEL ACCESS TUBE 1.5IN. SCHD 80 FLUSH THREAD PVC W/40FT. OF 0.02IN. SCREEN
CONCRETE PAD
(FEET)
0
400
800
1200
1600
2000
19IN. BOREHOLE INTERVAL: 0–60FT.
14IN. OD CS CASING 13.5IN. ID INTERVAL: 0–60FT.
2.375IN. OD CS FLUSH JOINT PIEZOMETER CASING 1.94IN. ID BLANK INTERVAL: 0–1,700FT. SLOTTED INTERVAL: 1,700–1,730FT.
12.25IN. BOREHOLE INTERVAL: 60–1,751FT.
0.25IN. SS BUBBLE TUBE INTERVAL: 0–1,100FT.
1.0IN. OD CS PUMP RISER PIPE
PUMP SET: GRUNDFOS 10S50–58DS
TOP OF PUMP: 1,306FT.
INTAKE: 1,311FT.
BOTTOM OF PUMP: 1,313FT.
1,157FT
1,310FT
1,315FT
1,320FT
5.5IN. OD CS CASING (INTERNAL EPOXY COATING) 5.047IN. ID.
BLANK INTERVAL: 0–1,325FT.
SLOTTED INTERVAL 1,325–1,507FT.
CEMENT IN WELL 1,507, TO 1,565FT.
1,593FT
TOTAL DEPTH 1,751FT
TOP OF FILL (SLOUGH) 1,730FT.
EXPLANATION
SLOUGH
PORTLAND TYPE II CEMENT
GRAVEL 1/8–1/4–in
NO. 6 SILICA SAND
BENTONITE CHIPS
IN. INCH
FT. FEET
ID INSIDE DIAMETER
OD OUTSIDE DIAMETER
CS CARBON STEEL
SS STAINLESS STEEL
PVC POLYVINYL CHLORIDE
BGS BELOW GROUND SURFACE
SCALE: 1–IN=400–FT
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