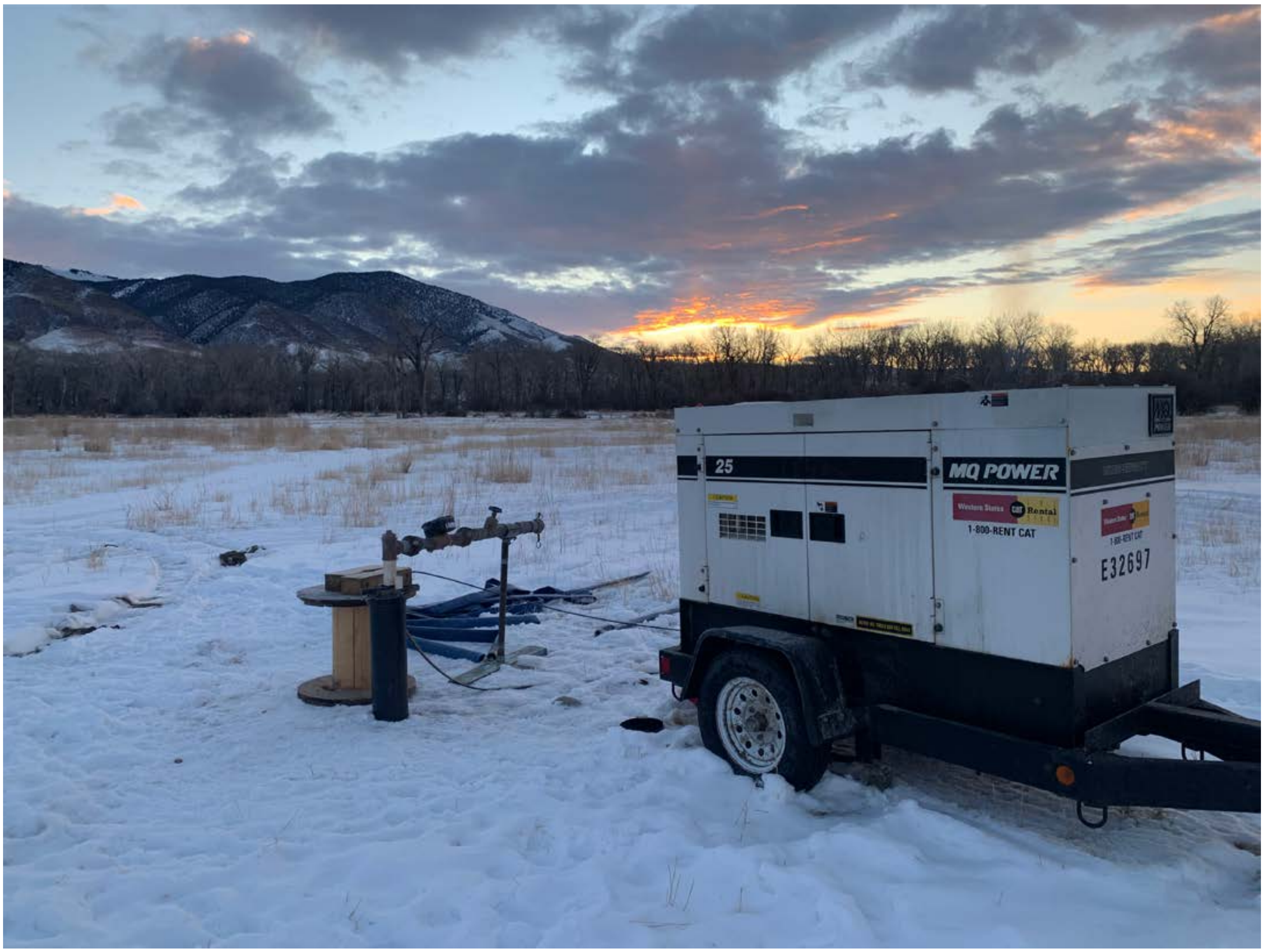
ANALYSES OF THREE CONSTANT-RATE AQUIFER TESTS IN THE LOWER BIG HOLE WATERSHED NEAR GLEN, MONTANA

Jenna M. Dohman and Todd Myse

Montana Bureau of Mines and Geology



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Cover Photo: Sunrise at aquifer test site B. Photo by Jenna Dohman, MBMG.

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ABSTRACT

The Big Hole River in southwestern Montana is an important water resource for the local economy. Low stream flows are common during the late summer, which is concerning to irrigators who rely on this water. Elevated stream temperatures combined with low stream flows also stress aquatic life on which local recreational tourism depends. A more detailed understanding of how groundwater and surface water interact in this area is needed to identify how changes in irrigation practices and infrastructure may impact river flows.

The Montana Bureau of Mines and Geology (MBMG) Ground Water Investigation Program (GWIP) performed three constant-rate aquifer tests near Glen, Montana to quantify aquifer properties. These tests were conducted in unconfined and semi-confined sand and gravel aquifers.

These tests show similar aquifer properties across aquifer test sites. Transmissivity is lowest at the site where the most fine-grained and/or clay lenses were observed, varying from 5,700 to 7,540 ft^2/d. The two other sites have transmissivities that range from 11,000 to 30,100 ft^2/d. The tests indicate that the alluvial aquifer system adjacent to the Big Hole River is productive with high transmissivities.

PURPOSE OF THE AQUIFER TESTS

Groundwater levels are shallow in the Glen Valley, typically ranging 5–10 ft below ground surface (bgs). As a result, most of the domestic and stock water wells are less than 40 ft bgs in the valley. Many of these wells also do not have available well log information. The seven wells drilled for these aquifer tests served two main purposes: (1) to provide detailed lithologic information of the alluvial aquifer, and (2) to quantify aquifer properties. Understanding the hydraulic characteristics of the alluvial aquifer will inform how irrigation changes could impact river flows.

HYDROGEOLOGIC SETTING

The Glen Valley is a north–south- to northwest–southeast-trending basin. The study area is bounded by the Pioneer Mountains to the west and the McCartney Mountain pluton to the northeast (fig. 1). The valley narrows at the lower end of the Glen Valley as a result of the river downcutting through bedrock, creating what locals refer to as “Notch Bottom” (Parker and others, in press).

Valley-fill sediments include Quaternary–Tertiary sediments that overlie Tertiary–Cretaceous volcanic, intrusive, and Cretaceous–Paleozoic sedimentary rocks (Parker and others, in press; Mosolf and McDonald, in press). The Quaternary and deeper Tertiary sediments are both water-bearing; however, most wells are completed in the shallow Quaternary sediments of the alluvial aquifer. The depth to bedrock is not well constrained. Gravity surveys suggest the valley fill is roughly 3,000 ft thick near Glen (Noble and others, 1982); however, nearby oil and gas wells in wider valleys show the depth to bedrock to be 1,100–1,800 ft (MBOG, 2025, API nos. 25001210090000, 25001210060000). Furthermore, the Glen Valley is narrower and bedrock outcrops near the valley perimeter, suggesting an even shallower depth to bedrock.

The Quaternary sediments consist of fine-to-coarse-grained sands and gravels. The contact between the Quaternary and Tertiary is poorly constrained; Kendy and Tresch (1996) remarked that this contact was difficult to determine in the Upper Big Hole Basin (Ruppel and others, 1993). In this report, the Quaternary–Tertiary contact is interpreted to be about 40 ft bgs as indicated by the presence of a silty-clay layer observed during drilling in all wells drilled past this depth, though it was slightly deeper in one well (328228, approximately 60 ft). This silty-clay layer is also described in a few other local water-well logs. Tertiary sediments are primarily composed of the Renova and Sixmile Creek Formations of late Eocene to Pliocene time (Yakovlev, 2019). The Sixmile Creek Formation overlies the Renova Formation, and is typically more coarse-grained. These fine- and coarse-grained sediments were locally sourced and deposited in an erosional basin. Well logs indicate the Tertiary sediments pinch out towards “Notch Bottom,” leaving less than 40 ft of Quaternary alluvium directly overlying the bedrock with no Tertiary sediments present. Both the Quaternary and Tertiary sediments vary in their properties (grain size, sorting, and cementation/lithification); thus aquifer properties will vary locally.

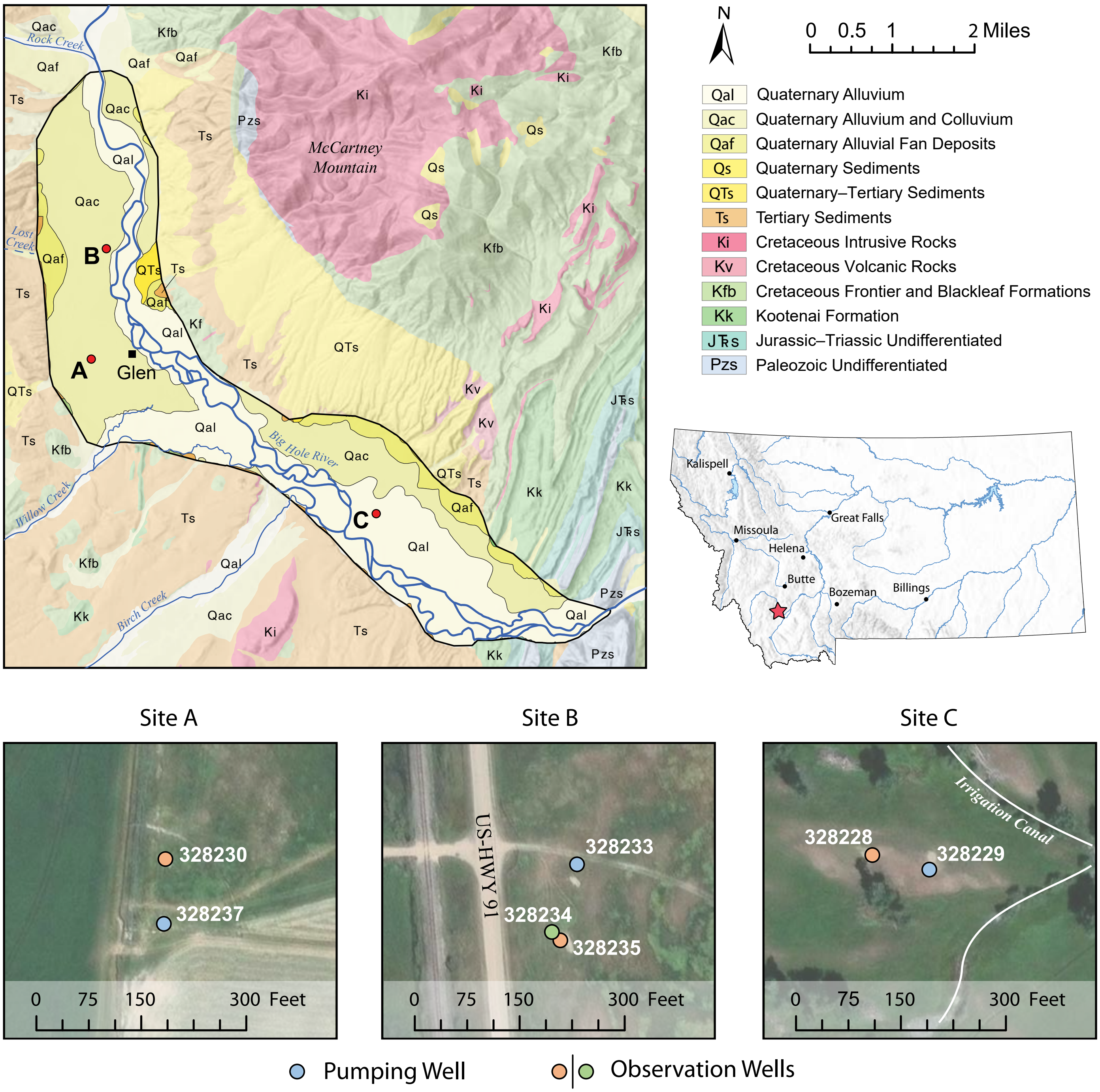

Figure 1. Geology of the study area simplified from Yakovlev (2019), McDonald and others (2012), Mosolf and McDonald (in press), and Parker (in press). The study area is outlined in black, and the locations of the three aquifer tests (A–C) are shown by red circles on the map. Aerial photos of each site are shown below with locations of the pumping wells and observation wells.

GENERAL PROCEDURES

At each test site, one pumping and one or two observation wells were drilled to conduct step and constant-rate aquifer tests. Test procedures were conducted in accordance with MBMG standard operating procedures (Gotkowitz, 2023). Step tests were conducted to determine an appropriate pumping rate for the constant-rate tests. Additional details are discussed in the "Site-Specific Data Collection" section of each test.

The wells were installed in May/June 2023. Aquifer tests were conducted during February/March 2024 to avoid irrigation influences in this agriculturally dominated landscape. Pumping wells at all three sites partially penetrate the alluvial aquifer. Observation wells partially penetrate either the alluvial aquifer or a semi-confined/confined aquifer.

During each test, wells were pumped at a near-constant rate. Discharge was routed 250 ft downgradient of the pumping site. The pumps were equipped with a check valve to prevent backflow into the well when pumping stopped. A totalizing flow meter was installed on the discharge line to monitor the volume pumped and flow rates. Discharge was measured manually throughout the tests to verify estimates from the totalizer.

During the tests, a vented transducer (InSitu Level-Troll 500) was installed in each well to measure water levels at a 1-min frequency. Unvented transducers (In-Situ RuggedTroll 100) measured water levels at a 1-h frequency before and after the test to detect any pre- or post-test water-level trends. Unvented transducer data were corrected with a nearby barometric logger (In-Situ BaroTroll 500) to account for barometric pressure fluctuations. Water levels were measured manually by electric tape to verify transducer data and provide a backup in case of transducer failure. Manual measurements were collected at a logarithmic frequency, measuring most frequently when the pump was turned on (or off) and then decreasing in frequency over time (Gotkowitz, 2023). Water levels were monitored until reaching 95% recovery.

All aquifer test data were analyzed using AQTESOLV software (Duffield, 2007). Aquifer test drawdown and recovery data were analyzed separately for each well. Solutions are discussed for each test in detail in the respective "Aquifer Properties" sections.

Most wells did not appear to reach infinite-acting radial flow (IARF) conditions, either due to the test being cut short from generator failure, or reaching a recharge boundary before IARF was clearly observed in the derivative plots. IARF is an assumption for all the analytical solutions used. In all cases, we fit solutions to the late-time data, prior to any boundary effects, to get the best estimates of aquifer properties given the available data.

Aquifer test data are available in 633 forms on the MBMG Ground Water Information Center online database (https://mbmggwic.mtech.edu/) using the pumping well GWIC ID number (table 1).

SITE A

Background

Test Overview

Site A is located near the corner of US-91 and Hartwig Lane (fig. 1). Both pumping well 328237 and observation well 328230 are completed in an unconfined sand and gravel aquifer (table 1).

The constant-rate test was conducted from 9:45 AM on 2/13/2024 to 9:15 AM on 2/15/2024. This was planned to be a 72-h constant-rate test; however, generator failure caused an early end to the test after 47.5 h of pumping. We were present onsite when the generator failed and immediately began measuring the recovery. The time-weighted average pumping rate was 53 gpm, with measured discharge values ranging from 49.8 to 55.9 gpm.

Well and Lithologic Descriptions

Pumping well 328237 is 40.5 ft deep, with a screened interval from 30.5 to 40.5 ft bgs in a zone of coarse sand and gravel (fig. 2A).

The borehole for observation well 328230 was drilled to 95 ft; a clay layer was encountered from 42.5 ft bgs to 95 ft bgs (fig. 2B). The well was backfilled to a depth of 38 ft bgs, a few feet above the observed clay layer, and screened from 28 to 38 ft bgs in fine-to-coarse sand and gravel (fig. 2B). The observation well is 91 ft north of the pumping well (fig. 1).

Site-Specific Data Collection

Hourly water levels were recorded in both wells from 6/27/2023 to 2/11/2024 prior to the constant-rate

Table 1. Summary of Glen area aquifer test results.

Site	Aquifer Type	GWIC ID No.	Well Type	Total Depth (ft)	Measuring Point Elevation (ft-amsl)	Screened Interval (ft-bgs)	Distance from PW (ft)	Static Water Level (ft-bMP)	Maximum Drawdown (ft)	Average Pumping Rate (gpm)	Estimated Transmissivity (ft²/d)	Estimated Storativity (unitless)	Estimated Specific Yield (unitless)	Solution Type
A	Quaternary Sediments	328237	PW	40.5	4996.06	30.5–40.5	—	9.64	2.34	53	14900–16000	—	—	Unconfined
		328230	OW	38	4994.90	28–38	91	8.38	0.38		11000–18300	1 x 10^{-6}	0.04	Unconfined
B	Quaternary Sediments	328233	PW	35.5	5007.38	25.5–35.5	—	8.66	6.64	108	5700–6100	—	—	Unconfined
		328234	OW	105	5005.87	95–105	99	6.76	0.20		—	—	—	—
		328235	OW	35.5	5006.45	25.5–35.5	112	8.26	1.22		7040–7540	0.002	0.02	Unconfined
C	Quaternary–Tertiary Sediments	328229	PW	28.5	4918.50	18.5–28.5	—	7.00	3.69	107	17200–18700	—	—	Unconfined
		328228	OW	96.5	4919.11	86.5–96.5	96	7.71	0.26		27900–30100	0.072	—	Leaky Confined

Note. See GWIC for additional details (https://mbmggwic.mtech.edu). PW, pumping well; OW, observation well; ft-amsl, feet above mean sea level; ft-bgs, feet below ground surface; ft-bMP, feet below measuring point; gpm, gallons per minute.

test. Pre-test water levels indicate a slight declining trend in groundwater levels (fig. 3). Water levels were manually measured in both wells before starting the pump, throughout the test, and during recovery (fig. 2).

Results

Water-Level Response

Groundwater levels dropped rapidly at the start of pumping and then decreased slowly for the remainder of the test (fig. 2). In pumping well 328237 the maximum drawdown was 2.34 ft (fig. 2A). When the pump was turned off, water levels surged, briefly rising approximately 8 ft in the first minute of recovery, before dropping down again and starting a slower recovery. Water levels reached 95% recovery after 4 h.

Observation well 328230 responded similarly to the pumping well with a slightly slower response. The maximum drawdown was 0.38 ft (fig. 2B). When the pump was turned off, water levels recovered to 95% in 11 h.

In both wells at Site A, a slightly decreasing trend in the water levels (~0.01 ft/d) occurred during the test (fig. 2). A linear correction for this trend was applied to both the pumping and observation wells prior to analysis.

Aquifer Properties

In pumping well 328237, water levels fell approximately 2 ft within the first 5 min of pumping, but then only changed ~0.2 ft throughout the test (fig. 2A). With minimal drawdown as well as generator failure ending the test early, analyses were particularly challenging for this aquifer test.

Data were initially evaluated using the Cooper–Jacob (1946) solution on a composite plot (fig. 4A). The drawdown curves for the pumping and observation well were approximately parallel, confirming that the wells are completed in the same aquifer.

The Cooper–Jacob (1946) solution was used to analyze pumping well 328237 drawdown data (fig. 4B). Although the Cooper–Jacob (1946) solution is traditionally used for confined aquifers, a data adjustment allows this solution to be applied to drawdown in an unconfined aquifer system. The derivative plot indicates that IARF was achieved towards the end of the pumping period. The Cooper–Jacob (1946) solution

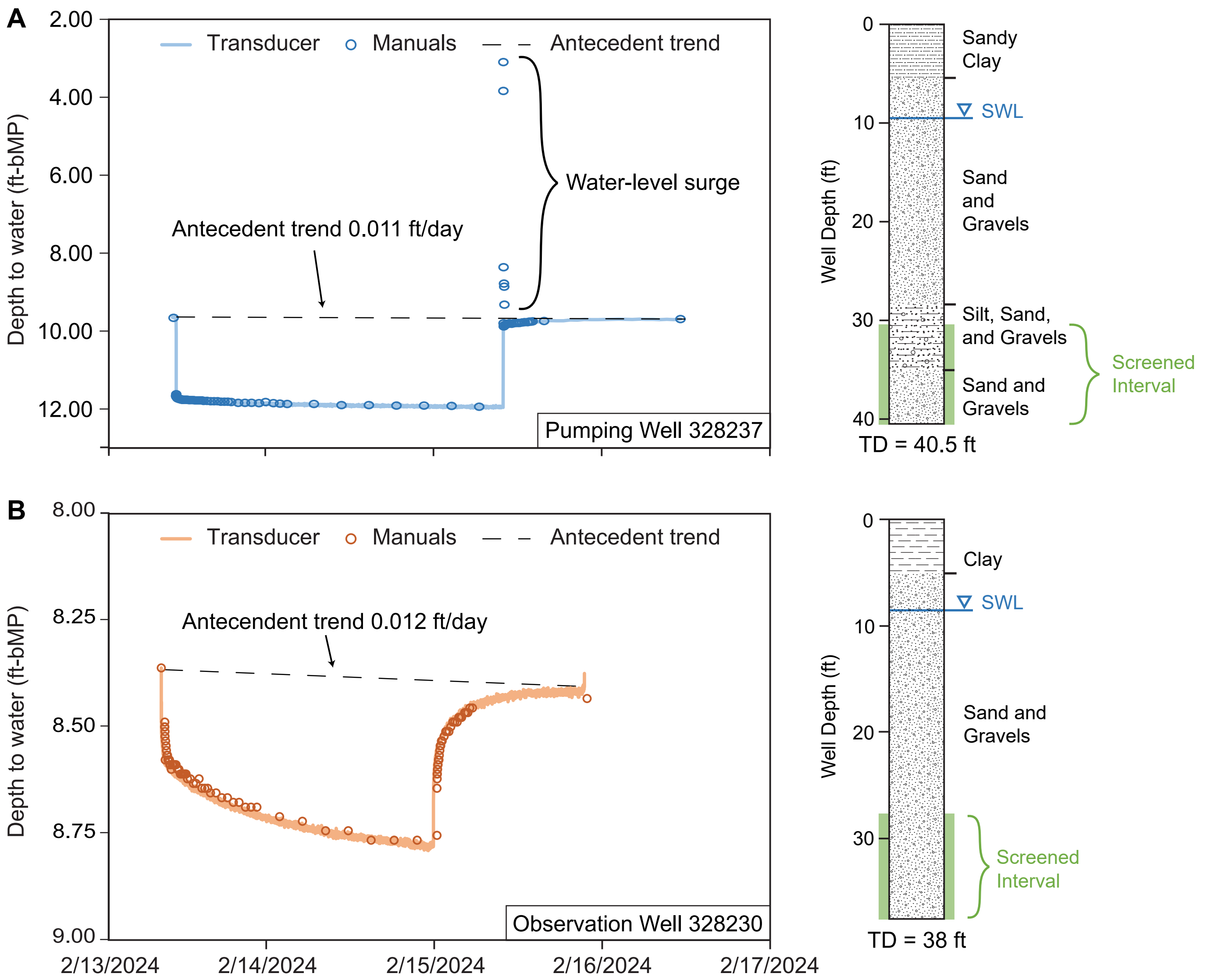

Figure 2. Hydrographs and well lithologies of (A) pumping well 328237 and (B) observation well 328230 at Site A. Hydrographs include the period of pumping and recovery. The blue line in the lithologic logs represents the static water level prior to the start of the test. bMP, below measuring point; SWL, static water level; TD, total depth.

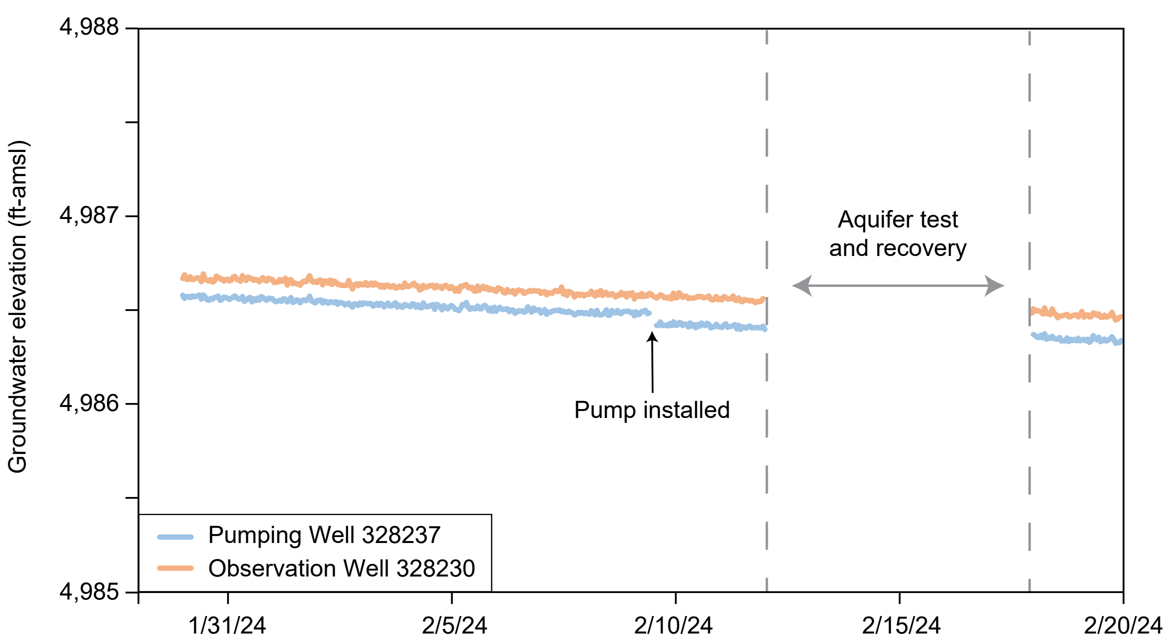

Figure 3. Pre-test monitoring at Site A shows a general downward antecedent trend in groundwater levels. amsl, above mean sea level.

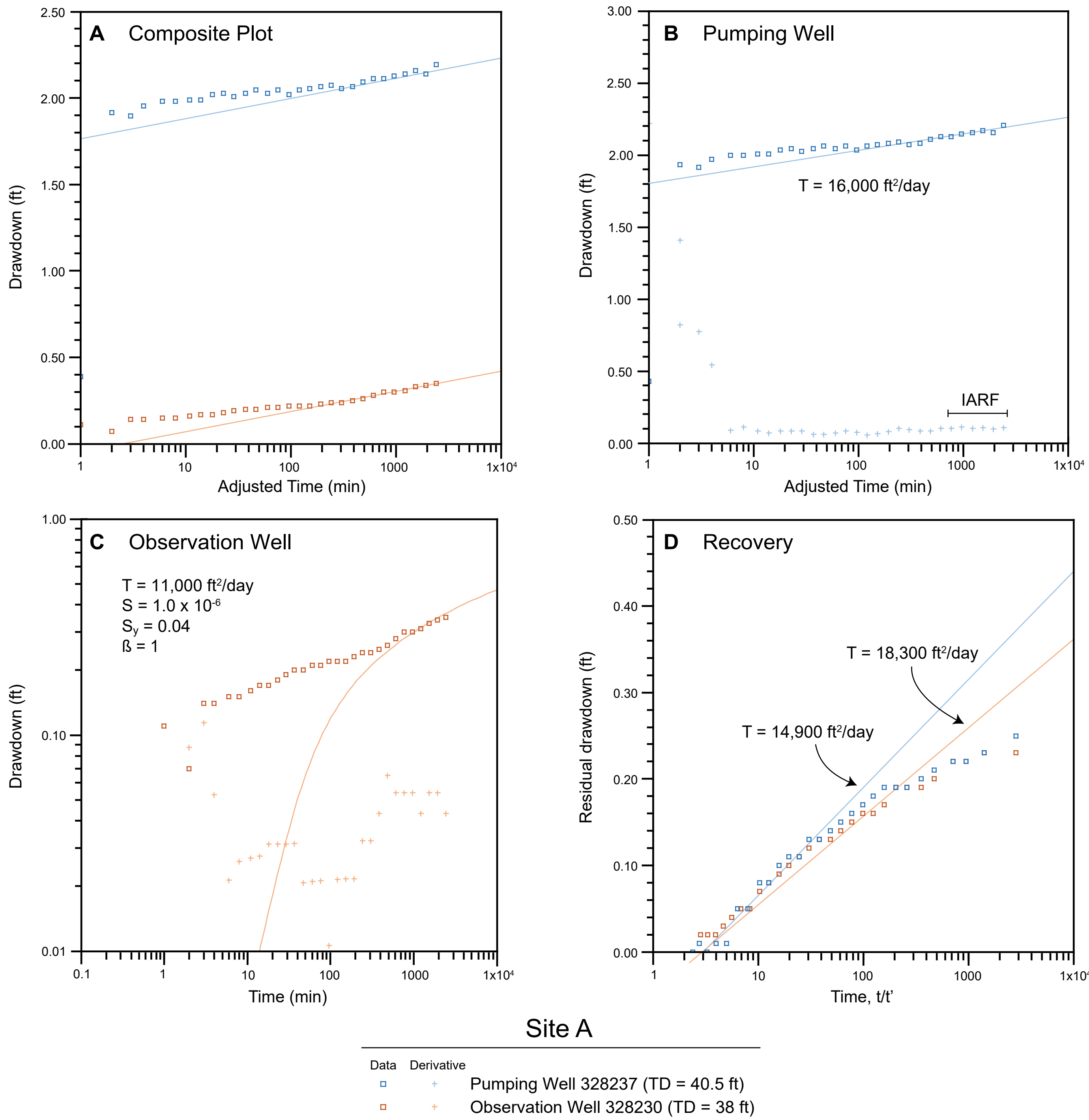

Figure 4. Analysis of Site A aquifer test data. (A) The composite plot indicates both wells are in the same aquifer. (B) The Cooper–Jacob solution was applied to the late-time drawdown data from the pumping well. (C) The Neuman solution was applied to the observation well drawdown data. (D) The Theis recovery solution was applied to the recovery data, which shows T values that are comparable to the pumping periods for each respective well. IARF, infinite-acting radial flow; TD, total depth.

estimated a transmissivity of 16,000 ft^2/d. Analysis of the recovery data using the Theis (1935) recovery solution produced a comparable transmissivity of 14,900 ft^2/d (fig. 4D).

For observation well 328230, the Neuman (1974) solution was used to analyze the drawdown data. This solution estimated an S_y of 0.04, which is a low value for sand and gravel aquifers (Fetter, 2014). However, fine-grained lenses were observed while drilling, and a thick clay layer was encountered below the screened layer of this well, which may lead to a lower S_y value than expected. Transmissivity was estimated at 11,000 ft^2/d. The Theis (1935) recovery solution was applied to the recovery data, resulting in a transmissivity of 18,300 ft^2/d (fig 4D).

SITE B

Background

Test Overview

Site B is located at a fishing access off of US-91 (fig. 1). Pumping well 328233 and two observation wells (328234 and 328235) were initially interpreted to be completed in an unconfined sand and gravel aquifer; however, results from the aquifer test suggest the deeper well is completed in a semi-confined aquifer (table 1).

The 72-h constant-rate test was conducted from 8:05 AM on 2/20/2024 to 8:25 AM on 2/23/2024. The time-weighted average pumping rate was 108 gpm, with measured discharge values ranging from 106.3 to 110.3 gpm.

Well and Lithologic Descriptions

Pumping well 328233 is 35.5 ft deep and screened from 25.5 to 35.5 ft bgs in a zone of medium-coarse sand and gravel (fig. 5A).

Observation well 328235 is 35.5 ft deep and screened from 25.5 to 35.5 ft bgs in a zone of fine-to-coarse sand and gravel (fig. 5B). This observation well is 112 ft southwest of the pumping well (fig. 1).

Observation well 328234 is 105 ft deep and screened from 95 to 105 ft bgs in a zone of silty fine-to-coarse sand and gravel (fig. 5C). This deep observation well is 99 ft southwest of the pumping well (fig. 1).

Site-Specific Data Collection

Hourly background water-level data were recorded from 6/14/2023 to 2/18/2024 in pumping well 328233 and deep observation well 328234. In shallow observation well 328235, background water levels were recorded from 2/9/2024 to 2/18/2024. Pre-test water levels indicate a slight declining trend in groundwater levels, and also show more variability in groundwater levels in observation well 328234 (fig. 6). Water-level elevations were consistently highest in the deeper observation well (328234), indicating an upward gradient. Water levels were manually measured in all wells before starting the pump, throughout the test, and early recovery (fig. 5).

Results

Water-Level Response

Groundwater levels dropped rapidly in pumping well 328233 at the start of pumping and continued to decrease slowly over the remainder of the test (fig. 5A). The maximum drawdown was 6.64 ft. After the test, it took 9.5 h to reach 95% recovery.

Shallow observation well 328235 responded similarly to the pumping well. The maximum drawdown was 1.20 ft (fig. 5B). After the pump was turned off, 95% recovery was achieved in 41.5 h. Manual measurements were used for analysis during the first 7 h of the test due to some transducer movement in the well.

In deep observation well 328234, water levels increased slightly in the first hour of pumping (by 0.04 ft) before slowly decreasing below the pre-test water level. Water levels did generally decrease while the pump was on and increase during recovery, but levels oscillated throughout the test (fig. 5C). These oscillations did not occur on a diurnal time-scale, and may be the result of pumping for stock wells in the area, though we were unable to confirm this. Pumping effects would propagate farther in a semi-confined to confined system, and there are numerous stock wells in the valley. The maximum drawdown was 0.20 ft, which occurred prior to the end of pumping, and the well reached 95% recovery after 63.5 h.

In all three wells at Site B, slightly increasing or upward antecedent trends (0.008–0.017 ft/d) in the water levels occurred during the test (fig. 5). This differed from slight decreasing or downward antecedent trends

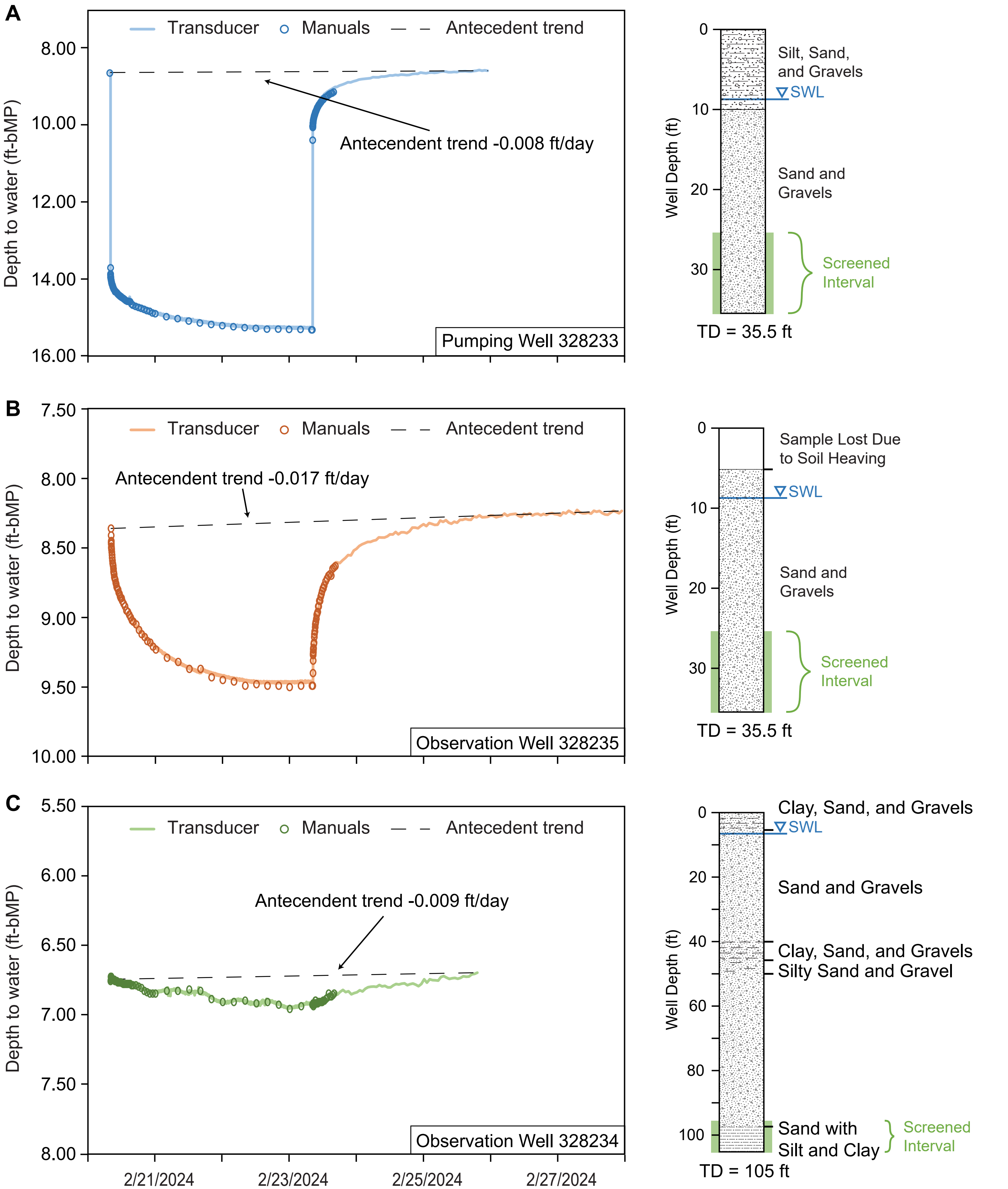

Figure 5. Hydrographs and well lithologies of (A) pumping well 328233, (B) observation well 328235 and (C) observation well 328234 at Site B. Hydrographs include the period of pumping and recovery. The blue line in the lithologic logs represents the static water level prior to the start of the test. bMP, below measuring point; SWL, static water level; TD, total depth.

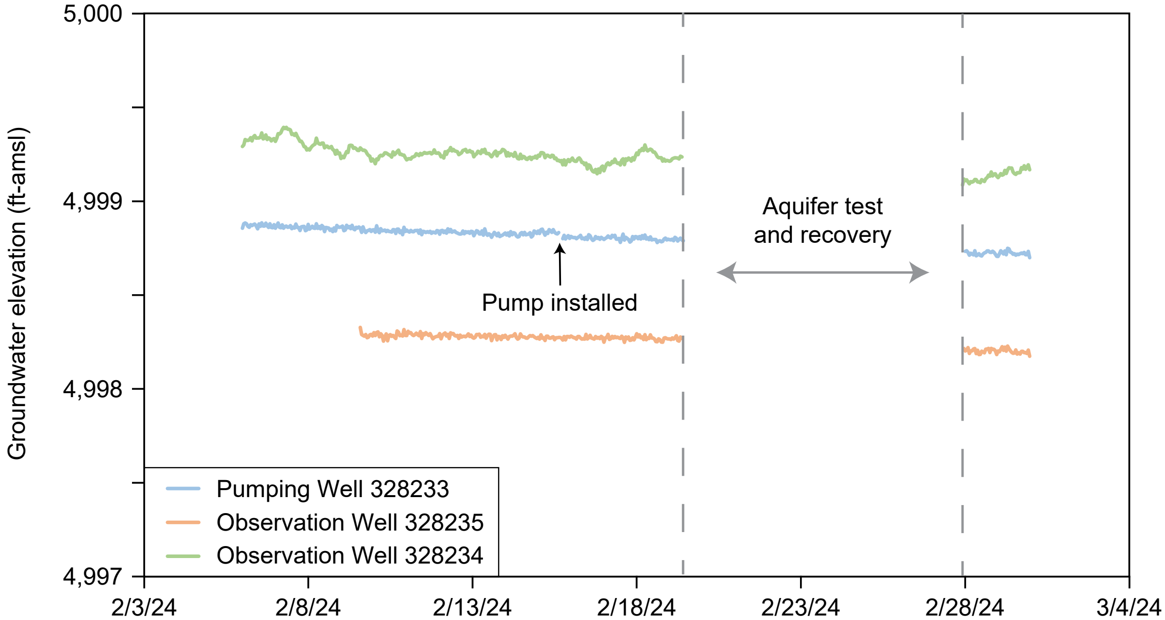

Figure 6. Pre-test monitoring at Site B shows a general downward antecedent trend in groundwater levels. Observation well 328234 shows more variability than pumping well 328233 and observation well 328235. amsl, above mean sea level.

(0.003–0.009 ft/d) observed in the long-term data (fig. 6). This difference is likely due to a small snowmelt event that occurred during the test. A linear correction was applied to both the pumping and observation wells prior to analysis to account for the increasing trend.

Aquifer Properties

Data were initially evaluated using the Cooper–Jacob (1946) solution on a composite plot (fig. 7A). The drawdown curves of pumping well 328233 and shallow observation well 328235 are approximately parallel; however, the drawdown curve of deep observation well 328234 shows that it was just beginning to respond and the slope appears flatter, suggesting that it is not in the same aquifer as the other wells. As such, deep observation well 328234 was not used to determine hydrogeologic properties of the pumped aquifer and is not included in further analyses.

For pumping well 328233, the Cooper–Jacob (1946) solution was used to analyze the drawdown data (fig. 7B), and provided an estimated transmissivity of 6,100 ft^2/d. Analysis of the recovery data using the Theis (1935) recovery solution produced a similar transmissivity of 5,700 ft^2/d (fig. 7D).

The Neuman (1974) solution was used to analyze observation well 328235 drawdown data (fig. 7C). Transmissivity was estimated to be 7,040 ft^2/d. The S_y is 0.02 and is low for a sand and gravel aquifer, which generally ranges from 0.20 to 0.35 (Fetter, 2014). We attribute this to the presence of fine-grained lenses in the subsurface, which were observed while drilling all three wells at this site. This site is in the floodplain close to the river, and likely has interfingered sand and gravel layers potentially with fine-grained and/or clay lenses, leading to lower T and S_y values than expected. The Theis (1935) recovery solution was applied to the recovery data, indicating a comparable transmissivity of 7,540 ft^2/d (fig. 7D).

A decrease in the rate of drawdown suggests a recharge boundary was reached after ~3,000 min of pumping (fig. 8A). Utilizing our estimated aquifer properties and forward-modeling in AQTESOLV, the cone of depression is predicted to extend ~1,400 ft from the pumping well after 3,000 min (fig. 8B). The closest side channel of the Big Hole River is ~800 ft away from the pumping well, so the cone of depression could have easily intersected the Big Hole River.

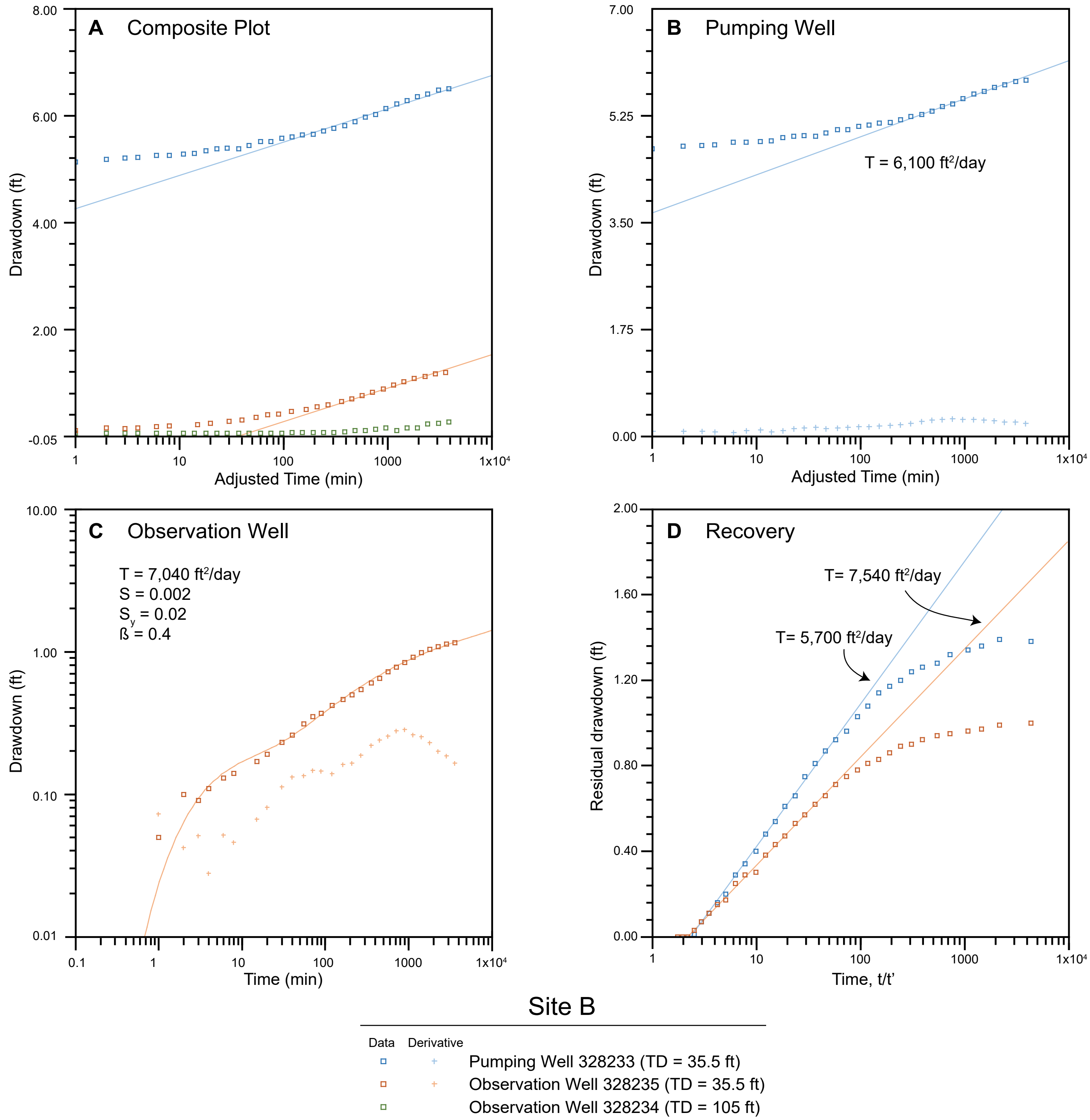

Figure 7. Analysis of Site B aquifer test data. (A) The composite plot indicates the deep observation well has a delayed response and is not in the same aquifer as the pumping well or shallow observation well. (B) The Cooper–Jacob solution was applied to the late-time drawdown data from the pumping well. (C) The Neuman solution was applied to the observation well drawdown data. (D) The Theis recovery solution was applied to the recovery data, which shows T values that are comparable to the pumping periods for each respective well. TD, total depth.

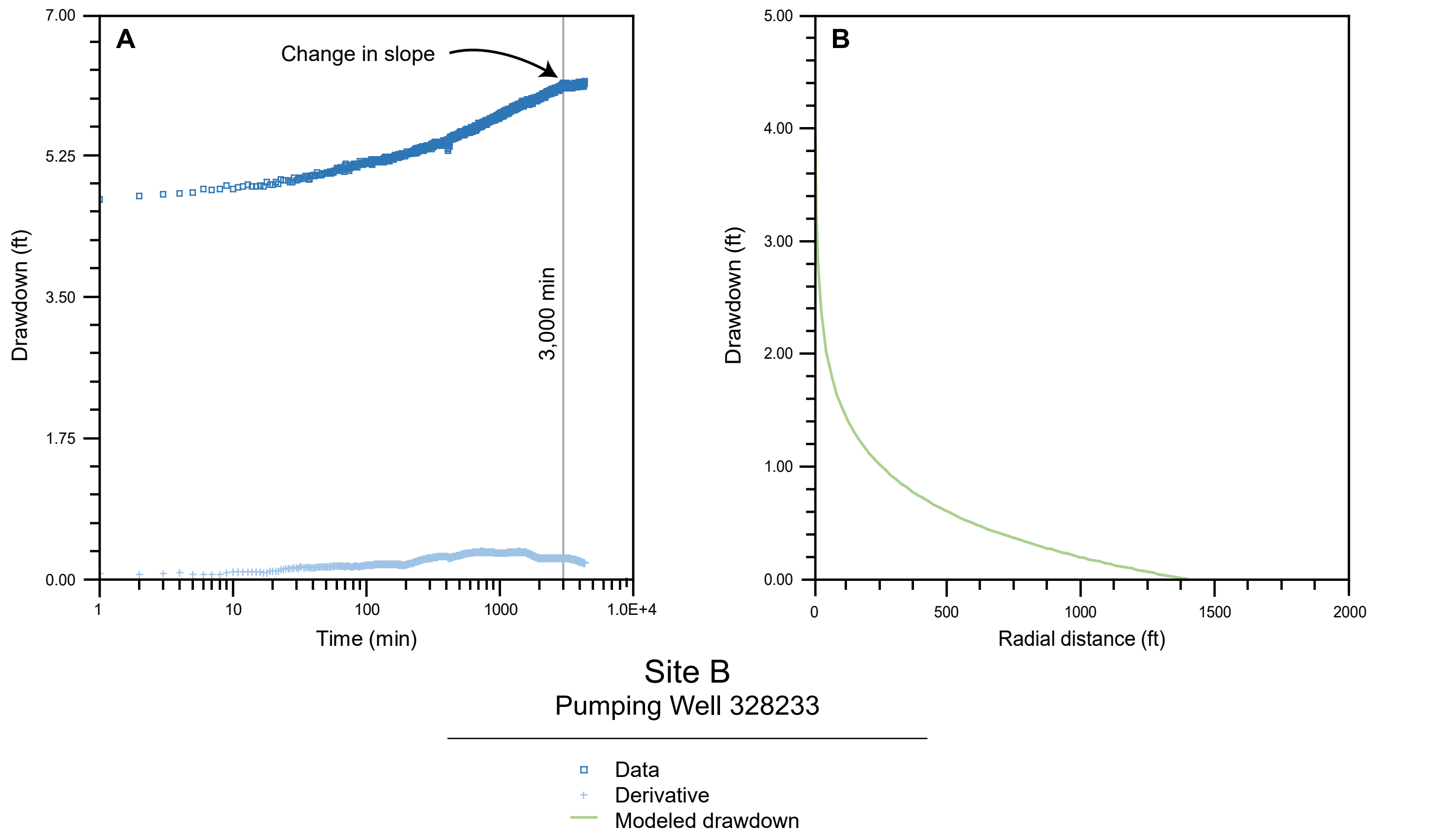

Figure 8. A recharge boundary was observed in the aquifer test data at Site B. (A) Unfiltered data from pumping well 328233 shows a decrease in the drawdown data at approximately 3,000 min, when the slope of the drawdown data becomes flatter. (B) Forward modeling in AQTESOLV using our estimated aquifer properties shows that during the pumping period, the cone of depression could extend out ~1,400 ft from the pumping well; at that distance, it could have intersected the Big Hole River.

SITE C

Background

Test Overview

Site C is located off of Burma Road, about 3 mi upstream from the "Notch" (fig. 1). Pumping well 328229 is completed in an unconfined sand and gravel aquifer, and observation well 328228 is completed in a confined sand and gravel aquifer (table 1).

The 72-h constant-rate test was conducted from 9:00 AM on 2/28/2024 to 9:10 AM on 3/2/2024. The time-weighted average pumping rate was 107 gpm, with measured discharge values ranging from 106.6 to 108.0 gpm.

Well and Lithologic Descriptions

Pumping well 328229 is 28.5 ft deep and screened from 18.5 to 28.5 ft in a zone of medium-coarse sand and gravel, above a clay layer that was encountered at 32.5 ft bgs (fig. 9A).

Observation well 328228 is 96.5 ft deep and screened from 86.5 to 96.5 ft bgs in a zone of fine-to-coarse sand and gravel, below a layer of sand with silt and clay (fig. 9B). The observation well is 96 ft northwest of the pumping well (fig. 1).

Site-Specific Data Collection

Hourly background water levels were recorded from 6/2/2023 to 2/26/2024 in both pumping well 328229 and observation well 328228. Pre-test water levels indicate a slight declining trend with a small rise in groundwater levels just prior to the test due to a small snowmelt event (fig. 10). Water levels were manually measured in both wells before starting the pump, during the test, and during the early recovery (fig. 9).

A canal is located 115 ft southeast from the pumping well (fig. 1). Although the canal was not diverting water, it had ~0.5 ft of stagnant water ponded during the aquifer test. Based on the water elevation in the pumping well, this was assumed to be a surface expression of groundwater. We installed a stilling well

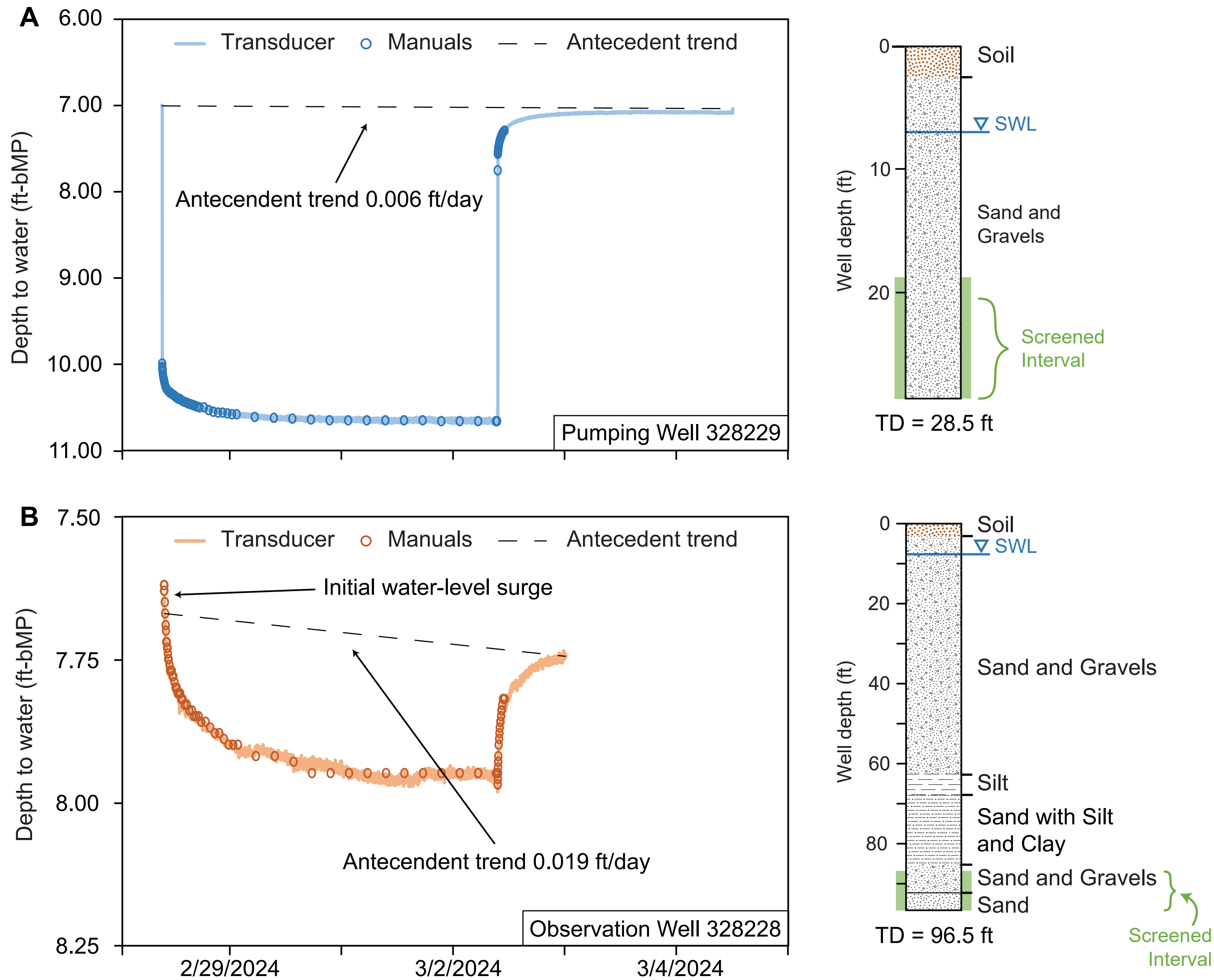

Figure 9. Hydrographs and well lithologies of (A) pumping well 328229 and (B) observation well 328228 at Site C. Hydrographs include the period of pumping and recovery. The blue line in the lithologic logs represents the static water level prior to the start of the test. bMP, below measuring point; SWL, static water level; TD, total depth.

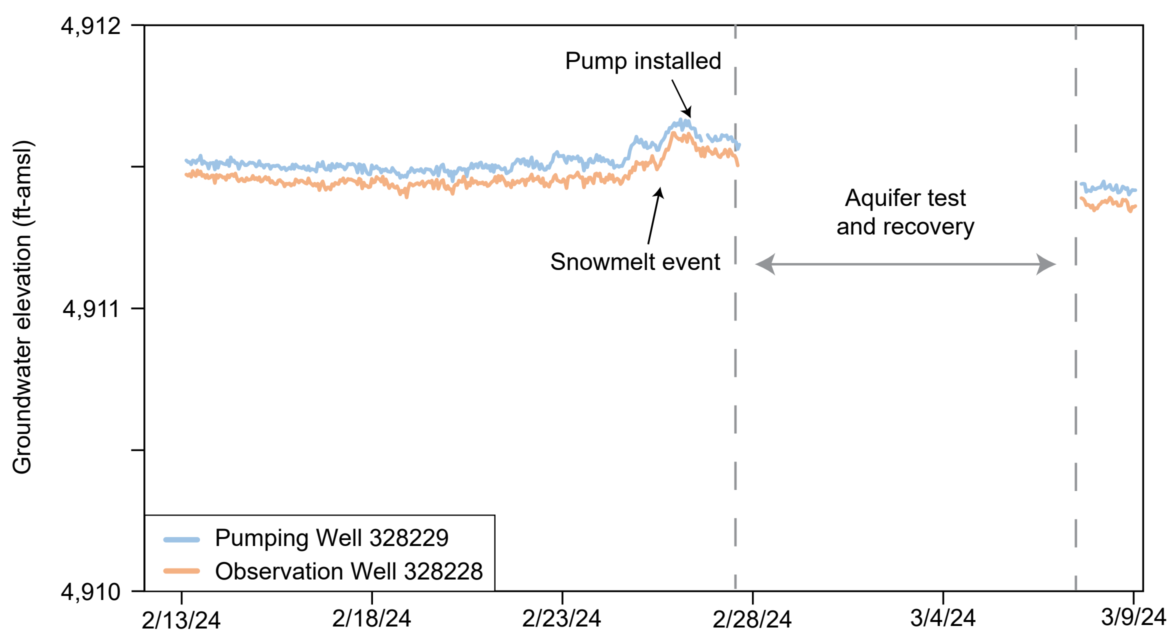

Figure 10. Pre-test monitoring at Site C shows a general downward antecedent trend in groundwater levels. A snowmelt event occurred just before the test, causing a rise in groundwater levels. amsl, above mean sea level.

in the ponded area of the canal with a transducer collecting measurements at 1-min intervals throughout the test.

Results

Water-Level Response

In pumping well 328229, groundwater levels responded immediately to the onset of pumping, reaching a maximum drawdown of 3.69 ft (fig. 9A). When the pump was turned off, water levels rose to within half a foot of the original static water level in the first minute and 95% recovery was reached in 3.75 h.

Groundwater levels initially rose in observation well 328228, rising 0.07 ft in the first 2 min of pumping (fig. 9B) before beginning to decrease. Maximum drawdown was 0.26 ft. When the pump was turned off, it took 17 h to achieve 95% recovery.

In both wells at Site C, a slightly decreasing trend (0.006–0.019 ft/d) in the water levels occurred during the test (fig. 9). The observation well had a stronger downward trend during the test than observed in the long-term antecedent data, indicating that it may still have been responding to the falling limb of the previously mentioned snowmelt event. A linear correction was applied to both the pumping and observation wells prior to analysis using the trend measured during the test.

Ponded water in the canal responded to the onset of pumping, initially rising slightly (0.07 ft) before beginning to decline. The canal was observed to be dry after 48 h of pumping; water levels continued to fluctuate around the ground surface at the base of the canal until the pump was turned off, when water levels began to rise again. Branches and wind impacted transducer measurements, so the manual measurements were primarily used to monitor canal water levels, though both generally follow similar trends.

Aquifer Properties

Data were initially evaluated using the Cooper–Jacob (1946) solution on a composite plot (fig. 11A). The drawdown curves were approximately parallel, indicating that despite being completed at different depths, the wells are completed in a hydraulically connected aquifer.

The Cooper–Jacob (1946) solution was used to analyze pumping well 328229 drawdown data (fig. 11B), which estimated a transmissivity of 18,700 ft^2/d. Analysis of the recovery data using the Theis (1935) recovery solution produced a similar transmissivity of 17,200 ft^2/d (fig. 11D).

For observation well 328228, the shape of the derivative plot suggests this well is in a leaky-confined aquifer (fig. 11C; Renard and others, 2008). Therefore, the Hantush–Jacob solution for a leaky-confined aquifer was used to analyze drawdown data (Hantush and Jacob, 1955; Hantush, 1964). This solution assumes there is no storage in the leaky aquitard. Transmissivity was estimated to be 27,900 ft^2/d. S is 0.072, which falls between the estimates for confined and unconfined aquifers (Heath, 1983). Recovery data were analyzed with the Hantush–Jacob residual drawdown solution (without aquitard storage), indicating a T of 30,100 ft^2/d (fig. 11E; Hantush and Jacob, 1955; Hantush, 1964).

A decrease in the rate of drawdown suggests a recharge boundary was reached after ~1,500 min of pumping (fig. 12A). Utilizing our estimated aquifer properties and forward-modeling in AQTESOLV, the cone of depression is predicted to extend ~1,700 ft from the pumping well (fig. 12B). The closest side channel of the Big Hole River is ~1,600 ft from the pumping well; as such, we suspect the cone of depression may have intersected the river.

SUMMARY

Aquifer tests conducted in the Glen Valley reveal a highly productive alluvial aquifer system adjacent to the Big Hole River. The aquifers range from unconfined to semi-confined sand and gravel aquifers. Transmissivities varied from 5,700 to 30,100 ft^2/d, with the lower values reflecting the presence of fine-grained layers in the subsurface. Aquifer properties estimated from these tests will be incorporated into groundwater flow models, which will improve the understanding of groundwater flow in the area.

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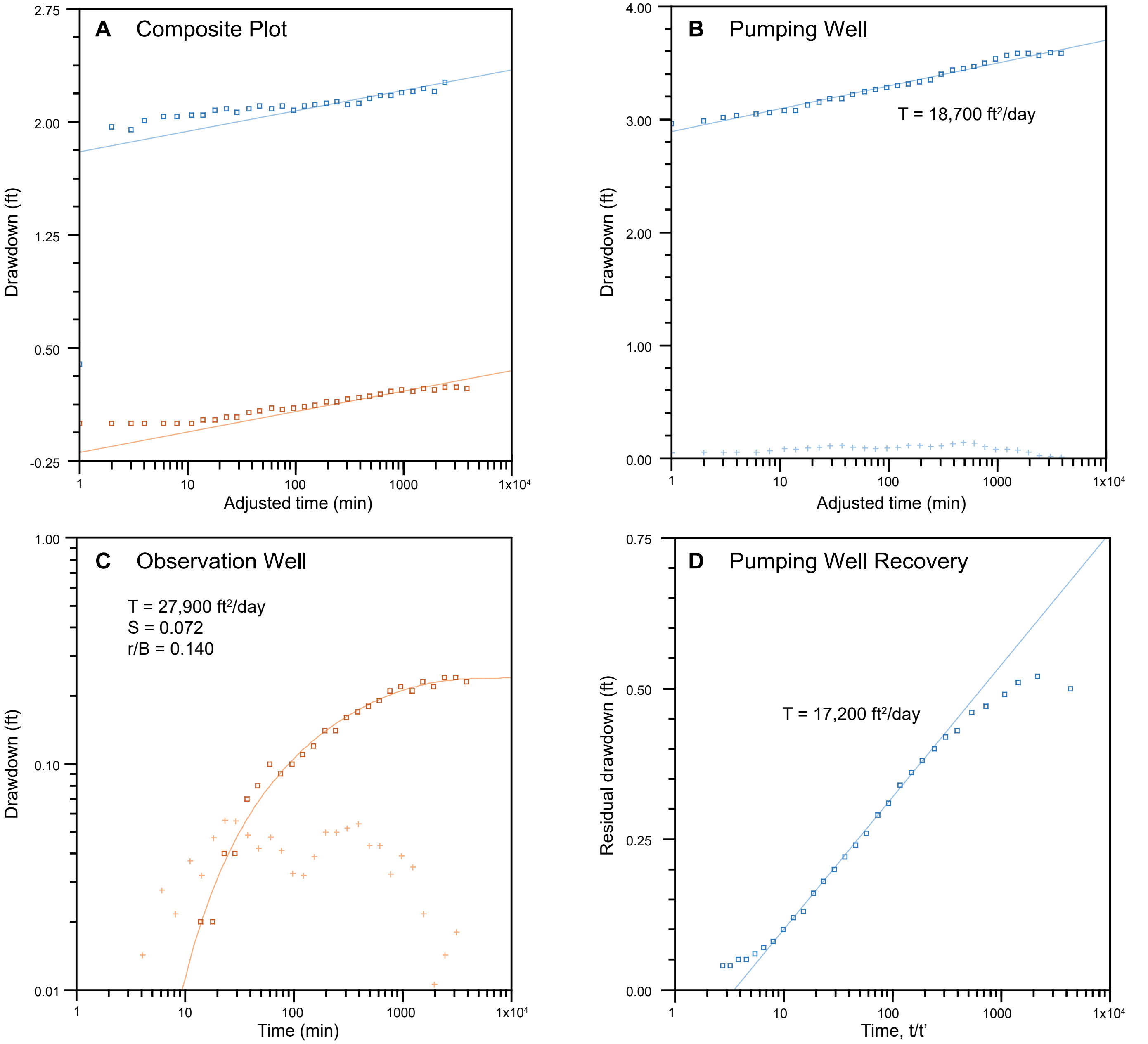

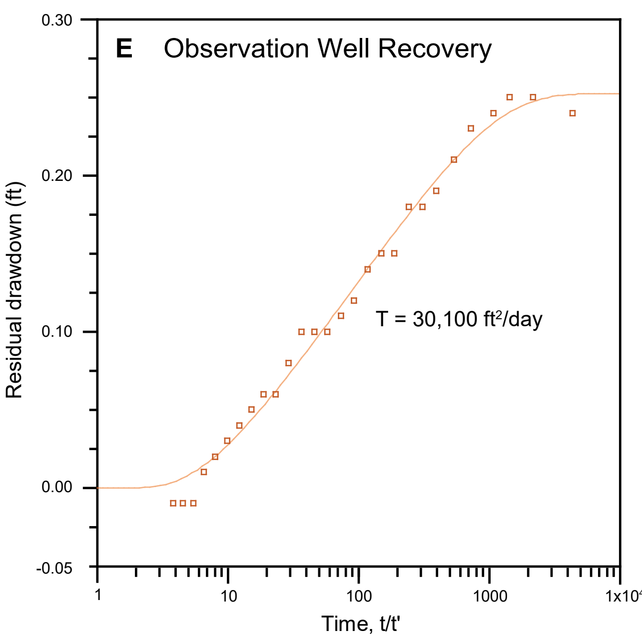

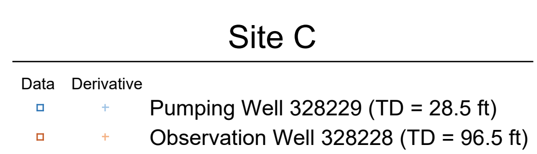

Figure 11. Analysis of Site C aquifer test data. (A) The composite plot indicates both wells are in the same aquifer. (B) The Cooper–Jacob solution was applied to the late-time drawdown data from the pumping well. (C) The Hantush–Jacob solution was applied to the observation well drawdown data. (D) The Theis recovery solution was applied to recovery data, which shows similar T values as the pumping period for pumping well 328229. (E) The Hantush–Jacob residual drawdown solution was applied to recovery data, which shows T values that are comparable to the pumping periods for observation well 328228. TD, total depth.

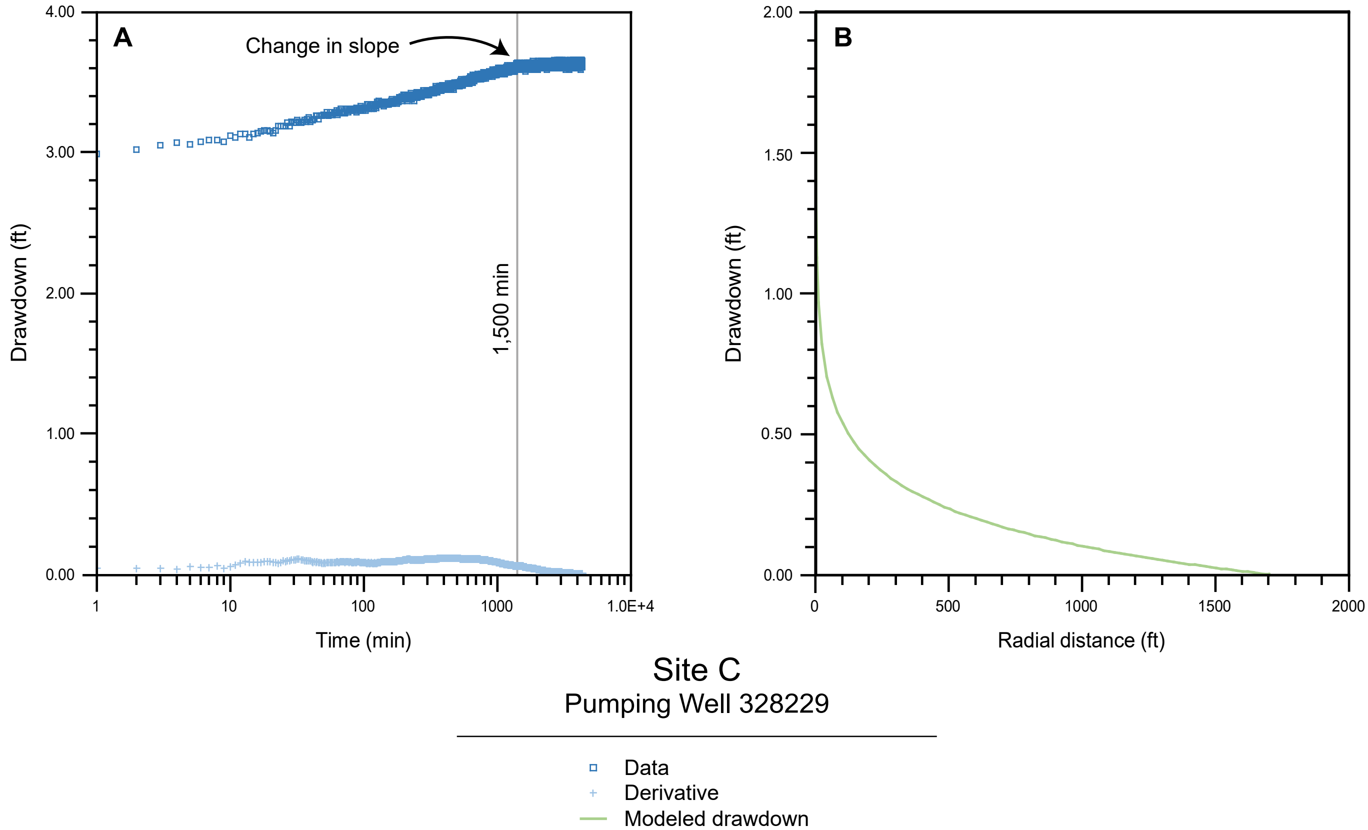

Figure 12. A recharge boundary was observed in the aquifer test data at Site C. (A) Unfiltered data from pumping well 328233 shows a decrease in the drawdown data at approximately 1,500 min, when the slope of the drawdown data becomes flatter. (B) Forward modeling in AQTESOLV using our estimated aquifer properties shows that during the pumping period, the cone of depression could extend out ~1,700 ft from the pumping well; at that distance, it could have intersected the Big Hole River.

REFERENCES

Cooper, H.H., and Jacob, C.E., 1946, A generalized graphical method for evaluation formation constants and summarizing well field history: American Geophysical Union Transactions, v. 27, p. 526–534, https://doi.org/10.1029/TR027i004p00526

Duffield, G.M., 2007, AQTESOLV for Windows Version 4.5 User's Guide, HydroSOLVE, Inc., Reston, VA.

Fetter, C.W, 2014, Applied Hydrogeology, 4th ed.: Noida, India, Pearson, 612 p.

Gotkowitz, M.B.,ed., 2023, Standard procedures and guidelines for field activities, Montana Bureau of Mines and Geology, version 2: Montana Bureau of Mines and Geology Open-File Report 758, 99 p., https://doi.org/10.59691/UUYM4848

Hantush, M.S., 1964, Hydraulics of wells, *in* Advances in Hydroscience, Chow, V.T., ed.: New York, Academic Press, p. 281–442.

Hantush, M.S., and Jacob, C.E., 1955, Non-steady radial flow in an infinite leaky aquifer: American Geophysical Union Transactions, v. 36, p. 95–100, https://doi.org/10.1029/TR036i001p00095

Heath, R.C., 1983, Basic ground-water hydrology: United States Geological Survey Water-Supply Paper 2220, https://doi.org/10.3133/wsp2220

Kendy, E., and Tresch, R.E., 1996, Geographic, geologic, and hydrologic summaries of intermontane basins of the northern Rocky Mountains, Montana: U.S. Geological Survey Water-Resources Investigations Report 96-4025, https://doi.org/10.3133/wri964025

McDonald, C., Elliott, C.G., Vuke, S.M., Lonn, J.D., and Berg, R.B., 2012, Geologic map of the Butte South 30' x 60' quadrangle, southwestern Montana: Montana Bureau of Mines and Geology Open-File Report 622, 1 sheet, scale 1:100,000.

Montana Board of Oil and Gas (MBOG), 2025, Online oil and gas information system, available at https://bogapps.dnrc.mt.gov/ [Accessed July 2025].

Mosolf, J.J., and McDonald, C., in press, Geologic map of the Dillon West 7.5' quadrangle, Beaverhead County, Montana: Montana Bureau of Mines and Geology Geologic Map.

Neuman, S.P., 1974, Analysis of pumping test data from anisotropic unconfined aquifers considering delayed gravity response: Water Resources Research, v. 11, no. 2, p. 329–342, https://doi.org/10.1029/WR011i002p00329

Noble, R.A., Bergantino, R.N., Patton, T.W., Sholes, B.C., Daniel, F., and Scofield, J., 1982, Volume II: Montana Bureau of Mines and Geology Open-File Report 99-B, 132 p.

Parker, S., McDonald, C., and Pearson, D.M., in press, Geologic map of the Block Mountain 7.5' quadrangle, southwest Montana: Montana Bureau of Mines and Geology Geologic Map, scale 1:24,000.

Renard, P., Glenz, D., and Mejias, M., 2008, Understanding diagnostic plots for well-test interpretation, Hydrogeology Journal, v. 17, no. 3, p. 589–600, https://doi.org/10.1007/s10040-008-0392-0

Ruppel, E.T., O'Neill, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1 x 2 degree quadrangle, Montana and Idaho: U.S. Geological Survey Miscellaneous Geologic Investigation 1803-H, 1 sheet, scale 1:250,000, https://doi.org/10.3133/i1803H

Theis, C.V., 1935, The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage: American Geophysical Union Transactions, v. 16, p. 519–524, https://doi.org/10.1029/TR016i002p00519

Yakovlev, P., 2019, Geologic map of the Glen 7.5' quadrangle, southwestern Montana: Montana Bureau of Mines and Geology Geologic Map 74, 1 sheet, scale 1:24,000.