AQUIFER PUMPING TEST OF CAMROSA WATER DISTRICT "UNIVERSITY" WELL

EVALUATION OF TEST RESULTS

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CONTAINS CONFIDENTIAL WELL INFORMATION

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Executive Summary

This technical report describes results of aquifer pumping tests conducted using Camrosa Water District's "University" well (1N/21W-14B3). Two tests were conducted in August and November 2010, including both pumping and recovery water level monitoring. Water levels were recorded in the pumping well and in six additional wells in the general area. Three of the wells also provided a continuous record of water temperature. Water quality samples were available from weekly monitoring of the pumping well.

Aquifer response to pumping exhibits a range of characteristics, with elements of confined and "leaky" aquifer responses, resulting from complex geology and a test area location that is relatively close to the bedrock mountain front. Combined results of step-drawdown test and a 48-hour constant-rate test suggest that a long-term production rate of approximately 1,000 gpm is possible for the University well. The current project design production rate of ~870 gpm would produce drawdown in the well to a level approximately 95 feet above the existing pump inlet elevation, providing a significant operating buffer in the pumping water level.

Long-term responses to sustained well production may be influenced by untested factors, such as drawdown in proximity to the mountain front, and the effects of other local production (for agricultural irrigation). Combined with the complex geology of the area, these considerations provide strong encouragement for diligent long-term monitoring of water levels and water quality in the area, to support a management strategy for groundwater production from the University well.

Pumping Test Program Overview

Aquifer testing was conducted in two phases, to provide a combination of data about the production well, the aquifers that provide groundwater to it, and how the well is hydraulically connected with nearby observation wells. The program consisted of:

1. A short-term step-test. This test was eight hours long, with four two-hour rate steps at 400, 600, 800 and 1,210 gpm. Pre- and post-production water level monitoring occurred in the pumping well and surrounding monitoring wells.
2. A medium-term constant-rate test. This 48-hour test was conducted at a constant production rate of 1,000 gpm, and included pre-and post-production water level monitoring.

Pre-production monitoring occurred for at least several hours prior to production, to establish baseline water levels before pumping. For both test phases, the production well was idle for at least 24 hours prior to the test, and nearby agricultural production was not observed. Post-production recovery water level monitoring was conducted over several days following each of the two production tests.

Water level monitoring was conducted by an air-line device in the production well and downhole pressure transducers in three of the monitoring wells, all of which provided effectively continuous water level records for the duration of each test. The three monitoring wells equipped with downhole transducers also provided a continuous record of water temperature during the two tests. Three other nearby wells were monitored for water levels using a manual tape.

Discharge from all the tests was piped to the District's wastewater system. This method of discharge was especially useful for the tests because it removed discharge from the area of the pumping test and correspondingly avoided potential impacts of increased infiltration to shallow aquifers during the test. Both tests were conducted on days without rainfall.

Hydrogeological Environment

Complex aquifer characteristics are expected in the study area because of:

- The study area location at the margin of the basin, where depositional characteristics of the aquifer's sedimentary layers are known to be heterogeneous and variable over both vertical and horizontal distances,
- Lithologic logs from the producing well, several of the monitoring wells and surrounding wells, all of which suggest highly variable stratigraphy in the area, and
- Variable bedrock "basement" depth below the sedimentary layers which, together with the proximity to the bedrock exposures of Round Mountain and the bedrock areas east of the study area, define an irregular geometry of producing layers, including probable truncations and disruptions of water-bearing units, particularly in the lowermost portion of the University well's perforated interval.

The University well and many of the monitoring wells used in the pumping tests can be seen in Figure 1 (from Brown, 2005). In this figure, the pumping well is noted by its short well number, 14B3. Of the three cross-section lines in Figure 1, only B-B' is reproduced in this report. Section B-B' (Figure 2) is a schematic cross-section (with vertical exaggeration) that illustrates the potential complications due to the relative proximity of the bedrock mountain front and the presence of a subsurface bedrock escarpment.

The section B-B' includes well information for 14B2, which was used as a monitoring well for the pumping tests and is close to 14B3. Wells 14B2 and 14B3 have very similar top and bottom perforation elevations.

Lithologic logs from many wells near the University well show significant clay layers at various depths; prominent zones of clay, or stratigraphic packages with dominant clay interbeds are noted with "c" in Figure 2. Even over the relatively short horizontal distances between these wells, significant clay layers are not easily correlated between wells. This finding may partly reflect the inherent inaccuracies and generalities of many well logs, but certainly also reflects a complicated stratigraphy in which local layers of clay or sand are interleaved and laterally discontinuous.

The result of this stratigraphy is an aquifer which, for the University well, produced mixed signatures of confined and semi-confined conditions during the aquifer tests. The University well penetrates the two principal aquifer packages recognized in the CSUCI study area: the Upper Aquifer System of the Pleasant Valley and Oxnard Plain Basins, and the overlying "Shallow" aquifers. Much of the shallow system is above the University well's top perforations, but the discontinuous stratigraphy may allow some vertical hydraulic connection between these units.

The lateral variation in aquifer units can help to create an environment where aquifer confinement can exist on a local scale, but more complex aquifer responses ("leaky" or semi-confined conditions) may exist over longer time periods or greater distances.

For the University well, the lowermost perforations may be associated with bedrock or a structurally-disrupted zone of mixed bedrock and sediment, such that a portion of production to the well may even come from fracture flow associated with bedrock structures at the subsurface bedrock-alluvial interface.

Wells Utilized in the Study

Using nomenclature preserved from previous hospital/university ownership of area wells, well 14B3 is shown in Figure 3 as "#4", and other wells are similarly shown by their former university system number. For convenience, the numbering used in Figure 3 will be retained for the discussion and display of well water level responses during the pumping tests.

Well #4 is equipped with a pump and was used as the production well for both tests, with all other numbered wells in Figure 3 utilized as observation wells during the tests.

Well Construction

A simplified cross-section drawn along Lewis Road from well #1 to well #5 (with wells #6 and 7 projected onto the section) illustrates the different depths and perforated intervals of wells used in the aquifer analysis (Figure 4).

The University test pumping well (#4) has a perforated interval over 600 feet long, beginning at 280 feet depth. Monitoring well #2, located 400 feet from the pumping well, has a very similar perforated interval, with exception of some blank portions in the middle of the perforated section. Top-of-perforation elevations are similar also in monitoring wells #1 and #3, but neither of these two wells produces from aquifer levels as deep as the pumping well and monitoring well #2.

Monitoring well #6 is relatively shallow, with only a short, shallow perforation. Its background water levels and test responses show these shallow aquifers maintain a different water level signature, but are also in limited hydraulic communication with the deeper units perforated in the other monitoring wells.

Pumping Tests

The step-drawdown and constant-rate tests were conducted using the District's installed pump in the University well. An air line with a data logging manifold was used to determine water levels in this well at 15-second intervals. The two nearest monitoring wells -- #2 and #3 -- were equipped with downhole pressure transducers with wellhead data loggers, providing 30-second interval water level (and temperature) measurements. During the constant-rate test, well #1 was also equipped with a downhole transducer and recorded data at 30-second intervals.

Given the aquifer complexity and likely conditions of vertical leakance, barometric adjustments were not considered necessary. However, some environmental influences can be seen in the pumping well water levels, particularly during the step-test, probably due to solar heating of wellhead equipment associated with the air line.

Step-Drawdown Test

An eight-hour step test was conducted beginning the morning of August 31, 2010. Very stable background water levels were recorded during the half hour prior to pumping. Of the numbered wells utilized in this study (Figure 3), only well #4 is equipped with a pump, and other area agricultural irrigation supply wells were not known to be active during the test. Discharge from the test was to a pipe, with all discharge water delivered to the District's nearby treatment facility.

Pre-production, static water levels exist in a range of about 20 feet elevation -- from about sea level in #4, to about -20' in #3. Well #5, which is believed to be a shallow well based on its previous use and very similar water levels to #6 (Figure 4), has water levels more than 30 feet higher than any of the other wells during this test.

Responses to pumping stresses, and post-production recovery of water levels are readily observed in all but one of the wells (during the step-test, well #6 did not yield reliable water level data); see Figure 5. The environmental degradation of the pumping well water level measurements can be observed in the following two days of recovery data, and is consistent with influences from solar heating of the data logging device (Figure 6). The magnitude of the artificial signal in the two recovery days (approximately 10' influence, September 1 and 2) suggest that the pumping water levels observed during the daytime step-test may be subject to similar error. This condition increases the value of the monitoring data collected from the other wells, which were measured with different instruments that are immune to this potential problem.

For the step-test, the most useful data are from wells #2, #3 and #4. Well #2 is 400' southwest of the University well, and well #3 is half-way between them (Figures 3 and 4). Temperature profiles for wells #2 and #3 show a very small but readily observed cooling of produced water during the pumping portion of the test, with rebound that strongly mimics water level recovery in the same wells (Figure 7).

At the end of the four production increments of 400, 600, 800 and 1,210 gpm (each with a duration of two hours), drawdown in the pumping well reached a maximum of 49 feet. Two hundred feet away in well #3, maximum drawdown was 12'. At four hundred feet distance in well #2, maximum drawdown was 11' (Figure 8). In the pumping well, maximum incremental drawdowns for each of the pumping steps provides a simple opportunity to estimate specific capacity (Q/s, where Q is production rate and s is drawdown in the well). Normally, specific capacity decreases with lowering water levels and higher production rates, but in this case, all three higher production rates produce $Q/s \cong 25$ gpm/ft (see inset table in Figure 9). The uniform result across all three production intervals may result partly from meteorological effects in the pumping well water levels, and the resulting distribution of specific capacity values prohibits methods to estimate coefficients for laminar and turbulent losses that are sometimes otherwise possible for near-field analysis.

The spike in water levels shortly after the start of the 1,210 gpm interval corresponds with a very brief period of non-pumping, just long enough for the well water levels to surge back up the well column before the pump restarted.

Figures 10 and 11 show drawdown and recovery curves for monitoring wells #2 and #3. Well #2, which is farther from the pumping well, and includes perforations at deeper units such as those penetrated by the pumping well, displays relatively smooth, progressive drawdown increases with each increase in production amount. Well #3 behaves similarly, but with more pronounced responses, as expected from its closer location to pumping well #4. The short-term "surge" in water levels associated with the brief cessation in pumping can be seen in the well #2 drawdown curve, but is only a very small signal at well #3.

Recovery data from monitoring wells #2 and #3 were evaluated using methods of Cooper-Jacob (1946), which assumes confined conditions without leakage from overlying or underlying units, and Hantush (1960), which accommodates leakage to the producing aquifer of the test. Both methods require simplifying assumptions about homogeneity of aquifer properties and flow, conditions that clearly generalize the complex conditions of basin-margin geology and aquifer flow that is governed by local, lenticular aquifer units and may even include a component of fracture flow. Nonetheless, such methods can provide a guide for investigation and delineation of aquifer properties, and a straightforward, initial estimate of aquifer transmissivity is provided by the Cooper-Jacob method, in which:

$$T = 264 * Q/\Delta s \qquad (1)$$

where T is aquifer transmissivity (gpd/ft), Q is production rate (gpm) and Δs is the change in drawdown over one log cycle (ft). This approximation of transmissivity results in values of 31,000 to 45,000 gpd/ft (Figure 11). This estimated range in T may overestimate true bulk aquifer transmissivity but is consistent with aquifer materials such as fine sand.

Constant-Rate Production Test

A 48-hour constant-rate test was conducted beginning the morning of November 16, 2010. Data acquisition methods were very similar to the step-drawdown test, except the environmental influences on well #4 (pumping well) water levels were greatly diminished by on-site shading of equipment at the pumping well. In addition, a pressure transducer was installed in observation well #1 for continuous recording of water levels (and temperature).

Figure 12 shows water level data for all wells during the test. The production portion of the test was conducted at a constant rate of 1,000 gpm, sustained for 48 hours. A more detailed view of the continuous-record data is provided in Figure 13. Temperature data is also included in Figure 13, showing the small but distinct temperature changes that mirror water level drawdown and recovery during the test period. Water levels in all wells do not completely stabilize during the test but, as with the step-test, are adequate for simple approximations of aquifer characteristics.

Following the method of equation (1), aquifer transmissivity is calculated to be T = 37,000 gpd/ft based on drawdown in the pumping well during the constant-rate test, and T = 24,000 gpd/ft based on recovery of water levels in the pumping well after cessation of production (Figures 14 and 15, respectively). Observation wells yield similar results, with T between 32,000 and 50,000 gpd/ft from data acquired during pumping (Figure 16). A similar range of transmissivity values is derived from observation well recovery data (Figures 17 and 18). For clarity and discussion the linear lines of fit are omitted from Figures 17 and 18; these two figures provide two views of the same data, both with residual drawdown on the vertical axis.

The range of T values derived from the production and observation well data largely reflect the difference between a geologically complex area and estimation methods that assume much more uniform aquifer properties. In this context, differences between well responses can be useful even if bulk aquifer characteristics are only able to be approximated. For example, In recovery data from the constant-rate test (e.g., Figure 17), wells #2 and #3 display considerable slope variability during the main period of water level recovery, again reflecting real-world complexities of the aquifer, but with well #3 indicating higher T. Well #3 has only a relatively short perforated interval, coincident with the upper perforated portion of well #2 (Figure 4), suggesting aquifer units in the higher portion of the perforated zone of the University well may be more hydraulically conductive than deeper zones.

Water level responses to pumping also show the possibility of a hybrid aquifer condition, in which local confined conditions evolve during well production to include a delayed yield from leaky units and potentially even an unconfined component during extended periods of pumping (Figure 19). This is one reason that estimates of storativity from the aquifer test data are not considered adequately reliable.

As an example of hybrid aquifer condition response to pumping, consider the shallow aquifer water levels recorded in wells #5 and #6 (Figure 12). These levels are distinctly different from aquifer water levels associated with the other wells -- a difference that cannot be attributed to ground surface elevation differences between the wells or other external characteristics. These shallow aquifers are at least are in some hydraulic communication with various shallow unconfined aquifer units (Brown, 2005). In contrast, the deeper aquifer units will have some degree of confinement, based on known geology at the wells and on comparable aquifer horizons of the Upper Aquifer System in adjacent portions of the Oxnard Plain Basin (Hanson et al., 2003). But in the study area, adjacent to the bedrock boundary of the mountain front, pumping from the deeper horizons in well #4 still produces a small but noticeable response in water levels in shallow wells #5 and #6 (Figure 12). In aggregate, the data for the aquifer horizons produced by well #4 suggest an aquifer system with at least locally confined conditions, some leaky confined aquifer units and, over time also some hydraulic communication with overlying partially-confined or unconfined units.

Using the method of Cooper-Jacob (1946), observation well responses can be used to estimate the steady-rate cone of depression limit (r_o) using a distance-drawdown analysis (Figure 20). The method is an approximation, but any range of reasonable r_o values derived from the graph would suggest that the University well's sphere of influence will extend to include more heterogeneous stratigraphy (and associated aquifer characteristics) toward the east and bedrock boundaries, potentially including strong hydraulic conductivity contrasts associated with bedrock-alluvial contacts (for comparison, see the distances shown in Figure 2).

Well Yield

Based on the test pumping results, drawdown is estimated for a range of University well pumping rates (Figure 21). At a rate of 1,000 gpm, total drawdown of 56 feet is predicted after 100 days (this period spans two log cycles of time for estimated responses and is a standard guide for long-term effects). With starting water level elevation of -5 ft msl and a ground surface elevation of 49 ft, in this scenario pumping water levels would be about 110 feet below surface, or about 90 feet above the existing pump inlet elevation (the inlet elevation is 198 feet below ground surface). Figure 21 shows predicted drawdown for other production amounts also, including the current project design production rate of approximately 870 gpm. At the design pumping rate, long-term production well drawdown is predicted to be 49 feet, with resulting pumping water levels 95 feet above the inlet elevation, providing a substantial operating buffer in pumping levels, and allowing for considerable differences between actual long-term pumping responses and those predicted from the pumping tests.

The predicted long-term production levels are simplifications that may overestimate drawdown if leaky conditions are prevalent and if regional hydraulic connection with shallow aquifer horizons is pronounced. Conversely, long-term sustained production may produce aquifer effects that extend to bedrock or other basin-margin geological boundaries that serve to limit recharge, correspondingly increasing production well drawdown. Such effects have not been tested by the 48-hour constant-rate study and create uncertainty for well yield predictions. In light of such uncertainty, a careful monitoring program will need to be developed in association with any long-term production of the University well.

Temperature

Temperature responses to pumping are readily evident in observation wells #1, #2 and #3 during both tests (#1 only during the constant-rate test), and mirror the drawdown and recovery behavior of water levels. Production is associated with cooler water flux through the observation wells. The 200-foot set-depth of the transducers would suggest these cooler waters are migrating through the observation points from relatively higher stratigraphic horizons, consistent also with general increasing temperature with depth in large basins. However, the lack of temperature data from other wells in the Pleasant Valley basin makes such conclusions generally supportive of the aquifer analysis but not conclusive of groundwater migration paths.

Water Quality

Water quality samples were acquired from the University well weekly for months prior to the pumping tests and during the general test periods. During this period water quality varied little, with consistently high chloride (~290 mg/l), sulfate (~650 mg/l) and TDS (~1,750 mg/l), as has been historically typical for this well. Water quality samples were not able to be collected at more frequent intervals during the test pumping and recovery periods, so short-term changes that may have been associated with well production are not documented.

Summary

Two aquifer pumping tests were conducted using Camrosa Water District's "University" well (1N/21W-14B3). The tests were conducted in August and November 2010, and included a step-drawdown test and a constant-rate test. Both tests included pre- and post production water level monitoring in the production well and six observation wells. The production well and three observation wells were fitted with continuous-recording devices for water level measurements. Three of the wells also provided a continuous record of water temperature. Water quality samples were available from weekly monitoring of the pumping well.

Aquifer response to pumping exhibits a wide range of characteristics, with elements of confined production (transmissivity ≅ 35,000 gpd/ft), "leaky" aquifer responses and delayed recharge, and hydraulic connection with overlying strata that are partially unconfined. Collectively, these well responses suggest both that the constant-rate production rate of 1,000 gpm and the project design pumping rate of 870 gpm could be sustained as long-term production rates, with a production water level operating buffer of 90 to 95 feet above the existing pump inlet elevation. An estimate of the well specific capacity from the step-test is 25 gpm/ft at an 800-1,000 gpm production rate range.

Geologic complexity associated with the aquifers, together with the basin-margin pumping location create uncertainty in predicted pumping well drawdown. To track aquifer responses over long term management periods, careful monitoring will be required to help understand local conditions that create uncertainty in the prediction of aquifer responses:

- Basin-margin subsurface characteristics include locally heterogeneous aquifer units that are likely lensoidal, interleaved and laterally discontinuous. Such conditions violate many of the assumptions used in traditional aquifer analysis and make quantitative conclusions about aquifer properties from the pumping tests useful approximations, but not firm fact.
- The bedrock mountain front boundary east of the University well, and the subsurface bedrock geology of this area have the potential to create highly asymmetric recharge zones to the University well, including possible recharge boundaries associated with the bedrock-alluvial interface.
- The lowermost screened portion of the University well may penetrate or abut bedrock (volcanics and volcanic sediments); contributions to well yield resulting from bedrock fracture flow potentially create unusual well responses to pumping and complications to long-term recharge patterns.

Long-term responses to sustained well production may also be influenced by other factors, such as well interference effects of other local production (for agricultural irrigation). Agricultural production was not believed to occur during either of the tests conducted for this study.

References

Brown, N.N., 2005, Shallow groundwater of eastern Pleasant Valley Basin: Report prepared for Camrosa Water District.

Jacob, C.E., 1946, Drawdown test to determine the effective radius of an artesian aquifer: Proc. Amer. Soc. Civil Engineers, v. 72, no. 5.

Hanson, R.T., P. Martin and K.M. Koczot, 2003, Simulation of ground-water/surface-water in the Santa Clara-Calleguas ground-water basin, Ventura County, California: USGS WRI, no. 02-4136.

Hantush, M.S., 1960, Modification of the theory of leaky aquifers: Jour. Geophys. Research, v. 65, no. 11, pp.3713-3725.

Figure 1. Map showing the regional area, from a shallow groundwater study of eastern Pleasant Valley Basin (Brown, 2005). The University well used for production in the pumping test is 14B3. Only section B-B' is reproduced in this report, for discussion purposes.

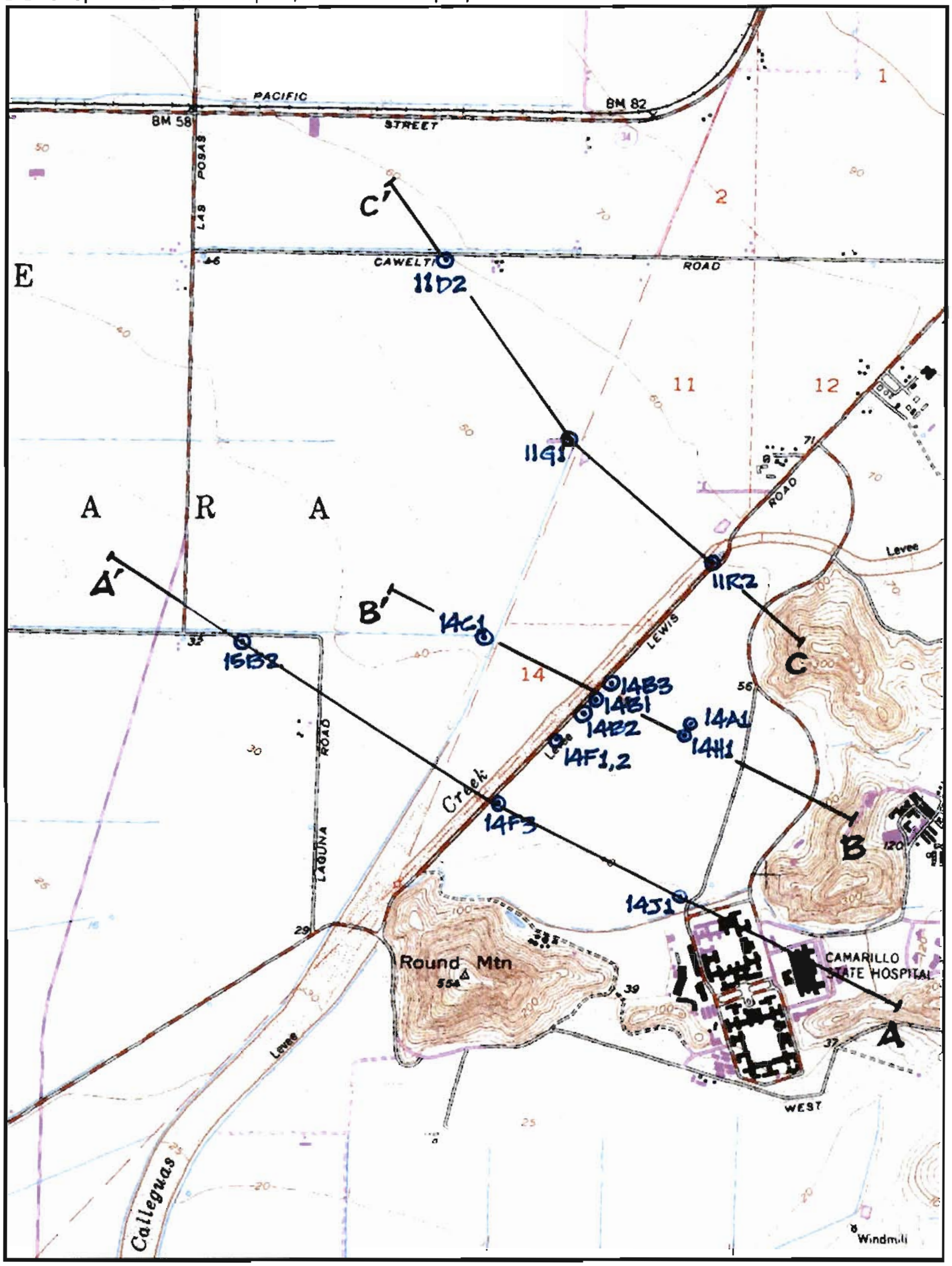
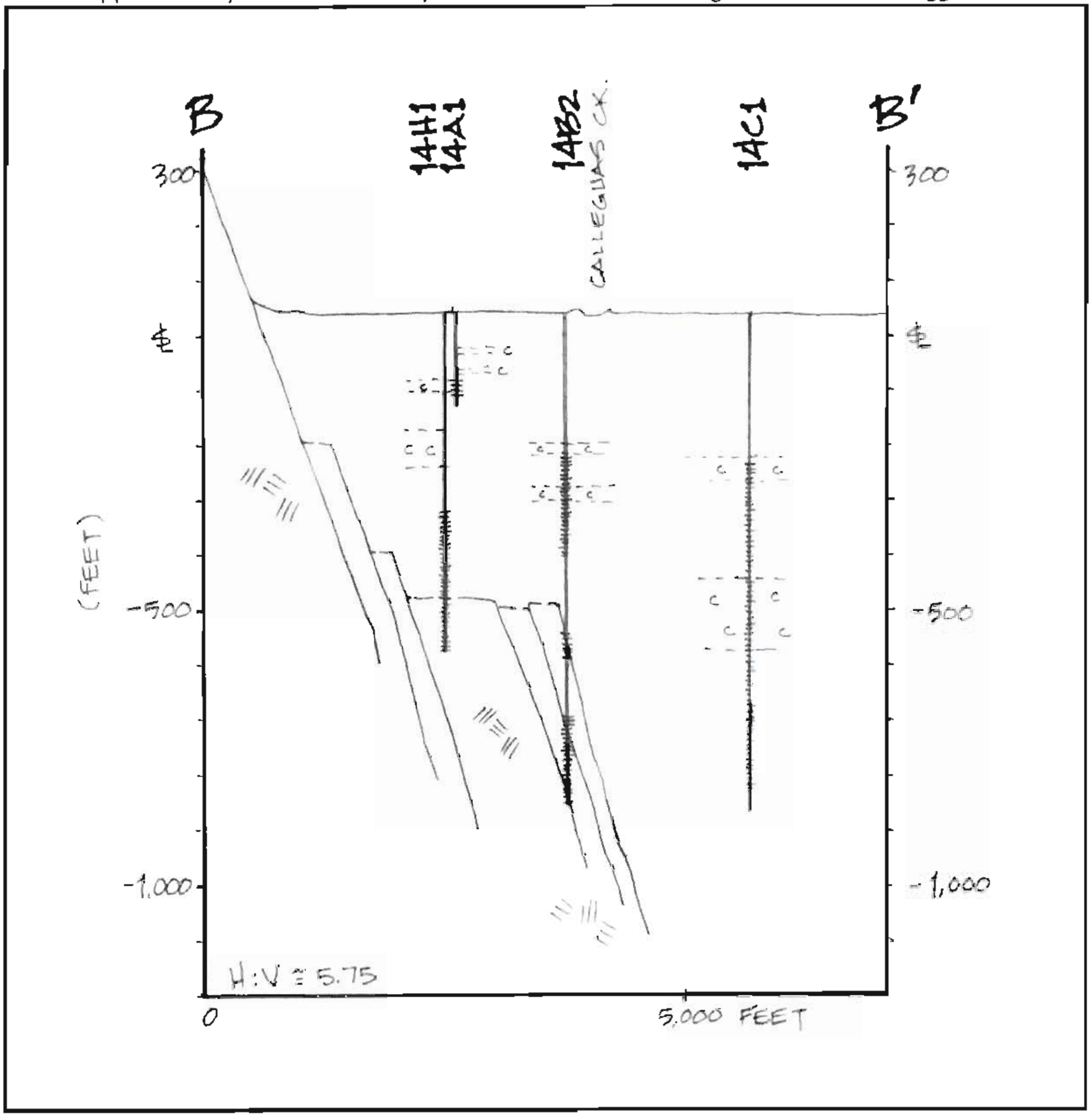


Figure 2. Cross-section B-B'; subsurface geology is schematic. Stratigraphic packages of all clay or predominantly clay units are demarcated by "c" labels. The University well is very close to well 14B2 and has approximately the same overall perforated interval. Note significant vertical exaggeration.



(from Brown, 2005)

Figure 3. Map of wells used in the pumping tests. Well #4 is the pumping well (same as 14B3 in previous figures).

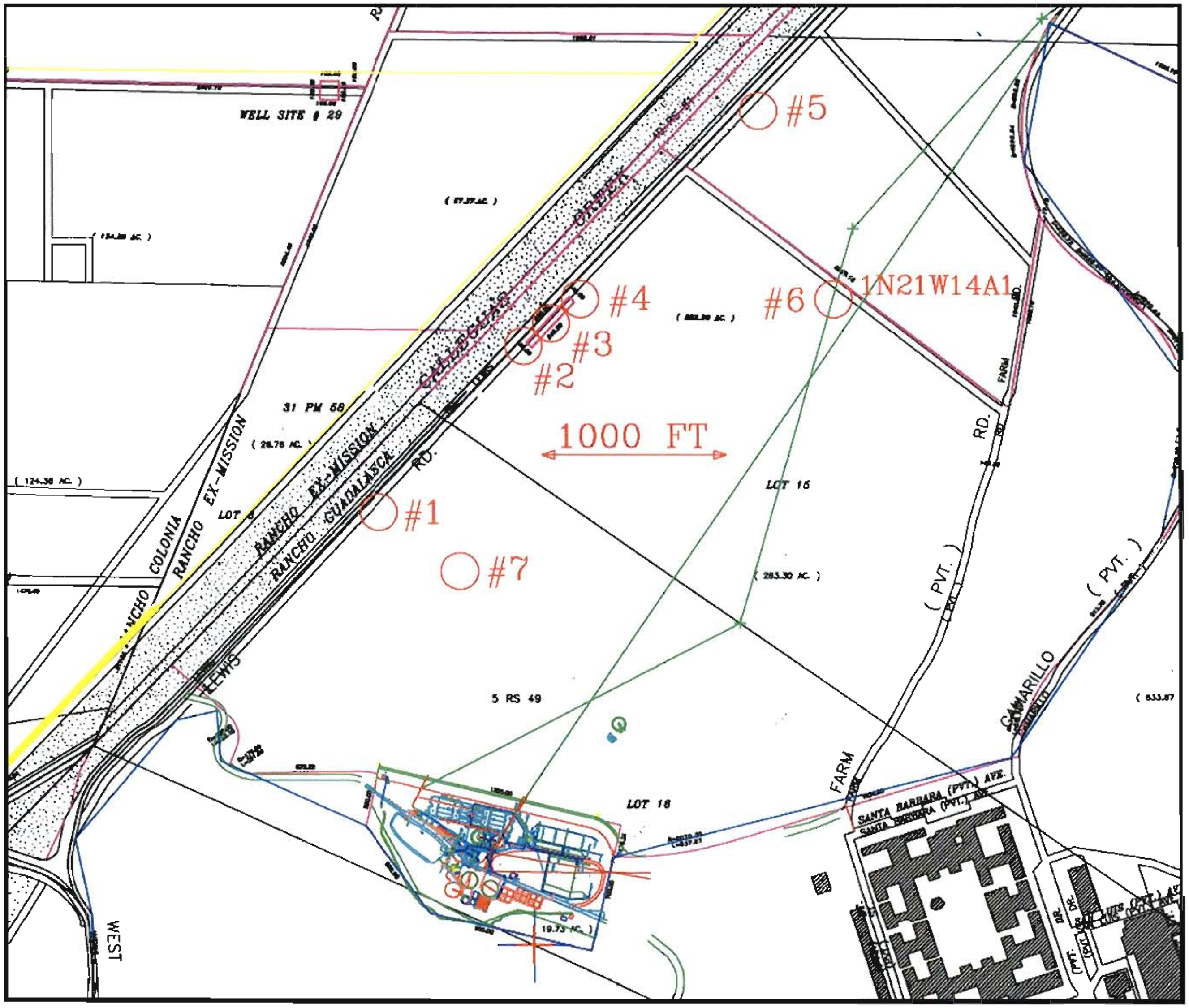


Figure 4. Cross-section of wells monitored during the University well pumping tests; perforated intervals are marked for wells with known construction details. The section is drawn along Lewis Road, through wells 1, 2, 3, 4 and 5. Note that there is slight vertical exaggeration.

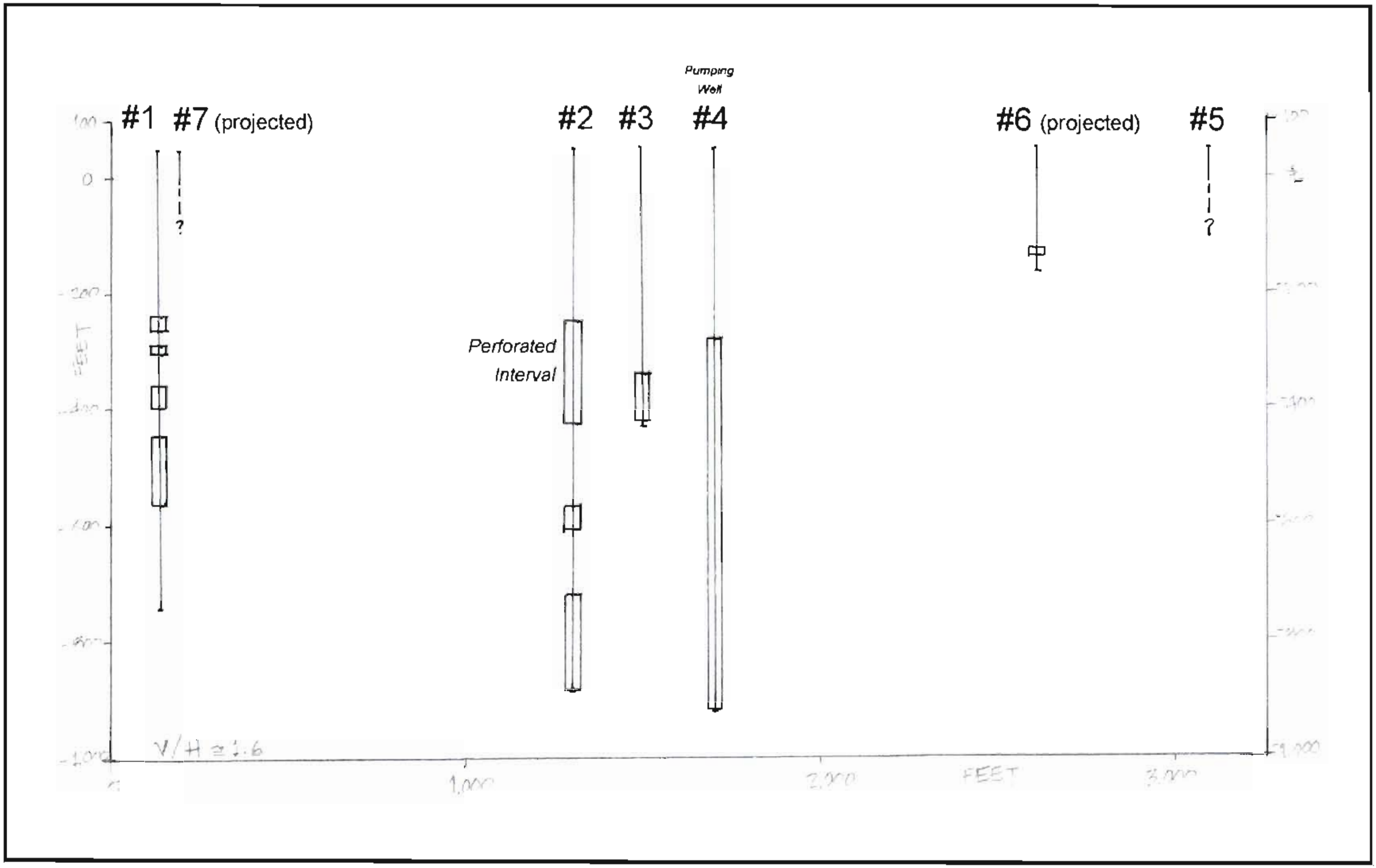


Figure 5. Water Levels and Temperatures recorded in all wells, step-drawdown test. The pumping well is #4.

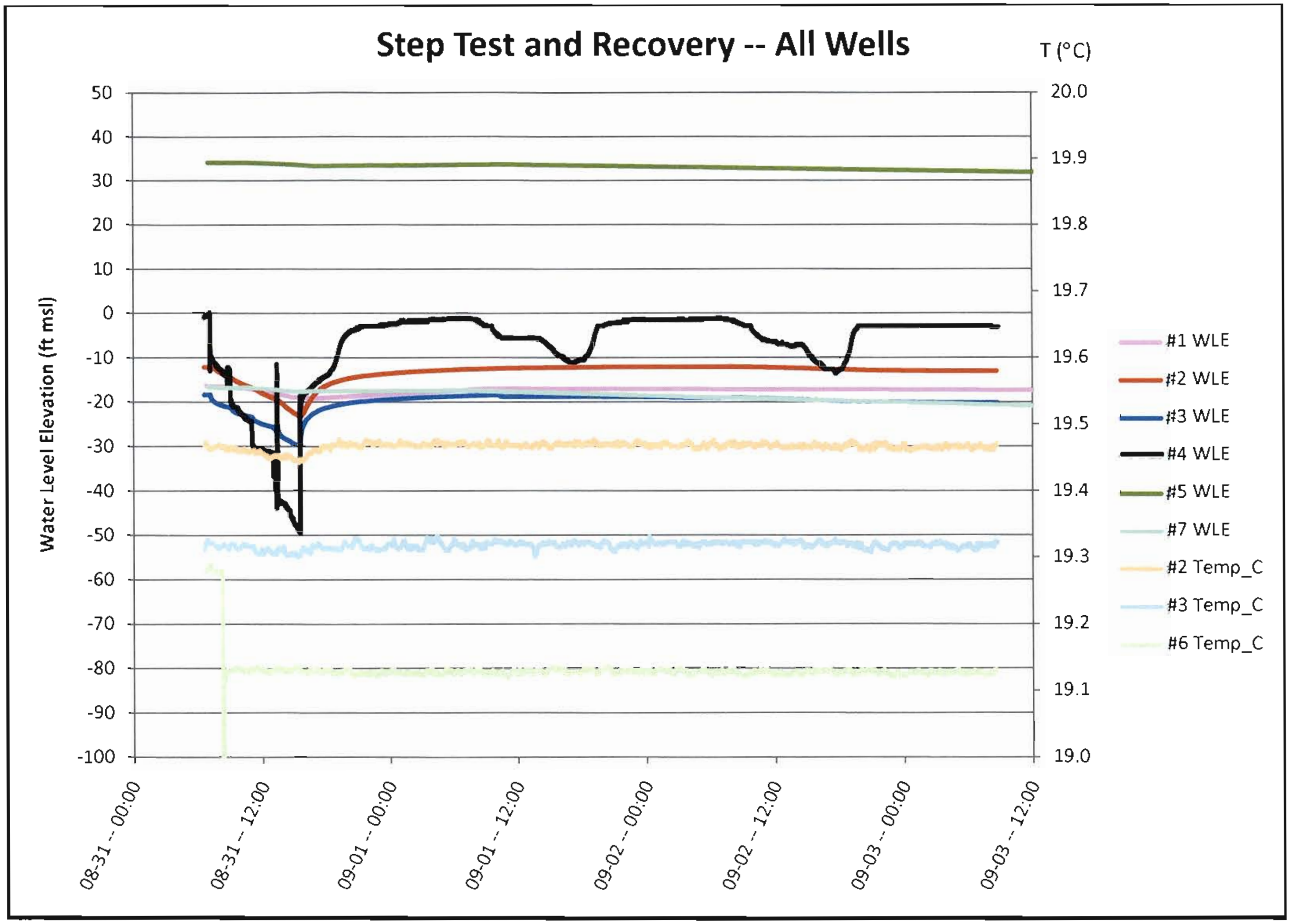


Figure 6. Pumping well water levels and meteorological conditions during the step-test.

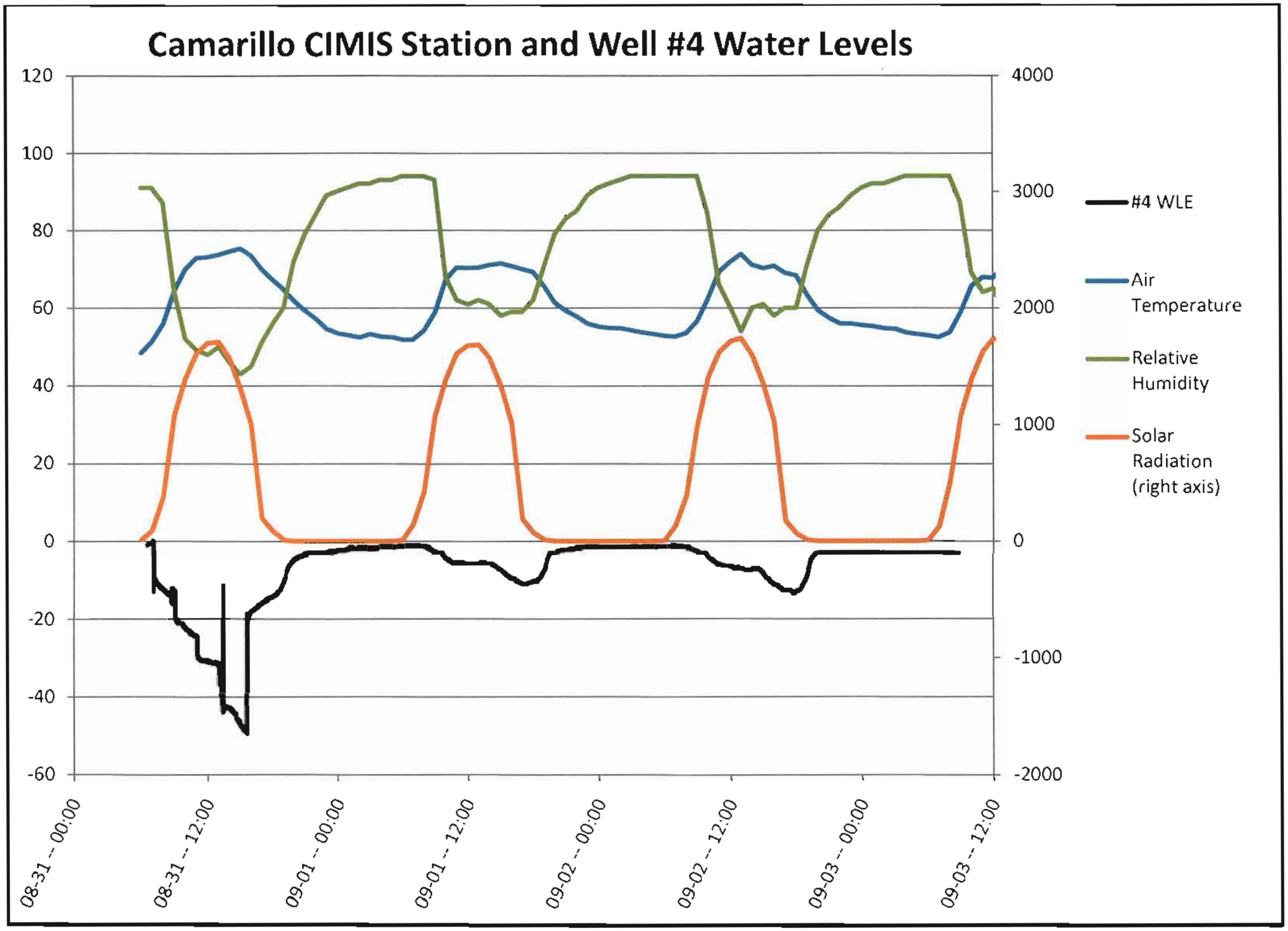


Figure 7. Step-test water level and temperature data for wells #2, #3 and #4.

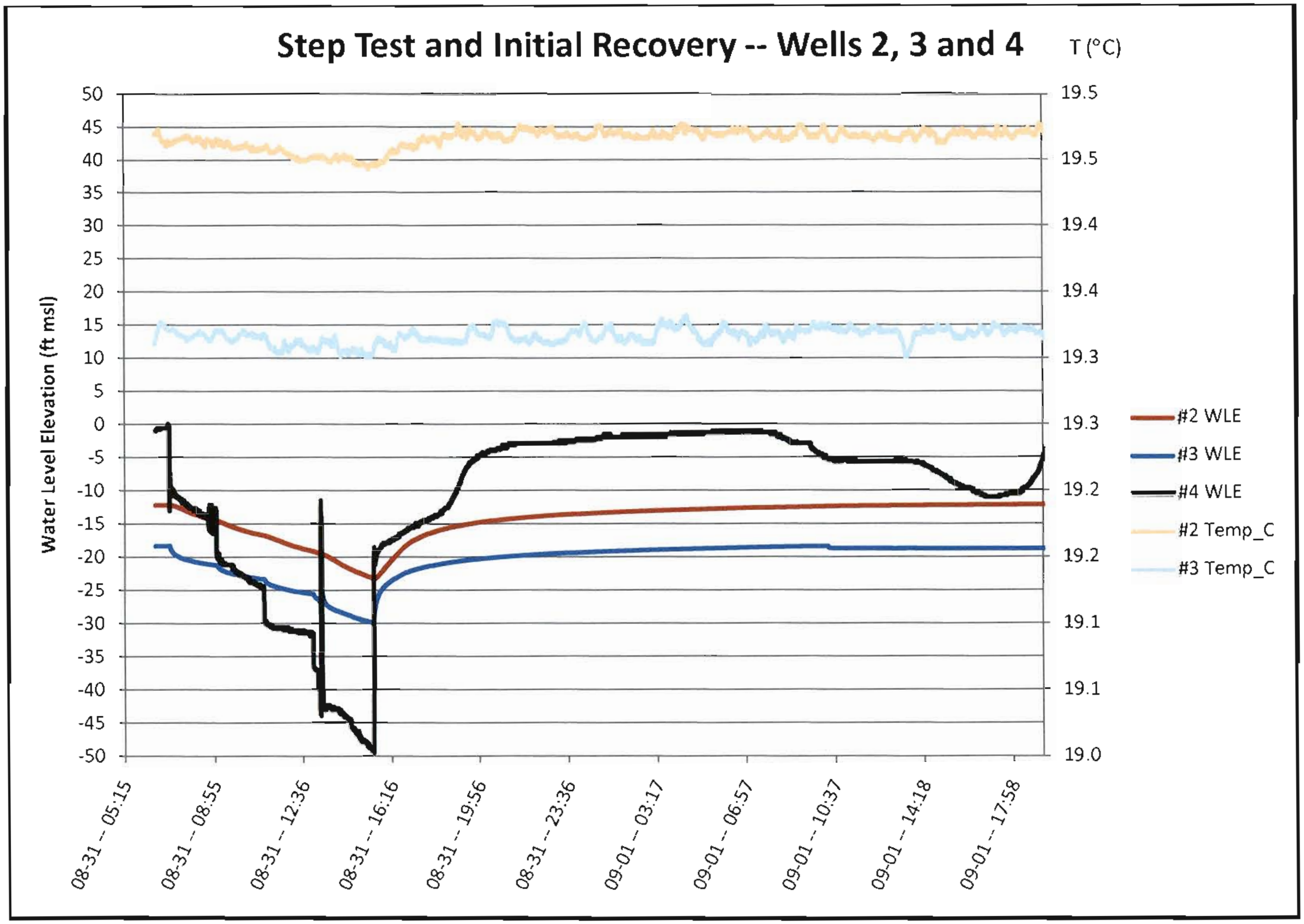


Figure 9. Step-test detail plot. Specific capacity calculations are based on maximum drawdown for each pumping interval; see text for discussion.

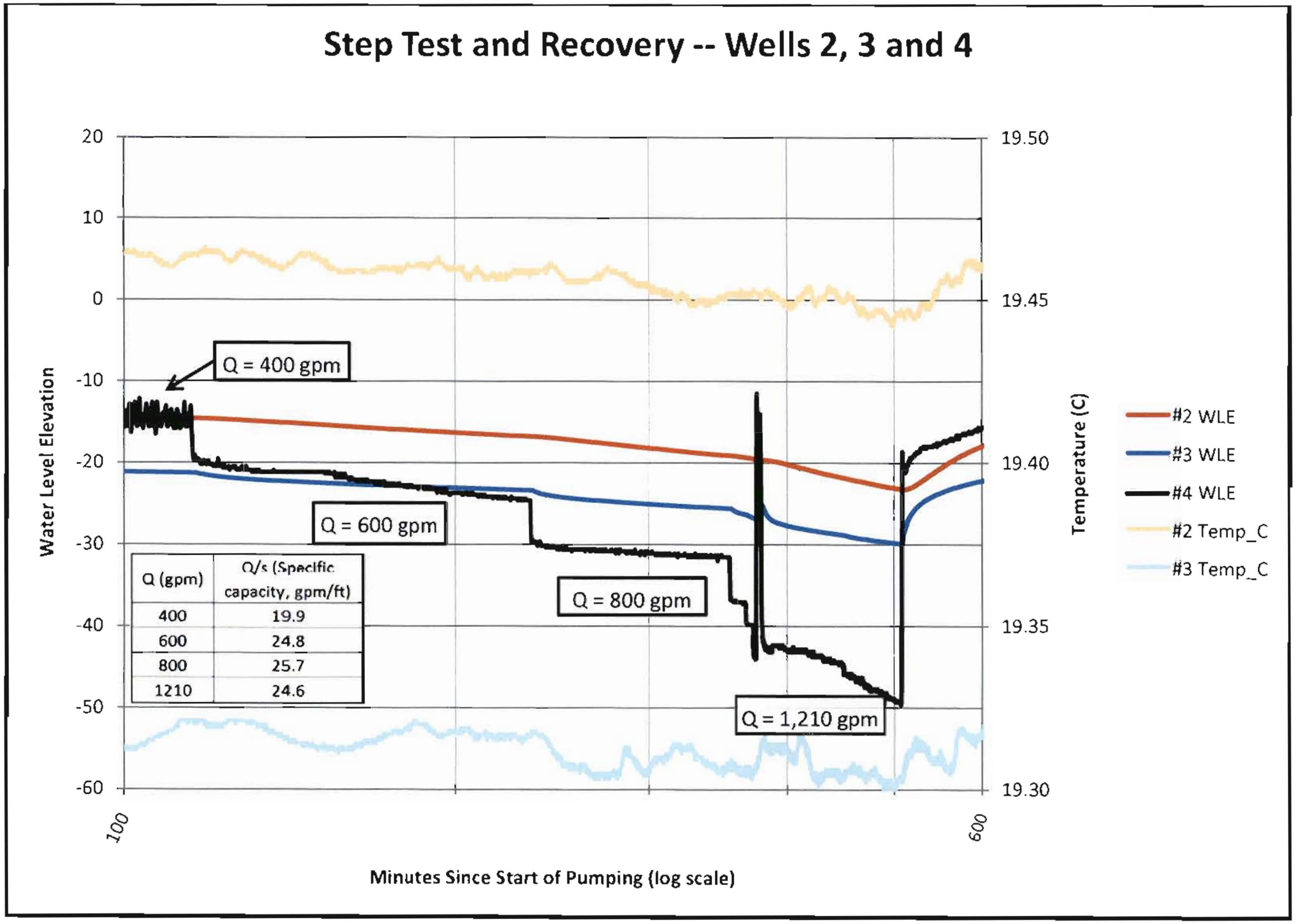


Figure 10. Drawdown in monitoring wells #2 and #3 during step-test production.

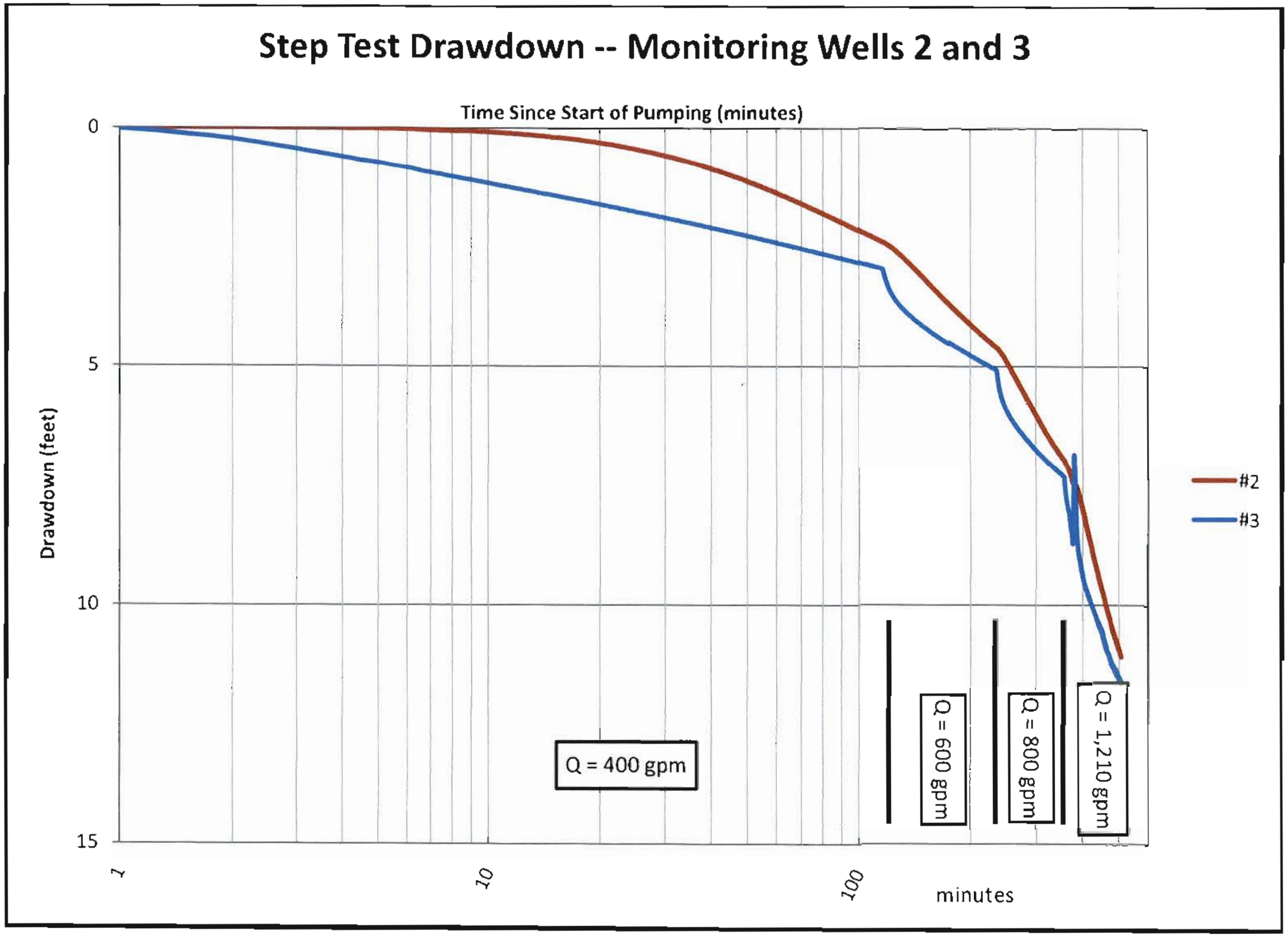


Figure 11. Water level recovery in monitoring wells #2 and #3 (step-test).

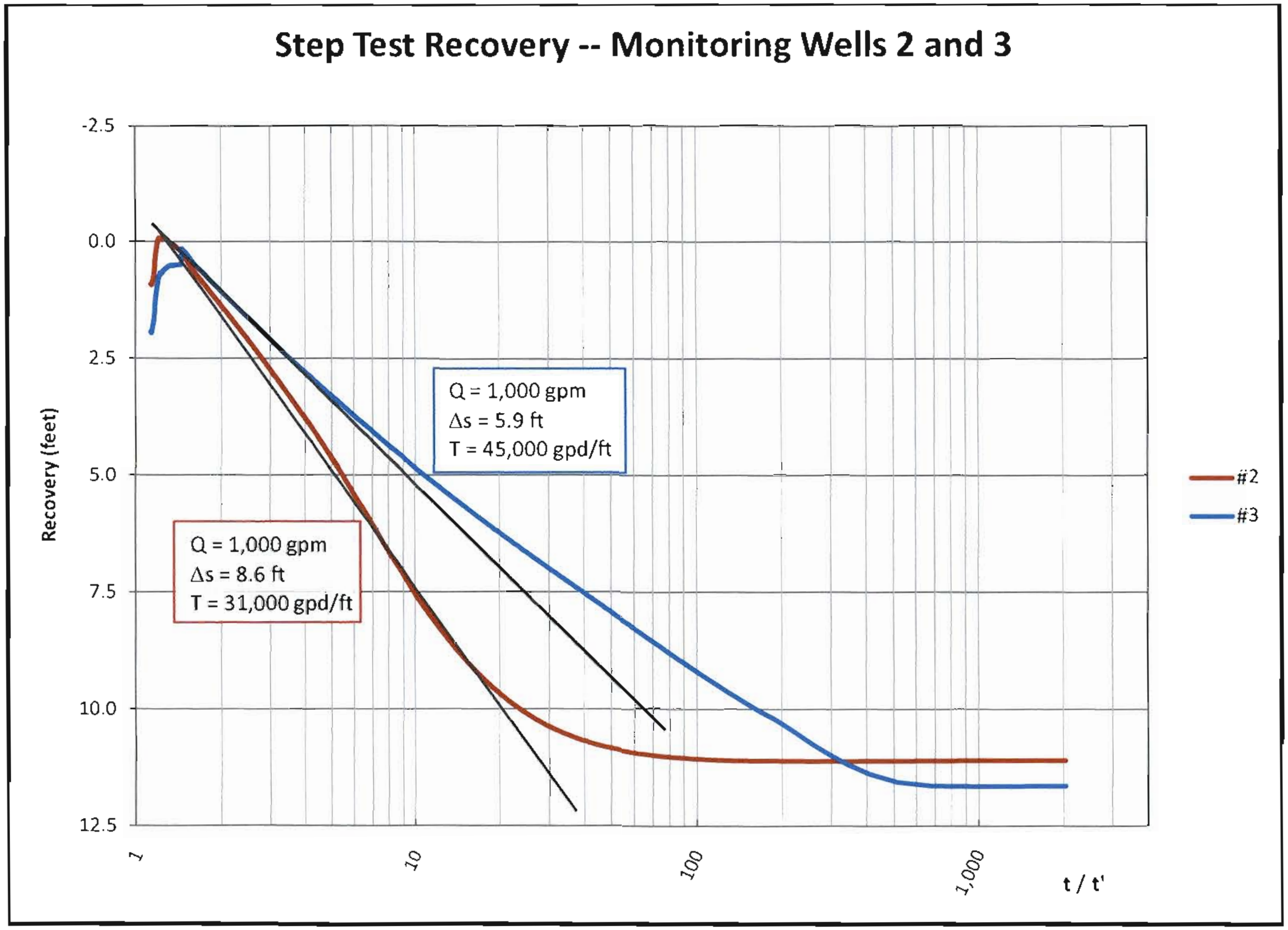


Figure 12. Constant-rate production test and recovery, all water level data. Grey vertical bars correspond with initiation and cessation of pumping during the test.

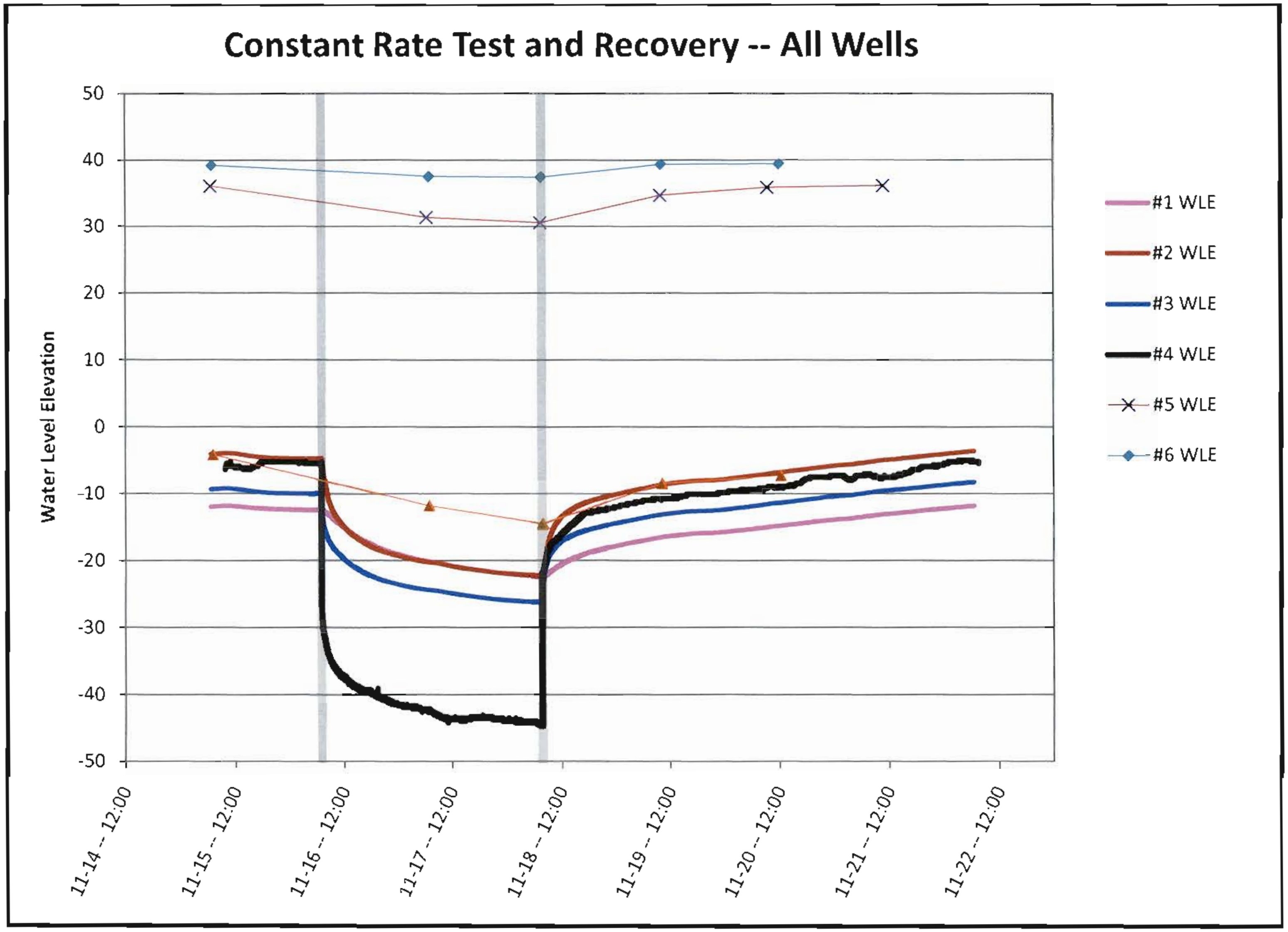


Figure 13. Detailed view of continuous-record data from the constant-rate production test and recovery period.

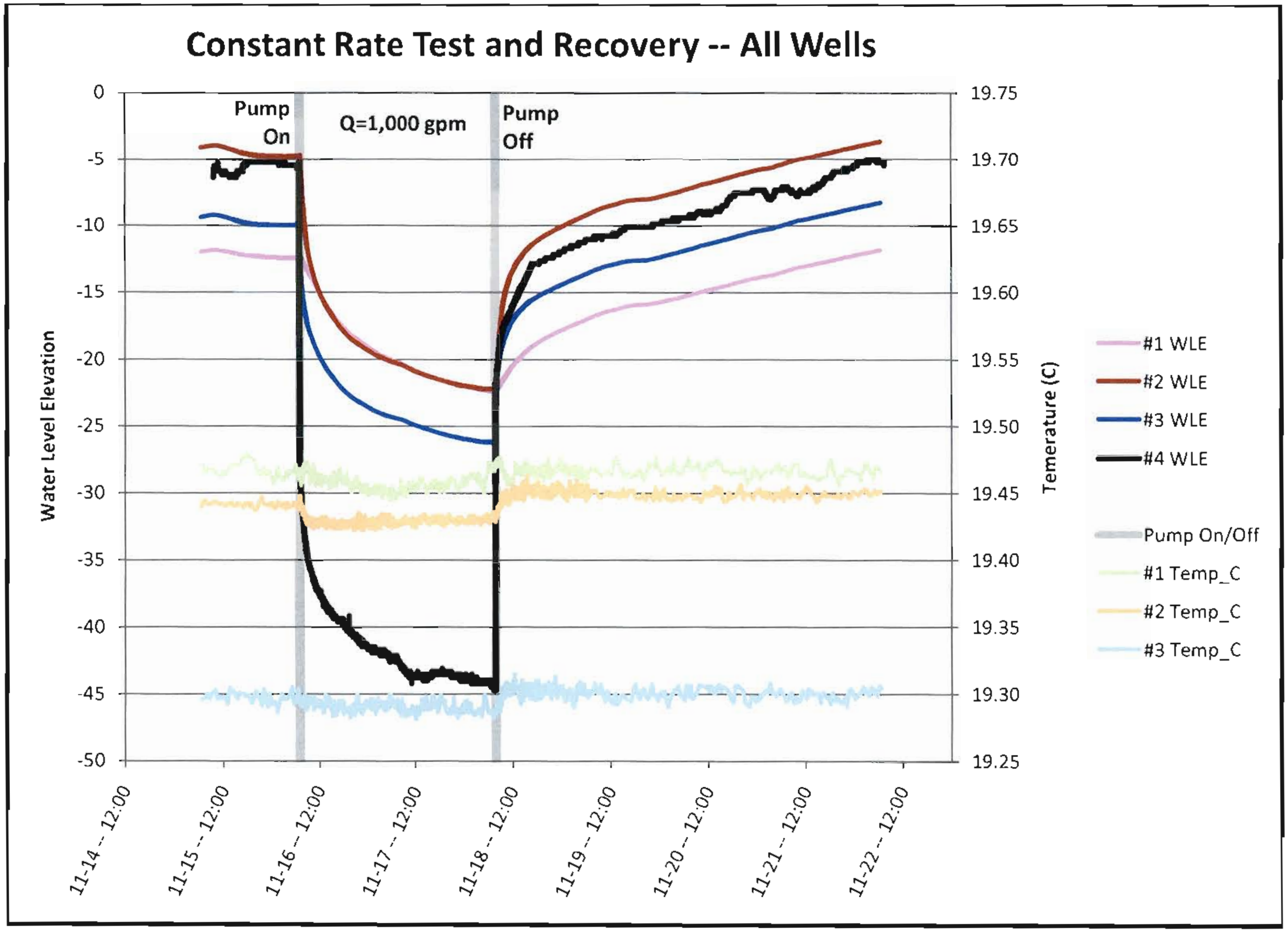


Figure 14. Drawdown in pumping well #4 during constant-rate test production.

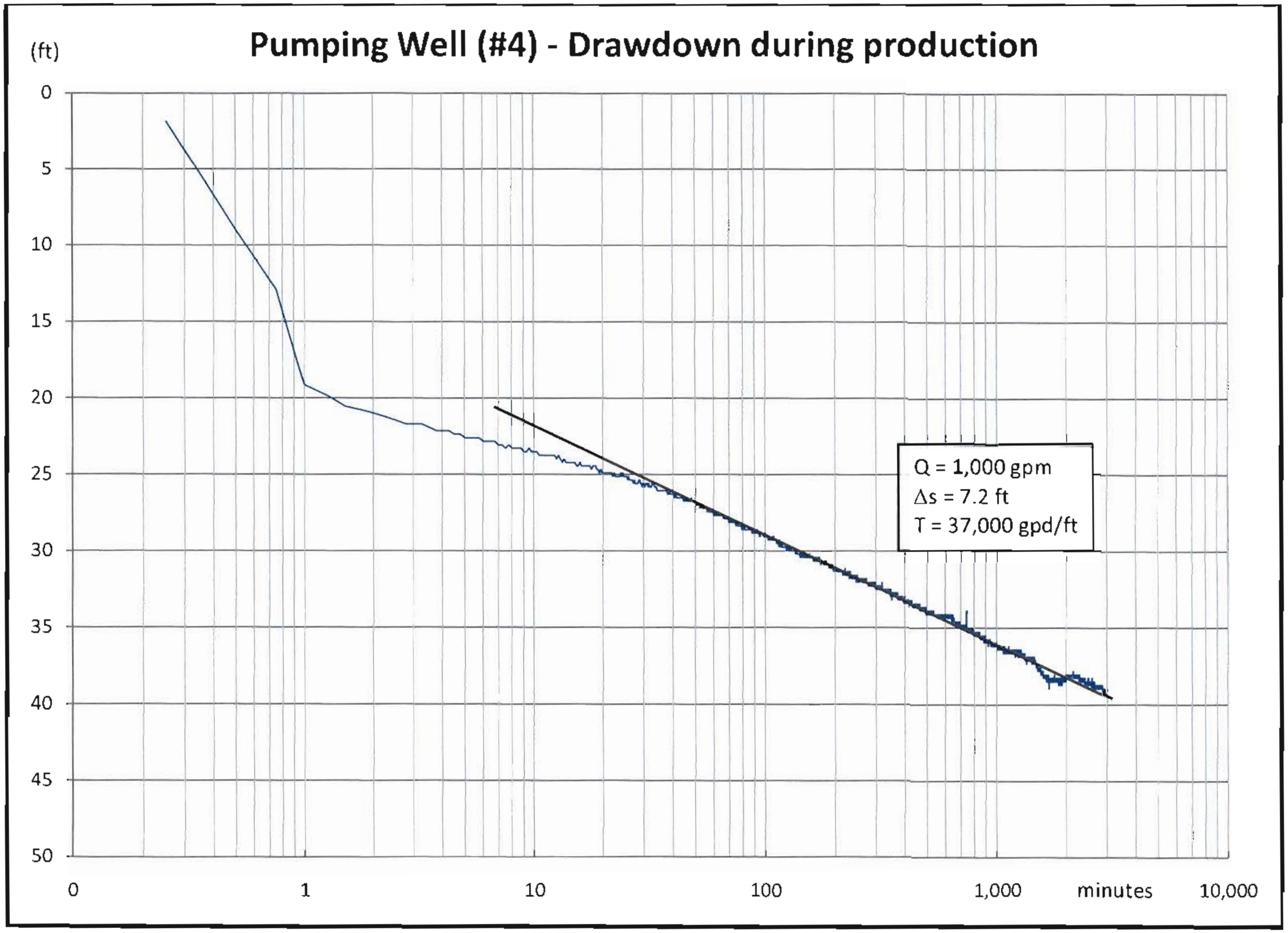


Figure 15. Water level recovery in production well #4 (constant-rate test).

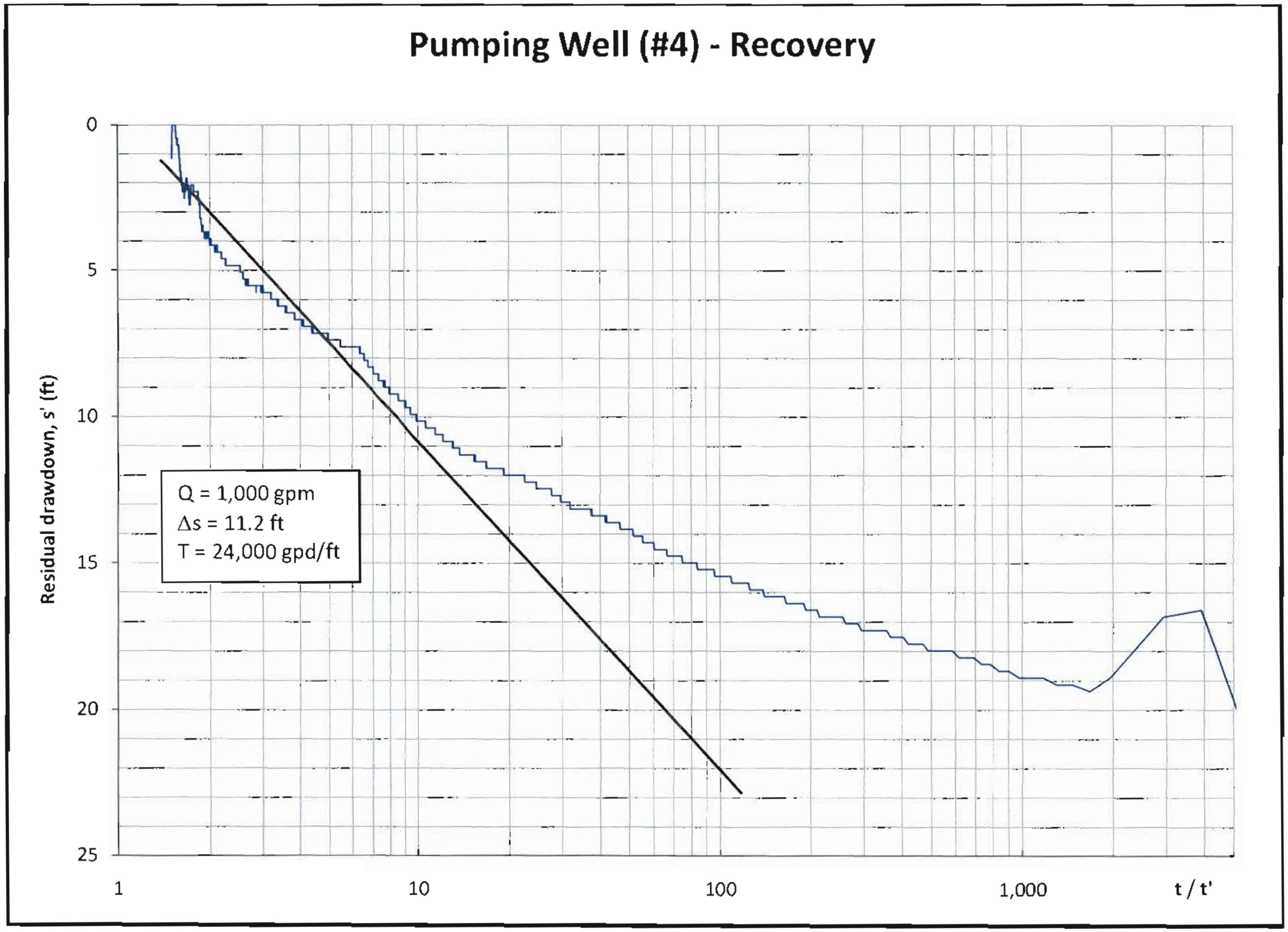


Figure 16. Drawdown during production in observation wells #1, #2 and #3; constant-rate test.

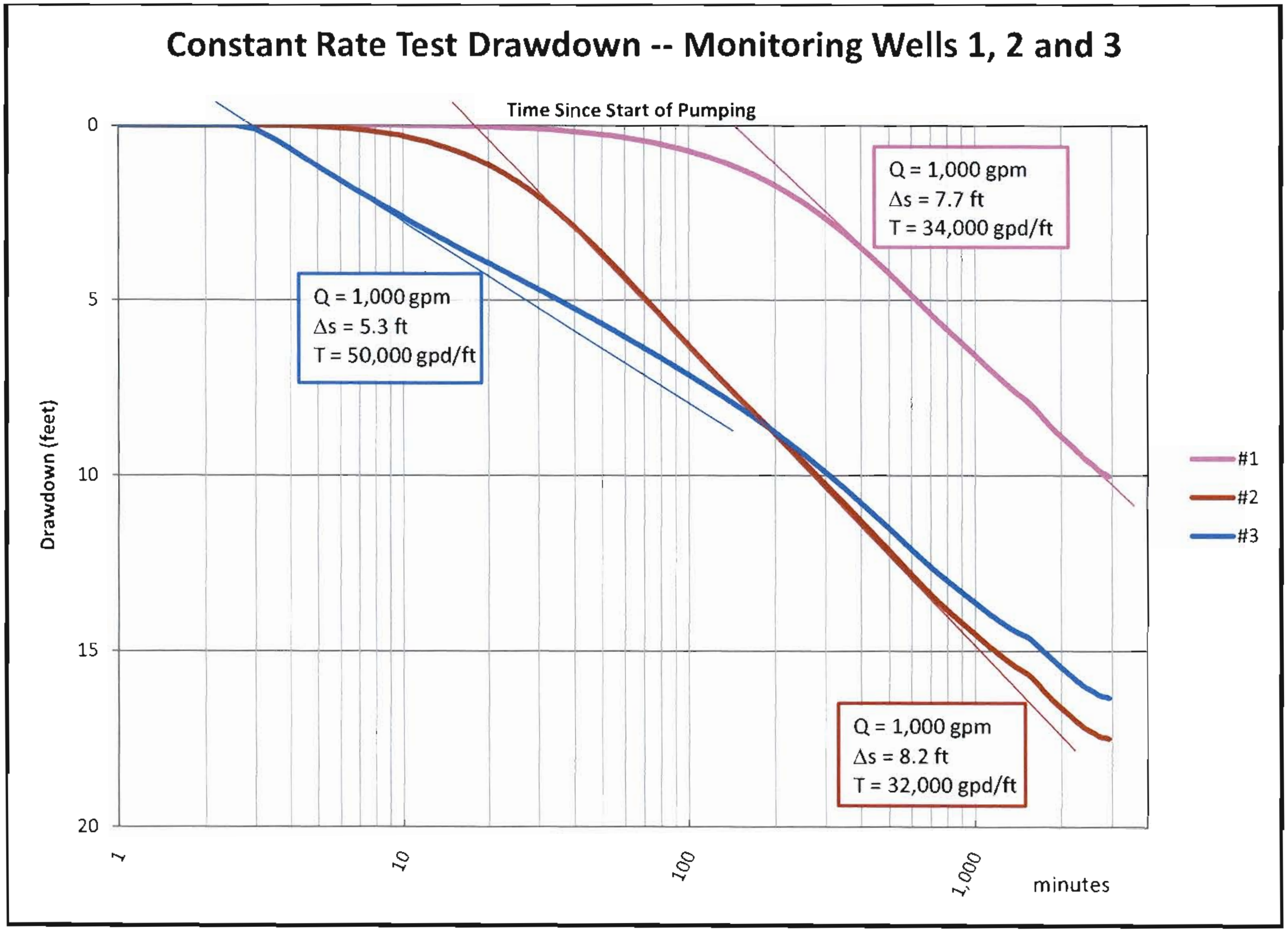


Figure 17. Water level recovery during production in observation wells #1, #2 and #3; constant-rate test. Horizontal axis is time elapsed since cessation of pumping (minutes, log scale).

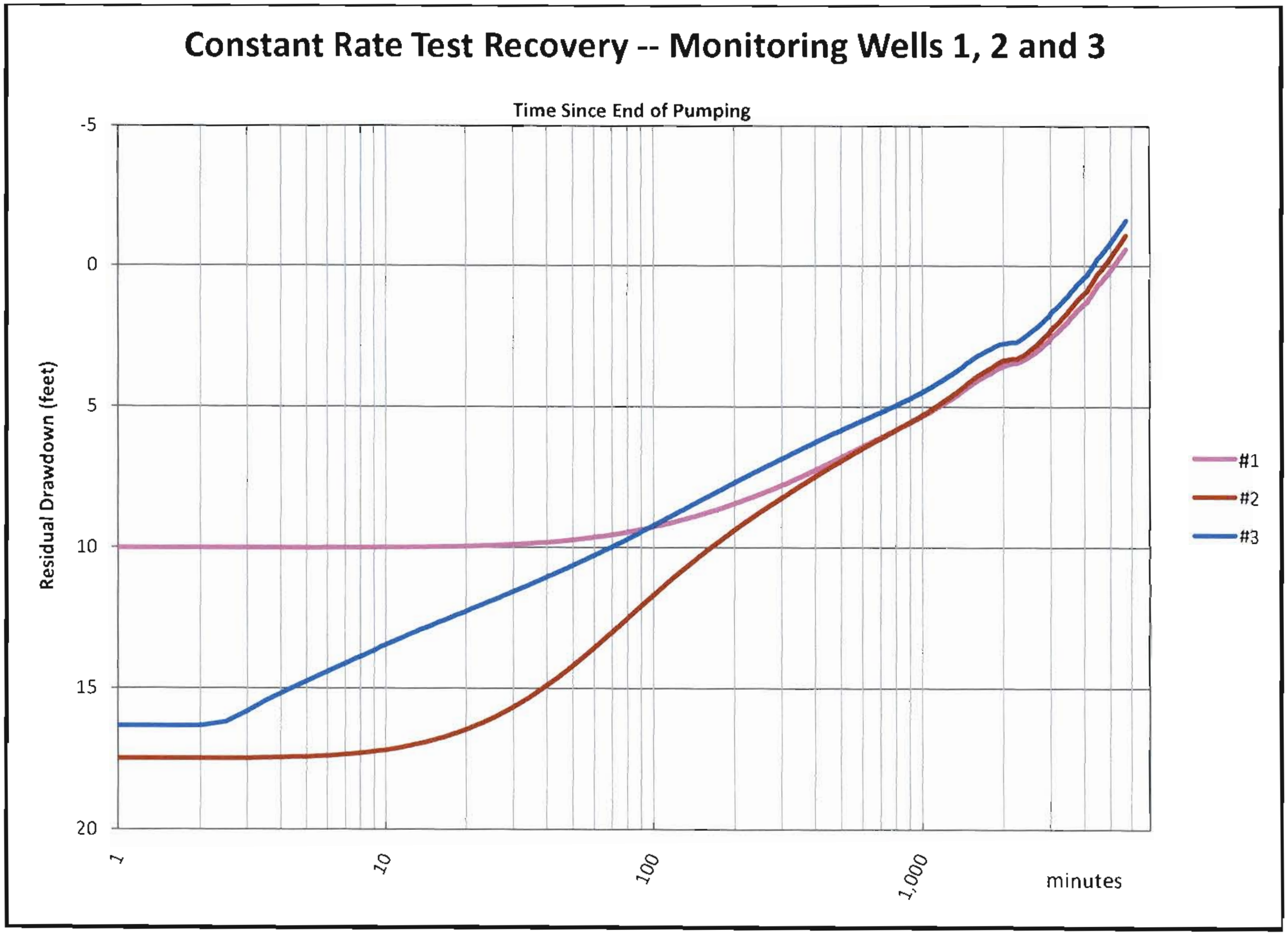


Figure 18. Water level recovery in observation wells #1, #2 and #3; constant-rate test. Horizontal axis is t/t' (unitless; total time since initiation of pumping, divided by time since start of recovery).

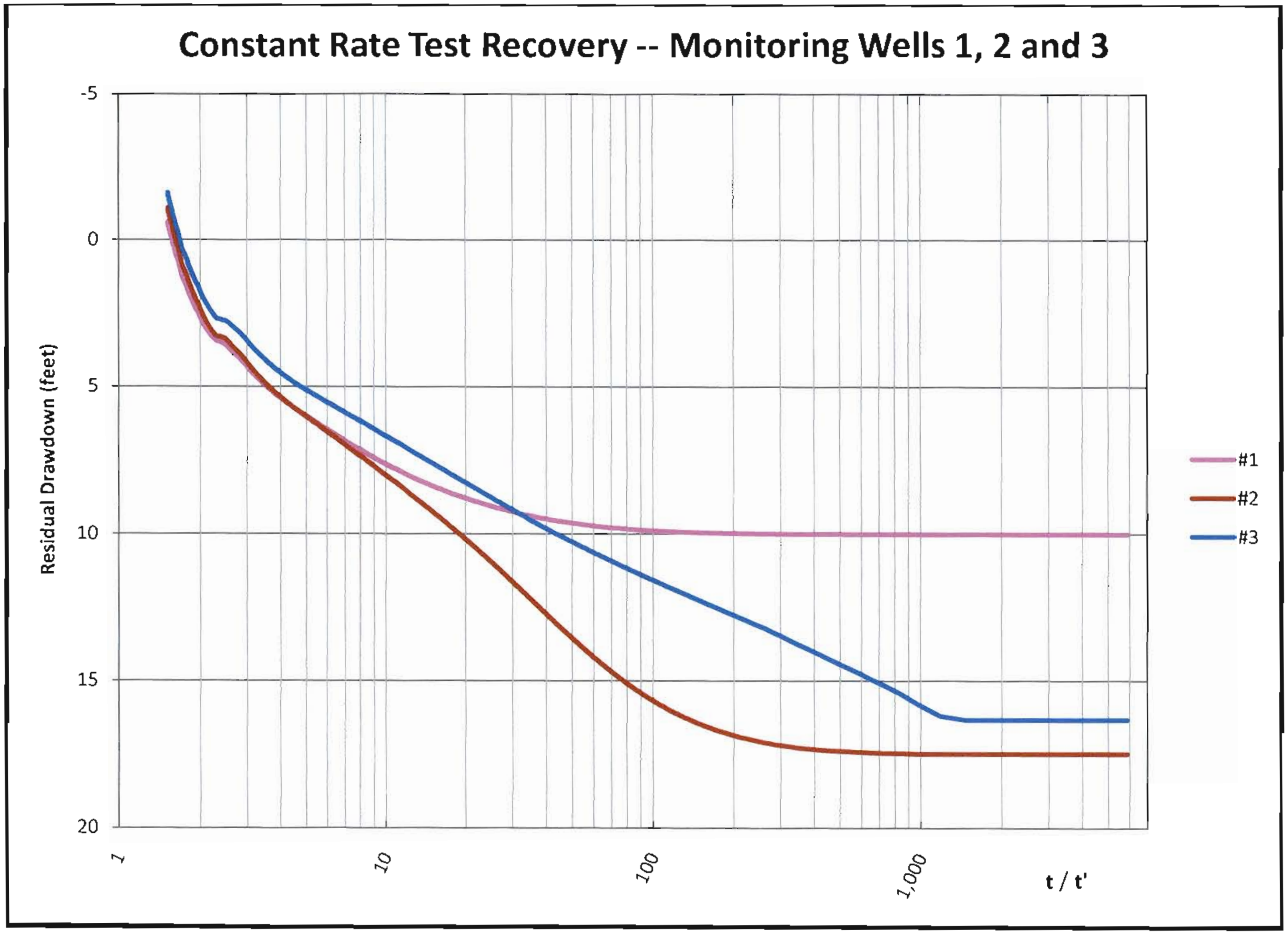


Figure 19. Schematic changes to aquifer response during constant-rate production period. The curve is observed water level data from well #4, with different components of possible aquifer contributions.

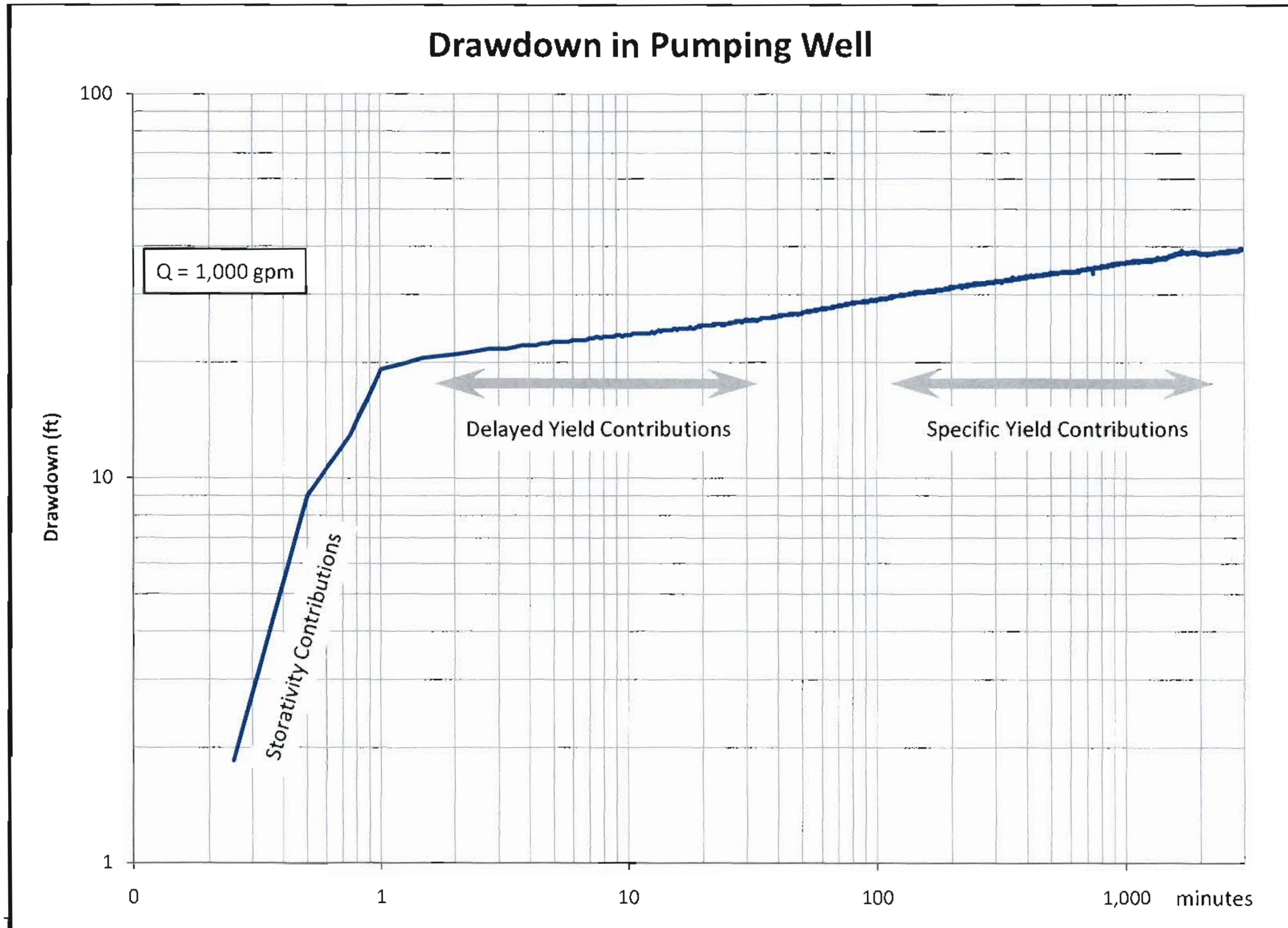


Figure 20. Distance-drawdown plot of all observation wells (constant-rate test). Shallow aquifer observation wells #5 and #6 are shown in lighter blue and were not considered in the trendline analysis.

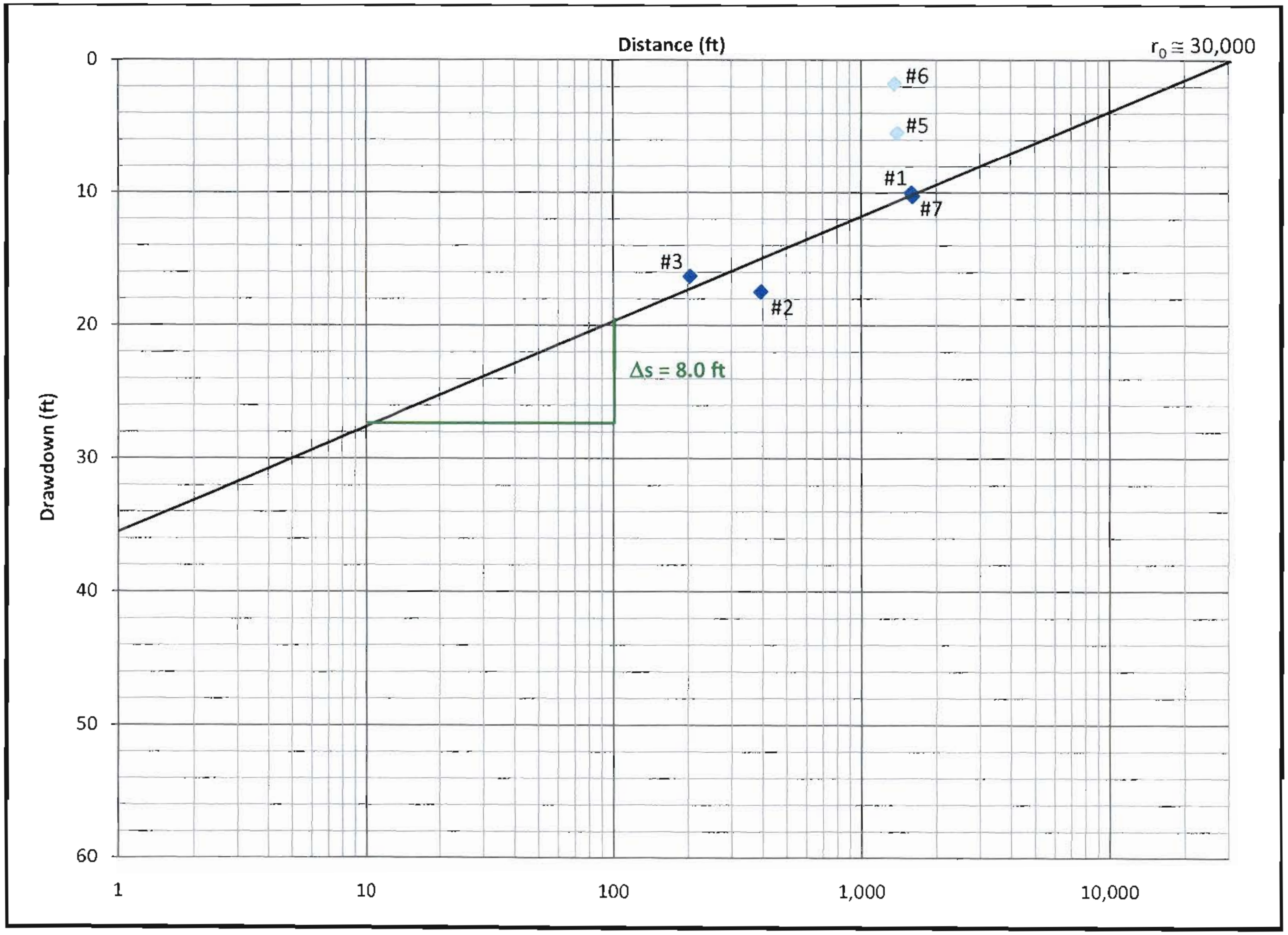


Figure 21. Predicted drawdown curves for University well; see text for discussion.