Aquifer Test Evaluation Conducted on the Middle Gravel Unit of the Alluvial Aquifer in Upper Metro Storm Drain Area, Butte, MT.

Drill cuttings of the middle gravel unit of the alluvial aquifer

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INTRODUCTION

Between 1-February-2010 and 4-February-2010, Pioneer Technical Services (PTS) acting on behalf of the BP-Atlantic Richfield Company (BP-ARCO), conducted a 72 hour aquifer test using well AMW-01B, which is a mid-level alluvial well completed in the parking lot of the Butte Civic Center at 1340 Harrison Avenue in Butte, MT (see figure 1). An aquifer test is used to estimate hydraulic properties of an aquifer and is evaluated by monitoring water-level responses in wells near a pumping well that is usually pumped at a constant rate. This aquifer test was conducted in order to fulfill a groundwater-monitoring requirement set forth in section 12.3.2.3 of the Butte Priority Soils Operable Unit (BPSOU) Record of Decision (ROD), which states that "one pumping test will be conducted on a mid-level well, in the upper Metro Storm Drain (MSD) to determine if the sub-drain will influence flow in the mid-level portion of the aquifer" (EPA, 2006). During this experiment, scientists from the Montana Bureau of Mines and Geology provided technical assistance by:

1) installing Solinst pressure transducers in 47 wells;
2) installing Hydrolab multi-parameter water-quality logging units in three wells;
3) collecting samples of the pumped groundwater for water-quality analysis every twelve hours during the aquifer test;
4) periodically measuring water levels in the pumping well and observation wells during the test;
5) and, periodically monitoring flow rates from the pumping well.

This report will summarize water-level fluctuations in wells monitored during the aquifer test and provide estimates of hydrogeologic properties for the middle zone of the alluvial aquifer.

SITE BACKGROUND

The Upper Metro Storm Drain (MSD), previously known as Silver Bow Creek, is a man-made storm water diversion ditch which runs along the ancestral Silver Bow Creek channel. Directly underlying the ditch is a French drain collection system, which captures contaminated groundwater and diverts it to Lower Area One (LAO) for conventional lime treatment. Possible sources of groundwater contamination in this area are the Parrot Tailings, North Side Tailings, and Diggings East Tailings (EPA, 2006). These buried and partially saturated deposits consist of tailings piles designated by the EPA as waste that is to be left in place. This area is part of the Butte Priority Soils Operable Unit Superfund (BPSOU) Site.

The hydrogeology of the site was originally characterized by the Primary Responsible Parties Group in the Phase II Remedial Investigation (RI) Report (PRP Group, 2001). Aquifer characteristics for the alluvial aquifer were described in this report using aquifer test and slug test data in wells and boreholes having a median depth of about 30 feet. The report characterizes the alluvial aquifer in the vicinity of the MSD as discontinuous units of sand, gravel, silt, and clay that is poorly sorted and not readily correlated between wells. In 2004, using aquifer properties from PRP, 2001, EPA released the Final Focused

Feasibility Study describing the alluvial material as having a significantly low hydraulic conductivity (2.5 feet/day in the upper reaches of the MSD, 15 feet/day in the middle reaches of the MSD, and 45 feet/day in the lower reaches west of Kaw Ave.) throughout the Metro Storm Drain. The report suggested that this low hydraulic permeability is due to the heterogenous nature of the alluvial aquifer itself, extending to a depth of at least 200 feet below ground surface (EPA, 2004). The low hydraulic conductivity (2.5 feet/day) for the upper portion of the MSD (Parrot Complex area) was primarily a function of the pumping well having been completed in a low permeability unit or aquitard (Chen Northern Inc and CH^{2}M Hill, 1990).

A study conducted by MBMG (Metesh and Madison, 2004), released prior to EPA (2004) final report, concluded that the alluvial deposits were less heterogenous with higher hydraulic conductivities than described in the 2004 EPA draft Focused Feasibility Study. Metesh and Madison (2004) described a locally continuous gravel unit, 10-15 feet thick, at a depth 40 to 50 feet below ground surface in borings from five different wells located in and extending down-gradient of the Parrot Complex, along the MSD (wells AMW-1B, MSD-1B, MSD-2B, MSD-3, and MSD-4). The gravel aquifer was bounded stratigraphically above and below by clay layers, which separated the gravel aquifer from transmissive layers above and below the gravel layer. The gravel layer appeared to extend in a southwesterly direction (in the direction of groundwater flow) along the historic Silver Bow Creek channel from the Parrot Complex to MSD-03 (just west of the Columbus Plaza on George Street; Figure 1). Additionally, water-quality results from these wells show elevated concentrations of Cd, Cu, and Zn and other metals similar to the water quality found in the Parrot plume, suggesting a connection exists between the Parrot Tailings plume, and the wells completed in the gravel layer.

Lithologic logs and geochemical data from a well drilled in 2005 (well MSD-05) near the bend in George Street (Figure 1) also show a gravel layer with water quality similar to up-gradient wells installed in the gravel layer (Tucci, 2010). There are no wells west of MSD-05 that intercept a stratigraphically similar gravel layer with poor water quality. However, wells that have been drilled to the west of MSD-05, as of this writing, are too shallow and only penetrate the shallow alluvial aquifer. Drilling is scheduled by the EPA for the summer of 2010 with the intent to determine how far downgradient the gravel layer extends from MSD-05.

For purposes of this report, the alluvial aquifer less than 200 feet deep is separated into three transmissive units or aquifers: the shallow alluvial (SA), middle alluvial (MA), and deep alluvial (DA) aquifers. The shallow alluvial aquifer, described by EPA (2004), refers to the top of the alluvial aquifer (upper 10 feet). The middle alluvial aquifer refers to the continuous gravel unit described by Metesh and Madison (2004) found starting between 35 and 50-feet. below ground surface, and the deep alluvial aquifer refers to highly transmissive zones (typically >100 feet.) found below the gravel unit. Each unit is bound above and below by discontinuous clay and silt layers with very low hydraulic conductivities, and is therefore semi-confined from other units. Additionally, the bedrock aquifer (BA) was monitored during the test, and refers to water moving through bedrock (granite) which underlies the alluvial aquifer.

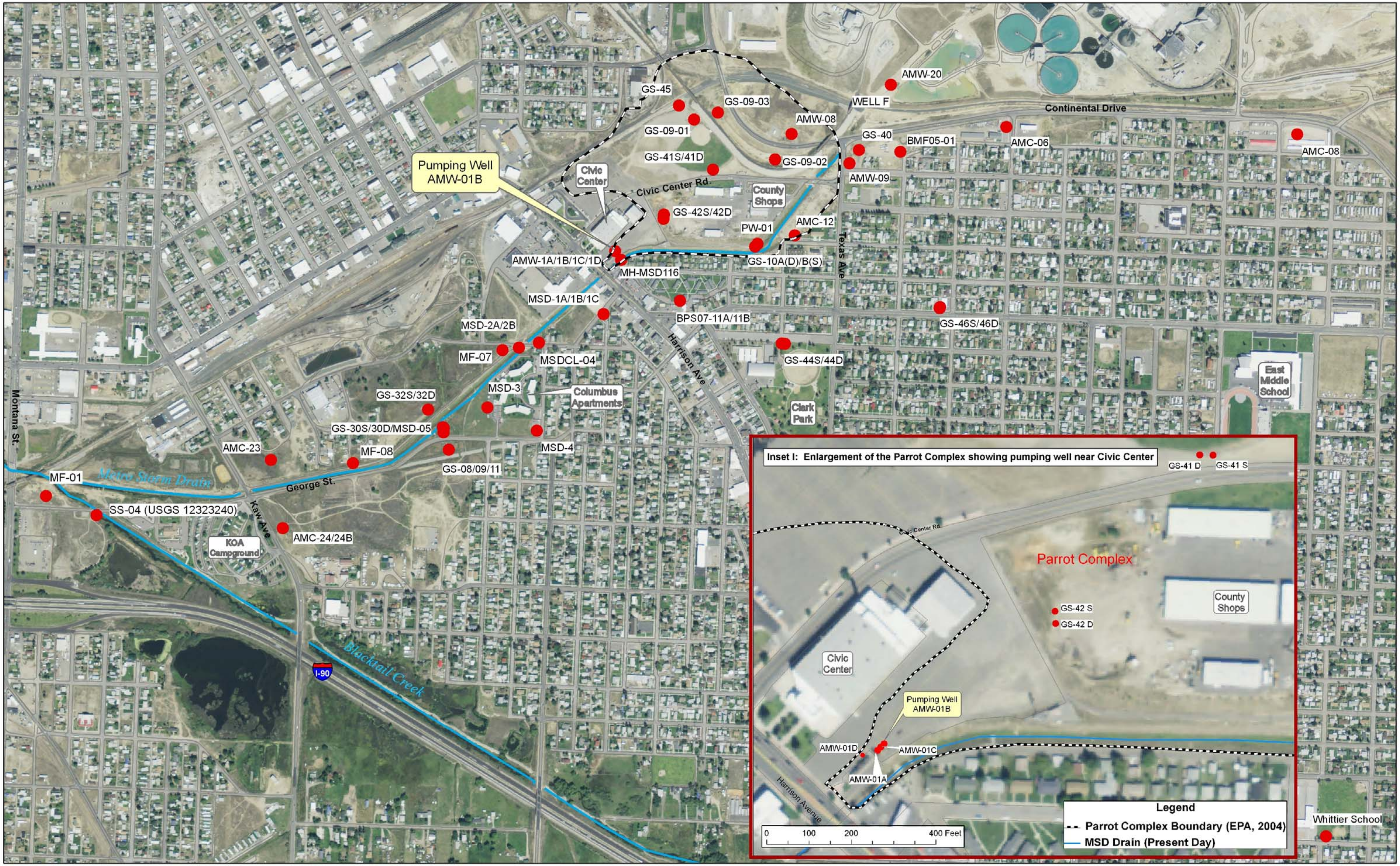

Figure 1. Location map showing groundwater monitoring sites during 72-hour aquifer test

Parrot Complex Boundary (EPA, 2004)

Groundwater sites fitted with pressure transducer

Aerial Imagery: 2009 NAIP imagery from NRIS

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OBJECTIVES

This report presents an independent analysis of the 72-hour aquifer test conducted by PTS for BP-ARCO. The aquifer test was designed to provide estimates of the hydraulic properties for the middle alluvial (MA) aquifer found throughout the MSD area, because the hydraulic properties of this unit have never been characterized or described.

METHODS

Well AMW-01B in the Civic Center parking lot was chosen as the pumping well for the following reasons:

1) Proximity to three additional observation wells completed at different depths of the alluvial aquifer (within a radial distance of 50 feet from AMW-01B). One well in particular (AMW-01D) is completed at the same depth as the pumping well (in the middle alluvial aquifer), and is one of the only wells in the area that could serve as a close observation well.
2) The well was drilled in 2004 with the intent that it be used as a pumping well for an aquifer test of the MA (33.5-43.5 feet below ground surface).

Drilling logs for AMW-01B indicates the MA is 15 feet thick at this location. With a 10-foot screen, well AMW-01B is considered a partially penetrating well. Additionally, well AMW-01B is a 4-inch diameter well, which limits the size of pump that can be installed and also restricts water flow into the well when pumping at a high rate. As a result of this diminished well efficiency, the pumping well was not used to estimate aquifer parameters.

PTS was the lead consultant responsible for conducting the 72-hour aquifer test. PTS contracted with Parson's Drilling for pump installation and operation, as well as Jordan Contracting for effluent-water storage and removal. Due to the elevated metal concentrations, effluent from the pumping well was pumped into 3,000 gallon tanker trucks and transported to LAO for conventional lime treatment and disposal. Additionally, Trec Environmental Inc. (Trec) was responsible for periodically downloading transducer data and monitoring water levels at certain wells.

Prior to the aquifer test (1/26/10 and 1/27/10) a step-drawdown aquifer test was conducted to determine an adequate pumping rate for the 72-hour test. Based on the step-drawdown test a pumping rate of 90 gallons per minute (gpm) was chosen for the aquifer test. Pumping for the 72 hour aquifer test began at 9:34:00 hrs on 2/1/10 and ceased at 9:50:00 hrs on 2/4/10. Pumping rates were maintained between 88 gpm and 95 gpm, and flow was measured via a Grey Line model PDFM 4.0 portable doppler flow meter. The tanker trucks were filled from the bottom, which resulted in variable head conditions on the pump and subsequently variable well-discharge rates. Pumping rates were recorded on a regular basis and incorporated into the aquifer test analysis.

During the aquifer test, MBMG was responsible for the installation and periodic downloading of 47, Solinst Gold series levelogger model F-15 or F-30 pressure transducers. Model F-15 transducers have slightly better accuracy (+/- 0.01 feet. vs. */- 0.016 feet.) than the model F-30 transducers, and model F-15 transducers were used in wells closest to the pumping well. Direct-read cables were installed with 16 transducers, which allowed the transducer to remain in place and continuously record during data downloads. The other transducers were suspended in the casing with a stainless steel cable and had to be removed from the well during downloads. Nine transducers were deployed by Trec. Table 1 summarizes water-level monitoring in the area via pressure transducers during the aquifer test.

The MBMG installed three Hach Hydrolab DS-5 multi-parameter water-quality meters capable of monitoring pH, specific conductivity (SC), oxidation-reduction potential (ORP), temperature, dissolved oxygen (DO), and turbidity. One Hydrolab was suspended in a well upgradient of the pumping well (GS-42D), one Hydrolab downgradient of the pumping well (MSD-01B), and one was attached to the discharge line of the pumping well. Hydrolabs were setup to collect temperature, pH, ORP, SC, DO, and turbidity data at 15 minute intervals. Figure 2 shows the Hydrolab meter connected to the discharge line of the pumping well.

Table 1. Sites monitored for water level fluctuations during the aquifer test. A description of the aquifer each site was completed in, transducer type, and monitoring interval is given.

Location	Aquifer or Setting*	Transducer	Agency	Direct Read Cable	Time Interval (minutes)
AMC-06	SA	F-30	MBMG	Y	15:00
AMC-08	SA	F-30	MBMG	Y	15:00
AMC-12	SA	F-30	MBMG	N	15:00
AMC-23	SA	F-30	MBMG	Y	15:00
AMC-24	SA	F-30	MBMG	Y	15:00
AMC-24B	MA	F-15	MBMG	Y	0:15
AMW-01A	SA	F-15	MBMG	N	15:00
AMW-01B	MA	F-15	MBMG	Y	0:15
AMW-01C	DA	F-15	MBMG	N	15:00
AMW-01D	MA	F-15	MBMG	Y	0:15
AMW-08	SA	F-30	MBMG	N	15:00
AMW-09	SA	F-30	MBMG	N	15:00
AMW-20	SA	F-30	MBMG	N	15:00
BMF-05-01	SA	F-30	MBMG	Y	15:00
BPS-07-11B	MA	F-15	MBMG	Y	0:15
BPS07-03A	SA	F-30	ARCO	N	15:00
BPS07-09A	SA	F-30	ARCO	N	15:00
BPS07-11A	SA	F-30	MBMG	N	15:00
GS-08	DA	F-30	MBMG	N	15:00
GS-09	MA	F-30	MBMG	N	15:00
GS-09-01	SA	F-30	MBMG	N	15:00
GS-09-02	SA	F-30	MBMG	N	15:00
GS-09-03	SA	F-30	MBMG	N	15:00
GS-10A	DA	F-30	MBMG	N	15:00
GS-10B	SA	F-30	MBMG	N	15:00
GS-11	SA	F-30	MBMG	N	15:00
GS-30D	MA	F-15	MBMG	N	15:00
GS-30S	SA	F-30	MBMG	N	15:00
GS-32D	MA	F-15	MBMG	N	15:00
GS-41D	MA	F-15	MBMG	Y	0:15
GS-41S	SA	F-15	MBMG	Y	0:15
GS-42D	MA	F-15	MBMG	Y	0:15
GS-44D	MA	F-30	MBMG	N	15:00
GS-44S	SA	F-30	MBMG	N	15:00
GS-45	SA	F-30	MBMG	N	15:00
GS-46D	MA	F-30	MBMG	N	15:00
GS-46S	SA	F-30	MBMG	N	15:00
MDS-02B	MA	F-15	ARCO	Y	0:15
MF-01	SA	F-15	MBMG	N	15:00
MF-07	SA	F-30	ARCO	N	15:00
MF-08	SA	F-30	ARCO	N	15:00
MF-08	SA	F-30	ARCO	N	15:00
MH-MSD116	MSD	F-30	ARCO	Y	0:15
MSD-01A	SA	F-30	MBMG	N	15:00
MSD-01B	MA	F-15	ARCO	Y	0:15
MSD-01C	DA	F-30	MBMG	N	0:15
MSD-02A	SA	F-30	MBMG	N	15:00
MSD-03	MA	F-30	MBMG	N	15:00
MSD-04	MA	F-30	MBMG	N	15:00
MSD-05	MA	F-30	MBMG	N	15:00
MSDCL-04	MSD	F-30	ARCO	Y	0:15
PW-01	MA	F-30	MBMG	N	15:00
SS-04	SW	F-30	MBMG	N	15:00
SS-05A	SW	F-15	MBMG	N	15:00
Well F	B	F-30	MBMG	N	15:00
Whittier School	SA	F-30	MBMG	N	15:00

*Aquifer or setting abbreviations: SA (shallow water-table aquifer), MA (middle gravel aquifer), DA (deep alluvial), B (bedrock), MSD (metro storm drain, either manhole or cleanout of the French drain system), SW (surface-water site).

Figure 2. Discharge line setup with in-line Hydrolab monitoring from pumping well.

Water-quality samples were collected at 12-hour intervals from the pumping well during the aquifer test. In total, six water samples were analyzed for both physical and chemical parameters. Water-quality samples were analyzed for the following parameters:

1. Dissolved metals - Al, As, Co, Cd, Cr, Cu, Fe, Mn, Mo, Ni, U, and Zn;
2. Major cations - Ca, Mg, Na, K, SiO_2;
3. Major anions - SO_4, HCO_3, CO_3, NO_3, Cl, hardness, alkalinity, and TDS;
4. Field parameters - pH, temperature, specific conductance, and oxidation-reduction potential (ORP).

Standard EPA protocols for sampling and analysis of groundwater were followed. A bulk sample was collected from the discharge line from a clean acid-rinsed bucket, and transported back to the vehicle for immediate sample preparation. Three sample aliquots were collected from the bulk sample, one of each type below:

1) 500 mL unfiltered/raw sample for basic parameters;
2) 500 mL filtered/acidified (1% HNO_3) sample for dissolved metal analysis; and,
3) 250 mL filtered/untreated sample for major anion analysis.

Sample containers were rinsed three times with sample solution prior to being filled. Filtered aliquots were taken using 0.45 micron disposable filters. Water-quality samples were preserved on ice and submitted to the MBMG lab for analysis.

Aquifer Test

The software program AQTESOLV version 4.5 (Duffield, 2007) was used to analyze the drawdown curves and estimate aquifer properties for the middle alluvial gravel layer (MA). Values of transmissivity (T), hydraulic conductivity (K), and storativity (S) were estimated using AQTESOLV (see table 3). The stratigraphic data and water-level response to pumping both indicated that the middle gravel aquifer is a leaky confined aquifer. Three leaky confined solution methods were used to estimate the aquifer characteristics using transient water-level data.

1) Hantush (Hantush, 1960; Hantush, 1964)
2) Cooley-Case (Cooley and Case, 1973)
3) Neuman-Witherspoon (Neuman and Witherspoon 1969)

The assumptions for these solution methods are listed below:

1) Aquifer has infinite areal extent
2) Aquifer is homogeneous and of uniform thickness
3) pumping well is fully penetrating (Hantush; Cooley-Case, Neuman-Witherspoon) or partially penetrating (Hantush)
4) Flow to pumping well is horizontal when pumping well is fully penetrating
5) Water is released instantaneously from storage with decline of hydraulic head
6) Diameter of pumping well is very small so that storage in the well can be neglected
7) The confining bed(s) has infinite areal extent, uniform vertical hydraulic conductivity, storage coefficient and thickness
8) Flow is vertical in the aquitard
9) Pumping rates were not constant
10) The gravel unit is a leaky semi-confined aquifer which receives recharge from an upper aquitard
11) Confining bed(s) is overlain or underlain by an infinite constant-head plane source (Hantush, 1960)

In order to create a mathematical solution that can be solved, all aquifer test solutions require assumptions that are not realistic when applied to natural aquifers, such as, the assumption that the aquifer is homogeneous and of infinite extent. However, the solution methods that were chosen satisfy to the greatest extent possible the requirements of the hydrogeologic setting with the minimum violation of the assumptions associated with the solution method.

RESULTS

Water-Level Elevations

Transducers were deployed in wells completed in three hydrogeologically conductive zones in the area. The shallow alluvial wells (SA) represent the water-table aquifer. The middle alluvial aquifer (MA) represents wells completed in the gravel layer, and the deep alluvial aquifer (DA) represents wells completed below the gravel layer (typically at a depth of ~100'). Most MBMG transducers were installed on 14-January-2010, and were left in place for continual monitoring before, during, and after the aquifer test. Hydrographs for all wells not presented in this section are presented in Appendix A. All transducer data were corrected for barometric fluctuations prior to compilation of hydrographs and analyses of drawdown curves.

In addition to the pumping-induced water-level fluctuations, there are also seasonal water level trends in the hydrographs for most wells. The seasonal trends may increase or decrease over several days depending on the location of well within the alluvial aquifer and rate of groundwater recharge, but the overall trend for the time monitored was that of decreasing water levels. The seasonal decline and short-term fluctuations are observable in the Whittier School well (Figure 3), which was selected to serve as a background site approximately 8,000 feet from the pumping well. During the three days of pumping the Whittier School well water level rose slightly due to short-term fluctuations, which is the opposite water-level response one would expect to see in a well influenced by pumping. The lack of a declining water level in this well during pumping indicates that this well was outside the zone influence of the pumping well.

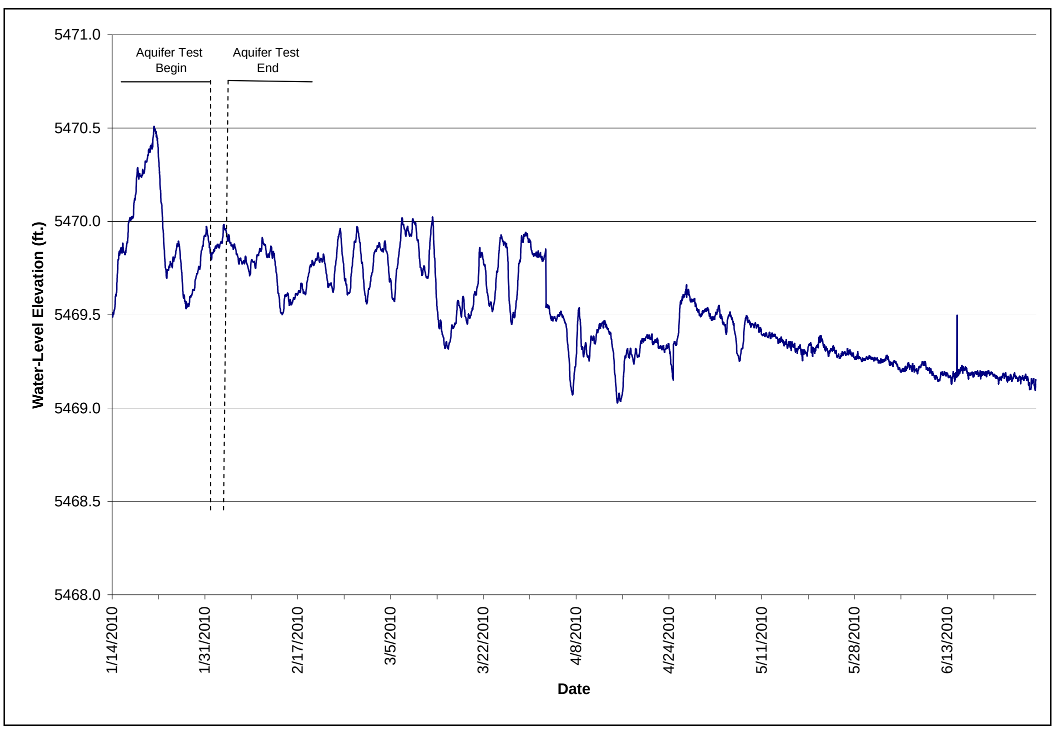

Figure 3. Hydrograph of Whittier School well.

Water-level responses in wells closer to the pumping well were influenced by the depth of the well and distance from the pumping well (Table 2). As expected, the wells nearer the pumping well and that were completed in the middle aquifer had the greatest response to pumping (Figure 4), but wells that were quite distal to the pumping well also had measurable responses. All wells installed in the middle gravel aquifer less than 2,300 feet from the pumping well had a measurable response to pumping. GS-09, the farthest southwest MA well from the pumping well (2,222 feet), did have a measurable response to pumping (Figure 6). At GS-09 there is a significant ambient (not induced from pumping) upward gradient between the shallow aquifer and both of the deeper aquifers. The upward gradient might be indicative of a confined or semi-confined system. This upward gradient from MA to SA was observed in most of the nested wells between the pumping well and GS-09. In general, confined systems are more responsive to pumping and at greater distances from the pumping well than unconfined systems.

Wells installed in the shallow aquifer were much less responsive to pumping than were the middle-aquifer wells; only six of the 30 wells monitored in the shallow aquifer had a measurable response (Table 2). Two paired shallow alluvial wells (figure 5), GS-32S (SA) and GS-32D (SA), located 2,100 feet from the pumping well (where a measured response to pumping in the MA wells were detected), showed no response to pumping. In paired SA-MA wells located closer to the pumping well, the magnitude of the water-level declines in the shallow aquifer wells were less than for wells installed in the middle aquifer (Figure 4). The response also appeared to be dependent on whether the observation well was up gradient or down gradient from the pumping well. Down gradient from the pumping well the furthest response was observed in shallow well MSD-01A, which was 566 feet from the pumping well. The responses in the shallow wells less than 600 feet from the pumping well may be explained by a leaky confining layer between the shallow and middle aquifers. Up gradient from the pumping well there were three shallow wells between 1,000 and 1,600 feet from the pumping well that had measurable responses to pumping. These up-gradient wells (> 600 feet from the pumping well) were in areas where there was a significant downward gradient from the shallow aquifer to the deeper aquifer (Figure 7) and may represent areas where the low permeability layer between the shallow and middle aquifer is discontinuous.

Water levels in all four wells installed in the deeper aquifer responded to pumping with the furthest well being 2,220 feet from the pumping well (Table 2). Although the responses in the deeper wells were not as great as the responses in the middle-aquifer wells in nested well sets, the fact that all the wells showed a response indicates that there a greater connection between the middle and deeper aquifers than between middle and shallow aquifers. Water levels in the one bedrock well (Well F) did not show a response to pumping, but this well was also located 2,772 feet from the pumping well, which was outside the range of responses observed even for middle-aquifer wells.

Water-level responses in wells near the pumping well responded rapidly to pumping rates. Within one hour of the pump being shut off, 95 percent recovery was observed in both the pumping well, and well AMW-01D (Figure 8). Some wells completed in the gravel layer did not fully recover during the measurement period after the pumping test. Well GS-41D (figure 7) recovered only 60 percent and well GS-42D (figure 4) recovered

68 percent after 72 hours of pump shut-off. There are two likely explanations for this incomplete recovery. Wells GS-41D and GS-42D are located near the groundwater divide (Tucci, 2010) and the aquifer in this area may have been temporarily depleted from the pumping. Another, more likely explanation is that the aquifer test was conducted during seasonal decline in groundwater levels, when observed water-levels in the Summit Valley decrease an average of 0.1feet. per month. Well GS-41D was within 0.06 feet. of 100 percent recovery, and well GS-42D was within 0.11 feet. of full recovery.

Table 2. Summary of the maximum water-level drawdowns during pumping at all groundwater monitoring sites. Sites are listed with respect to aquifer completion and distance to the pumping well.

Well	Aquifer*	Distance from Pumping Well (Feet)	Max Drawdown (Feet)**		Well	Aquifer*	Distance from Pumping Well (Feet)	Max Drawdown (Feet)**
AMW-01B* **	MA	0	19.72		**GS-09-03**	SA	1,487	NR
AMW-01D	MA	31	4.31		**AMC-12**	SA	1,547	0.15
GS-42D	MA	503	0.87		**GS-09-02**	SA	1,586	NR
MSD-01B	MA	563	1.01		**GS-44S**	SA	1,638	NR
BPS07-11B	MA	679	0.81		**AMW-08**	SA	1,840	NR
MSD-02B	MA	1,021	0.26		**GS-30S**	SA	2,107	NR
GS-41D	MA	1,096	0.26		**GS-32D**	SA	2,132	NR
PW-01	MA	1,226	0.1		**GS-32S**	SA	2,135	NR
GS-44D	MA	1,660	0.14		**AMW-09**	SA	2,160	NR
MSD-04	MA	1,682	0.1		**GS-11**	SA	2,226	NR
MSD-03	MA	1,733	0.11		**GS-40**	SA	2,290	NR
GS-30D	MA	2,105	0.03		**MF-08**	SA	2,525	NR
MSD-05	MA	2,142	0.05		**BMF-05-01**	SA	2,590	NR
GS-09	MA	2,222	0.06		**AMW-20**	SA	2,768	NR
GS-46D	MA	2,829	NR		**GS-46S**	SA	2,847	NR
AMC-06	SA	3,525	NR		**AMC-23**	SA	3,446	NR
AMW-01A	SA	10	0.77		**AMC-24B**	SA	3,700	NR
GS-42S	SA	505	0.34		**AMC-24**	SA	3,704	NR
MSD-01A	SA	566	0.24		**MF-01**	SA	5,447	NR
BPS07-11A	SA	676	NR		**AMC-08**	SA	5,925	NR
MSD-02A	SA	1,022	NR		**Whittier School**	SA	7,963	NR
GS-41S	SA	1,077	0.15		**AMW-01C**	DA	7	1.33
MF-07	SA	1,162	NR		**MSD-01C**	DA	560	0.64
GS-10B	SA	1,198	0.08		**GS-10A**	DA	1,197	0.37
GS-09-01	SA	1,324	NR		**GS-08**	DA	2,220	0.05
GS-45	SA	1,380	NR		**Well F**	B	2,772	NR

*Aquifer abbreviations: SA (shallow alluvial, water-table aquifer), MA (middle alluvial, gravel layer), DA (deep alluvial), B (bedrock)
**NR – no response to pumping
***Pumping well

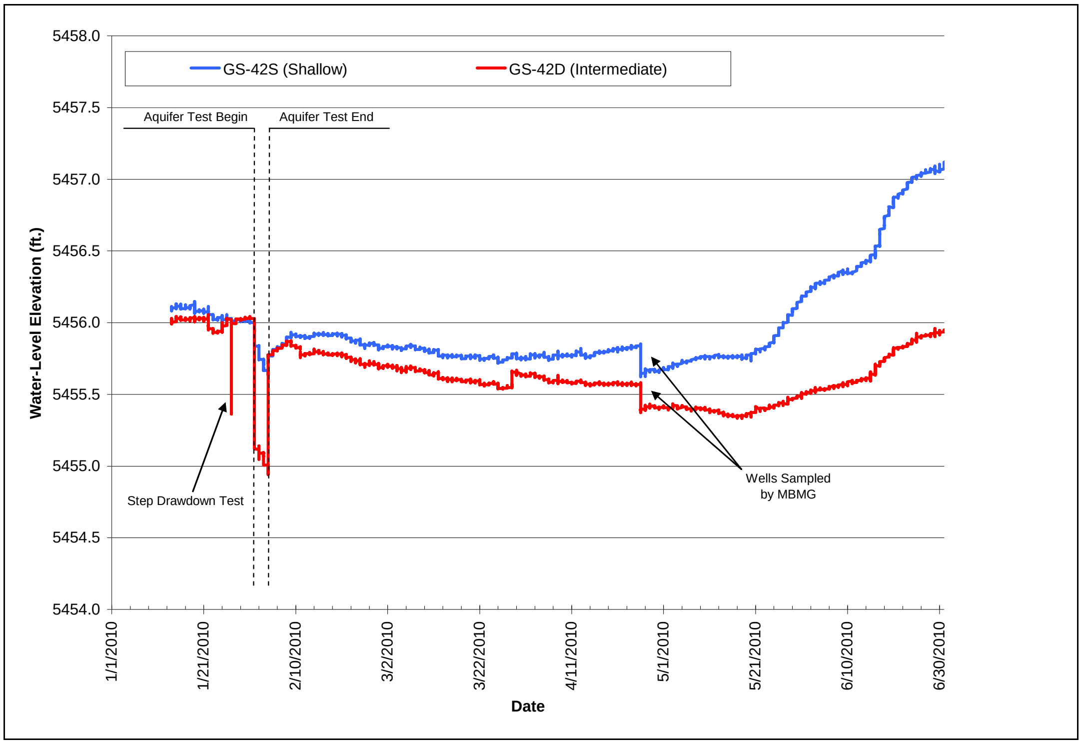

Figure 4. Hydrographs of wells GS-42S and GS-42D in the Parrot plume area near the pumping well before, during and after pumping. Well located 505 feet from pumping well.

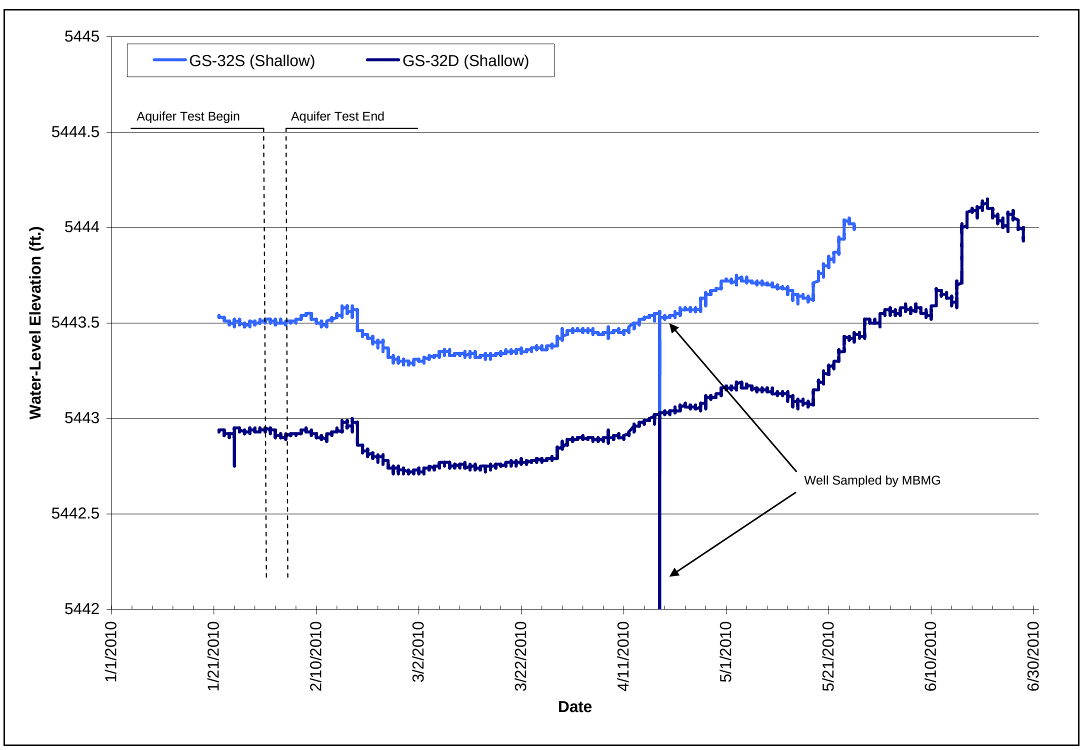

Figure 5. Hydrographs of shallow alluvial wells GS-32S and GS-32D before, during and after pumping. Wells located roughly 2,100 feet from pumping well.

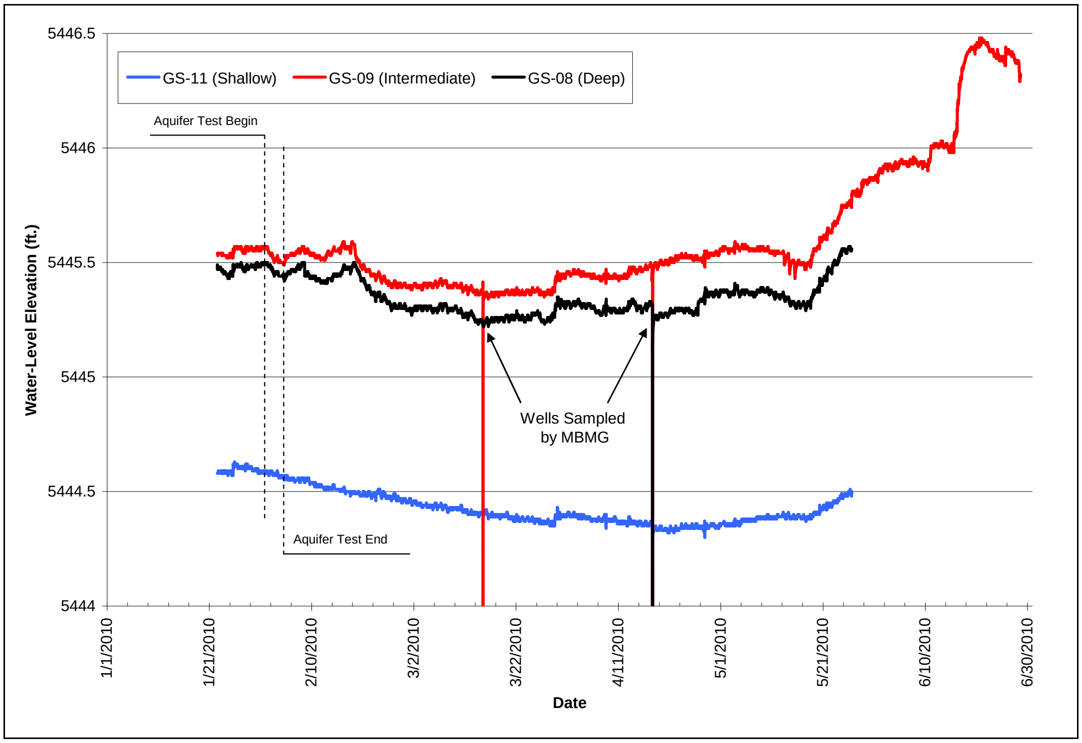

Figure 6. Hydrographs of paired wells GS-11, GS-09, and GS-08 before, during and after pumping. Wells located roughly 1,300 feet from pumping well.

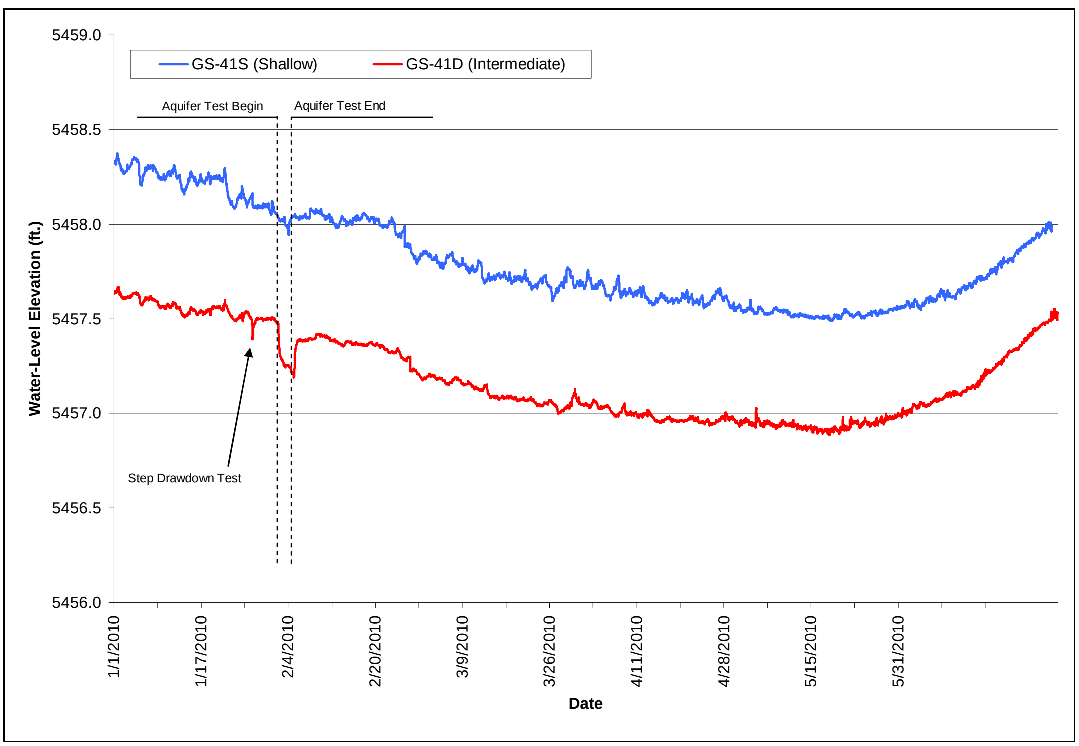

Figure 7. Hydrographs of paired wells about 1,000 feet up gradient of the pumping well in the Parrot plume.

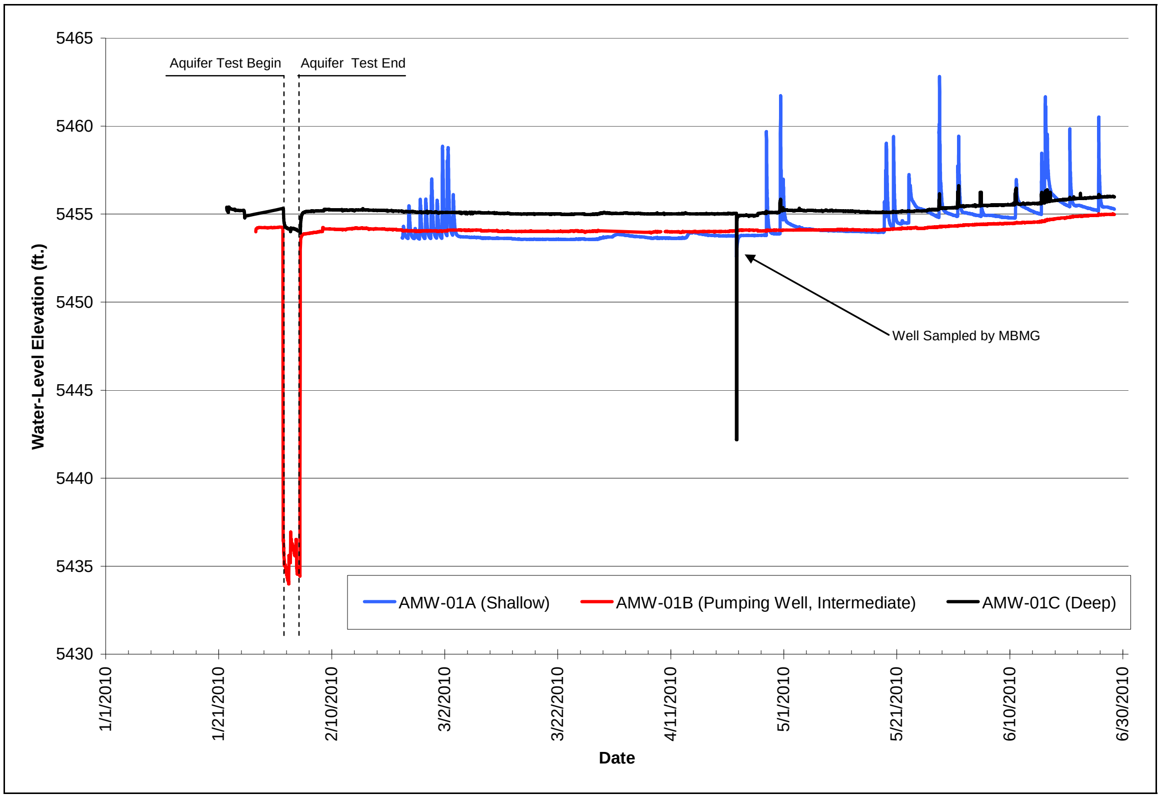

Figure 8. Hydrographs of the pumping well and paired wells near pumping well. Wells located at a distance of about 30 feet from pumping well.

Hydraulic Parameter Estimation

Three issues were encountered during pumping, which may have affected drawdown curves in the observation wells are explained below:

1) The method of filling the tankers, where effluent entered the tankers from the bottom of the tanker resulted in constantly changing head conditions for the pump and caused small fluctuations in flow rates during pumping.
2) Two shutoff valves were installed on the discharge line so that flow could be transferred between two tanker trucks. During transition from one tanker to the other, both valves were accidentally shut off at the same time, and discharge from the well ceased for approximately 30-45 seconds.
3) Corrosion to the galvanized steel used in the construction of the discharge line led to a temporary shutdown of the pumping test on 2-February-2010 at 16:44:00 hrs. The corrosion was caused by the low pH, high electrical conductivity, and high concentrations of dissolved copper (80,000 ug/L) which dissolved the iron of the pipe resulted in a discharge line failure. As a result, flow from the pumping well was terminated for approximately 17 minutes so that repairs could be made.

Figure 9 shows the corrosion caused by discharge water from the pumping well. Although variable discharge rates are not ideal for the aquifer test analysis, AQTESOLV is capable of incorporating the variable discharge rates as part of the three solution methods chosen to estimate aquifer parameters for this evaluation.

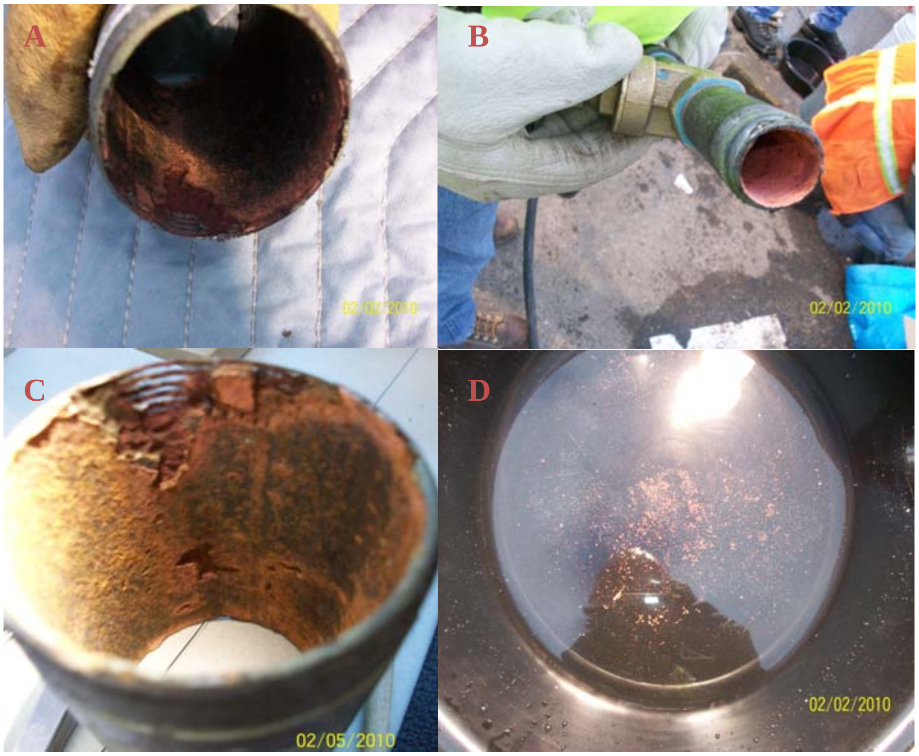

Figure 9. Corrosion in galvanized steel pipe used in the discharge line caused by the discharge water. Note: copper plating from pumped groundwater (pictures A and B) onto galvanized pipe, corrosion of galvanized steel (picture C) in discharge line, and elemental copper flakes in discharge bucket (picture D).

The AQTESOLV output typically includes transmissivity (T), storativity (S), and possibly other variables depending on the solution method. Storativity, transmissivity, and hydraulic conductivity (K) were the aquifer properties of primary concern for this evaluation. Hydraulic conductivity was obtained by dividing the transmissivity by the aquifer thickness (b). At most locations the aquifer thickness ranged from 10 to 15 feet and for the purposes of the calculating a K, the aquifer thickness was assumed to be 15 feet throughout the aquifer. This aquifer thickness was chosen because several good lithologic logs describe the aquifer as 15 feet thick, and a thicker aquifer results in K estimates that are lower.

The three solutions used to estimate aquifer parameters generally agreed with one another for observations from a single well and the estimates from the three solutions were averaged to produce an estimate from the drawdown at each well (Table 3). Hydraulic conductivity (K) values ranged from 120 – 1000 feet/day (Table 3), which is a typical K for coarse sand to gravel aquifer (Freeze and Cherry, 1979). The storativity (S) estimates (Table 3) are also in the range typical of a confined aquifer (< 0.005; Freeze and Cherry, 1979). An example of the curve matching produced by AQTESOLV for MSD-1B is presented in Figure 10, and the rest of the curve matches are presented in Appendix B.

Although 16 wells completed within the middle alluvial aquifer were monitored during the aquifer test, only six wells were deemed suitable for AQTESOLV analysis. In most wells the drawdown from pumping was imprinted on background water-level trends.

Where the background trends and the change in water-levels from pumping were of similar magnitude, the resulting transmissivities were unreasonable. In order to use these data for the aquifer test analysis, it would have been necessary to manipulate the data

Table 3. Summary of transmissivity (T), hydraulic conductivity (K), and storativity values for well completed in the gravel layer.

T, K, and S Values For Wells Completed in the Gravel Layer					
Well	**Distance from Pump Well**	**Method**	**T feet^2/day**	**K feet/day**	**S**
GS-41D	1096	Hantush w/ aquifer storage	9,560	637	1.94E-06
	1096	Cooley-Case	9,560	637	1.94E-06
	1096	Neuman-Witherspoon	9,560	637	1.94E-06
		AVERAGE	**9,560**	**637**	**1.94E-06**
GS-42D	503	Hantush w/ aquifer storage	7,620	508	2.53E-04
	503	Cooley-Case	6,500	433	3.53E-05
	503	Neuman-Witherspoon	7,620	508	2.86E-04
		AVERAGE	**7,250**	**483**	**1.92E-04**
AMW-1D	31	Hantush w/ aquifer storage	1,850	124	1.07E-03
	31	Cooley-Case	1,860	124	1.10E-03
	31	Neuman-Witherspoon	1,670	111	1.07E-03
		AVERAGE	**1,790**	**120**	**1.08E-03**
MSD-1B	563	Hantush w/ aquifer storage	9,030	602	1.31E-04
	563	Cooley-Case	7,680	512	1.10E-04
	563	Neuman-Witherspoon	**4,800**	320	**2.94E-04**
		AVERAGE	**7,170**	**478**	**1.79E-04**
MSD-2B	1021	Hantush w/ aquifer storage	15,500	1,000	7.62E-04
	1021	Cooley-Case	15,500	1,000	7.62E-04
	1021	Neuman-Witherspoon	15,500	1,000	7.61E-04
		AVERAGE	**15,500**	**1,000**	**7.62E-04**
MSD-3	1733	Hantush w/ aquifer storage	13,500	902	5.52E-04
	1733	Cooley-Case	13,500	902	5.52E-04
	1733	Neuman-Witherspoon	13,500	902	5.52E-04
		AVERAGE	**13,500**	**902**	**5.52E-04**

to remove the background water-level trends. Instead of manipulating the data, only wells with a large pumping response relative to the background water-level trends were used for the AQTESOLV analysis (Table 3). Additionally, the pumping well was not used for the AQTESOLV analysis due to well efficiency issues and well BPS07-11B was not used for the AQTESOLV analysis because there was not a complete water-level record for BPS07-11B. Two middle alluvial wells had no discernable response to pumping.

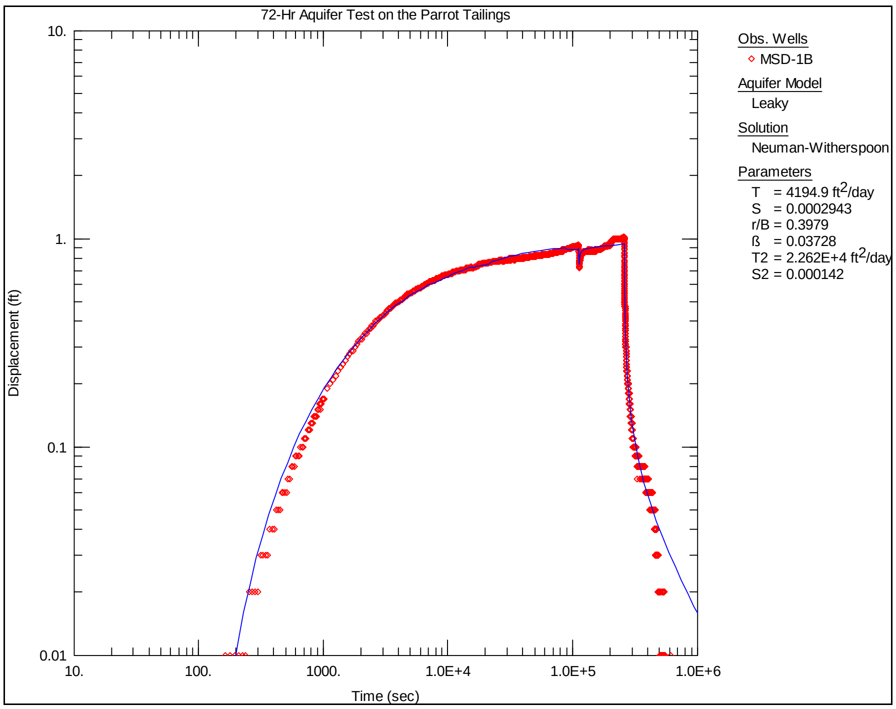

Figure 10. Drawdown curve aquifer test analysis of well MSD-1B.

Distance Drawdown Method

Since data were available from more than three monitoring wells, the distance-drawdown method was also used in conjunction with the Hantush-Jacob method for a partially penetrating pumping well in a leaky confined aquifer (AQTESOLV; Duffield, 2007). Instead of using the drawdown data over time from an individual well, the distance-drawdown method uses drawdown data at a specific time from multiple wells to calculate transmissivity (T) and storativity (S). Since the calculation of T and S is based on multiple wells, the distance-drawdown method can be a more robust method for estimating transmissivity and storativity than estimates from single wells. The wells used in this analysis were AMW-1D, MSD-1B, GS-41D, GS-42D, MSD-2B, and MSD-3. In addition to T and S, the model also calculated the leakage parameter (r/B) and the hydraulic conductivity anisotropy ratio (Kz/Kr). The distance-drawdown fit was obtained for two times during pumping. The first time fit was for the data at 112,000 seconds, which was just prior to the first interruption of flow. The second time fit was for 260,200 seconds, which was just prior to the termination of pumping. These times were chosen because the first time was just prior to the first major interruption and the second time was near the end of pumping when the greatest stress had been put on the system. Both analyses yielded the same results with estimates of 2,200 $feet^2$/day for transmissivity (T) and 7.00 E-05 for storage (Table 4).

Table 4. Results from the distance-drawdown approach using the Hantush-Jacob method for a partially penetrating pumping well in a leaky confined aquifer

Time (sec)	T ($feet^2$/day)	S	K (feet/day)
112,000	2,200	7.00E-05	150
260,200	2,200	7.00E-05	150

The Hantush-Jacob method for a partially penetrating pumping well in a leaky confined aquifer (Duffield, 2007) was selected for the distance-drawdown analysis for several reasons. Based on the drawdown data, the intermediate gravel aquifer appeared to be a leaky-confined aquifer that was hydrologically connected to both the near surface aquifer and the deeper aquifer. The Hantush-Jacob method was the simplest method with the fewest assumptions of the leaky confined methods available in the AQTESOLV program, and since the data could be fit to the model, more complex modeling was not necessary. Also, a straight-line solution was available in the AQTESOLV program for the Hantush-Jacob method. The assumptions associated with the Hantush-Jacob method are as follows;

- aquifer has infinite areal extent
- aquifer is homogeneous and of uniform thickness
- pumping well is fully or partially penetrating
- flow to pumping well is horizontal when pumping well is fully penetrating
- aquifer is leaky confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of pumping well is very small so that storage in the well can be neglected
- confining bed(s) has infinite areal extent, uniform vertical hydraulic conductivity and uniform thickness
- confining bed(s) is overlain or underlain by an infinite constant-head plane source
- flow is vertical in the aquitard(s).

One assumption specific to the Hantush-Jacob method is that there is a constant-head source of water either below or above pumped aquifer. Flow through at least one of the confining layers is the definition of a leaky confined system, so in real-world applications this assumption is almost always violated and it becomes a matter of the degree of violation. The maximum drawdown in the upper aquifer was less than 0.8 feet, and it was assumed that this amount of head change was not significant enough to preclude the use of this method.

Pumping Well Water Quality

The following section provides water-quality results obtained from the Hach Hydrolab multiparameter monitors, as well as, selected elemental data from samples collected during pumping. A full list of water-quality results are presented in Appendix C.

The pH and specific conductance in the pumping well changed very little during aquifer test (Figures 11 and 12 respectively). In general, slight decreases in pH and specific conductance were observed shortly after pumping began, however all parameters stabilized after the first several hours of pumping and remained stable thereafter.

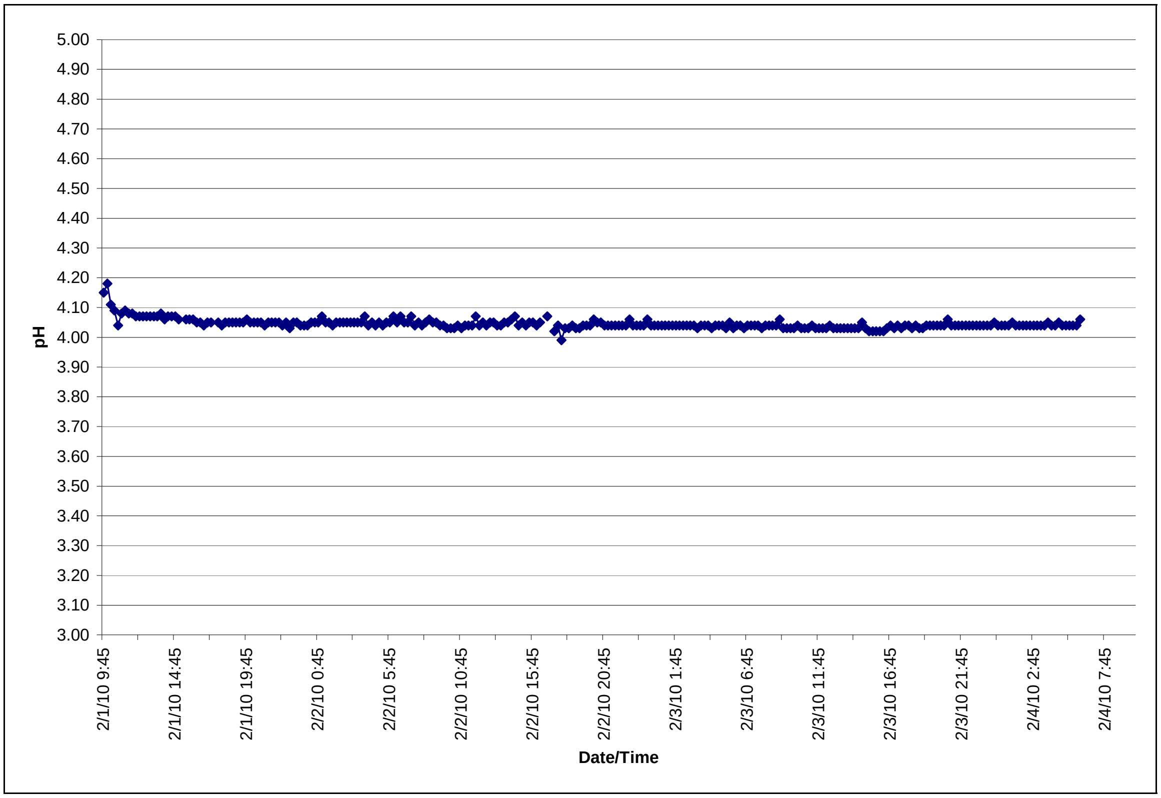

Figure 11. Time-series plot of pH in well AMW-01B (pumping well during aquifer test).

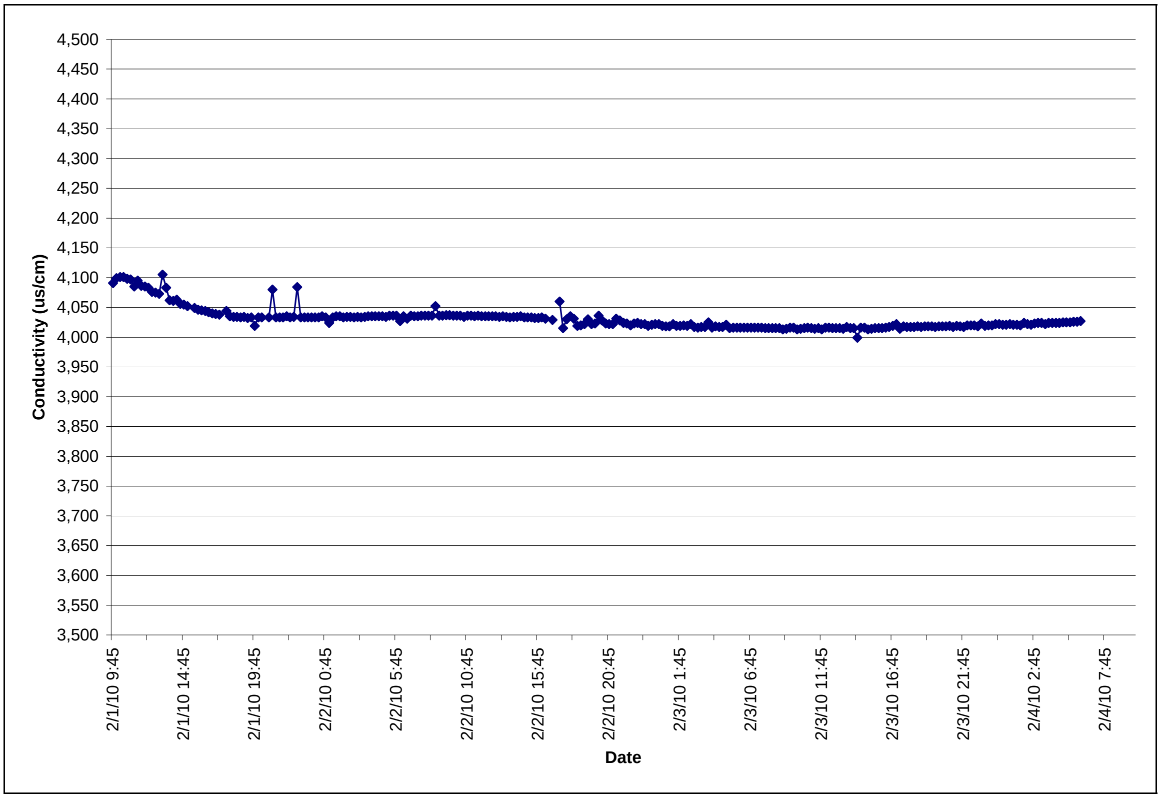

Figure 12. Time-series plot of specific conductance in well AMW-01B (pumping well) during 72-hour aquifer test.

Dissolved copper concentrations decreased approximately 10 percent within 36 hours after pumping started and then stabilized for the remainder of the aquifer test (Figure 13). Similarly, dissolved zinc concentrations decreased approximately 6 percent within 36 hours and then stabilized (Figure 14). While these decreases are within the error of the analytical method, the presence of a repeatable trend indicates that the water chemistry was changing. A changing water chemistry is supported by the dissolved iron concentrations, which show a gradual increase in the first 36 hours to approximately double the initial concentration and then increased at a greater rate after 36 hours to approximately six times the initial concentration. A possible explanation for these observations is that the pumping started to draw in water from other areas of the aquifer having different water chemistries. The gradual nature of the trends suggests a large volume of water which, in turn, suggests a large areal extent of the gravel aquifer. The most likely source of dissolved iron in the area is from the Parrot Tailings complex (Tucci, 2010).

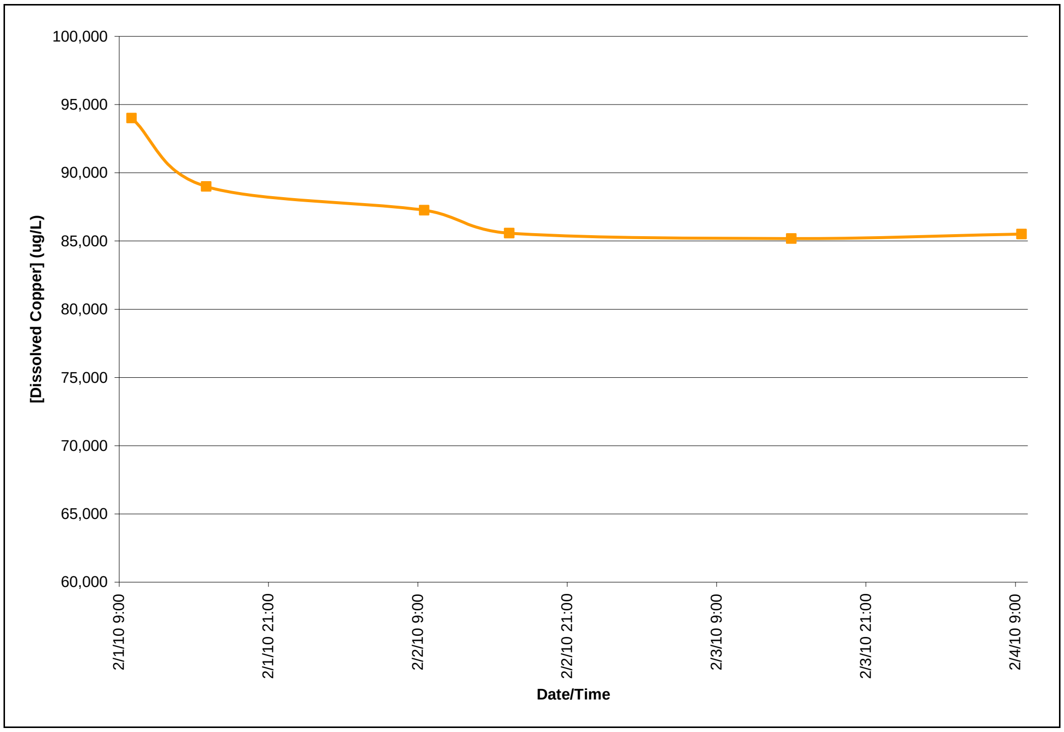

Figure 13. Dissolved copper concentrations in the pumping well during 72-hour aquifer test.

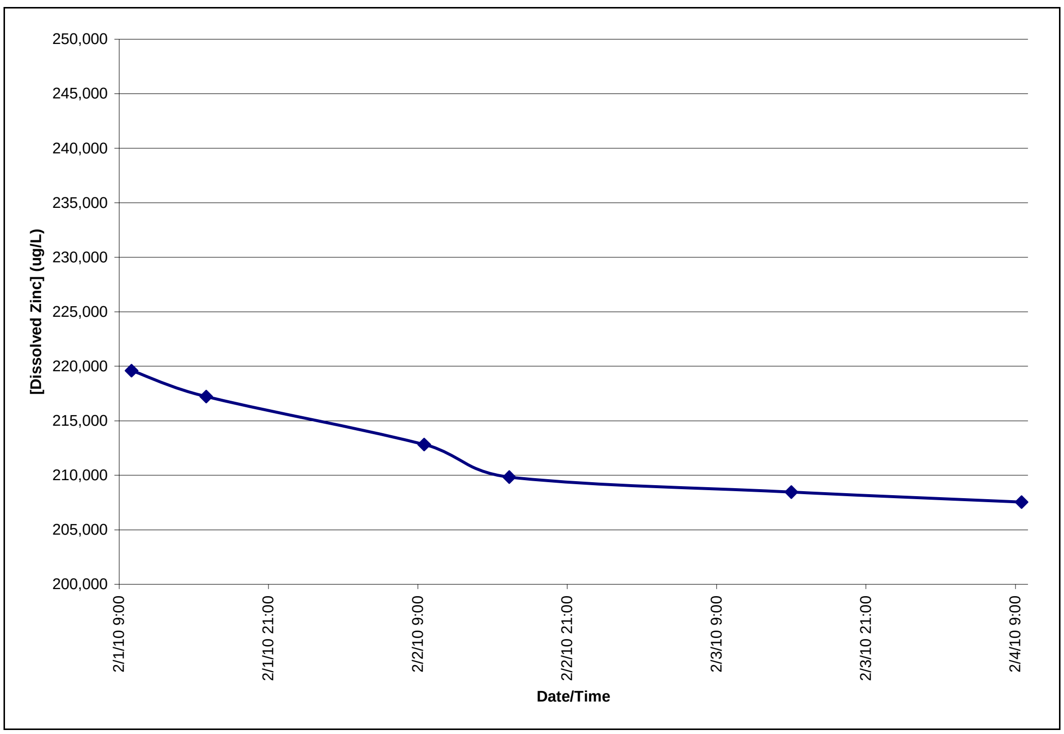

Figure 14. Dissolved zinc concentrations in the pumping well during 72-hour aquifer test.

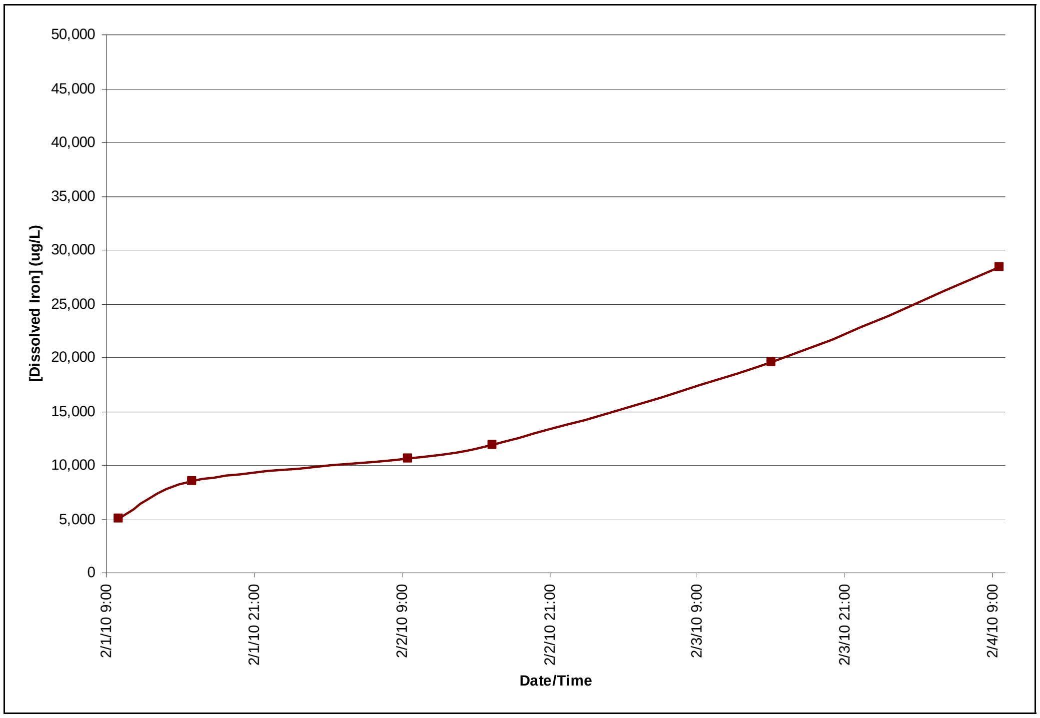

Figure 15. Dissolved iron concentrations in the pumping well during 72-hour aquifer test.

DISCUSSION

Water-level responses in wells as far away as 2,222 feet from the pumping well demonstrate that the middle alluvial aquifer is continuous and well connected. Most of the wells that intercept the middle alluvial aquifer are adjacent to the MSD and the lateral extent (north or south of the MSD) of the middle alluvial aquifer is not well defined. However, water levels in GS-44D (1660 feet southwest of the pumping well) did respond to pumping, which indicates that the middle alluvial aquifer extends at least that far south. The known northern boundary of the MA where gravel is observed in drill logs are wells AMW-08, BMF05-01, and GS-40. The down-gradient extent of the middle alluvial aquifer is also unknown with GS-09 being the furthest downgradient well to have intercepted the middle alluvial aquifer. Based on the water-level responses to pumping and the upward gradients along the MSD, it seems likely that the middle gravel aquifer is a confined to semi-confined aquifer from AMW-1 to at least GS-09. This hypothesis is supported by the presence of low quality groundwater in the middle alluvial aquifer from AMW-1 to GS-09 (Tucci, 2010). Conversely, water-level responses to pumping and downward gradients suggest that the confining layer separating the shallow alluvial aquifer and the middle alluvial aquifer is less continuous in the Parrot Complex area. Again, this hypothesis is supported by the highly contaminated groundwater observed in both shallow and middle alluvial aquifers in the Parrot Complex area (Tucci, 2010). Contaminated water entering the middle alluvial aquifer in the Parrot Complex area will likely travel to at least GS-09 before encountering an area where it might disperse to the shallow aquifer or discharge to the surface. In fact, water samples collected from wells completed in the middle alluvial aquifer throughout the MSD have degraded water quality with elevated metal concentrations that decrease down gradient from the Parrot complex (Tucci, 2010). The hydrogeologic evaluation discussed in the current study and the groundwater quality discussed in Tucci (2010) both suggest that the source of metal loading to the middle alluvial aquifer (as far away as MSD-05 and GS-09) is the tailings associated with the Parrot Complex.

The average hydraulic conductivity estimated in the current study for the middle gravel layer in the MSD area was 609 feet/day. Based on previous studies (CH^2M Hill and Chen Northern, 1990; PRP Group, 2001), EPA (2004) reported an average hydraulic conductivity of 2.5 feet/day in the upper 200 feet of the alluvium northeast of Harrison Avenue (Parrot Complex), and 15 feet/day between Harrison Avenue and Kaw Avenue (figure 1). West of Kaw, the average hydraulic conductivity reported was on the order of 45 feet/day (EPA, 2004). Table 5 compares reported values from EPA, 2004 to the results of the current study. The hydraulic conductivities estimates obtained in this report are larger than previous findings by 1 to 2 orders of magnitude.

Table 5. Comparison of hydraulic conductivities (K) between previous investigations and the current study.

	K (current study) feet/day	K (EPA, 2004) feet/day	Difference (Orders of Magnitude)
Above Harrison	120 to 640	2.5	2
Below Harrison	480 to 1000	15	1 to 2

Average linear velocities based on the estimates from this report for the aquifer above Harrison Avenue ranged from 580 to 3,100 feet per year (assuming a gradient of 0.004 and a porosity of 30 percent). For the aquifer below Harrison Avenue, the average linear velocities ranged from 2,300 to 4,800 feet per year (assuming a gradient of 0.004 and a porosity of 30 percent), compared to 80 feet per year below Harrison Avenue estimated by EPA (2004).

The average linear velocities can be used to estimate minimum travel times for contaminates coming from the Parrot Complex (Table 6) and compared to previous travel time estimates (EPA, 2004). The travel times are considered "minimum travel times" because these estimated represent travel times for water and chemical contaminants will be attenuated and/or diluted as they migrate with groundwater. The new travel-time estimates are one to three orders of magnitude less than the previous estimates, although the comparison is somewhat misleading because the previous study assumed the hydraulic properties of the shallow aquifer were similar to those of the middle gravel aquifer. Since the current analysis is for the semi-confined middle gravel aquifer, travel times between the Parrot Complex (GS-41) to GS-32 (approximately equidistant with GS-09) should be given the most weight. Based on the current analysis, water originating in the Parrot Complex area is predicted to take between 0.78 to 2.7 years to reach well GS-09.

Table 6. Approximate groundwater travel time (horizontal travel times) in the Upper Metro Storm Drain.

Flow Path	From	To	Distance (Feet)	Travel Time (this study)	Travel Time (EPA, 2004)
County Shops to Civic Center	GS-41	AMW-1	1,050	0.34 – 1.8 years	144 years
Harrison Ave. To Casey St.	AMW-1	MF-07	1,330	0.27 – 0.57 years	18 Years
Casey St. Through upper half of North Side Tails	MF-07	GS-32	840	0.17 – 0.36 years	3 years
Through lower half of North Side Tails	GS-32	MF-08	770	0.16 – 0.33 years	46 years
Through North Side Tailings	MF-07	MF-08	1,610	0.33 – 0.69 years	49 years
County Shops though upper North Side Tails	GS-41	GS-32	3,220	0.78 – 2.7 years	165 years
Through Diggings East Tails	GS-11	MF-08	840	0.17 – 0.36 years	15 years

*Travel time calculated by dividing distance of travel by average linear velocity.
*Average linear velocities used in calculations are described in paragraph above.
*For distances that cross Harrison Avenue, the travel times above and below Harrison Avenue were calculated separately and added together.

ACKNOWLEDGEMENTS

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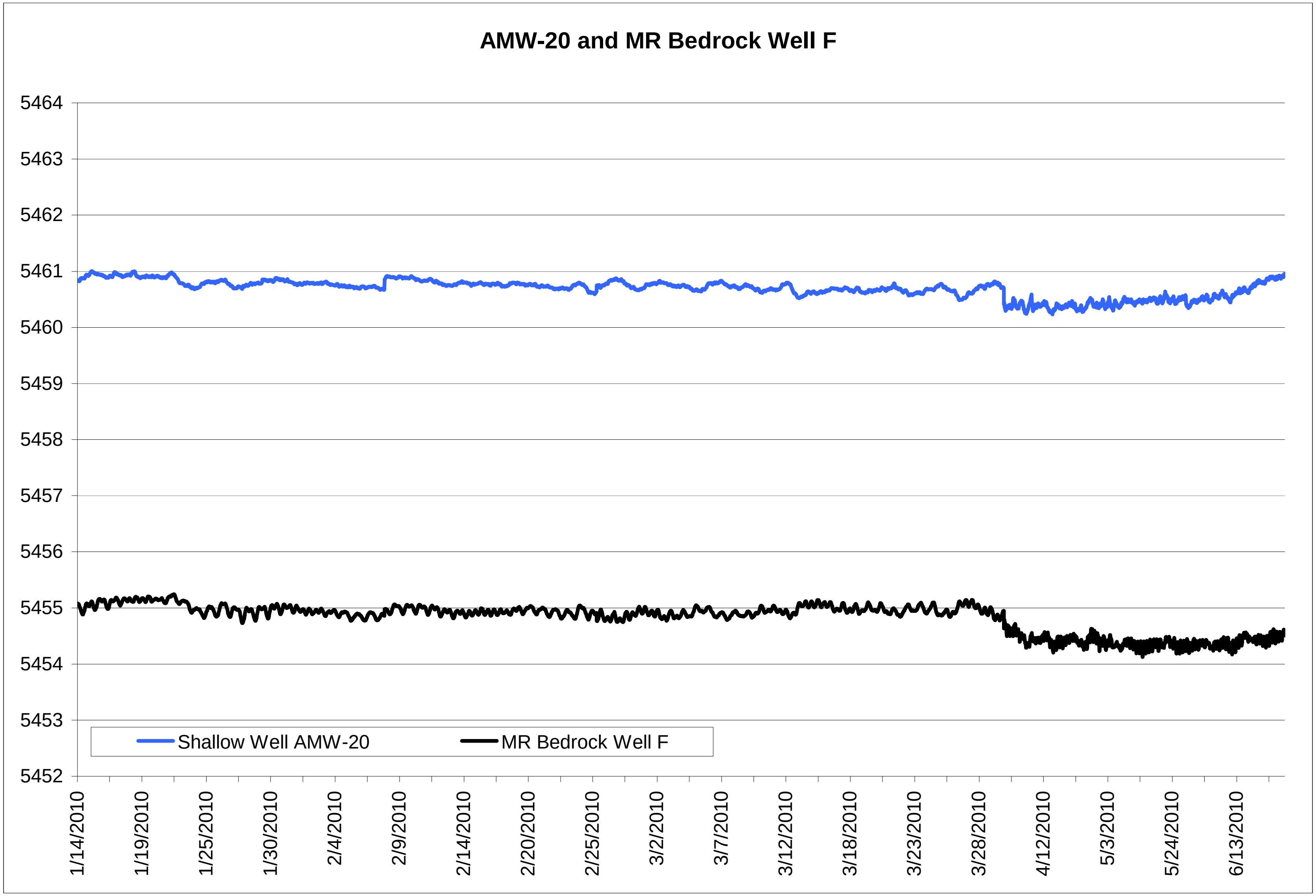
APPENDIX A Groundwater Hydrographs


AMW-20 and MR Bedrock Well F
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5452
Shallow Well AMW-20
MR Bedrock Well F
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1/19/2010
1/25/2010
1/30/2010
2/4/2010
2/9/2010
2/14/2010
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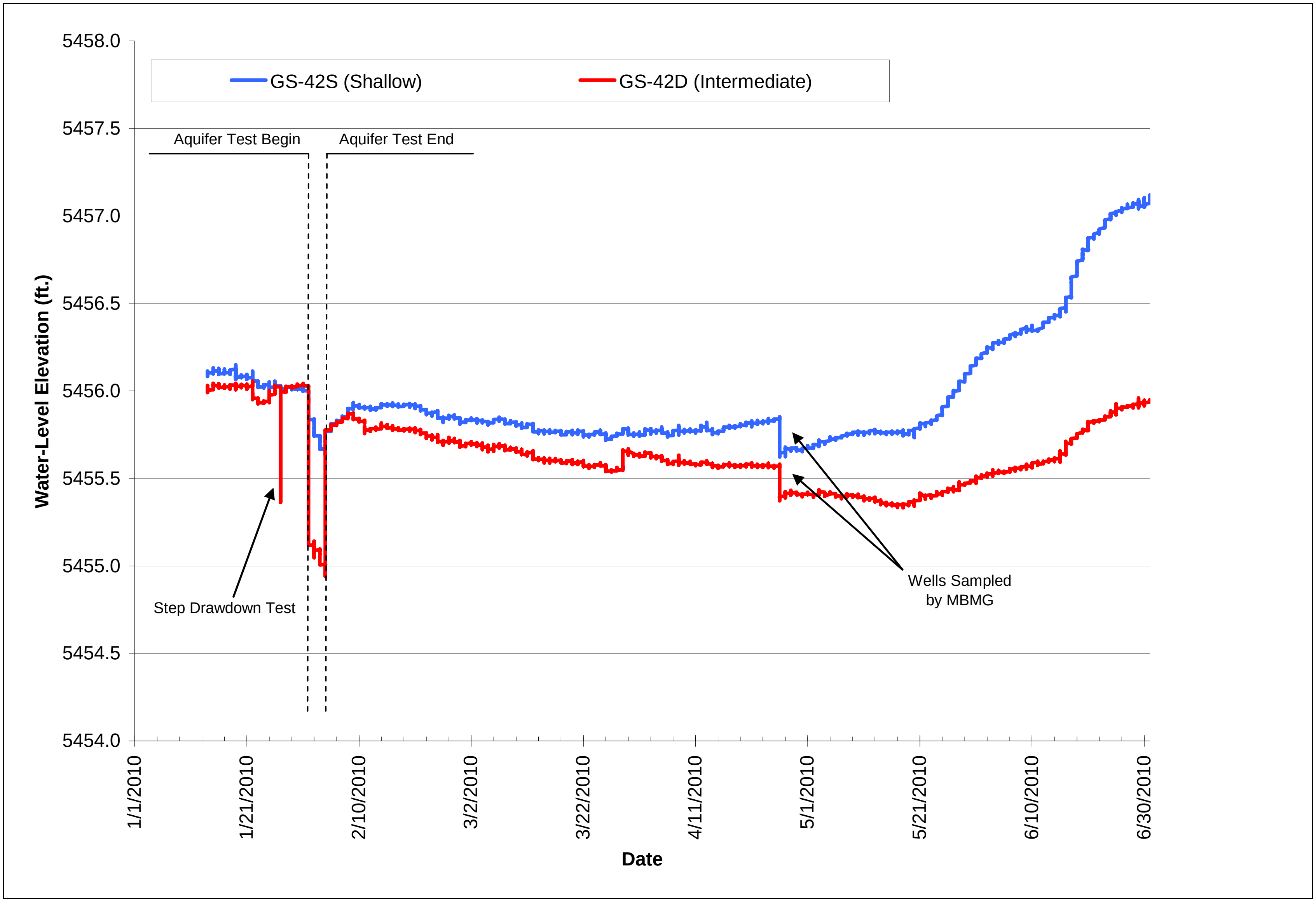

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GS-42S (Shallow)
GS-42D (Intermediate)
Aquifer Test Begin
Aquifer Test End
Step Drawdown Test
Wells Sampled by MBMG
Water-Level Elevation (ft.)
1/1/2010
1/21/2010
2/10/2010
3/2/2010
3/22/2010
4/11/2010
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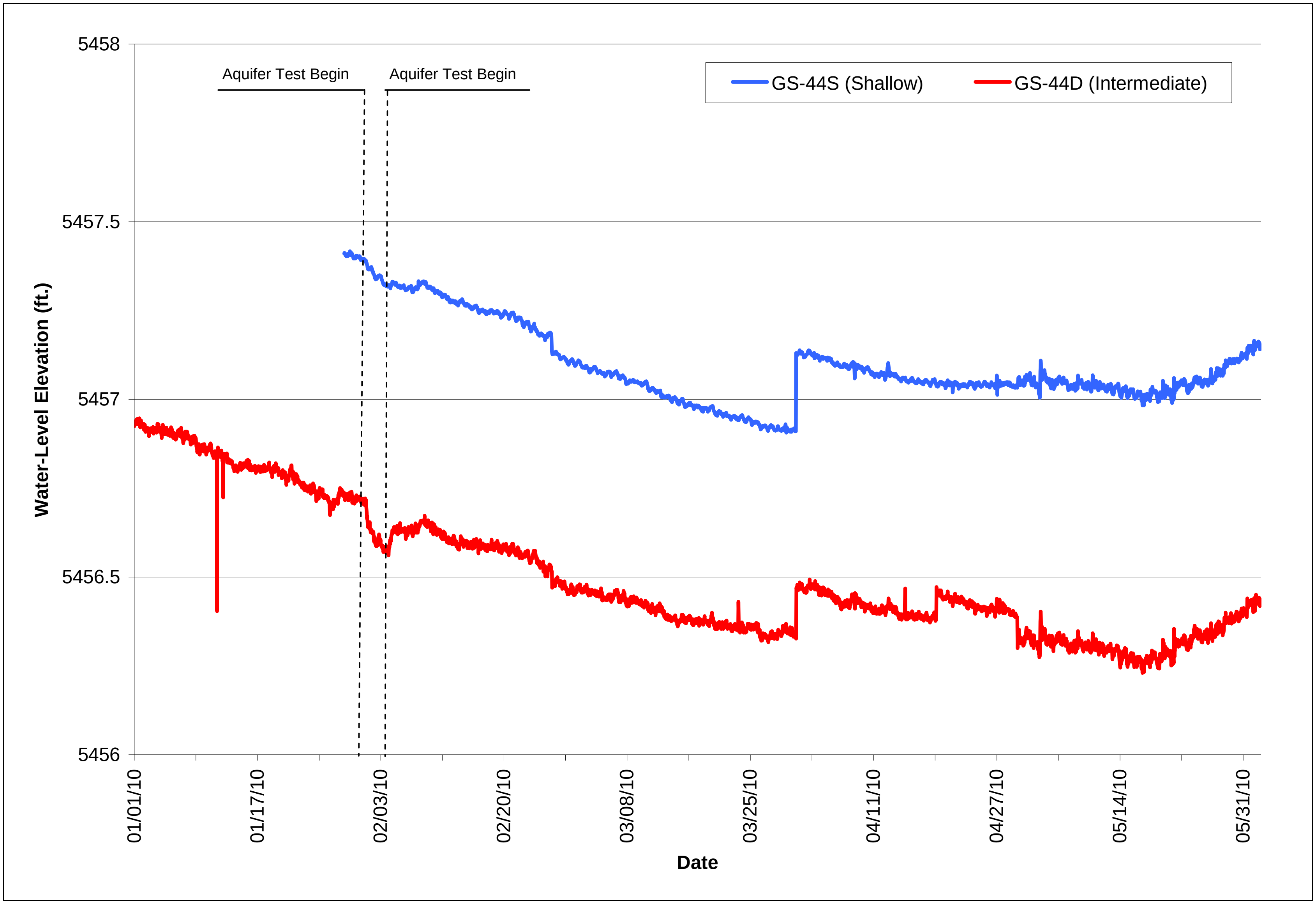
6/10/2010
6/30/2010
Date



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Water-Level Elevation (ft.)
Aquifer Test Begin
Aquifer Test Begin
GS-44S (Shallow)
GS-44D (Intermediate)
01/01/10
01/17/10
02/03/10
02/20/10
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03/25/10
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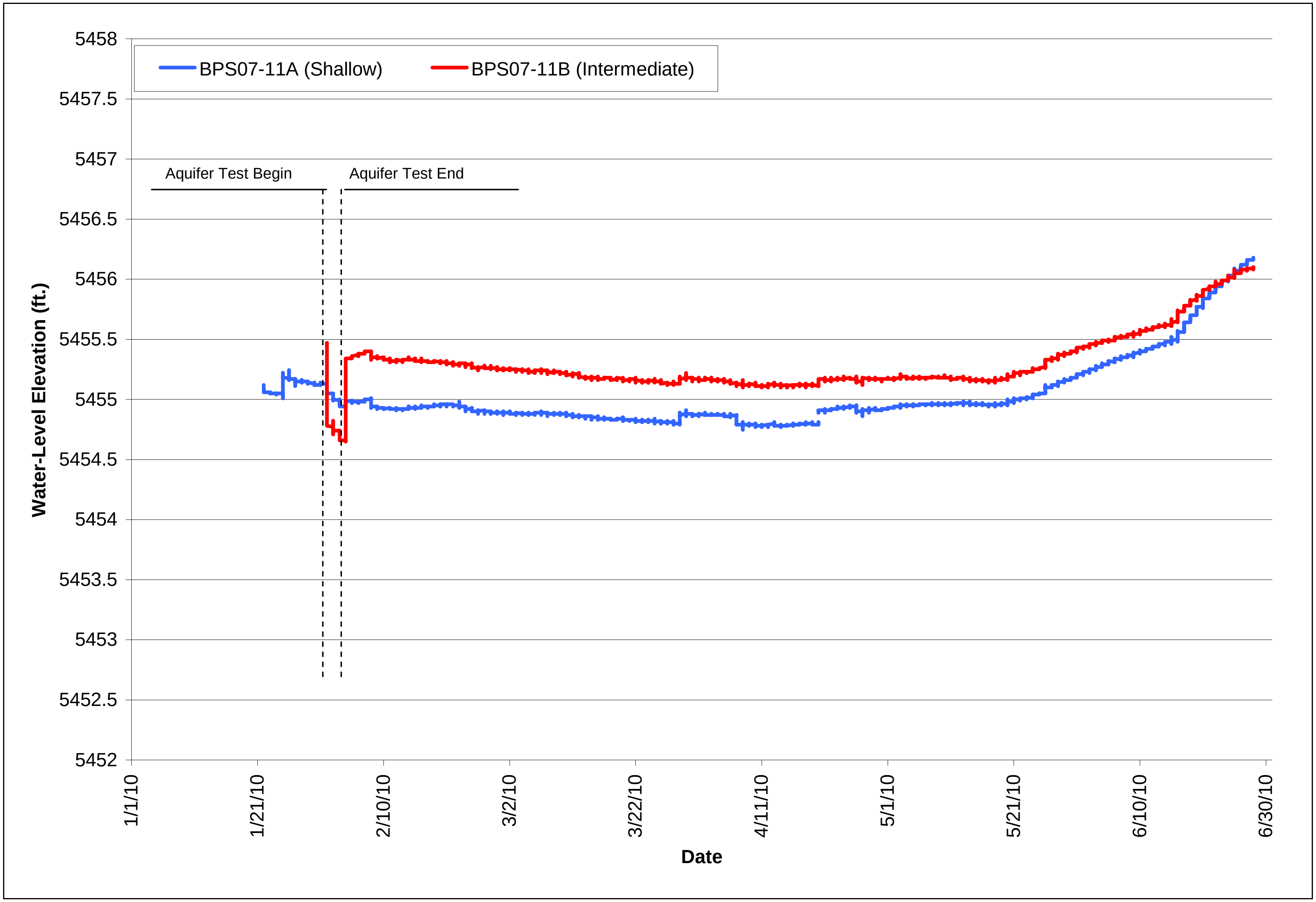
05/14/10
05/31/10
Date



BPS07-11A (Shallow)
BPS07-11B (Intermediate)
Aquifer Test Begin
Aquifer Test End
Water-Level Elevation (ft.)
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5453
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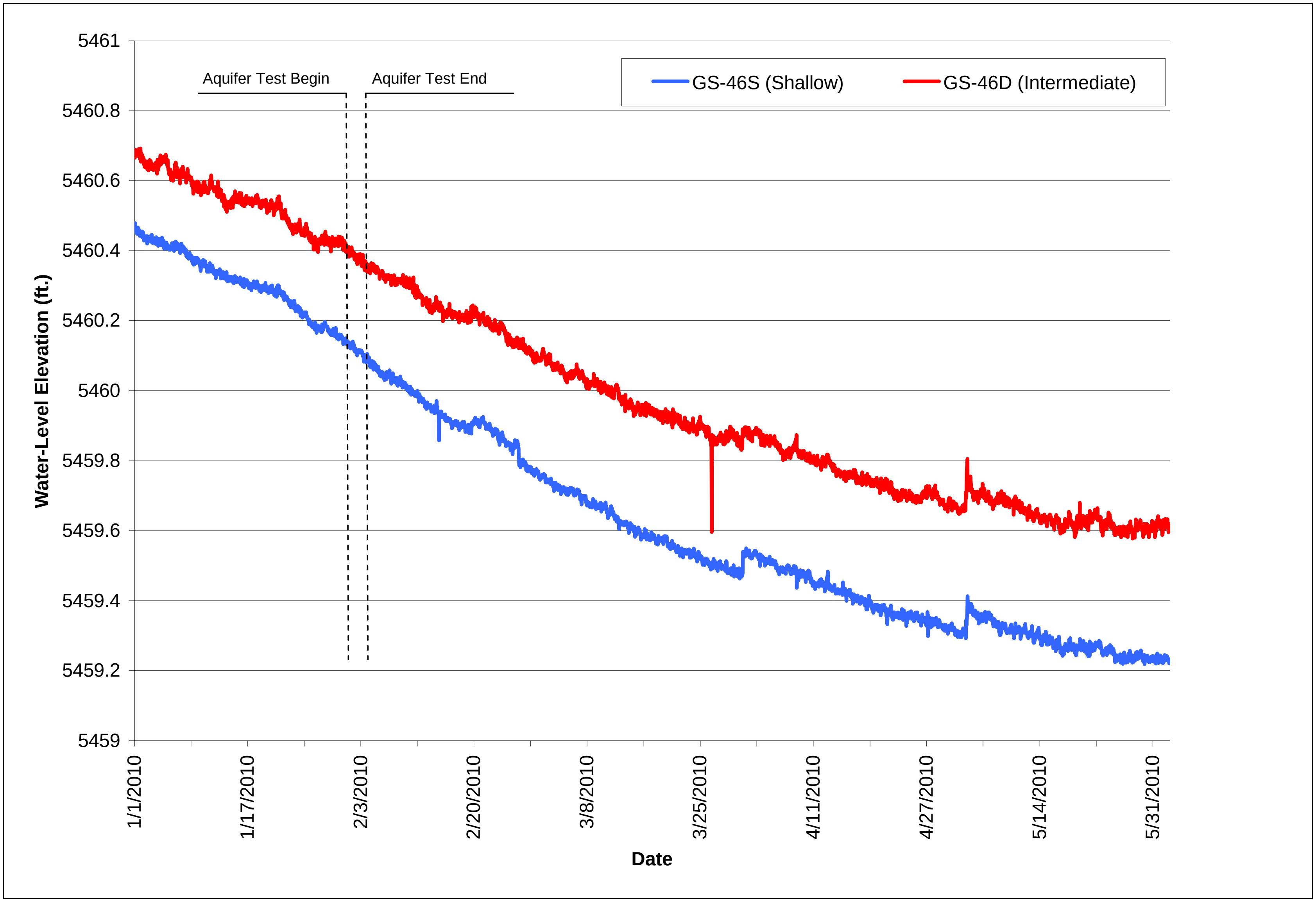
Date



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5459.2
5459
Water-Level Elevation (ft.)
Aquifer Test Begin
Aquifer Test End
GS-46S (Shallow)
GS-46D (Intermediate)
1/1/2010
1/17/2010
2/3/2010
2/20/2010
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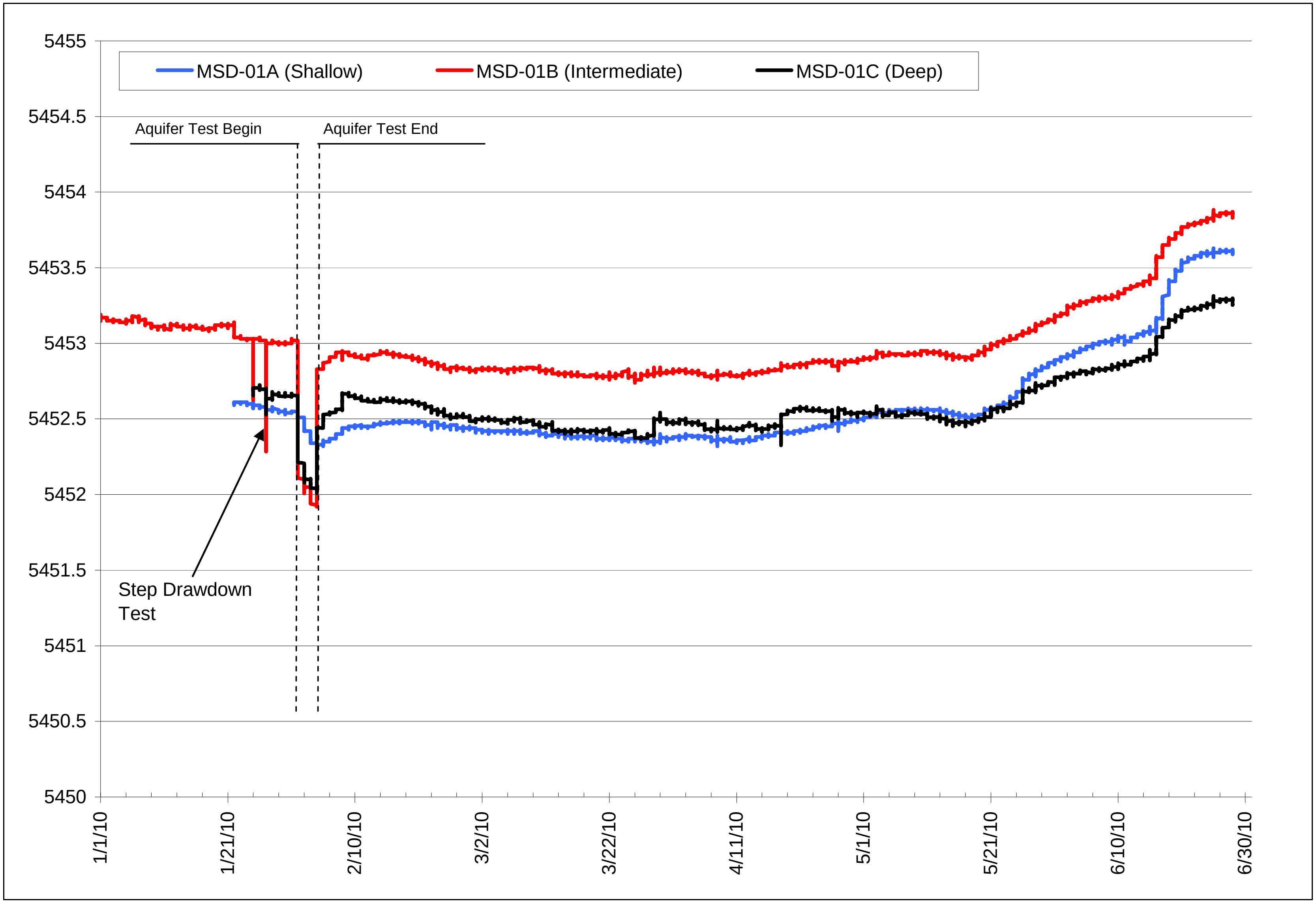
5/31/2010
Date



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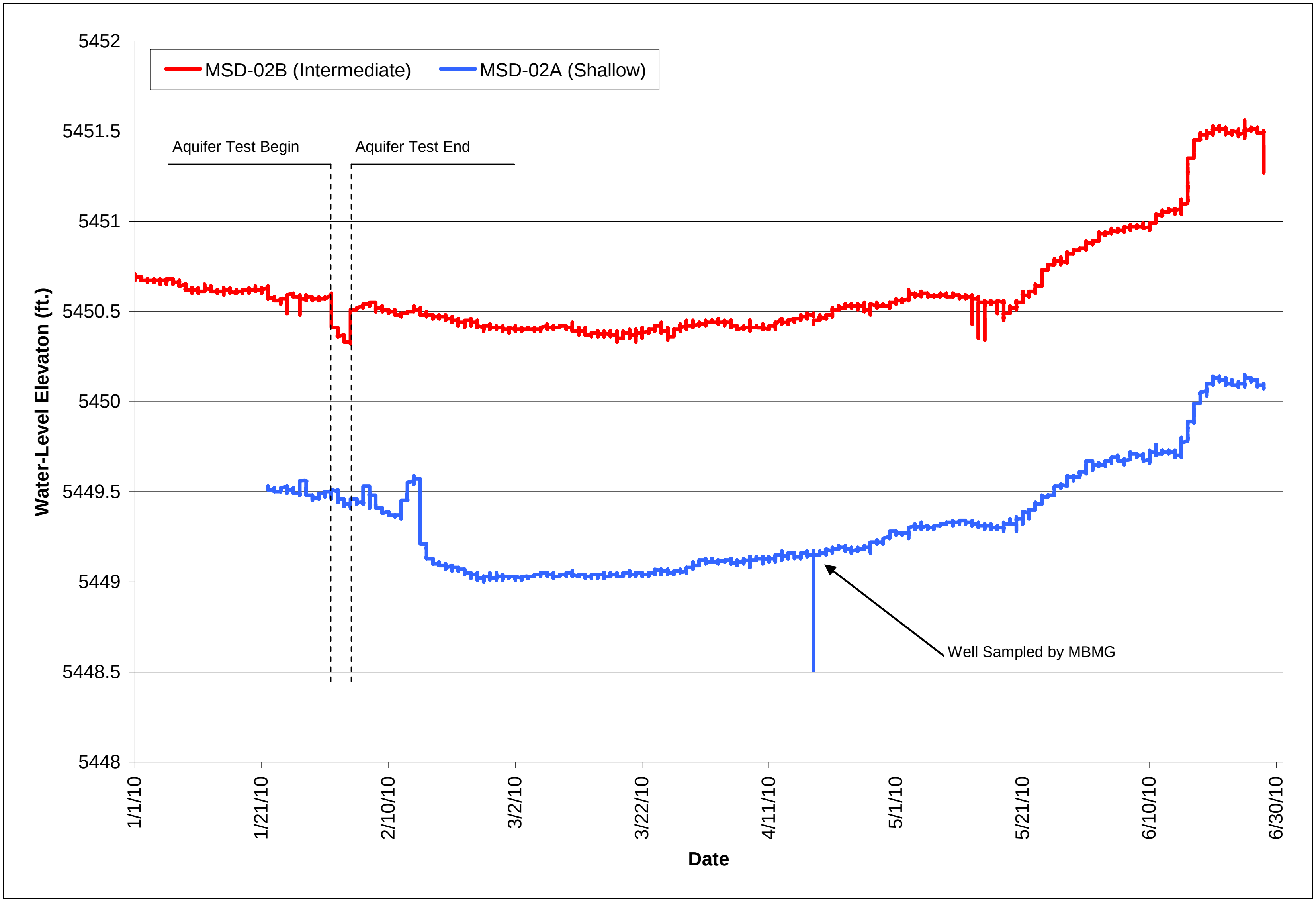
MSD-01A (Shallow)
MSD-01B (Intermediate)
MSD-01C (Deep)
Aquifer Test Begin
Aquifer Test End
Step Drawdown Test
1/1/10
1/21/10
2/10/10
3/2/10
3/22/10
4/11/10
5/1/10
5/21/10
6/10/10
6/30/10



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5449
5448.5
5448
MSD-02B (Intermediate)
MSD-02A (Shallow)
Aquifer Test Begin
Aquifer Test End
Well Sampled by MBMG
Water-Level Elevaton (ft.)
1/1/10
1/21/10
2/10/10
3/2/10
3/22/10
4/11/10
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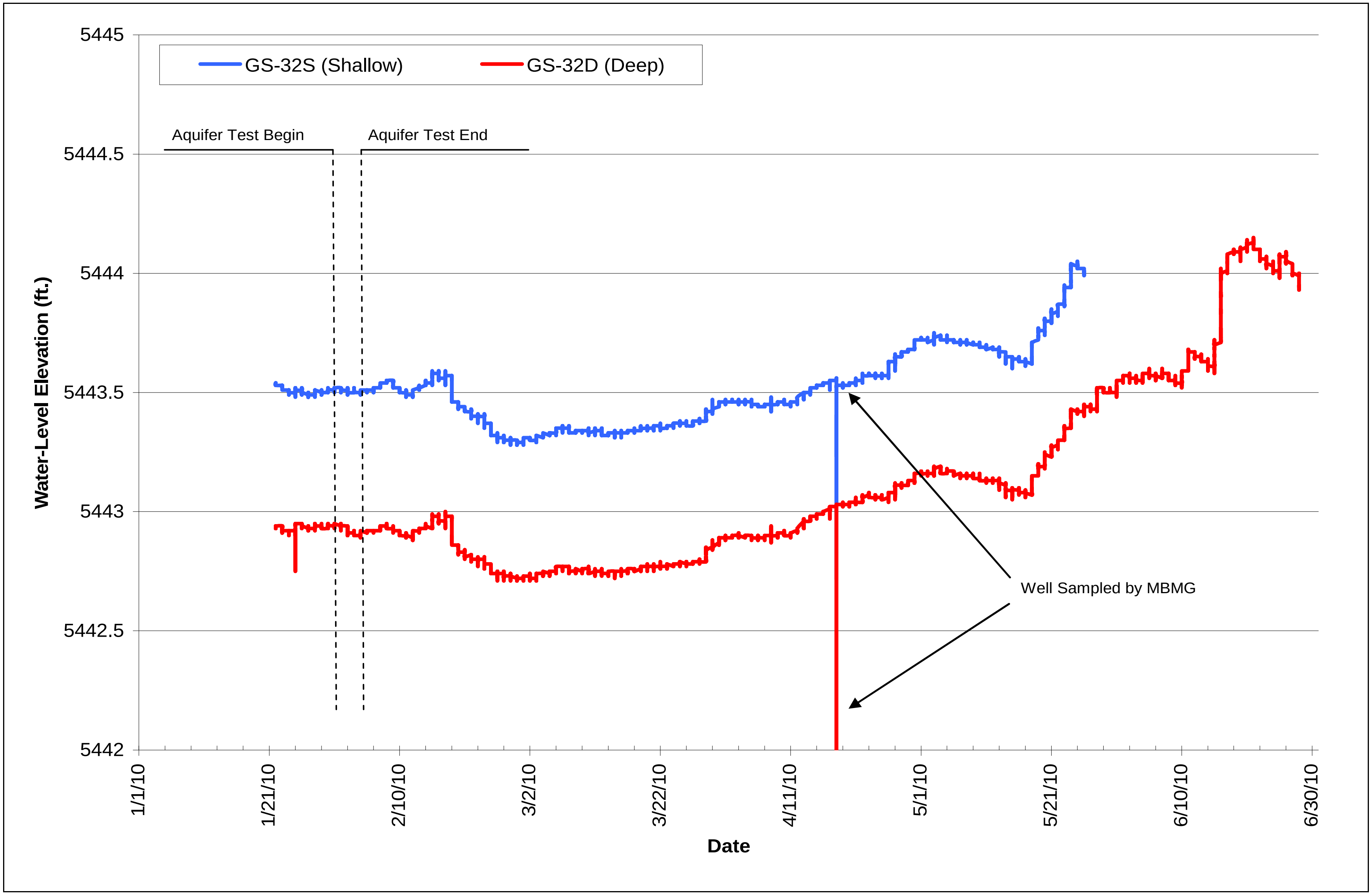
6/30/10
Date



GS-32S (Shallow)
GS-32D (Deep)
Aquifer Test Begin
Aquifer Test End
Well Sampled by MBMG
Water-Level Elevation (ft.)
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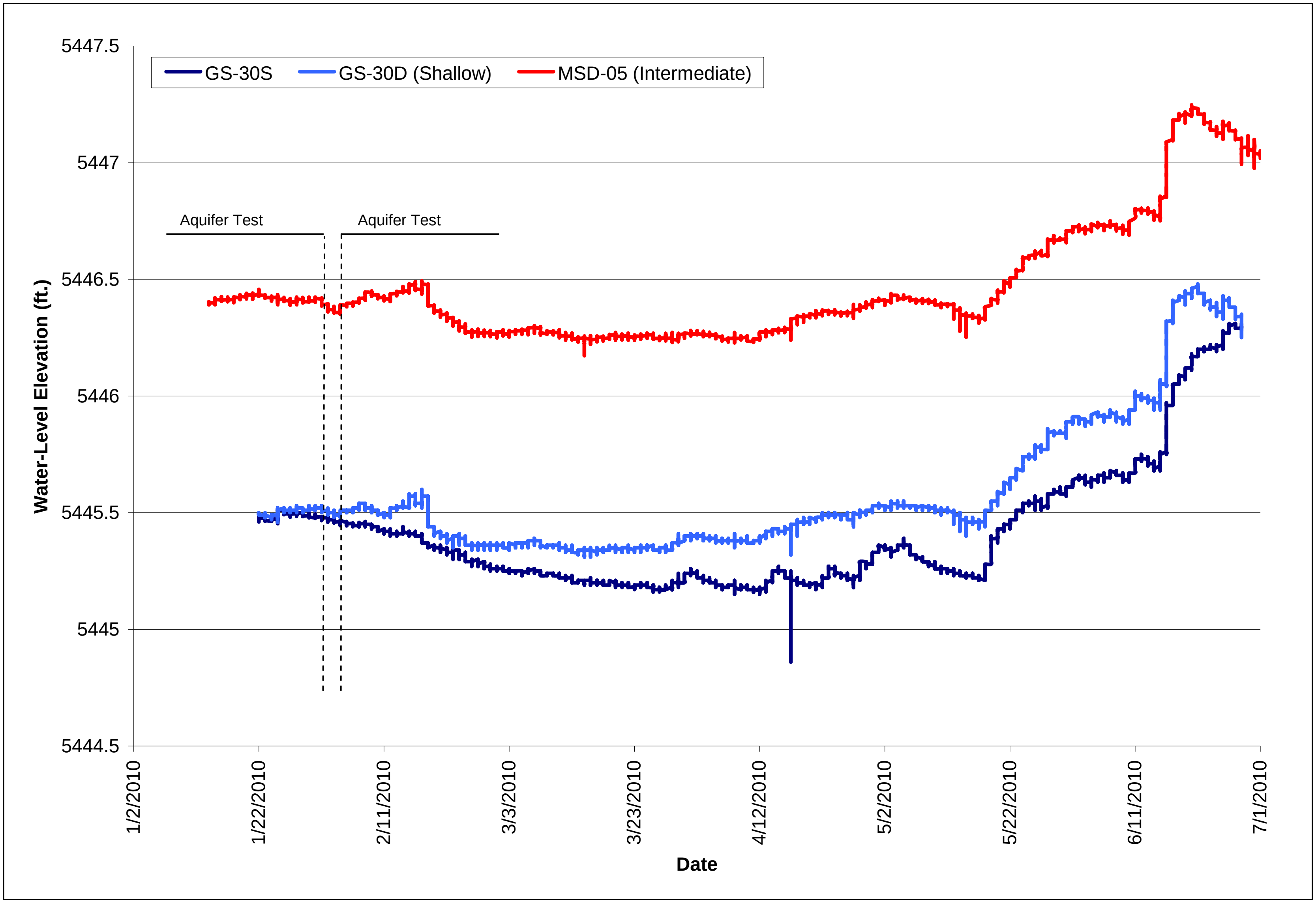
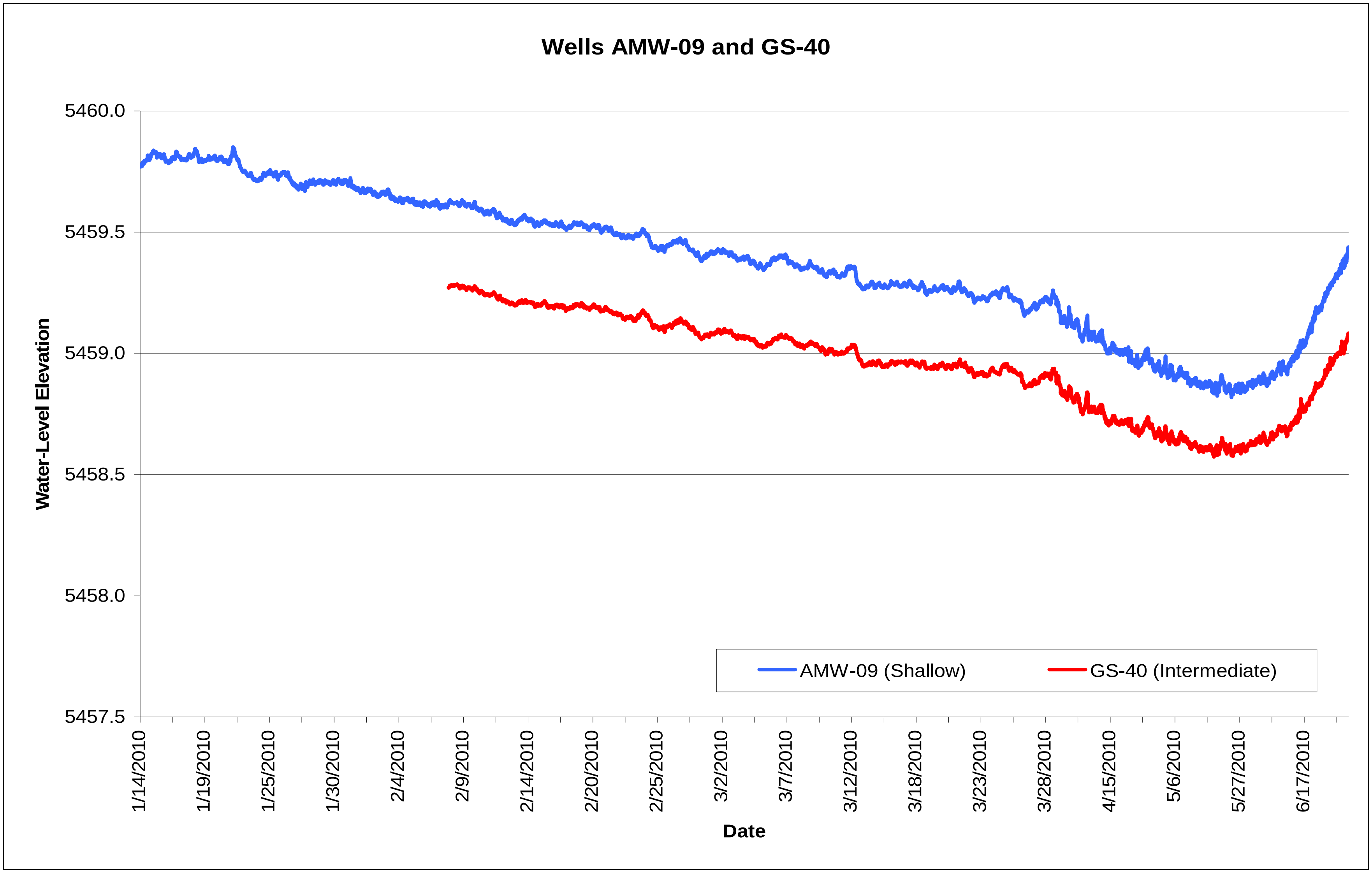
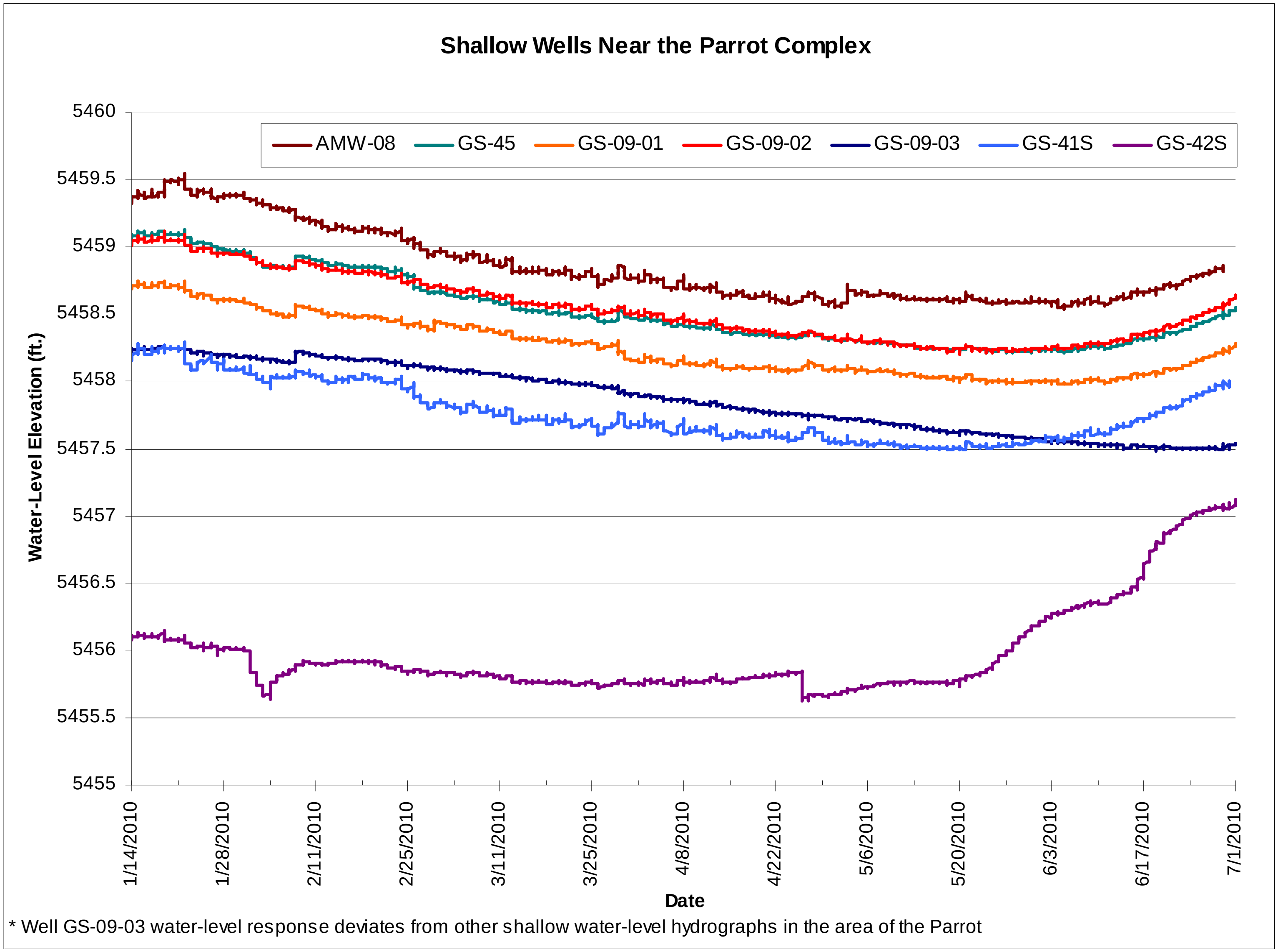
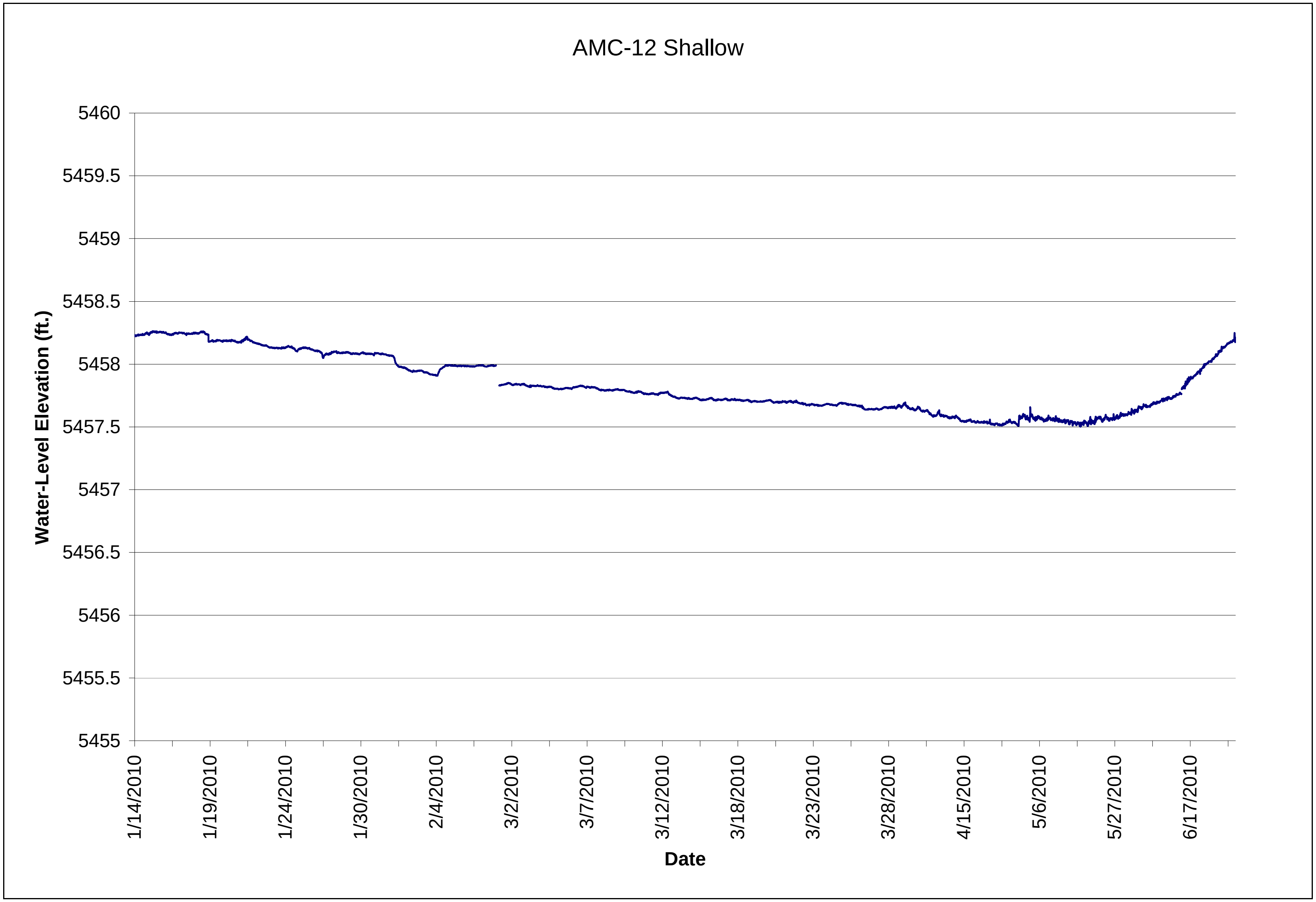
5443.5
5443
5442.5
5442
1/1/10
1/21/10
2/10/10
3/2/10
3/22/10
4/11/10
5/1/10
5/21/10
6/10/10
6/30/10
Date

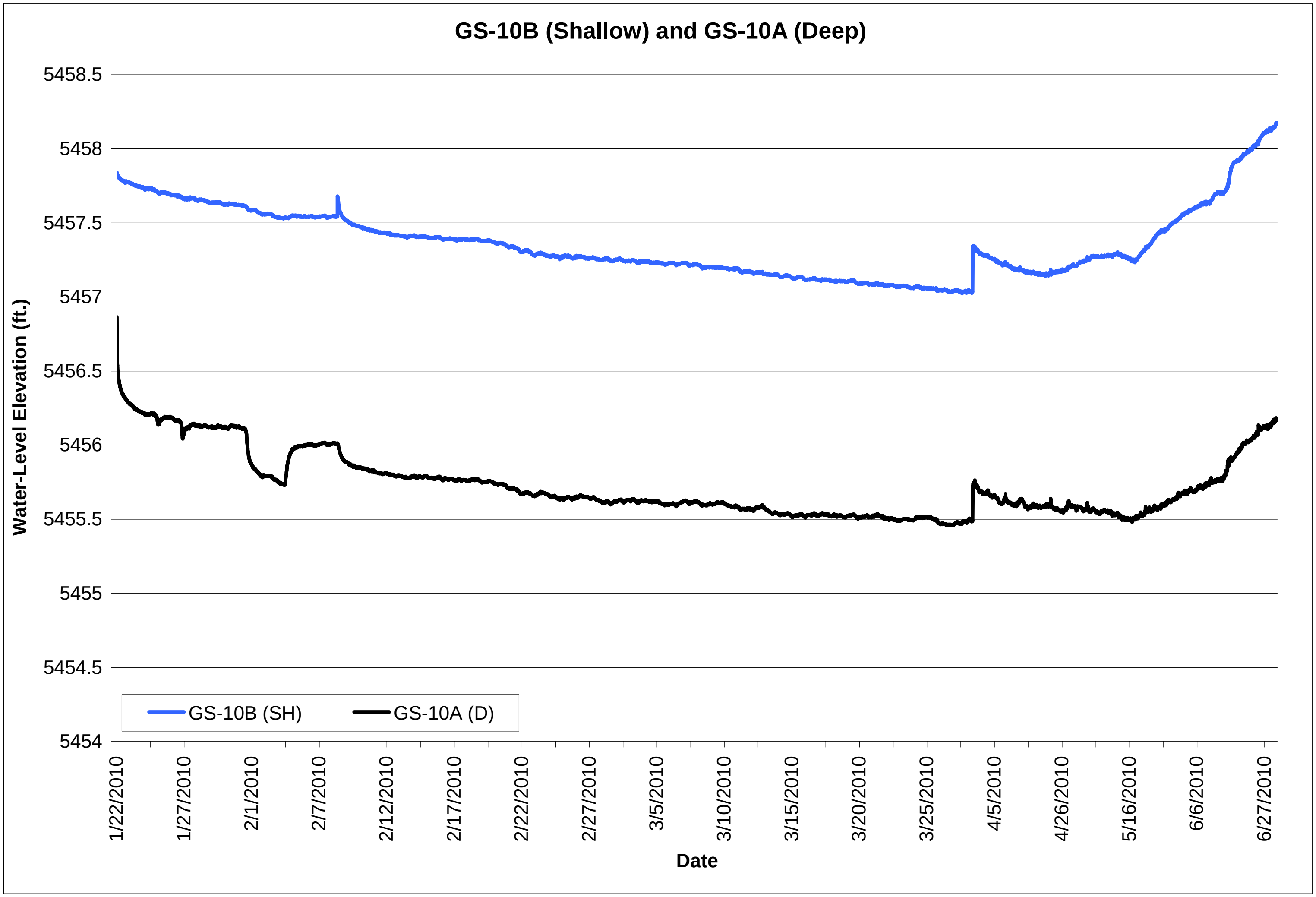

GS-30S
GS-30D (Shallow)
MSD-05 (Intermediate)
Aquifer Test
Aquifer Test
5447.5
5447
5446.5
5446
5445.5
5445
5444.5
Water-Level Elevation (ft.)
1/2/2010
1/22/2010
2/11/2010
3/3/2010
3/23/2010
4/12/2010
5/2/2010
5/22/2010
6/11/2010
7/1/2010
Date



Wells AMW-09 and GS-40
Water-Level Elevation
5460.0
5459.5
5459.0
5458.5
5458.0
5457.5
AMW-09 (Shallow)
GS-40 (Intermediate)
1/14/2010
1/19/2010
1/25/2010
1/30/2010
2/4/2010
2/9/2010
2/14/2010
2/20/2010
2/25/2010
3/2/2010
3/7/2010
3/12/2010
3/18/2010
3/23/2010
3/28/2010
4/15/2010
5/6/2010
5/27/2010
6/17/2010
Date

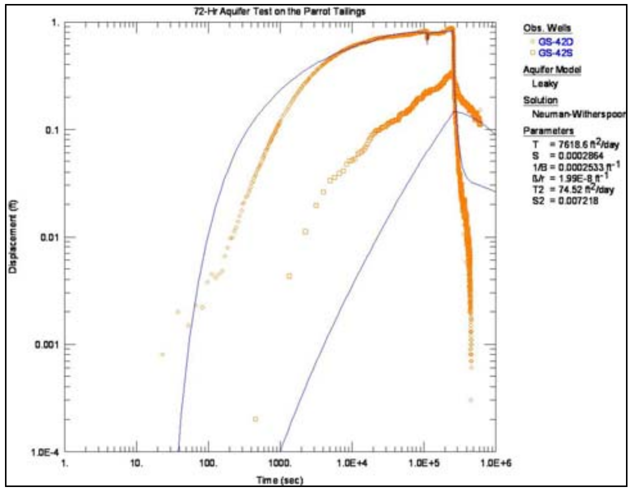

Shallow Wells Near the Parrot Complex
AMW-08
GS-45
GS-09-01
GS-09-02
GS-09-03
GS-41S
GS-42S
Water-Level Elevation (ft.)
5460
5459.5
5459
5458.5
5458
5457.5
5457
5456.5
5456
5455.5
5455
1/14/2010
1/28/2010
2/11/2010
2/25/2010
3/11/2010
3/25/2010
4/8/2010
4/22/2010
5/6/2010
5/20/2010
6/3/2010
6/17/2010
7/1/2010
Date
* Well GS-09-03 water-level response deviates from other shallow water-level hydrographs in the area of the Parrot

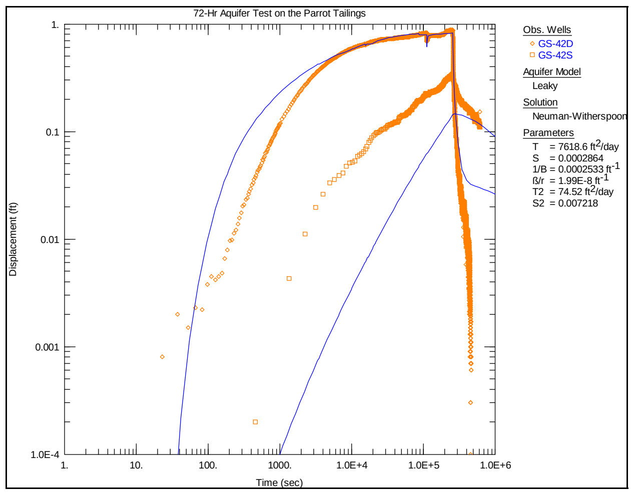

AMC-12 Shallow
Water-Level Elevation (ft.)
5460
5459.5
5459
5458.5
5458
5457.5
5457
5456.5
5456
5455.5
5455
1/14/2010
1/19/2010
1/24/2010
1/30/2010
2/4/2010
3/2/2010
3/7/2010
3/12/2010
3/18/2010
3/23/2010
3/28/2010
4/15/2010
5/6/2010
5/27/2010
6/17/2010
Date

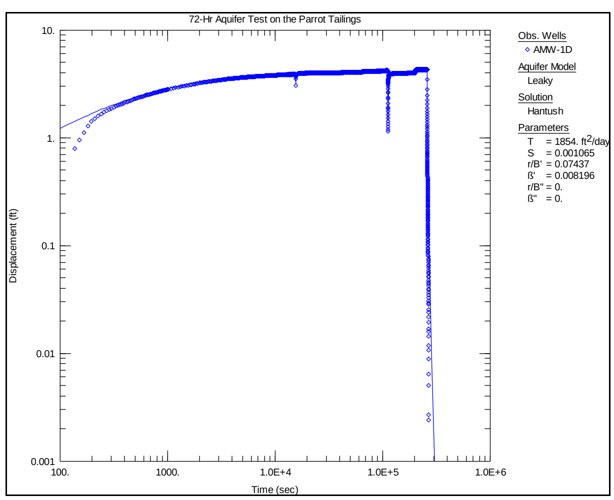


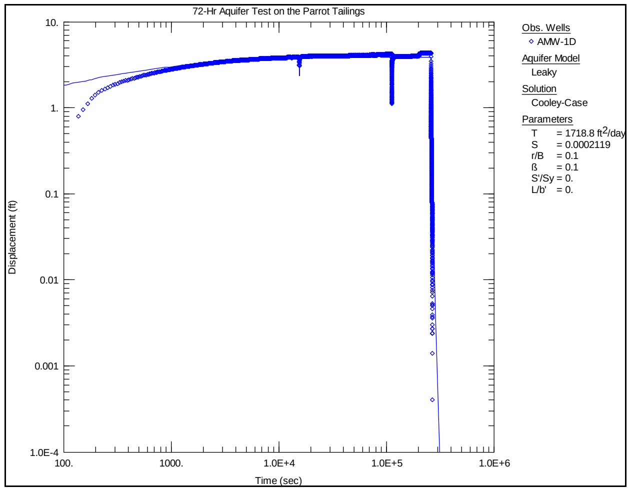
GS-10B (Shallow) and GS-10A (Deep)
Water-Level Elevation (ft.)
5458.5
5458
5457.5
5457
5456.5
5456
5455.5
5455
5454.5
5454
GS-10B (SH)
GS-10A (D)
1/22/2010
1/27/2010
2/1/2010
2/7/2010
2/12/2010
2/17/2010
2/22/2010
2/27/2010
3/5/2010
3/10/2010
3/15/2010
3/20/2010
3/25/2010
4/5/2010
4/26/2010
5/16/2010
6/6/2010
6/27/2010
Date

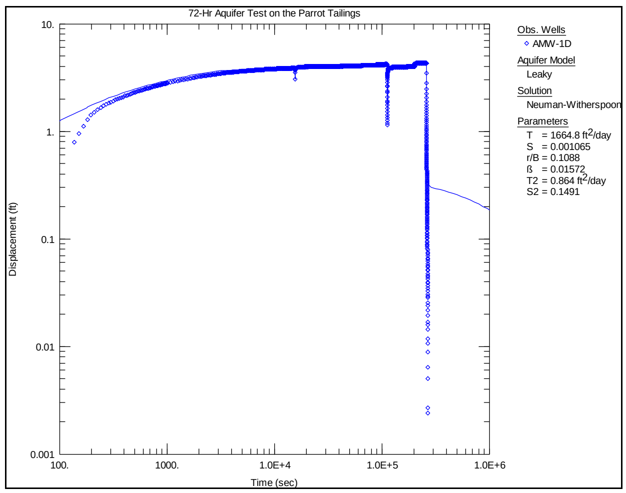
APPENDIX B Drawdown Curve Matches from AQTESOLV analysis

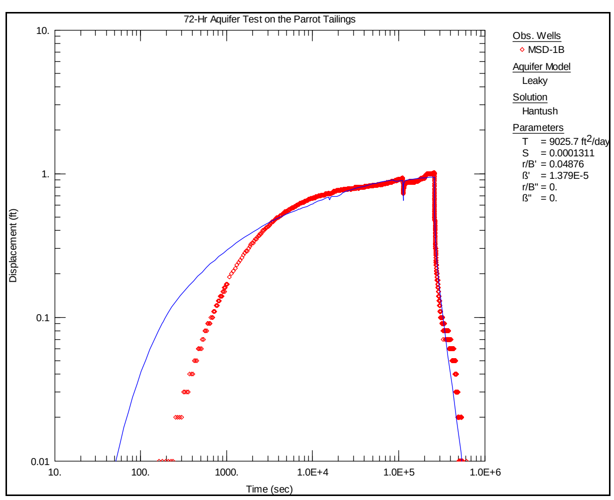

72-Hr Aquifer Test on the Parrot Tailings
Obs. Wells
GS-42D
GS-42S
Aquifer Model
Leaky
Solution
Neuman-Witherspoon
Parameters
T = 7618.6 ft2/day
S = 0.0002864
1/B = 0.0002533 ft-1
ß/r = 1.99E-8 ft-1
T2 = 74.52 ft2/day
S2 = 0.007218
Displacement (ft)
Time (sec)

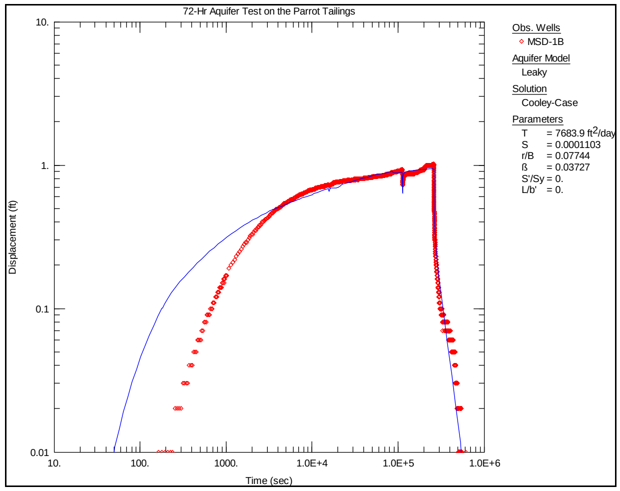

72-Hr Aquifer Test on the Parrot Tailings
Obs. Wells
GS-42D
GS-42S
Aquifer Model
Leaky
Solution
Neuman-Witherspoon
Parameters
T = 7618.6 ft2/day
S = 0.0002864
1/B = 0.0002533 ft-1
ß/r = 1.99E-8 ft-1
T2 = 74.52 ft2/day
S2 = 0.007218
Displacement (ft)
Time (sec)

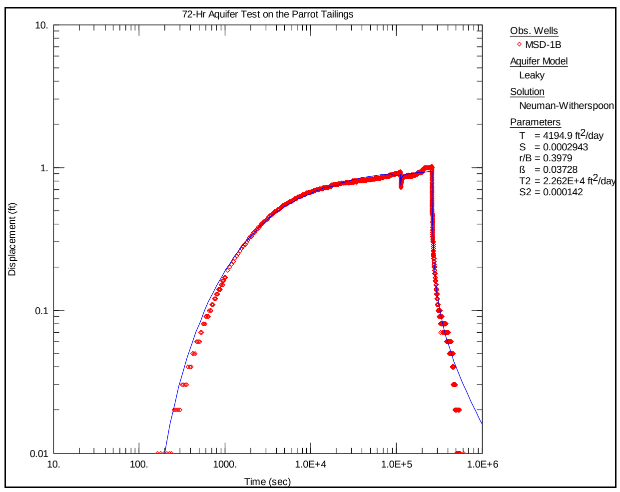

72-Hr Aquifer Test on the Parrot Tailings
Obs. Wells
AMW-1D
Aquifer Model
Leaky
Solution
Hantush
Parameters
T = 1854. ft2/day
S = 0.001065
r/B' = 0.07437
ß' = 0.008196
r/B" = 0.
ß" = 0.
Displacement (ft)
Time (sec)

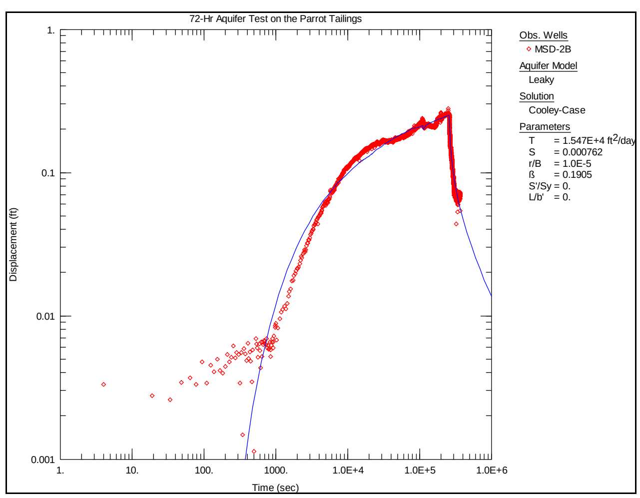

72-Hr Aquifer Test on the Parrot Tailings
Obs. Wells
AMW-1D
Aquifer Model
Leaky
Solution
Cooley-Case
Parameters
T = 1718.8 ft2/day
S = 0.0002119
r/B = 0.1
ß = 0.1
S'/Sy = 0.
L/b' = 0.
Displacement (ft)
Time (sec)

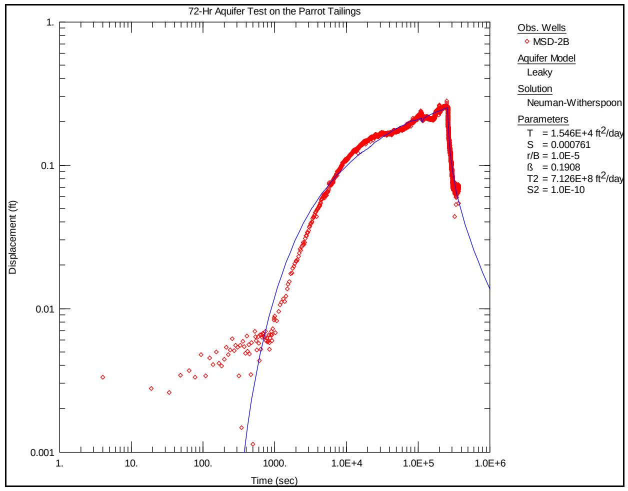

72-Hr Aquifer Test on the Parrot Tailings
Obs. Wells
AMW-1D
Aquifer Model
Leaky
Solution
Neuman-Witherspoon
Parameters
T = 1664.8 ft2/day
S = 0.001065
r/B = 0.1088
ß = 0.01572
T2 = 0.864 ft2/day
S2 = 0.1491
Displacement (ft)
Time (sec)

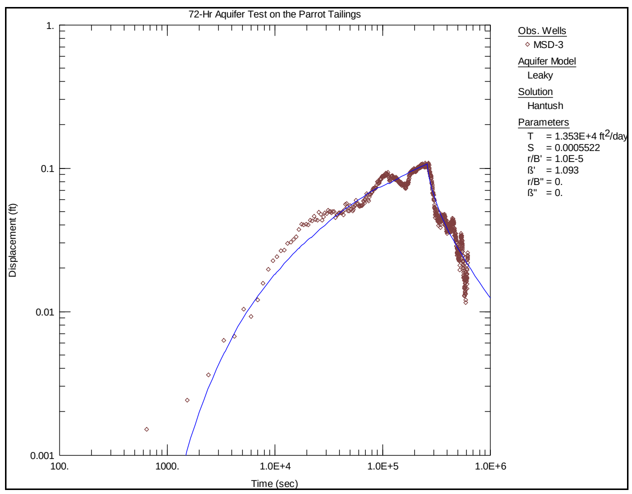

72-Hr Aquifer Test on the Parrot Tailings
Obs. Wells
MSD-1B
Aquifer Model
Leaky
Solution
Hantush
Parameters
T = 9025.7 ft2/day
S = 0.0001311
r/B' = 0.04876
ß' = 1.379E-5
r/B" = 0.
ß" = 0.
Displacement (ft)
Time (sec)

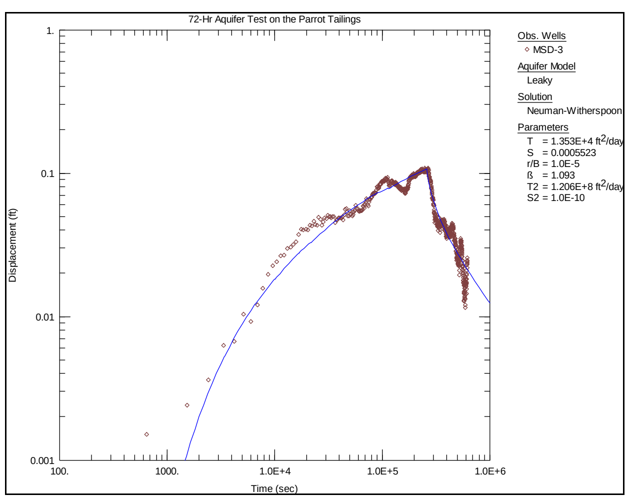

72-Hr Aquifer Test on the Parrot Tailings
Displacement (ft)
Time (sec)
Obs. Wells
MSD-1B
Aquifer Model
Leaky
Solution
Cooley-Case
Parameters
T = 7683.9 ft2/day
S = 0.0001103
r/B = 0.07744
ß = 0.03727
S'/Sy = 0.
L/b' = 0.


72-Hr Aquifer Test on the Parrot Tailings
Displacement (ft)
Time (sec)
Obs. Wells
MSD-1B
Aquifer Model
Leaky
Solution
Neuman-Witherspoon
Parameters
T = 4194.9 ft2/day
S = 0.0002943
r/B = 0.3979
ß = 0.03728
T2 = 2.262E+4 ft2/day
S2 = 0.000142


72-Hr Aquifer Test on the Parrot Tailings
Displacement (ft)
Time (sec)
Obs. Wells
MSD-2B
Aquifer Model
Leaky
Solution
Cooley-Case
Parameters
T = 1.547E+4 ft2/day
S = 0.000762
r/B = 1.0E-5
ß = 0.1905
S'/Sy = 0.
L/b' = 0.


72-Hr Aquifer Test on the Parrot Tailings
Displacement (ft)
Time (sec)
1.
0.1
0.01
0.001
1.
10.
100.
1000.
1.0E+4
1.0E+5
1.0E+6
Obs. Wells
MSD-2B
Aquifer Model
Leaky
Solution
Neuman-Witherspoon
Parameters
T = 1.546E+4 ft2/day
S = 0.000761
r/B = 1.0E-5
ß = 0.1908
T2 = 7.126E+8 ft2/day
S2 = 1.0E-10


72-Hr Aquifer Test on the Parrot Tailings
Displacement (ft)
Time (sec)
1.
0.1
0.01
0.001
100.
1000.
1.0E+4
1.0E+5
1.0E+6
Obs. Wells
MSD-3
Aquifer Model
Leaky
Solution
Hantush
Parameters
T = 1.353E+4 ft2/day
S = 0.0005522
r/B' = 1.0E-5
ß' = 1.093
r/B" = 0.
ß" = 0.


72-Hr Aquifer Test on the Parrot Tailings
Displacement (ft)
Time (sec)
1.
0.1
0.01
0.001
100.
1000.
1.0E+4
1.0E+5
1.0E+6
Obs. Wells
MSD-3
Aquifer Model
Leaky
Solution
Neuman-Witherspoon
Parameters
T = 1.353E+4 ft2/day
S = 0.0005523
r/B = 1.0E-5
ß = 1.093
T2 = 1.206E+8 ft2/day
S2 = 1.0E-10

APPENDIX C Water Quality in Pumping Well During 72-Hour Pumping Test

					PHYSICAL PARAMETERS						**CHEMICAL PARAMETERS**							
SAMPLE SITE	DATE (MM/DD/YR)	TIME (HRS)	SWL (FT)	FLOW (GPM)	FIELD pH	SC (UMHOS)	TEMP (C)	REDOX (mv)	LAB pH	SC (UMHOS)	HARDNESS (MG/L)	ALKALINITY (MG/L)	PERCENT MEQ/L Ca	Mg	Na	HCO_3	CO_3	SO_4
AMW-1B	**M#211600**																	
Pump Test	2/1/10 10:00	10:00	26.01	90.0	4.18	4,099	11.37	390	4.29	4,220	1,891	0	36.3	21.9	5.3	0.0	0.0	92.7
Pump Test	2/1/10 16:00	16:00	27.96	90.0	4.06	4,045	11.35	383	4.24	4,160	1,848	0	35.6	22.3	5.3	0.0	0.0	92.9
Pump Test	2/2/10 9:30	9:30	29.20	90.0	4.04	4,037	11.30	334	4.18	4,310	1,867	0	37.1	21.4	5.1	0.0	0.0	93.1
Pump Test	2/2/10 16:20	16:20		90.0	4.05	4,031	11.30	335	4.13	4,290	1,827	0	36.6	22.0	5.1	0.0	0.0	93.2
Pump Test	2/3/10 15:00	15:00	29.19	90.0	4.03	4,013	11.26	335	4.16	4,290	1,820	0	36.2	21.6	5.3	0.0	0.0	93.6
Pump Test	2/4/10 9:30	9:30		90.0	4.06	4,027	11.12	314	4.30	4,340	1,849	0	36.9	21.0	5.1	0.0	0.0	92.9
	Mean				4.07	4,042	11.28	349	4.22	4,268	1,850	0	36.5	21.7	5.2	0.0	0.0	93.1
	Max				4.18	4,099	11.37	390	4.30	4,340	1,891	0	37.1	22.3	5.3	0.0	0.0	93.6
	Min				4.03	4,013	11.12	314	4.13	4,160	1,820	0	35.6	21.0	5.1	0.0	0.0	92.7

MAJOR CATIONS AND ANIONS

SAMPLE SITE	DATE (MM/DD/YR)	TIME (HRS)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	Mn (mg/L)	SiO_2 (mg/L)	HCO_3 (mg/L)	CO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	NO_3-N (mg/L)	F (mg/L)
AMW-1B	**M#211600**														
Pump Test	2/1/10 10:00	10:00	472.0	173.0	78.4	28.5	5.1	321	77.5	0	0	143.4	2,885	5.57	5.90
Pump Test	2/1/10 16:00	16:00	455.0	173.0	77.6	28.1	8.5	313	77.4	0	0	136.1	2,853	5.34	5.86
Pump Test	2/2/10 9:30	9:30	474.0	166.0	75.2	26.7	10.6	306	74.7	0	0	131.8	2,841	4.49	6.42
Pump Test	2/2/10 16:20	16:20	458.0	166.0	74.8	26.8	11.9	293	75.6	0	0	132.2	2,875	4.34	6.53
Pump Test	2/3/10 15:00	15:00	457.0	165.0	76.7	26.6	19.6	299	74.7	0	0	128.7	2,992	4.02	6.32
Pump Test	2/4/10 9:30	9:30	472.0	163.0	75.4	26.0	28.4	296	73.1	0	0	136.8	2,830	3.94	6.34
	Mean		464.7	167.7	76.4	27.1	14.0	305	75.5	0.0	0.0	135	2,879	4.62	6.23
	Max		474.0	173.0	78.4	28.5	28.4	321	77.5	0.0	0.0	143	2,992	5.57	6.53
	Min		455.0	163.0	74.8	26.0	5.1	293	73.1	0.0	0.0	129	2,830	3.94	5.86

DISSOLVED METAL CONCENTRATION

SAMPLE SITE	DATE (MM/DD/YR)	TIME (HRS)	Al (ug/L)	Ag (ug/L)	As (ug/L)	B (ug/L)	Ba (ug/L)	Be (ug/L)	Cd (ug/L)	Co (ug/L)	Cr (ug/L)	Cu (ug/L)	Hg (ug/L)	Li (ug/L)	Mo (ug/L)	Ni (ug/L)	Pb (ug/L)	Se (ug/L)	Sr (ug/L)	U (ug/L)	Zn (ug/L)
AMW-1B	**M#211600**																				
Pump Test	2/1/10 10:00	10:00	11,359	<1.62	<4.04	169	12.0	11.0	57.1	627	<1.62	94,009	NR	745	<1.62	634	18.4	4.58	4,621	57.2	219,586
Pump Test	2/1/10 16:00	16:00	11,306	<1.62	<4.04	177	10.3	11.2	57.0	658	<1.62	88,998	NR	738	<1.62	627	14.4	4.07	4,429	59.6	217,220
Pump Test	2/2/10 9:30	9:30	12,440	<1.62	<4.04	168	10.2	12.8	55.4	694	<1.62	87,257	NR	742	<1.62	632	12.9	4.32	4,444	64.6	212,813
Pump Test	2/2/10 16:20	16:20	12,397	<1.62	<4.04	170	10.2	13.0	54.9	675	<1.62	85,571	NR	741	<1.62	635	13.7	<4.04	4,310	65.1	209,832
Pump Test	2/3/10 15:00	15:00	12,908	2.18	<4.04	170	10.2	13.3	54.0	721	<1.62	85,178	NR	717	<1.62	622	12.9	<4.04	4,313	67.4	208,454
Pump Test	2/4/10 9:30	9:30	13,057	3.76	<4.04	176	9.9	13.3	54.6	748	<1.62	85,513	NR	703	<1.62	620	13.2	<4.04	4,323	67.9	207,545
	Mean		12,245	2.97	#DIV/0!	172	10.5	12.4	56	687.2	#DIV/0!	87,754	#DIV/0!	731	#DIV/0!	628	14.3	4.3	4,407	63.6	212,575
	Max		13,057	3.76	0.00	177	12.0	13.3	57	748.0	0	94,009	0	745	0.00	635	18.4	4.6	4,621	67.9	219,586
	Min		11,306	2.18	0.00	168	9.9	11.0	54	627.0	0	85,178	0	703	0.00	620	12.9	4.1	4,310	57.2	207,545

RARE EARTH ELEMENTS

SAMPLE SITE	DATE (MM/DD/YR)	TIME (HRS)	Cerium Ce (ug/L)	Cesium Cs (ug/L)	Gallium Ga (ug/L)	Lanthanum La (ug/L)	Niobium Nb (ug/L)	Neodymium Nd (ug/L)	Palladium Pd (ug/L)	Praseodymium Pr (ug/L)	Rubidium Rb (ug/L)	Thallium Tl (ug/L)	Thorium Th (ug/L)	Tin Sn (ug/L)	Titanium Ti (ug/L)	Tungsten W (ug/L)
AMW-1B	**M#211600**															
Pump Test	2/1/10 10:00	10:00	930	<1.7	3.88	194	<1.62	121	10.2	36.1	34.9	<1.33	<0.93	<1.66	34.0	<2.02
Pump Test	2/1/10 16:00	16:00	938	<1.7	4.17	195	<1.62	121	11.7	36.0	34.9	<1.33	<0.93	<1.66	33.9	<2.02
Pump Test	2/2/10 9:30	9:30	1,026	<1.7	4.02	214	<1.62	131	10.6	38.8	35.8	<1.33	<0.93	<1.66	33.0	<2.02
Pump Test	2/2/10 16:20	16:20	1,064	<1.7	3.91	228	<1.62	135	10.7	41.1	35.7	<1.33	<0.93	<1.66	32.2	<2.02
Pump Test	2/3/10 15:00	15:00	1,084	<1.7	4.13	231	<1.62	136	11.4	41.0	34.9	<1.33	<0.93	<1.66	32.5	<2.02
Pump Test	2/4/10 9:30	9:30	1,122	<1.7	4.25	242	<1.62	141	11.9	42.4	34.7	<1.33	<0.93	<1.66	29.3	<2.02
	Mean		95													
	Max															
	Min															

TOTAL RECOVERABLE CONCENTRATION

SAMPLE SITE	DATE (MM/DD/YR)	TIME (HRS)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Fe (mg/L)	Mn (mg/L)	SiO2 (mg/L)	Al (ug/L)	Ag (ug/L)	As (ug/L)	B (ug/L)	Ba (ug/L)	Be (ug/L)	Cd (ug/L)	Co (ug/L)
AMW-1B	**M#211600**																
Pump Test	2/1/10 10:00	10:00															
Pump Test	2/1/10 16:00	16:00															
Pump Test	2/2/10 9:30	9:30															
Pump Test	2/2/10 16:20	16:20															
Pump Test	2/3/10 15:00	15:00															
Pump Test	2/4/10 9:30	9:30	490	183	80	28	28	305	NR	NR	7.1	0.93	NR	9.85	9.96	1,092	694
	Mean																
	Max																
	Min																

SAMPLE SITE	DATE (MM/DD/YR)	TIME (HRS)	Cr (ug/L)	Cu (ug/L)	Hg (ug/L)	Li (ug/L)	Mo (ug/L)	Ni (ug/L)	Pb (ug/L)	Se (ug/L)	Sr (ug/L)	U (ug/L)	Zn (ug/L)
AMW-1B	**M#211600**												
Pump Test	2/1/10 10:00	10:00											
Pump Test	2/1/10 16:00	16:00											
Pump Test	2/2/10 9:30	9:30											
Pump Test	2/2/10 16:20	16:20											
Pump Test	2/3/10 15:00	15:00											
Pump Test	2/4/10 9:30	9:30	0.725	88,890	NR	671	<0.5	346	18.9	3.5	4,306	76.9	214,625
	Mean												
	Max												
	Min												