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Hydraulic Testing of Lost Lake Aquifer Near Recovery Wells RWM018, RWM 3, and RWM 5

K. L. Dixon

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EXECUTIVE SUMMARY

An aquifer pumping test was conducted on the Lost Lake Aquifer Zone (LLAZ) at the recently installed recovery well RWM018 in accordance with the approved test plan (Dixon, 2018). The objective of the testing was to determine baseline well performance parameters and aquifer hydraulic conductivity. Well performance parameters determined included specific capacity, well efficiency, and head loss coefficients. The specific capacity of RWM018 was determined to be approximately 3.2 gpm/ft of drawdown. At baseline conditions (all active recovery wells operating except RWM018), RWM018 has approximately 26 ft of head above the well screen. This suggests that RWM018 can sustain a maximum pumping rate of 83 gpm with drawdown at the top of screen. Well efficiency was inversely related to pumping rate and decreased from 97% to 91% over a pumping range of approximately 20 to 55 gpm. These results suggest that RWM018 is an efficient well and does not require any further well development activities. The aquifer head loss coefficient was determined to be 2.1 $ft/ft^3/min$ and the well loss coefficient was determined to be 0.03 min^2/ft^5.

Aquifer response to pumping at RWM018 was measured in several nearby monitoring wells screened within the LLAZ. These data were used to evaluate aquifer hydraulic properties using the Hantush-Jacob (1955, 1961a, and b) leaky aquifer model as implemented in the computer code AQTESOLV. The average transmissivity (T) of the aquifer was determined to be 0.816 ft^2/min with a standard deviation of 0.139 ft^2/min. The average storativity of the aquifer was determined to be 0.0005 with a standard deviation of 0.0008. Using an average aquifer thickness of 55 ft, the hydraulic conductivity of the LLAZ near RWM018 was determined to be 21.4 ft/day (7.54E-03 cm/sec) with a standard deviation of 3.6 ft/day. For comparison, Hiergesell (1992) reported an average transmissivity of 0.836 ft^2/day (K = 30 ft/day, b =40.1) near RWM 16 whereas Geraghty and Miller (1987) reported a transmissivity of 1.49 ft^2/min (K = 38.9 ft/day, b =73 ft) for RWM 8 which is the nearest recovery well to RWM018. Aquifer compaction due to the reduction in hydraulic head associated with operation of the recovery well network may explain the difference between transmissivity and storativity values calculated in this evaluation compared to values measured by Geraghty and Miller (1987) at the start of pump and treat operations.

Following an extended shut down of the entire recovery well system, an aquifer pumping test was conducted to estimate the zone of capture (ZOC) of RWM 3 and RWM 5. The objective of this testing was to determine whether the area of the aquifer near RWM 9 and RWM 11 is hydraulically controlled by RWM 3 and RWM 5. When the recovery well network was restarted, RWM 9 and RWM 11 were not restarted. The maximum drawdown observed for RWM 9 was 1.6 ft. The maximum drawdown observed for

RWM 11 was 1.2 ft. Therefore, it was concluded that both wells were likely within the ZOC of RWM 3 and RWM 5 under the operating conditions tested.

In support of the ZOC analysis for RWM 3 and RWM 5, aquifer response was measured in several nearby monitoring wells screened within the LLAZ. These data, in combination with pumping rates from all operating recovery wells, were used to determine aquifer hydraulic properties using the Hantush-Jacob (1955, 1961a, and b) leaky aquifer model as implemented in the computer code AQTESOLV. All wells were simulated simultaneously. The transmissivity of the LLAZ aquifer was determined to be 0.9917 ft^2/min with a storativity value of 0.001. Using an average aquifer thickness of 73 ft (near RWM 3 and RWM 5), the hydraulic conductivity of the aquifer is 19.6 ft/day (6.90E-03 cm/sec). This compares favorably with the hydraulic conductivity estimated near RWM018 (21.4 ft/day).

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LIST OF ABBREVIATIONS

EC&ACP	Environmental Compliance and Area Completion Projects
CBUC	Crouch Branch Upper Clay
GCCZ	Green Clay Confining Zone
HWMF	Hazardous Waste Management Facility
ISCO	In-situ chemical oxidation
LLAZ	Lost Lake Aquifer Zone
LLLAZ	Lower Lost Lake Aquifer Zone
msl	mean sea level
MAAZ	M-Area Aquifer Zone
SRNL	Savannah River National Laboratory
PCE	Tetrachloroethylene
S	Storativity
SCDHEC	South Carolina Department of Health and Environmental Control
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
T	Transmissivity
TA	Temporary Authorization
TCE	Trichloroethylene
ULLAZ	Upper Lost Lake Aquifer Zone
ZOC	Zone of Capture

1.0 Background

Groundwater beneath the M-Area Hazardous Waste Management Facility (HWMF) is contaminated with chlorinated ethenes including trichloroethylene (TCE) and tetrachloroethylene (PCE). SRS operates a network of groundwater recovery wells designed to hydraulically contain and capture the high concentration VOC plume in the Lost Lake Aquifer Zone (LLAZ) (Figure 1). The recovery wells are connected to the M-1 Air Stripper and the system is permitted by the South Carolina Department of Environmental Control (SCDHEC) to operate at a total flow of 610 gpm. In March of 2016 the South Carolina Department of Health and Environmental Control (SCDHEC) approved a temporary authorization (TA) allowing SRNS to evaluate in situ chemical oxidation (ISCO) technologies to address the high concentration of dissolved phase volatile organic compounds and any residual dense non-aqueous phase liquid present in the LLAZ in A/M Area. A new groundwater recovery well (RWM018) was installed to target the higher concentration area of dissolved VOC plume that is outside of the zone of capture (ZOC) of the existing M-1 Air Stripper recovery wells and to provide hydraulic control for the ISCO test area.

Although modified over time, the original recovery well network was installed in the 1980s. Extensive aquifer testing was conducted using the original well network and estimates of specific capacity, well efficiency, transmissivity, and storage coefficient were made for the LLAZ (Geraghty and Miller, 1987). Transmissivities for the LLAZ ranged from 0.12 to 10.49 ft^2/min with a median of 1.86 ft^2/min. The closest original recovery well to RWM018 is RWM 8. Transmissivity values for RWM 8 ranged from 1.49 to 1.67 ft^2/min and storativity ranged from 0.001 to 0.02.

Installation of RWM018 provided an opportunity to obtain hydrologic property information about the LLAZ in an area of the aquifer not previously studied. As a result, tests were designed to determine specific well performance parameters for RWM018 (e.g., specific capacity, well efficiency, and head loss coefficients) and to determine aquifer hydraulic properties (e.g., transmissivity and storativity). Hydrologic tests included step-drawdown testing of RWM018 and a longer duration variable rate pumping test where water levels were monitored in several nearby monitoring wells.

SRNS has proposed converting recovery wells RWM 9 and RWM 11 to observation wells. In March of 2018, SCDHEC approved a TA allowing SRNS to install an additional groundwater recovery well (RWM 19) in the out-years and convert recovery wells RWM 9 and RWM 11 to monitoring wells. Within the TA request, SRNS petitioned that groundwater previously captured by the two wells would be encompassed by the capture zones of other wells in the system, specifically (RWM 3 and RWM 5). This contention was based upon an update to the A/M area groundwater flow model that incorporated the effects of RWM018 and the proposed RWM019 (SRNS 2017). A system wide shutdown of the recovery well network provided an opportunity to assess the ZOC of RWM 3 and RWM 5.

This report discusses the hydrologic tests conducted following the installation of RWM018. It also addresses the ZOC analysis associated with RWM 3 and RWM 5. The information provided in this report may serve as input to subsequent updates to the groundwater flow and contaminant transport model for A/M Area.

2.0 Hydrologic Test Methods

There were multiple objectives to the testing conducted as part of this project. Initially, aquifer testing was only planned for RWM018 and nearby monitoring wells. After an extended system wide shut down, the opportunity arose to investigate the ZOC of recovery wells RWM 3 and RWM 5. Therefore, the primary objectives of this project were expanded to:

- Assess the performance of RWM018 and establish baseline estimates of specific capacity and well efficiency
- Determine the hydraulic properties of the LLAZ near RWM018 based upon aquifer response measured in nearby observation wells due to pumping of RWM018
- Assess the ZOC for recovery wells RWM 3 and RWM 5

The following sections describe the test methods used to meet the project objectives identified above.

2.1 Hydrogeologic Conceptual Model

The location of RWM018 and nearby monitoring wells is shown in Figure 2 and a generalized north-south geologic cross-section is given in Figure 3. A detailed description of the hydrostratigraphic setting in A/M area is provided by (Aadland and Bledsoe, 1990) and details pertinent to this test are summarized here. The generalized hydrostratigraphy pertinent to the study area consists of: 1) the M-Area aquifer zone (MAAZ), 2) the Green Clay Confining Zone (GCCZ), 3) the Lost Lake Aquifer Zone (LLAZ), and 4) the upper clay of the Crouch Branch Confining Unit (UC_CBCU).

The MAAZ is the water table aquifer and it overlies the GCCZ. The GCCZ ranges in thickness from 8 to 10 ft across the RWM018 study area with an average thickness of 9.3 ft. The GCCZ serves as the leaky confining layer in the subsequent analysis of RWM018 pumping test data. The LLAZ ranges in thickness from about 40 to 70 ft across the study area with an average thickness of 55 ft. The LLAZ is bounded on the bottom by the UC_CBCU which ranges in thickness from 2.6 to 13.8 ft with an average thickness of 10.1 ft. The LLAZ can be divided into an upper (ULLAZ) and lower (LLLAZ) portion based on contaminant stratification. Near RWM018, the LLAZ is comprised of a series of interbedded sands and clays with the sand of the ULLAZ having a higher percentage of silt than sands compared to the LLLAZ. The recovery wells are generally screened across both intervals.

The location of RWM 3 and RWM 5 and nearby monitoring wells is shown in Figure 4 and a generalized cross-section is given in Figure 5. The generalized hydrostratigraphy in this area is similar to RWM018. The GCCZ near RWM 3 and RWM 5 ranges in thickness from 4 to 17 ft with an average thickness of 10.5 ft. The LLAZ ranges in thickness from 62 to 84 ft with an average thickness of 73 ft. The UC_CBCU is about 14 ft thick near RWM 3 and RWM 5.

The average layer thicknesses obtained from the generalized geologic cross-sections were used to establish the boundaries applied in the subsequent pumping test analyses for RWM018 and RWM 3 and RWM 5.

2.2 Step Drawdown Pumping Tests

Step-drawdown tests are conducted to assess well performance and to identify the optimum pumping rate for a recovery well. A step-drawdown test is conducted as a series of short duration, constant-rate pumping tests consisting of a minimum of three steps that are of approximate equal duration (Kruseman and Ritter, 1994).

Two step-drawdown tests were conducted for well RWM018. Both tests were conducted at flow rates of approximately 20, 40, and 55 gpm. Drawdown in RWM018 was monitored with a vented, data logging pressure transducer. Each individual pumping period lasted for approximately 2 hours. Following the completion of the first step test, pumping was terminated. Recovery of the pumping well was monitored, and these data were included in the analysis. The second step-drawdown test used the same flow rate intervals as the first test, but pumping continued after the third test interval.

The specific capacity of a pumping well is defined as discharge per unit drawdown (Q/s) as measured in the pumping well (Kruseman and Ritter, 1994). It provides an indicator of initial well performance and is useful in quantifying subsequent declines in performance over time that may arise as pumping progresses. The specific capacity of RWM018 was assessed by plotting drawdown as a function of discharge for each pumping interval for both step-drawdown tests.

Head loss coefficients for RWM018 were determined by comparing discharge, Q, to the ratio of drawdown and pumping rate (s/Q). The ratio s/Q is defined as specific discharge. Jacob (1946) defined the relationship between well loss and drawdown as follows:

$$s_t = BQ + CQ^2 \quad (2\text{-}1)$$

where s_t is the total drawdown, BQ is the laminar aquifer head loss, and CQ^2 is the turbulent well head loss. A plot of specific discharge as a function of pumping rate provides the coefficients B and C (Figure 6).

Well efficiency is the ratio of the theoretical drawdown (without well losses) expected in a pumping well and the observed drawdown in the well. Efficiency is calculated directly using this ratio if estimates of transmissivity and storativity are available. Efficiency may also be calculated from Equation 2-1 as follows:

$$E = \frac{BQ}{BQ + CQ^2} * 100 \quad (2\text{-}2)$$

This is simply the aquifer head loss divided by the total head loss in the well. Simplifying Equation 2-2 gives:

$$E = \frac{100}{1 + \frac{CQ}{B}} \quad (2\text{-}3)$$

where B is the aquifer head loss coefficient and C is the well loss coefficient.

2.3 Aquifer Pumping Test

An aquifer pumping test was conducted at RWM018 and later at RWM 3 and RWM 5. The goal of an aquifer pumping test is to induce head loss in the aquifer that can be analyzed to determine hydraulic properties. This is accomplished by pumping water from an extraction well (e.g., RWM018) and monitoring aquifer response in nearby monitoring wells screened in the same aquifer that is being stressed. Following the second step-drawdown test, extraction of groundwater from RWM018 continued for a period of several days at a reasonably constant rate. During the test period, there were two shutdowns where pumping was unexpectedly stopped due to issues with the controls for the newly installed well. These shutdown periods provided recovery data that were included in the analysis of the test data. RWM018 is one well in network of eleven recovery wells. During the pumping test at RWM018, the system configuration (recovery wells in use and pumping rates) was maintained as close to constant as possible so that the measured aquifer response could be attributed entirely to RWM018.

An extensive monitoring well network exists near RWM018 and several of those wells are screened in the LLAZ. These wells were used to monitor aquifer response due to pumping at RWM018 (Figure 2 and Table 1) Figure 7 shows a plot of screen intervals for RWM018 compared to the monitoring wells chosen for this test.

An unplanned system wide shut down due to a leaking pipe occurred during the latter portion of the testing at RWM018. This event ended the RWM018 pumping test. The system shutdown was longer than expected due to the complexity of finding and repairing the leak. This allowed water levels in the LLAZ to recover to nearly static conditions providing an opportunity to conduct an aquifer pumping test focused on the area near RWM 3 and RWM 5. RWM 9 and RWM 11 have been identified as candidates for conversion to monitoring wells. As such, they were not scheduled for restart once the piping system was repaired. Therefore, the objective of the second aquifer pumping test was to establish whether water previously captured by RWM 9 and RWM 11 would be captured by RWM 3 and RWM 5 as indicated by recent groundwater modeling (SRNS, 2017).

As with RWM018, the area near RWM 3 and RWM 5 includes an extensive monitoring well network. Along with RWM 9 and RWM 11, these monitoring wells were used to measure aquifer response (Figure 4 and Table 2). Figure 8 shows a plot of screen intervals for RWM 3 and RWM 5 compared to the monitoring wells chosen for this test.

For both aquifer pumping tests, data logging pressure transducers were used to monitor aquifer response. Pressure transducers are submerged below the water column in the well and record the pressure due to the weight of the water column above the transducer. Changes in water level result in a change in pressure sensed by the transducer. The pressure measured by the transducer was recorded in feet of water above the sensor. These data were converted to elevation using the initial water level in the well (manually recorded using an electric water level tape) and the reference elevation for the top of casing.

Most of the pressure transducers used for both aquifer pumping tests were vented transducers (In-Situ Inc., Troll 700). For the RWM018 aquifer pumping test, two wells were instrumented with unvented data logging transducers (Onset Inc., HOBO U20L). Unvented transducers record absolute pressure (weight of water column and weight of air above the transducer). Data from these transducers were converted to water level using the method described above and subtracting the head caused by the weight of the air column above the transducer (barometric pressure). Barometric pressure was monitored continuously near RWM018 (In-Situ, Inc., Barotroll).

Each recovery well in the system is equipped with a direct reading flow meter and pressure gauge. In addition to the LCD display, these flow meters also output a 4-20ma signal for logging pumping rate. For the RWM018 aquifer pumping test, pumping rate was recorded using a 4-20ma data logger (Onset Inc., HOBO U12-008). Data were also recorded manually on a periodic basis for comparison purposes. For the testing near RWM 3 and RWM 5, pumping rates were recorded manually for all recovery wells in the network. Pumping rates remained nearly constant for all wells during the RWM 3 and 5 aquifer testing.

2.4 Analysis of Pumping Test Data

The LLAZ is considered a leaky confined aquifer being bounded by the GCCZ at the top and UC_CBCU on the bottom. The GCCZ in M-Area has been described as discontinuous (Marine and Bledsoe, 1984) and identified as a leaky confining layer (Hiergesell, 1992). Therefore, the method chosen for analyzing the bulk of data from the aquifer pumping tests considers leakage from an overlying confining layer. Initial estimates of aquifer properties and a verification calculation were made using the Theis solution for confined aquifers (Theis, 1935).

The Theis equation is given as:

$$s = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-y}}{y}dy \tag{2-4}$$

where s is drawdown in the aquifer, Q is the pumping rate (Fetter, 1994). The parameter u is given as:

$$u = \frac{r^2 S}{4Tt} \tag{2-5}$$

where r is the radial distance from the pumping well, S is the storativity of the aquifer, T is the transmissivity of the aquifer, and t is the time since pumping started.

Equation 2-4 is typically abbreviated as:

$$s = \frac{Q}{4\pi T} W(u) \tag{2-6}$$

where W(u) is referred to as the Theis well function (Chow, 1964).

The Theis well function W(u) is given as:

$$W(u) = -0.5772 - \ln(u) + u - \frac{u^2}{2*2!} + \frac{u^3}{3*3!} - \frac{u^4}{4*4!} + \cdots \tag{2-7}$$

Assumptions associated with the Theis method include:

- The aquifer has infinite aerial extent
- aquifer is homogeneous and of uniform thickness
- the pumping well is fully or partially penetrating
- flow to the pumping well is horizontal when the pumping well is fully penetrating
- aquifer is nonleaky confined
- flow is unsteady
- water is released instantaneously from storage with decline of hydraulic head
- diameter of a pumping well is very small so that storage in the well can be neglected

The Theis solution for non-leaky confined aquifers was used to analyze data from startup testing on RWM018 to provide initial estimates of transmissivity and storativity. The simplicity of the Theis solution allows for easy implementation in a spreadsheet calculation, and it is a reasonable approximation given that leakage is not a significant factor over the short duration of the startup testing. The Theis solution was also used to estimate the theoretical drawdown expected in RWM018 based on aquifer properties calculated from a nearby observation well (MSB107CC). The analysis included both drawdown data and recovery data. Recovery data were also analyzed using the Theis equation. Using the superposition principle, the recovery of a well after pumping is stopped is equal to:

$$s_r = \frac{Q}{4\pi T}\left(\frac{4Tt}{r^2 S}\right) - \frac{Q}{4\pi T}\left(\frac{4T(t - t_1)}{r^2 S}\right) \tag{2-8}$$

where s_r is the recovery of drawdown, t is the time since pumping started, and t_1 is the time since pumping stopped (Freeze and Cherry, 1979). Equation 2-8 simplifies to:

$$\boldsymbol{s_r = \frac{Q}{4\pi T} \ln\left(\frac{(t - t_1)}{t}\right)} \tag{2-9}$$

Hantush and Jacob (1955, 1961a and b) developed a well function that accounts for confining layer leakage and it is one of the most common solutions used to analyze leaky aquifers. Walton (1991) gives the equation for drawdown in a leaky confined aquifer as:

$$\boldsymbol{s = \frac{Q}{4\pi T} W\left(u,\ \frac{r}{B}\right)} \tag{2-10}$$

where Q is the extraction flow rate, T is the transmissivity. W(u, r/B) is the Hantush-Jacob leaky well function defined by:

$$\boldsymbol{W\left(u,\ \frac{r}{B}\right) = \int_u^{\infty} \frac{1}{y} e^{\left\{-y-\frac{\left(\frac{r}{B}\right)^2}{4y}\right\}} dy} \tag{2-11}$$

where u is defined by Equation 2-5 and:

$$\boldsymbol{\frac{r}{B} = \frac{r}{\sqrt{\left(\frac{Tb'}{k'}\right)}}} \tag{2-12}$$

where r is the radial distance from the pumping well, S is the storativity, t is time, b' is the confining layer thickness, and k' is the permeability of the confining layer. The assumptions of the Hantush-Jacob solution are the same as those for the Theis solution with the exception of leakage from the confining layer.

Transmissivity is converted to hydraulic conductivity with following equation:

$$\boldsymbol{K = \frac{T}{b}} \tag{2-13}$$

where K is hydraulic conductivity, T is transmissivity, and b is aquifer thickness.

The Hantush-Jacob method was implemented using a computer code named AQTESOLV developed by Geraghty and Miller Inc. (2007). Parameters used in the Hantush-Jacob model for leaky aquifers include the saturated thickness of the aquifer, the thickness of the overlying confining layer, and the zone of penetration of the pumping and observation wells. The hydrogeologic conceptual model described in Section 2.1 was used to establish the layer thicknesses used in AQTESOLV.

2.5 Barometric Effects

Fluctuations in barometric pressure can impact water level measurements in a confined aquifer even when vented pressure transducers are used because the well serves as a direct connection to the atmosphere for the aquifer. Any change in atmospheric pressure is immediately transmitted to the aquifer through the opening provided by the well screen. For wells near the pumping well, barometric effects may be minimal in comparison to the head change induced by pumping. However, for wells further away where the head change in the aquifer is smaller, barometric effects can be significant. All data collected for both aquifer pumping tests were corrected for barometric effects.

Corrections to water level data were made using the following equations (Gonthier, 2007).

$$\boldsymbol{\Delta w_{cor} = w_{obs} - B_{eff} * \Delta BP} \tag{2-14}$$

where w_{cor} = corrected water level, ft H_2O
w_{obs} = observed water level, ft H_2O
B_{eff} = Barometric efficiency
ΔBP = change in barometric pressure, ft H_2O

$$\boldsymbol{B_{eff} = \frac{\Delta wl}{\Delta BP}} \tag{2-15}$$

where B_{eff} = Barometric efficiency
Δwl = change in water level, ft H_2O

ΔBP = change in barometric pressure, ft H_2O

Water level measurements were made in the observation wells for several weeks prior to the RWM018 aquifer test to establish baseline hydraulic conditions. These data were used to calculate the barometric efficiency of each well which was then used to correct the water level measurements collected during the test. The average barometric efficiency calculated from these data was used to correct water level measurements associated with the aquifer testing near RWM 3 and RWM 5.

3.0 Results

Well performance and aquifer testing were conducted at RWM018. This was followed by a ZOC analysis for recovery wells RWM 3 and RWM 5. The test methods employed are described in Section 2.0. The following sections provide a discussion and analysis of the results obtained from the hydrologic testing.

3.1 Barometric Efficiency

Prior to the RWM018 aquifer pumping test, water level measurements were recorded for several weeks to evaluate the effects of barometric pressure. Barometric efficiencies were calculated for each observation well using the methods described in 2.5. Calculated barometric efficiencies for RWM018 and nearby monitoring wells are presented in Table 6. Values ranged from 44 to 67% with an average value of 61% and are consistent with values reported by Hiergesell (1992). Figure 9 presents a plot of uncorrected and corrected water level measurements for MSB107CC. The average barometric efficiency was used to correct water level measurements collected as part of the ZOC analysis for RWM 3 and RWM 5 (Figure 10). All data for both aquifer pumping tests were corrected for barometric effects. The magnitude of the correction averaged 0.05 ft.

3.2 RWM018 Startup Testing

RWM018 was installed in July 2017 and startup testing occurred in April 2018. The objective of the startup testing was to verify operation of the well and associated control equipment. This testing also provided an opportunity to collect aquifer response data for making initial estimates of hydraulic properties. RWM018 startup testing commenced on the afternoon of April 16, 2018. There were two pumping periods. The first period lasted 25 minutes at a pumping rate of 55 gpm (maximum pump capacity). At 25 minutes the pump was stopped for 10 minutes before restarting for an additional 10 minutes at a pumping rate of 55 gpm (Figure 11). Drawdown measured in RWM018 is presented in Figure 11. The maximum drawdown during the startup testing was 16.2 ft which yields a specific capacity of 3.4 GPM/ft. Prior to pumping, there was about 26 ft of water above the top of screen and about 10 ft of water above the top of screen at the end of the startup testing.

Aquifer response during the startup testing was measured in several nearby monitoring wells. MSB1017CC was chosen for this initial analysis due to its proximity to RWM018 and because it is screened in the middle of the interval for RWM018. The intent of this analysis was to provide initial estimates of aquifer properties for use in analyzing the results of the aquifer pumping test. Figure 12 shows the measured and predicted aquifer response for MSB107CC during startup testing (Theis confined aquifer solution). The analysis indicates a preliminary value of transmissivity of 0.76 ft^2/min and a storativity of 0.0001. Using an average aquifer thickness of 55 ft yields a hydraulic conductivity of about 20 ft/day (7.0E-03 cm/sec). These values were used as initial estimates in the subsequent analysis of aquifer pumping data.

3.3 Step Drawdown Testing

Step-drawdown testing was conducted as discussed in Section 2.2. The goal of the step-drawdown testing was to establish the baseline performance characteristics of RWM018. Estimates of specific capacity, well efficiency, and head loss coefficients were made based on the results. Two step-drawdown tests were conducted.

The first step-drawdown test commenced on the morning of May 10,2018. Pumping rate was increased in 3 increments with approximately 2 hours per interval. The pumping rates were approximately 20, 40, and 55 gpm (pump maximum). Figure 13 shows the water level response in RWM018 associated with the step-drawdown test. Specific capacities were determined for each pumping interval and are shown in Figure 13 and provided in Table 7. These data were converted to specific discharge (s/Q) and plotted as a function of pumping rate (Q) [Figure 14]. A linear regression fit to the data provided the well loss coefficients B (y-intercept) and C (slope) [Table 8]. These coefficients were used to calculate the well efficiency using Equation 2-3. Figure 15 shows a plot of well efficiency as a function of pumping rate for step-drawdown test 1.

The second step-drawdown test was conducted in the same manner as the first and produced similar results. This test was initiated on May 14, 2018. Targeted pumping rates were 20, 40 and 55 gpm (pump maximum) and pumping intervals were approximately 2 hours. Figure 16 shows the water level response in RWM018 associated with the step drawdown test. Specific capacities were determined for each pumping interval and are shown in Figure 16 and provided in Table 7. These data were converted to specific discharge (s/Q) and plotted as a function of pumping rate (Q) [Figure 17]. As with the first step-drawdown test, a linear regression fit to the data provided the well loss coefficients B and C (Table 8). These coefficients were used to calculate the well efficiency using Equation 2-3. Figure 18 shows a plot of well efficiency as a function of pumping rate for step-drawdown test 2.

Figure 19 and Figure 20 present head loss plots for the two step-drawdown tests. These plots illustrate the effects of well losses on the total head loss in the pumping well. As expected, well losses increase with increasing pumping rate. The predicted head loss compares reasonably well with the observed data.

The specific capacity at the final step for both step-drawdown tests was approximately 3.2 GPM/ft of drawdown. This compares favorably to the initial estimate of 3.4 GPM/ft calculated from the startup testing data. The data from the startup testing may overestimate specific capacity given the short duration of the test. The static water level in RWM018 prior to the first step-drawdown test was approximately 205 ft msl. With a top of screen elevation of 179 ft msl, this yields 26 ft of useable head. Based on a specific capacity of 3.2 GPM/ft, RWM018 can produce a maximum of 83 gpm with drawdown at the top of screen. Well efficiencies at the final step of the step-drawdown tests were approximately 91% using the well loss coefficients and Equation 2-3.

3.4 Aquifer Pumping Test at RWM018

The aquifer pumping test at RWM018 was conducted as described in Section 2.3 and took place between May 14, 2018 10:02 AM and May 24, 2018 13:29 PM. The pumping test ended when an unplanned system wide shutdown occurred. Water levels were monitored in RWM018 and several nearby monitoring wells (Table 1). Data collected from these wells were corrected for barometric effects as described in Section 2.5. Data were analyzed using the Hantush-Jacob method (1955, 1961a and b) for leaky, confined aquifers using the computer code AQTESOLV (Geraghty and Miller Inc., 2007) as described in 2.4. This method provides estimates of average aquifer properties including transmissivity and storativity.

The drawdown data for each monitoring well was analyzed separately in AQTESOLV. The results of these analyses are presented in Table 9 and Figure 22 through Figure 34. The maximum drawdown measured for each monitoring well over the duration of the pumping test is presented in Table 10. Results from all wells are presented in Table 9 except MSB101C. The estimated transmissivity for MSB101C was 1.72 ft^2/min which is more than 6 standard deviations (σ) from the mean of the other values. MSB101C is one of the most distant observation wells used in this test and is screened near the top of the LLAZ where transmissivity is expected to be lower. The maximum drawdown measured at MSB101C was 0.53 ft which is comparable to the range in barometric pressure during the pumping test (0.40 ft). Therefore, measurements collected at MSB101C were not analyzed or evaluated.

Transmissivity values for all wells ranged from 0.66 to 1.09 ft^2/min with an average value of 0.816 ft^2/min (σ =0.139 ft^2/min). Transmissivity was converted to hydraulic conductivity using Equation (2-13. For the RWM018 aquifer pumping test, an average aquifer thickness of 55 ft was used. Therefore, hydraulic conductivity ranged from 17.3 to 28.4 ft/day with an average value of 21.4 ft/day (7.54E-03 cm/sec) which is comparable to a clean sand (Freeze and Cherry, 1979). Storativity values ranged from 0.0001 to 0.00287 with an average value of 0.00052 (σ =0.00075). Leakage values (r/B) ranged from 0.0346 to 0.6078 with an average value of 0.2461 (σ = 0.1747). Equation 2-12 was solved for K' which is the hydraulic conductivity of the overlying confining layer (GCCZ). Values for K' ranged from 0.0011 to 0.0432 ft/day with an average value of 0.0062 ft/ day (2.34E-06 cm/sec) which is indicative of silt/clay (Freeze and Cherry, 1979).

Figure 35 shows the steady state drawdown in the LLAZ at RWM018 using the average hydraulic properties from the aquifer pumping test. Good agreement is noted between the model fit and observed drawdown values. The wells selected for this plot transect the study area (Figure 2) and are screened in the middle of the aquifer (Figure 7).

In addition to the single well analyses, all the drawdown data from the RWM018 aquifer pumping test were combined and analyzed in AQTESOLV. Figure 36 shows the results of the analysis and a good fit to the test data is noted. The transmissivity was estimated to be 0.9034 ft^2/min (K = 23.7 ft/day) and the storativity was estimated to be 0.0004. These values compare favorably to those from the single well analyses.

The LLAZ transmissivity data was plotted on a probability plot and linear regression was used to identify the best fit line for the data (Figure 37). The slope and y-intercept of the best fit line represent the mean and of the data (transmissivity plotted as a function of z-score) assuming a normal distribution to the data (Mandel, 1964). Figure 37 shows the transmissivity data are normally distributed (r^2=0.91) and all the data are within 2 standard deviations of the mean. Figure 38 presents a probability density function generated from the mean and standard deviation of the transmissivity data.

3.5 Verification Calculation

A verification calculation was performed using a subset of data from the RWM018 aquifer pumping test for MSB107CC. A spreadsheet calculation was made using the equations provided in Section 2.4 to estimate transmissivity and storativity using the Theis confined aquifer solution. Figure 21 shows a plot of the observed and predicted drawdown for MSB107CC (Theis method). The transmissivity (0.897 ft^2/min) and storativity (0.0001) values from this analysis were consistent with those determined using AQTESOLV.

3.6 Discussion of RWM018 Aquifer Test Results

Hydraulic properties estimated from the RWM018 aquifer pumping test compare well to those reported by Hiergesell (1992) [Table 5]. However, the current estimate of average transmissivity (0.816 ft^2/min) is slightly more than half the value at the start of system operations (RWM 8, 1.49 ft^2/min). The M-Area recovery well network has been in operation since the mid 1980s and has treated over 6.8 billion gallons of groundwater (SRNS, 2018). Marine and Bledsoe (1984) performed extensive groundwater characterization in M-Area and reported groundwater levels for the LLAZ as ranging from 230 to 240 ft msl (east to west) in the test area (Figure 39). Following an extended shutdown of the entire recovery well network in June 2018, water levels ranged from 202 to 216 ft msl. This represents a decrease in hydraulic head across the area of nearly 30 ft. As a confined aquifer is dewatered, load bearing capacity previously provided by pressurized water filling the sediment pore space is transferred to the granular skeleton of the aquifer. Therefore, a reduction in hydraulic head in a confined aquifer increases the effective stress on the aquifer skeleton and may result in aquifer compaction (Freeze and Cherry, 1979). Sand and gravel deposits are relatively incompressible, and the increase in effective stress has negligible effect on these aquifer materials. However, finer grained sediments such as silt and clay are more compressible. The increase in effective stress as water is removed from the aquifer can result in compaction which results in a reduction in transmissivity and storativity. These changes in aquifer hydraulics will be reflected in reduced well performance (i.e., specific capacity and efficiency). The upper portion of the LLAZ is comprised of a series of interbedded sands and clays. Therefore, it is possible that compaction of LLAZ sediments due to long term dewatering caused by operation of the recovery well network has caused an overall reduction in aquifer transmissivity and storativity compared to previously reported values measured at the start of operations.

3.7 Zone of Capture Analysis for RWM3 and RWM 5

A substantial hydrologic test data set was collected for the wells identified in Table 2 during the aquifer pumping test focused on RWM 3 and RWM 5. The main objective of the testing was to identify whether RWM 9 and RWM 11 are within the ZOC of RWM 3 and RWM 5. Table 12 presents the steady state maximum drawdown during the aquifer test. The maximum observed drawdown in RWM 9 was 1.6 ft and for RWM 11 it was 1.2 ft (Table 12). The range of barometric pressure fluctuations during the test covered a range of approximately 0.6 ft. The corrected drawdown at both RWM 9 and RWM 11 was 2 times greater than the range of barometric pressure. This suggests that both these wells are likely within the ZOC of RWM 3 and RWM 5 for the operating conditions tested.

Due to time constraints, the analysis of the data for aquifer hydraulic properties was limited to a combined analysis of drawdown using AQTESOLV. The transmissivity of the LLAZ was estimated to be 0.9917 ft^2/min and storativity was estimated to be 0.001 (Table 11). The average aquifer thickness near RWM 3 and RWM 5 was estimated to be 73 ft. This yields a hydraulic conductivity of 19.6 ft/day (6.9E-03 cm/sec) which is remarkably comparable to the average hydraulic conductivity from the RWM018 testing (21.4 ft/day). The AQTESOLV predicted drawdown values using average aquifer properties were output in grid format and contoured to show the effects of pumping near RWM 9 and RWM 11 (Figure 42). Based on observed maximums, using the average aquifer properties slightly overestimates drawdown near RWM 9 and RWM 11.

4.0 Conclusions

An aquifer pumping test was conducted on the Lost Lake Aquifer Zone (LLAZ) at the recently installed recovery well RWM018 in accordance with the approved test plan (Dixon, 2018). The objective of the testing was to determine baseline well performance parameters and aquifer hydraulic conductivity. Well performance parameters determined included specific capacity, well efficiency, and head loss coefficients. The specific capacity of RWM018 was determined to be approximately 3.2 gpm/ft of drawdown. At static conditions (all active recovery wells operating except RWM018), RWM018 has approximately 26 ft of head above the well screen. This suggests that RWM018 can sustain a maximum pumping rate of 83 gpm with drawdown at the top of screen. Well efficiency was inversely related to pumping rate and decreased from 97% to 91% over a pumping range of approximately 20 to 55 gpm. These results suggest that RWM018 is an efficient well and does not require any further well development activities. The aquifer head loss coefficient was determined to be 2.1 ft/ft^3/min and the well loss coefficient was determined to be 0.03 min^2/ft^5.

Aquifer response to pumping at RWM018 was measured in several nearby monitoring wells screened within the LLAZ. These data were used to calculate aquifer hydraulic properties using the Hantush-Jacob (1955, 1961a, and b) leaky aquifer model as implemented in the computer code AQTESOLV. The average transmissivity of the aquifer was determined to be 0.816 ft^2/min with a standard deviation of 0.139 ft^2/min. The average storativity of the aquifer was determined to be 0.0005 with a standard deviation of 0.0008. Using an average aquifer thickness of 55 ft, the hydraulic conductivity of the LLAZ near RWM018 is 21.4 ft/day (7.54E-03 cm/sec) with a standard deviation of 3.6 ft/day. For comparison, Hiergesell (1992) reported an average transmissivity of 0.836 ft^2/day (K = 30 ft/day, b =40.1) near RWM 16 whereas Geraghty and Miller (1987) reported a transmissivity of 1.49 ft^2/min (K = 38.9 ft/day, b =73 ft) for RWM 8 which is the nearest recovery well to RWM018. Aquifer compaction due to the reduction in hydraulic head associated with operation of the recovery well network may explain the difference between transmissivity and storativity values estimated for this project compared to values measured by Geraghty and Miller (1987) at the start of operations.

Following an extended shut down of the entire recovery well system, an aquifer pumping test was conducted to evaluate the zone of capture (ZOC) of RWM 3 and RWM 5. The objective of this testing was to determine whether the area of the aquifer near RWM 9 and RWM 11 is hydraulically controlled by RWM 3 and RWM 5. When the recovery well network was restarted, RWM 9 and RWM 11 were not restarted. The maximum drawdown observed for RWM 9 was 1.6 ft. The maximum drawdown observed for RWM 11 was 1.2 ft. Therefore, it was concluded that both wells were likely within the ZOC of RWM 3 and RWM 5 for the operating conditions tested.

In support of the ZOC analysis for RWM 3 and RWM 5, aquifer response was measured in several nearby monitoring wells screened within the LLAZ. These data, in combination with pumping rates from all operating recovery wells, were used to determine aquifer hydraulic properties using the Hantush-Jacob (1955, 1961a, and b) leaky aquifer model as implemented in the computer code AQTESOLV. All wells were simulated simultaneously. The transmissivity of the LLAZ aquifer was determined to be 0.9917 ft^2/min with a storativity value of 0.001. Using an average aquifer thickness of 73 ft (near RWM 3 and RWM 5), the hydraulic conductivity of the aquifer is 19.6 ft/day (6.90E-03 cm/sec). This compares favorably with the hydraulic conductivity estimated near RWM018 (21.4 ft/day).

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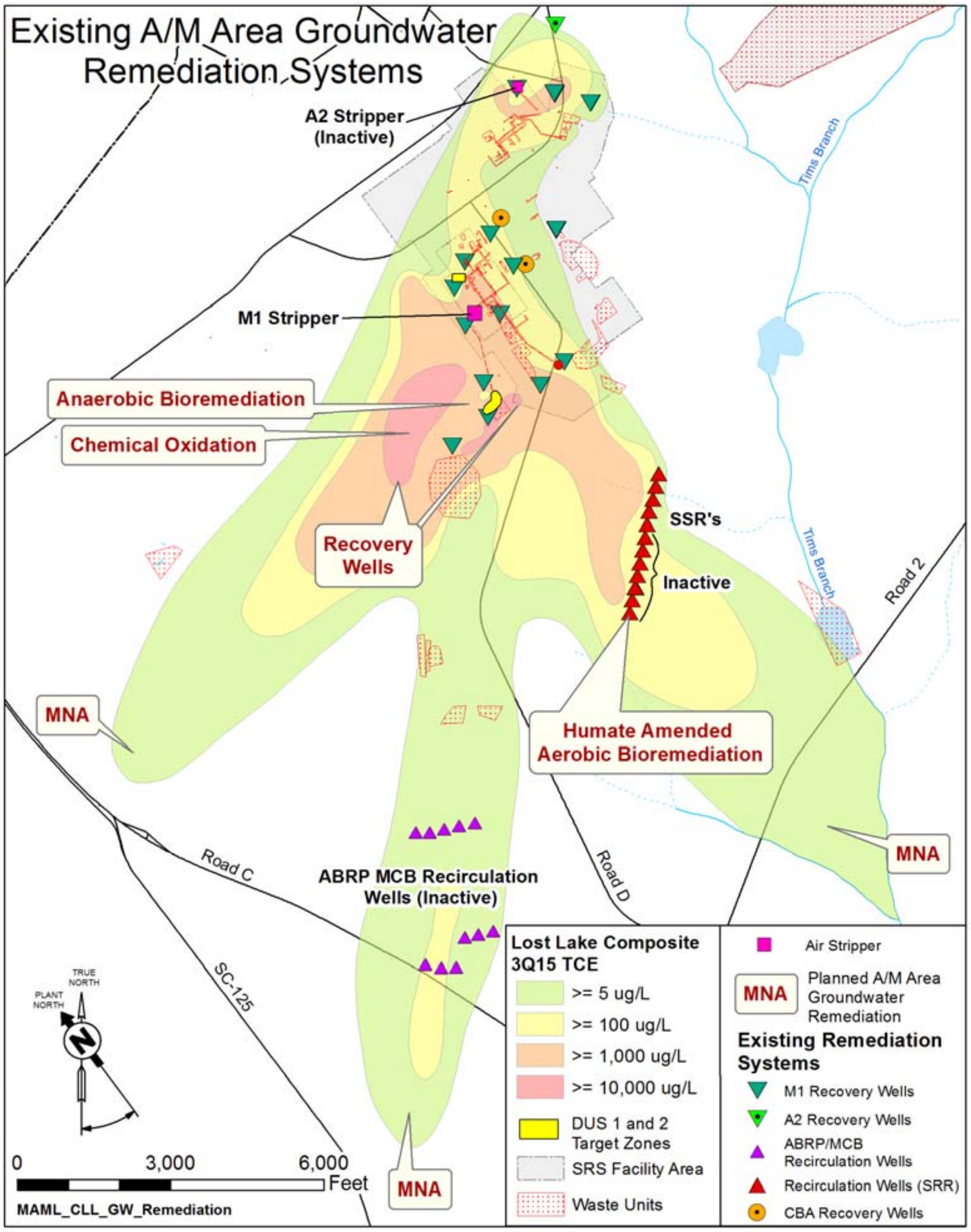

Figure 1. A/M Area VOC Plume and Groundwater Remediation Systems

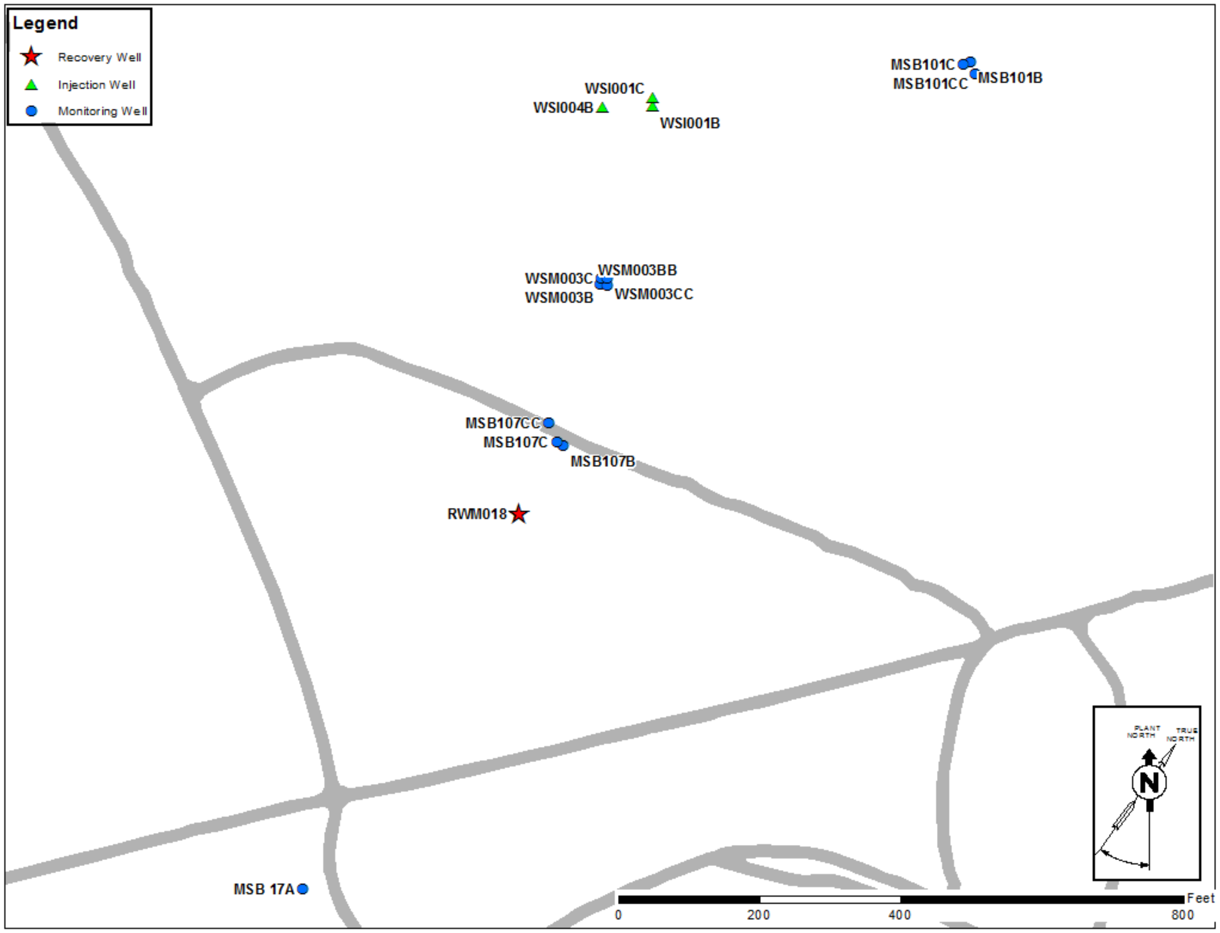

Figure 2: Location of Recovery Well RWM018 and Nearby Observation Wells.

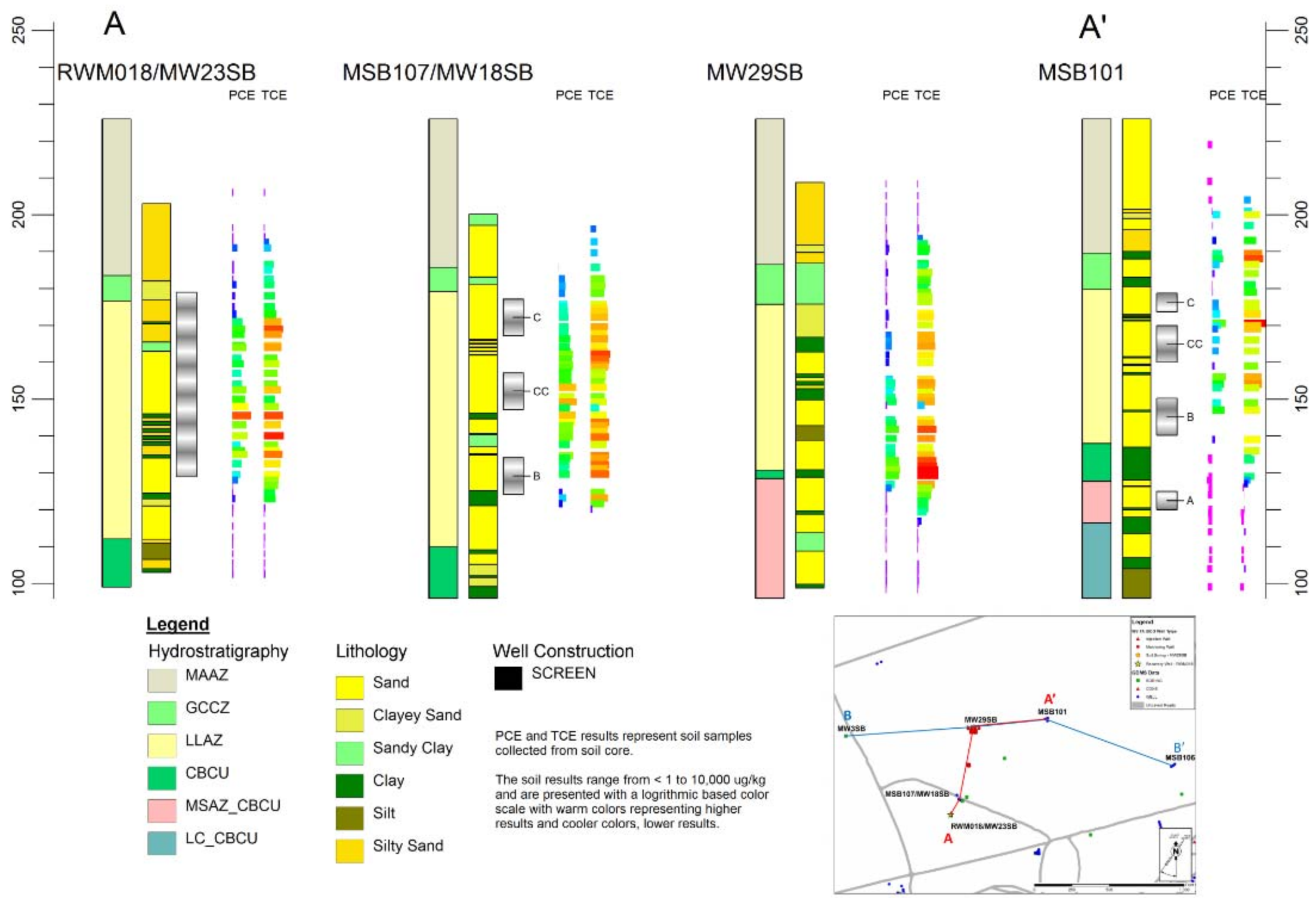

Figure 3: Generalized Geologic Cross-Section Across RWM018 Study Area.

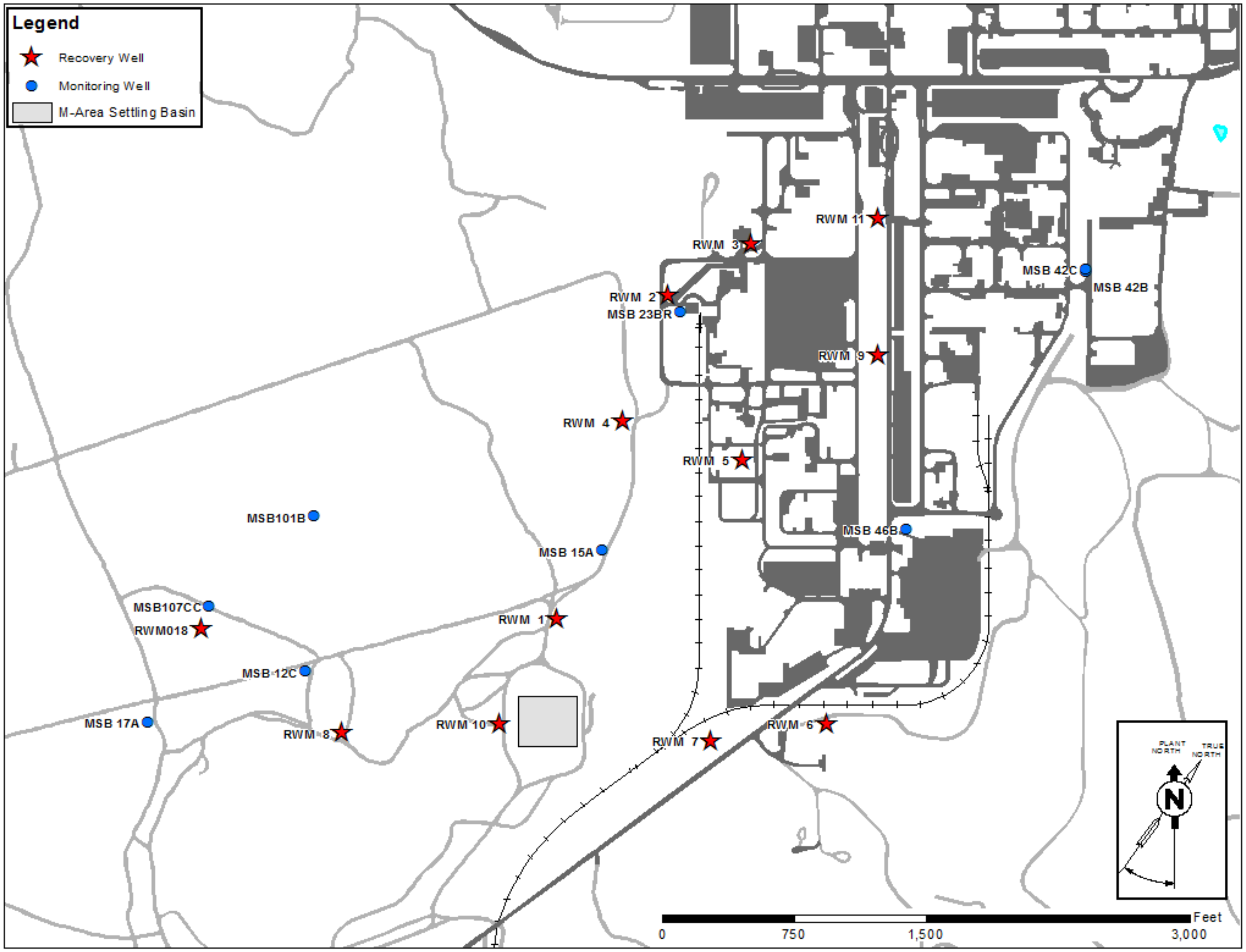

Figure 4: Recovery Well Network and Observation Wells Near RWM 3 and RWM 5.

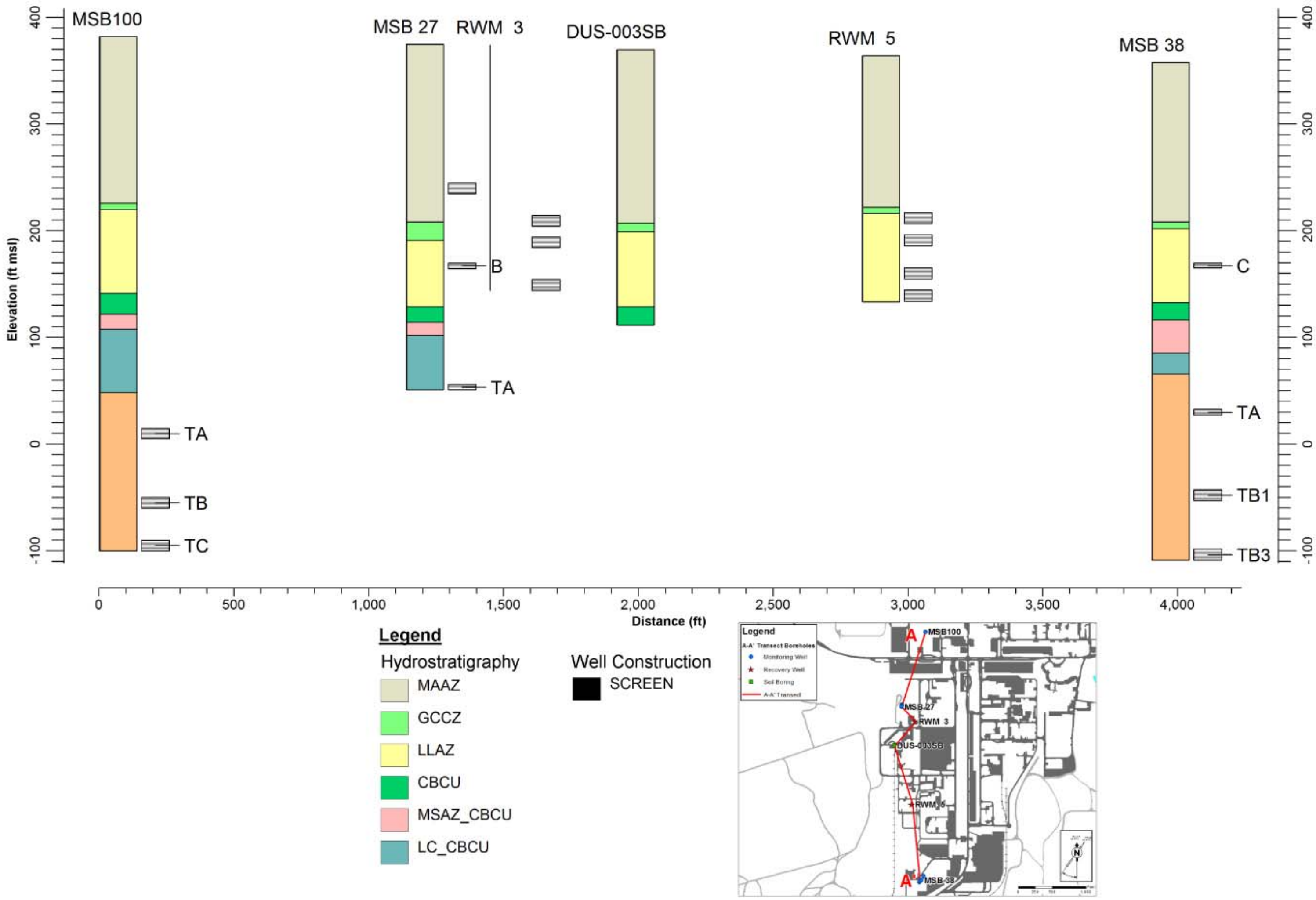

Figure 5: Generalized Geologic Cross-Section Across RWM 3 and RWM 5 Study Area.

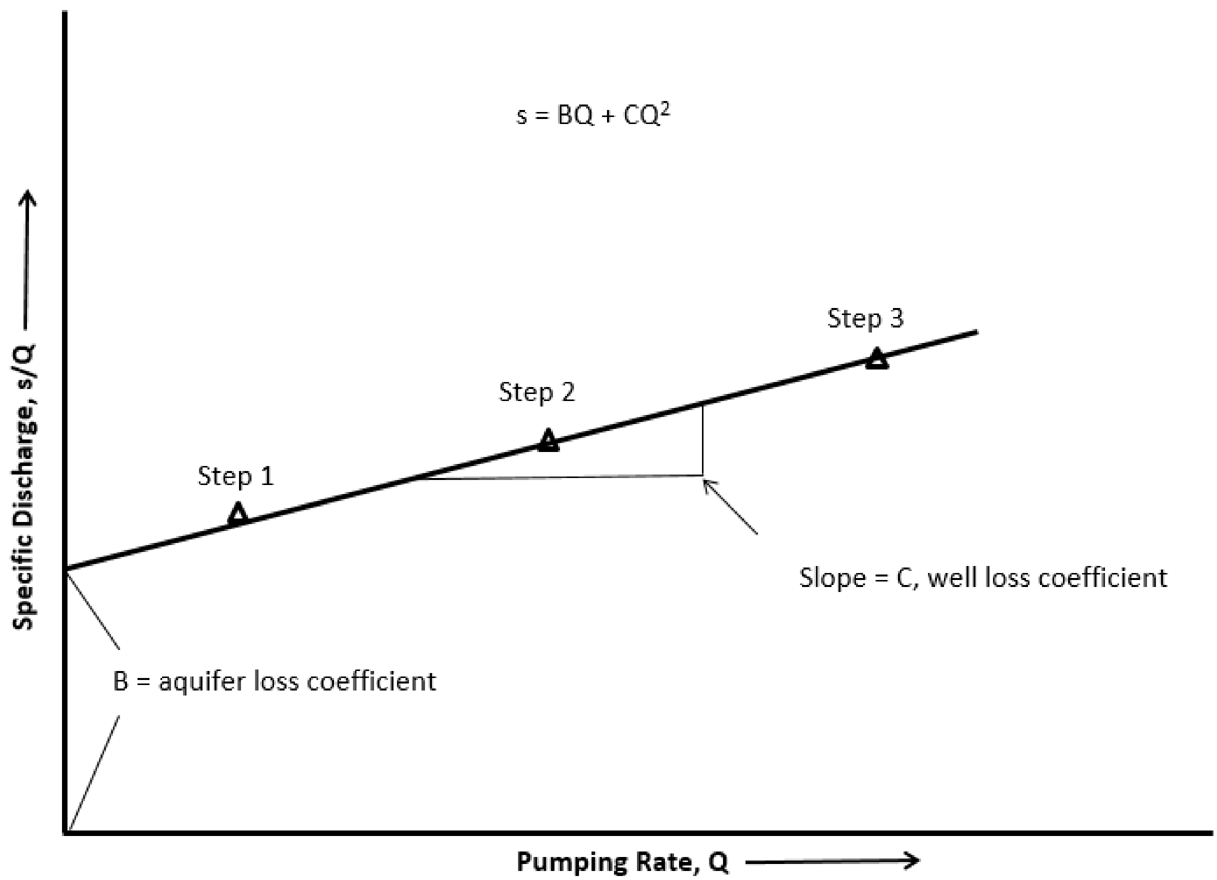

Figure 6: Plot for Calculating Formation Loss Coefficient B and Well Lose Coefficient C from Step Drawdown Tests (adapted from Spane and Newcomer, 2007).

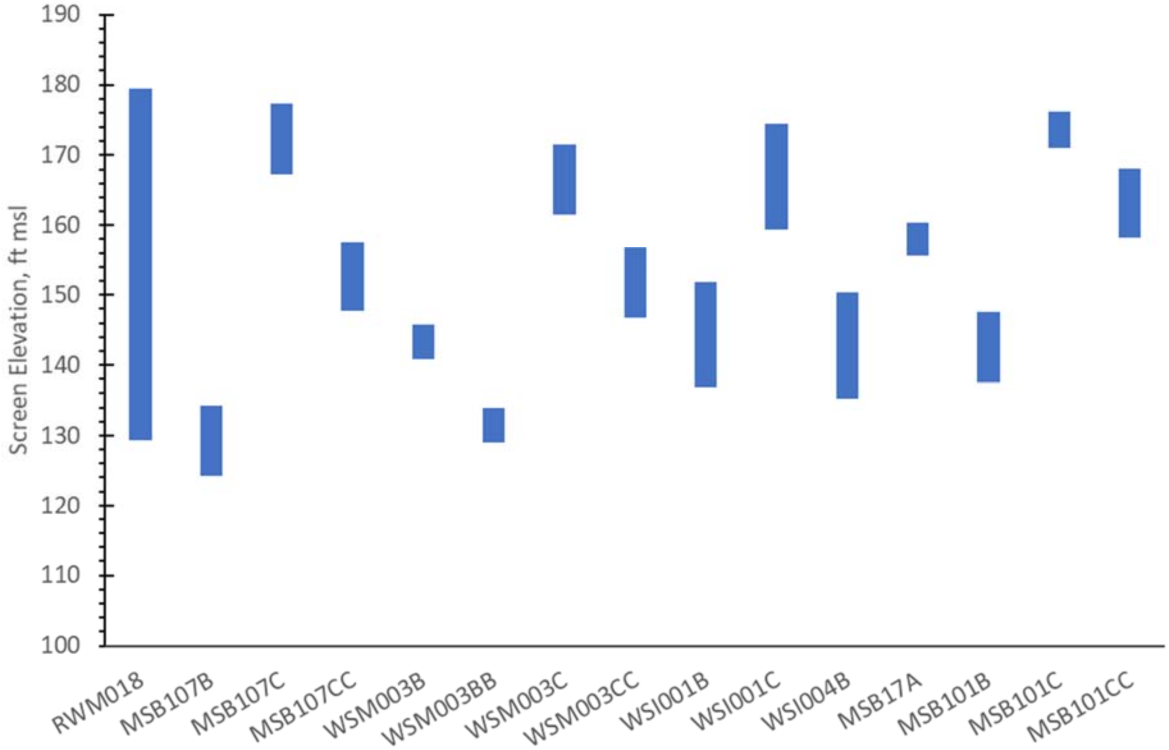

Figure 7: Screen Elevations for Lost Lake Aquifer Test at RWM018

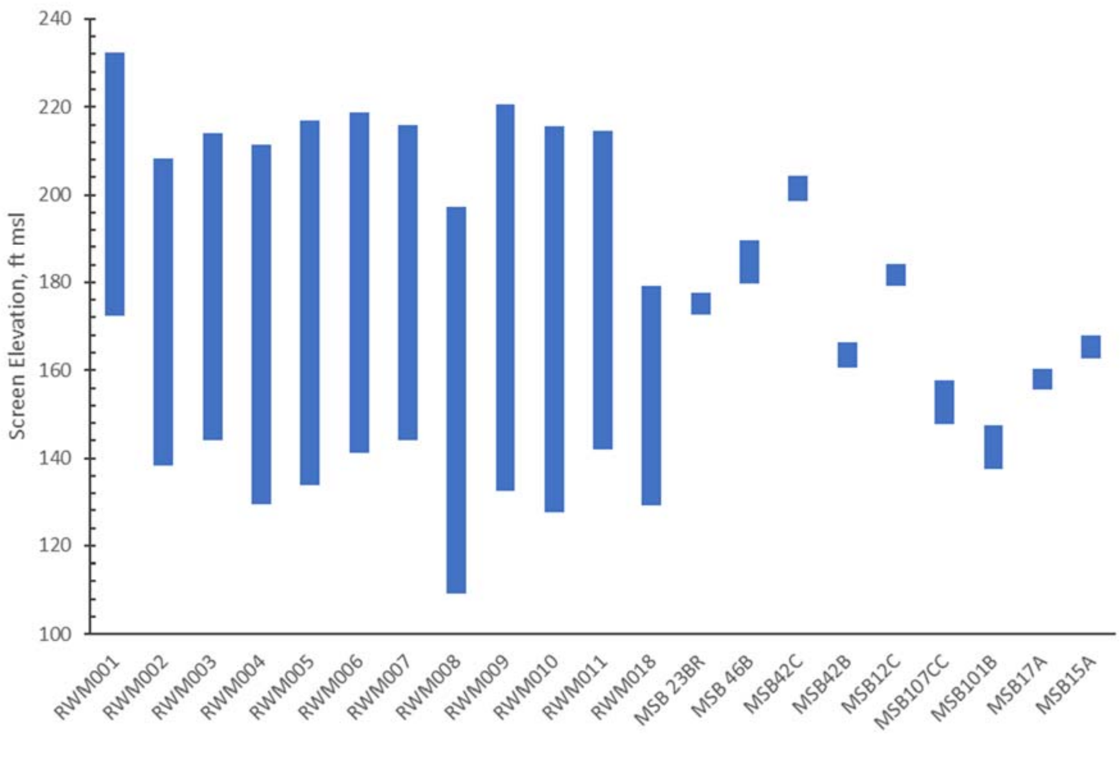

Figure 8: Screen Elevations for Lost Lake Aquifer Test at RWM 3 and RWM 5

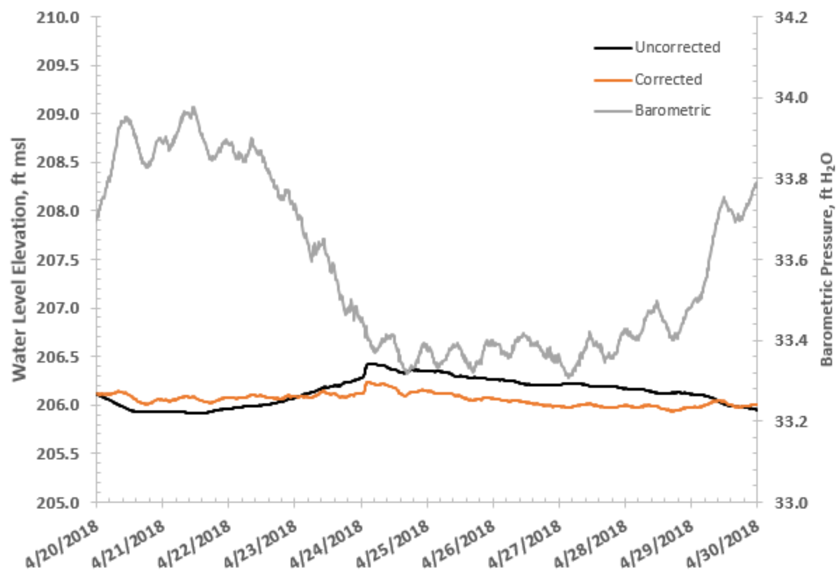

Figure 9: Effect of Barometric Efficiency Corrections to Water Level Data from MSB107CC.

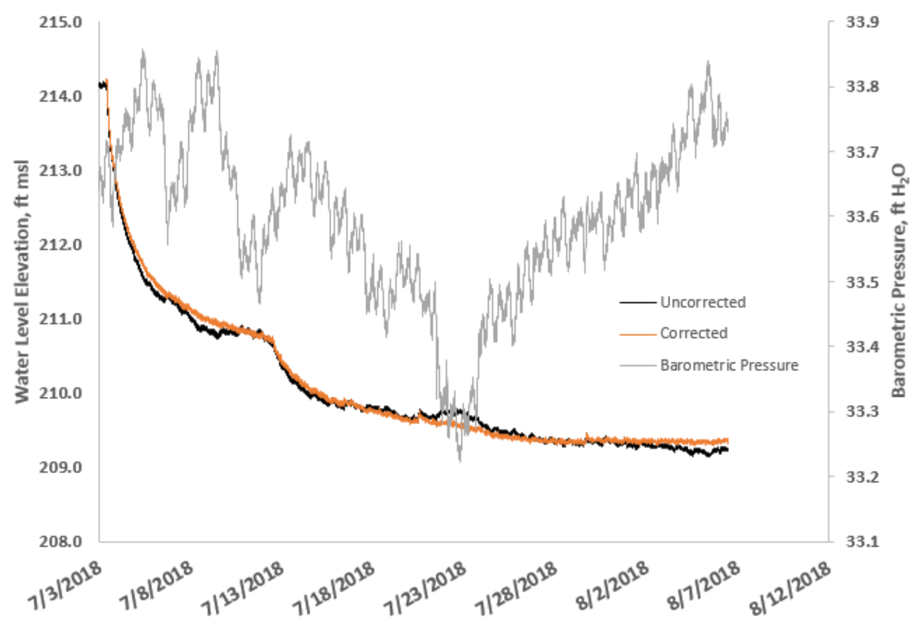

Figure 10: Effect of Barometric Efficiency Corrections to Water Level Data from MSB15A.

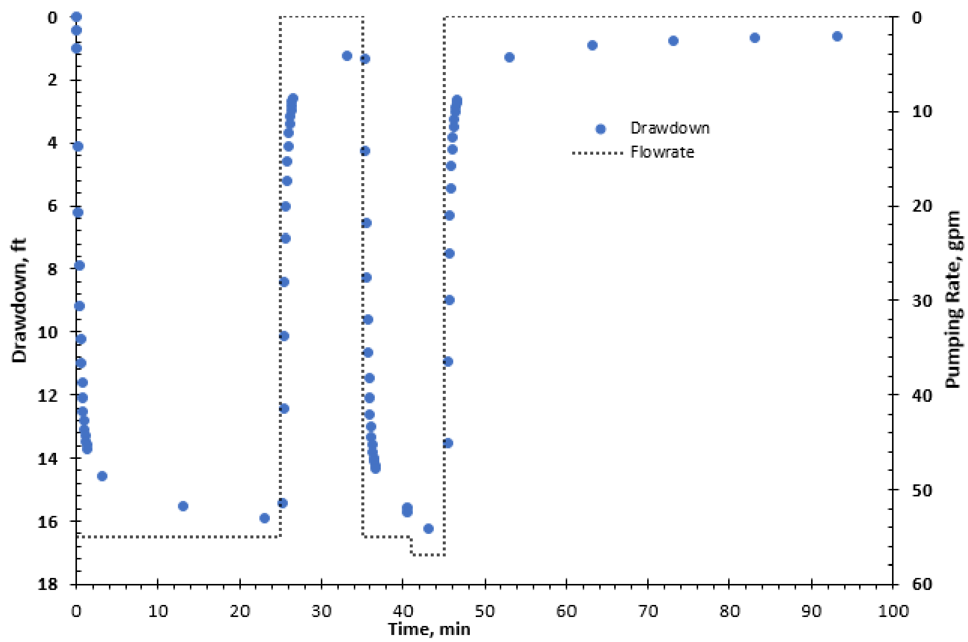

Figure 11. Drawdown Measured in RWM018 as a Function of Time During Startup Testing on 4/16/2018.

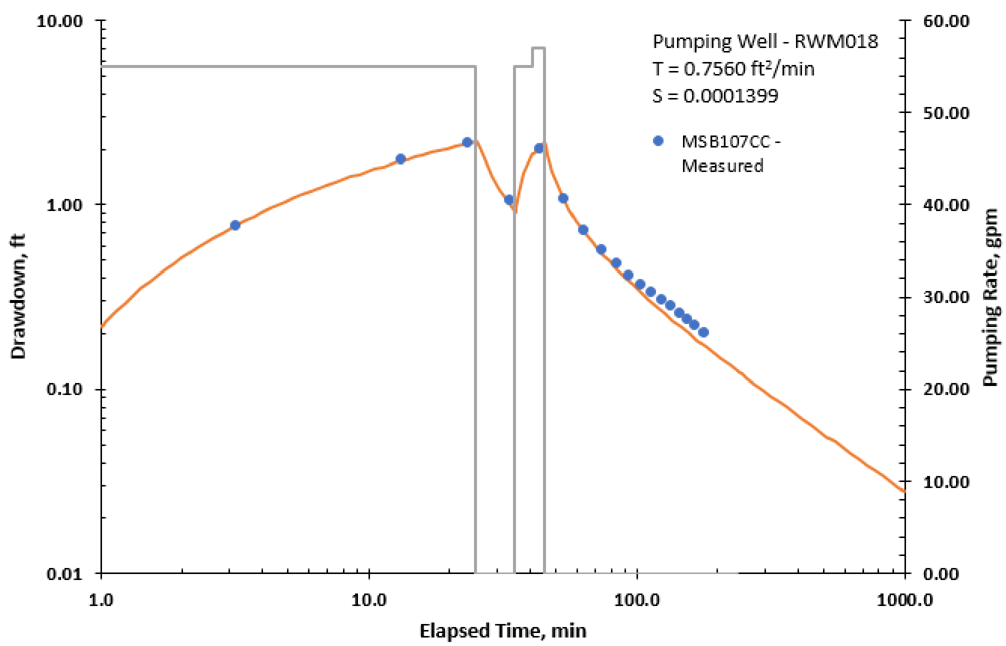

Figure 12. Drawdown as a Function of Time for MSB107CC Using Hantush-Jacob Solution and Startup Testing Data.

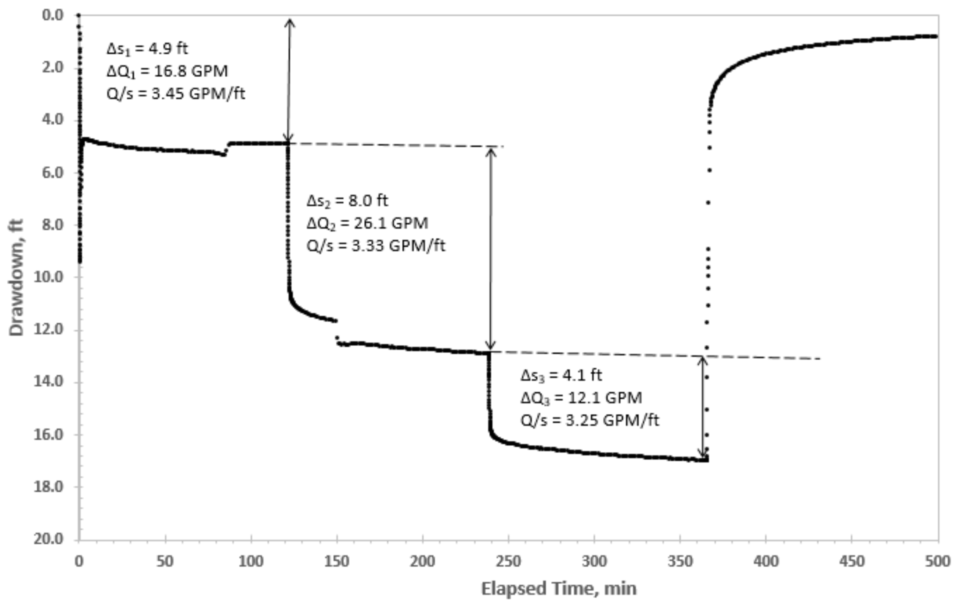

Figure 13. Drawdown as a Function of Time for Step-Drawdown Test 1 at RWM018.

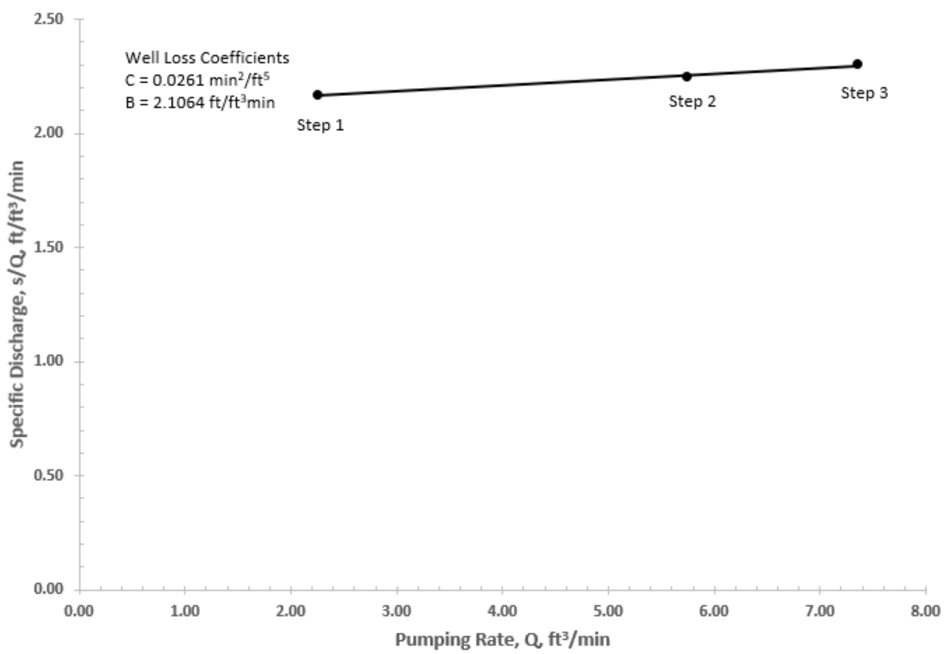

Figure 14. Specific Discharge as a Function of Pumping Rate for Step-Drawdown Test 1 at RWM018.

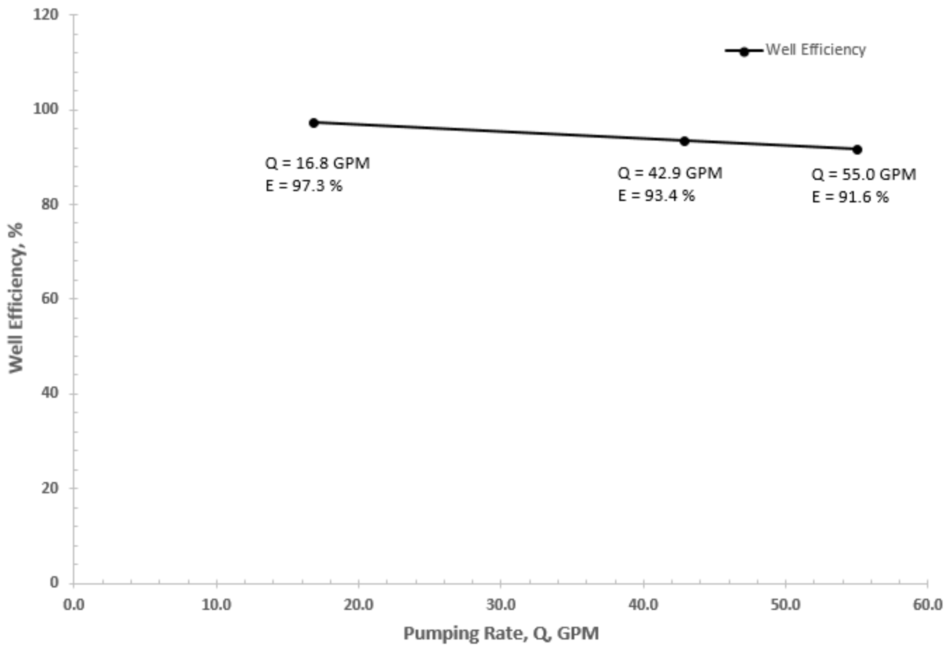

Figure 15. Well Efficiency as a Function of Pumping Rate for Step-Drawdown Test 1 at RWM018.

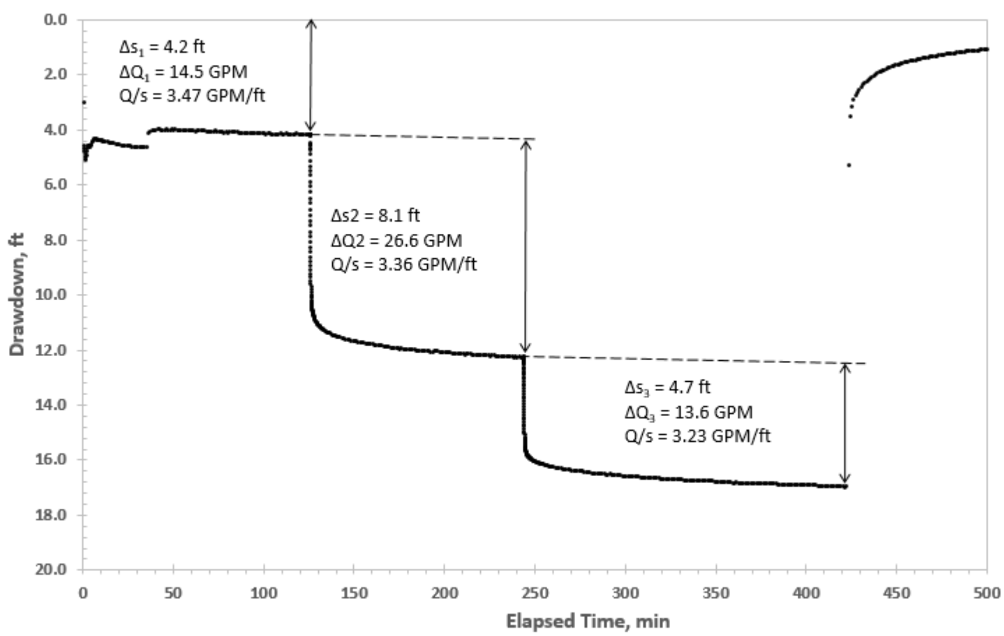

Figure 16. Drawdown as a Function of Time for Step-Drawdown Test 2 at RWM018.

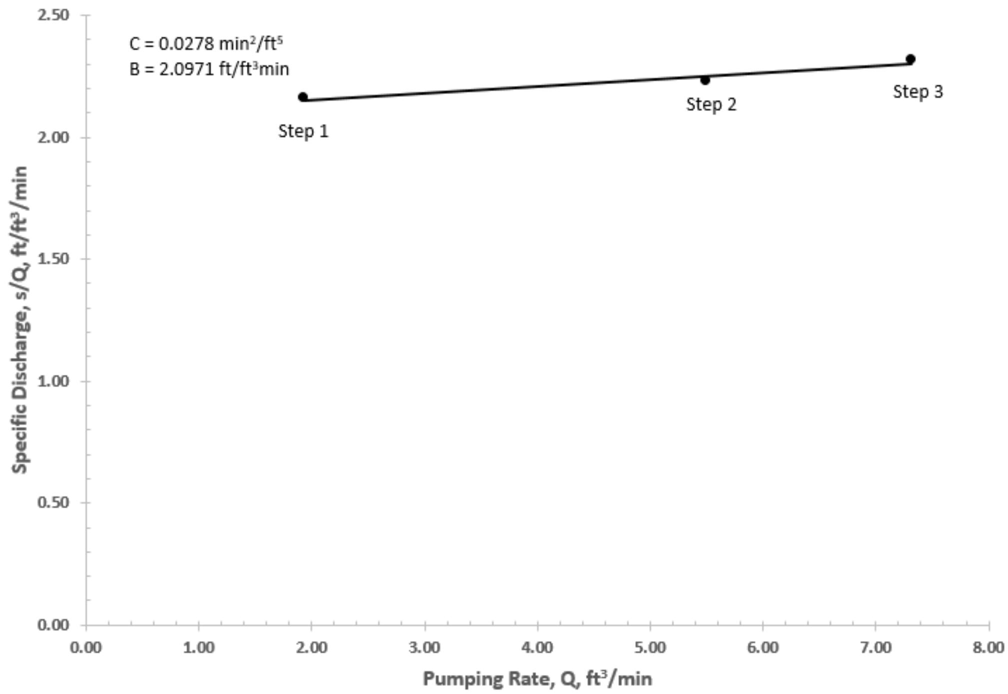

Figure 17. Specific Discharge as a Function of Pumping Rate for Step-Drawdown Test 2 at RWM018.

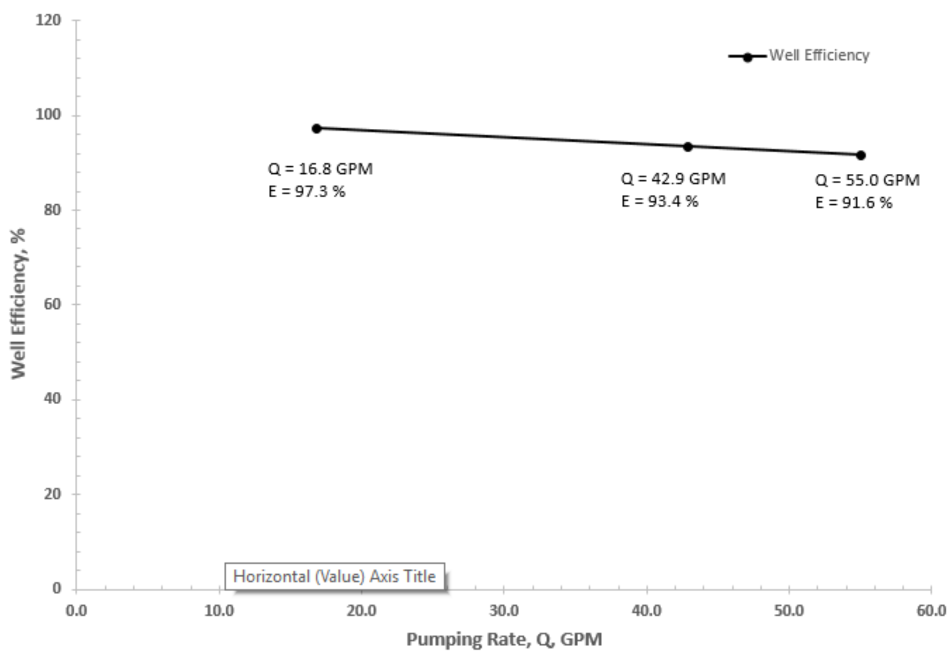

Figure 18. Well Efficiency as a Function of Pumping Rate for Step-Drawdown Test 2 at RWM018.

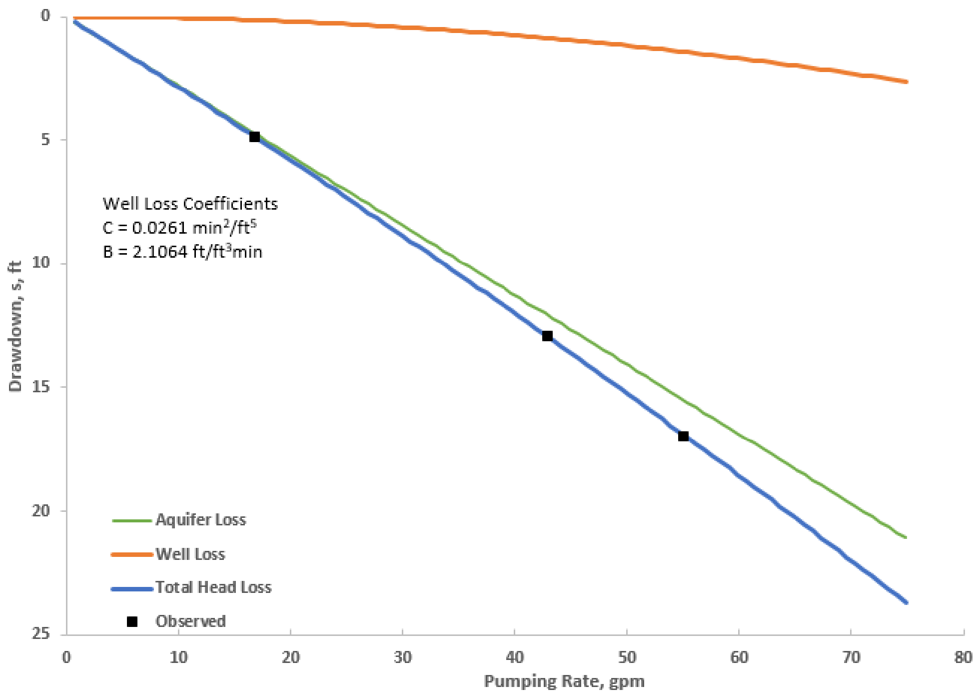

Figure 19. Head Loss Plot for Step-Drawdown Test 1 (RWM018).

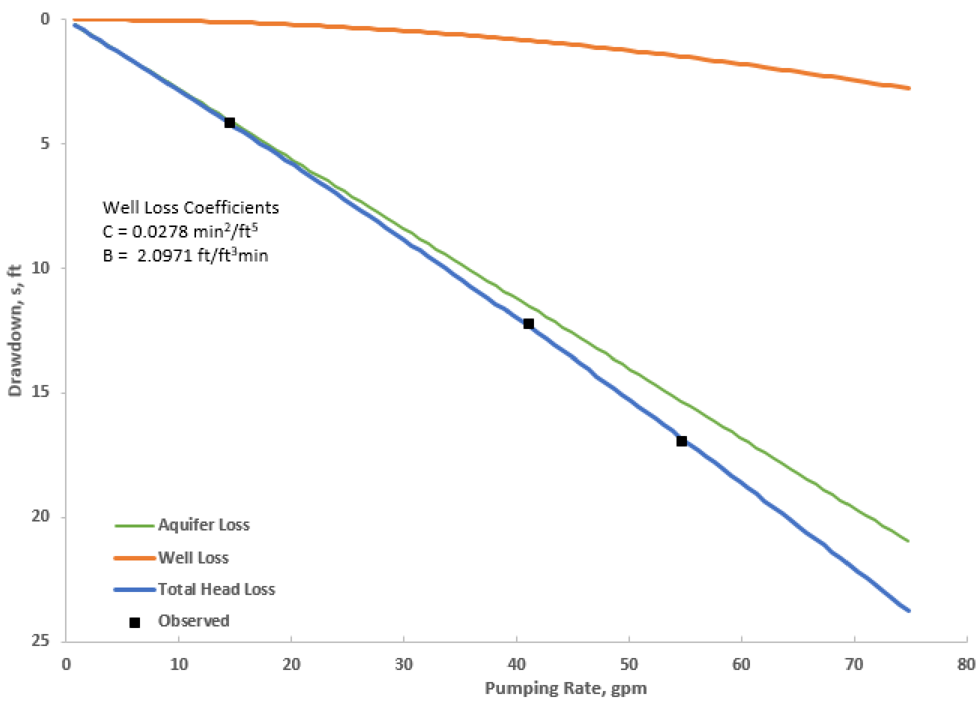

Figure 20. Head Loss Plot for Step-Drawdown Test 2 (RWM018).

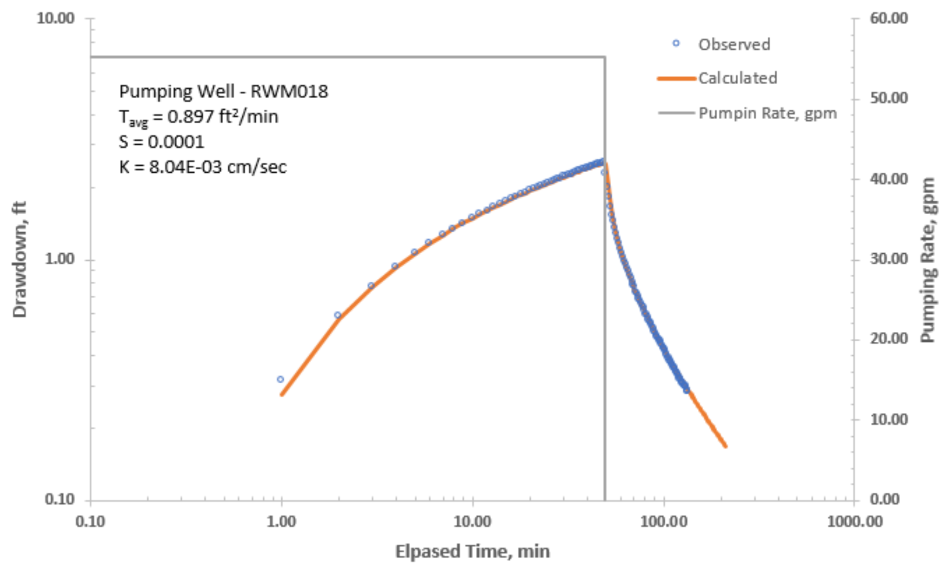

Figure 21. Drawdown as a Function of Time for MSB107CC Using Theis Solution (spreadsheet calculation for verification).

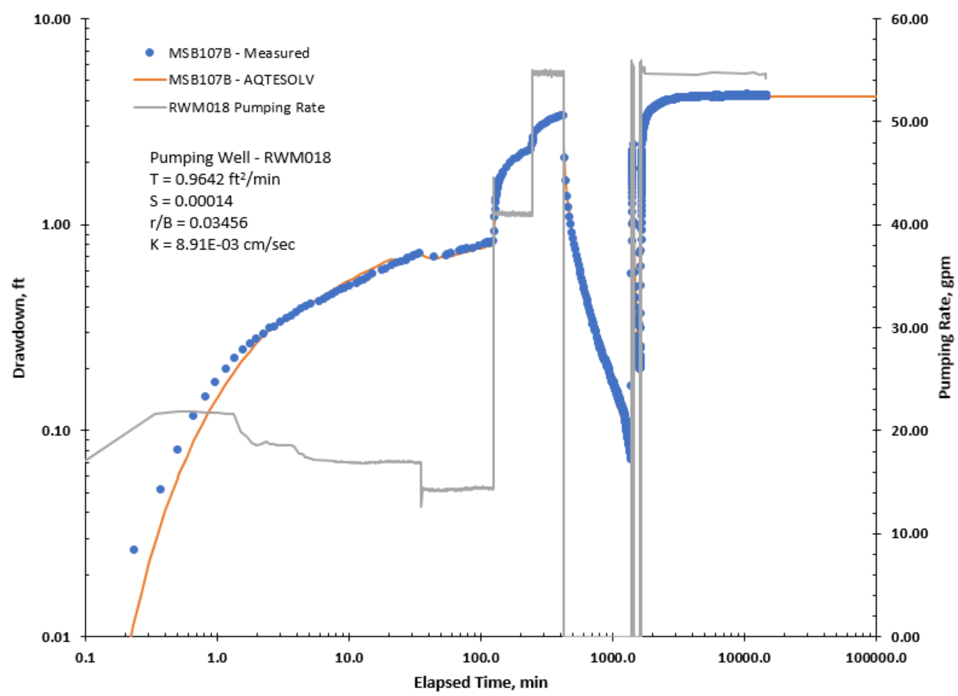

Figure 22. Drawdown as a Function of Time for MSB107B Using Hantush-Jacob Leaky Aquifer Solution.

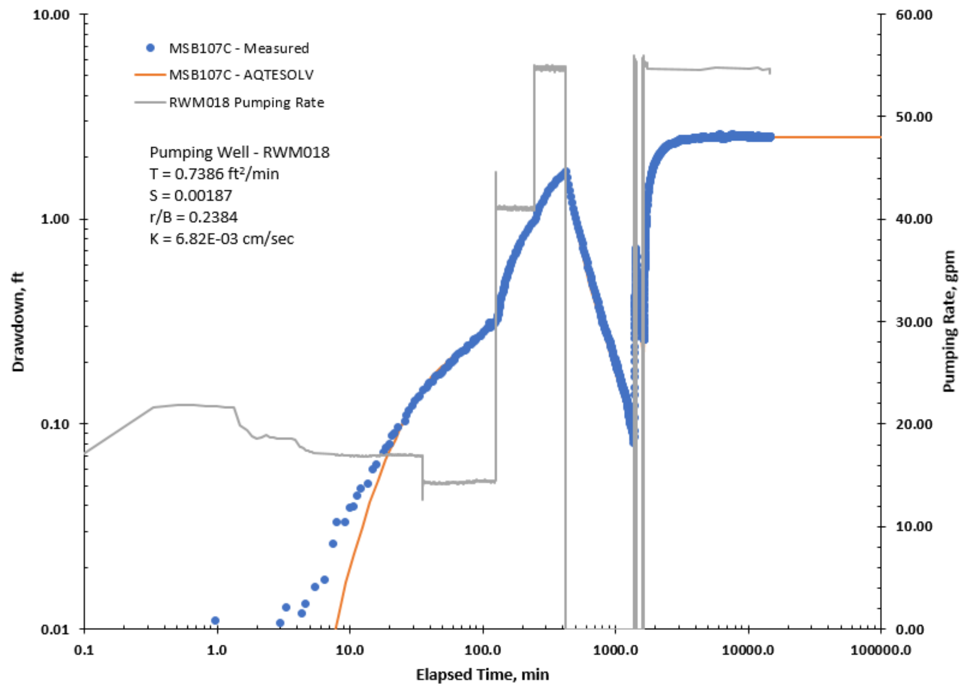

Figure 23. Drawdown as a Function of Time for MSB107C Using Hantush-Jacob Leaky Aquifer Solution.

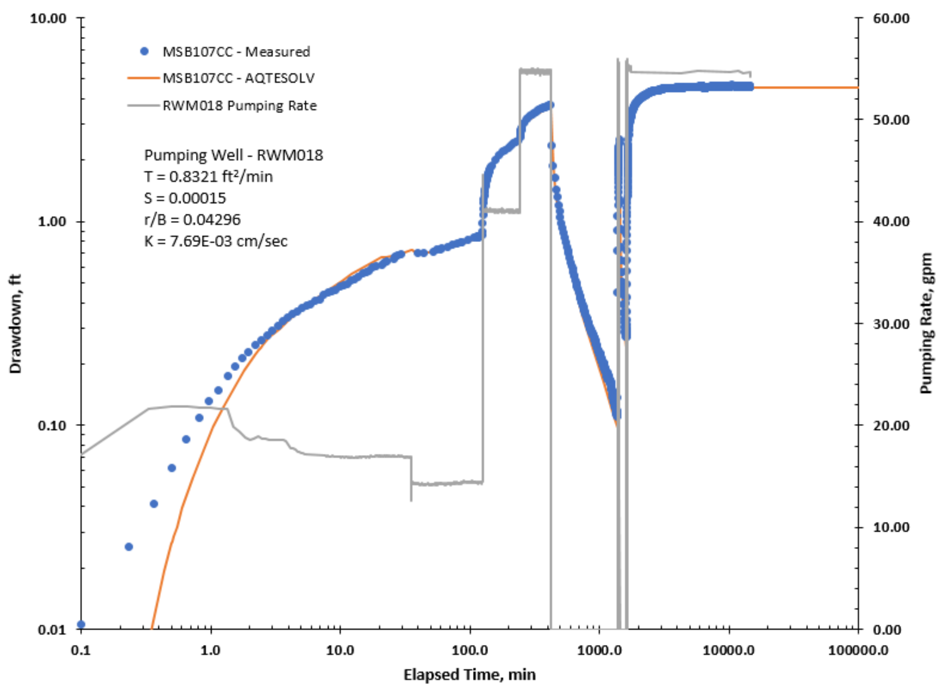

Figure 24. Drawdown as a Function of Time for MSB107CC Using Hantush-Jacob Leaky Aquifer Solution.

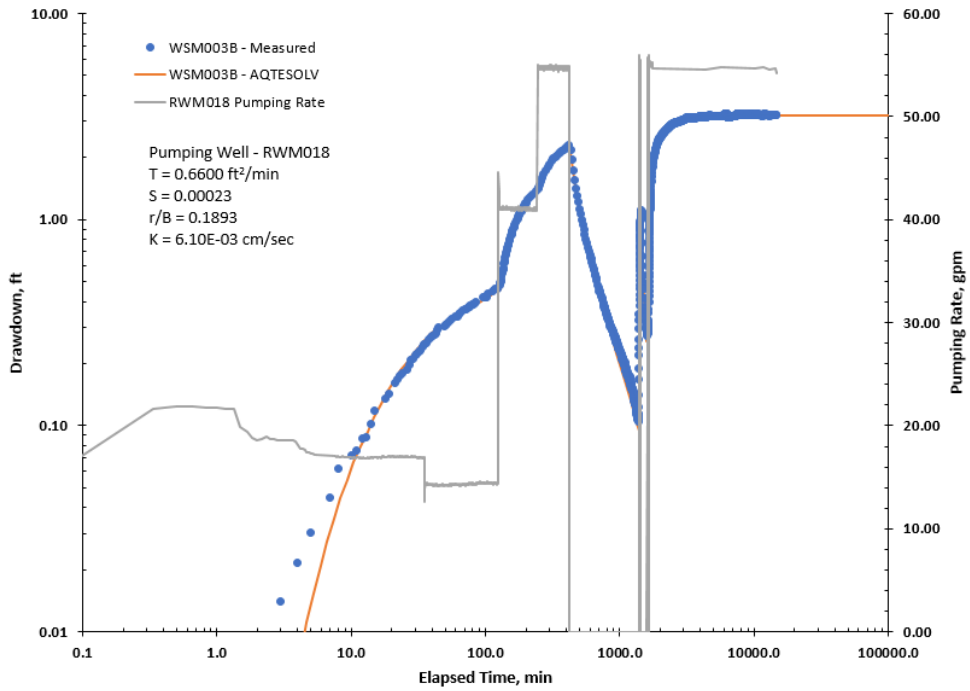

Figure 25. Drawdown as a Function of Time for WSM003B Using Hantush-Jacob Leaky Aquifer Solution.

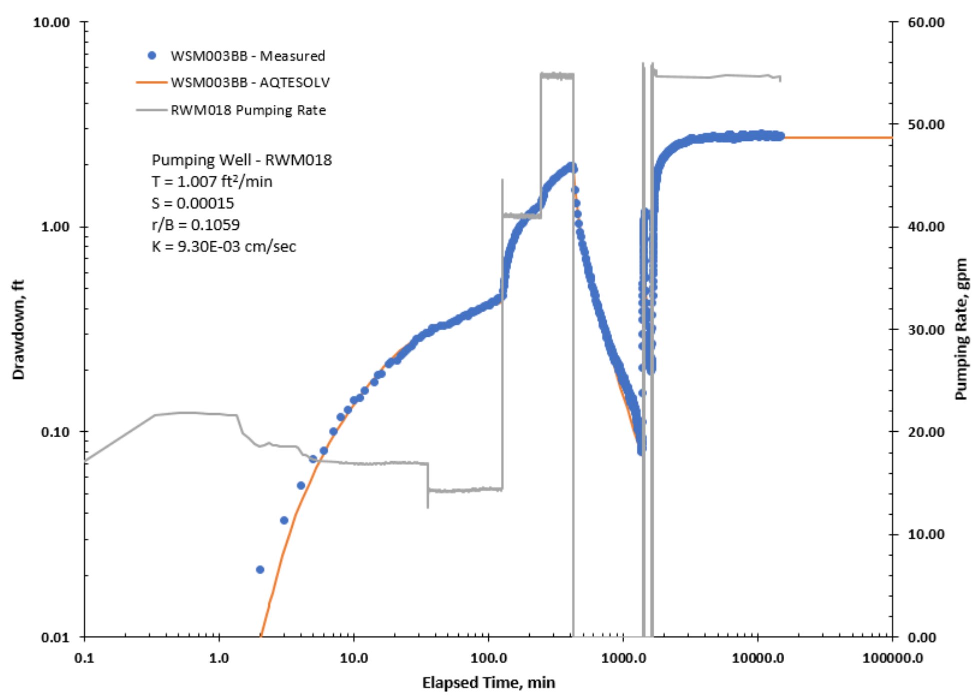

Figure 26. Drawdown as a Function of Time for WSM003BB Using Hantush-Jacob Leaky Aquifer Solution.

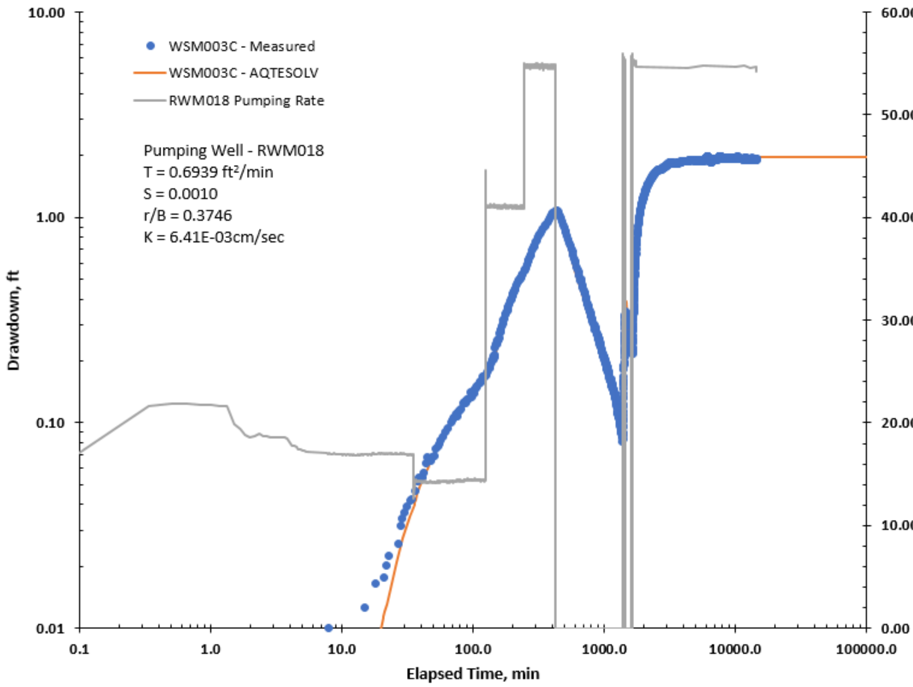

Figure 27. Drawdown as a Function of Time for WSM003C Using Hantush-Jacob Leaky Aquifer Solution.

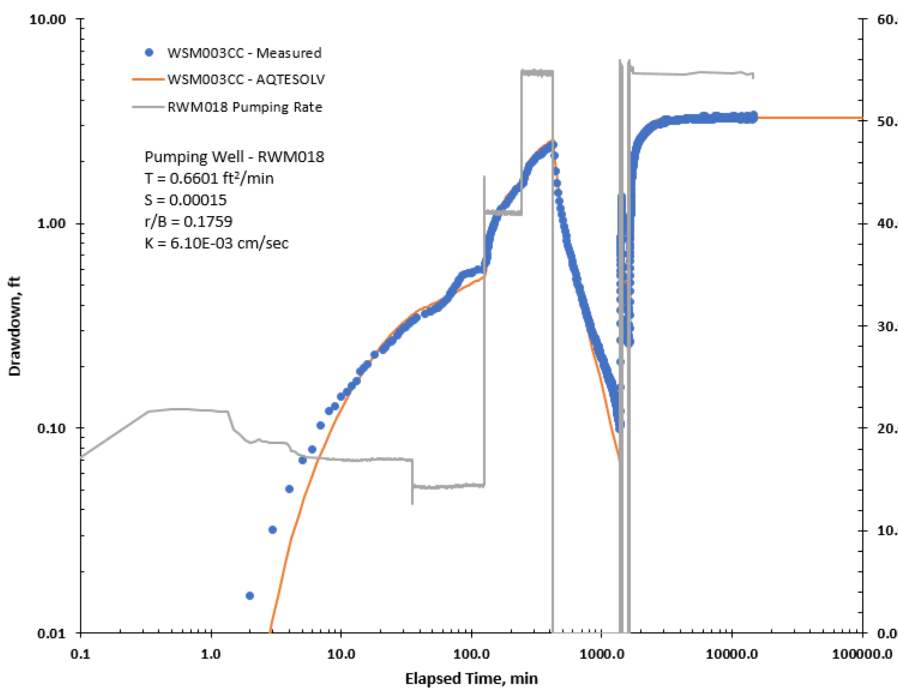

Figure 28. Drawdown as a Function of Time for WSM003CC Using Hantush-Jacob Leaky Aquifer Solution.

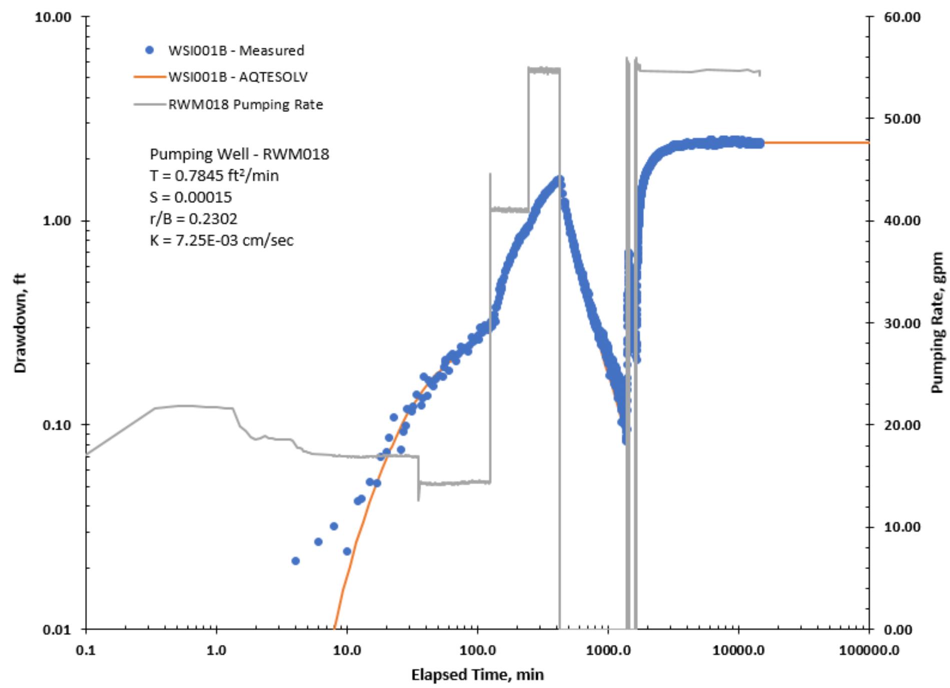

Figure 29. Drawdown as a Function of Time for WSI001B Using Hantush-Jacob Leaky Aquifer Solution.

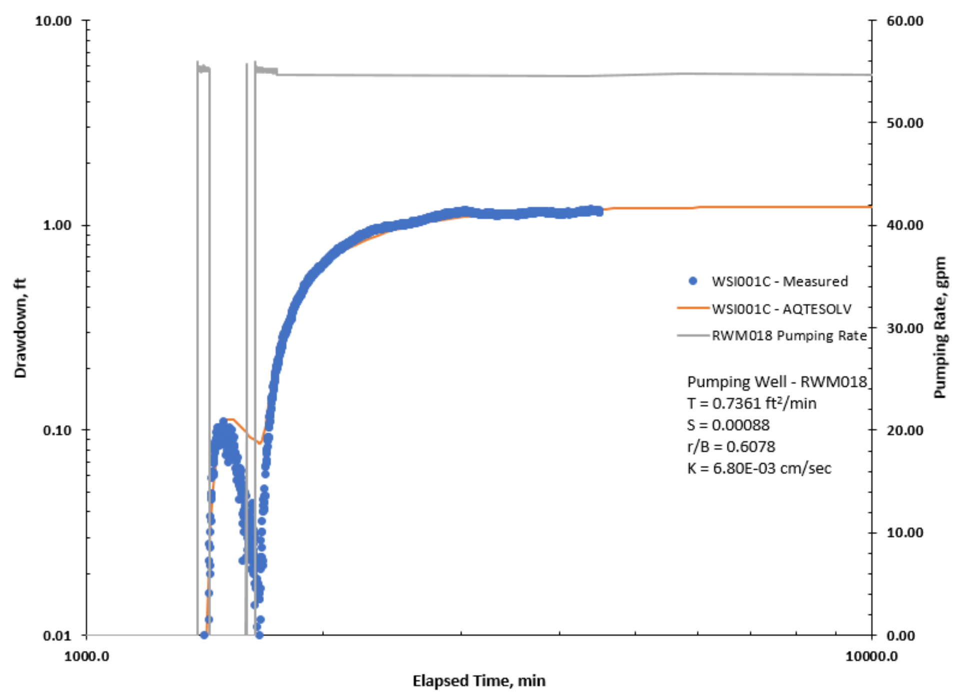

Figure 30. Drawdown as a Function of Time for WSI001C Using Hantush-Jacob Leaky Aquifer Solution.

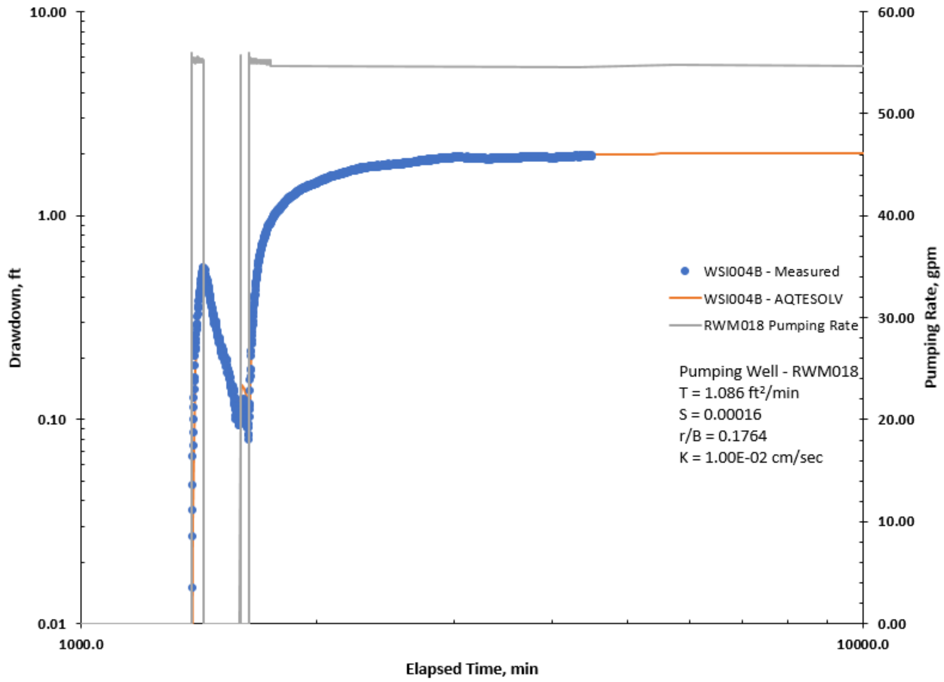

Figure 31. Drawdown as a Function of Time for WSI004B Using Hantush-Jacob Leaky Aquifer Solution.

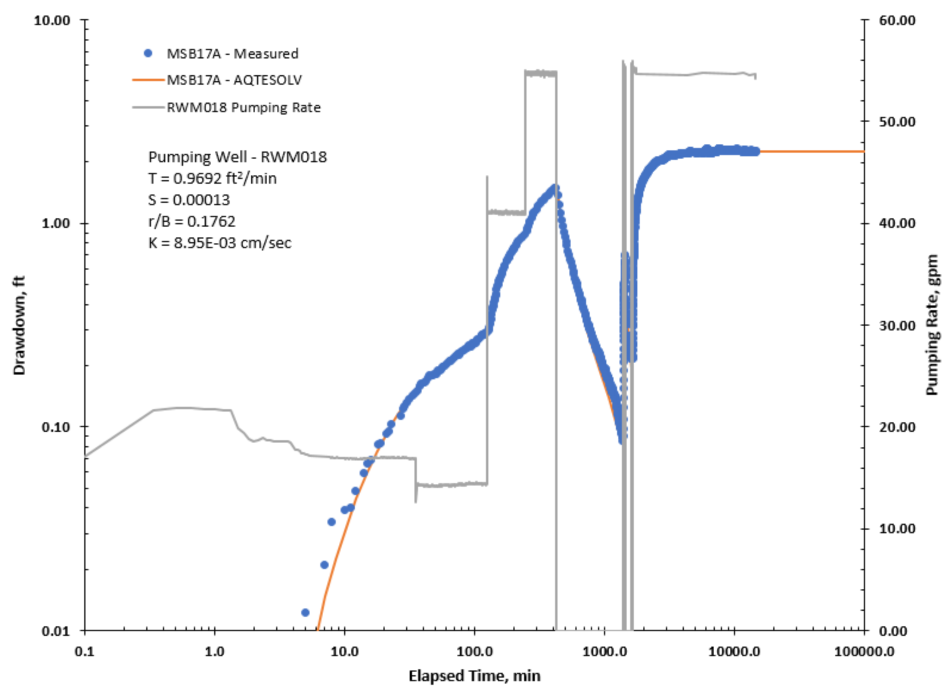

Figure 32. Drawdown as a Function of Time for MSB17A Using Hantush-Jacob Leaky Aquifer Solution.

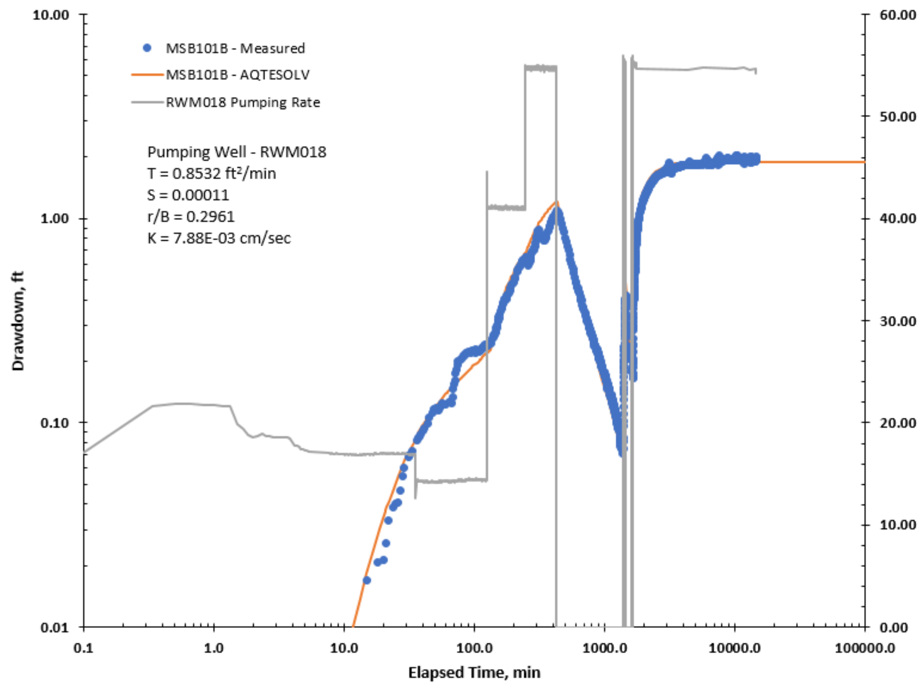

Figure 33. Drawdown as a Function of Time for MSB101B Using Hantush-Jacob Leaky Aquifer Solution.

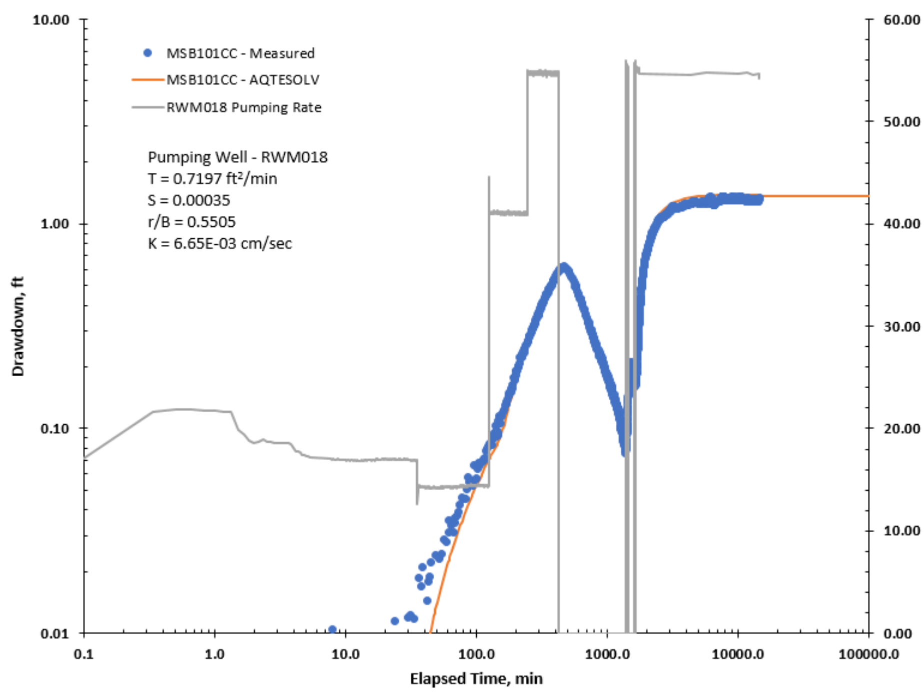

Figure 34. Drawdown as a Function of Time for MSB101CC Using Hantush-Jacob Leaky Aquifer Solution.

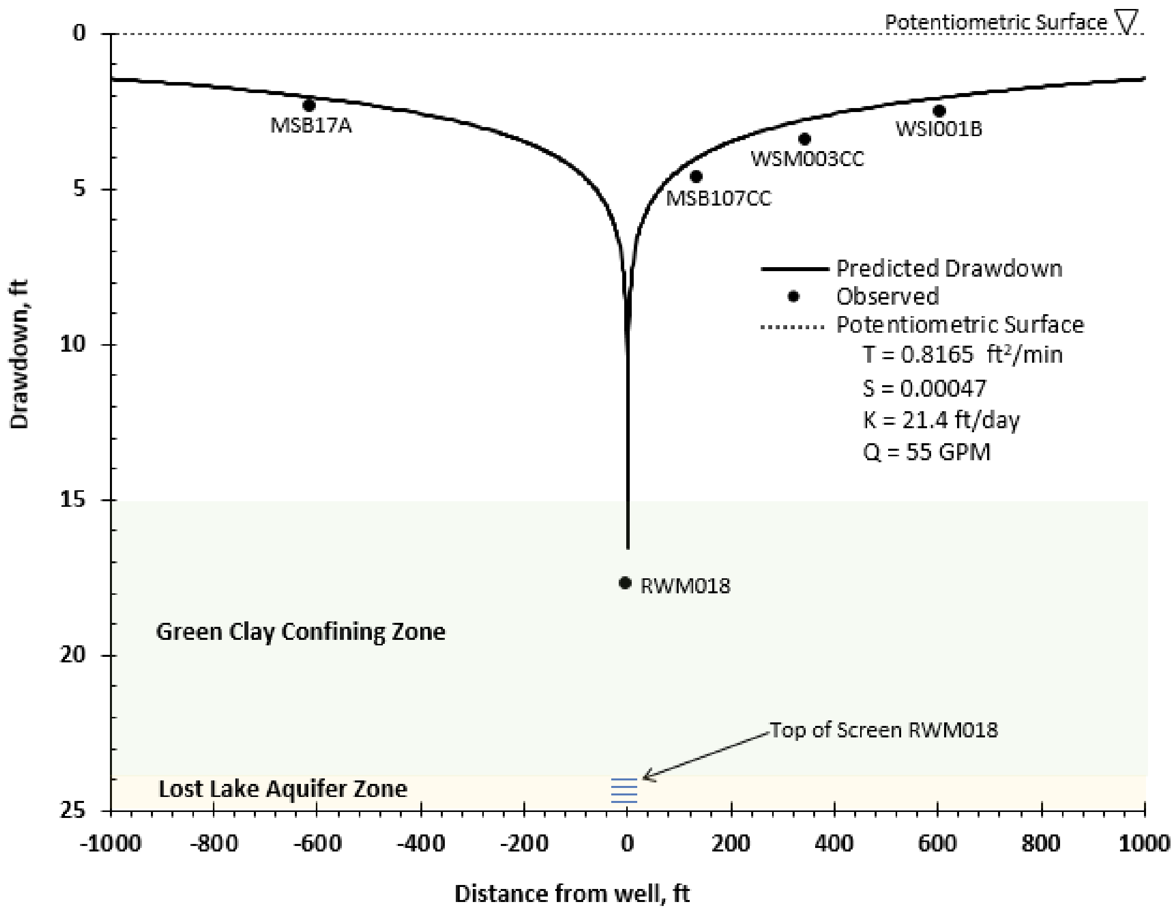

Figure 35. Approximate Steady State Drawdown in the Lost Lake Aquifer Due to Pumping at RWM018 (55GPM).

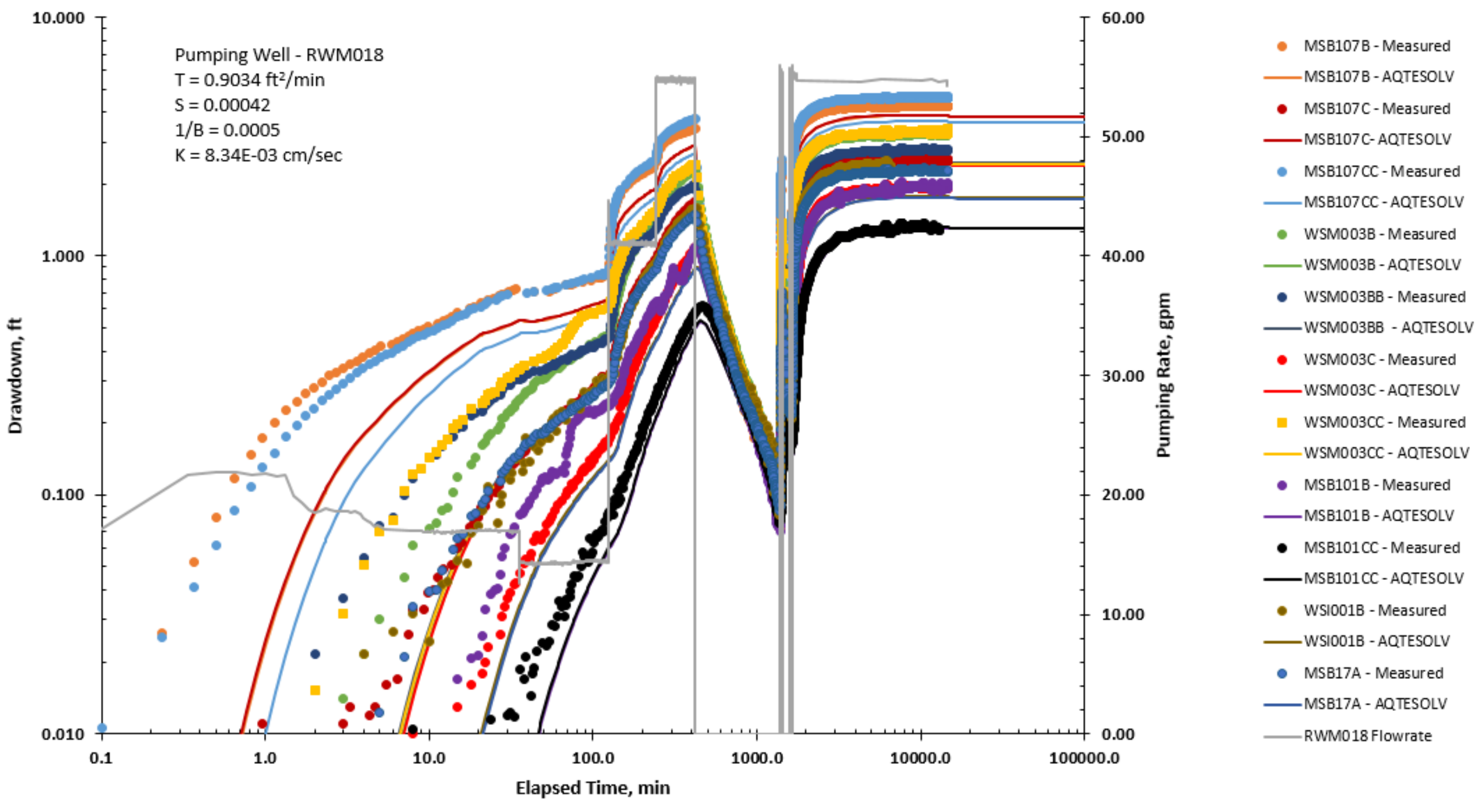

Figure 36. Drawdown as a Function of Time for All RWM018 Wells Using Hantush-Jacob Leaky Aquifer Solution.

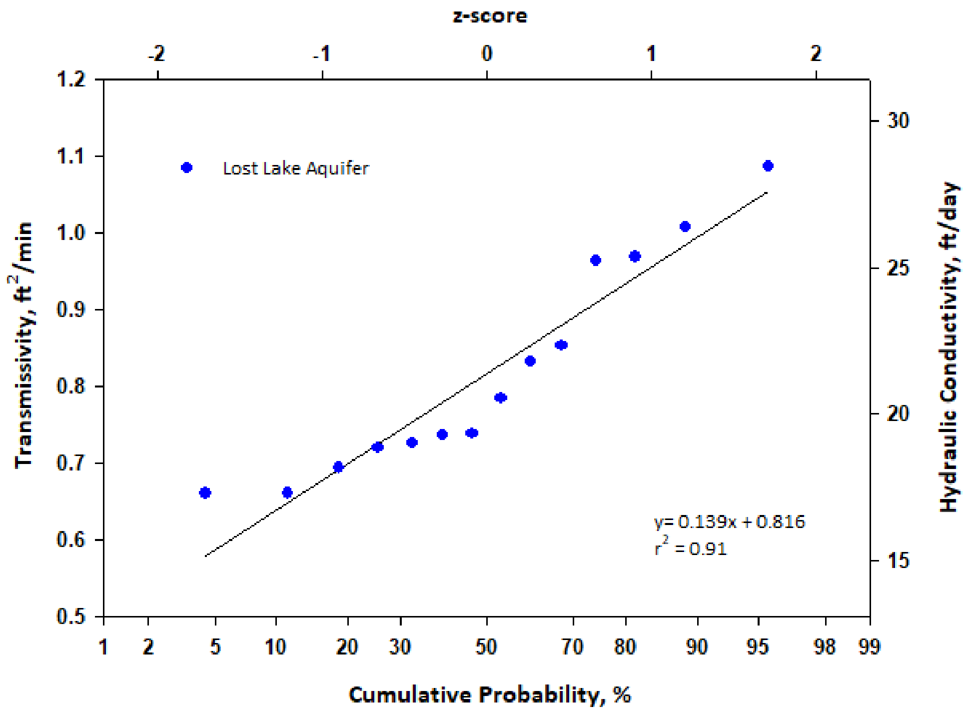

Figure 37. Probability Plot of Transmissivity for the Lost Lake Aquifer Near RWM018.

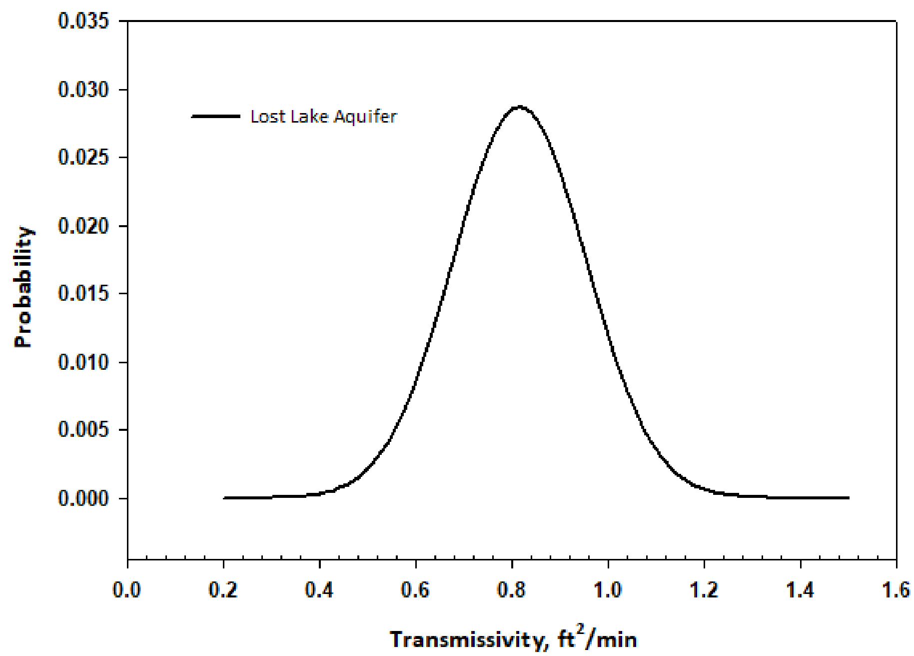

Figure 38. Probability Density Function for Transmissivity of the Lost Lake Aquifer Near RWM018.

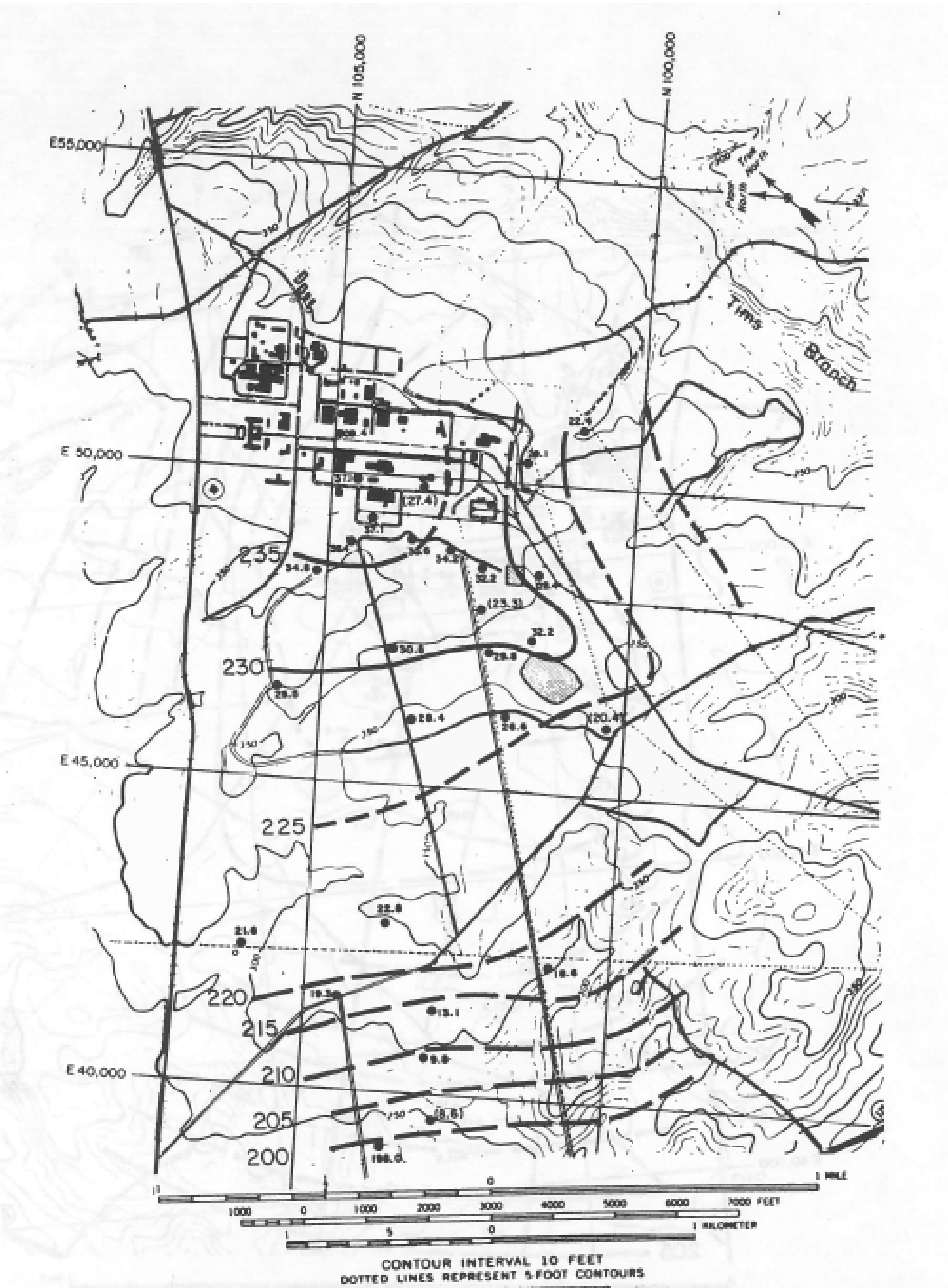

Figure 39. Potentiometric Surface of the LLAZ April-June 1984 (from Marine and Bledsoe, 1984)

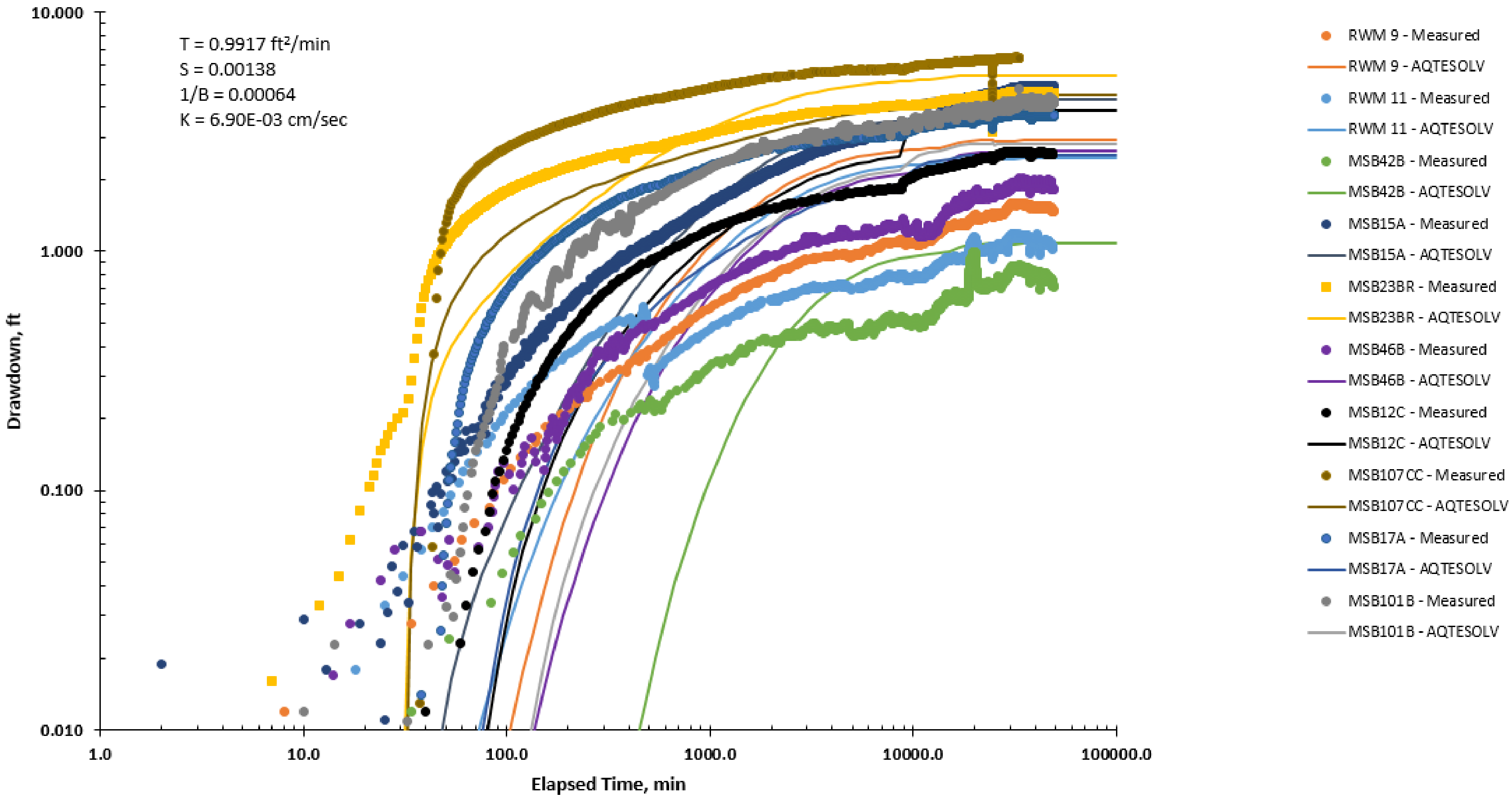

Figure 40. Drawdown as a Function of Time for LLAZ Wells Using Hantush-Jacob Leaky Aquifer Solution.

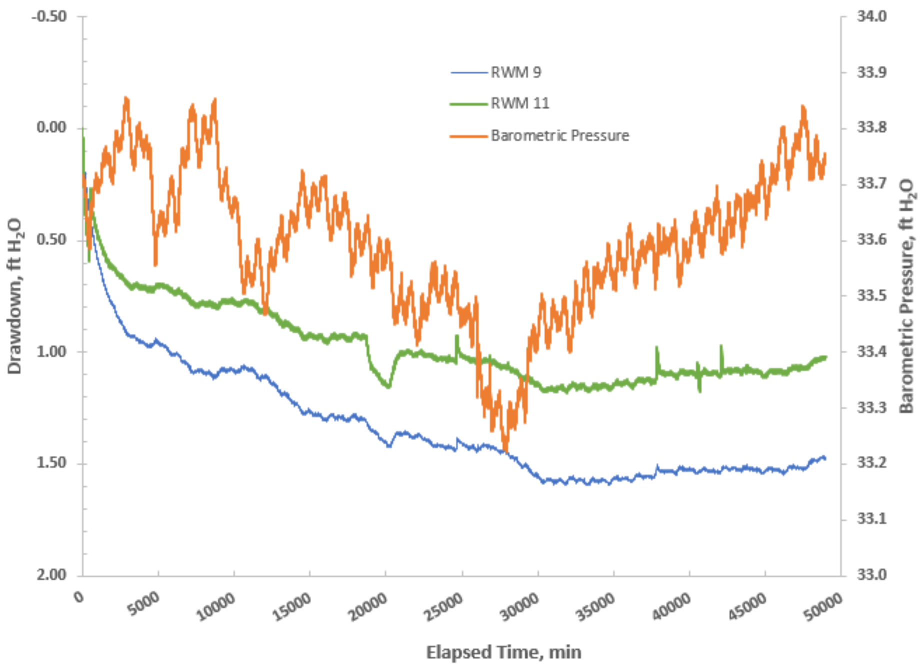

Figure 41. Drawdown as a Function of Time for RWM 9 and RWM 11.

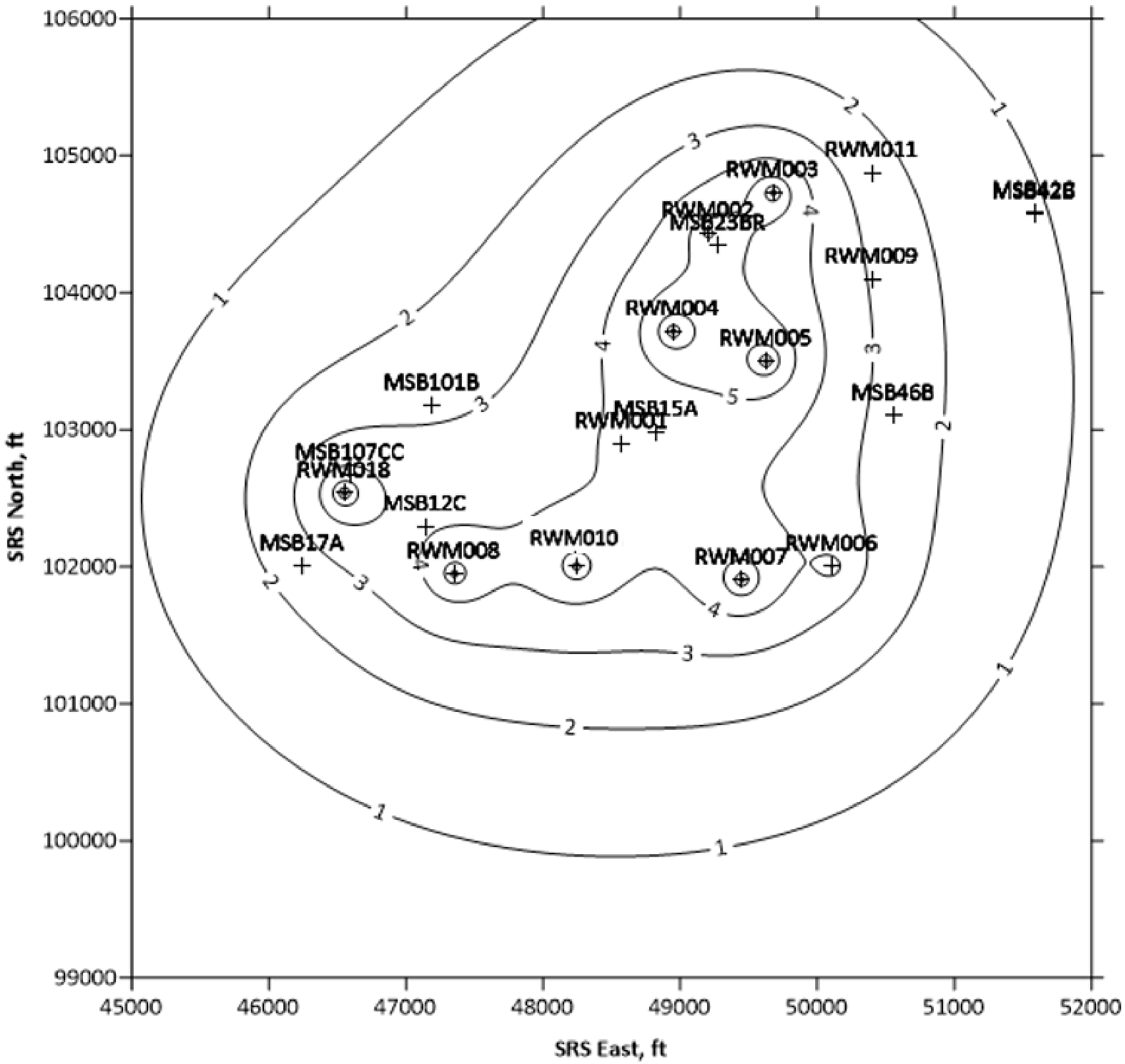

Figure 42. Steady State Drawdown Near RWM 3 and RWM 5 using Average Aquifer Properties (T=1.097 ft^2/min).

Table 1: Construction Details for Wells Near RWM018.

Well	SRS East (ft)	SRS North (ft)	Distance from RWM018 (ft)	Ground Elevation (ft msl)	Top of Screen (ft msl)	Bottom of Screen (ft msl)	Diameter (inches)	Screen Length (ft)	Aquifer Zone[1]
RWM018	46551.0	102538.7	0	350.00	179.41	129.41	6	50	LLAZ
MSB107B	46614.4	102634.7	115.1	347.24	134.24	124.24	2	10	LLLAZ
MSB107C	46605.1	102639.1	114.1	347.29	177.29	167.29	2	10	LLLAZ
MSB107CC	46593.8	102667.3	135.5	347.65	157.65	147.65	2	10	MLLAZ
WSM003B	46667.6	102872.4	353.5	345.79	145.79	140.79	2	5	LLLAZ
WSM003BB	46666.7	102862.7	344.1	345.96	133.96	128.96	2	5	LLLAZ
WSM003C	46676.5	102871.6	355.8	345.61	171.61	161.61	2	10	ULLAZ
WSM003CC	46676.9	102862.0	346.9	345.72	156.72	146.72	2	10	LLLAZ
MSB101B	47191.1	103177.4	904.3	347.40	147.60	137.60	2	10	LLLAZ
MSB101C	47181.2	103174.4	895.1	347.40	176.10	171.10	2	5	ULLAZ
MSB101CC	47198.4	103161.0	898.0	348.17	168.17	158.17	2	10	MLLAZ
WSI001B	46740.5	103114.6	606.2	345.92	151.92	136.91	2	15	MLLAZ
WSI001C	46741.4	103127.0	618.4	345.79	174.48	159.48	2	15	ULLAZ
WSI004B	46669.3	103113.2	586.5	346.63	150.31	135.31	2	15	MLLAZ
WSI004C	46668.0	103124.5	597.3	346.69	172.24	157.24	2	15	LLLAZ
MSB17A	46244.3	102006.6	614.2	357.30	160.60	155.60	4	5	MLLAZ

[1]LLAZ – Lost Lake Aquifer Zone, ULLAZ – Upper Lost Lake Aquifer Zone, MLLAZ – Middle Lost Lake Aquifer Zone, LLLAZ – Lower Lost Lake Aquifer Zone

Table 2: Construction Details for Wells Near RWM 3 and RWM 5.

Well	SRS East	SRS North	Distance from RWM 3	Distance from RWM 5	Diameter (inches)	Top of Screen (ft msl)	Bottom of Screen (ft msl)	Ground Elevation (ft msl)	Total Screen Length (ft)	Aquifer Zone[1]
RWM 1	48575	102599	2400.4	1387.0	8	232.30	172.30	362.80	60	MAAZ_GCCZ_ULLAZ
RWM 2	49206	104434	559.2	1023.1	8	208.30	138.30	368.30	70	GCCZ_ULLAZ_LLLAZ
RWM 3	49680	104730	0.00	1229.1	8	214.00	144.00	374.00	70	MAAZ_GCCZ_ ULLAZ_LLLAZ
RWM 4	48948	103719	1248.1	713.8	8	211.90	129.50	363.50	82	GCCZ_ULLAZ_LLLAZ_ UCCZ_CBCU
RWM 5	49628	103502	1229.1	0.00	8	216.80	133.90	363.90	83	LLLAZ
RWM 6	50107	102002	2762.0	1575.4	8	218.70	141.10	346.10	78	GCCZ_ULLAZ_LLLAZ_ UCCZ_CBCU
RWM 7	49450	101905	2835.0	1607.5	8	216.30	144.00	346.00	72	GCCZ_ULLAZ_LLLAZ_ UCCZ_CBCU
RWM 8	47353	101948	3626.7	2754.9	8	197.20	109.30	345.30	88	GCCZ_ULLAZ_LLLAZ_ UCCZ_CBCU
RWM 9	50400	104100	957.0	976.3	8	220.60	132.60	377.60	88	LLLAZ
RWM 10	48244	102001	3084.0	2041.8	8	215.50	127.50	352.50	88	MAAZ_GCCZ_ULLAZ_ LLLAZ_MSAZ_CBCU
RWM 11	50400	104875	734.6	1575.1	8	214.60	141.90	380.30	73	MAAZ_GCCZ_ULLAZ _LLLAZ
RWM018	46551	102539	3820.1	3224.3	6	179.16	129.16	349.75	50	LLAZ
MSB12C	47141	102295	3517.9	2764.5	4	184.10	179.10	347.20	5	ULLAZ
MSB15A	48827	102984	1943.9	954.3	4	167.80	162.80	365.80	5	ULLAZ
MSB17A	46244	102007	4384.2	3699.4	4	160.60	155.60	357.30	5	LLLAZ
MSB 23BR	49275	104342	560.8	911.1	4	177.70	172.70	380.30	5	ULLAZ
MSB42B	51589	104570	1909.6	2227.4	4	166.30	160.70	374.30	6	LLLAZ
MSB42C	51583	104582	1908.6	2233.2	4	204.30	198.70	374.30	6	ULLAZ
MSB 46B	50556	103102	1849.2	1011.8	4	189.80	179.80	370.80	10	ULLAZ
MSB101B	47191	103177	903.0	904.3	2	147.60	137.60	347.40	10	LLLAZ
MSB107CC	46594	102667	3712.1	3146.9	2	157.65	147.65	348.17	10	LLLAZ

[1]MAAZ – M-Area Aquifer Zone, GCCZ – Green Clay Confining Zone, LLAZ – Lost Lake Aquifer Zone, ULLAZ – Upper Lost Lake Aquifer Zone, LLLAZ – Lower Lost Lake Aquifer Zone, CBCU, Crouch Branch Confining Zone.

Table 3: Relative Well Dimensions Used in AQTESOLV Analysis of RWM018 Pumping Test Data.

	Distance from RWM018 (ft)	Depth Below GCCZ (ft)	Screen Length (ft)	Well Casing Radius (ft)	Effective Radius (ft)
RWM018	0.0	-2.41	50.00	0.25	0.50
MSB107B	115.1	42.76	10.00	0.08	0.17
MSB107C	114.1	-0.29	10.00	0.08	0.17
MSB107CC	135.5	19.35	10.00	0.08	0.17
WSM003B	353.5	31.01	5.00	0.08	0.17
WSM003BB	344.1	43.15	5.00	0.08	0.17
WSM003C	355.8	5.11	10.00	0.08	0.17
WSM003CC	346.9	20.21	10.00	0.08	0.17
MSB101B	904.3	29.40	10.00	0.08	0.17
MSB101C	895.1	0.90	5.00	0.08	0.17
MSB101CC	898.0	8.83	10.00	0.08	0.17
MSB17A	614.2	16.40	5.00	0.17	0.33
WSI001B	606.2	25.08	15.00	0.08	0.17
WSI001C	618.4	2.52	15.00	0.08	0.17
WSI004B	586.5	26.69	15.00	0.08	0.17
WSI004C	597.3	4.76	15.00	0.08	0.17

Table 4: Relative Well Dimensions Used in AQTESOLV Analysis of RWM 3 and RWM 5 Pumping Test Data.

	SRS East	SRS North	Depth Below GCCZ (ft)	Effective Screen Length[1] (ft)	Well Casing Radius (ft)	Effective Radius (ft)
RWM 1	48575.1	102599.2	0.00	31.7	0.33	0.67
RWM 2	49205.7	104434.0	0.00	73.0	0.33	0.67
RWM 3	49680.0	104730.2	0.00	60.0	0.33	0.67
RWM 4	48948.0	103719.3	0.00	73.0	0.33	0.67
RWM 5	49628.0	103502.2	0.00	73.0	0.33	0.67
RWM 6	50107.4	102001.5	0.00	73.0	0.33	0.67
RWM 7	49449.6	101904.6	0.00	73.0	0.33	0.67
RWM 8	47353.1	101948.2	0.00	73.0	0.33	0.67
RWM 9	50400.0	104099.8	0.00	73.0	0.33	0.67
RWM 10	48244.1	102000.9	0.00	62.1	0.33	0.67
RWM 11	50400.2	104875.0	0.00	73.0	0.33	0.67
RWM018	46551.0	102538.6	0.00	50.0	0.25	0.50
MSB12A	47140.9	102303.9	82.40	5.0	0.17	0.33
MSB15A	48827.0	102983.5	36.70	5.0	0.17	0.33
MSB17A	46244.3	102006.6	43.90	5.0	0.17	0.33
MSB 23BR	49275.1	104342.1	26.80	5.0	0.17	0.33
MSB42B	51582.8	104569.8	38.20	5.6	0.17	0.33
MSB42C	51582.8	104581.9	0.20	5.6	0.17	0.33
MSB 46B	50557.5	103102.4	14.70	10.0	0.17	0.33
MSB101C	47191.1	103177.4	0.90	5.0	0.08	0.17
MSB107CC	46593.8	102667.3	46.85	10.0	0.08	0.17

[1]Effective screen length (EL) is the total screen length (TL) multiplied by the ratio of the screen length in the LLAZ (LLAZ_L) divided by the total screen length (EL=TL*(LLAZ_L)/TL).

Table 5. Previously Reported Hydraulic Properties of the Lost Lake Aquifer Zone

Well[a]	**T**[b] **(ft^2/min)**	**S**[b]	**r/B**[c]	**Observed Specific Capacity (gpm/ft)**	**Well Efficiency (%)**
RWM 1	2.32	0.001	-	0.9	-
RWM 2	2.32	0.001	-	0.6	-
RWM 3[a]	2.32	0.001	-	4.2	-
RWM 4[a]	1.11	0.001	-	4.3	82
				3.9	75
				4.6	62
RWM 5[a]	3.53	0.00005	-	5.3	79
				5.8	65
				5.9	55
RWM 6[a]	1.76	0.0006	-	2.8	-
RWM 7[a]	1.95	0.0006	-	1.9	78
				1.8	64
				1.4	52
RWM 8[a]	1.49	0.001	-	5.3	75
				5.7	64
				4.3	53
RWM 9[a]	10.49	0.01	-	6.5	91
				6.8	87
				7.8	81
RWM 10[a]	2.32	0.0009	-	3.1	88
				2.9	85
				3.4	81
				2.8	75
				2.6	69
RWM 11[a]	9.10	0.0003	-	4.0	90
				4.3	85
				4.0	81
RWM 16PA[c]	0.899	0.00065	0.0823	-	-
RWM 16PB[c]	0.826	0.00073	0.0460	-	-
MSB-40B[c]	0.782	0.00053	0.0458	-	-

[a]Data compiled from Geraghty and Miller (1987) and Hiergesell (1992).
[b]Values determined using Theis confined aquifer method unless otherwise noted.
[c]Values determined using Hantush-Jacob leaky confined aquifer method (1955).

Table 6. Calculated Barometric Efficiencies for RWM018 and Nearby Observation Wells.

Well ID	Barometric Efficiency (%)
RWM018	65
MSB107B	64
MSB107C	58
MSB107CC	63
MSB17A	65
MSB101B	44
MSB101C	60
MCB101CC	59
WSM003B	62
WSM003BB	63
WSM003C	56
WSM003CC	67
WSI001B	62
Average	**61**
Median	**62**

Table 7. Specific Capacity and Efficiencies Calculated for RWM018, RWM 3, and RWM 5.

Well ID	Test	Q (gpm)	ΔQ/Δs GPM/ft	Well Efficiency (%)
RWM018	Step-Drawdown Test 1	16.8	3.45	97.3
		42.9	3.25	93.4
		55.0	2.98	91.6
RWM018	Step-Drawdown Test 2	14.5	3.47	97.5
		41.1	3.30	93.2
		54.7	2.90	91.2
RWM018	Long Term Test	54.8	3.22	69.6
RWM 3	Long Term Test	57.4	4.02	66.5
RWM 5	Long Term Test	48.1	3.33	61.3

Table 8. Well Loss Parameters Calculated for RWM018.

Well ID	Test	B (ft/ft^3/min)	C (min^2/ft^5)	P
RWM018	Step-Drawdown Test 1	2.1064	0.0261	2
RWM018	Step-Drawdown Test 2	2.0971	0.0278	2

Table 9. Hydraulic Properties of the Lost Lake Aquifer Near RWM018.

	Transmissivity (ft²/min)	95 % Confidence Interval (ft²/min)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/sec)	Storativity	r/B	Green Clay Hydraulic Conductivity (ft/day)	Green Clay Hydraulic Conductivity (cm/sec)	Aquifer Zone[1]
RWM018	0.726	0.044	19.0	6.70E-03	0.00010				LLAZ
MSB107B	0.964	0.005	25.2	8.91E-03	0.00014	0.0346	0.0012	4.11E-07	LLLAZ
MSB107C	0.739	0.007	19.3	6.82E-03	0.00287	0.2384	0.0432	1.52E-05	ULLAZ
MSB107CC	0.832	0.005	21.8	7.69E-03	0.00014	0.0430	0.0011	3.95E-07	MLLAZ
WSM003B	0.660	0.005	17.3	6.10E-03	0.00023	0.1893	0.0025	8.94E-07	LLLAZ
WSM003BB	1.007	0.006	26.4	9.30E-03	0.00015	0.1059	0.0013	4.51E-07	LLLAZ
WSM003C	0.694	0.009	18.2	6.41E-03	0.00100	0.3746	0.0103	3.63E-06	Upper
WSM003CC	0.660	0.012	17.3	6.10E-03	0.00015	0.1759	0.0023	8.02E-07	MLLAZ
MSB101B	0.853	0.029	22.3	7.88E-03	0.00011	0.2961	0.0012	4.32E-07	LLLAZ
MSB101CC	0.720	0.009	18.8	6.65E-03	0.00035	0.5505	0.0036	1.28E-06	MLLAZ
WSI001B	0.785	0.007	20.5	7.25E-03	0.00015	0.2302	0.0015	5.34E-07	MLLAZ
MSB17A	0.969	0.007	25.4	8.95E-03	0.00013	0.1762	0.0011	3.77E-07	MLLAZ
WSI001C	0.736	0.026	19.3	6.80E-03	0.00088	0.6078	0.0095	3.36E-06	ULLAZ
WSI004B	1.086	0.005	28.4	1.00E-02	0.00016	0.1764	0.0013	4.64E-07	LLLAZ
Average	**0.816**	**-**	**21.4**	**7.54E-03**	**0.00047**	**0.2461**	**0.0062**	**2.17E-06**	**-**
Median	**0.762**	**-**	**19.9**	**7.03E-03**	**0.00015**	**0.1893**	**0.0015**	**5.34E-07**	**-**
Standard Deviation	**0.139**	**-**	**3.6**	**1.28E-03**	**0.00075**	**0.1747**	**0.0116**	**4.08E-06**	**-**

[1]LLAZ – Lost Lake Aquifer Zone, ULLAZ – Upper Lost Lake Aquifer Zone, MLLAZ – Middle Lost Lake Aquifer Zone, LLLAZ – Lower Lost Lake Aquifer Zone

Table 10. Maximum Observed Drawdown for Wells Near RWM018 (Q=~55 gpm).

	SRS East	SRS North	Distance from RWM 18 (ft)	Maximum Observed Drawdown (ft H_2O)
RWM018	46551.0	102538.7	0.0	17.75
MSB107B	46614.4	102634.7	115.1	4.31
MSB107C	46605.1	102639.1	114.1	2.59
MSB107CC	46593.8	102667.3	135.5	4.67
WSM003B	46667.6	102872.4	353.5	3.30
WSM003BB	46666.7	102862.7	344.1	2.85
WSM003C	46676.5	102871.6	355.8	1.99
WSM003CC	46676.9	102862.0	346.9	3.45
WSI001B	46740.5	103114.6	606.2	2.51
MSB17A	46244.3	102006.6	614.2	2.33
MSB101B	47191.1	103177.4	904.3	2.05
MSB101C	47181.2	103174.4	895.1	0.53
MSB101CC	47198.4	103161.0	898.0	1.37

Table 11. Hydraulic Properties of the Lost Lake Aquifer Near RWM 3 and RWM 5.

	Transmissivity (ft^2/min)	95 % Confidence Interval (ft^2/min)	Hydraulic Conductivity (ft/day)	Hydraulic Conductivity (cm/sec)	Storativity	1/B	Green Clay Hydraulic Conductivity (ft/day)	Green Clay Hydraulic Conductivity (cm/sec)	Aquifer Zone[1]
	0.9917	0.01882	19.6	6.90E-03	0.00138	0.00064	0.0062	2.18E-06	LLAZ

[1]LLAZ – Lost Lake Aquifer Zone

Table 12. Maximum Observed Drawdown Data for Wells RWM 3 and RWM 5.

Well	Median Pumping Rate (gpm)	Max Drawdown (ft H_2O)
RWM 1	10.80	-
RWM 2	28.10	-
RWM 3	57.40	14.3
RWM 4	46.83	-
RWM 5	48.10	14.5
RWM 6	19.89	16.4[a]
RWM 7	46.30	-
RWM 8	38.96	9.6[a]
RWM 9	0.00	1.6
RWM 10	42.45	-
RWM 11	-	1.2
RWM018	55.31	-
MSB12C	-	2.6
MSB15A	-	4.9
MSB17A	-	3.8
MSB23BR	-	4.7
MSB42B	-	1.0
MSB42C	-	0.2
MSB46B	-	2.0
MSB101B	-	4.8
MSB107CC	-	6.5

[a]From manual water level measurements.

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