AQUIFER TESTS COMPLETED IN THE BITTERROOT VALLEY, HAMILTON, MONTANA

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Cover:Aquifer test setup at the Arrow Hill site, Hamilton, Montana.

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OVERVIEW

Three aquifer tests were conducted as a part of the Ground Water Investigation Program (GWIP) Hamilton, Montana groundwater investigation, carried out by the Montana Bureau of Mines and Geology (MBMG). These tests were conducted in the Bitterroot Valley, western Montana, in and near Hamilton, Ravalli County (fig. 1).

The aquifer tests were conducted in late February and March 2016 to avoid influence from nearby irrigation activities. For each test, one pumping well and one to three observation wells were installed by the MBMG in 2015. Nearby domestic wells were also monitored during two of the three tests. Sites were selected based on landowner permission and the hydrogeologic setting. The River Park site is in the Bitterroot Valley bottom, the Skalkaho Park site is near Skalkaho Creek, and the third test site, Arrow Hill, is on the eastern bench in an area of Tertiary sediments (fig. 2).

The Bitterroot Valley is an intermontane basin, surrounded by the Bitterroot Mountains to the west and the Sapphire Mountains to the east. The valley is filled with sediment transported from these mountains and with modern sediment associated with Bitterroot River deposits. Tertiary and Quaternary pediment gravels occur along the bases of the mountains. Quaternary alluvium underlies the modern floodplain and relatively fine-grained Tertiary sediment underlies the Quaternary alluvium (Smith and others, 2013). Estimated thickness of unconsolidated Tertiary and Quaternary basin-fill material ranges up to 3,000 ft (Noble and others, 1982).

Aquifer test results are summarized in table 1. The aquifer testing consisted of pumping a well at a constant discharge and plotting the resulting drawdown of water levels in the pumping and nearby observation wells as a function of time after the start of pumping. These time-drawdown plots are analyzed by matching with type curves based on modifications of the original Theis nonequilibrium equation (Theis, 1935). The Theis solution is valid for the following conditions:

1. The aquifer is homogeneous and isotropic.
2. The aquifer is uniform in thickness and effectively infinite in lateral extent.
3. The pumped well fully penetrates and is open to the entire thickness of the aquifer.
4. All water removed from the aquifer comes from storage; that is, the aquifer receives no recharge during the test.
5. The water removed from aquifer storage is released instantaneously.
6. The water table or potentiometric surface has no slope.
7. The pumped well is 100 percent efficient.

As with a majority of aquifer tests, the test sites in the Bitterroot Valley reported here did not satisfy all of these conditions. The inhomogeneity, anisotropy, and limited lateral extent of the valley-fill are not fully consistent with conditions 1 and 2. We applied modifications of the Theis solution that account for partially penetrating wells (condition 3), and recharge boundaries (condition 4), to the aquifer test data from the three sites.

The nature of the aquifer and boundaries at each site were evaluated based on derivative plots, drawdown observations (Renard and others, 2009), and/or water-chemistry analyses of the pumped water. The tests at River Park and Skalkaho Park showed an unconfined response that corresponded to our conceptual model for these two sites. These tests also indicated that the radius of influence may have intersected the recharge boundary. Results of the Arrow Hill test, including the drawdown data, derivative plot analysis, and geologic logs, indicate locally leaky-confined aquifer conditions.

Well and staff gage locations are referred to by their Ground Water Information Center (GWIC) number. The well logs, aquifer test data, and chemistry data can be accessed through the GWIC database (http://mbmggwic.mtech.edu/). The aquifer test data are accessed by the pumping well GWIC number as an Excel file (Form 633 created by the Montana Department of Natural Resources).

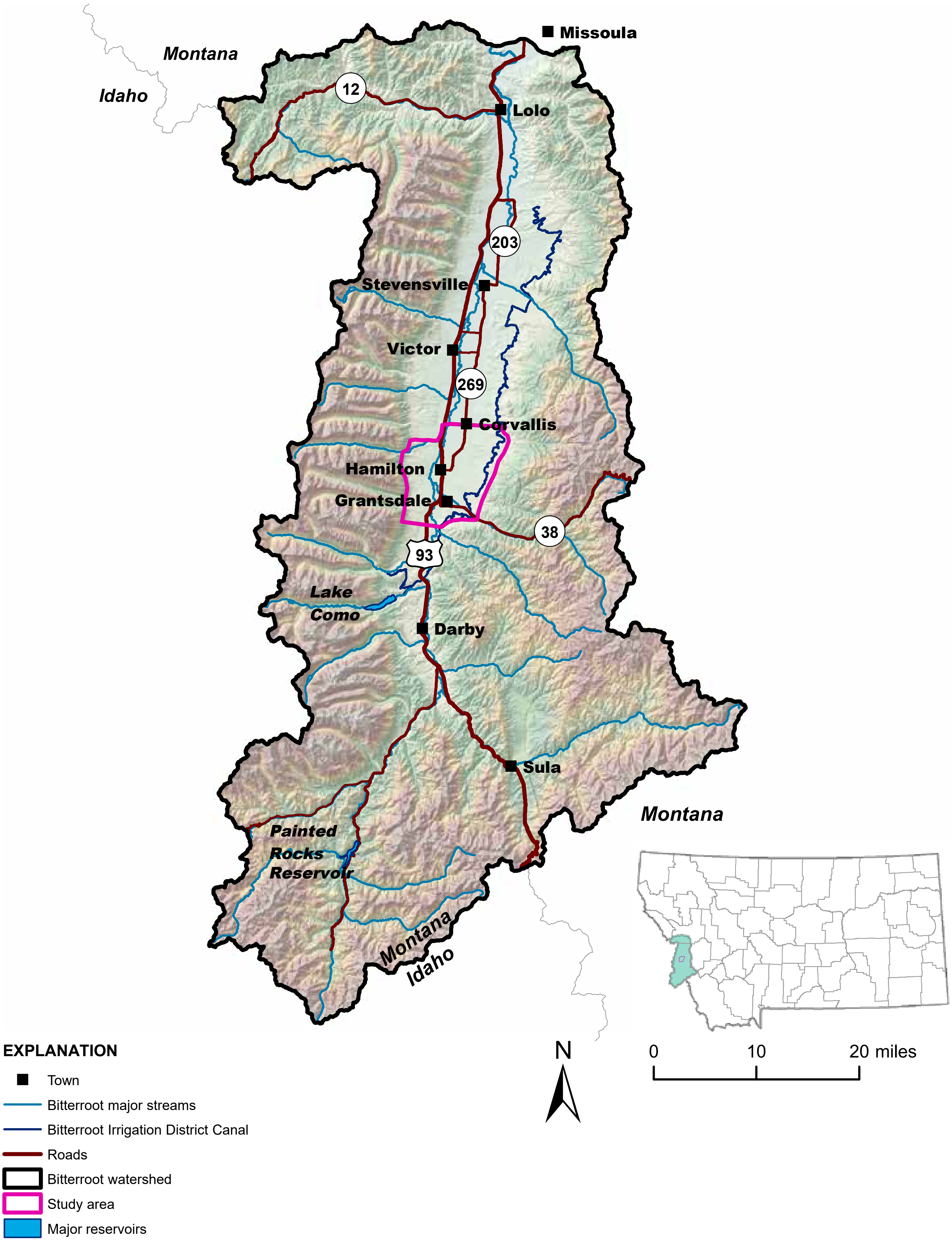


Figure 1. Location of study area near Hamilton, Montana.

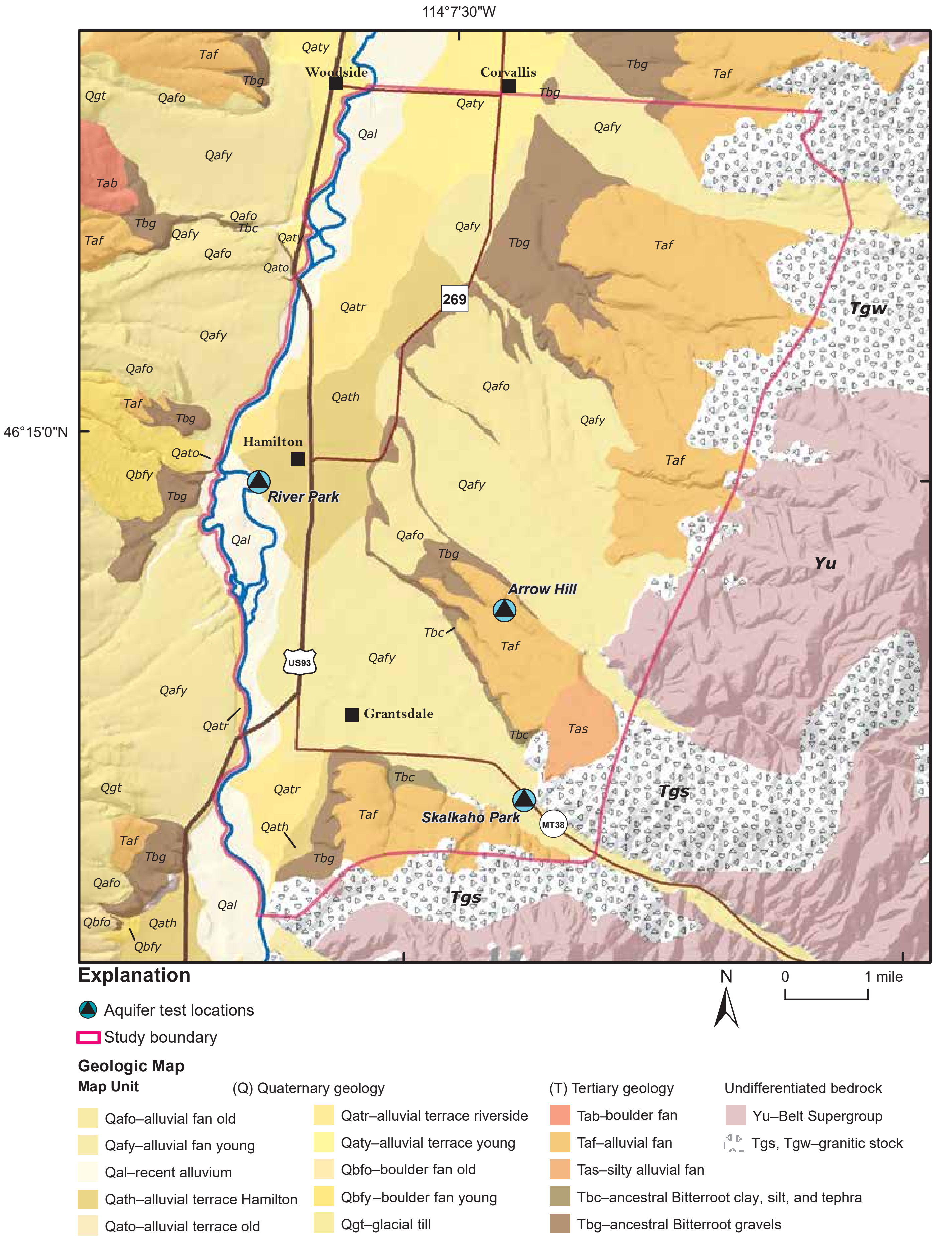


Figure 2. Generalized geology of the Hamilton area and the locations of the three aquifer tests (Lonn and Sears, 2001).

Table 1. Aquifer parameter results.

River Park	GWIC ID	T ft^2/day	Sy
From Composite Plot of RP-S1 & -S2	286259/287096	21,390	0.00065
RP-S1	286259	20,320	0.0026
RP-S2	287096	19,110	0.0007
RP-D1	286256	29,850	0.49
Skalkaho Park			
From Composite Plot of SP-S1 & -S2	286266/286270	12,250	0.006
SP-S1	286266	12,170	0.01
SP-S2	286270	11,210	0.005
Arrow Hill			
AH-D1	286217	4,500	0.00007

Note. T, transmissivity; Sy, specific yield.

1 RIVER PARK SITE

1.1 Background

1.1.1 Purpose of Test

The purpose of this test is to estimate the aquifer properties of the shallow sand and gravel alluvial aquifer near the Bitterroot River.

1.1.2 Test Location

The aquifer test site is located within the city limits of Hamilton at River Park (latitude 46.2432, longitude, -114.1685. River Park (fig. 3) is located on South 9th Street, just west of downtown Hamilton.

1.1.3 Test Type

This constant-rate aquifer test was conducted at an average pumping rate of 141 gallons per minute (gpm). Wells included the pumping well 286258 (RP-PW) and three observation wells: 286259 (RP-S1), 286256 (RP-D1), and 287096 (RP-S2). The pumping portion of the 121-h aquifer test began February 29, 2016 at 09:00 and ended on March 5, 2016 at 09:59. Recovery water levels were monitored manually with an e-tape for 50 h.

1.1.4 Hydrogeologic Setting

The pumping and observation wells were located within the floodplain of the Bitterroot River. The wells were completed in alluvium consisting of sand, gravel, and cobbles. The lithology logged for the deepest well (well 286256) consisted of:

- sand and fine gravel (0–20 ft),
- medium sand and coarse gravel (20–30 ft), and
- predominantly sandy, fine gravel (30–75 ft).

Logs from the other wells indicated similar lithology. The pumping well and two observation wells had total depths between 38 and 39 ft below ground surface (bgs) while the other observation well was completed at a total depth of 69 ft (table 2). Groundwater is about 8 ft bgs and ranged between 7.5 and 11 ft from late October 2015 through early June 2016.

1.1.5 Hydrologic Features

The primary hydrologic feature is the east branch of the Bitterroot River located about 160 ft southwest of the pumping well (fig. 3). An irrigation ditch is located about 30 ft north of the pumping well, but water was not flowing in the ditch during the test.

1.2. Field Procedure

1.2.1 Monitoring Locations

In addition to the pumping well and three observation wells, a staff gage was installed in the Bitterroot River (fig. 3; table 2). Each well is partially penetrating and completed in the floodplain deposits aquifer. Two observation wells were screened 28–38 ft bgs and the third observation well was screened between 59 and 69 ft bgs.

The staff gage (site 286330) was installed with a stilling well to monitor Bitterroot River stage throughout the test.

Figure 3. River Park aquifer test site map.

Table 2. River Park well information.

GWIC ID	Name	Diameter (in)	Well Depth (ft)	Screened Interval (ft-bgs)	Distance from PW (ft)	Max Drawdown (ft)
286258	RP-PW	8	39	19–39	0	3.92
286259	RP-S1	6	38	28–38	73	1.01
287096	RP-S2	6	38	28–38	35	1.40
286256	RP-D1	6	75	59–69	13	0.60

1.2.2 Data Collection

Each monitoring location was equipped with a pressure transducer with a data logger (transducer). Before the test, the transducers were programmed to record every hour. They were reprogrammed to record every minute during the step-test, aquifer test, and recovery test. Manual depth to water measurements were taken at a frequency shown in table 3. A totalizing flowmeter installed on the pumping well discharge line tracked the total amount of water pumped and was used to calculate the pumping rate. The pumping rate was manually verified throughout the test by timing the fill-rate of a 20-gal plastic can. Transducers were installed in all wells from about mid-October 2015 until early May 2016. These data were used to ascertain if there were any pre- or post-pumping water-level trends.

A step-test was performed on February 26, 2016, 3 days prior to the constant-rate aquifer test, to determine an appropriate pumping rate. Four steps were conducted at rates of about 55, 91, 113, and 145 gpm. Each of the first three steps lasted about 1 h, and the last step was 2 h in duration.

During the last step, pumping at 145 gpm, drawdown was observed in all observation wells. This rate was sustained for 2 h and was considered a sufficient yield for the constant-rate test. Water levels fully recovered prior to the start of the constant-rate test.

Table 3. Manual water-level measurement frequency.

0–5 min	Pumping well as frequently as possible Others monitoring wells, when possible
5–60 min	5 min
1–2 h	10 min
2–4 h	15 min
4–8 h	30 min
8–16 h	1 h
>16 h	4 h

The constant-rate aquifer test began February 29, 2016 at 09:00 and continued until March 5 at 09:59 for a total of 121 h of pumping at a time-weighted average of 141 gpm. Recovery was monitored for 50 h, until March 7 at 10:00. All wells recovered from 99% to 100% of pre-pumping levels by the end of the recovery period, except for the deep observation well (well 286256), which recovered to 95%.

Water-chemistry samples (major cation/anions and stable-water isotopes) were collected from the pumping well at the start of the aquifer test, the middle, and before the pump was turned off.

1.3. Results

The time-weighted average pumping rate of 141 gpm was used for test analysis. Water levels monitored before and after the aquifer test indicated no measurable background trends that needed to be removed from the drawdown data.

1.3.1 Hydrographs

Figure 4 shows the pumping well hydrograph for 2 weeks prior to pumping, the pumping interval, and data for 1 week after the recovery period. Figure 5 shows the hydrographs for the same date range for the observation wells. Table 2 includes the maximum drawdown for each well.

1.3.2 Aquifer properties

A Cooper–Jacob (1946) analysis was performed on the late-time data (after the derivative plot flattened) to estimate transmissivity (T) and specific yield (Sy) values (table 4; figs. 6–8).

A composite plot was prepared using data from the observation wells (fig. 9). Composite plots can indicate groundwater responses that differ from one another (e.g., an observation well that is not in the pumped aquifer or an observation well that is screened in a pocket of material with significantly different properties, etc.). The variability in groundwater response is

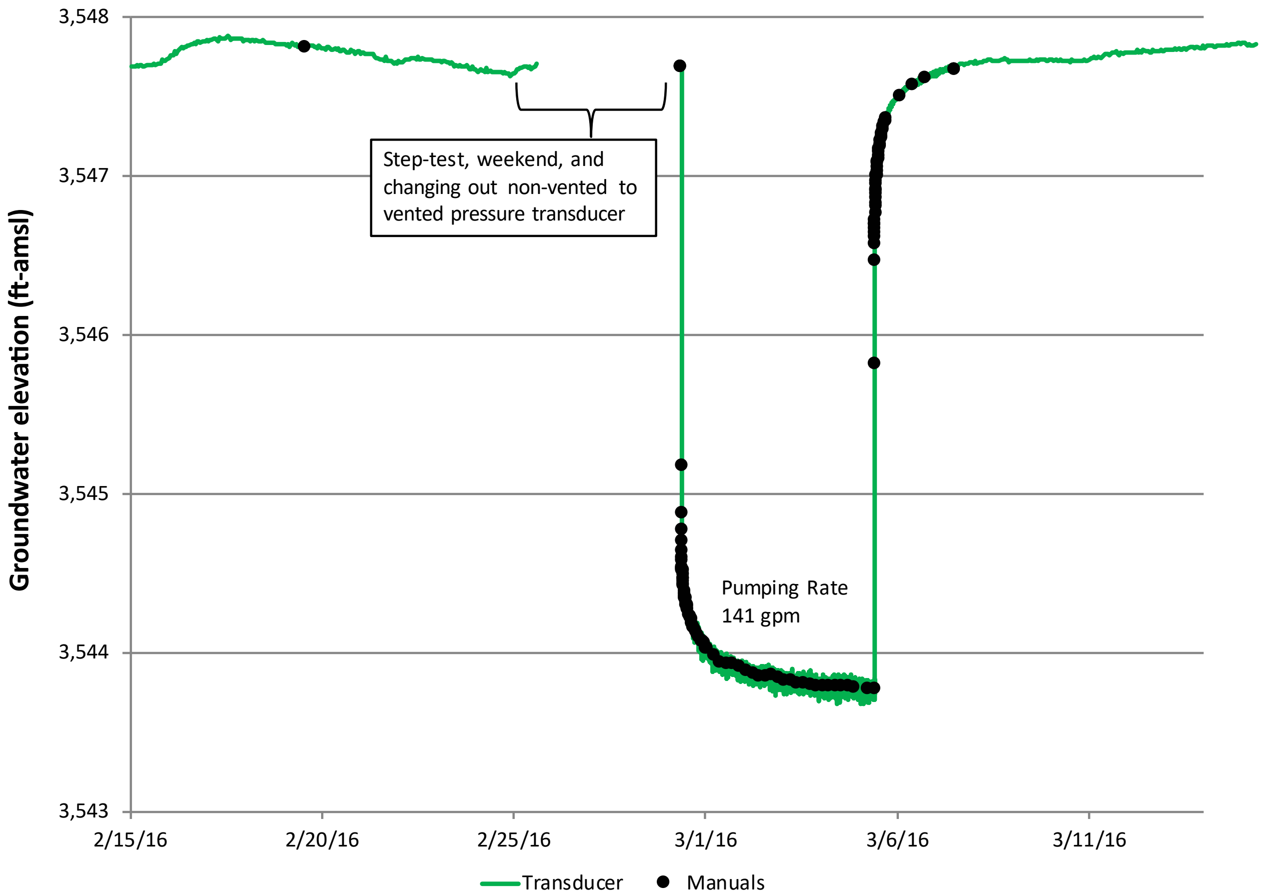


Figure 4. Hydrograph for the River Park pumping well (RP-PW).

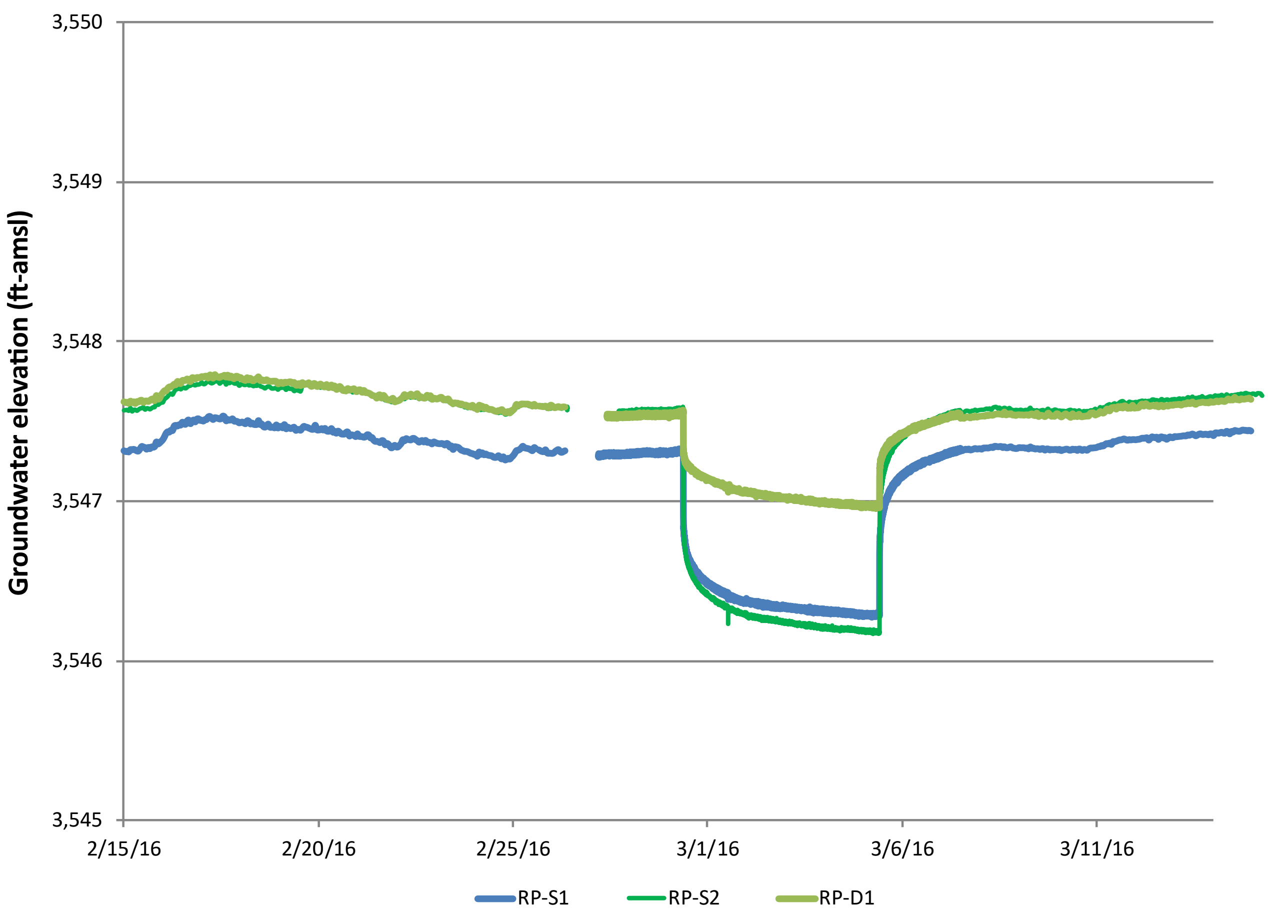


Figure 5. Hydrographs for the River Park observation wells.

Table 4. Aquifer parameters from the River Park aquifer test.

	GWIC ID	T (ft^2/day)	Sy
Composite plot		21,390	0.00065
RP-S1 and RP-S2	286259/287096		
RP-S1	286259	20,320	0.0026
RP-S2	287096	19,110	0.0007
RP-D1	286256	29,850	0.49

Note. T, transmissivity; Sy, specific yield.

identified by a difference in the slopes of data points from the observation wells. The data from well RP-D1 indicates a different flow regime; therefore, these data were not used in the analysis. RP-D1 is deeper than both RP-S1 and RP-S2, and the difference is attributed to vertical anisotropy in hydraulic conductivity (i.e., Kz/Kh is less than 1).

Assuming an aquifer thickness between 50 and 80 ft (based on LaFave, 2006 and drilling results), the range of hydraulic conductivity of 239 to 428 ft/d calculated from the reported transmissivities (table 4) falls within the range of sand and gravel (Fetter, 1994).

Specific yield for unconfined aquifers is often difficult to obtain through aquifer testing (as is the case with specific storage for confined systems), but a more accurate result may be obtained from the well that is farthest away from the pumping well (Midwest GeoSciences, 2013). A specific yield of 0.003 was calculated for well RP-S1, the farthest from the pumping well. Specific yield in well RP-S2 and RP-D1 was 0.0007 and 0.49, respectively, and 0.00065 from the composite plot (table 4). For unconfined systems, the range of specific yield is typically 0.02–0.30 (Fetter, 1994), and on the higher end for sand and gravel aquifers. Even though two of the three calculated specific yields suggest a confined system, the depositional setting and lack of a confining unit indicate an unconfined system.

1.3.3 Water Chemistry

Water samples from the pumping well and the river were collected to evaluate changes in water chemistry during the aquifer test. Water was sampled from the pumping well (286258) three times during the test: once soon after the pump was started, about 2 days after the pumping started, and immediately before the pump was turned off. Water chemistry from the river was collected on March 3, 2016. The samples were analyzed for major cations, anions, and trace metals. There were no notable differences in chemistry between groundwater and the Bitterroot River in any of the samples.

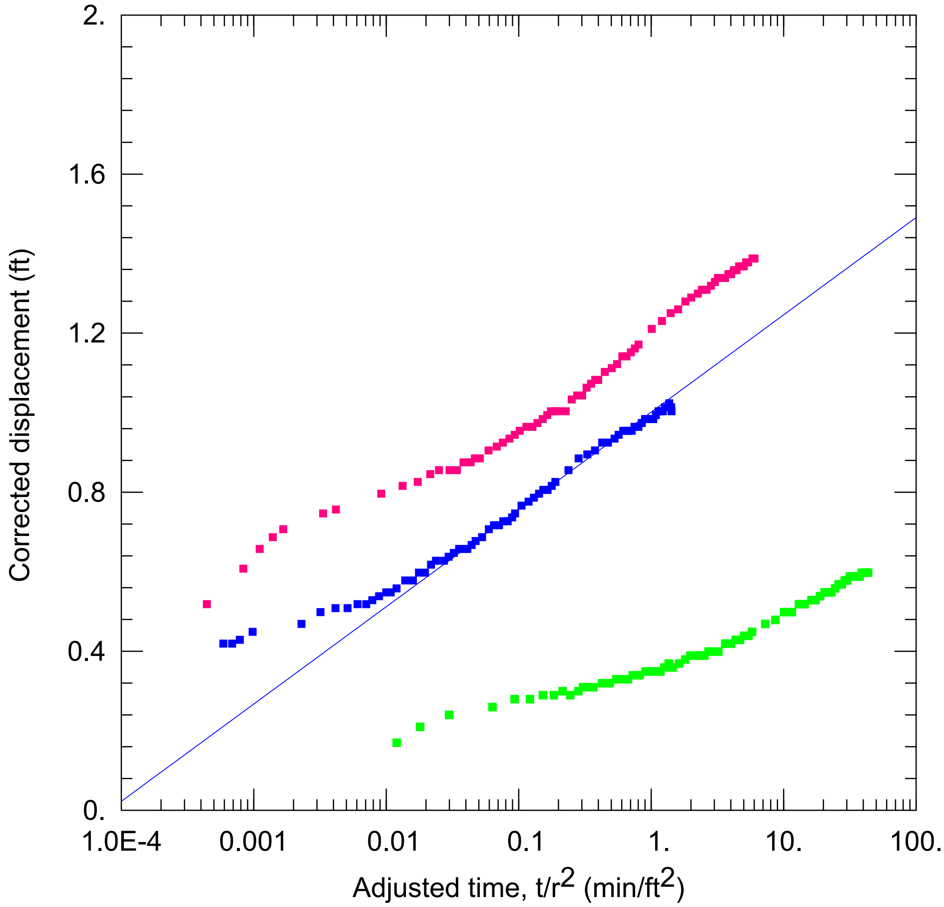
Stable-water isotopes, hydrogen (H) and oxygen (O), were also collected at the same frequency as samples for inorganic analysis. Although the isotopic composition of the samples changed during the test, the results are within the analysis error.

1.3.4 Aquifer Boundaries

Groundwater drawdown data and the derivative plots (fig. 10) suggest that around 20–24 h after the start of the test, water levels were influenced by a recharge boundary. Therefore, influence of the Bitterroot River on the aquifer test was examined more closely. During the test, stage in the Bitterroot River shows a downward trend during pumping (fig. 11). However, the stage in the Bitterroot River at Woodside Crossing, also shown in figure 11 (located about 4.8 mi downstream from the aquifer test site), shows a similar trend, suggesting this is not due to the test pumping.

If the pumping was inducing groundwater flow towards the well instead of the stream or if pumping was directly capturing stream flow, this amount would be too small to be observed in the stage data. The pumping rate of 141 gpm is about 0.31 cubic feet per second (cfs). Even if all of the pumped water was coming from direct stream capture, the 0.31 cfs is below the sensitivity of the staff gage and flow measurements.

We used a stream depletion model (Hunt, 1999) to predict if there would be any depletion in the Bitterroot River. The model predicted that after 7,200 min (120 h) of pumping there would have been a 49 gpm, or 0.11 cfs, of influence. Although the river stage data are inconclusive, the drawdown and derivative plot data suggest a recharge boundary, presumably the Bitterroot River.



WELL TEST ANALYSIS

Data Set: M:\...\RiverPark - Manual wo PW.aqt
Date: 06/23/17 Time: 16:25:19

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: River Park
Test Well: 286258
Test Date: 2.29.16

AQUIFER DATA

Saturated Thickness: 80. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
RP-PW	0	0

Observation Wells

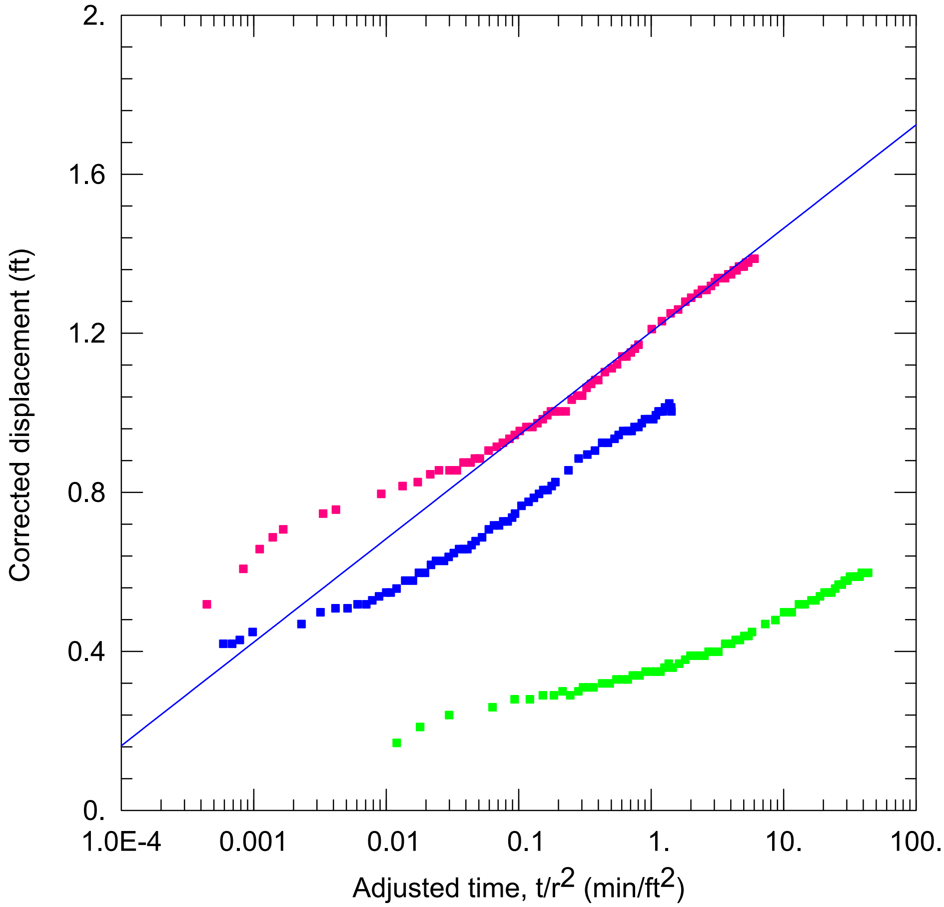
Well Name	X (ft)	Y (ft)
▪ RP-S1	34.61	62.41
▪ RP-S2	34.61	0
▪ RP-D1	12.9	0

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 2.032E+4 ft^2/day S = 0.00257

Figure 6. Cooper–Jacob analysis for observation well RP-S1.



WELL TEST ANALYSIS

Data Set: M:\...\RiverPark - Manual wo PW.aqt
Date: 07/25/17 Time: 18:18:55

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: River Park
Test Well: 286258
Test Date: 2.29.16

AQUIFER DATA

Saturated Thickness: 80. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
RP-PW	0	0

Observation Wells

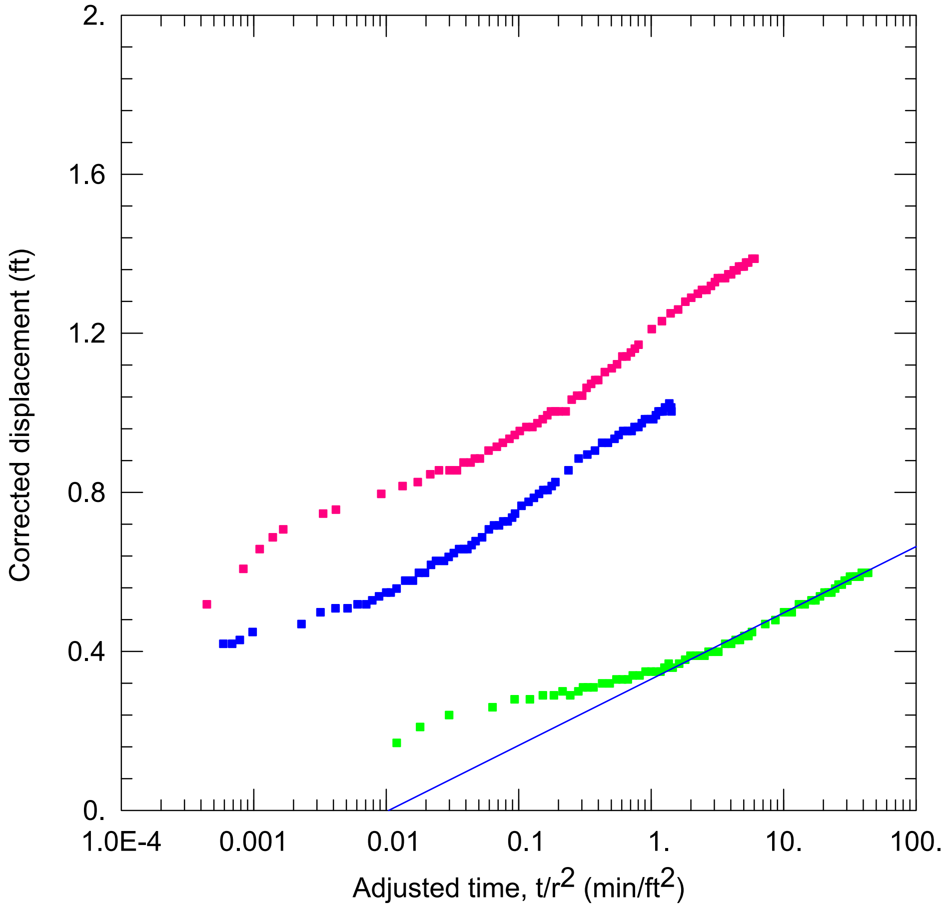
Well Name	X (ft)	Y (ft)
▪ RP-S1	34.61	62.41
▪ RP-S2	34.61	0
▪ RP-D1	12.9	0

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 1.911E+4 ft^2/day S = 0.0007073

Figure 7. Cooper–Jacob analysis for observation well RP-S2.



WELL TEST ANALYSIS

Data Set: M:\...\RiverPark - Manual wo PW.aqt
Date: 06/23/17 Time: 16:26:08

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: River Park
Test Well: 286258
Test Date: 2.29.16

AQUIFER DATA

Saturated Thickness: 80. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
RP-PW	0	0

Observation Wells

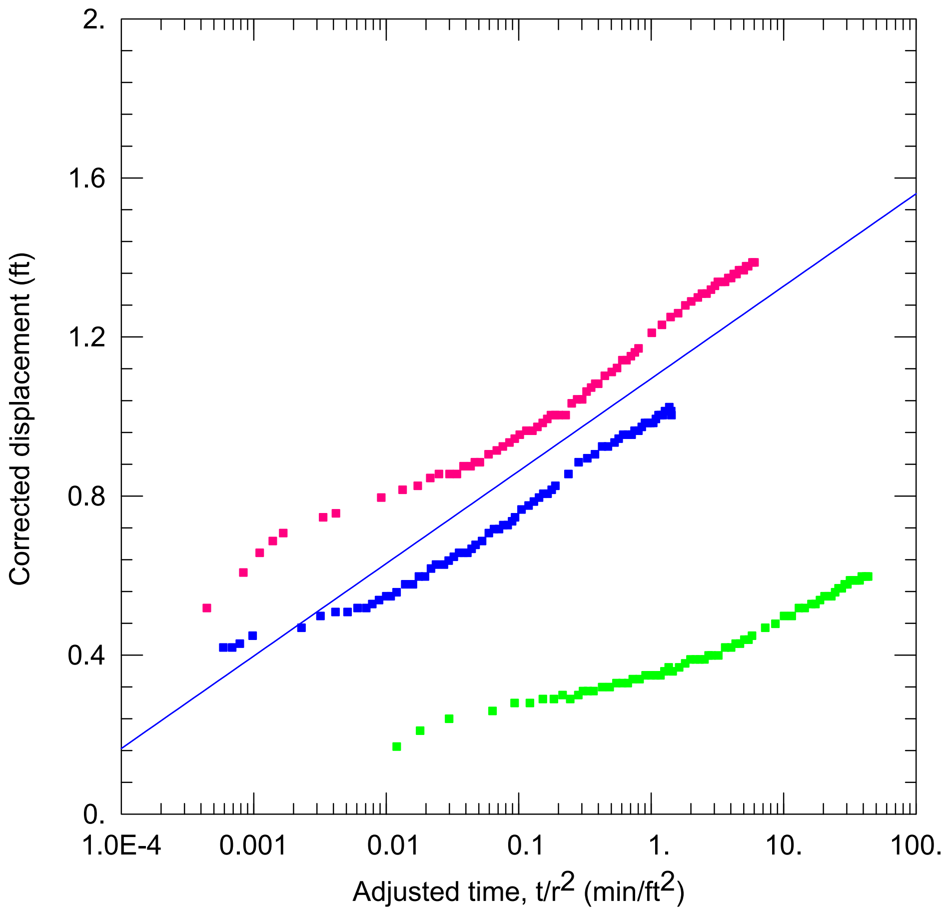
Well Name	X (ft)	Y (ft)
▪ RP-S1	34.61	62.41
▪ RP-S2	34.61	0
▪ RP-D1	12.9	0

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 2.985E+4 ft^2/day S = 0.4858

Figure 8. Cooper–Jacob analysis for observation well RP-D1.



WELL TEST ANALYSIS

Data Set: M:\...\RiverPark - Manual wo PW.aqt
Date: 06/23/17 Time: 16:27:00

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: River Park
Test Well: 286258
Test Date: 2.29.16

AQUIFER DATA

Saturated Thickness: 80. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
RP-PW	0	0

Observation Wells

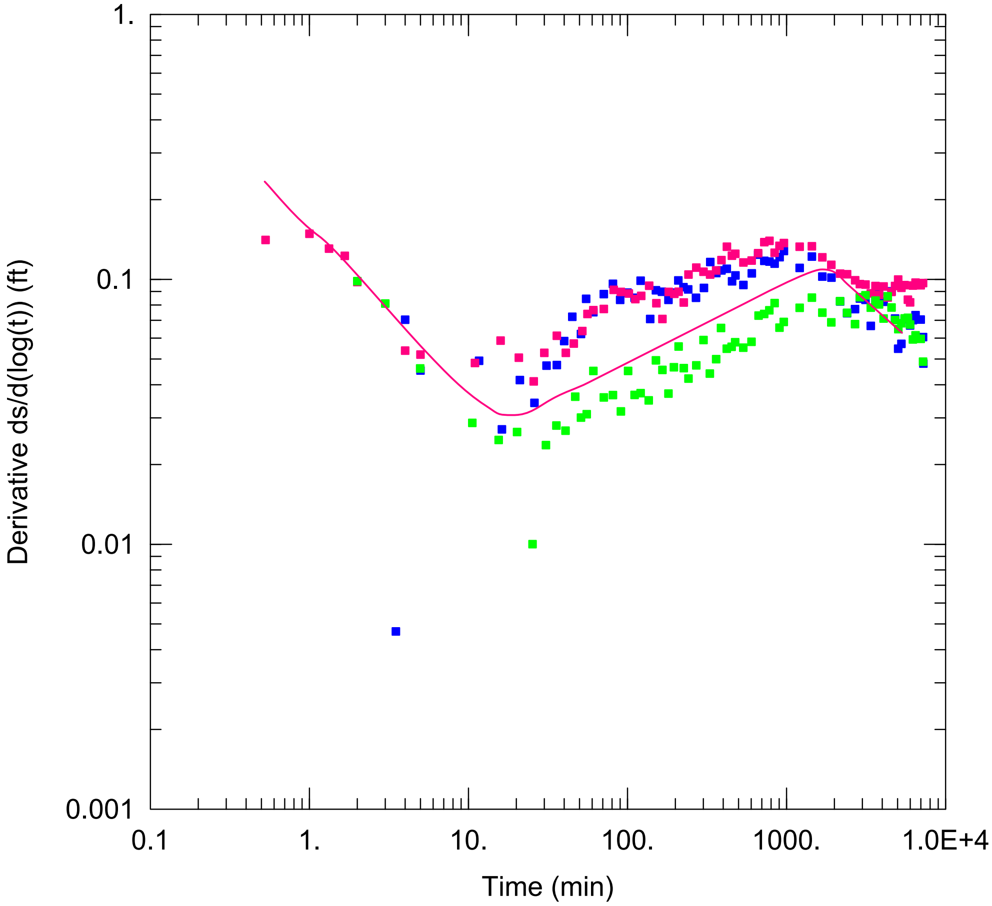
Well Name	X (ft)	Y (ft)
▪ RP-S1	34.61	62.41
▪ RP-S2	34.61	0
▪ RP-D1	12.9	0

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 2.139E+4 ft^2/day S = 0.0006517

Figure 9. Cooper–Jacob composite plot analysis for all the observation wells.



WELL TEST ANALYSIS

Data Set: M:\...\RiverPark - Manual wo PW.aqt
Date: 06/23/17 Time: 16:35:50

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: River Park
Test Well: 286258
Test Date: 2.29.16

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
RP-PW	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
▪ RP-S1	34.61	62.41
▪ RP-S2	34.61	0
▪ RP-D1	12.9	0

Figure 10. Derivative plot of all the River Park observation wells. This derivative plot indicates an unconfined aquifer and likely influence of a recharge boundary (Renard and others, 2009).

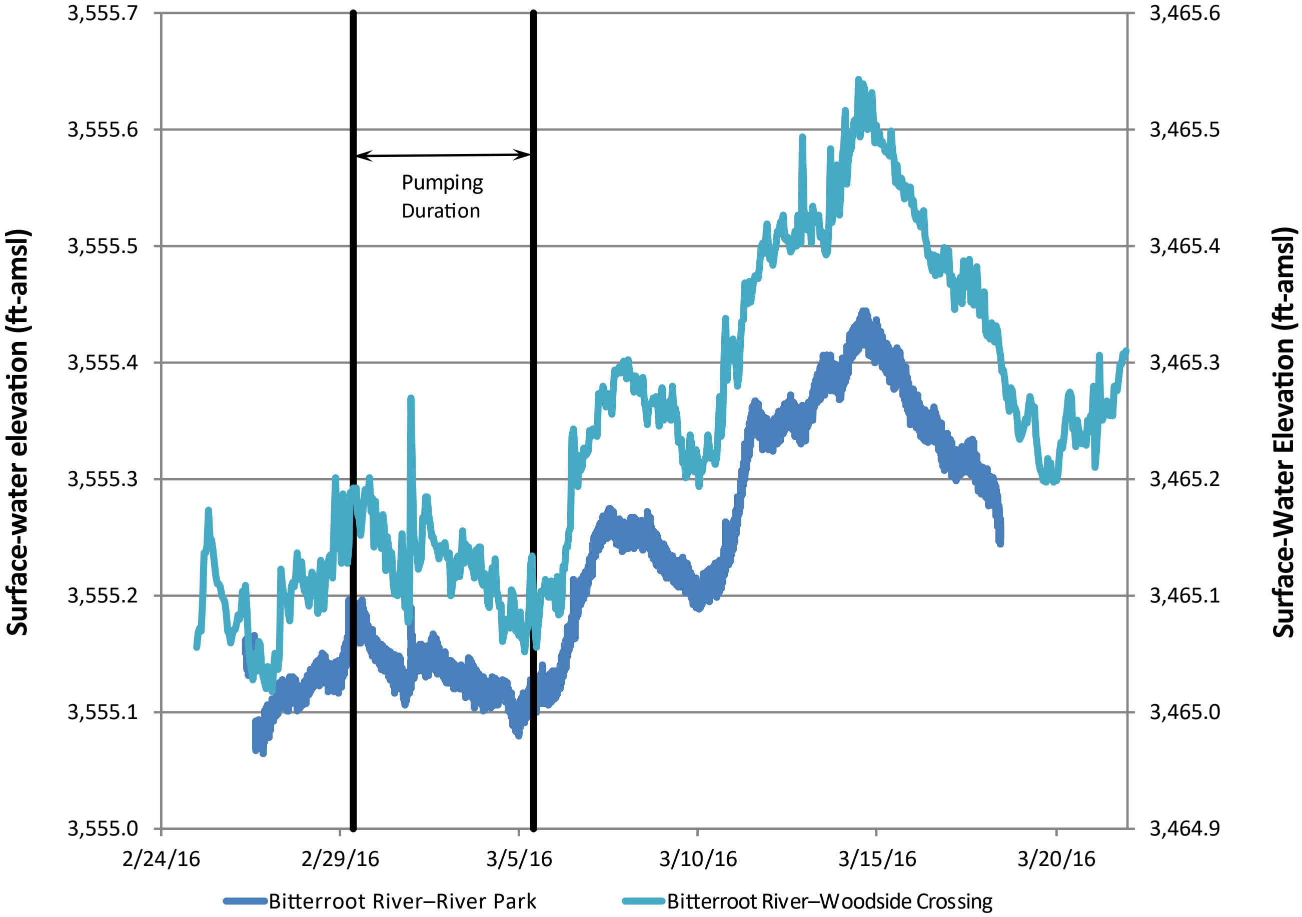


Figure 11. Hydrographs of the Bitterroot River at the River Park test site and Woodside Crossing. Both hydrographs decline during the constant-rate aquifer test. This indicates that the decline seen at the Bitterroot River at River Park is not due to pumping.

1.4. Summary

Based on the drawdown data, derivative plot analysis, and a distance–drawdown analysis, the cone of depression at the River Park site probably intersected the Bitterroot River. However, the influence from pumping was not great enough to be measured directly through stage or discharge measurements. The transmissivity results are within the range of a sand and gravel aquifer. The estimated storativity value of 0.003 indicates a semi-confined aquifer; however, lithologic logs demonstrate an unconfined aquifer. The estimated storativity may reflect relatively thin beds of fine materials creating vertical anisotropy.

2 SKALKAHO PARK SITE

2.1 Background

2.1.1 Purpose of Test

The purpose of this test was to estimate aquifer properties of the shallow sand and gravel alluvial aquifer near Skalkaho Creek.

2.1.2 Test Location

The aquifer test site is located south of Hamilton in a small county park, at lat/long coordinates of 46.1904, -114.0970. The park is located near Skalkaho Creek northwest of the intersection of Skalkaho Highway and South Shoshone Loop (fig. 12).

2.1.3 Test Type

This was a constant-rate aquifer test, conducted at an average pumping rate of 74 gpm. Wells included the pumping well 286267 (SP-PW) and three observation wells: 286266 (SP-S1), 286270 (SP-S2), and 196136 (Santos). The Santos well is a nearby domestic well, which was not pumped during this test. The pumping portion of the 96-h aquifer test started on March 9, 2016 at 09:01 and ended on March 13, 2016 at 09:05. Recovery water levels were monitored for 24 h.

2.1.4 Hydrogeologic Setting

The pumping and observation wells were installed within the floodplain of Skalkaho Creek. The geol-

Figure 12. Skalkaho Park aquifer test site map.

ogy includes sands, gravels, and cobbles consistent with floodplain deposits. The lithology logged for the pumping well consisted of:

- light-brown sand and gravel (0–17 ft),
- gravel and cobbles (17–23 ft), and
- yellowish-brown sand with little gravel (23–50 ft).

Lithologic descriptions were similar in the observation wells. Groundwater was encountered 16 ft bgs and ranged between 10 and 18 ft bgs during late October 2015 through early June 2016.

2.1.5 Hydrologic Features

The primary hydrologic feature at the site is Skalkaho Creek. It is located about 125 ft northeast of the pumping well (fig. 12).

2.2 Field Procedure

2.2.1 Monitoring Locations

The pumping well, three observation wells, and a staff gage were monitored during this test (fig. 12; table 5). Additional well information is included on the 633 form for well 286267. Each well is completed as a partially penetrating well in the shallow sand and gravel alluvial aquifer. Two observation wells were screened 35–45 ft bgs. The third observation well, the Santos domestic well, has an open bottom at 40 ft bgs.

A staff gage (site 283536) with a stilling well was installed to monitor creek stage throughout the test.

2.2.2 Data Collection

A transducer was installed at each location. Recording intervals were hourly before the test and set to a 1-min interval for the step-test, aquifer test, and recovery test. Water levels were measured manually at the frequencies shown in table 3. A totalizing flowmeter installed on the discharge line tracked the total amount of water pumped and was used to calculate the pumping rate. Transducers in all wells, with the exception of the Santos well, recorded water levels from mid-October 2015 until early May 2016. These data were used to ascertain if there were any pre- or post-pumping water-level trends.

A step-test was performed on March 8, 2016, prior to the aquifer test, to determine an appropriate pumping rate. The step test started at 100 gpm, but water levels declined too quickly in the pumping well. We stopped the test until water levels recovered and then restarted the test at a lower rate. Ultimately, three steps were completed: at 56 and 75 gpm for about 1 h each and at 85 gpm for 2 h. Drawdown was observed in all wells at 85 gpm, but the pumping well exhibited a continuous, slow decline in water level at this rate over the 2-h test. We established a target rate of about 80 gpm for the constant-rate test (though the rate stabilized around 74 gpm during the actual constant-rate test) to prevent water-level decline below the pump intake.

The aquifer test began on March 9, 2016 at 09:01 following full water-level recovery in all wells after the step-test.

Pumping during this test lasted until March 13 at 09:05, for a total of 96 h of pumping at a time-weighted average pumping rate of 74 gpm. Recovery was monitored for a total of 24 h, until March 14 at 09:05, when all wells recovered to 100% of pre-test levels.

Water-chemistry samples for analysis of major cation/anions, trace metals, and stable-water isotopes were collected from the pumping well at the start, middle, and end of the pumping portion of the aquifer test. Water chemistry from the river was collected on March 10, 2016.

2.3 Results

The average pumping rate of 74 gpm was used in test analysis. Water levels monitored before and after the aquifer test indicated no measurable background trends that needed to be removed from the drawdown data.

Table 5. Skalkaho Park well information.

GWIC	Name	Diameter (in)	Well Depth (ft)	Screened Interval (ft-bgs)	Distance from PW (ft)	Max Drawdown (ft)
286267	SP-PW	8	50	35–45	0	9.96
286266	SP-S1	6	45	35–45	47	0.75
286270	SP-S2	6	100	35–45	69	0.81
196136	Santos	6	40	Open bottom	436	0.25

2.3.1 Hydrographs

Figure 13 shows the pumping well hydrograph for 2 weeks prior to pumping, the pumping interval, and for 1 week after the recovery period. Figure 14 show the observation wells' hydrographs for the same date range. Table 5 reports the maximum drawdown at each well.

2.3.2 Aquifer Properties

A Cooper–Jacob (1946) analysis was performed on the late-time data to estimate transmissivity and specific yield (table 6). The AQTESOLV plots for the observation wells are shown in figures 15 and 16.

Figure 17 represents a composite plot for SP-S1 and SP-S2. Composite plots also provide estimates of a single, bulk average of the transmissivity from the Cooper–Jacob analysis for the tested aquifer.

Assuming an aquifer thickness between 50 and 80 ft (thickness based on LaFave, 2006 and drilling results), hydraulic conductivities ranging from 116 to 210 ft/d were calculated from the estimated transmissivities. These fall within the range of sand and gravel aquifers (Fetter, 1994). Specific yield for unconfined aquifers is often difficult to obtain through aquifer testing (as is the case with specific storage for confined systems). For unconfined systems, the range of specific yield is typically 0.02–0.30 and on the higher end for sand and gravel type aquifers (Fetter, 1994). Our estimated specific yields of 0.01 and 0.02 may indicate more fine-grained material within the aquifer.

2.3.3 Water Chemistry

There was no discernible difference in chemistry between the groundwater and creek water. Stable-water isotopes, hydrogen and oxygen, were collected at the same frequency as the inorganic samples, and also showed no discernible difference in the well water and creek water samples.

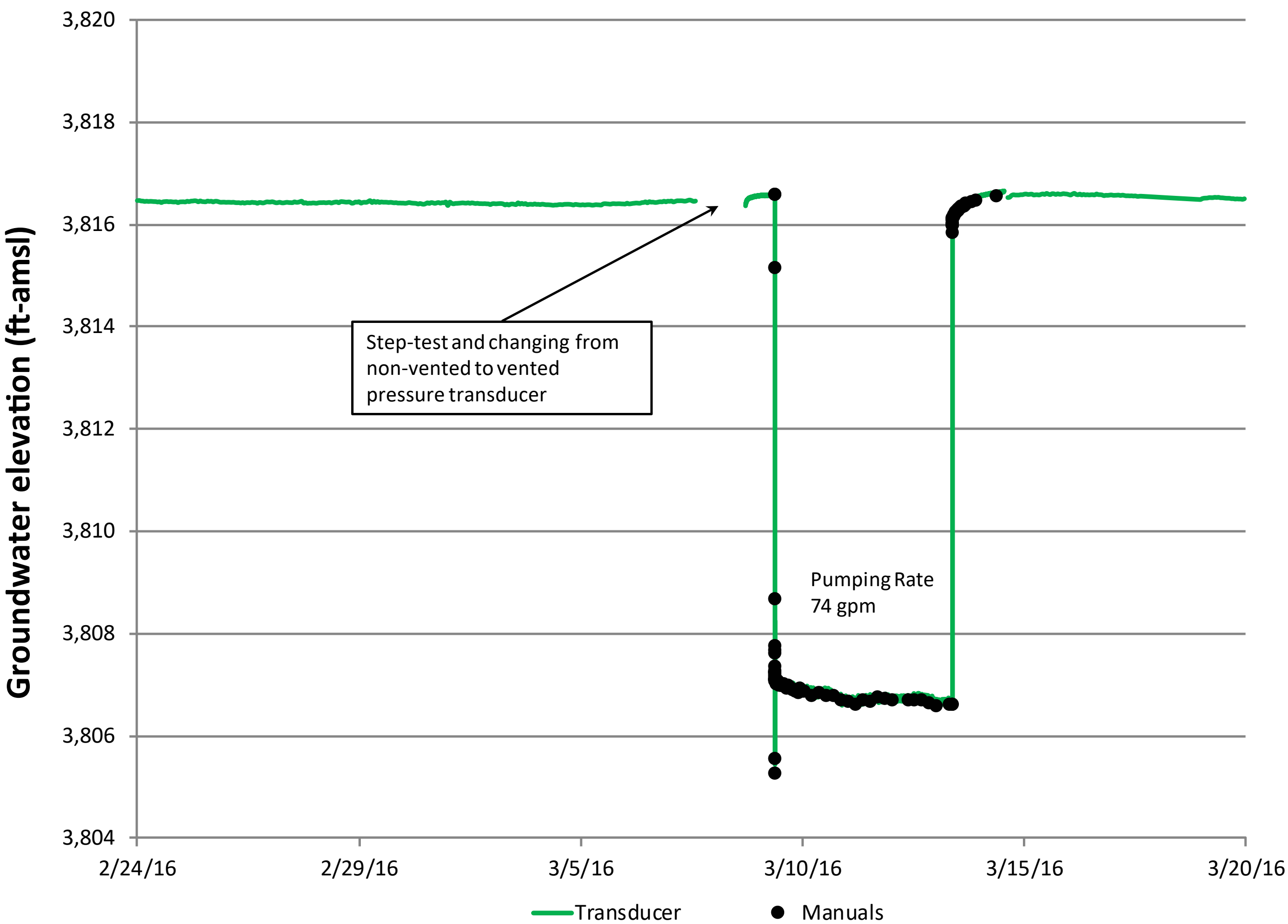


Figure 13. Hydrograph for the Skalkaho Park pumping well (SP-PW). The “dip” in the beginning of the aquifer test data is the result of adjusting the pumping rate.

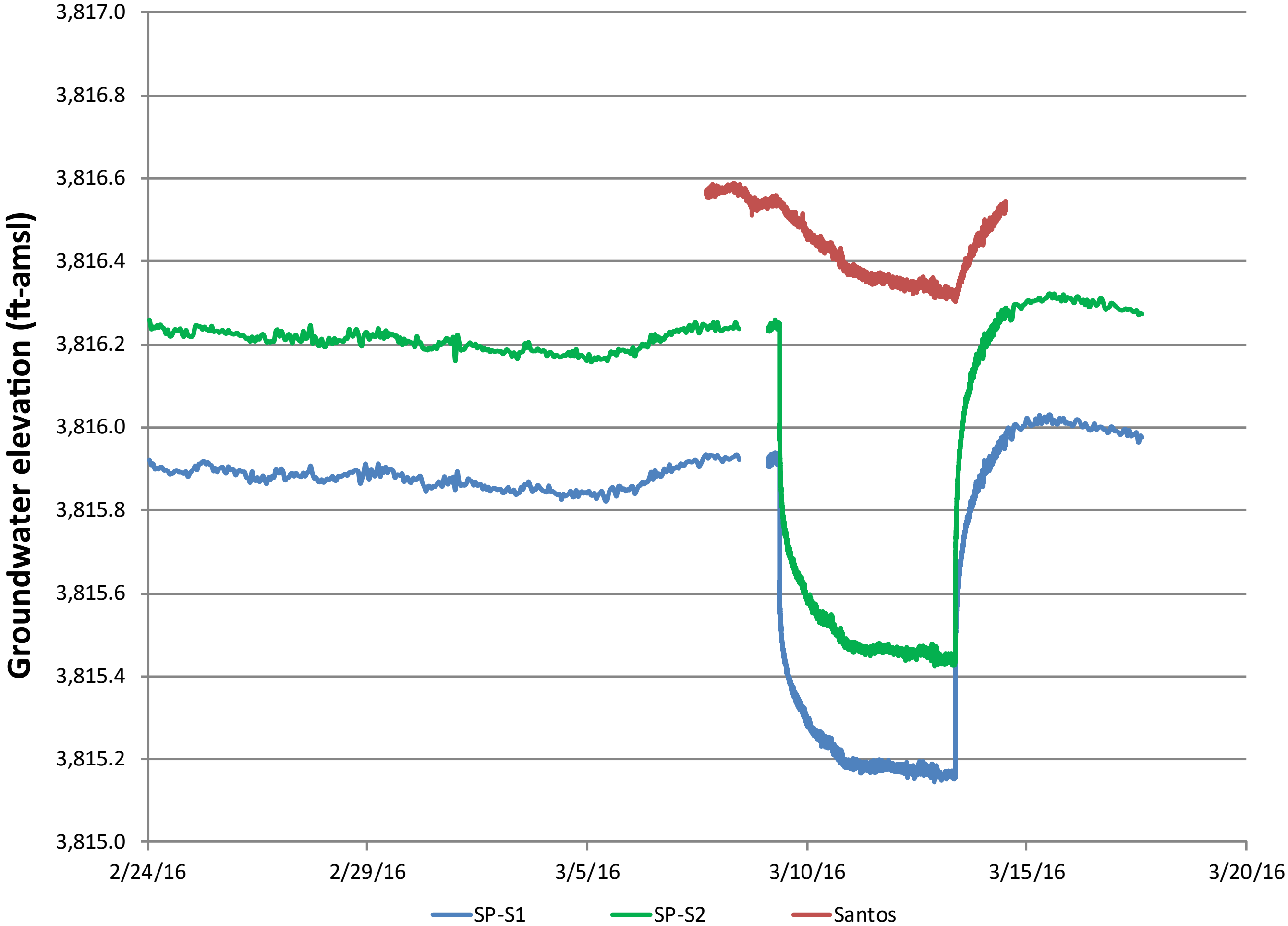


Figure 14. Hydrographs for the River Park observation wells and the nearby domestic well, Santos.

2.3.4 Aquifer Boundaries

The well drawdown data (figs. 13, 14) and the derivative plots (fig. 18) suggest that around 25 h after the start of the test, the observation well drawdowns were influenced by a recharge boundary presumed to be Skalkaho Creek. In addition, a stream depletion model (Hunt, 1999) was used to predict if there would be any depletion in Skalkaho Creek. The model predicted that after 93 h of pumping there would have been 28 gpm, or 0.06 cfs, of influence.

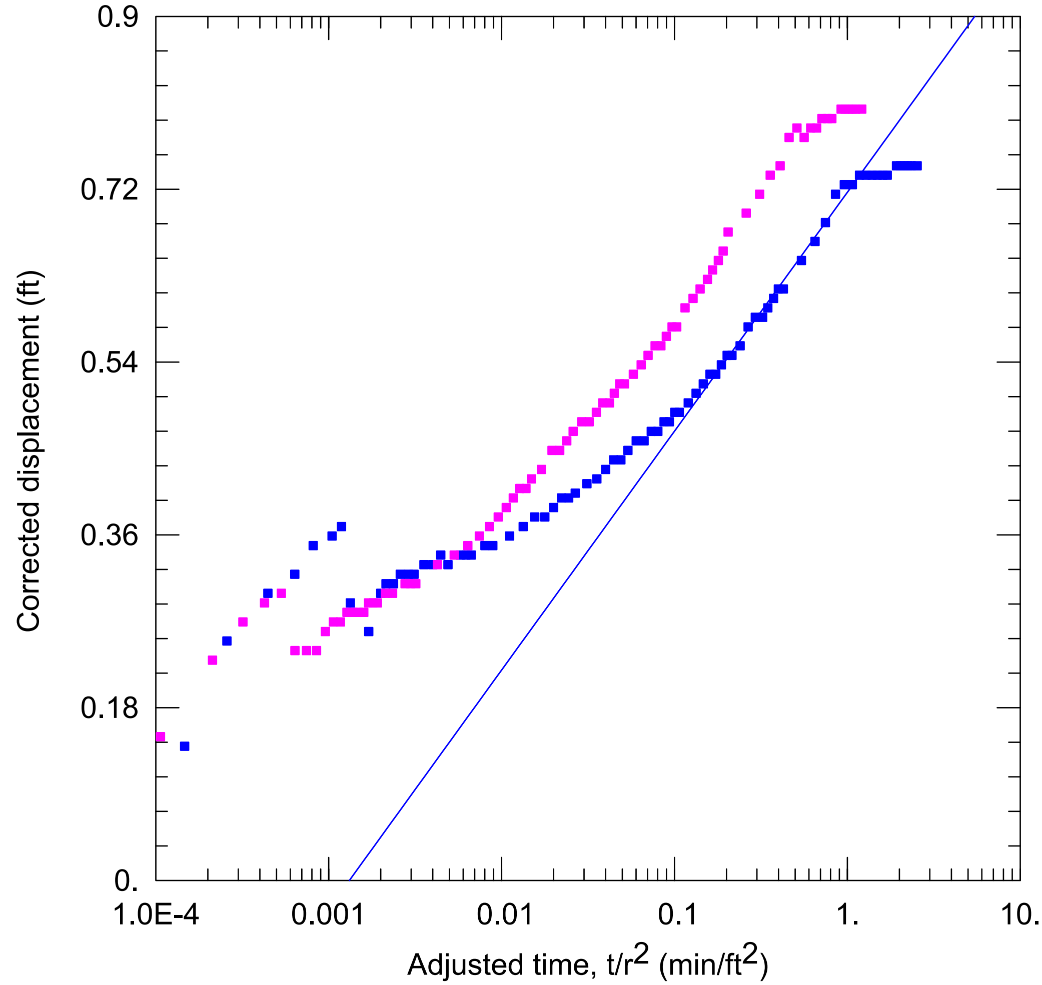
2.4 Summary

Based on the drawdown data and derivative plot analysis, the cone of depression intersected a recharge boundary at Skalkaho Creek. The transmissivity results are within the range of a sand and gravel aquifer. The storativity values suggest the presence of fine-grained materials within the sand and gravel aquifer.

Table 6. Aquifer parameter results for Skalkaho Park aquifer test.

	GWIC ID	T (ft^2/day)	Sy
Composite plot of S1 & S2		9,259	0.02
SP-S1 and SP-S2	286266/286270		
SP-S1	286266	10,490	0.02
SP-S2	286270	9,752	0.01

Note. T, transmissivity; Sy, specific yield.



WELL TEST ANALYSIS

Data Set: M:\...\SkalkPark - SP-1 Manual wo PW.aqt
Date: 03/05/20 Time: 17:19:42

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: Skalkaho Park
Test Well: 286267
Test Date: 3.9.16

AQUIFER DATA

Saturated Thickness: 50. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

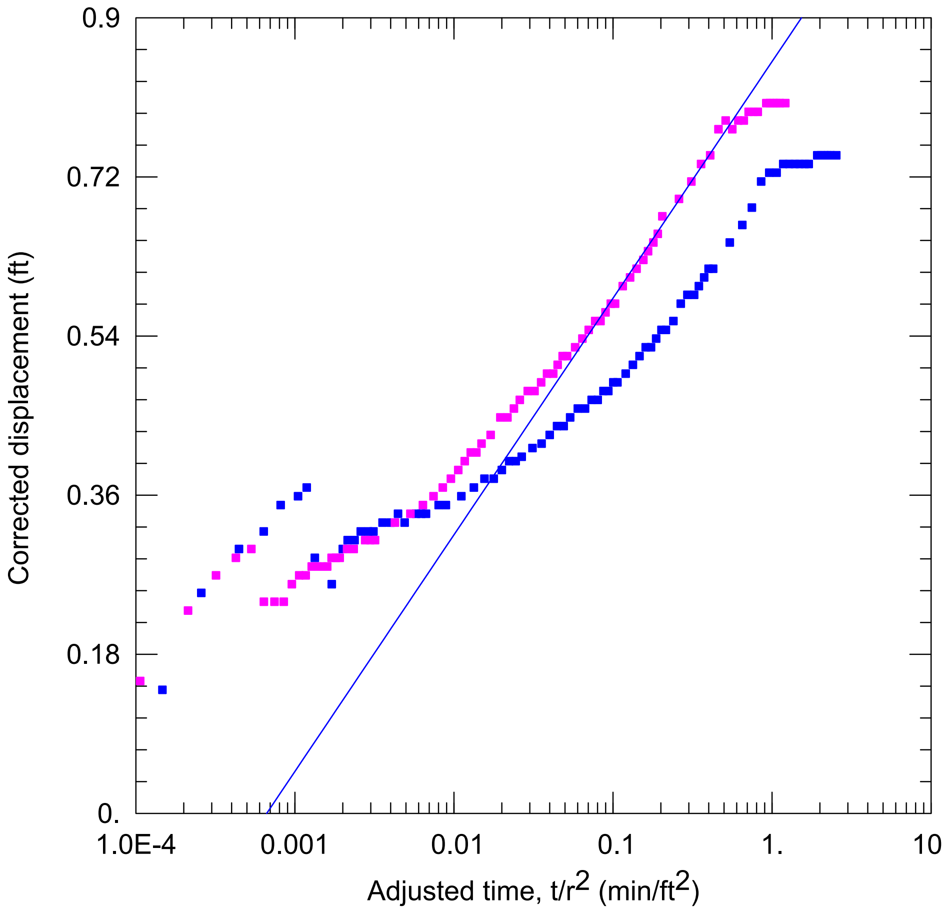
Well Name	X (ft)	Y (ft)
SP-PW	0	0

Observation Wells

Well Name	X (ft)	Y (
▪ SP-S1	47.4	0
▪ SP-S2	-18.5	66

SOLUTION

Figure 15. Cooper–Jacob analysis for observation well SP-S1.



WELL TEST ANALYSIS

Data Set: M:\...\SkalkPark - SP-2 Manual wo PW.aqt
Date: 03/05/20 Time: 17:22:21

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: Skalkaho Park
Test Well: 286267
Test Date: 3.9.16

AQUIFER DATA

Saturated Thickness: 50. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SP-PW	0	0

Observation Wells

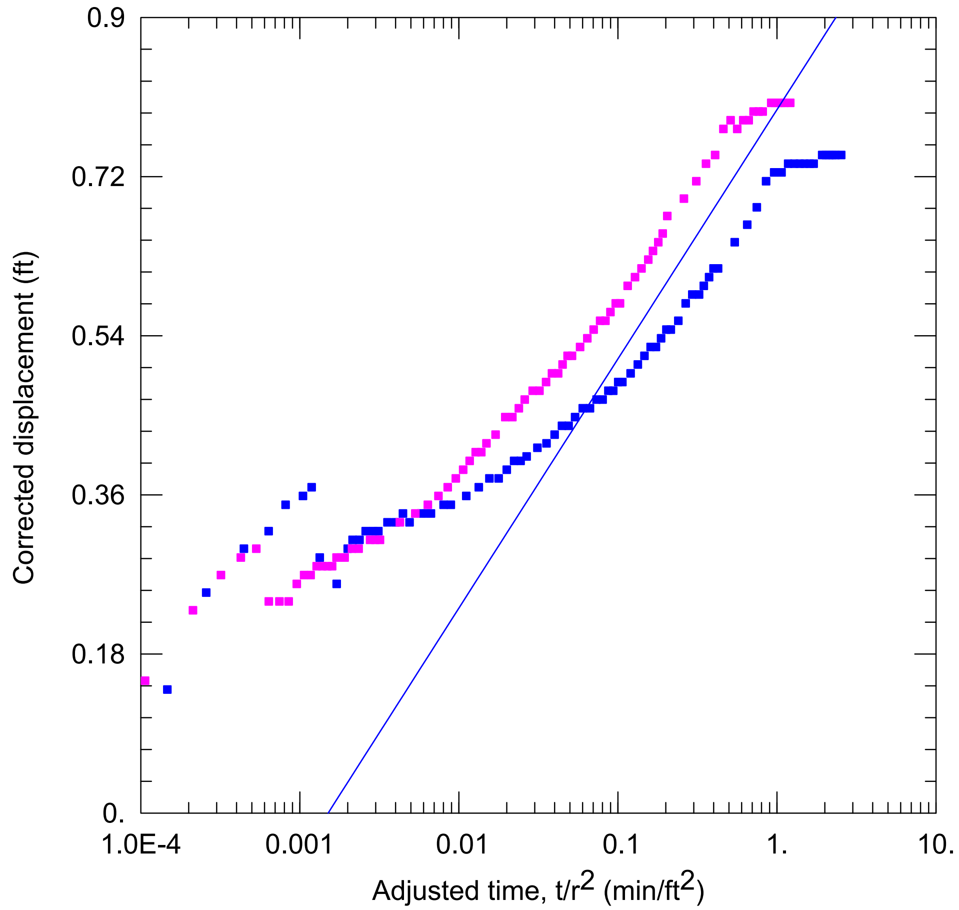
Well Name	X (ft)	Y (ft)
▪ SP-S1	47.4	0
▪ SP-S2	-18.5	66

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 9752.3 ft^2/day S = 0.01012

Figure 16. Cooper–Jacob analysis for observation well SP-S2.



WELL TEST ANALYSIS

Data Set: M:\...\SkalkPark - COMPOSITE Manuals wo PW.aqt
Date: 03/05/20 Time: 17:24:45

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: Skalkaho Park
Test Well: 286267
Test Date: 3.9.16

AQUIFER DATA

Saturated Thickness: 50. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SP-PW	0	0

Observation Wells

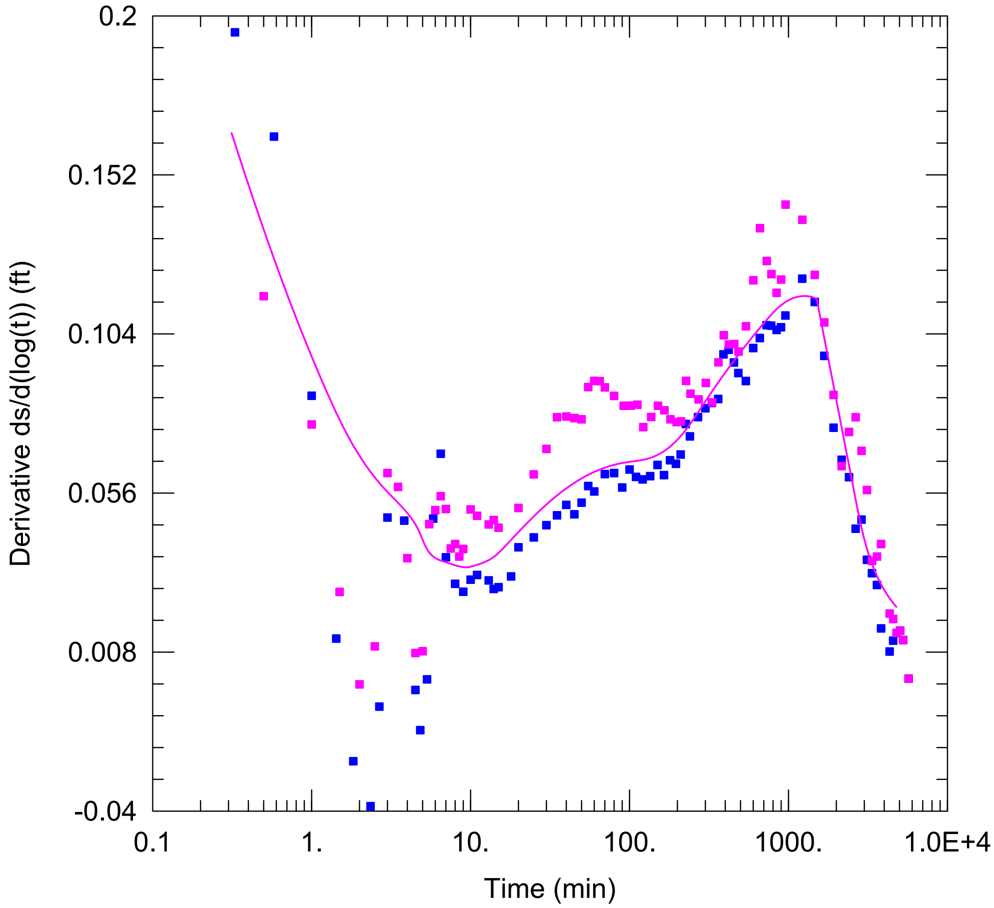
Well Name	X (ft)	Y (ft)
▪ SP-S1	47.4	0
▪ SP-S2	-18.5	66

SOLUTION

Aquifer Model: Unconfined Solution Method: Cooper-Jacob

T = 9259.3 ft^2/day S = 0.02175

Figure 17. Cooper–Jacob composite plot analysis for all the observation wells.



WELL TEST ANALYSIS

Data Set: M:\...\SkalkPark - Manual wo PW.aqt
Date: 08/24/17 Time: 19:18:52

PROJECT INFORMATION

Company: MBMG
Client: Hamilton
Location: Skalkaho Park
Test Well: 286267
Test Date: 3.9.16

AQUIFER DATA

Saturated Thickness: 50. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
SP-PW	0	0

Observation Wells

Well Name	X (ft)	Y (ft)
▪ SP-S1	47.4	0
▪ SP-S2	-18.5	66

Figure 18. Derivative plot of the observation wells. This derivative plot indicates an unconfined aquifer and influence from a recharge boundary (Renard and others, 2009).

3 ARROW HILL SITE

3.1 Background

3.1.1 Purpose of Test

The purpose of this test was to determine hydrologic properties of the Tertiary sediments underlying the eastern bench (fig. 2). These sediments supply water to many domestic wells.

3.1.2 Test Location

The aquifer test site is southeast of Hamilton in the Arrow Hill community, at a lat/long of 46.2239, -114.1056. Arrow Hill (fig. 19) is located southwest of the intersection of Golf Course Road and Duus Lane.

3.1.3 Test Type

This constant-rate aquifer test ran for 95.5 h at a time-weighted average pumping rate of 167 gpm. Wells included the pumping well, AH-PW (286280), and two observation wells: 286217 (AH-D1) and a nearby domestic well 255273 (Shonkwiler). The Shonkwiler well was in use during the aquifer test. However, we wanted to investigate whether pumping influences would be observed in this well, which was located 244 ft northwest of the pumping well (fig. 19). The pumping portion of the test began on March 4, 2016 at 10:06 and ended on March 8, 2016 at 09:35. Water-level recovery was monitored for 24 h.

3.1.4 Hydrogeologic Setting

The pumping and observation wells were screened within Tertiary sediments, primarily consisting of clay, silt, and fine sand, with occasional thin beds of coarse sand and gravel. These coarse sediments were encountered in dry conditions at 42–48 ft-bgs, and in saturated conditions at 153–165 and 205–215 ft-bgs. Sediment color changed from yellow/red/brown to olive green/white at 155 ft-bgs, although sediment size remained fine to coarse gravel and coarse sand through the color change. Light green/gray clay was encountered from 165 to 190 ft-bgs and may serve as a local confining layer. The static groundwater in the pumping well was 136 ft-bgs at the time of installation. Water levels declined steadily from late December 2015 through the aquifer test period. This trend was removed from the drawdown data during analysis.

3.1.5 Hydrologic Features

There were no notable hydrologic features in the area during the aquifer test. Irrigation canals are located 390 ft southwest and 580 ft northeast of the pumping well, but they were dry at the time of the test.

3.2 Field Procedure

3.2.1 Monitoring Locations

In addition to the pumping well 286280, response to pumping was monitored in wells 286217 (AH-D1) and 255273 (fig. 19; table 7). Additional well information is included on the 633 form accessed through GWIC (well 286280). The observation well AH-D1 is completed in the Tertiary aquifer as a partially penetrating well screened from 205 to 215 ft-bgs. The Shonkwiler domestic well is screened from 190 to 195 ft-bgs.

3.2.2 Data Collection

Transducers installed in each well before the test recorded water levels at hourly intervals. They were reprogrammed to record every minute during the step-test, aquifer test, and recovery test. Manual water-level measurements were taken at the frequencies shown in table 3. A totalizing flowmeter installed on the discharge line tracked the total amount of water pumped and was also used to calculate the pumping rate.

A step-test was performed on March 3, 2016, prior to the aquifer test. Five steps, conducted at rates of about 75, 100, 125, 150, and 175 gpm, were each about 1 h in duration. Results indicated 170 gpm would be sustainable for the constant-rate test. During the 175 gpm portion of the step-test, all monitoring wells exhibited measurable drawdown and groundwater levels in the pumping well stabilized.

The aquifer test started on March 4, 2016 at 10:06, after water levels had recovered from the step-test (fig. 20). The pumping portion of the constant-rate test extended until March 8 at 09:30, for a total of 95.5 h of pumping. Recovery was monitored for 24 h, until March 9 at 09:35. The pumping well recovered by 96%, AH-D1 recovered by 89%, and Shonkwiler recovered by 99% during that time.

Water-chemistry samples (major cation/anions and stable-water isotopes) were collected from the pumping well at the start, middle, and end of the aquifer test just before the pump was turned off.

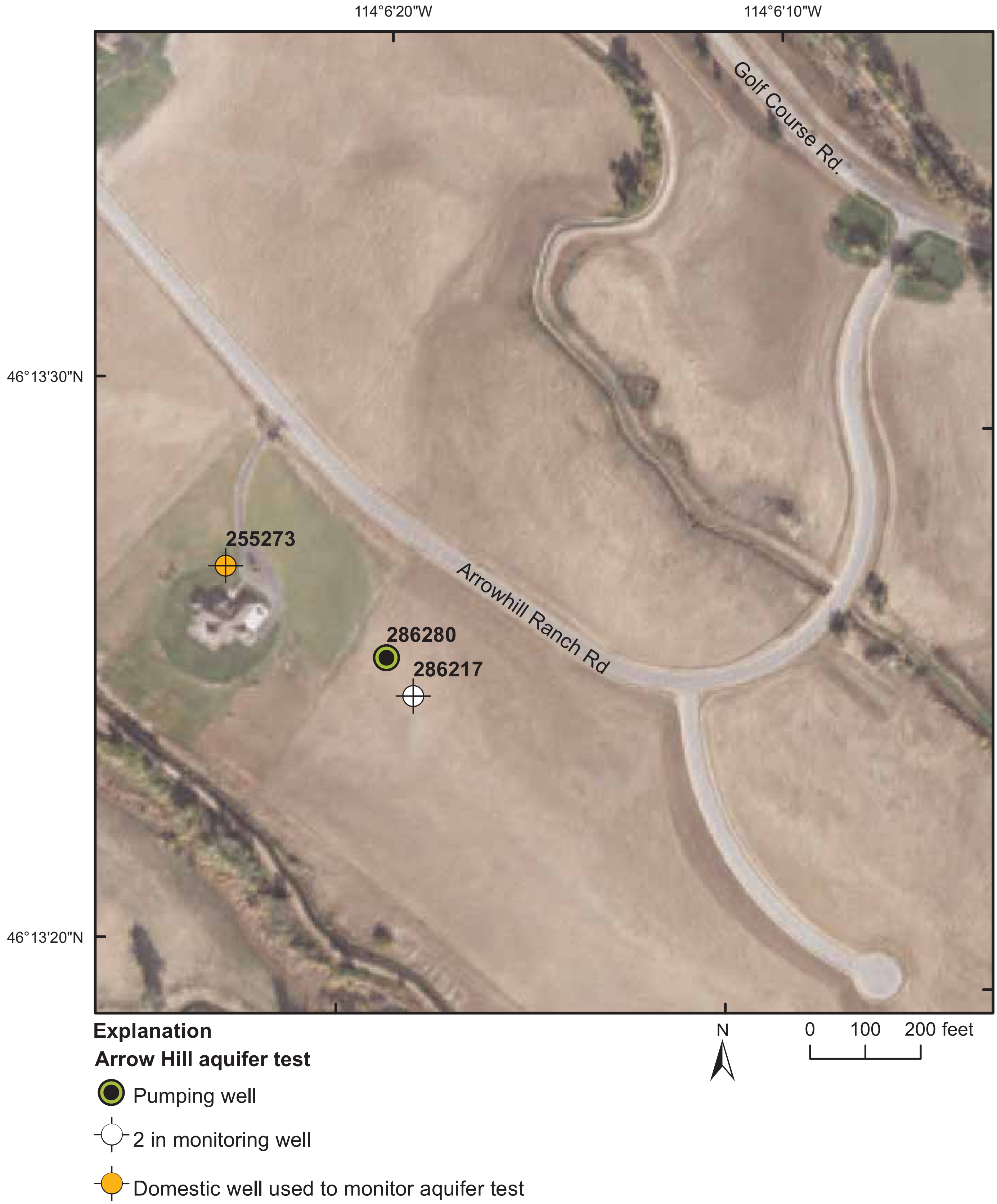


Figure 19. Arrow Hill aquifer test site map.

Table 7. Well information.

GWIC	Name	Diameter (in)	Well Depth (ft)	Screened Interval (ft-bgs)	Distance from PW (ft)	Max Drawdown (ft)
286280	AH-PW	8	205	195–205	0	15.95
286217	AH-D1	6	215	205–215	84	5.48
255273	Shonkwiler	6	200	190–195	244	2.44

3.3 Results

Water levels monitored before and after the aquifer test showed a slight decreasing background trend. This trend was removed from the drawdown data prior to analysis for hydraulic parameters.

3.3.1 Hydrographs

Figure 20 shows the hydrograph for the pumping and observation wells 2 two weeks prior to pumping, the pumping interval, and 1 week after the recovery period. Figure 21 shows the hydrograph for the Shonkwiler well. Table 7 shows the maximum drawdown for each well.

3.3.2 Aquifer Properties

A Cooper–Jacob (1946) analysis was performed on the late-time data in the flat portion of the derivative plot, which indicates infinite acting radial flow (IARF; fig. 22; Renard and others, 2009). This analysis resulted in estimates of transmissivity and storativity of 4,700 ft^2/day and 0.00005, respectively. This transmissivity exceeds the range reported by McMurtrey and others (1972) of 440–2,500 ft^2/day. However, their tests were of shorter duration and were conducted on shallow domestic and stock wells. The shorter pumping periods of their tests were insufficient to estimate storativity and perhaps not long enough to achieve a condition of IARF for their analysis.

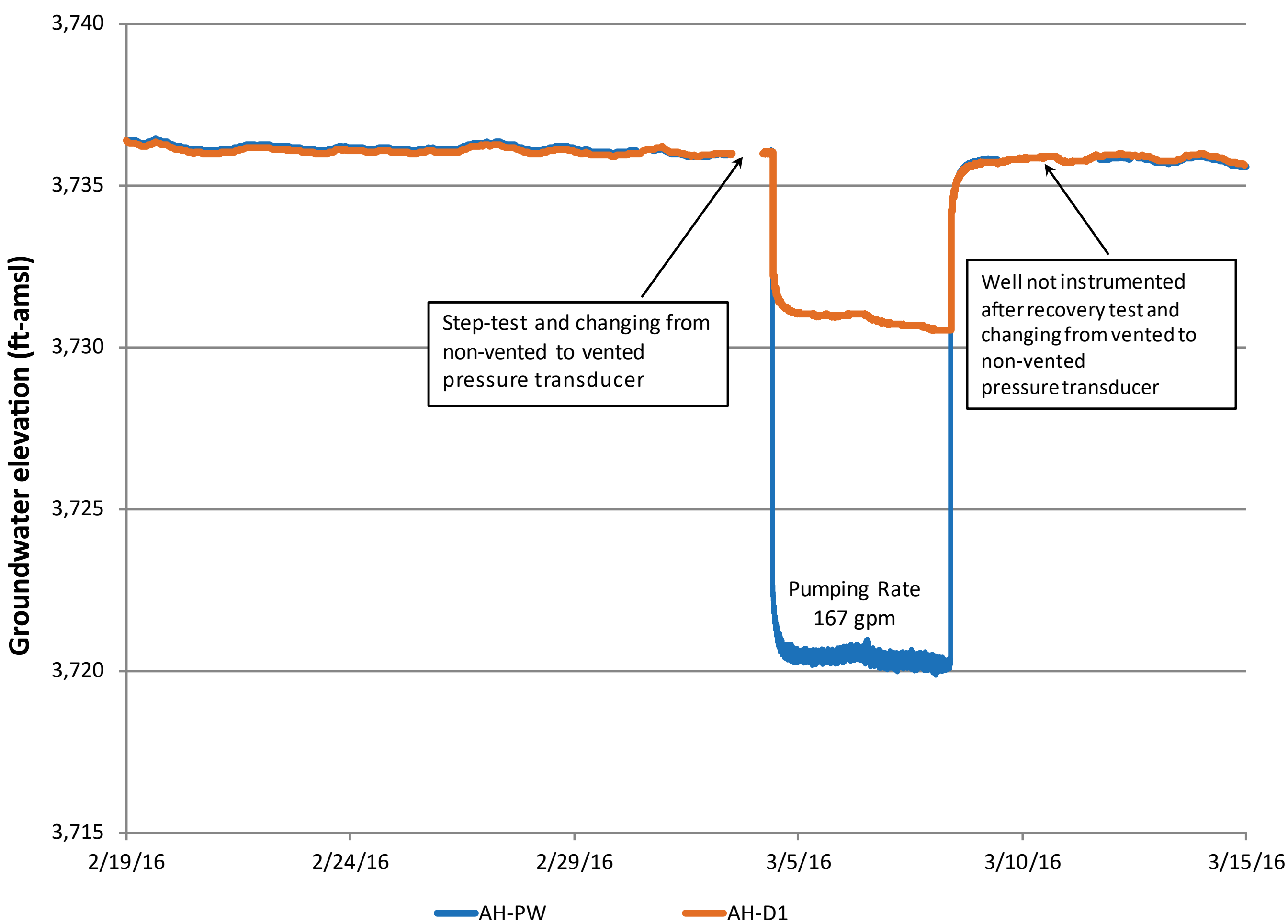


Figure 20. Hydrographs for the Arrow Hill pumping well (SP-PW) and observation well (AH-D1).

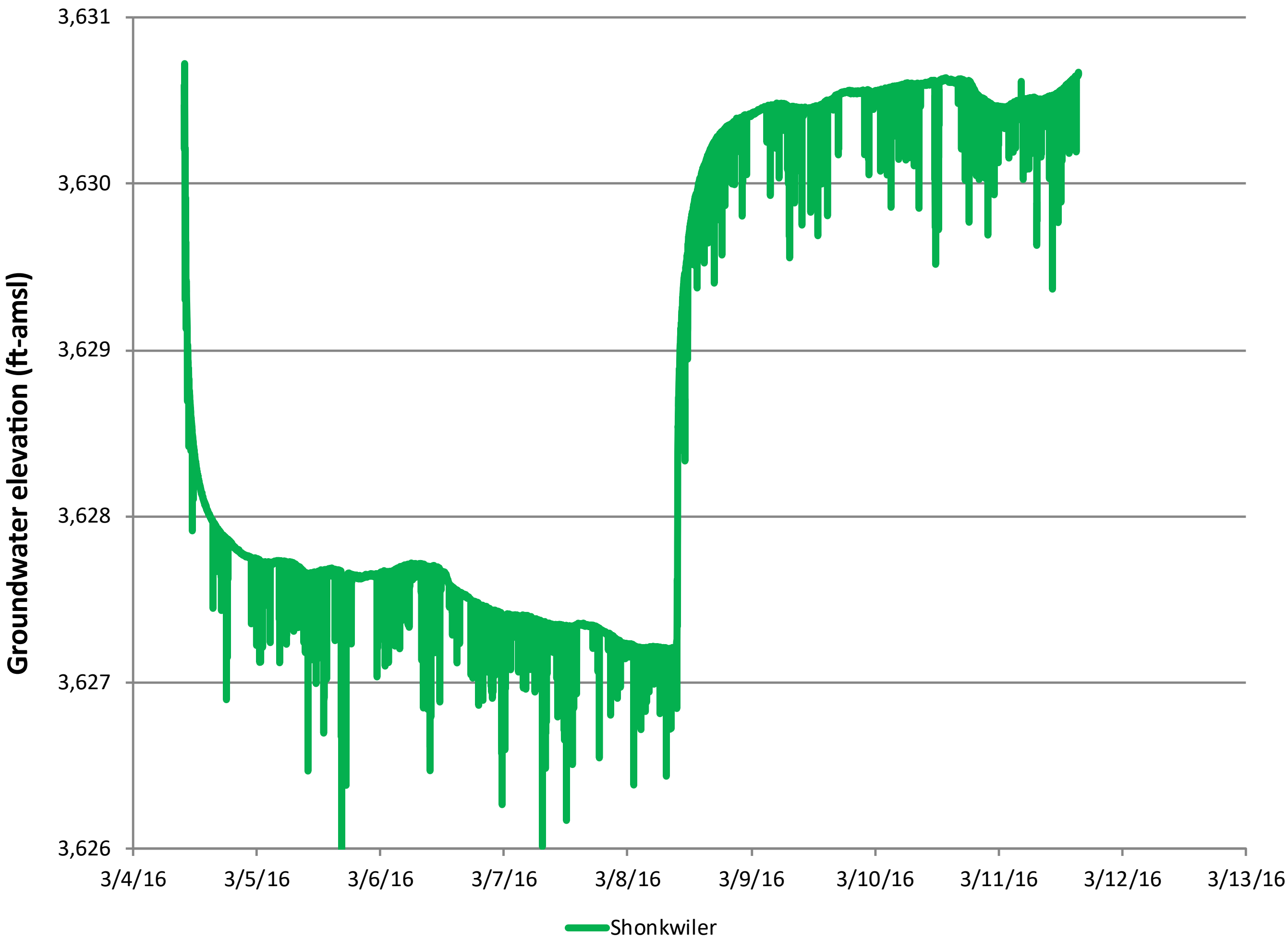


Figure 21. Hydrograph for the nearby domestic well, Shonkwiler. During the aquifer test, the well was being used as indicated in the hydrograph. Even with the well being used by the residence, the water levels are still being influenced by the pumping well.

3.3.3 Water Chemistry

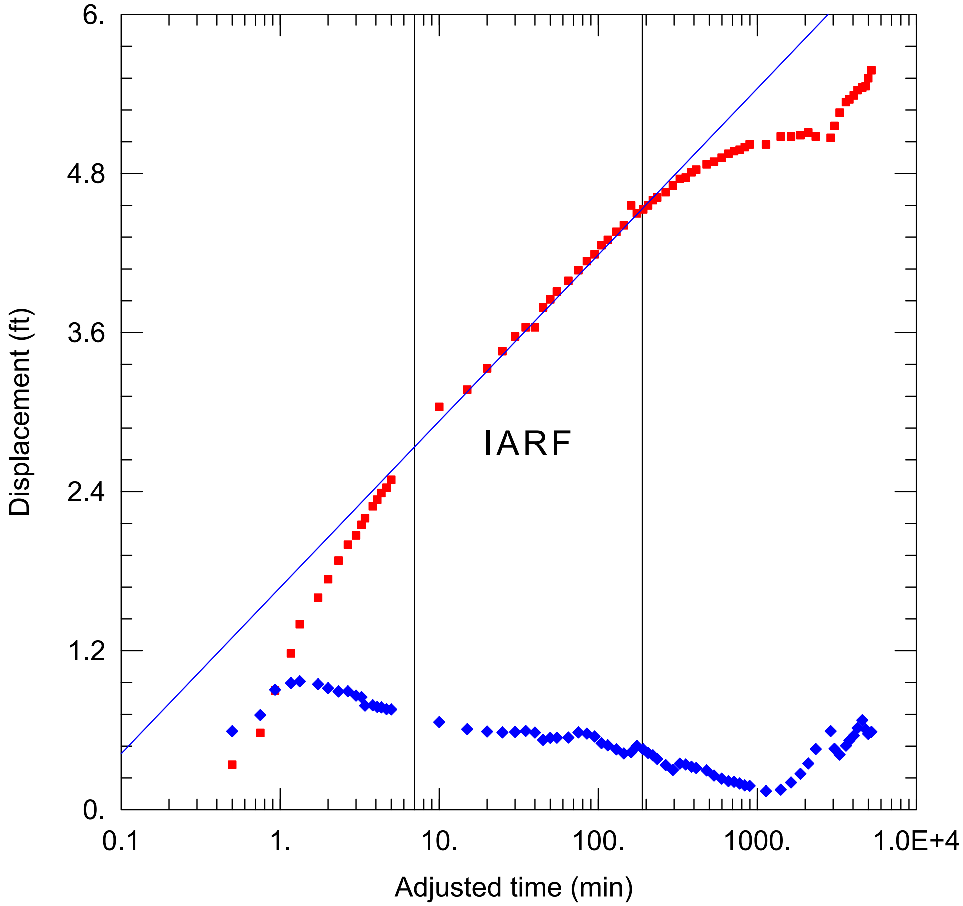
Water samples from the pumping well were collected to evaluate if the aquifer water quality changed during the constant-rate test. There was no discernable difference in the three samples.

3.3.4 Aquifer Boundaries

The well drawdown data and the derivative plots (fig. 22) suggest that around 1,500 min (25 h) after the start of the test, drawdown in the observation well decreased, apparently influenced by a limited constant-head boundary. This is attributed to some type of heterogeneity in the aquifer sediment, such as a gravel lens, which supplied a limited amount of additional water that acts as a recharge boundary (oral commun., Duffield, 2018).

3.4 Summary

Based on the drawdown data and derivative plot analysis, the drawdown was affected by a constant-head boundary, but it subsequently returned to a normal drawdown shape. This finding indicates heterogeneity within the aquifer. The transmissivity results are within the range of literature values for Montana's Tertiary sediment aquifers (Hackett and others, 1960). The storativity values indicate a locally confined or leaky-confined aquifer. This is consistent with drilling logs from the area that document various clay layers that may act as local confining units, and the presence of gravel layers. The lateral extent of these heterogeneous deposits is not known.



WELL TEST ANALYSIS

Data Set: M:\...\ArrowHill - Manual_w_derivative_usedforReport.aqt
Date: 01/26/21 Time: 15:34:33

PROJECT INFORMATION

Company: MBMG
Project: BWIPHM
Location: Arrow Hill
Test Well: AH-PW
Test Date: 3.4.16

AQUIFER DATA

Saturated Thickness: 240. ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Pumping Wells

Well Name	X (ft)	Y (ft)
AH-PW	0	0
AH-OBS	0	84.1

Observation Wells

Well Name	X (ft)	Y (ft)
▪ AH-OBS	0	84.1

SOLUTION

Aquifer Model: Confined Solution Method: Cooper-Jacob

T = 4693.8 ft^2/day S = 4.777E-5

Figure 22. Cooper–Jacob analysis of data from observation well AH-D1 and the derivative plot. The portion of the data that reflect infinite acting radial flow (IARF) is also indicated. Curve-matching was applied to this portion of the data.

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