

Technical Report

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Task 11 Aquifer Tests

**Indian Wells Valley Multi-well Aquifer Test Analysis: IWWVD Well 10 and Quist Ranch
21-hour and 48-hour Tests, Ridgecrest, CA**

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Introduction

Desert Research Institute (DRI) performed multi-well aquifer testing in Indian Wells Valley, California, to better characterize the hydrologic properties of an unconfined basin-fill aquifer. This aquifer property data may be used to refine and improve the hydrogeologic conceptual model and the numerical groundwater model used by the Indian Wells Valley Groundwater Authority (IWVGA) to manage groundwater resources in the basin as part of the Indian Wells Valley Groundwater Sustainability Plan (GSP). This work is supported by California Department of Water Resources (DWR) Proposition 1 funding.

Three aquifer tests were conducted in Indian Wells Valley in 2020. The Indian Wells Valley Water District (IWVWD) met with Stetson Engineers and DRI to select a suitable municipal well field and agreed to operate a well pump during a multi-day constant-rate pumping test. Similarly, the owners of Quist Ranch pistachio orchard provided access to their wells to conduct a 21 hour (hr) pumping test and a 48 hr pumping test in agricultural irrigation wells. This technical memorandum summarizes the field work and results of the 2020 aquifer tests.

Field Methods – IWVWD Well 10 Test

A constant-rate pumping test was performed at IWVWD Well 10 in July 2020 at a discharge rate of 1,109 gallons per minute (gpm). Nearby IWVWD wells were outfitted as monitoring wells and a U.S. Navy monitoring well was also used for water level measurements. The IWVWD operates a groundwater well field on the southeast corner of West Ward Avenue and North Primavera Street in Ridgecrest, California. Three wells exist in the area: Well 8 is 444 feet (ft) to the northwest of Well 10 and Well 9A is 366 ft to the southwest of Well 10. Well 8 was installed in 1964 and has since been inactive (although it is usable as a monitoring well), and two active pumping wells, Well 9A and Well 10, were installed in 2003 and 1974, respectively. Discharge from Well 10 is pumped into a water treatment plant prior to entering the municipal water supply pipeline system. The U.S. Navy monitoring well, 26S39E25K1, is located 8,278 ft to the west of Well 10. Figure 1 shows the well locations and Table 1 presents the well construction and location information. Well 10, Well 9A, and Well 8 are screened approximately from water level to 800 ft below land surface (bls), 796 ft bls, and 730 ft bls, respectively.

Water level measurements were taken in Well 10 via a downhole air line, which was pressurized at the surface Schrader valve by a portable air compressor. The resolution of the analog pressure gage was poor (approximately 1.0 pounds per square inch). The sounding tube in Well 10 was obstructed and unavailable for pressure transducer deployment. A digital flow meter and totalizer was operational at the pump head. The monitoring frequency of Well 10 water level and discharge (Table 2) is consistent with a monitoring schedule used during a similar aquifer pumping test in Indian Wells Valley. Solinst datalogging pressure transducers (Solinst Canada Ltd. [Georgetown, Ontario, Canada] Levellogger Model 3001) were deployed in 26S39E25K1 and deployed in Well 8 and Well 9A via sounding tubes. The Model 3001 has an accuracy of ± 0.164 ft and a resolution of 0.002 ft (Solinst Canada Ltd., 2020). A Solinst barologger was deployed at ground surface at 26S39E25K1. All water level measurements are corrected for

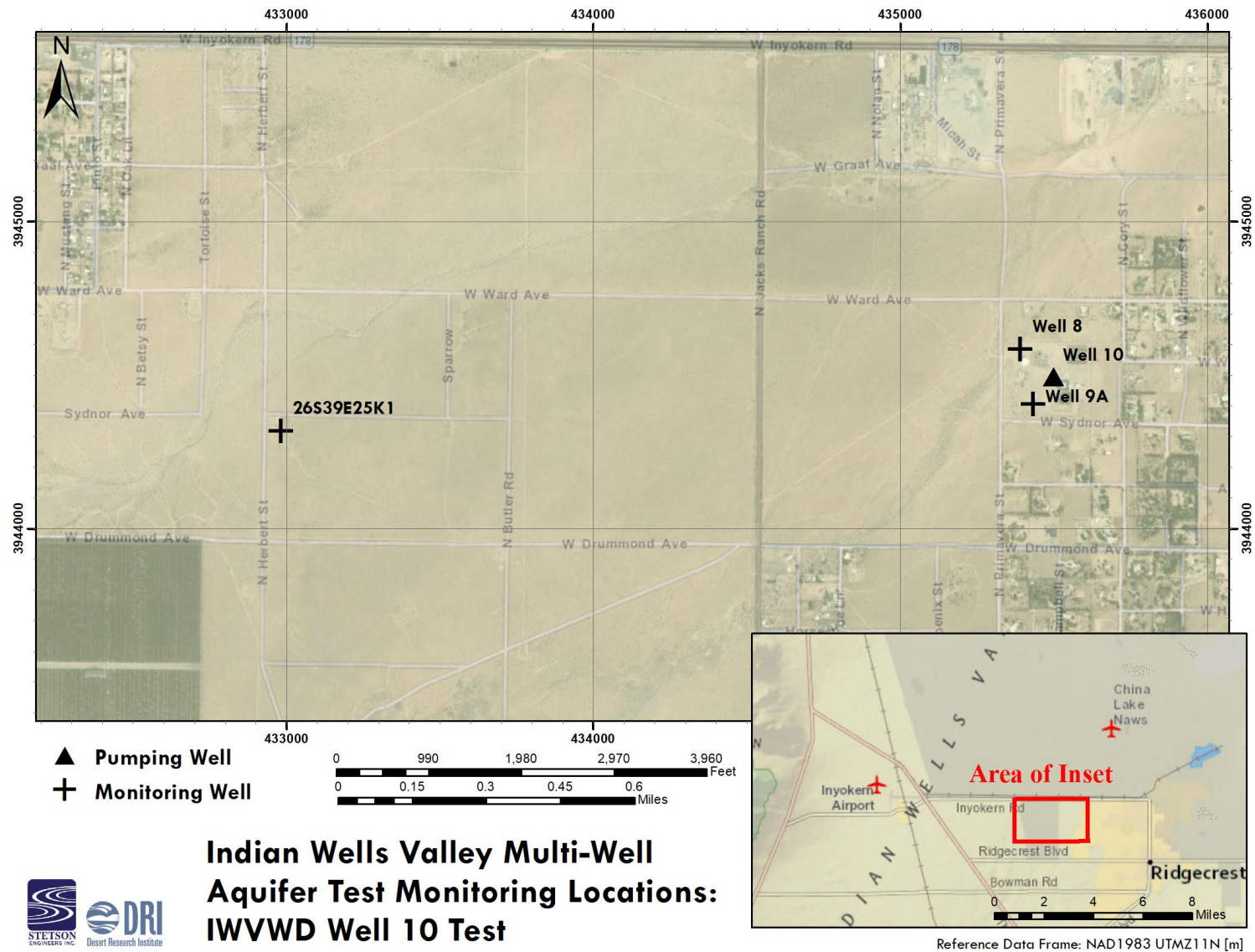


Figure 1. Indian Wells Valley multi-well aquifer test monitoring locations during the IWVWD Well 10 test.

Table 1. Well data for monitoring and pumping wells during the IWVWD Well 10 constant-rate test.

Well Name	Latitude (NAD83UTM Z11N) [meters]	Longitude (NAD83UTM Z11N) [meters]	Ground Surface Elevation [ft amsl]	Total Depth [ft bls]	Screened Interval [ft bls]	Casing Diameter [inches]	Distance from Well 10 [ft]	Well Type	Monitoring Equipment
Well 10	3944496	435498	2,346.1	800	250-500, 560-800	16	0	Active pumping	Air line
Well 9A	3944406	435433	2,348.1	816	300-460, 600-796	16	366	Active pumping	Pressure transducer
Well 8	3944584	435391	2,344.5	730	430-730	16	444	Abandoned pumping	Pressure transducer
26S39E25K1	3944318	432982	2,393.0	580	440-540	6	8,278	Active monitoring	Pressure transducer

ft amsl = feet above mean sea level

ft bls = feet below land surface

Table 2. Approximate monitoring schedule of field measurements excluding pressure transducers^A.

Interval from Pump On	Monitoring Frequency	Interval from Pump Off	Monitoring Frequency
0-10 minutes	Every minute	0-4 minutes	Every minute
10-60 minutes	Every 5 minutes	4-10 minutes	Every 2 minutes
60-120 minutes	Every 10 minutes	10-60 minutes	Every 10 minutes
2-12 hours	Every hour	60-120 minutes	Every 20 minutes
12-24 hours	Every 6 hours	2-6 hours	Every hour
>24 hours	Every 24 hours	6-12 hours	At end of 6 hours
		>12 hours	Every 24 hours

^AThe monitoring schedule is consistent with previous aquifer testing in Indian Wells Valley (Krieger & Stewart Inc., 1997).

barometric pressure observed by the barologger. Table 3 lists the measurement frequency and period of record for water level and barometric pressure observations.

The constant-rate test began on July 13, 2020, when the Well 10 pump first started at 07:08:48 Pacific Daylight Time (PDT). However, high pressure at the treatment plant caused the pump to shut off at 07:14:39 PDT. The issue was resolved and the pump was restarted at 07:21:49 PDT. Discharge was observed to increase quickly to approximately 1,300 gpm, and then the rate lowered to less than 1,120 gpm in approximately 15 minutes. This behavior is expected and consistent with the pump programming. The pump operated properly through the duration of the four-day test until the pump was stopped on July 17, 2020, at 12:00:01 PDT. The observed average discharge from 07:36:49 PDT (i.e., 15 minutes after pump start) until pump stop on July 17, 2020, was $1,109 \pm 10.7$ gpm. Recovery was observed until Well 10 was started again on July 28, 2020, at approximately 08:10 PDT.

Calibration checks were performed approximately daily in Well 9A, Well 8, and 26S39E25K1 using an electric-tape water level sounder. The average differences between the electric-tape sounder and the pressure transducer readings were 0.12 ft, 0.13 ft, and 0.05 ft in Well 9A, Well 8, and 26S39E25K1, respectively. All observed calibration checks were less than the manufacturer's listed accuracy for the pressure transducer (± 0.164 ft). Comparing the Well 10 pump volume totalizer with the observed discharge over time indicated that the difference between the actual totalized volume and the expected volumetric total between pump start and stop was $1.0 \pm 0.96\%$.

Results – IWVWD Well 10 Test

Table 4 summarizes the drawdown and recovery observations during the four-day constant-rate test. Figure 2 presents the Well 10 pump discharge and water level observations, which show that the maximum drawdown in Well 10 was 32 ft and most drawdown occurred in the first few minutes. Drawdown in Well 9A and Well 8 increased logarithmically up to a maximum drawdown of 10.65 ft and 8.55 ft in Well 9A and Well 8, respectively (Figure 3). In Well 10, 100% recovery occurred after 4.0 hours, whereas 95% recovery was observed in 197 hours (8 days, 5 hours) and 194 hours (8 days, 2 hours) in Well 9A and Well 8, respectively. Recovery of 100% was not observed in Well 9A and Well 8 in the 12-day recovery time frame. The pumping test had no distinguishable effect on water levels 8,278 ft away at 26S39E25K1 (Figure 4). Figure 4 also includes barometric pressure observations.

Data Analysis – IWVWD Well 10 Test

Drawdown data were reviewed for quality control and culled (i.e., resampled) prior to input into analysis software. The Well 10 initial pump start on July 13, 2020, at 07:08:48 PDT that resulted in a failed initiation to the constant-rate test caused observable water level displacement in Well 9A and Well 8 and the wells did not fully recover by the time the Well 10 pump was restarted at 07:21:49 PDT. To correct for the offset, the early time curves of the 07:08:48 PDT and 07:21:49 PDT pump start times were examined. It was determined that the drawdown curves for each well during the first six minutes of pumping (i.e., the duration of

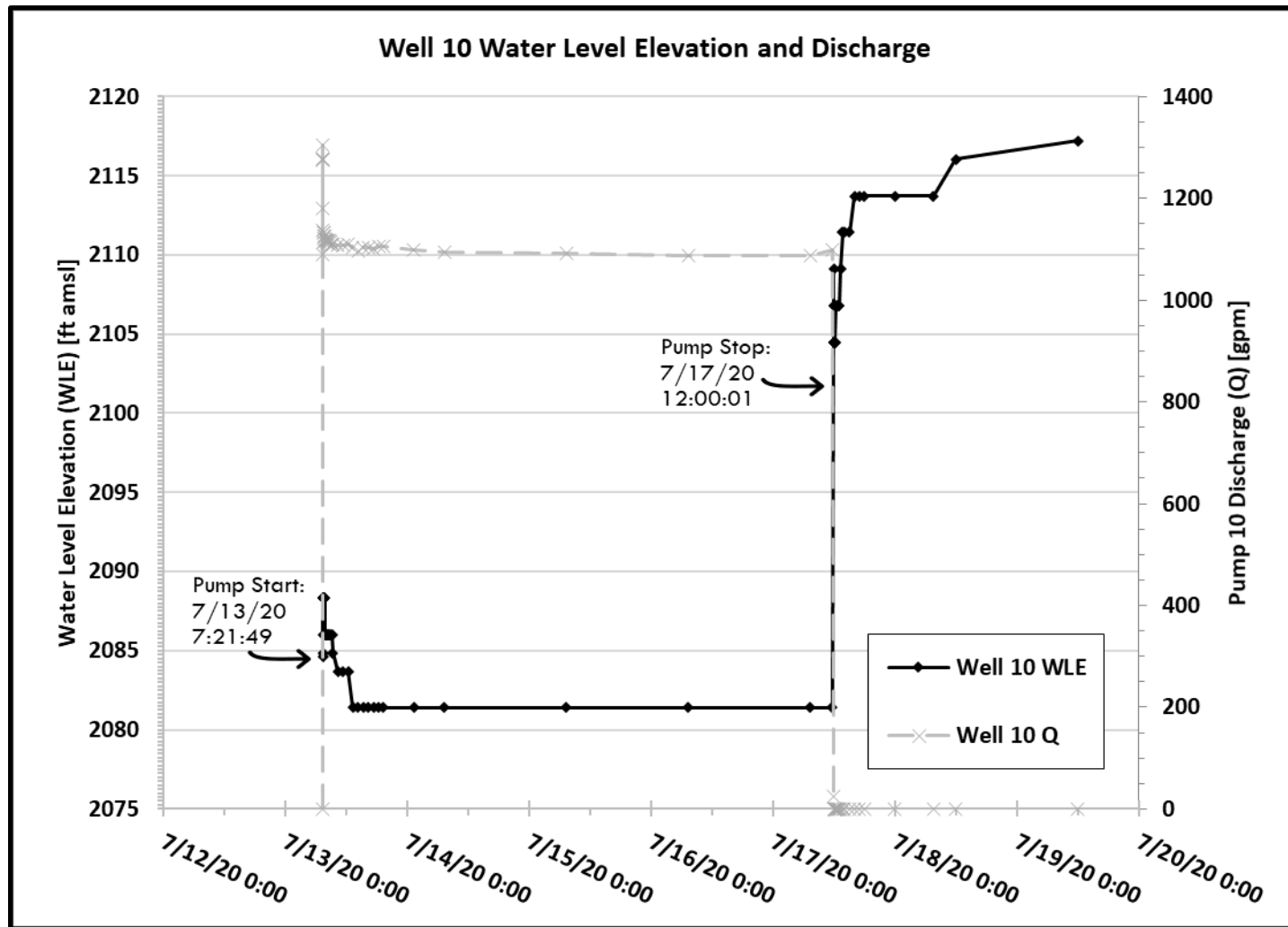
Table 3. Measurement frequency and period of record for water level and barometric pressure observations during the IWVWD Well 10 test.

Observation	Frequency	Start Date/Time (PDT)	End Date/Time (PDT)
Well 9A Water Level	10 minute	7/7/2020 08:50:00	7/29/2020 08:50:00
	30 second	7/12/2020 08:50:00	7/22/2020 08:50:00
Well 8 Water Level	10 minute	7/7/2020 08:30:00	7/29/2020 08:30:00
	30 second	7/12/2020 08:30:00	7/22/2020 08:30:00
26S39E25K1 Water Level	1 hour	10/7/2019 11:00	N/A
	30 second	7/13/2020 05:00:00	7/25/2020 05:00:00
26S39E25K1 Barometric Pressure	1 hour	7/7/2020 08:00	11/19/2020 15:00

N/A: Not applicable; water level monitoring is ongoing by Stetson Engineers Inc.

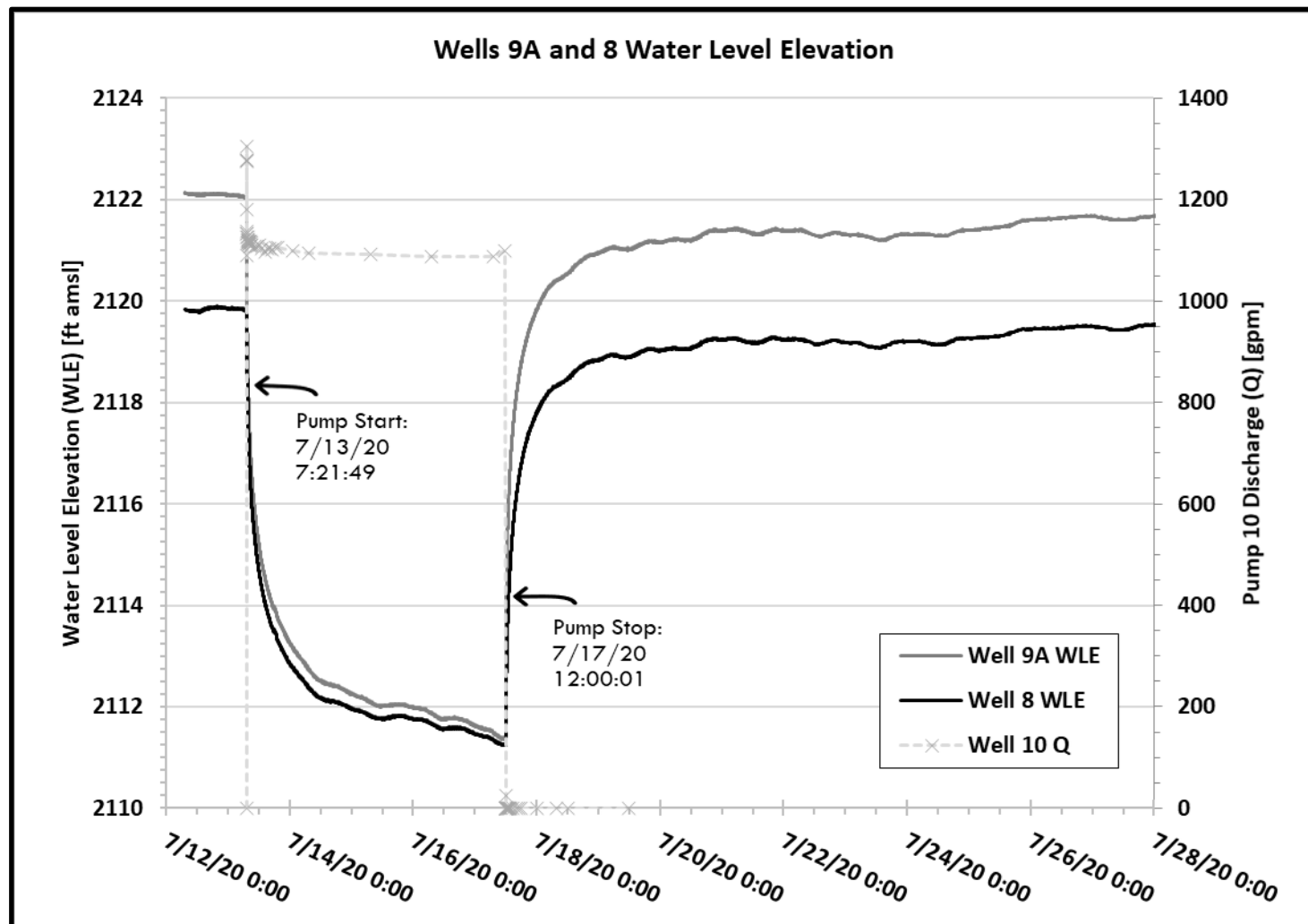
Table 4. Summary of drawdown and recovery data from the IWVWD Well 10 constant-rate pumping test.

Well ID	Parameter	Value
Well 10 (pumping well)	Discharge	1,109 ± 10.7 gpm
	Static water level	232 ft bls
	Drawdown after 24 hours	32 ft
	Maximum drawdown	32 ft
	Time to max. drawdown	6.0 hours
	Pumping duration	100.6 hours
	Recovery	85% after 1.3 hours
		95% after 1.7 hours
		100% after 4.0 hours
Well 9A	Distance from Well 10	366 ft
	Static water level	226.5 ft bls
	Drawdown after 24 hours	9.28 ft
	Maximum drawdown	10.65 ft
	Time to max. drawdown	99.1 hours
	Recovery	85% after 20.7 hours
		95% after 197 hours
Well 8	Distance from Well 10	444 ft
	Static water level	225.07 ft bls
	Drawdown after 24 hours	7.42 ft
	Maximum drawdown	8.55 ft
	Time to max. drawdown	99.4 hours
	Recovery	85% after 25.0 hours
		95% after 194 hours
26S39E25K1	Distance from Well 10	8,278 ft
	<i>No observed effect</i>	



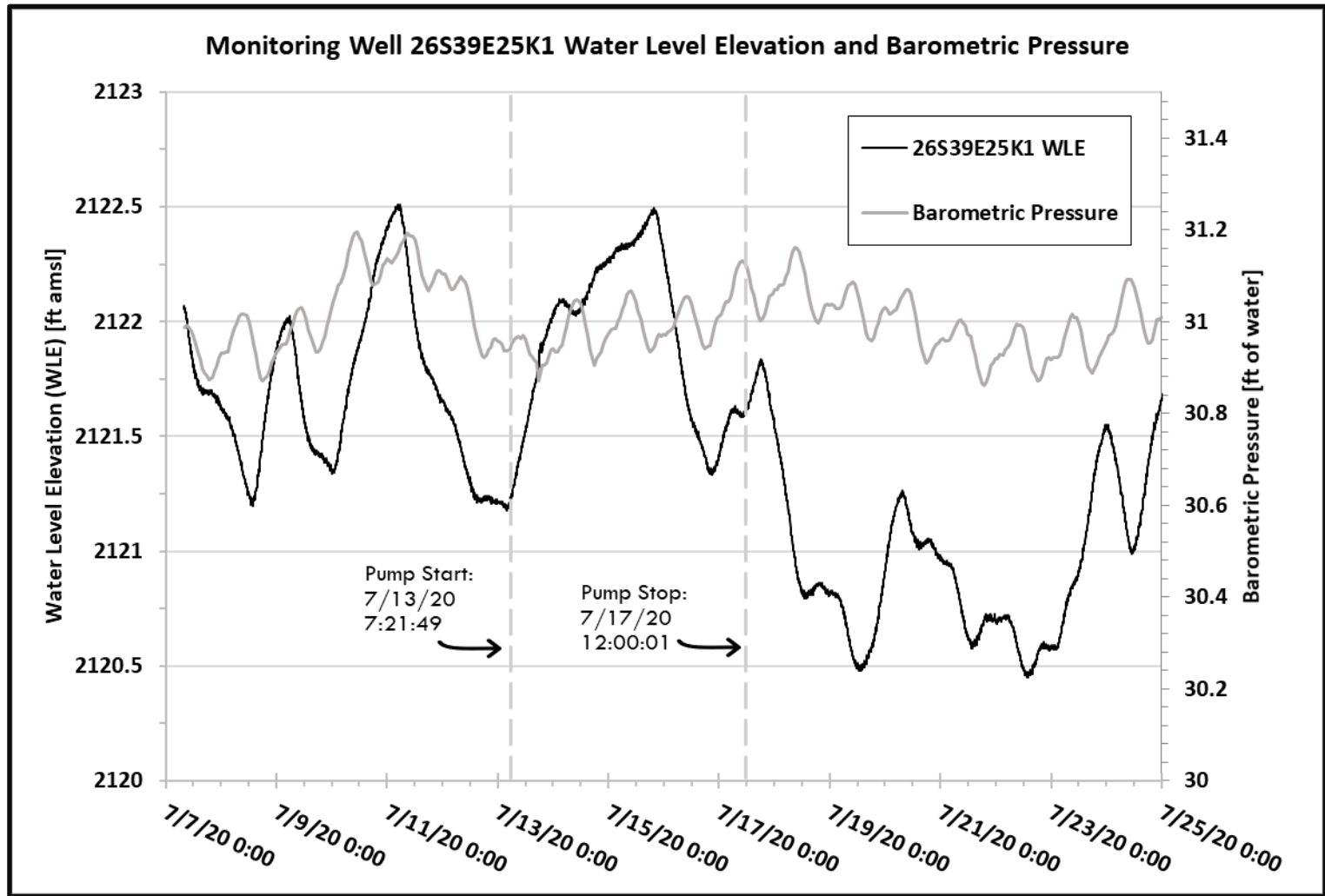
ft amsl = feet above mean sea level

Figure 2: Well 10 water level elevation and discharge data.



ft amsl = feet above mean sea level

Figure 3. Well 9A and Well 8 water level elevation data.



ft amsl = feet above mean sea level; 2.3067 ft of water = 1 pounds per square inch

Figure 4. Monitoring well 26S39E25K1 water level elevation and barometric pressure data during the IWVWD Well 10 test. Water level elevation is corrected for barometric pressure.

pump operation of the initial start) were consistent, indicating that no significant differences exist in the early time drawdown pattern. Therefore, drawdown analysis was considered from the last water level measurement prior to the 07:21:49 PDT pump start. The difference between the last water level measurement and the pre-test static water level was 0.51 ft and 0.38 ft in Well 9A and Well 8, respectively. Once corrected, time-drawdown data were resampled at a lower frequency to reduce repeated data and provide appropriate computational weight to early time drawdown and recovery data. The resample frequency was 30-second data for the first 0-10 minutes after pump start or stop, 1-minute data for 10-120 minutes after pump start or stop, and 10-minute data for greater than 120 minutes after pump start or stop.

Pumping test analysis was performed in Aquifer^{Win32} software (Environmental Simulations Inc., 2003) and included solution methods for distance-drawdown, time-drawdown, and time-recovery. Table 5 presents a summary table of analysis methods and calculated values of transmissivity, hydraulic conductivity, and storativity. Calculated transmissivity ranged between 58,750 gallons per day per foot (gpd/ft) and 103,425 gpd/ft; calculated hydraulic conductivity ranged between 13.83 feet per day (ft/day) and 24.34 ft/day; and calculated storativity ranged between 0.00040 and 0.00537. Theis (1935) distance-drawdown analysis was performed for all four wells considering 24 hours as well as four days after pump start (Appendix A; Figures A-1 and A-2, respectively). Well 9A and Well 8 were analyzed using Cooper and Jacob (1946) straight-line time-drawdown (Appendix A; Figures A-3 and A-4, respectively) and time-recovery (Appendix A; Figures A-5 and A-6, respectively) methods. The Theis (1935) type-curve method was applied to Well 9A and Well 8 (Appendix A; Figures A-7 and A-8, respectively). Solution methods were chosen based on analysis assumptions, which are described below in the discussion of the IWVWD Well 10 test.

Discussion – IWVWD Well 10 Test

Numerous pumping wells exist in the vicinity of Well 10 and 26S39E25K1, which affected observed water levels in 26S39E25K1 and minimally affected water levels near Well 10. Water level measurements were corrected for barometric pressure and the timing and magnitude of water level changes do not generally correspond to barometric pressure changes. Therefore, water level variations are assumed to represent changes induced by external pumping. Eleven private domestic pumping wells and one industrial supply well were identified within a 3,000 ft radius of Well 10. Three private domestic pumping wells, three agricultural pumping wells, and another industrial supply well were identified within a 3,000 ft radius of 26S39E25K1. Pumping rate and duration data for these external wells are unavailable, but pumping is expected because of high water demands in summer. Pre-test daily water level variations were up to 1.0 ft in 26S39E25K1 (Figure 4), which suggests this monitoring well is sensitive to nearby pumping. Thus, any potential water level change from the Well 10 pumping test is indistinguishable from the background variation. Pre-test daily water level variations were up to 0.15 ft in both Well 9A and Well 8 and multi-day trends were not noticeable, which indicates that the effects of external pumping are minimal. However, the inability for Well 9A

Table 5. Calculated transmissivity, hydraulic conductivity, and storativity from the IWVWD Well 10 constant-rate pumping test.

Method	Transmissivity [gpd/ft]	Hydraulic Conductivity ^A [ft/day]	Storativity	Figure (Appendix A)
Theis (1935) Distance-drawdown (24 hours)	58,750	13.83	0.00313	A-1
Theis (1935) Distance-drawdown (4 days)	62,530	14.72	0.00537	A-2
Cooper and Jacob (1946) Time-drawdown				
Well 9A	83,866	19.74	0.00057	A-3
Well 8	88,054	20.73	0.00099	A-4
Cooper and Jacob (1946) Time-recovery				
Well 9A	79,551	18.73	0.00045	A-5
Well 8	82,429	19.40	0.00090	A-6
Theis (1935) Type-curve				
Well 9A	95,074	22.34	0.00040	A-7
Well 8	103,425	24.34	0.00072	A-8

^ASaturated thickness of 568 ft is assumed and represents the interval between the static water level and the total depth in Well 10.

and Well 8 to fully recover to static water levels may be attributed to long-term (i.e., multi-week) falling water levels observed in 26S39E25K1 (Figure 4), even though this trend was not observed in Well 10.

The aquifer test solution methods assume that the aquifer is confined and the well fully penetrates the aquifer. However, the confined assumption can be applied to unconfined aquifers if the drawdown is small compared to the saturated thickness of the aquifer (Environmental Simulations Inc., 2003). The observed maximum drawdown in the monitoring wells (i.e., 10.65 ft in Well 9A) is less than 2% of the aquifer saturated thickness. The saturated thickness is assumed to be the interval between the static water level and total depth in Well 10 (i.e., 568 ft). The wells do not fully penetrate the entire alluvial aquifer, but they are screened throughout the high-production zone of gravels and coarse sand. Lithological logs from USBR-04-SM drilling (https://iwvgsp.com/wells/well_info.php?DBID=88; IWVGA Data Management System [2020a] accessed on August 13, 2020), which is approximately 1.8 miles (mi) to the northwest, report that lower units below 990 ft bls are composed of silts, silty- to fine- sands, and clays that are likely low hydraulic conductivity units. The Indian Wells Valley Groundwater Model (Pohlmann *et al.*, 2020) assumes the hydraulic conductivity of the lower layer (i.e., below the screened interval) is up to two orders of magnitude less than the upper layer. The assumption of a confined aquifer with fully penetrating wells is consistent with a similar constant-rate pumping test in Indian Wells Valley (Krieger & Stewart Inc., 1997).

The lithological logs gathered from drilling at Well 10, Well 9A, and Well 8 report heterogeneous layers of unconsolidated alluvial material in the screened interval, including gravel, fine- to coarse- sand, and clay varying in distribution and thickness. A pronounced clay unit tens of feet thick is interbedded between the coarser alluvial lithology, generally between 500 ft bls and 600 ft bls. Aquifer test solution methods rely on the simplification that the aquifer is homogenous and isotropic. However in the Indian Wells Valley Groundwater Model, the vertical anisotropy ratio of hydraulic conductivity throughout the entire aquifer is assumed to be less than or equal to 0.3 (Pohlmann *et al.*, 2020; Brown and Caldwell, 2009). The simplification to a homogenous and isotropic aquifer introduces an unknown degree of uncertainty in aquifer test analysis.

The calculated transmissivity for Well 9A ranged from 79,551 gpd/ft to 95,074 gpd/ft; and the calculated transmissivity for Well 8 ranged from 82,429 gpd/ft to 103,425 gpd/ft (Table 5). Well 8 exhibited higher transmissivity as well as corresponding hydraulic conductivity for each calculation method. The difference between the transmissivity of Well 9A and Well 8 ranged between 2.4% and 5.7% comparing three different methods.

The calculated storativity for Well 9A ranged from 0.00040 to 0.00057; and the calculated storativity for Well 8 ranged from 0.00072 to 0.00099 (Table 5). Similar to transmissivity, Well 8 exhibited higher storativity for the three different analyses shown in Table 5. The difference between the calculated storativity of Well 9A and Well 8 for each analysis method ranged between 39% and 50%. The cause of higher calculated transmissivity and storativity at Well 8 is unknown, but they may indicate better hydraulic connectivity between Well 8 and Well 10 and may be a function of local vertical anisotropy.

Field Methods – Quist Ranch 21 hr and 48 hr Tests

Two constant-rate pumping tests were performed at Quist Ranch in November 2020: (1) 21 hr test that pumped 26S39E35G01 at a rate of 285 gpm, and (2) 48 hr test that pumped 26S39E35G02 at a rate of 285 gpm. Water levels were allowed to fully recover to background levels from the 21 hr test before starting the second pumping test. Four nearby wells, two owned by Quist Ranch and two U.S. Navy monitoring wells were outfitted as monitoring wells for water level measurements during the tests.

Quist Ranch operates a network of groundwater irrigation wells on the southeast corner of Drummond Avenue and Rhebas Way in Ridgecrest, California (Figure 5). Four irrigation wells exist within this pistachio orchard: 26S39E35B01 and 26S39E35B02 (installed in 1994 and currently inactive), 26S39E35G01 (installed in 1995), and 26S39E35G02 (recompleted in 2015). Wells 26S39E35G01 and 26S39E35G02 were pumped for the two aquifer tests and Well 26S39E35B01 was used for monitoring. Well 26S39E35B02 had an obstruction at 260.0 ft bls above the water table and was not used to collect groundwater level measurements. Discharge from the wells was distributed throughout the orchard in multiple drip irrigation zones that were rotated during pumping.

Wells 26S39E35B01, 26S39E35B02, 26S39E35G02, and 26S39E35G01 are aligned north-south through the center of the orchard, and are each separated by approximately 640 ft to 680 ft. The U.S. Navy monitoring wells, 26S39E35A and 26S39E25K1, are located 2,297 ft and 3,915 ft to the northeast of 26S39E35G01, respectively. Figure 5 shows the well locations and Table 6 presents the well construction and location information. Wells 26S39E35B01 and 26S39E35G01 are screened from approximately water level to 455 ft bls, and 26S39E35G02 is screened from 440 ft bls to 500 ft bls. An electric submersible pump was set at approximately 315 ft bls and pumped water is lifted via a four-inch pipe in the production wells at the Quist Ranch orchard.

Water level measurements were taken at three Quist Ranch orchard irrigation wells using an electric-tape water level sounder. The casing access at the irrigation wellheads was too small to accommodate pressure transducers. The resolution of the electric-tape water level sounder was 0.01 ft in 26S39E35G01 and 26S39E35G02, and 0.1 ft in 26S39E35B01. The difference is because an older-style sounder was used in 26S39E35B01. However, water levels were approximated at 0.01 ft resolution in 26S39E35B01 by marking the water level tape as compared to a ruler. Flow meters were not installed at the wellheads, and flow is assumed to be 285 gpm based on pump specifications. The monitoring frequency of water levels using sounders, shown in Table 2, is consistent with the measurement frequency used in the IWVWD Well 10 test. Solinst datalogging pressure transducers (Solinst Canada Ltd. [Georgetown, Ontario, Canada] Levellogger Model 3001) were deployed in 26S39E35A and 26S39E25K1. A Solinst barologger was deployed at ground surface at 26S39E25K1. The water level measurements taken by the pressure transducers are corrected for barometric pressure. Table 7 lists the measurement frequency and period of record for pressure transducer water level and barometric pressure observations.

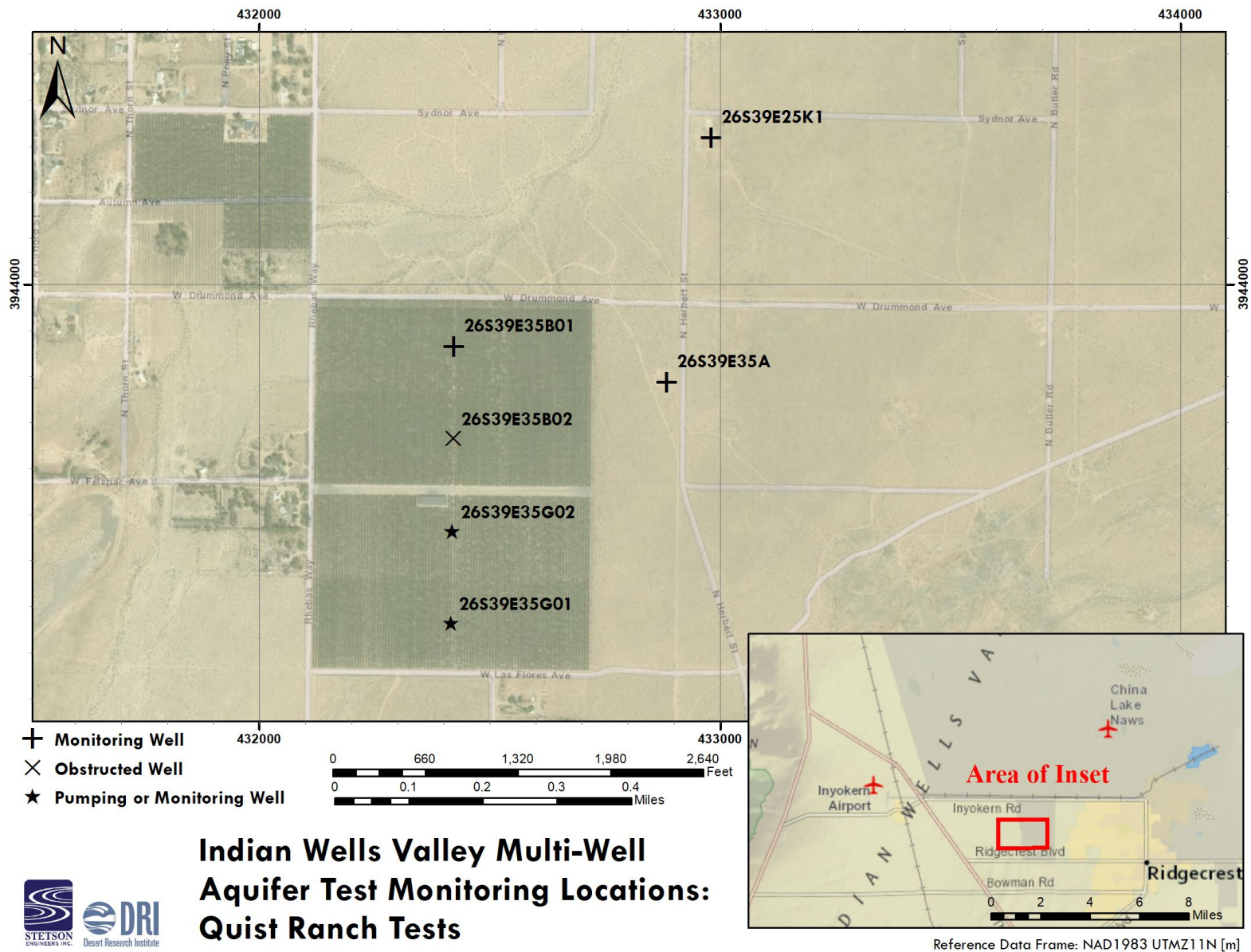


Figure 5. Indian Wells Valley multi-well aquifer test monitoring locations during the Quist Ranch 21 hr and 48 hr tests.

Table 6. Well data for monitoring and pumping wells during the Quist Ranch 21 hr and 48 hr tests.

Well Name	Latitude (NAD83UTM Z11N) [meters]	Longitude (NAD83UTM Z11N) [meters]	Ground Surface Elevation [ft amsl]	Total Depth [ft bls]	Screened Interval [ft bls]	Casing Diameter [inches]	Distance from 21 hr Pumping Test [ft]	Distance from 48 hr Pumping Test [ft]	Well Type	Monitoring Equipment
26S39E35B01	3943865	432422	2,400.5	455	235-455	8	1,964	1,323	Non-active Pumping	Water Level Sounder
26S39E35G02	3943463	432419	2,411.0	500	440-500	8	641	<i>48 hr test well</i>	Active Pumping	Water Level Sounder
26S39E35G01	3943264	432416	2,421.0	455	245-455	8	<i>21 hr test well</i>	641	Active Pumping	Water Level Sounder
26S39E35A	3943787	432886	2,405.0	560	^A	6	2,297	1,888	Active Monitoring	Pressure Transducer
26S39E25K1	3944318	432982	2,393.0	580	440-540	6	3,915	3,368	Active Monitoring	Pressure Transducer

ft amsl = feet above mean sea level

ft bls = feet below land surface

^A Unknown screened interval (IWVGA Data Management System, 2020b).

Table 7. Pressure transducer measurement frequency and period of record for water level and barometric pressure observations during the Quist Ranch 21 hr and 48 hr tests.

Observation	Frequency	Start Date/Time (PST)	End Date/Time (PST)
26S39E35A Water Level	10 minute	11/6/2020 07:50:00	11/19/2020 14:10:00
	30 second	11/9/2020 04:00:00	11/19/2020 04:00:00
26S39E25K1 Water Level	1 hour	10/7/2019 11:00	N/A
	10 minute	11/6/2020 07:40:00	11/19/2020 14:00:00
	30 second	11/9/2020 04:00:00	11/19/2020 04:00:00
26S39E25K1 Barometric Pressure	1 hour	7/7/2020 08:00	11/19/2020 15:00

N/A: Not applicable; water level monitoring is ongoing by Stetson Engineers Inc.

The first constant-rate (285 gpm) test began on November 9, 2020, when the 26S39E35G01 pump started at 14:35:00 Pacific Standard Time (PST). The pump operated properly through the 21.4 hr duration of the test until the pump was stopped on November 10, 2020, at 12:00:00 PST. Full recovery was observed prior to the start of the 48 hr test when 26S39E35G02 was started on November 11, 2020, at 10:00:00 PST. The pump operated properly through the 48.0 hr duration of the test until the pump was stopped on November 13, 2020, at 10:00:00 PST. Water level recovery measurements were taken for the ensuing 48 hours.

Results – Quist Ranch 21 hr and 48 hr Tests

Tables 8 and 9 summarize the drawdown and recovery observations during the 21 hr and 48 hr constant-rate tests, respectively. Figure 6 presents the 26S39E35G02 and 26S39E35G01 water level elevation data, which show that most drawdown and recovery in the pumped well occurred in the first few minutes of pump start or stop. Drawdown 641 ft away in 26S39E35G02 during the 21 hr test and in 26S39E35G01 during the 48 hr test increased logarithmically up to a maximum drawdown of 0.80 ft and 0.68 ft, respectively (Figure 6). Minimal drawdown was observed in 26S39E35B01 (Figure 7), which was 1,964 ft and 1,323 ft away from the pumped well in the 21 hr and 48 hr tests, respectively. During the 21 hr test, 100% recovery occurred after 20.5 hours in 26S39E35G01, whereas 100% recovery was observed in 5.0 hours and 1.7 hours in 26S39E35G02 and 26S39E35B01, respectively. During the 48 hr test, 100% recovery occurred after 8.3 hours in 26S39E35G02, whereas 100% recovery was observed in 4.0 hours and 5.0 hours in 26S39E35G01 and 26S39E35B01, respectively.

The pumping tests had no distinguishable effect on water levels at 26S39E35A and 26S39E25K1 (Figures 8 and 9, respectively). Well 26S39E35A was 2,297 ft and 1,888 ft away from the pumped well in the 21 hr and 48 hr tests, respectively. Well 26S39E25K1 was 3,915 ft and 3,368 ft away from the pumped well in the 21 hr and 48 hr tests, respectively.

Data Analysis – Quist Ranch 21 hr and 48 hr Tests

Drawdown data were reviewed for quality control. Figures 8 and 9 include barometric pressure observations, which show that meaningful changes in barometric pressure occurred days before the start of the 21 hr test and these changes continued through the 21 hr and 48 hr tests and affected local water levels. The abrupt changes in barometric pressure correspond closely to changes in water level observed in 26S39E35A and 26S39E25K1. The barometric pressure fell on November 5, 2020, and then rose during the morning of November 9, 2020 (the barometric pressure values in Figures 8 and 9 are shown in reverse order). This trough represents the largest magnitude change in barometric pressure observed since August 2020. The barometric pressure change recorded on the barologger was confirmed with atmospheric pressure observations near the Inyokern Airport (<https://www.wunderground.com/dashboard/pws/KCAINYOK23>; Weather Underground Koch Station [2020] accessed on December 14, 2020).

Table 8. Summary of drawdown and recovery data from the Quist Ranch 21 hr pumping test.

Well ID	Parameter	Value
26S39E35G01 (pumping well)	Discharge	285 gpm
	Static water level	284.67 ft bls
	Maximum drawdown	6.03 ft
	Time to max. drawdown	0.33 hours
	Pumping duration	21.4 hours
	Recovery	85% after 1.15 hours
		95% after 12.0 hours
		100% after 20.5 hours
26S39E35G02	Distance from pumping well	641 ft
	Static water level	275.35 ft bls
	Maximum drawdown	0.80 ft
	Time to max. drawdown	18.0 hours
	Recovery	85% after 3.0 hours
		95% after 4.0 hours
		100% after 5.0 hours
26S39E35B01	Distance from pumping well	1,964 ft
	Static water level	265.70 ft bls
	Maximum drawdown	0.05 ft
	Time to max. drawdown	0.75 hours
	Recovery	85% after 1.0 hours
		100% after 1.7 hours
26S39E35A	Distance from pumping well	2,297 ft
	<i>No observed effect</i>	
26S39E25K1	Distance from pumping well	3,915 ft
	<i>No observed effect</i>	

Table 9. Summary of drawdown and recovery data from the Quist Ranch 48 hr pumping test.

Well ID	Parameter	Value
26S39E35G02 (pumping well)	Discharge	285 gpm
	Static water level	275.11 ft bls
	Maximum drawdown	14.19 ft
	Time to max. drawdown	7.1 hours
	Pumping duration	48.0 hours
	Recovery	85% after 0.5 hours
		95% after 2.0 hours
		100% after 8.3 hours
26S39E35G01	Distance from pumping well	641 ft
	Static water level	284.69 ft bls
	Maximum drawdown	0.68 ft
	Time to max. drawdown	24.25 hours
	Recovery	85% after 3.0 hours
		100% after 4.0 hours
26S39E35B01	Distance from pumping well	1,323 ft
	Static water level	265.55 ft bls
	Maximum drawdown	0.11 ft
	Time to max. drawdown	24.4 hours
	Recovery	85% after 3.0 hours
		100% after 5.0 hours
26S39E35A	Distance from pumping well	1,888 ft
	<i>No observed effect</i>	
26S39E25K1	Distance from pumping well	3,368 ft
	<i>No observed effect</i>	

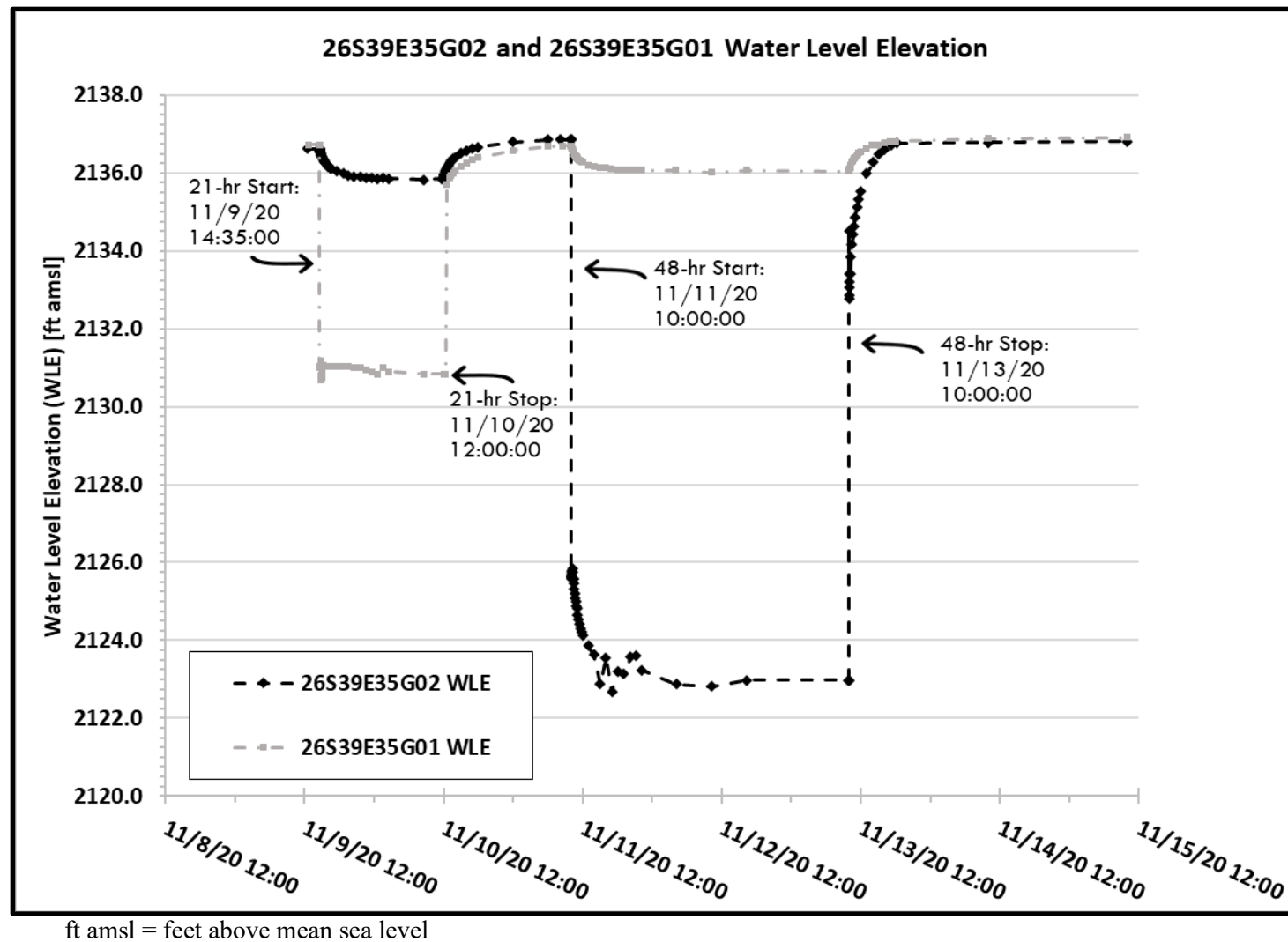


Figure 6: Wells 26S39E35G02 and 26S39E35G01 water level elevation data.

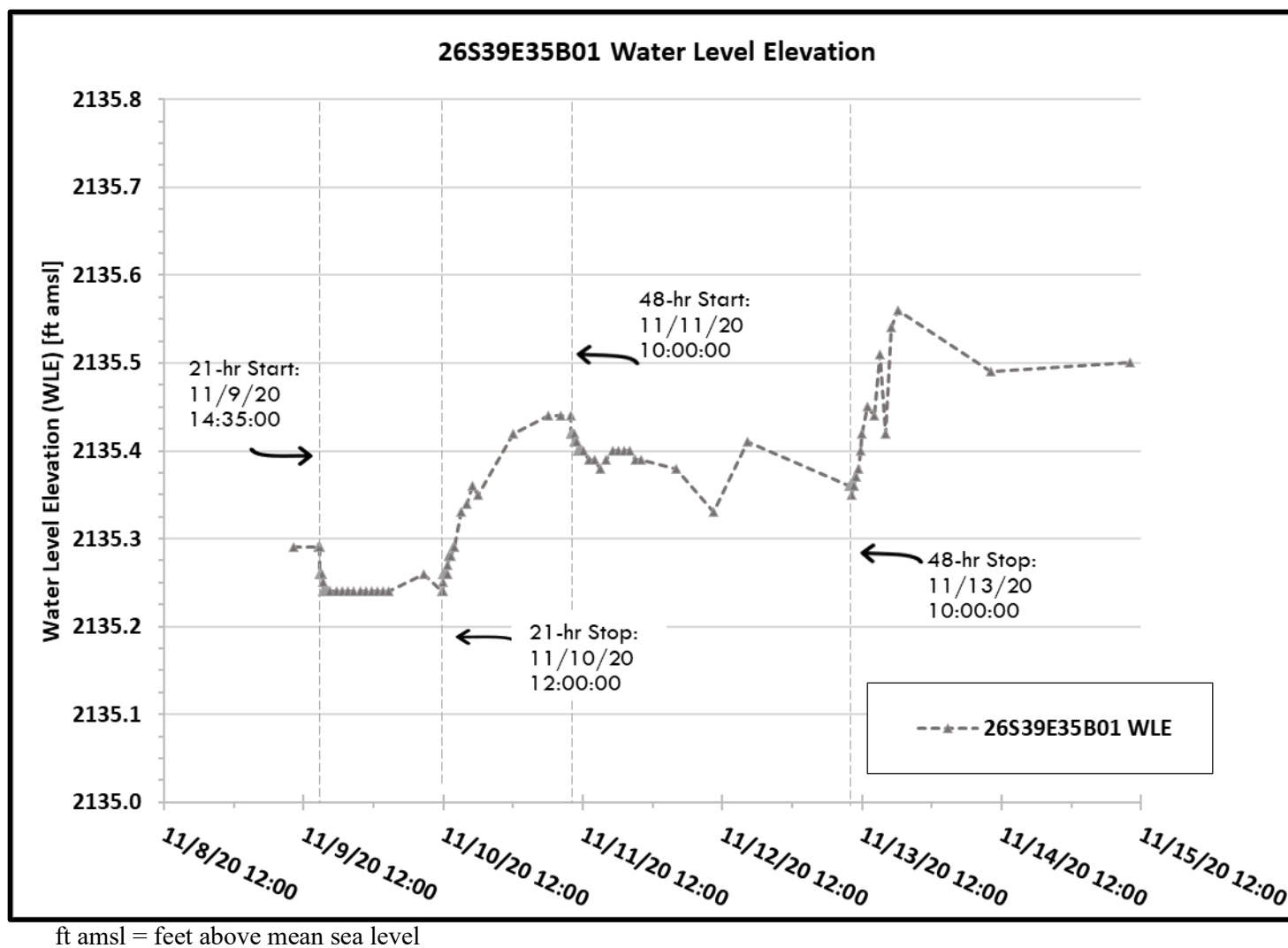
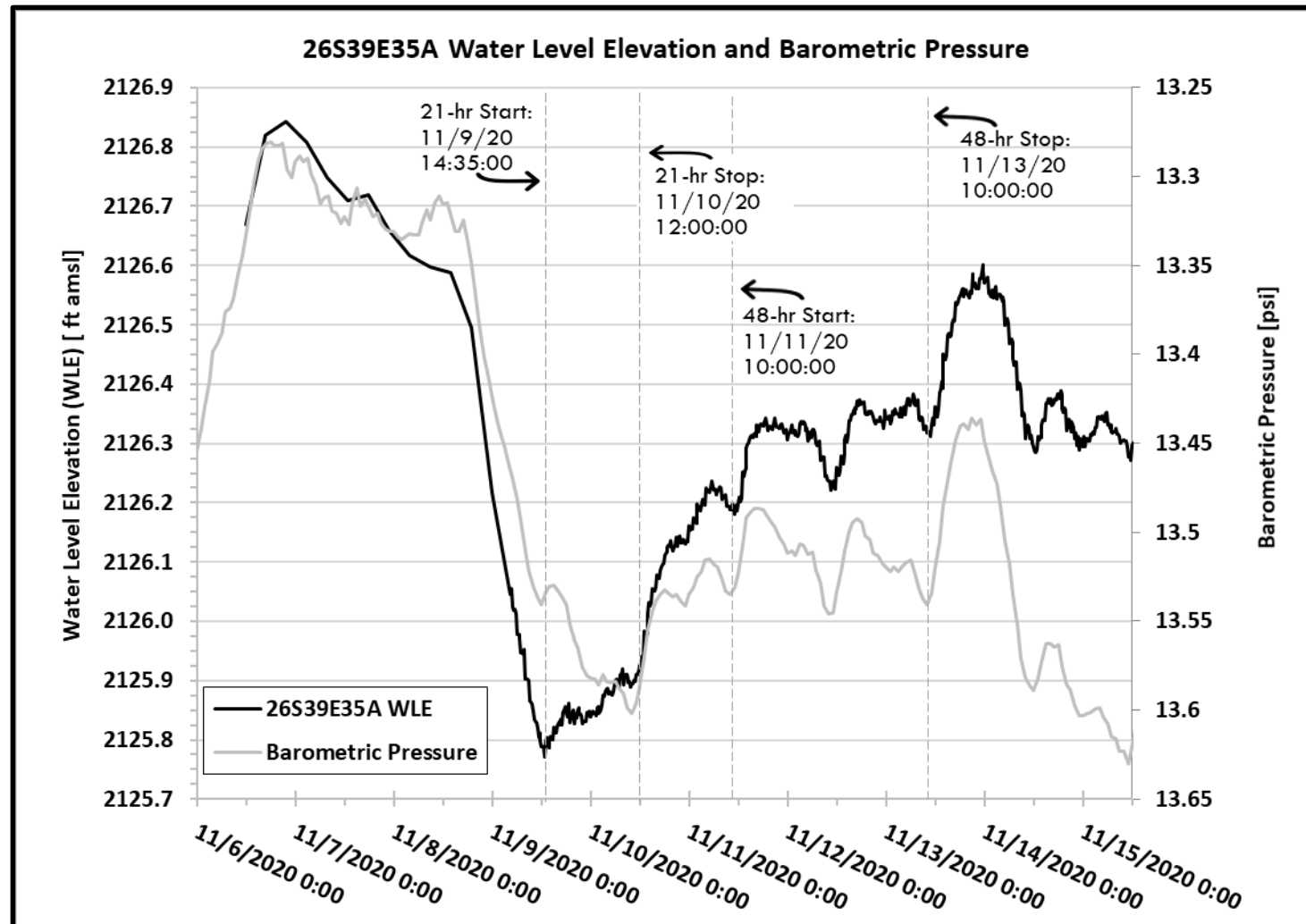
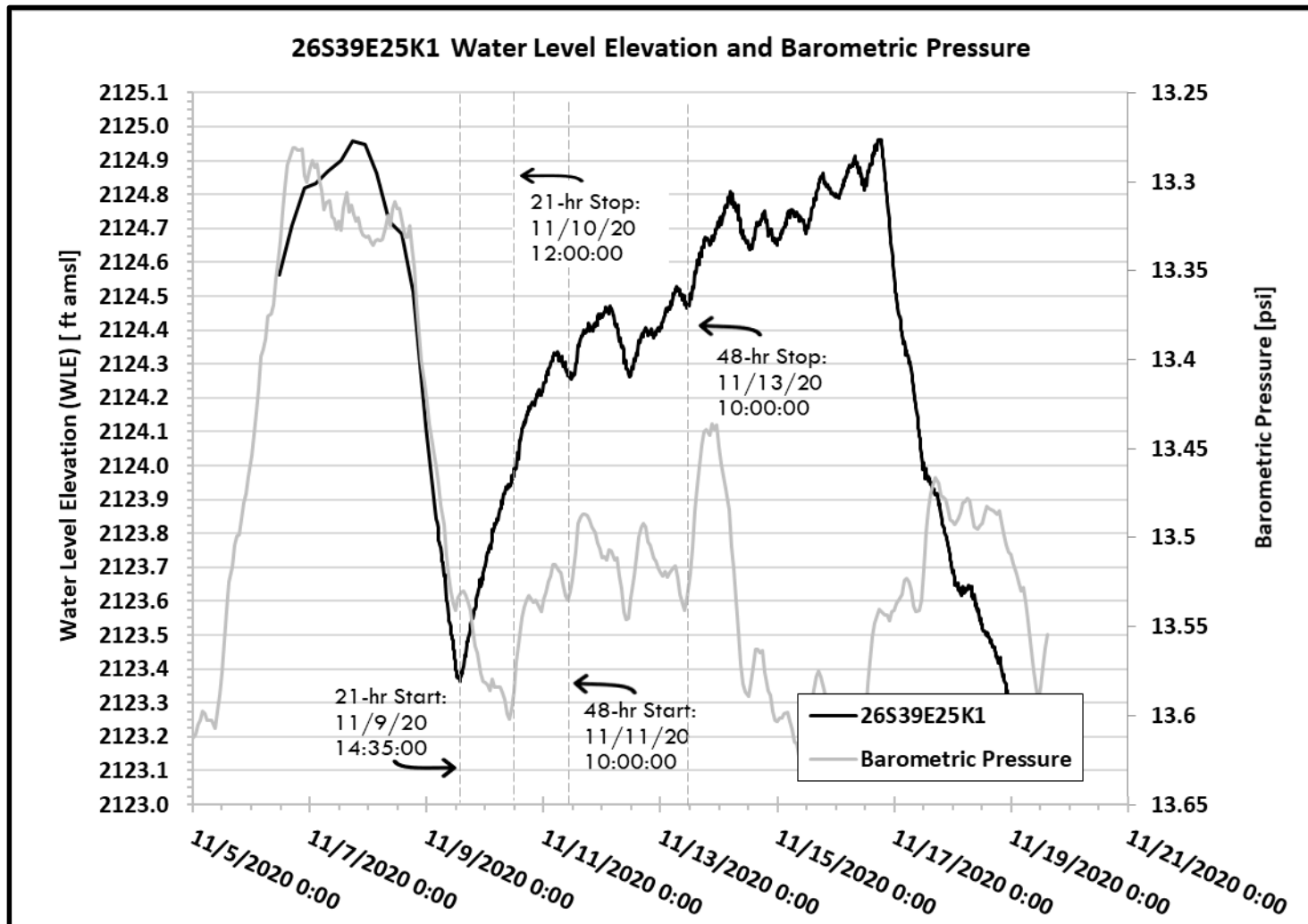


Figure 7. Well 26S39E35B01 water level elevation data.



ft amsl = feet above mean sea level; psi = pounds per square inch; 1 psi = 2.3067 ft of water

Figure 8. Monitoring well 26S39E35A water level elevation and barometric pressure data. Note that barometric pressure values are shown in reverse order on the y-axis because of the inverse relationship between groundwater level and barometric pressure.



ft amsl = feet above mean sea level; psi = pounds per square inch; 1 psi = 2.3067 ft of water

Figure 9. Monitoring well 26S39E25K1 water level elevation and barometric pressure data during the Quist Ranch tests. Note that barometric pressure values are shown in reverse order on the y-axis because of the inverse relationship between groundwater level and barometric pressure.

The increase in barometric pressure on November 9, 2020, corresponded to a water level drop in 26S39E35A and 26S39E25K1 by approximately 0.80 ft and 1.2 ft, respectively, prior to the start of the 21 hr test. Water levels in 26S39E35A and 26S39E25K1 generally increased during the 21 hr and 48 hr tests. Any potential signal in 26S39E35A or 26S39E25K1 from the pumping tests were unobservable because of the daily and multi-day variance in water level measurements.

An apparent multi-day rise in water levels in 26S39E35B01 (Figure 7) was observed during the period of testing, resulting in water levels during recovery that exceed the pre-test static water levels. An interpolated water level was assumed following guidance in Stallman (1971), and drawdown or recovery data were calculated relative to the interpolated level to correct for the water level rise. In wells 26S39E35G01 and 26S39E35G02 (Figure 6), similar changes in background water levels were minimal relative to the maximum drawdown and not included. Therefore, no corrections are applied to the drawdown and recovery data of these two wells.

Pumping test analysis was performed in Aquifer^{Win32} software (Environmental Simulations Inc., 2003) and included solution methods for distance-drawdown, time-drawdown, and time-recovery for both the 21 hr and 48 hr pumping tests. Solution methods were chosen based on analysis assumptions and for consistency with the IWVWD Well 10 test.

Table 10 presents a summary table of analysis methods and calculated values of transmissivity, hydraulic conductivity, and storativity for the 21 hr test. Calculated transmissivity ranged between 84,530 gpd/ft and 171,603 gpd/ft; calculated hydraulic conductivity ranged between 66.48 ft/day and 135.0 ft/day; and calculated storativity ranged between 0.00073 and 0.0019. Theis (1935) distance-drawdown analysis was performed considering maximum drawdown (Appendix B; Figure B-1). The nearest monitoring well, 26S39E35G02, was analyzed using Cooper and Jacob (1946) straight-line time-drawdown (Appendix B; Figure B-2) and time-recovery (Appendix B; Figure B-3) methods, as well as the Theis (1935) type-curve method (Appendix B; Figure B-5). The Theis (1935) time-recovery method was applied to the pumping well, 26S39E35G01 (Appendix B; Figure B-4).

Table 11 presents a summary table of analysis methods and calculated values of transmissivity, hydraulic conductivity, and storativity for the 48 hr test. Calculated transmissivity ranged between 34,314 gpd/ft and 196,506 gpd/ft; calculated hydraulic conductivity ranged between 20.39 ft/day and 116.8 ft/day; and calculated storativity ranged between 0.00076 and 0.0032. Theis (1935) distance-drawdown analysis was performed considering maximum drawdown (Appendix C; Figure C-1). The nearest monitoring well, 26S39E35G01, was analyzed using Cooper and Jacob (1946) straight-line time-drawdown (Appendix C; Figure C-2) and time-recovery (Appendix C; Figure C-3) methods, as well as the Theis (1935) type-curve method (Appendix C; Figure C-5). The Theis (1935) time-recovery method was applied to the pumping well, 26S39E35G02 (Appendix C; Figure C-4).

Table 10. Calculated transmissivity, hydraulic conductivity, and storativity from the Quist Ranch 21 hr pumping test.

Method	Transmissivity [gpd/ft]	Hydraulic Conductivity ^A [ft/day]	Storativity	Figure (Appendix B)
Theis (1935) Distance-drawdown	84,530	66.48	0.0019	B-1
Cooper and Jacob (1946) Time-drawdown 26S39E35G02	171,603	135.0	0.00076	B-2
Cooper and Jacob (1946) Time-recovery 26S39E35G02	148,690	116.9	0.00073	B-3
Theis (1935) Time-recovery 26S39E35G01	93,213	73.31	N/A	B-4
Theis (1935) Type-curve 26S39E35G02	167,988	132.1	0.00085	B-5

N/A = Not applicable; Theis (1935) recovery cannot solve for storativity.

^ASaturated thickness of 170 ft is assumed and represents the interval between the static water level and the total screened depth in 26S39E35G01.

Table 11. Calculated transmissivity, hydraulic conductivity, and storativity from the Quist Ranch 48 hr pumping test.

Method	Transmissivity [gpd/ft]	Hydraulic Conductivity ^A [ft/day]	Storativity	Figure (Appendix C)
Theis (1935) Distance-drawdown	62,808	37.32	0.0032	C-1
Cooper and Jacob (1946) Time-drawdown 26S39E35G01	196,506	116.8	0.00093	C-2
Cooper and Jacob (1946) Time-recovery 26S39E35G01	161,231	95.81	0.00076	C-3
Theis (1935) Time-recovery 26S39E35G02	34,314	20.39	N/A	C-4
Theis (1935) Type-curve 26S39E35G01	196,149	116.6	0.0012	C-5

N/A = Not applicable; Theis (1935) recovery cannot solve for storativity.

^ASaturated thickness of 225 ft is assumed and represents the interval between the static water level and the total screened depth in 26S39E35G02.

Discussion – Quist Ranch 21 hr and 48 hr Tests

Analysis methods were unable to properly fit drawdown or recovery data for 26S39E35B01 or drawdown data for the pumping wells in either the 21 hr or 48 hr tests. Well 26S39E35B01 data analysis issues included minimal drawdown relative to the local water level rise and poor resolution of the water level sounder. Analysis methods were invalid and unusable despite attempts that assumed both corrected and uncorrected drawdown input for water level rise. In the pumping wells, 26S39E35G01 for the 21 hr test and 26S39E35G02 for the 48 hr test, most drawdown occurred immediately and drawdown patterns were occasionally variable, which caused incompatible curves for analyses.

Pre-test daily water level variations were up to 0.80 ft and 1.2 ft in 26S39E35A and 26S39E25K1, respectively, during the large magnitude barometric pressure change. However, daily variations were minimal (approximately 0.15 ft) during the testing period. These minor variations appear to be related to changes in barometric pressure (Figures 8 and 9), but the timing and trends do not correspond precisely with barometric pressure changes, indicating that observed local water levels were also sensitive to other influences, such as aquifer rebound following heavy summer water demand. A multi-day water level rising trend during the testing period was also identified in USBR-04-SM (IWVGA Data Management System, 2020b) and may affect water levels in the monitoring wells on Quist Ranch. Groundwater levels at the monitoring wells recovered within 10 hours of turning off pumping during the 21 hr and 48 hr tests (Tables 8 and 9). This recovery is much faster when compared to the IWVWD Well 10 constant-rate test in which full recovery was not achieved in monitoring wells after hundreds of hours. The quick recovery indicates a higher transmissivity at the Quist Ranch wells, and may also be a function of the aquifer rebound trend during testing. If a multi-day water level rise occurred at the Quist Ranch wells then observed recovery would occur sooner than if water level was static.

This analysis assumes that the aquifer is confined and the wells fully penetrate the aquifer (same assumptions used in the aquifer test solution methods of the IWVWD Well 10 test, above). This assumption can typically be applied when drawdown is a small percentage of the overall saturated thickness. The observed maximum drawdown in the monitoring wells (i.e., 0.80 ft in 26S39E35G02 and 0.68 ft in 26S39E35G01) is less than 1% of the aquifer saturated thickness. The saturated thickness is assumed to be the interval between the static water level and total screen depth (i.e., 170 ft in 26S39E35G01 and 225 ft in 26S39E35G02). The wells do not fully penetrate the entire alluvial aquifer, but they are screened throughout the high-production zone of gravels/cobbles and sand. The screened section is representative of the high hydraulic conductivity upper layer identified in local wells (e.g., USBR-04-SM, IWVWD Wells 10, 9A, and 8) and in the Indian Wells Valley Groundwater Model. The assumption of a confined aquifer with fully penetrating wells is also consistent with a similar constant-rate pumping test in Indian Wells Valley (Krieger & Stewart Inc., 1997).

The lithological logs gathered from drilling at 26S39E35B01, 26S39E35B02, and 26S39E35G01 report heterogeneous layers of unconsolidated alluvial material in the screened interval, including cobbles, boulders, gravel, and medium fine- to coarse- sand varying in

distribution and thickness. Well 26S39E35G02 is screened exclusively in medium fine-sand because of the lower placement of the screen and the larger clasts that overlay this sand unit. Aquifer test solution methods rely on the simplification that the aquifer is homogenous and isotropic. However, the calibrated Indian Wells Valley Groundwater Model estimates a vertical anisotropy ratio less than or equal to 0.3 for hydraulic conductivity throughout the entire aquifer. The simplification to a homogenous and isotropic aquifer introduces an unknown degree of uncertainty in aquifer test analysis.

The differences between the aquifer hydraulic properties when comparing the 21 hr and 48 hr tests are likely attributed to heterogeneity in the geologic environment of the two pumping wells. The difference between the calculated transmissivity of 26S39E35G01 and 26S39E35G02 during the 21 hr and 48 hr tests was 14.7% using distance-drawdown methods, and it ranged between 6.8% and 7.7% using time-drawdown methods and between 4.1% and 46.2% using time-recovery methods. The difference between the calculated storativity of 26S39E35G01 and 26S39E35G02 during the 21 hr and 48 hr tests was 25.5% using distance-drawdown methods, 2.0% using time-recovery methods, and it ranged between 10.0% and 17.1% using time-drawdown methods. When comparing each analysis method between wells, higher transmissivity and storativity was calculated during the 48 hr test¹, and higher hydraulic conductivity was calculated during the 21 hr test. The 21 hr test exhibits a higher hydraulic conductivity because of the lesser saturated thickness of 26S39E35G01. Analyses curves (Appendix B and Appendix C) often did not fit late-time data (e.g., greater than 1,000 minutes [17 hours]), indicating there was minimal difference in hydraulic properties as a function of the duration of the test. The higher calculated transmissivity and storativity during the 21 hr test is likely a difference in hydraulic conductivity around the two pumping wells. The sand units that 26S39E35G02 is pumping from likely exhibit lower conductivity than the units comprised of larger clasts from which 26S39E35G01 is pumping, which impede groundwater flow toward 26S39E35G02.

The calculated transmissivities and corresponding hydraulic conductivities of the 21 hr and 48 hr tests are generally greater than the calculated transmissivities and hydraulic conductivities of the IWVWD Well 10 test. The calculated storativities of the 21 hr and 48 hr tests are generally comparable to the calculated storativities of the IWVWD Well 10 test.² The model-calibrated hydraulic conductivity and specific yield of the Indian Wells Valley Groundwater Basin presented in Pohlmann *et al.* (2020) does not show an appreciable change in the spatial distribution of these parameters between the locations of these pumping tests.

¹ An exception was the computed transmissivity of 26S39E35G02 using Theis (1935) recovery of 34,314 gpd/ft, which is significantly lower than computed transmissivity for all other wells and methods. The curve-fit for Theis (1935) recovery at 26S39E35G02 (Appendix C; Figure C-4) demonstrates an acceptable fit for most recovery data, but outliers exist that cause curve-fitting to be uncertain.

² Krieger & Stewart Inc. (1997) performed aquifer testing for the IWVWD at the IWVWD southwest well field, which is about four miles to the southwest of Quist Ranch. The calculated transmissivities of the southwest well field are generally greater than the 2020 aquifer tests; and the calculated storativities are generally comparable to the 2020 aquifer tests.

According to Pohlmann *et al.* (2020), the specific yield in this area is 0.08 and the hydraulic conductivity is categorized between 50 ft/day and 100 ft/day. It is recommended that the findings from the IWVWD Well 10 test and the Quist Ranch tests be evaluated for inclusion into Indian Wells Valley Groundwater Model updates.

Summary

Three constant-rate pumping tests were conducted in Indian Wells Valley in Ridgecrest, California, during 2020. A four-day test was performed in July 2020, and then a one-day and a two-day test were performed in November 2020. During the four-day test, a maximum drawdown of 32 ft was observed in the pumping well and maximum drawdowns of 10.65 ft and 8.55 ft were observed in monitoring wells 366 ft and 444 ft away, respectively. Aquifer testing solution methods calculated a transmissivity range between 58,750 gpd/ft and 103,425 gpd/ft, a hydraulic conductivity range between 13.83 ft/day and 24.34 ft/day, and a storativity range between 0.00040 and 0.00537. During the 21 hr test, a maximum drawdown of 6.03 ft was observed in the pumping well and maximum drawdowns of 0.80 ft and 0.05 ft were observed in monitoring wells 641 ft and 1,964 ft away, respectively. The calculated transmissivity ranged between 84,530 gpd/ft and 171,603 gpd/ft, the calculated hydraulic conductivity ranged between 66.48 ft/day and 135.0 ft/day, and calculated storativity ranged between 0.0073 and 0.0019. During the 48 hr test, a maximum drawdown of 14.19 ft was observed in the pumping well and maximum drawdowns of 0.68 ft and 0.11 ft were observed in monitoring wells 641 ft and 1,323 ft away, respectively. The calculated transmissivity ranged between 34,314 gpd/ft and 196,506 gpd/ft, the calculated hydraulic conductivity ranged between 20.39 ft/day and 116.8 ft/day, and calculated storativity ranged between 0.00076 and 0.0012.

The calculated transmissivity, hydraulic conductivity, and storativity from these aquifer tests address data gaps in the conceptual and numerical groundwater models used by the IWVGA to manage basin groundwater resources.

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Appendix A: Pumping Test Analysis Graphs for IWVWD Well 10 Four-day Constant-rate Test.

Theis (1935) Distance-Drawdown at 24 Hours

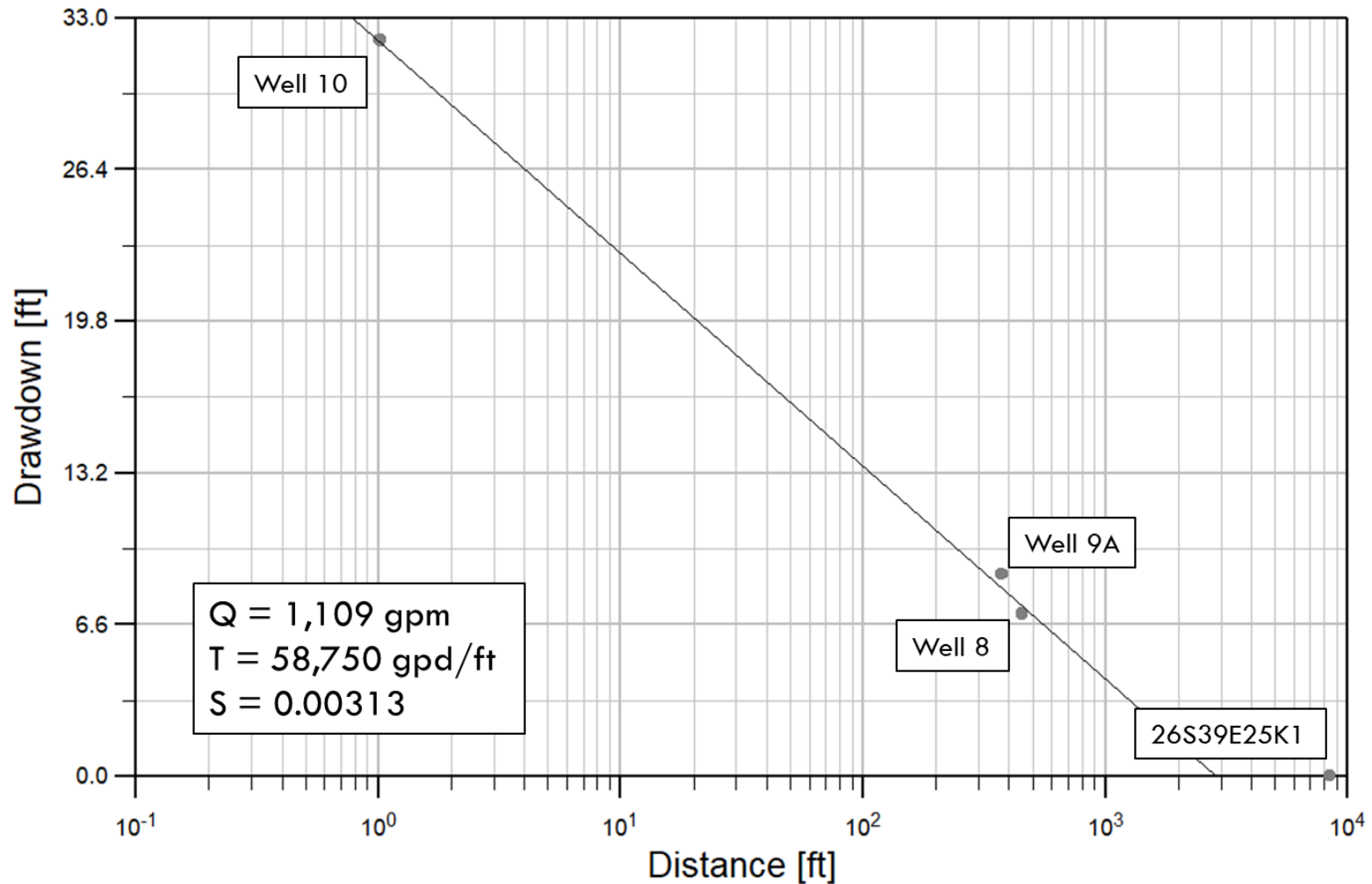


Figure A-1. Theis (1935) distance-drawdown analysis at 24 hours, IWVWD Well 10 test.

Theis (1935) Distance-Drawdown at 4 Days

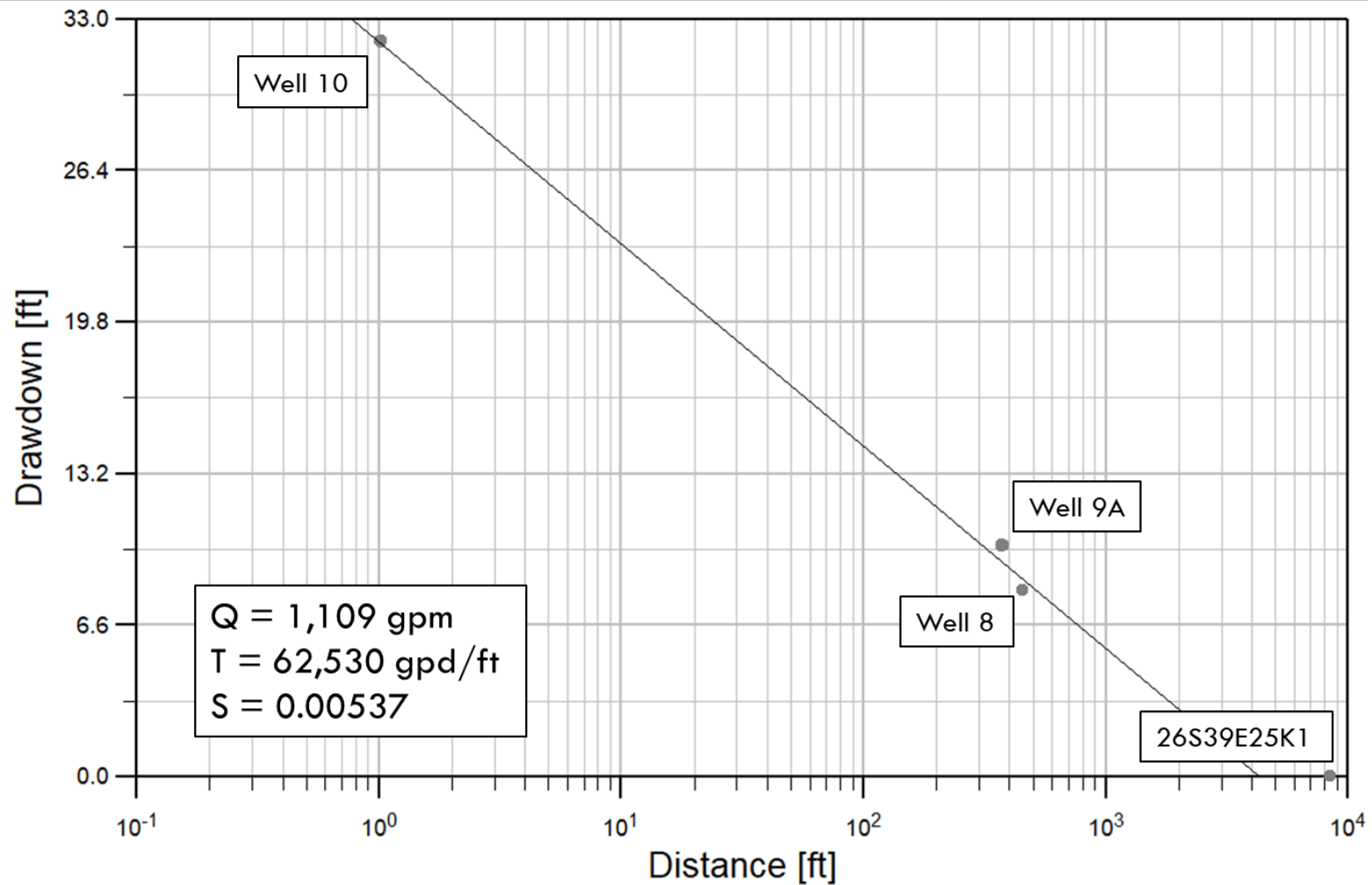


Figure A-2. Theis (1935) distance-drawdown analysis at four days, IWVWD Well 10 test.

Well 9A: Cooper and Jacob (1946) Drawdown

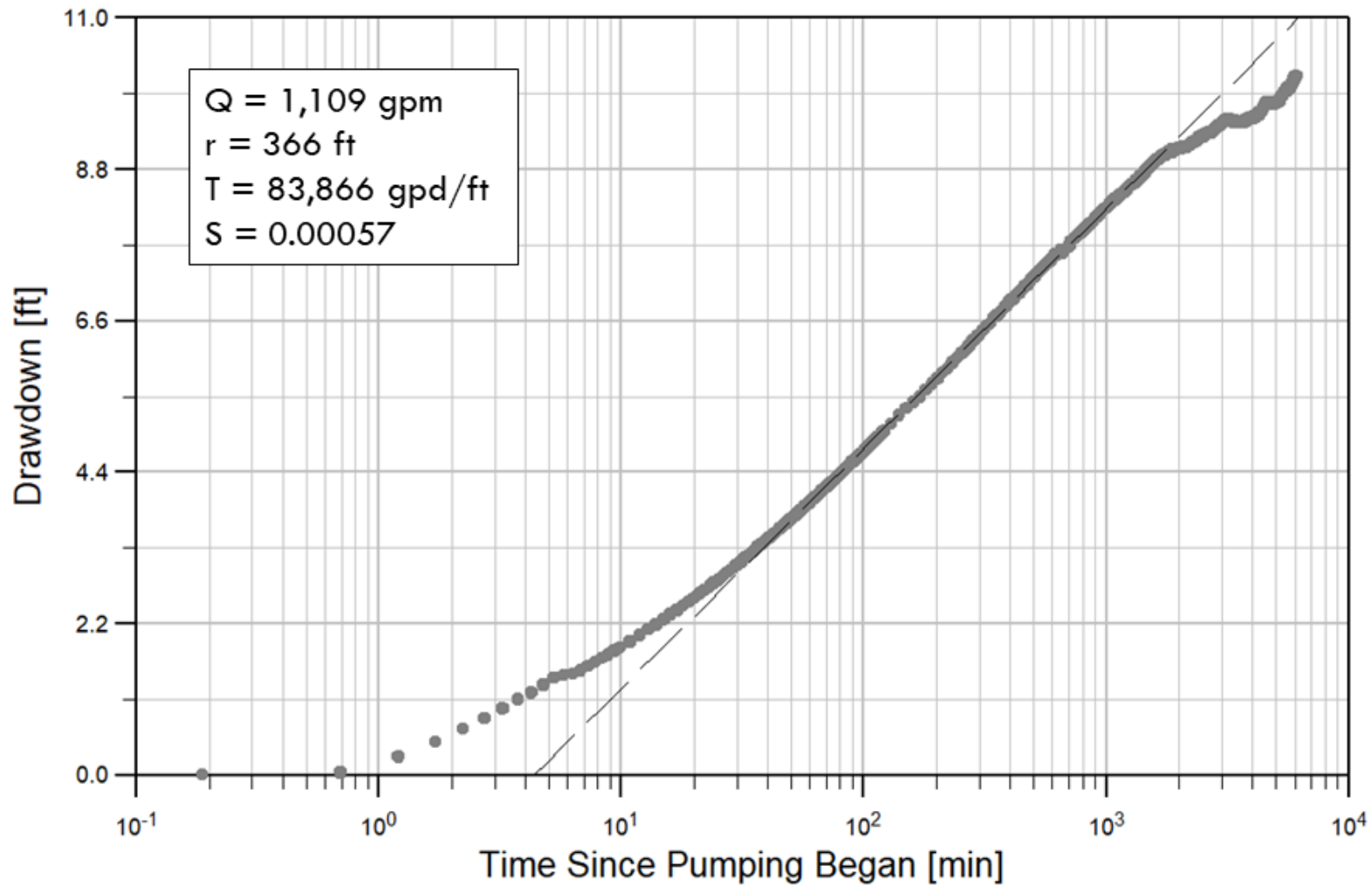


Figure A-3. Well 9A Cooper and Jacob (1946) time-drawdown analysis, IWVWD Well 10 test.

Well 8: Cooper and Jacob (1946) Drawdown

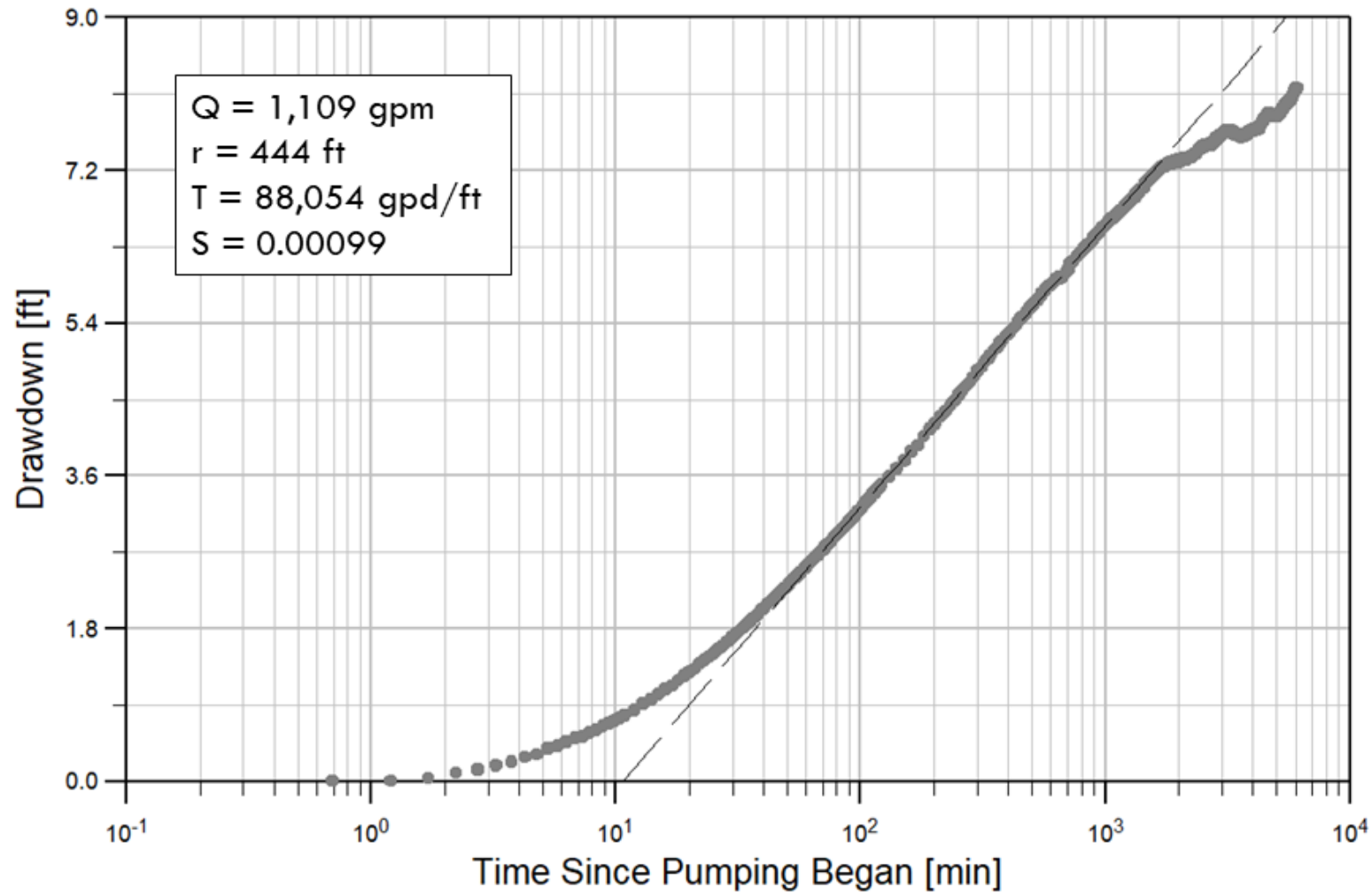


Figure A-4. Well 8 Cooper and Jacob (1946) time-drawdown analysis, IWVWD Well 10 test.

Well 9A: Cooper and Jacob (1946) Recovery

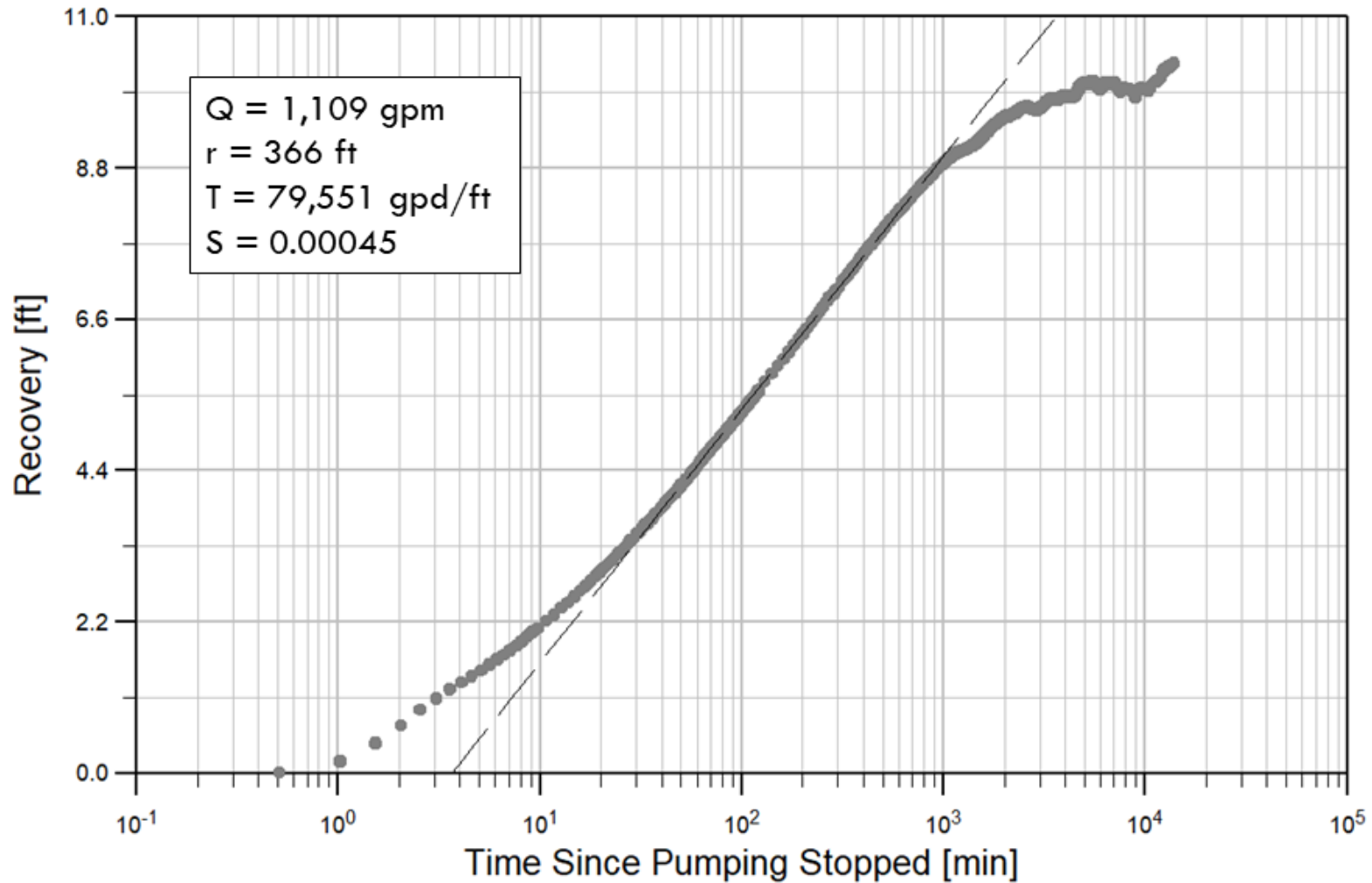


Figure A-5. Well 9A Cooper and Jacob (1946) time-recovery analysis, IWVWD Well 10 test.

Well 8: Cooper and Jacob (1946) Recovery

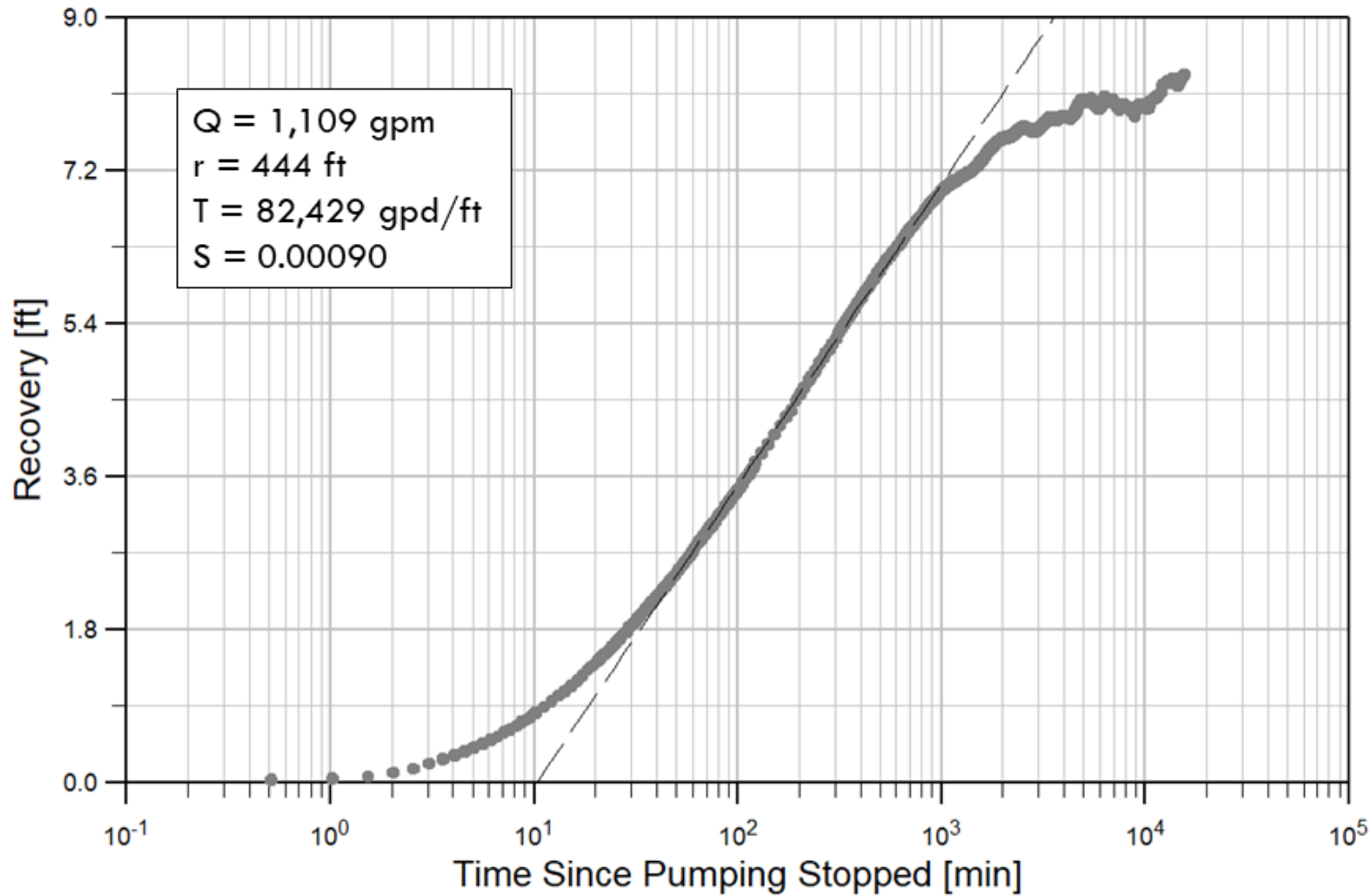


Figure A-6. Well 8 Cooper and Jacob (1946) time-recovery analysis, IWVWD Well 10 test.

Well 9A: Theis (1935) Type Curve Analysis

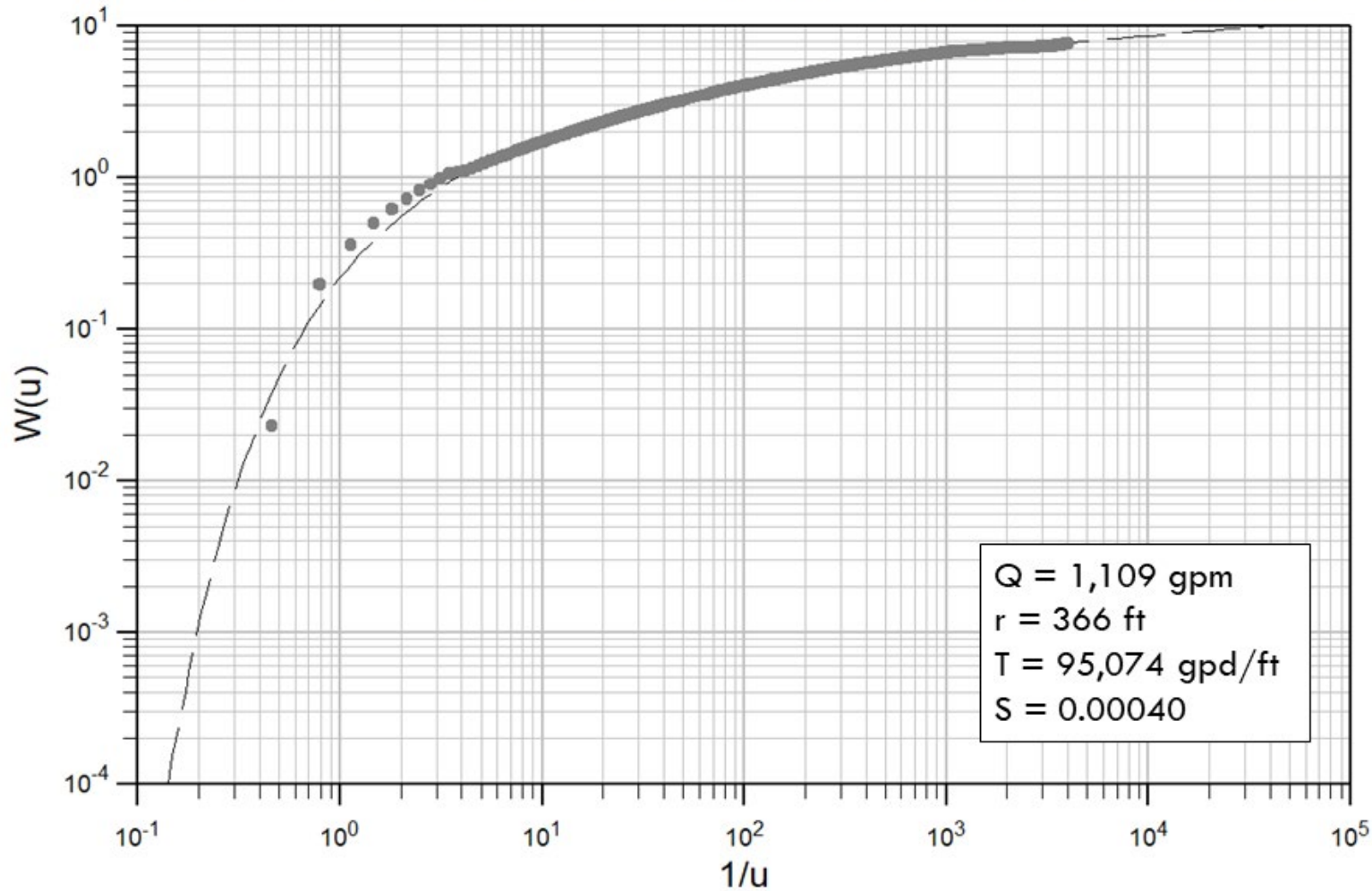


Figure A-7. Well 9A Theis (1935) type-curve analysis, IWVWD Well 10 test.

Well 8: Theis (1935) Type Curve Analysis

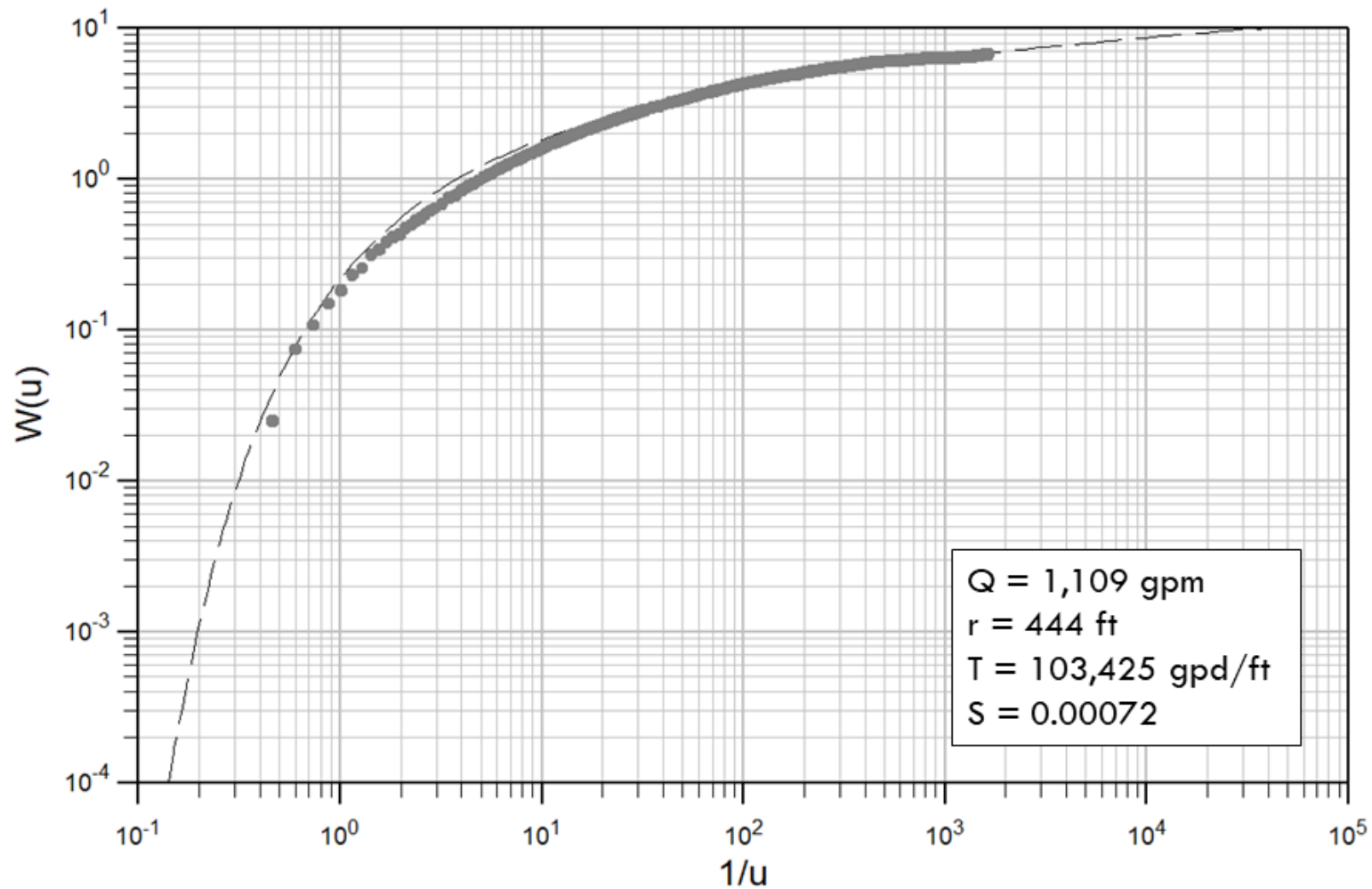


Figure A-8. Well 8 Theis (1935) type-curve analysis, IWVWD Well 10 test.

Appendix B: Pumping Test Analysis Graphs for Quist Ranch 21 hr Constant-rate Test.

Theis (1935) Distance-Drawdown

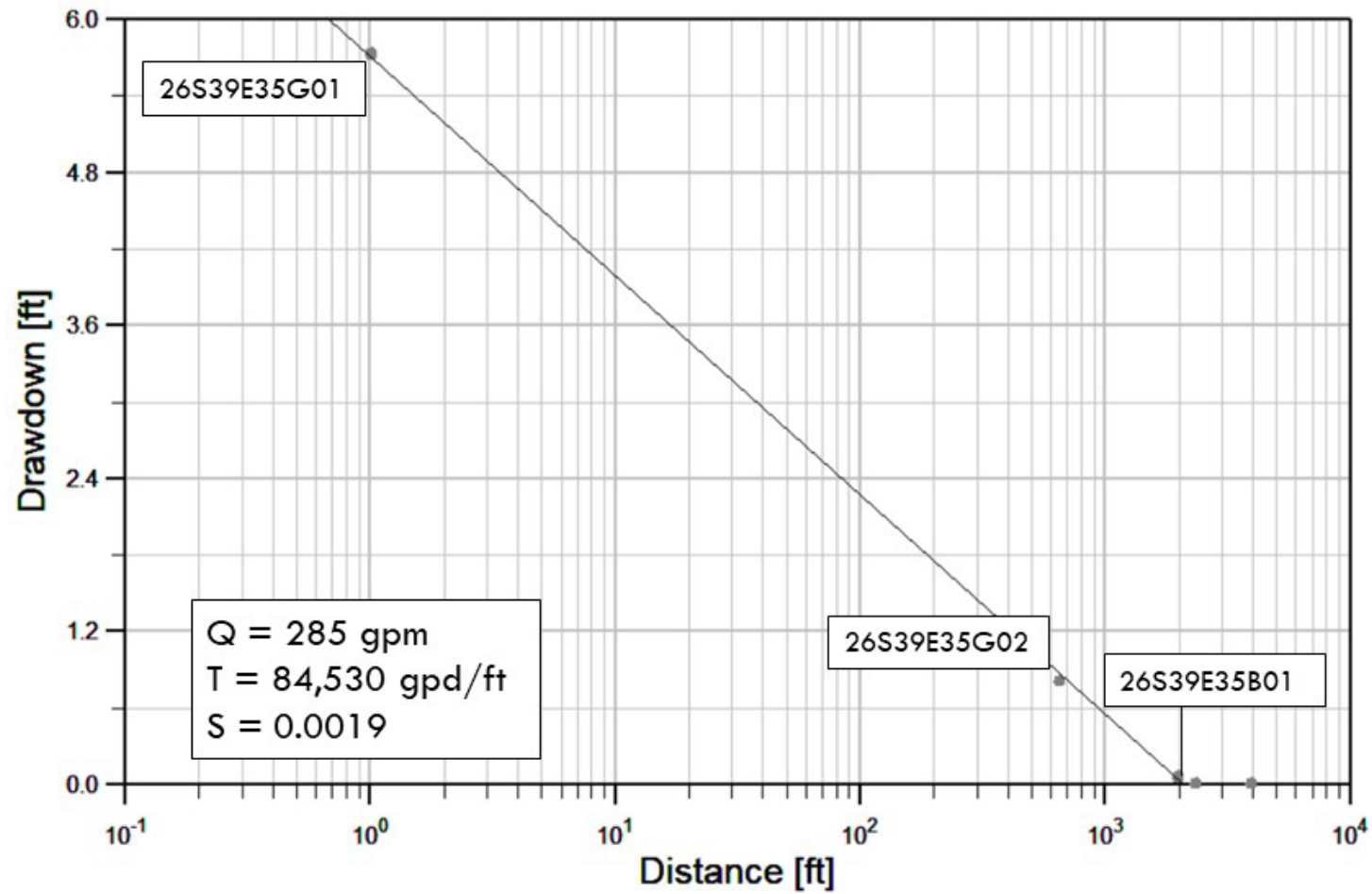


Figure B-1. Theis (1935) distance-drawdown analysis, Quist Ranch 21 hr test.

26S39E35G2: Cooper and Jacob (1946) Drawdown

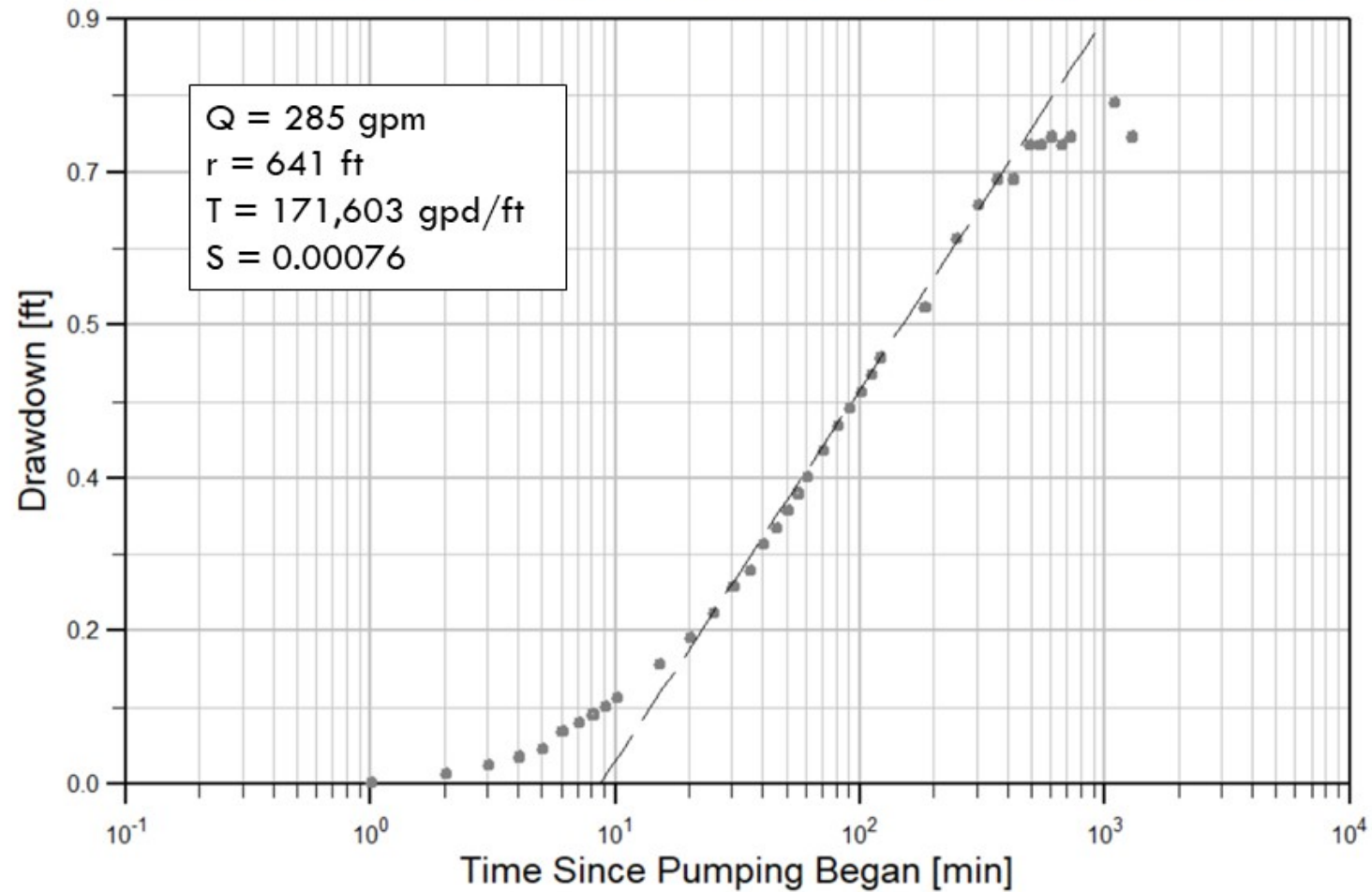


Figure B-2. 26S39E35G02 Cooper and Jacob (1946) time-drawdown analysis, Quist Ranch 21 hr test.

26S39E35G2: Cooper and Jacob (1946) Recovery

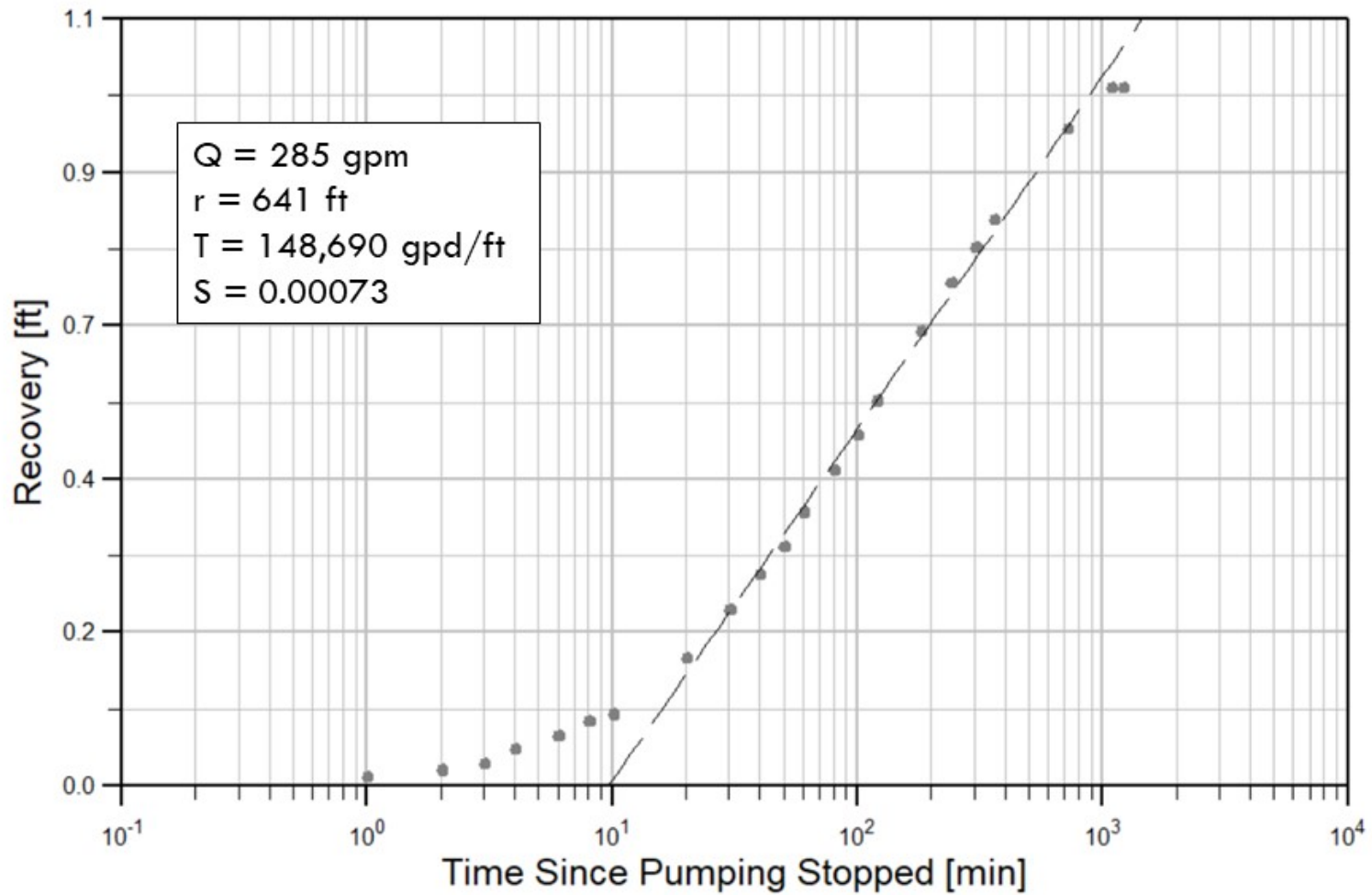


Figure B-3. 26S39E35G02 Cooper and Jacob (1946) time-recovery analysis, Quist Ranch 21 hr test.

26S39E35G1:Theis (1935) Time-Recovery

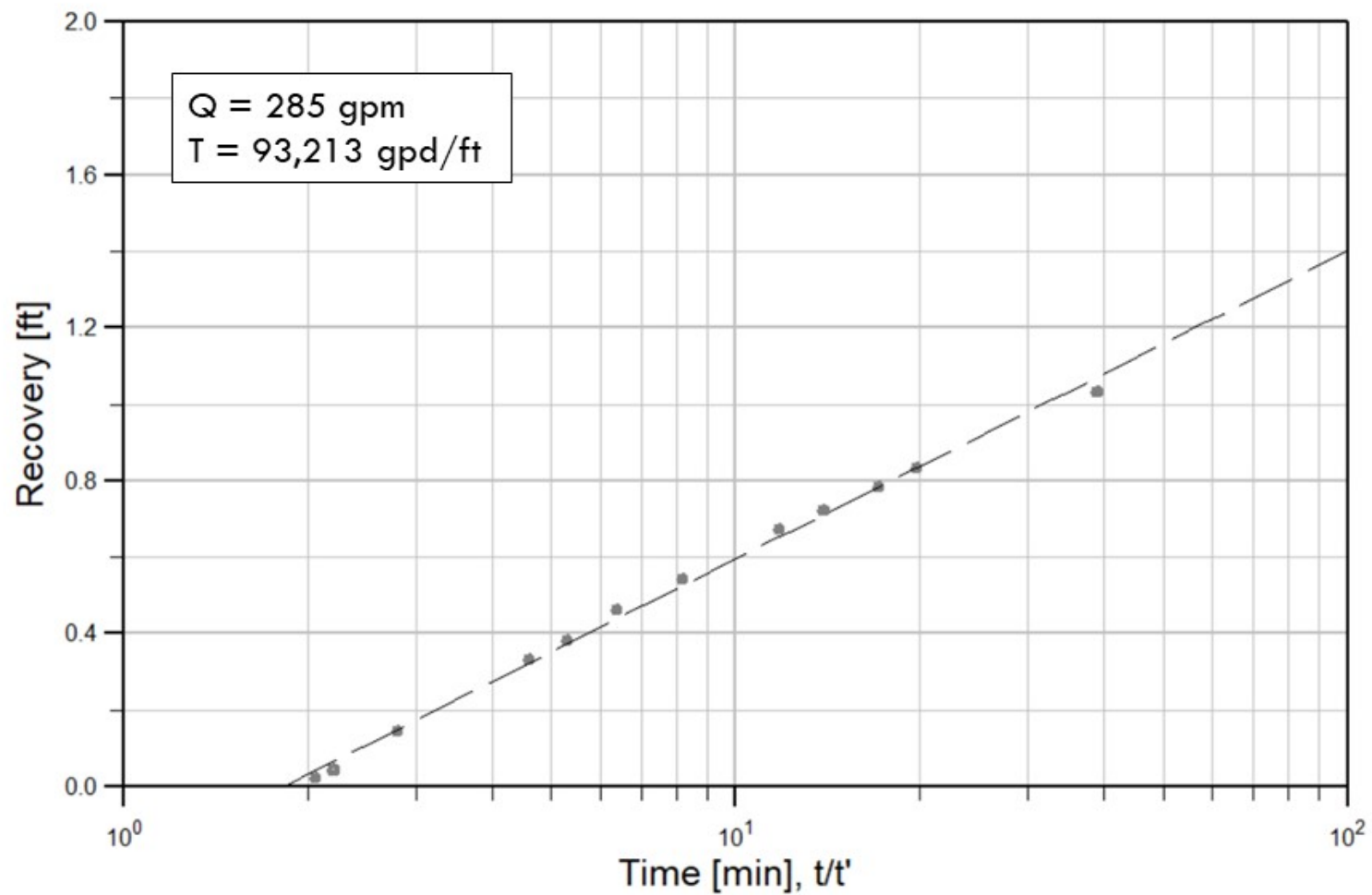


Figure B-4. 26S39E35G01 Theis (1935) time-recovery analysis, Quist Ranch 21 hr test.

26S39E35G2: Theis (1935) Type Curve Analysis

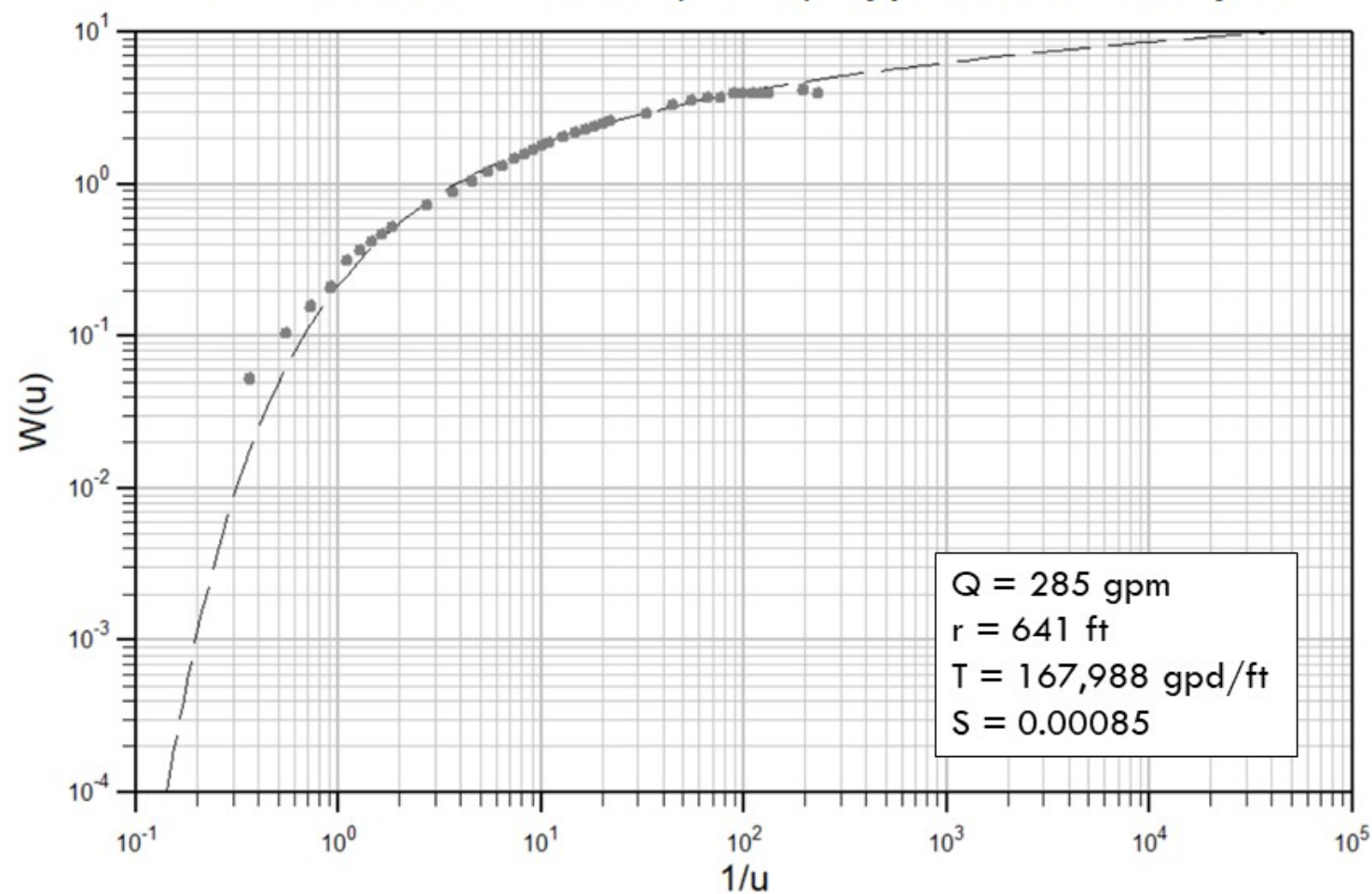


Figure B-5. 26S39E35G02 Theis (1935) type-curve analysis, Quist Ranch 21 hr test.

Appendix C: Pumping Test Analysis Graphs for Quist Ranch 48 hr Constant-rate Test.

Theis (1935) Distance-Drawdown

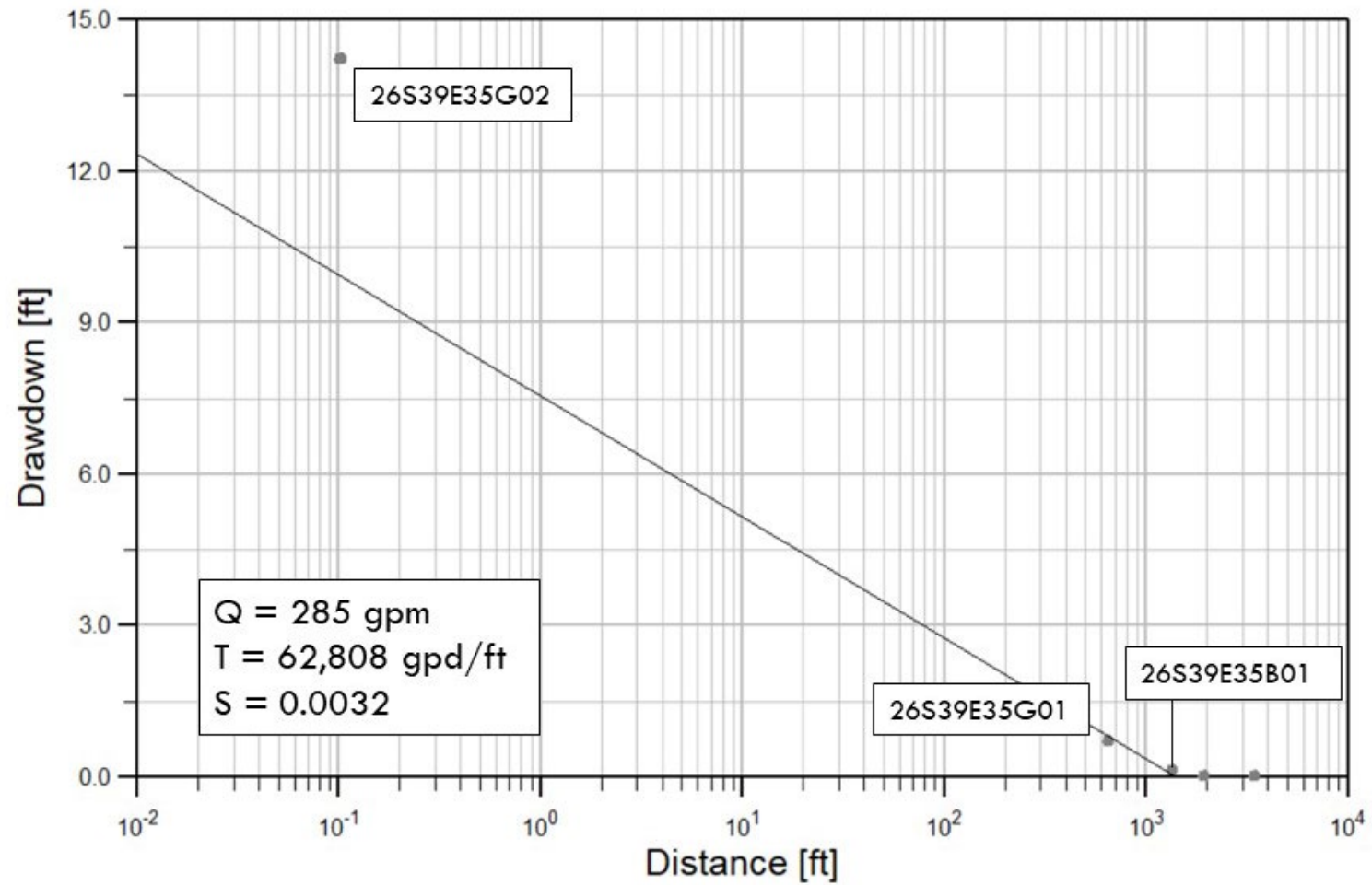


Figure C-1. Theis (1935) distance-drawdown analysis, Quist Ranch 48 hr test.

26S39E35G1: Cooper and Jacob (1946) Drawdown

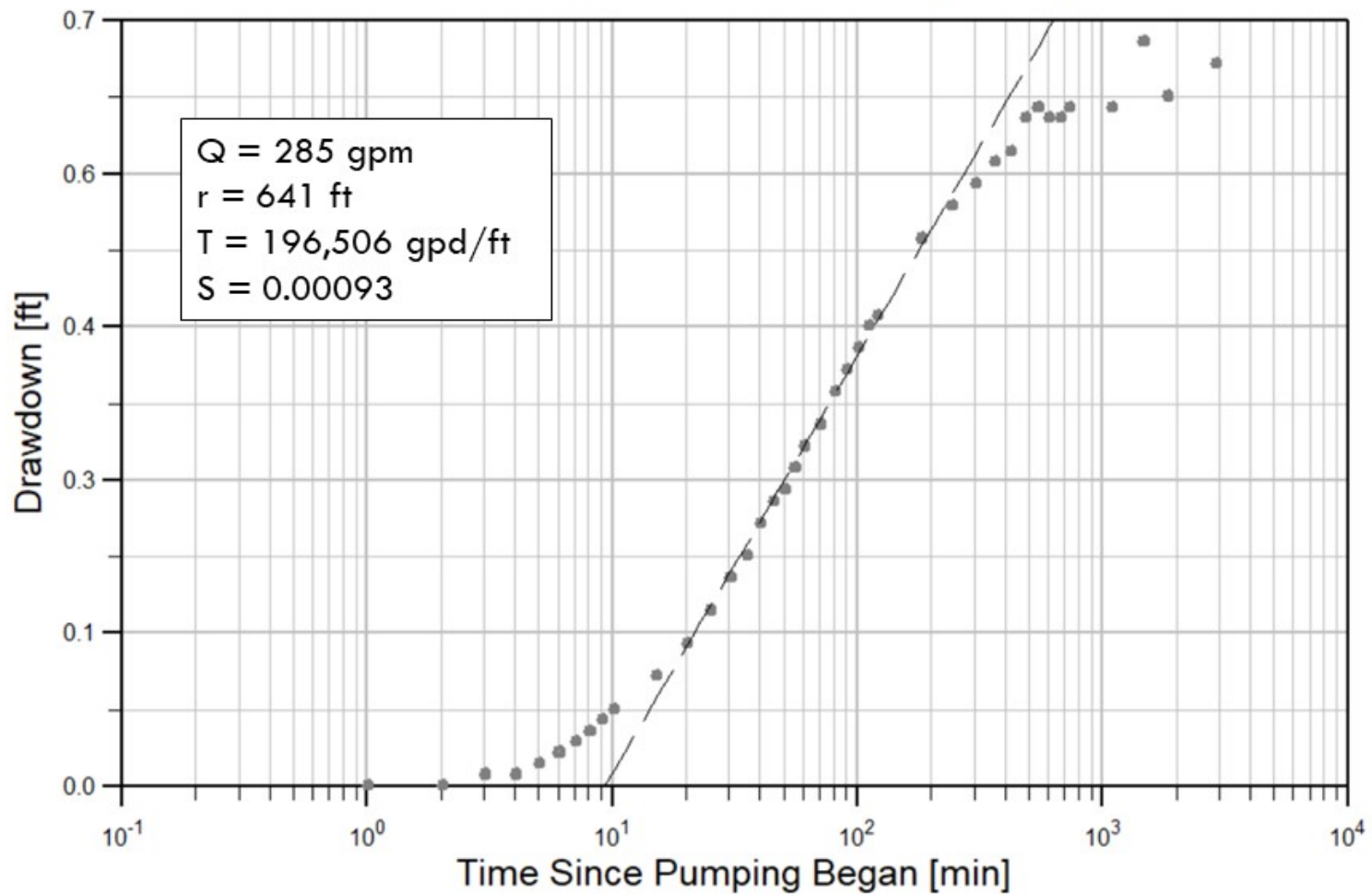


Figure C-2. 26S39E35G01 Cooper and Jacob (1946) time-drawdown analysis, Quist Ranch 48 hr test.

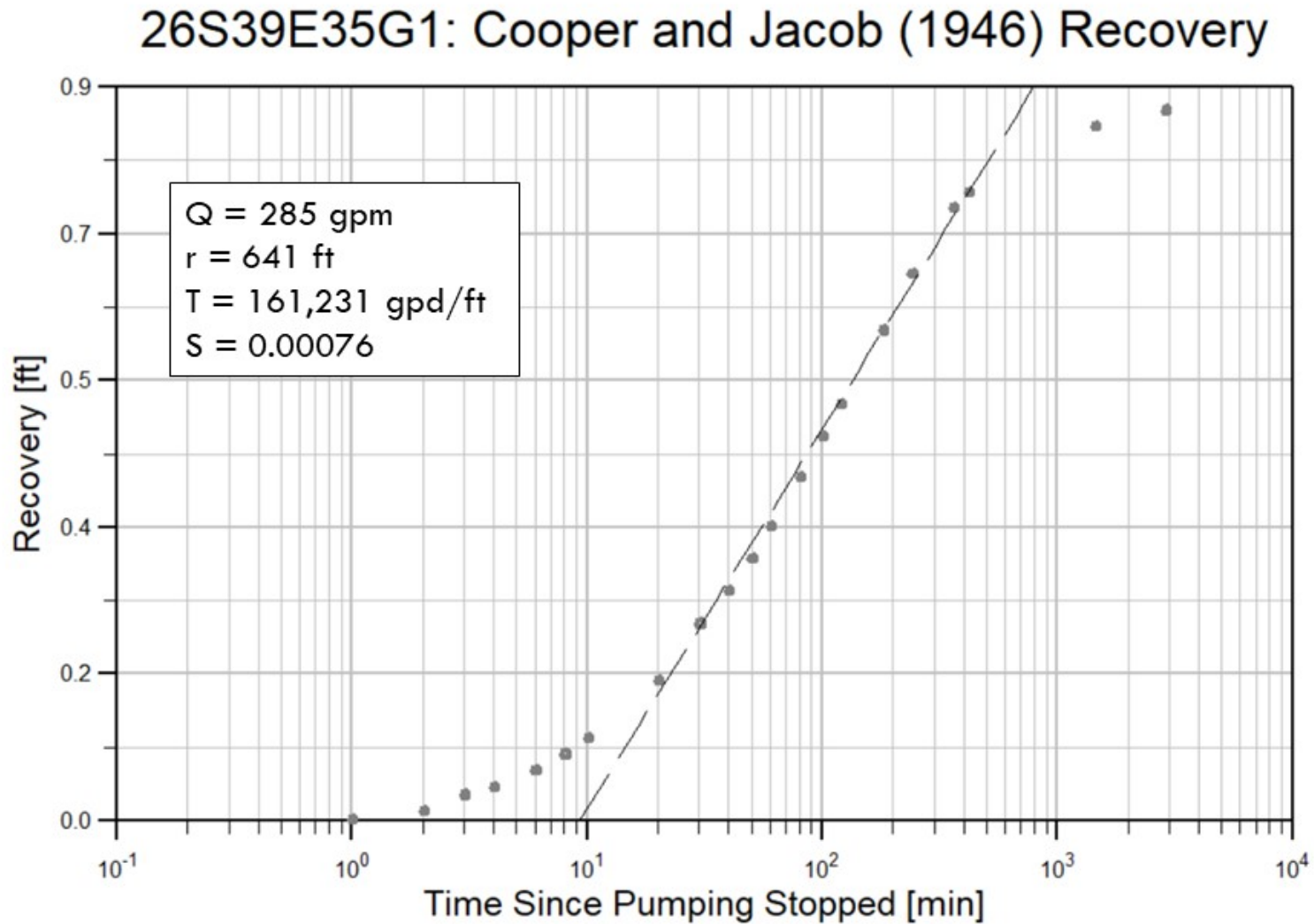


Figure C-3. 26S39E35G01 Cooper and Jacob (1946) time-recovery analysis, Quist Ranch 48 hr test.

26S39E35G2:Theis (1935) Time-Recovery

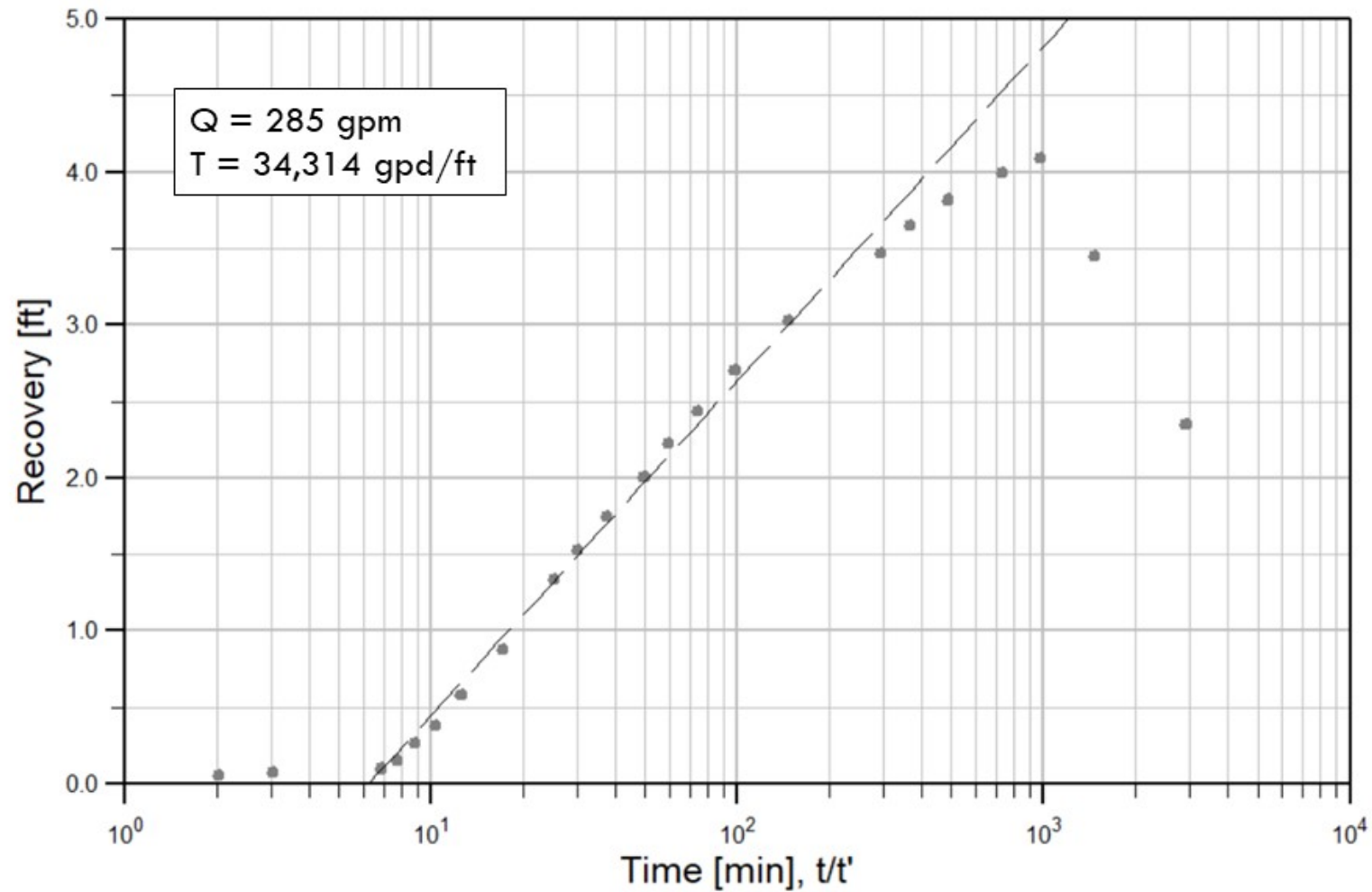


Figure C-4. 26S39E35G02 Theis (1935) time-recovery analysis, Quist Ranch 48 hr test.

26S39E35G1: Theis (1935) Type Curve Analysis

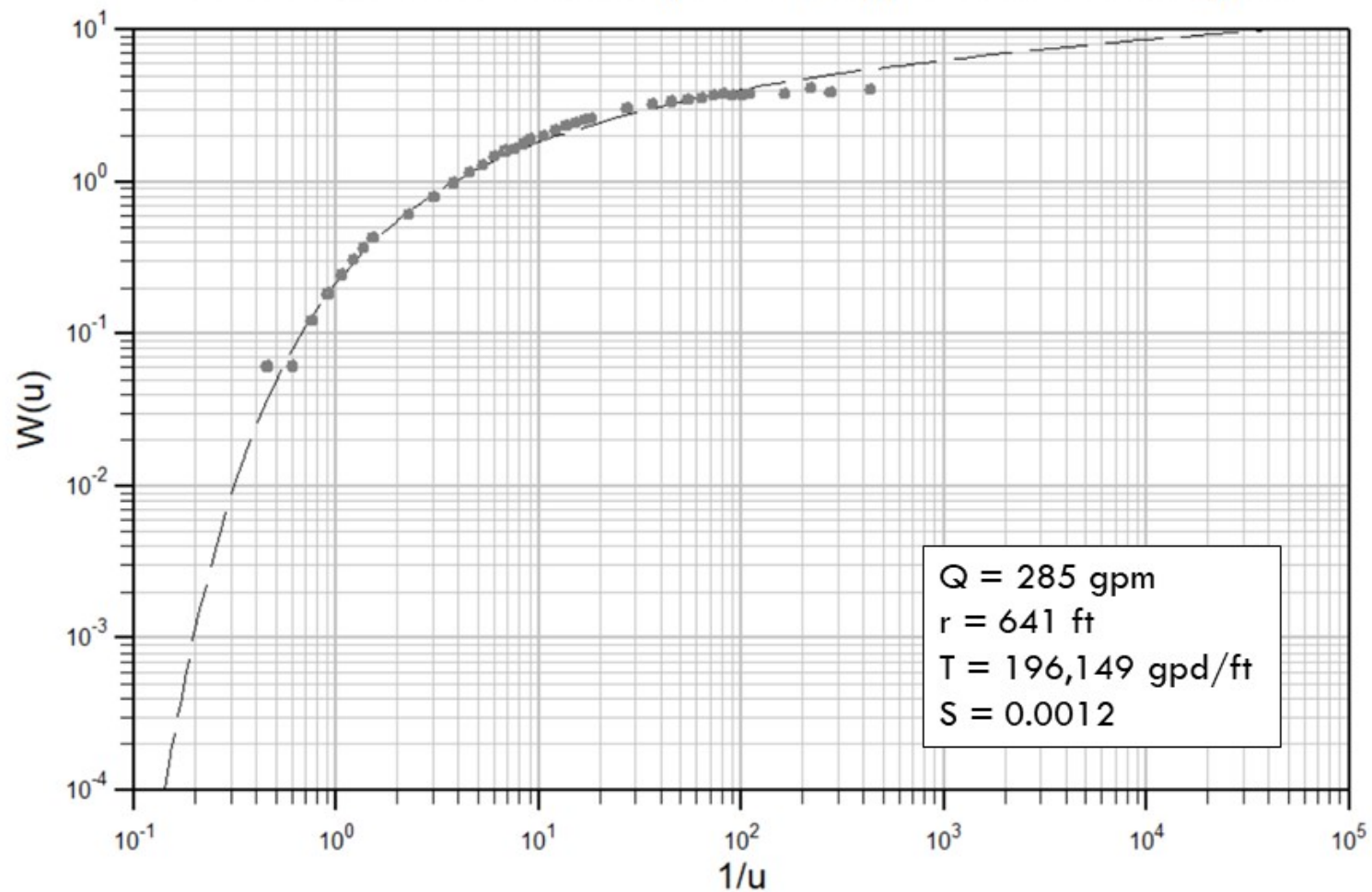


Figure C-5. 26S39E35G01 Theis (1935) type-curve analysis, Quist Ranch 48 hr test.