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Draft A

Aquifer Treatability Test Report for the 200-BP-5 Groundwater Operable Unit

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

U.S. DEPARTMENT OF ENERGY | Richland Operations Office

P.O. Box 550
Richland, Washington 99352

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Terms

bgs	below ground surface
BRF	barometric response function
CCU	Cold Creek unit
DQO	data quality objective
DWS	drinking water standard
EE/CA	engineering evaluation/cost analysis
EPA	U.S. Environmental Protection Agency
FBR	fluidized bed reactor
FS	feasibility study
gpm	gallons per minute
IX	ion exchange
K_d	distribution coefficient
MRCX	Multiple Regression in Excel
N/A	not applicable
OU	operable unit
P&T	pump and treat
P2R	Central Plateau to Columbia River
RD/RAWP	remedial design/remedial action work plan
TEDF	Treated Effluent Disposal Facility
TMR	telescopic mesh refinement
TPA	Tri-Party Agreement
VOC	volatile organic compound
WMA	waste management area

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1 Introduction

This treatability test report documents the performance of a field-scale aquifer treatability test as described in DOE/RL-2010-74, *Treatability Test Plan for the 200-BP-5 Groundwater Operable Unit*. The treatability test evaluated the practicality of performing groundwater extraction for remediating contaminant plumes in the B Tank Farm Complex (referred to as the B Complex in this report) within the 200-BP-5 Groundwater Operable Unit (OU) at the Hanford Site (Figure 1-1). The requirement for a treatability test is identified in Ecology et al., 1989, *Hanford Federal Facility Agreement and Consent Order*, also known as Tri-Party Agreement (TPA) Milestone M-015-82. This report documents the test results as part of the remedial investigation for the 200-BP-5 OU, conducted as part of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* process.

This treatability test report is structured according to U.S. Environmental Protection Agency (EPA) guidance for a treatability study report (EPA/540/R-92/071a, *Guidance for Conducting Treatability Studies Under CERCLA, Final*) as follows:

- Purpose and scope
- Site description
- Treatment technology
- Treatability test approach
- Results and discussions
- Conclusions

1.1 Purpose and Scope

The treatability test evaluated whether a 189 L/min (50 gallons per minute [gpm]) pumping rate can be sustained in the unconfined aquifer in the area of the uranium and technetium-99 groundwater plumes near the B Complex (Figure 1-2). The test was designed to provide information on the effectiveness of a pump and treat (P&T) alternative to hydraulically contain and reduce the mass of the uranium and commingled technetium-99 plumes near the B Complex. Specific objectives for the treatability test according to DOE/RL-2010-74 include the following:

1. Determine the sustainable yield of an extraction test well placed near the source of the uranium and technetium-99 plumes.
2. Directly measure aquifer response to sustained pumping near the uranium and technetium-99 plumes, and calculate aquifer properties (i.e., aquifer transmissivity and specific yield) that are representative of large-scale conditions.
3. Measure the concentrations of uranium and technetium-99 in the extracted groundwater during sustained pumping near the uranium and technetium-99 plumes.

The test objectives were achieved through the collection and evaluation of water level drawdown and water quality data.

The sustainable yield information can be used to develop and evaluate a P&T alternative (e.g., in a feasibility study [FS] or an engineering evaluation/cost analysis [EE/CA]) to support cleanup decisions for the OU. If a P&T remedy or removal action is selected for the OU, the information would also be used to support the design and implementation (e.g., remedial design/remedial action work plan [RD/RAWP]) of the remedy.

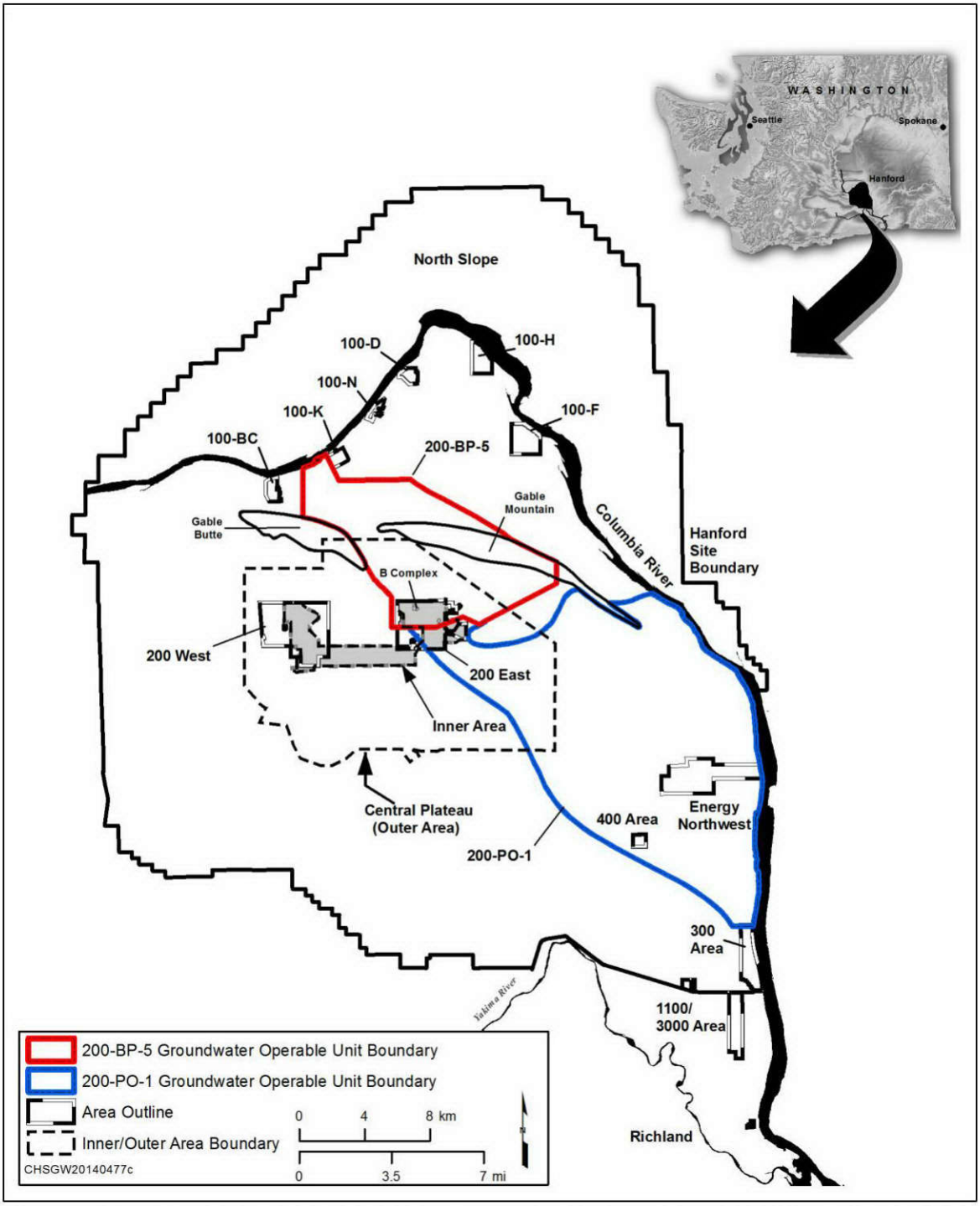


Figure 1-1. Location of the Hanford Site in Southeastern Washington State, Including the 200-BP-5 OU and 200 East Area Boundaries

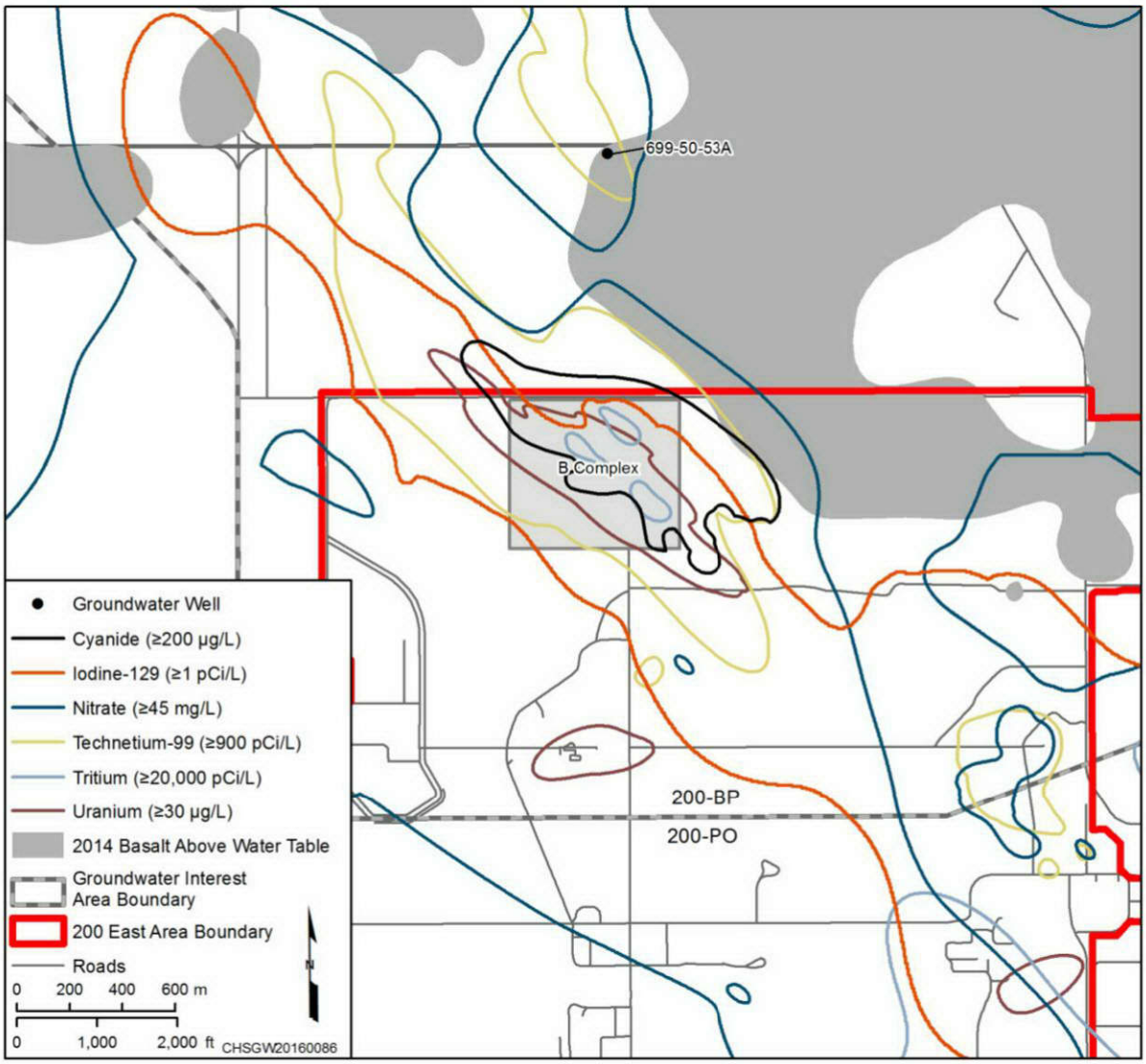


Figure 1-2. Groundwater Contaminant Plumes in the Area of B Complex, 200 East Area

The large-scale aquifer property information (transmissivity and specific yield) obtained from the treatability test was used to refine the localized hydrologic numerical model. The numerical hydrologic model would be used to support the design and evaluation of a P&T alternative in the FS or EE/CA. Such models provide a means of rapidly evaluating design alternatives for optimization, demonstrating that regulatory or performance requirements will be met, and estimating remedial action timeframes.

The concentrations of uranium and technetium-99 measured in extracted groundwater were used to estimate initial mass removal rates. Although the test was focused on the B Complex uranium and technetium-99 plume, additional sampling and analysis were performed for other collocated groundwater contaminants that exceeded maximum contaminant levels, including cyanide, iodine-129, nitrate, and tritium, for 200 West Groundwater Treatment Facility process control and waste designation.

The treatability test system consisted of a single extraction well (299-E33-268) connected to an aboveground pipeline to convey extracted groundwater to the 200 West Groundwater Treatment Facility for treatment (Figure 1-3). Water treated at the 200 West Groundwater Treatment Facility is returned to the aquifer using injection wells. A more detailed description of the system is provided in DOE/RL-2009-124, *200 West Pump and Treat Operations and Maintenance Plan*.

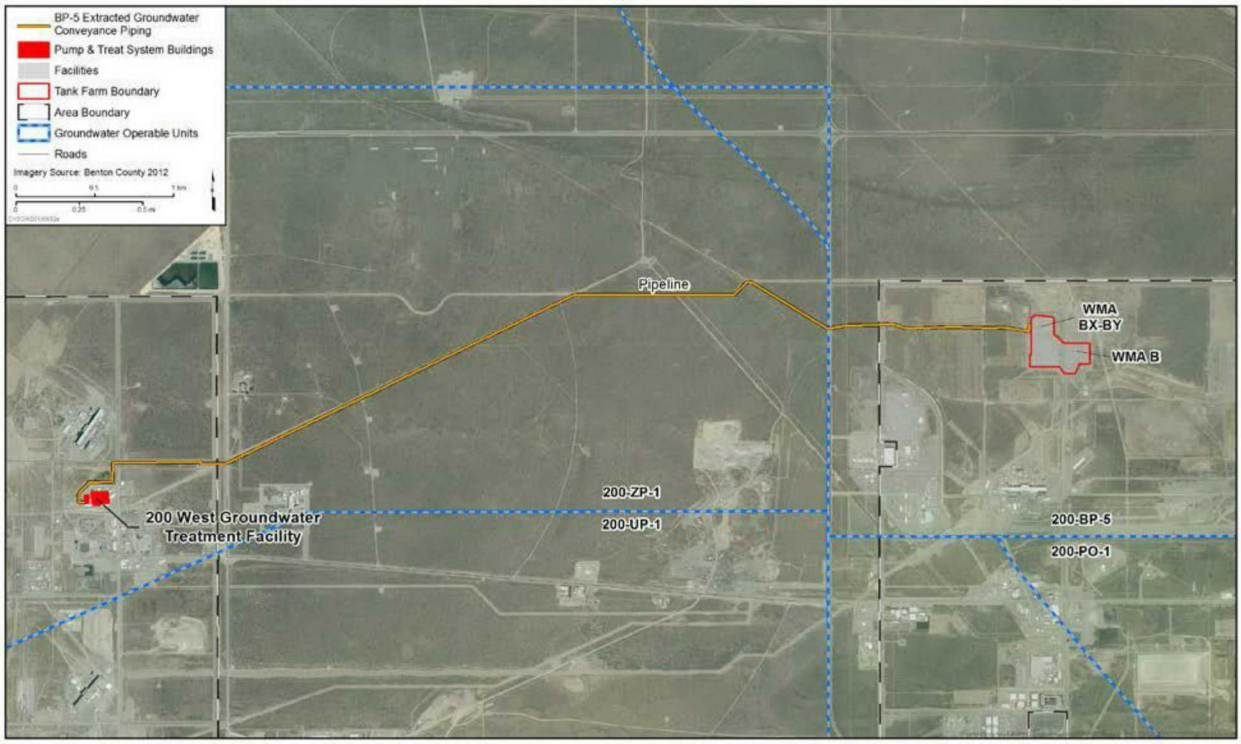


Figure 1-3. Diagram of the Conveyance Pipeline from the 200-BP-5 Test Extraction Well to the 200 West Groundwater Treatment Facility

1.2 Site Description

The 200-BP-5 OU extends from the 200 East Area northwest between Gable Butte and Gable Mountain (Gable Gap) to the Columbia River (Figure 1-1). The B Complex (Figure 1-2) is located within the 200-BP-5 OU on the northern end of the 200 East Area. The B complex consists of inactive crib and trench facilities known as BY Cribs, BX Trenches, B-7-A&B Crib, B-8 Crib and Tile Field, B-11A&B French Drains, B-51 French Drain, and B-57 Crib. In addition, three single-shell tank farms are contained within the following areas:

- Waste Management Area (WMA) B-BX-BY: 241-B Tank Farm (16 tanks)
- 241-BX Tank Farm (12 tanks)
- 241-BY Tank Farm (12 tanks) (Figure 1-4)

A more detailed description of the B Complex can be found in PNNL-19277, *Conceptual Models for Migration of Key Groundwater Contaminants Through the Vadose Zone and Into the Unconfined Aquifer Below the B-Complex*.

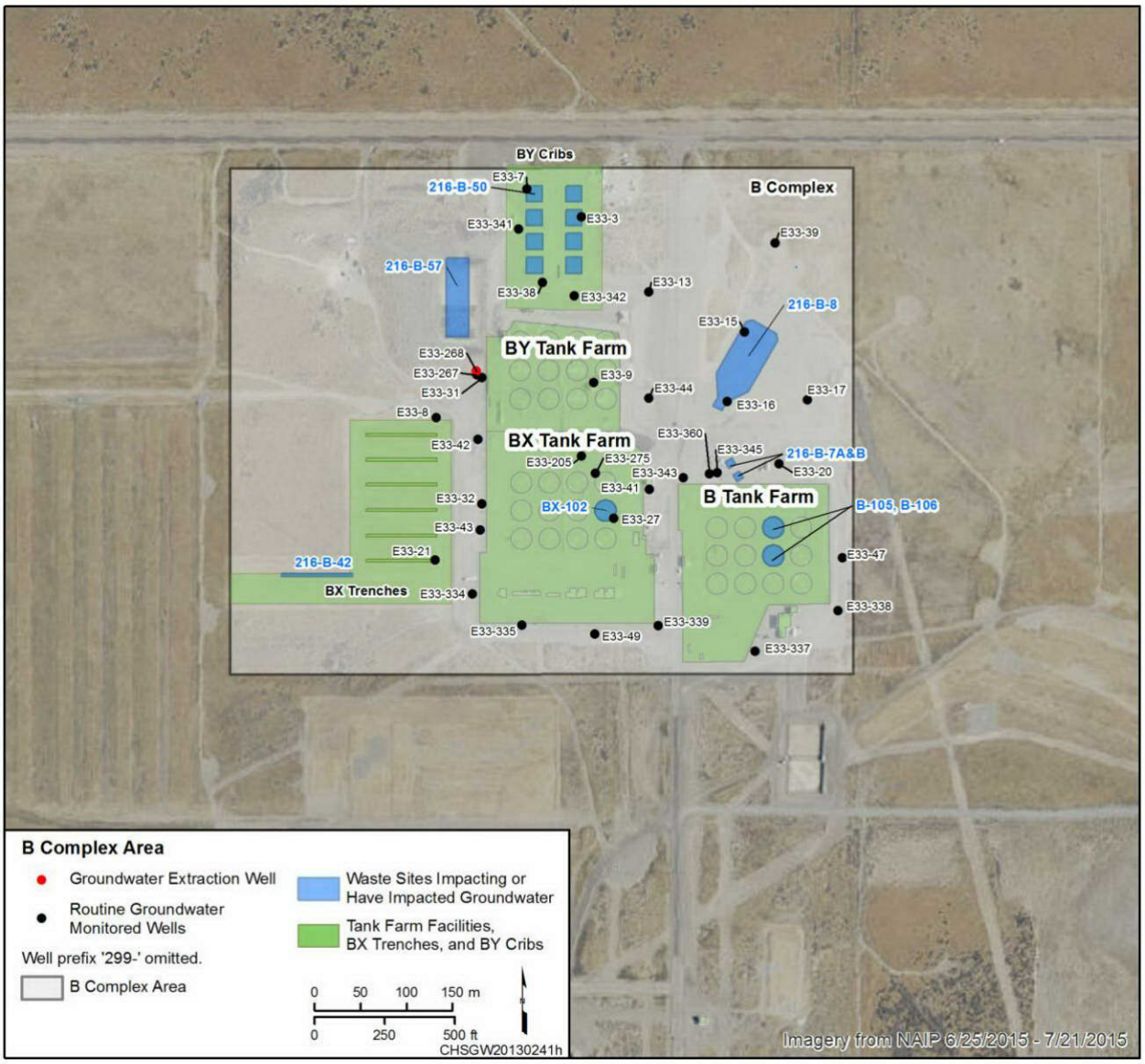


Figure 1-4. B Complex Waste Sites and Additional Waste Sites within the 200-BP-5 OU Associated with or Potentially Associated with Affected Groundwater Quality

Groundwater contaminants in the area of the B Complex at concentrations that exceed drinking water standards (DWSs) include cyanide, iodine-129, nitrate, technetium-99, tritium, and uranium (Table 1-1). All but iodine-129 originate from the sources within the B Complex. The sources of groundwater contamination are primarily the BY Cribs, 241-BX-102 unplanned release, and an unplanned release near the 241-B-105 and 241-B-106 tanks (Figure 1-4). Groundwater monitoring of cyanide, nitrate, technetium-99, and uranium demonstrates that the highest contaminant concentrations between 2010 and 2015 in the 200-BP-5 OU are at the B Complex beneath the 216-BY Cribs and along the northern and eastern sides of the complex. Nitrate and technetium-99, which have a lower soil-water distribution coefficient (K_d) ($K_d = 0$ mL/g) than that of uranium ($K_d = 0.4$ mL/g), have migrated farther from the source area (Figure 1-2). The groundwater plumes extend northwest and southeast within an ancestral Columbia River paleochannel because of a preexisting northwestern flow direction followed by a southeastern flow direction over the past 4 years. Tritium, also originating from this area, has diminished in concentration and areal extent to levels just above the DWSs (Figure 1-2). Iodine-129 migrated into this area

in the past from the 200-PO-1 Groundwater OU. Further discussion of the history of contamination is presented in Chapter 4 of DOE/RL-2009-127, *Remedial Investigation Report for the 200-BP-5 Groundwater Operable Unit*.

The unconfined aquifer in the B Complex area is currently recharged from a transmissive northwest-southeast-trending buried paleochannel. The paleochannel extends from Gable Gap, as defined by the water table gradient (Figure 1-5). Recharge varies temporally, with higher gradients in the summer and fall because of spring runoff into the Columbia River. The elevated spring stages propagate through the Gable Gap and into the 200 East Area along the paleochannel.

According to RHO-BW-SA-318 P, *Paleodrainage of the Columbia River System on the Columbia Plateau of Washington State: A Summary*, late Pliocene/early Pleistocene erosion by the ancestral Columbia River created a transmissive paleochannel in this region. The ancestral Columbia River incised semiconsolidated gravels, cohesive fluvial-lacustrine Ringold deposits, and the underlying basalt. As the basal elevation of erosion was reached, gravels of the Cold Creek unit (CCU) were deposited. The 2012 top of basalt and aquifer thickness are shown in Figure 1-6. Figure 1-6 shows how the aquifer thins between the 200 East Area and the Gable Gap. The paleochannel extending from the Gable Gap to the 200 East Area are described further in PNNL-19702, *Hydrogeologic Model for the Gable Gap Area, Hanford Site*.

The saturated stratigraphy in the B Complex consists of unconsolidated CCU gravels (PNNL-19277). Sediment samples collected at the treatability extraction well 299-E33-268 during drilling consisted of subrounded to rounded gravel-size granites, quartzite, chert, and basalt (Figures 1-7 and 1-8). Geologist log descriptions of the gravel indicate 40 percent quartzite and granite, 20 percent metamorphics, and 40 percent basalt consistent with Cold Creek gravel composition (DOE/RL-2002-39, *Standardized Stratigraphic Nomenclature for Post-Ringold-Formation Sediments Within the Central Pasco Basin*). Sieve results indicate that the unit is approximately 64 percent gravel, 34 percent sand, and 2 percent silt (Table 1-2).

Table 1-1. B Complex Groundwater Contaminant Concentrations Compared to the Drinking Water Standard

Contaminant	Maximum Concentration and Date	Location of Maximum Concentration	Drinking Water Standard
Cyanide	1,680 µg/L (5/8/2015)	Eastern Side of B Tank Farm	200 µg/L
Iodine-129	5.38 pCi/L (5/24/2011)	Northern Side of B Tank Farm	1 pCi/L
Nitrate	1,700,000 µg/L (8/9/2011)	Beneath BY Cribs	45,000 µg/L
Technetium-99	42,000 pCi/L (1/24/2014)	Northern Side of B Tank Farm	900 pCi/L
Tritium	35,000 pCi/L (2/23/2010)	Beneath BY Cribs	20,000 pCi/L
Uranium	5,600 µg/L (1/12/2015)	Northern Side of B Tank Farm	30 µg/L

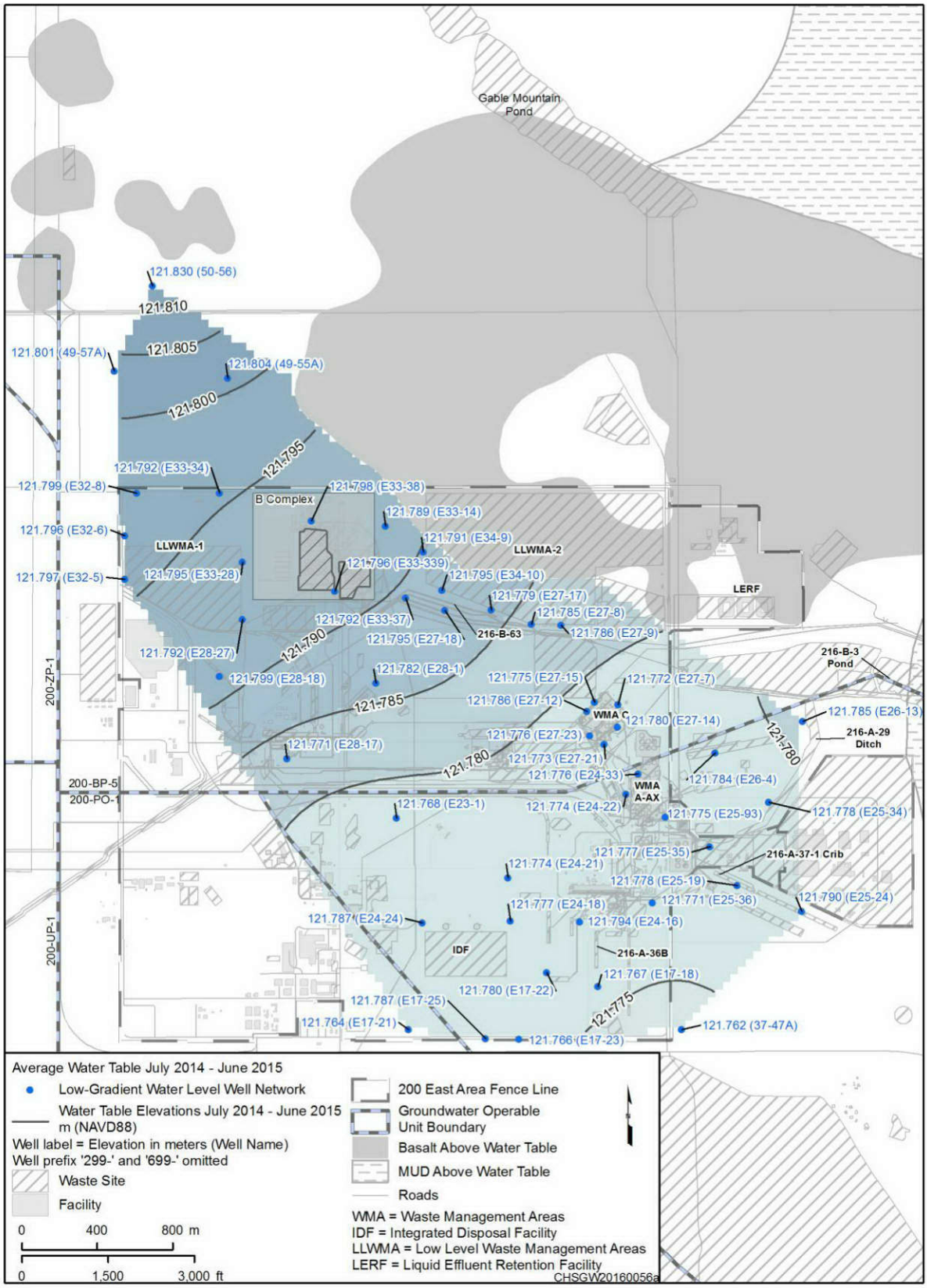


Figure 1-5. Annual Average 200 East Area Water Table Measurements and Associated Isopleths for the Period of July 2014 through June 2015

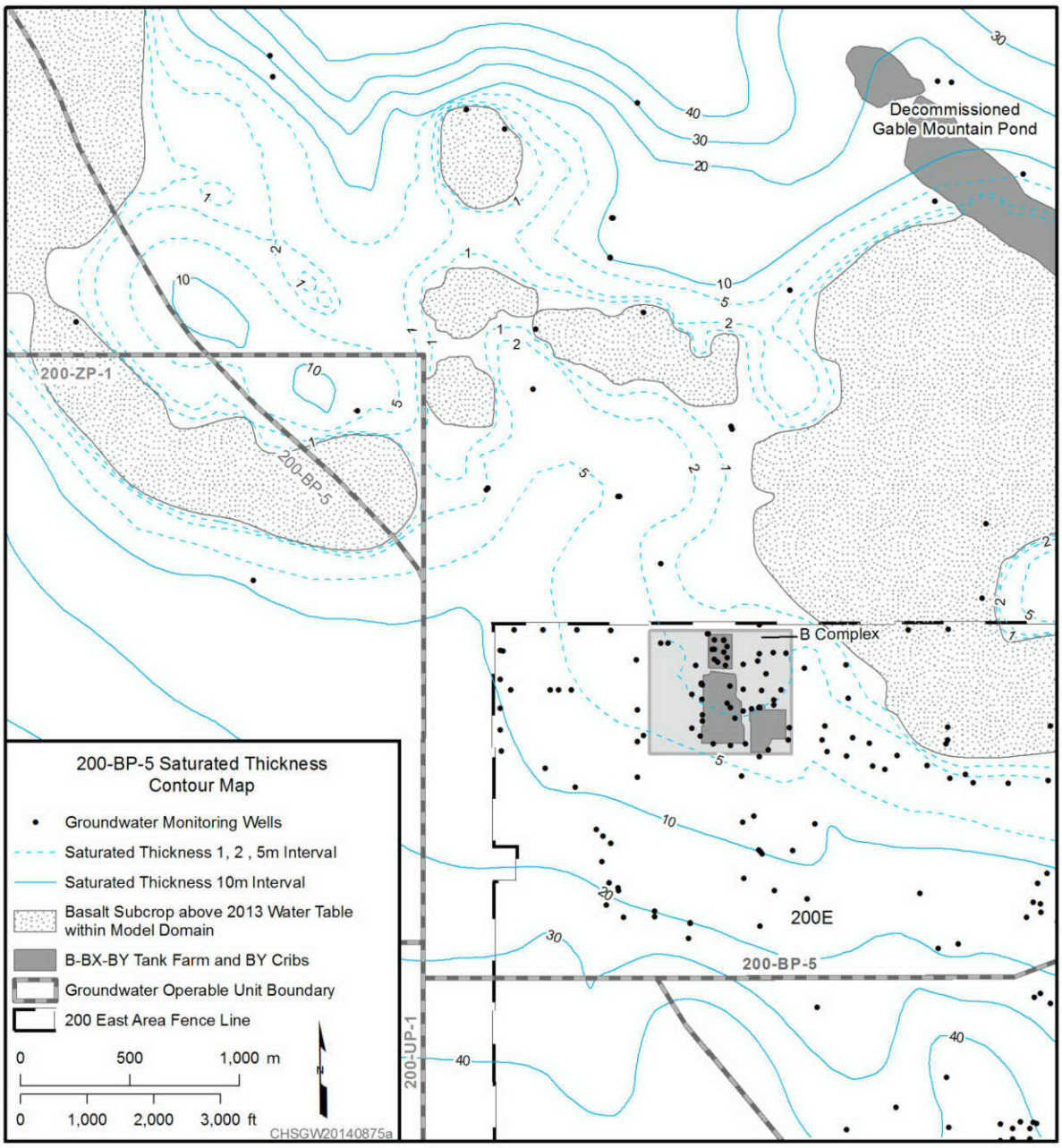


Figure 1-6. Unconfined Aquifer Saturated Thickness Contour Map in the B Complex

The water table is nearly flat in the 200 East Area (Figure 1-9), and the uppermost surface of the basalt is irregular (Figure 1-6). As a result, the aquifer's saturated thickness at the B Complex ranges from 0.3 m (1 ft) to 4.5 m (15 ft). North of the 200 East Area, the saturated aquifer sediments thin across a buried basalt ridge, where past attempts using P&T were deemed not feasible because the sustainable pumping rate was too low (Section 1.3). As part of the treatability test planning, numerical modeling indicated that the B Complex aquifer should sufficiently sustain groundwater pumping rates of 50 gpm with little drawdown (ECF-200BP5-10-0254, *Initial Evaluation of Extraction Well Location Alternatives with B-BX-BY Local-Scale Groundwater Model*) (Figure 1-10). The figure illustrates the predicted capture zone within the B Complex unconfined aquifer while pumping at 178 L/min (50 gpm). Also, because of the high aquifer transmissivity there was little drawdown estimated to occur at the extraction well.

Figure 1-7. Extraction Well 299-E33-268 Sediment Sample from 76.2 m (250 ft) bgs or 0.76 m (2.5 ft) above Elephant Mountain Basalt

Figure 1-8. Extraction Well 299-E33-268 Sediment Sample from 76.8 m (252 ft) bgs or 0.15 m (0.5 ft) above Elephant Mountain Basalt

Table 1-2. Sieve Analysis of Extraction Well 299-E33-268, Sediment Sample Taken from 76.2 m (250 ft) bgs within the Unconfined Aquifer, Approximately 0.76 m (2.5 ft) above Basalt Bedrock

Sieve Analysis				
Sieve Size	**Cumulative Weight (g)**	**% Weight Retained**	**% Passing**	**Grain Size (mm)**
2 in.	240.7	28.8	71.2	50.80
1.5 in.	240.7	28.8	71.2	38.10
3/4 in.	382.3	45.8	54.2	19.05
3/8 in.	562.8	67.4	32.6	9.42
#4	636.8	76.3	23.7	4.70
#10	707.9	84.8	15.2	1.98
#20	757.4	90.7	9.3	0.83
#40	788.5	94.4	5.6	0.42
#60	803.2	96.2	3.8	0.25
#100	812.5	97.3	2.7	0.150
#200	820.4	98.3	1.7	0.074

Temporal water table effects (which have been studied over the past decade in this area) generally produce the largest gradient in the fall. In addition, recent significant Treated Effluent Disposal Facility (TEDF) discharges (greater than 10^7 L/month), in association with single underground tank retrievals, have affected the groundwater within the 200 East Area (DOE/RL-2011-01, *Hanford Site Groundwater Monitoring Report for 2010*; SGW-59423, *WMA C April through June 2015 Quarterly Groundwater Monitoring Report*). The TEDF temporal effects can offset Columbia River effects.

1.3 Prior Removal and Remediation

Two previous treatability tests evaluated P&T technology for remediation of 200-BP-5 OU groundwater from August 1994 through May 1995 (DOE/RL-95-59, *200-BP-5 Operable Unit Treatability Test Report*). One pilot-scale treatability test system was set up proximal to the 216-B-5 reverse well because the associated strontium-90, cesium-137, and plutonium-239/240 concentrations were identified as candidates for an interim response measure (DOE/RL-92-19, *200 East Groundwater Aggregate Area Management Study Report*) (Figure 1-3). The treatability test at this location was discontinued because the future risk from these plumes was assessed as low (DOE/RL-95-59).

The other pilot-scale treatability test was performed at well 699-50-53A, located along the basalt ridge north of the 200 East Area (Figure 1-2). The test started August 29, 1994 and ended May 29, 1995. This well was modified to an extraction well during the test because it was in the most contaminated portion of the 216-BY Crib cobalt-60 and technetium-99 plumes and no other wells evaluated produced appreciable amounts of groundwater during pumping. Although the treatment system performed satisfactorily for removal of cobalt-60 and technetium-99, it was discontinued because of the low extraction rates associated with the thin aquifer (0.6 m [2 ft] thick). The flow rate average was approximately 13.2 L/min (3.5 gpm), so the system had to be operated on a batch-like processing schedule.

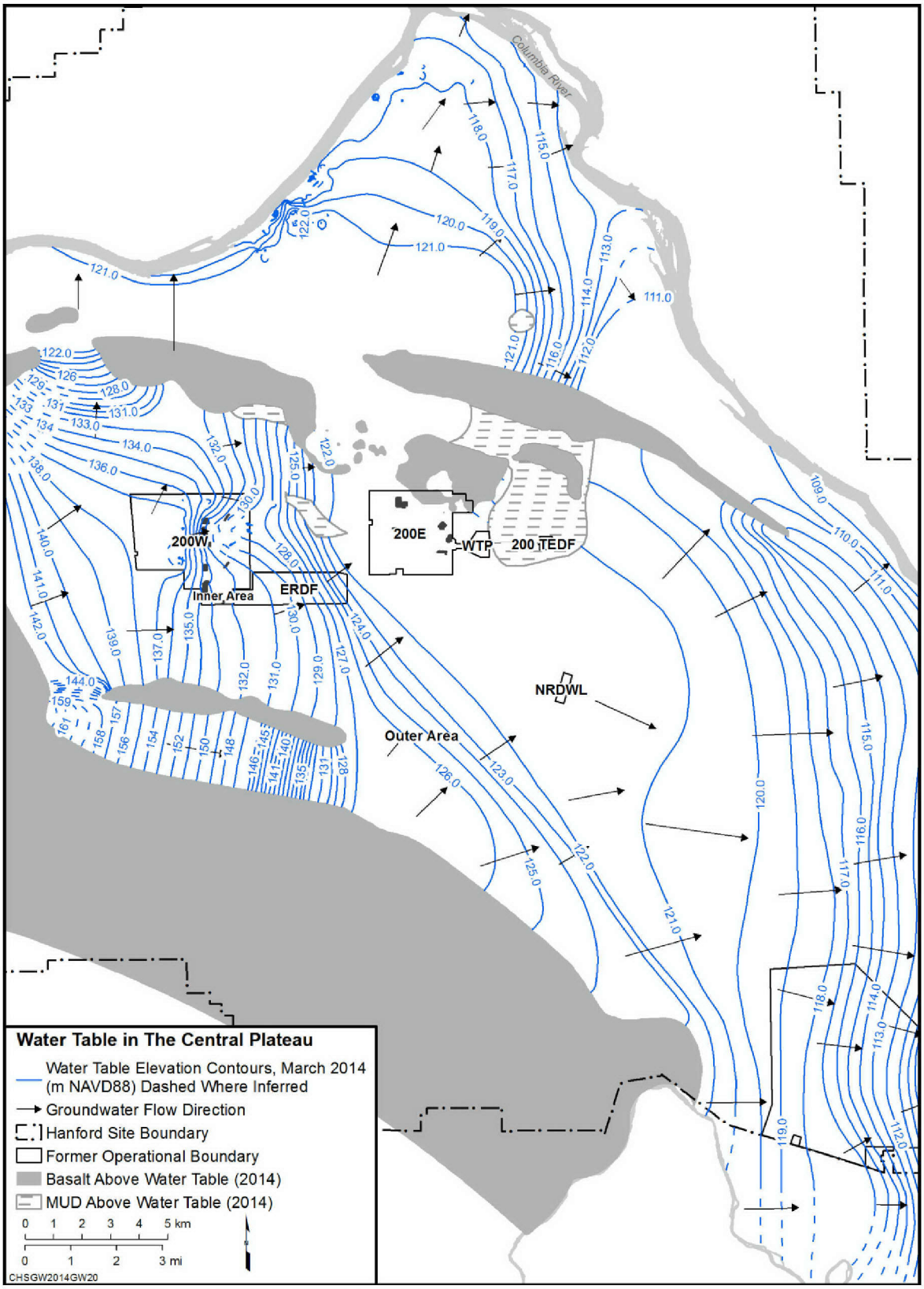
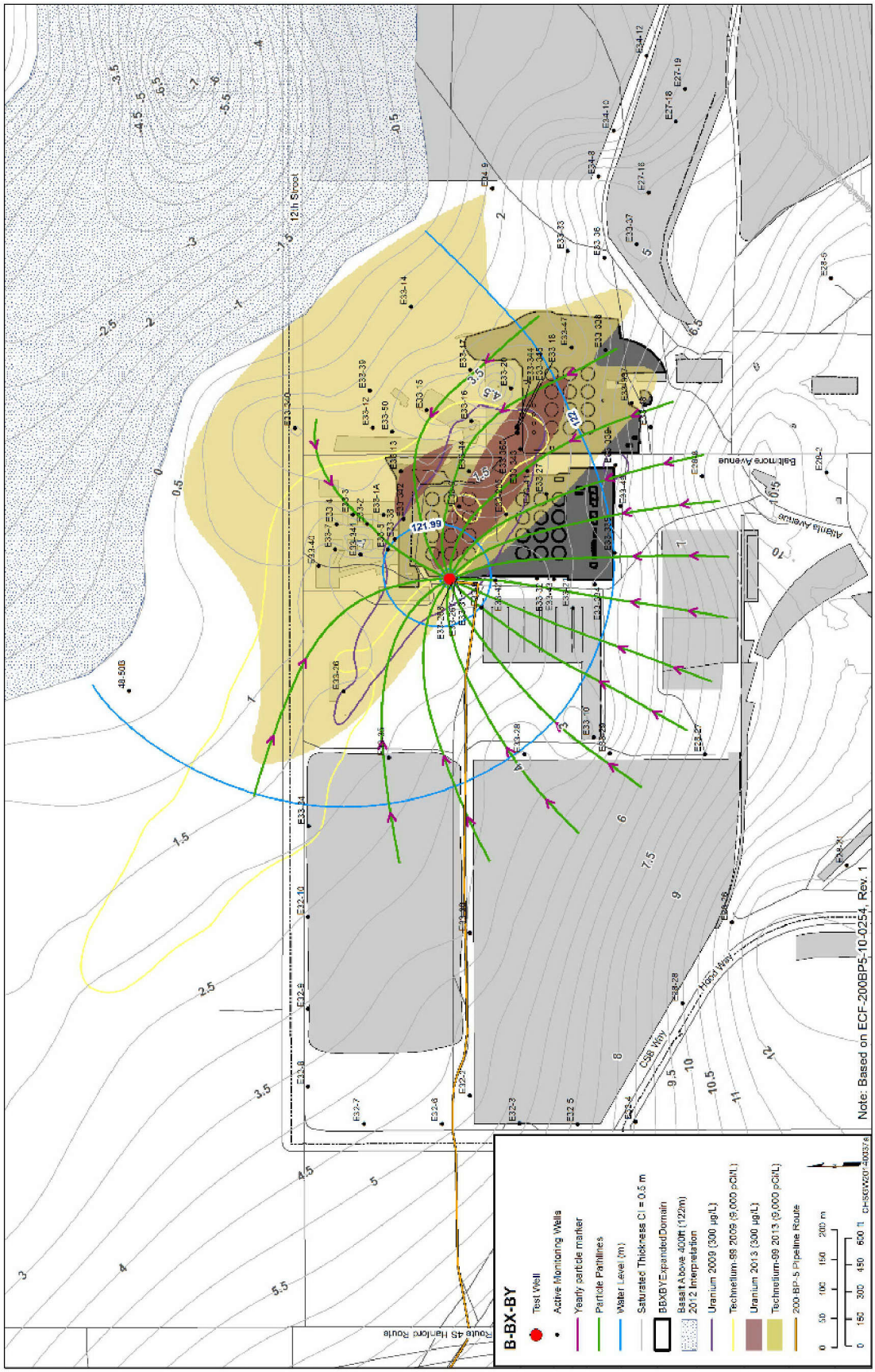


Figure 1-9. Hanford Site Water Table Map Showing Groundwater Flow Directions (2014)



Reference: DOE/RL-2010-74, *Treatability Test Plan for the 200-BP-5 Groundwater Operable Unit*, Figure 4-2 with updated plumes.

Figure 1-10. Conceptual Capture Zone Simulated for 189 L/min (50 gpm)

1.4 Treatment Technology

P&T technology was used to conduct this treatability test and included the use of the 200 West Groundwater Treatment Facility for the treatment of extracted groundwater. An aboveground pipeline was constructed in 2015 to convey groundwater from extraction well 299-E33-268 to the treatment facility (Figure 1-3). The treatment technologies used by the 200 West Groundwater Treatment Facility includes ion exchange (IX) columns to remove radionuclides; fluidized bed reactor (FBR) for removal of nitrate, metals, and volatile organic compounds (VOCs); membrane bioreactor to remove VOCs and filter out biosludge; and air strippers to remove VOCs. A block diagram of the facility is provided in Figure 1-11. DOE/RL-2009-124 discusses the operational philosophy for the P&T system, as well as the programs and procedures in place for preventative, routine, and corrective maintenance. These measures ensure that the system will perform as intended and will operate safely and efficiently. Average contaminant concentrations sent to the facility during the test are provided in Table 1-3 for uranium and technetium-99 and for the following collocated contaminants: cyanide, iodine-129, nitrate, and tritium. Samples were collected at the 299-E33-268 extraction well at 24-hour intervals during the 3-day optimum constant-rate test (~473 L/min [125 gpm]) and weekly during the remaining 30-day constant-rate test (~379 L/min [100 gpm]). Samples were also collected in October and November 2015 within the 200 West Groundwater Treatment Facility. Table 1-3 also shows that average effluent concentrations were below the DWSs before injection at the 200-ZP-1 injection wells.

Table 1-3. Analytical Sample Results for B Complex Contaminants at Three Locations during the 200-BP-5 OU Treatability Test

Contaminant	Average Concentration at Well 299-E33-268	Average Blended Influent Concentration at Treatment Facility[a]	Average Blended Effluent Concentration at Treatment Facility[b]	Federal DWS[c]
Uranium (µg/L)	127	80	1.65	30
Technetium-99 (pCi/L)	7,016	4,530	64	900
Nitrate (µg/L)	436,355	85,000	6,640	45,000
Iodine-129 (pCi/L)	2.75	1.8	0.62	1
Cyanide (µg/L)	296	147	3.4	4.8[d]
Tritium (pCi/L)	12,300	6,290	2,608	20,000

Note: The three test locations were (1) 299-E33-268 wellhead, (2) sample port prior to treatment in the uranium IX, and (3) sample port after 200 West P&T and prior to transfer to the 200-ZP-1 injection wells.

a. Blend of 200-BP-5 and 200-UP-1 extracted groundwater collected prior to uranium IX.

b. Treated blend of 200-BP-5, 200-UP-1, and 200-ZP-1 water discharged from 200 West P&T to the 200-ZP-1 injection wells.

c. Federal DWSs from 40 CFR 141, "National Primary Drinking Water Regulations," with iodine-129 and technetium 99 values from EPA 816-F-00-002, *Implementation Guidance for Radionuclides*.

d. WAC 173-340-705, "Model Toxics Control Act—Cleanup," "Use of Method B," cleanup levels for noncarcinogens at hazard quotient = 1.

DWS = drinking water standard
EPA = U.S. Environmental Protection Agency
IX = ion exchange
P&T = pump and treat

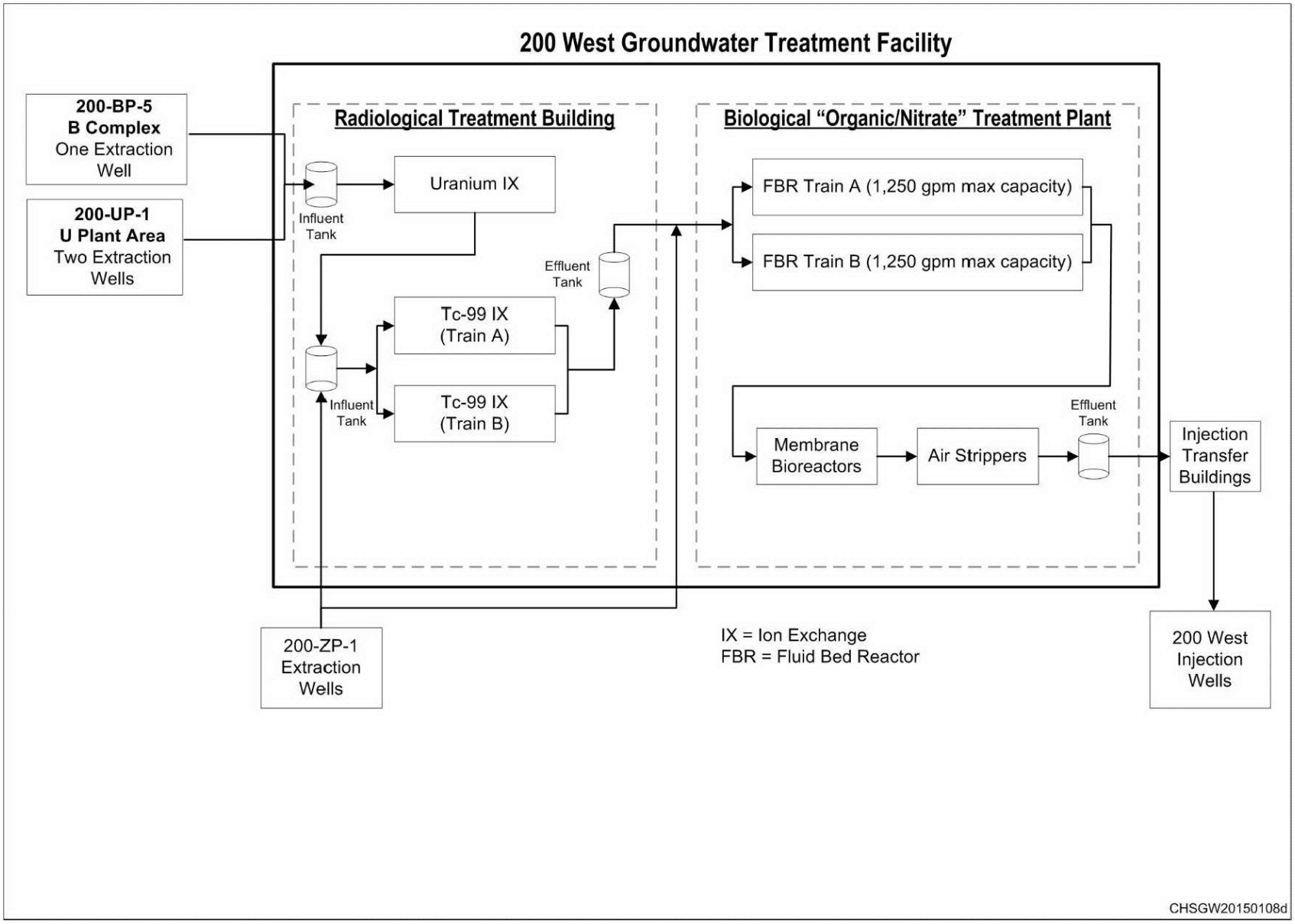


Figure 1-11. Conceptual Block Flow Diagram for the 200-BP-5 OU Treatability Test

2 Treatability Study Approach

Performance objectives/data quality objectives (DQOs) were used to clarify and guide the treatability test approach. Test performance objectives and identified informational needs to accomplish the purpose of the test are provided in this chapter. The DQOs linked the informational requirements with the intended data uses to define the quantity and quality required for the measured variables. The approach provides the logic necessary to ensure that data were collected at the appropriate time under the appropriate conditions.

2.1 Test Objectives and Rational

The objective for the treatability test was to determine whether groundwater pumping at a rate of 189 L/min (50 gpm) can be sustained as a measure of the effectiveness of the P&T alternative to hydraulically contain and reduce the mass of the uranium and commingled technetium-99 plumes near the B Complex. If pumping could be sustained and a reasonable capture zone established, then P&T would be considered a viable technology for containment and cleanup of the commingled plumes at the B Complex. Specific objectives for the treatability test included the following:

- Objective 1 - Determine the sustainable yield of an extraction test well placed near the source of the uranium and technetium-99 plumes.

The sustainable yield can be used to develop and evaluate a P&T alternative in the FS or RD/RAWP.

- Objective 2 - Directly measure aquifer response to sustained pumping near the uranium and technetium-99 plumes, and calculate aquifer properties (i.e., aquifer transmissivity and specific yield) that are representative of large-scale conditions.

The large-scale aquifer property information (transmissivity and specific yield) obtained from the treatability test will be used to refine the localized hydrologic numerical model. The use of a numerical hydrologic model is required to support the design and evaluation of a P&T alternative in the FS and the RD/RAWP. Such models provide a means of rapidly evaluating design alternatives for optimization, demonstrating that regulatory or performance requirements will be met, and estimating remedial action timeframes.

- Objective 3 - Measure the concentrations of uranium and technetium-99 in the extracted groundwater during sustained pumping near the uranium and technetium-99 plumes.

The concentrations of uranium and technetium-99 measured in extracted groundwater will be used to estimate initial mass removal rates by multiplying the concentrations by the pumping rate. The concentrations of uranium, technetium-99, and other constituents in the groundwater also will provide data for waste designation and contaminated groundwater acceptance at the 200 West Groundwater Treatment Facility.

2.2 Data Quality Objectives and Rationale

The DQO summary report (SGW-44329, *200-BP-5 OU Data Quality Objectives Summary Report*) identified the following measurements required for treatability test success:

1. Pumping rates (initial, final, and average)
2. Water levels (initial, intermediate, and final) in the pumping well and specified monitoring wells
3. Observed barometric pressure trends at the test location or the Hanford Meteorological Station

These measurements are required for the calculations identified in treatability Objective 2 in Section 2.1. Equipment considerations for measuring these parameters are discussed in Section 2.3.1.

2.3 Experimental Design, Equipment, and Methodology

The 200-BP-5 OU treatability test consisted of a pumping test at a newly constructed extraction well, 299-E33-268, located west of the BY Tank Farm (Figure 2-1). The test design considered the aquifer transmissivity, the nearly flat water table gradient, and the thin aquifer. The test plan predicted little drawdown in most of the monitoring wells (Figures 2-1 and 2-2), and temporal changes to the groundwater gradient after removal of barometric effects (Figure 2-3).

2.3.1 Design and Equipment for the Treatability Test

This section presents the equipment, design, and rationale used for completing this successful test given the aquifer characteristics:

- The extraction well screen was extended across the entire saturated thickness of the unconfined aquifer to match the assumptions inherent in the methods used for analysis of the drawdown and recovery data.
- Numerical modeling was used to estimate a pumping rate sufficient to create measurable drawdown. ECF-200BP5-10-0254 predicted measurable drawdowns of 1 cm (0.4 in.) with a pumping rate of 189 L/min (50 gpm) at 150 m (492 ft) from the extraction well (Figure 2-2).
- A well screen slot size (65 mesh) and sediment pack (6-12 silica sand) were selected based on aquifer characteristics for a 568 L/min (150 gpm) groundwater pumping rate.
- A 25.4 cm (6 in.) Grundfos® 230S250-8 pump was installed in the extraction well to reach pumping rates of up to 568 L/min (150 gpm).
- A 20.3 cm (8 in.) diameter well with a 3 m (10 ft) long sump was used to house the extraction pump and associated downhole equipment. Details of the well installation are presented in SGW-52357, *Borehole Summary Report for the Installation of Two Wells in the 200-BP-5 Operable Unit, FY2012*.
- A shroud was installed to direct water into the sump and around the pump motor to cool the motor during pumping (Figure 2-4).
- A foot valve was installed in the bottom of the pump to stop water from back-flowing into the well and aquifer during the recovery period (Figure 2-5).
- Barometric and water level transducers (absolute Barologger® [Solinst 3100 Gold] for barometric pressure readings and absolute Levelogger® [Solinst 3100 Gold] for water pressure reading) with variable time settings and large memory capacity were used to reduce the signal-to-noise ratio for measuring small water level changes during pumping within the monitoring well network (Figure 2-6).
- Seven existing monitoring wells were used to collect drawdown measurements during the test for deriving aquifer hydraulic parameters (Figure 2-1).

® Grundfos is a registered trademark of Grundfos Pumps Corporation, Fresno, California.
® Barologger and Levelogger are registered trademarks of Solinst, Georgetown, Ontario, Canada.

- Two existing monitoring wells, 299-E34-10 and 699-49-57A, located 1 km (0.62 mi) or more from the extraction well were used to measure background temporal water level changes during the test at locations not affected by pumping.
- An electromagnetic flow meter (Endress+Hauser, [1] Promag 53P50, 2 in.) with variable time settings and large memory was used for monitoring and adjusting the pump extraction rate (Figure 2-7).
- New monitoring well 299-E33-267 was installed 4.6 m (15 ft) from the extraction well, halfway between the extraction well and existing well 299-E33-31, to increase the probability of acquiring sufficient drawdown data at multiple well sites for improved estimates of aquifer transmissivity and storativity (Figure 2-1).
- A sample port was installed to collect groundwater samples during extraction (Figure 2-8).
- A pressure-indicating transmitter (Endress+Hauser, Cerabar S PMP71) was installed to measure in-line water pressure, ensure flow through the electromagnetic flow meter, and verify suitable pressure within the conveyance pipe (Figure 2-9).
- A 30-day baseline water table measurement period was completed to normalize the barometric water level response for each well used in the test.
- Three sequential 2-hour step drawdown tests were performed to define the optimum sustainable pumping rate at the extraction well for the 3-day constant-rate test.
- The 3-day constant-rate pumping test was performed to measure water table drawdown at several monitoring wells for derivation of aquifer hydraulic parameters.
- The 3-day and following 27-day constant-rate tests were completed to determine mass removal rates by the extraction well with samples collected daily and weekly.

2.3.2 Approach for Normalization of Hydraulic Heads to a Constant Barometric Pressure

This section describes the method used to normalize water level measurements to a constant barometric or atmospheric pressure.

Within unconfined aquifers, changes in ambient barometric pressure can cause changes in well water level elevations if the barometric change causes an imbalance of air pressure between the well and the adjacent vadose zone at the water table. This occurs in relatively deep wells because of the thick vadose zone and in other wells where low-permeability units within the vadose zone inhibit the migration of air pressure pulses. Barometric pressure changes introduce variability into water level measurements in two ways: (1) barometric pressure may change while a set of water level measurements is collected from a well network, and (2) different wells may respond differently to barometric pressure changes. To account for these sources of variability, the water level measurements collected for the treatability test were normalized to a constant barometric pressure using multiple regression/deconvolution (Rasmussen and Crawford, 1997, "Identifying and Removing Barometric Pressure Effects in Confined and Unconfined Aquifers;" Spane, 2002, "Considering barometric pressure in groundwater flow investigations").

[1] Endress+Houser, Inc., Greenwood, Indiana

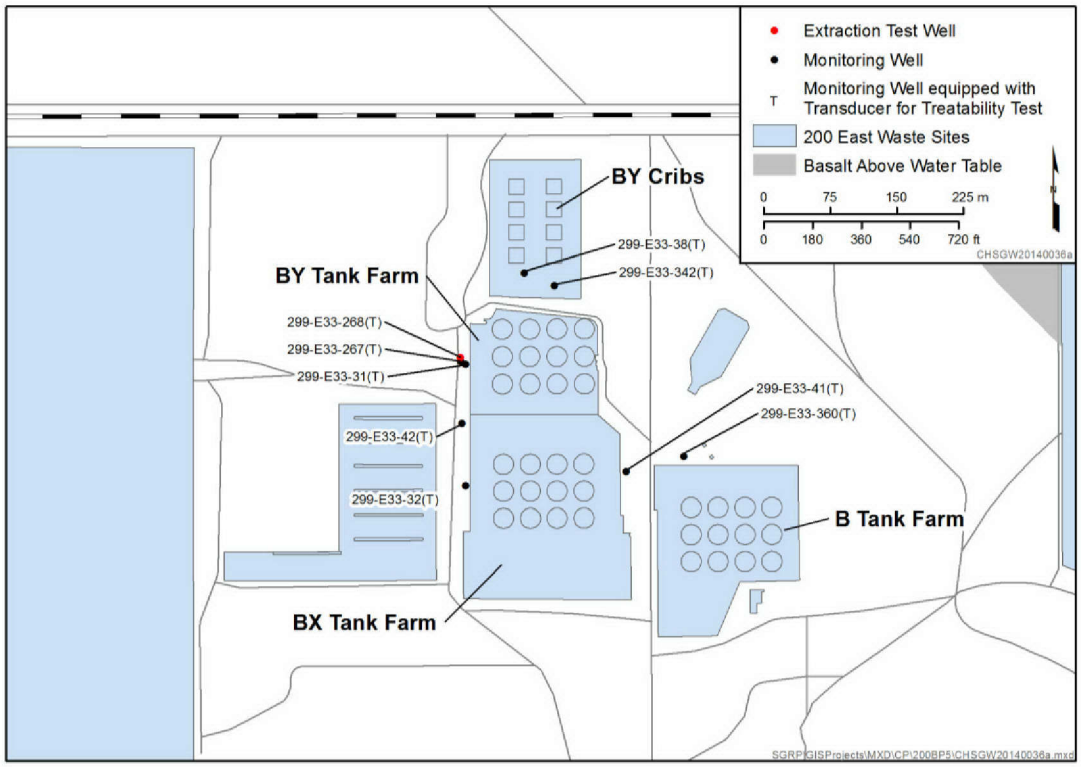


Figure 2-1. Location of Extraction Test Well 299-E33-268 and Associated Groundwater Monitoring Wells for the Treatability Test near the B Complex

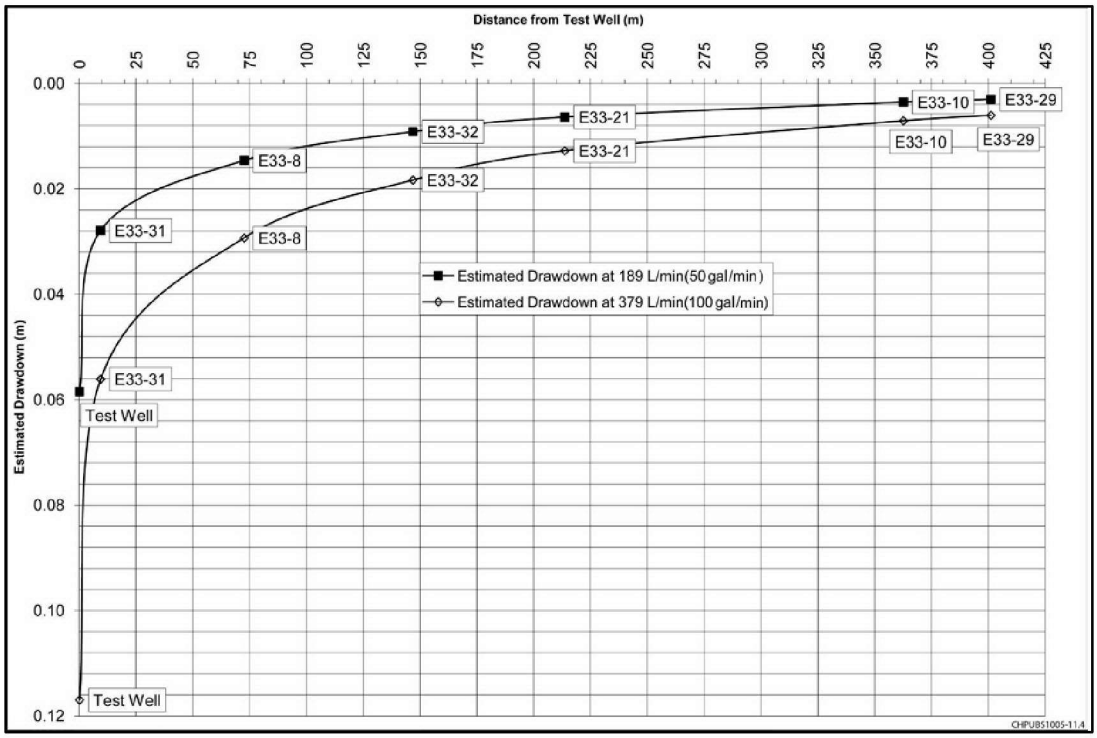


Figure 2-2. Estimated Water Level Drawdown at Pumping Rates of 189 and 379 L/min (50 and 100 gpm) in the Vicinity of the Extraction Well Using the Initial Hydrologic Numerical Model

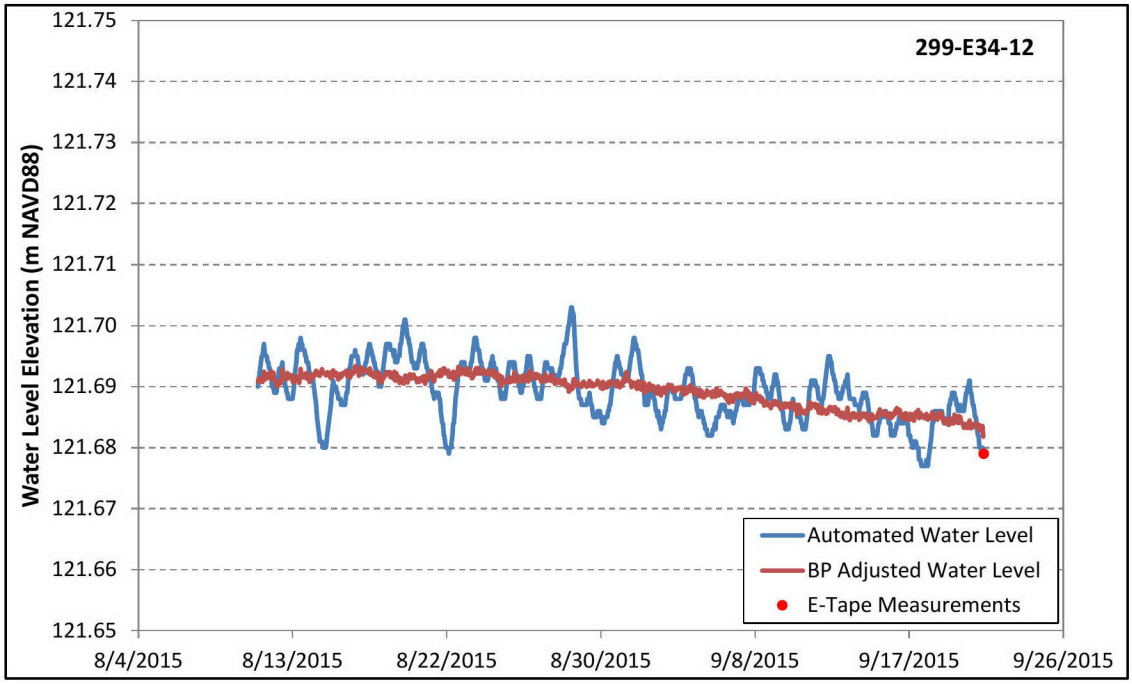


Figure 2-3. Declining Water Elevation Because of Subsiding Columbia River Spring Stages, and Comparison of Automated Water Level Measurement Uncorrected for Barometric Effects and Barometrically Corrected Water Level Measurement for Well 299-E34-12

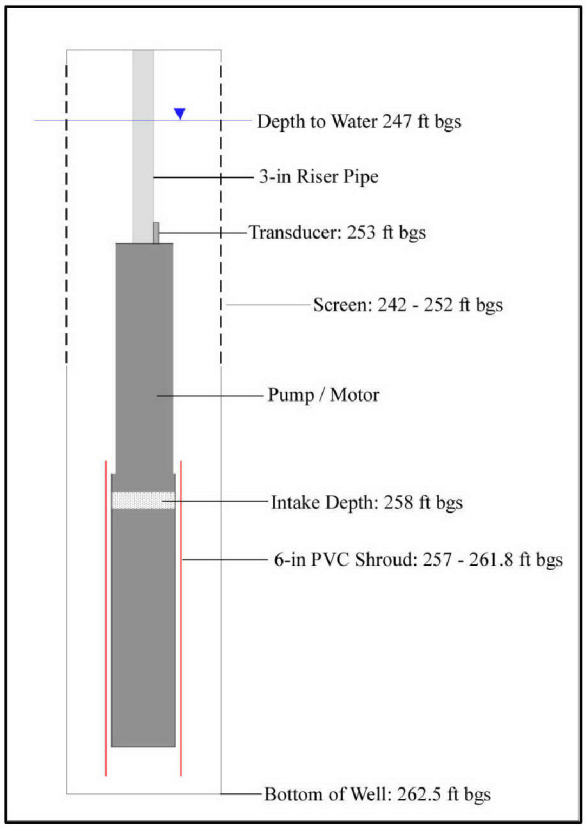


Figure 2-4. Configuration of Extraction Well 299-E33-268

Figure 2-5. Foot Valve Located on the Bottom of the Pump in Well 299-E33-268

Figure 2-6. Transducer Assembly and Shroud at Well 299-E33-268

Figure 2-7. Endress+Hauser Electromagnetic Flow Meter at 299-E33-268

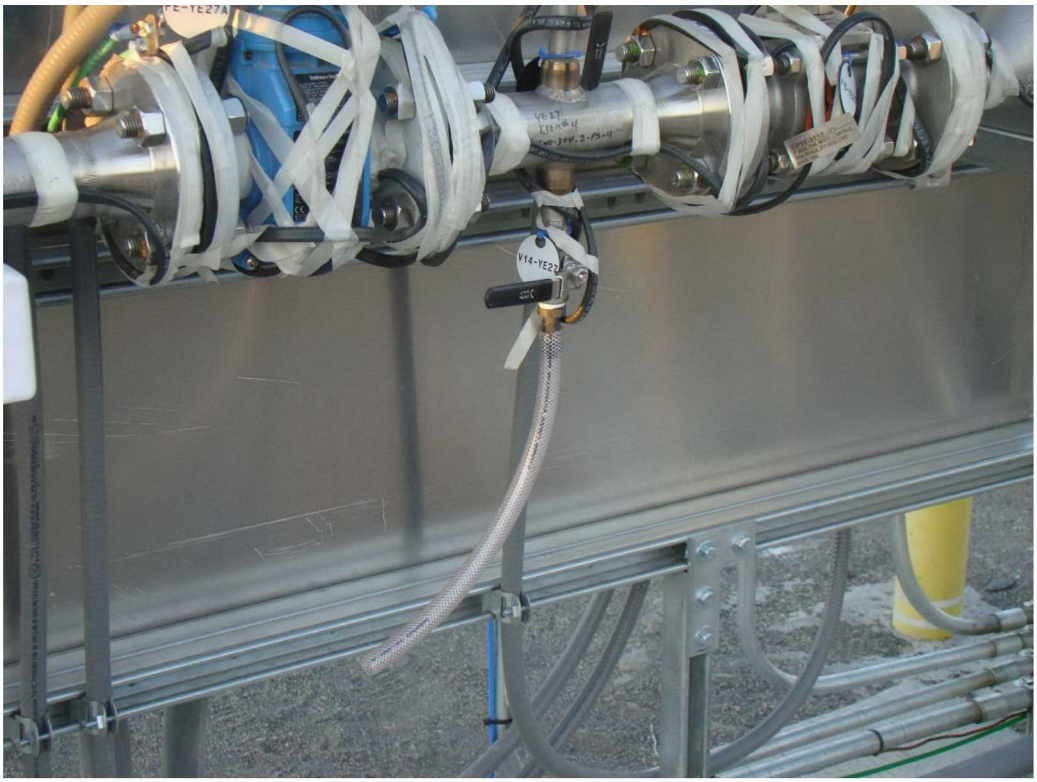


Figure 2-8. Sampling Port at 299-E33-268, Also referred to as YE27 by 200 West P&T

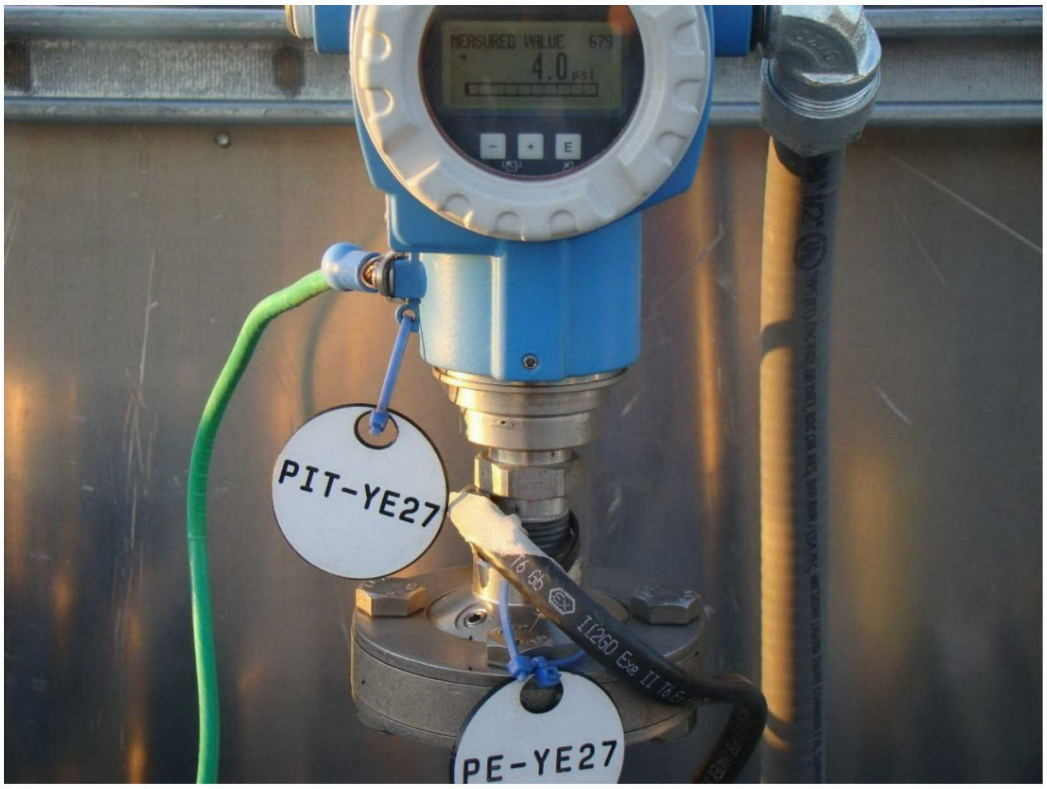


Figure 2-9. Line Pressure Gauge at Well 299-E33-268

Using the 30-day baseline water level data for the pumping well and each monitoring or observation well, multiple regression was used to determine the quantitative relationship between barometric pressure and well water level response (using time series data for both parameters). This relationship was then used to determine a barometric response function (BRF) describing how the well water level would change in response to an instantaneous unit change in barometric pressure.

The multiple regression was performed using the Multiple Regression in Excel (MRCX) software developed by Pacific Northwest National Laboratory (PNNL-19775, *Guide to Using Multiple Regression in Excel (MRCX v. 1.1) for Removal of River Stage Effects from Well Water Levels*). MRCX is based on Microsoft Excel®. Although this software was specifically designed for assessing river stage effects, it can also be used for barometric pressure effects because the mathematical equations are identical. The water level measurements and barometric pressure time series were detrended (using Excel) and then input into MRCX. The regression was performed using the "original data" or "first differences" options in MRCX, whichever provided the best results. The original data option corresponds to the following regression equation from Rasmussen and Crawford, 1997, Equation 7:

$$h_O(t) = \beta_0 + \beta_1 t + \Delta u_0 B(t) + \Delta u_1 B(t-1) + \ldots + \Delta u_n B(t-n) \qquad \textbf{(Equation 1)}$$

where:

h_O = observed well water level elevation (m) as a function of time t (hr)

β_0 = offset coefficient (m)

® Excel is a registered trademark of Microsoft Corporation, Redmond, Washington.

β_1 = linear trend coefficient (m/hr) (which was determined to be 0 during the regression analysis because the data were detrended beforehand)

Δu_n = fitted barometric response coefficient (i.e., regression coefficients) for time lags of 0 to n (m/m)

B = barometric pressure measurements (m of water) as a function of time

n = maximum time lag (hr)

The first differences option uses an equation of the same form, except that changes in water levels are related to changes in barometric pressure:

$$\Delta h_O(t) = \beta_0 + \beta_1 t + \Delta u_0 \Delta B(t) + \Delta u_1 \Delta B(t-1) + \ldots + \Delta u_n \Delta B(t-n) \qquad \textbf{(Equation 2)}$$

where:

Δh_O and ΔB = change in observed well water level elevation and change in barometric pressure, respectively, between successive times

When performing the multiple regression in MRCX, the maximum time lag (n) was increased to a value at which a good fit was achieved between the predicted and measured water levels, and a further increase did not substantially improve the fit. The BRF was determined by MRCX from the regression coefficients as follows (Rasmussen and Crawford, 1997, Equation 5):

$$u(\tau) = \sum_{i=0}^{\tau} \Delta u_i \qquad \textbf{(Equation 3)}$$

where:

u = water level response (m) to an instantaneous unit change in barometric pressure as a function of the time lag, τ (hr)

The BRFs for each well used in this test are provided in Appendix A.

Deconvolution was used to normalize the water level measurements collected for this test to a constant barometric pressure using Excel. The net change in well water level in response to a recent history of barometric pressure changes (n + 1 hourly measurements total) was computed using the following numerical approximation of a convolution integral (Rasmussen and Crawford, 1997, Equation 4):

$$\Delta h_B(t) = \sum_{\tau=0}^{n} u(\tau) \cdot \Delta B(t-\tau) \qquad \textbf{(Equation 4)}$$

where:

Δh_B = change in well water level elevation (m) at some time t (hr) resulting from changes in barometric pressure for the previous n time lags

τ = time lag (hr) between a previous hourly barometric pressure change and the associated well water level response at the current time

ΔB = change in barometric pressure (m of water) over the previous hourly time steps

Finally, the change in well water level elevation was added or subtracted as appropriate to the observed well water level elevation (i.e., deconvolved) to produce an adjusted well water level elevation in which barometric pressure effects had been removed (i.e., normalized to a constant barometric pressure).

The equations presented in Rasmussen and Crawford, 1997, are written in terms of total head (i.e., the sum of hydraulic head and barometric pressure head), whereas the equations presented in this section are in terms of hydraulic head (i.e., well water level elevation). To normalize water level measurements to a constant barometric pressure, well water level response functions are needed instead of total head response functions. The use of well water level elevations instead of total head is valid because convolution can be used on any pair of variables exhibiting a linear stress-response relationship (Olsthoorn, 2008, "Do a Bit More with Convolution").

2.3.3 Approach to Determination of Optimal Sustainable Pumping Rate

The step drawdown test was designed to determine an optimum pumping rate for the 3-day constant-rate test. The step drawdown test included pumping from well 299-E33-268 at 189, 379, and 586 L/min (50, 100, and 150 gpm), based on hydrologic numerical model aquifer responses from ECF-200BP5-10-0254. The pumping rates were expected to encompass the range of sustained pumping rates that would yield drawdown in monitoring wells sufficient to calculate aquifer hydraulic parameters accurately during the 3-day constant-rate test (DOE/RL-2010-74). Thus, the following were completed as required by DOE/RL-2010-74:

- Design and construct a test well calculated to produce laminar flow at rates exceeding 586 L/min (150 gpm).
- Install automated water level measuring devices at well 299-E33-268 and associated monitoring wells.
- Complete a 30-day baseline barometric pressure evaluation.
- Monitor water level changes in response to temporal river stage fluctuations and TEDF discharges.

2.3.4 Approach to Determination of Large-Scale Hydraulic Parameters

Objective 2 was to initiate an optimum pumping rate, as determined from Objective 1, for up to 3 days and up to 568 L/min (150 gpm), followed by pumping at an average rate of at least 189 L/min (50 gpm) and not to exceed 568 L/min (150 gpm), for a total pumping duration of 30 days or more (DOE/RL-2010-74). To measure the water table response and for calculation of the large-scale aquifer properties, the same requirements as those in Objective 1 were required. One additional requirement from DOE/RL-2010-74 was to upload the derived hydraulic properties from this test into a local-scale hydrologic numerical model to update plume capture simulations.

Barometrically corrected water level drawdown data used for this test, as discussed in Section 2.3.1, were obtained from the 3-day constant-rate discharge test and analyzed using the AQTESOLV[2] software. AQTESOLV can be used to derive aquifer hydraulic parameters from the water level drawdown and recovery test data using various analysis methods. The various methods are applicable to a variety of situations (e.g., slug tests, pump tests, confined aquifers, unconfined aquifers, and leaky confined aquifers). Drawdown data from constant-rate discharge tests can be directly analyzed to estimate hydraulic properties by applying the three methods that follow this paragraph. However, to analyze recovery data using these methods, the water level recovery data obtained after pumping stops must be expressed in terms of the Agarwal equivalent time (Agarwal, 1980, "A New Method to Account for Producing Time Effects when Drawdown Type Curves are Used to Analyze Pressure Buildup and other Test Data") discussed in Section 2.3.4.4. The following three methods were used to derive large-scale aquifer hydraulic parameters from barometrically corrected water level drawdown data:

[2] AQTESOLV is copyrighted by HydroSOLVE, Inc., Reston, Virginia.

1. Theis, 1935, "The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage," as modified by Hantush, 1961a, "Drawdown around a Partially Penetrating Well," and Hantush, 1961b, "Aquifer Tests on Partially Penetrating Wells"
2. Neuman, 1974, "Effect of Partial Penetration on Flow in Unconfined Aquifers Considering Delayed Gravity Response"
3. Moench, 1997, "Flow to a Well of Finite Diameter in a Homogeneous, Anisotropic, Water Table Aquifer"

2.3.4.1 Method 1 - Theis

The Theis method was developed for nonsteady flow to a fully penetrating well in a confined aquifer. The equations are as follows (Freeze and Cherry, 1979, *Groundwater*):

$$s = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-u}}{u}du \qquad \textbf{(Equation 5)}$$

in which:

$$u = \frac{r^2 S}{4Tt} \qquad \textbf{(Equation 6)}$$

where:

s = drawdown from static water level (length)
Q = pumping rate (length^3/time)
T = transmissivity (length^2/time)
r = radial distance from the pumping well to the observation well (length)
S = storage coefficient (unitless)
t = time (time)

The integral in Equation 6 is the exponential integral and is commonly represented as a function, $W(u)$, known as the well function. Values of the well function can be determined numerically.

Hantush (1961a,b) extended the Theis method to account for partially penetrating wells and anisotropy (vertical hydraulic conductivity can differ from the horizontal hydraulic conductivity). The equations are complex: details are provided in Hantush, 1961a,b, and the AQTESOLV online help.

Although developed for confined aquifers, the Theis/Hantush method can be used to determine hydraulic properties for unconfined aquifers if the amount of drawdown is small relative to the aquifer thickness (Freeze and Cherry, 1979). Once infinite-acting radial flow conditions have been achieved during the test, straight-line analysis methods can be used (e.g., Cooper and Jacob, 1946, "A Generalized Graphical Method for Evaluating Formation Constants and Summarizing Well-Field History"). This condition is indicated by a constant pressure derivative following the wellbore storage and gravity drainage responses (PNL-8539, *Selected Hydraulic Test Analysis Techniques for Constant-Rate Discharge Tests*). The advantage of the straight-line method is that it can be readily implemented graphically; however, type curves were used for analyzing the 200-BP-5 OU treatability test data because these curves can be automatically or manually fitted with AQTESOLV software.

2.3.4.2 Method 2 - Neuman

The Neuman (1974) method was developed for nonsteady flow to a fully or partially penetrating well in a homogeneous, anisotropic unconfined aquifer with delayed gravity drainage from the vadose zone. The anisotropy component refers only to differences between the horizontal and vertical hydraulic conductivity with the horizontal hydraulic conductivity isotropic (i.e., constant regardless of direction). Additional details are provided in Neuman, 1974, and the AQTESOLV online help.

2.3.4.3 Method 3 - Moench

Like Neuman's method, the Moench (1997) method also applies to nonsteady flow to a fully or partially penetrating well in a homogeneous, anisotropic (horizontal versus vertical hydraulic conductivity only) unconfined aquifer with delayed gravity drainage from the vadose zone. However, the method also includes wellbore storage and skin effects. Thus, drawdown in the pumping well can be included in the analyses, whereas with the other methods, only observation well drawdown data are used. Additional details are provided in Moench, 1997, and the AQTESOLV online help.

2.3.4.4 Evaluation of Water Level Recovery Data

To analyze water level recovery data using these methods, the buildup of the water level after the termination of pumping has to be expressed in terms of the Agarwal equivalent time, as follows:

$$t_e = \frac{t \cdot t'}{t + t'} \qquad \textbf{(Equation 7)}$$

where:

t_e = Agarwal equivalent time
t = duration of pumping
t' = time since pumping terminated

Pressure derivatives were calculated using the method of Spane and Wurstner, 1993, "DERIV: A Computer Program for Calculating Pressure Derivatives for Use in Hydraulic Test Analysis."

2.4 Numerical Model Analysis

As required by DOE/RL-2010-74, the derived hydraulic properties from this treatability test were to be used to update local-scale hydrologic numerical model plume capture simulations. A local-scale telescopic mesh refinement (TMR) model, part of the Central Plateau to Columbia River (P2R) model, was used to update local-scale hydrologic numerical model plume capture simulations.

A previous plume modeling exercise was performed to evaluate alternative well locations for the treatability test on the basis of whether the unconfined aquifer in these locations exhibited hydraulic properties that would be sufficient to allow sustained pumping at 189 L/min (50 gpm) or higher (DOE/RL-2010-74). The timing of the previous numerical model analysis was the point at which groundwater declines in 200 East Area resulted in water levels being nearly equal to water levels in Gable Gap. As a result, groundwater contamination beneath certain waste sites in the B Complex area was increasing to historical highs, indicating flow was nearly stagnant.The previous simulated capture zone produced a circular geometry (Figure 1-10), reflecting the nearly stagnant groundwater flow conditions at the time. Hydraulic parameters used for the previous capture zone included porosity of 0.15 and horizontal hydraulic conductivity of 3,000 m/day, with no discernable gradient. Since mid-2011, the groundwater flow direction has become predominantly southeast at the B Complex (Figure 1-5).

The new model will use the hydraulic parameters derived from this test to simulate the update plume capture for comparison to actual field measurements. The model design and basis for the hydraulic parameters for the local-scale TMR and regional P2R model are summarized in the following paragraphs.

The P2R model was designed to support the evaluation of contaminant plumes that have migrated or will migrate beyond the Central Plateau (CP-57037, *Model Package Report: Plateau to River Groundwater Transport Model, Version 7.1*). Figure 2-10 shows the areal extent of the numerical model grid for the P2R model. Each grid block measures 200 m by 200 m (656 ft by 656 ft).

The methodology for developing the local-scale TMR model is to extract the numerical model and simulated outputs from the P2R model as inputs for the TMR model (Figure 2-11). The grid for the TMR model ranges from 2 m by 2 m near important well locations to 200 m by 200 m when nearing the outer boundary, to align with the P2R model grid spacing (Figure 2-12).

Both the P2R and the B Complex TMR models are implemented in MODFLOW to calculate groundwater flow. The TMR model spans the B Complex and Gable Gap evaluation areas of the P2R model (Figure 2-12). The TMR model head values were adjusted to the local low-gradient water table as shown in Figure 1-5. The groundwater gradient as defined by the low-gradient water table is 6.5×10^{-6} m/m in a southeastern direction. More discussion is provided in Appendix B.

The geologic representation for the TMR model was the same as that for the P2R model, which was derived from the 2013 Hanford South Geoframework (soil) Model (ECF-Hanford-13-0029, *Development of the Hanford South Geologic Framework Model, Hanford Site Washington*). The model includes geologic interpretations for the 200-BP-5 OU through the end of 2013, including interpretations from the geophysical work completed between 2008 and 2012. The soil model has seven layers used to represent the hydrostratigraphic units within the P2R model; however, within the B Complex area, only two layers were used because of the thin aquifer (Figure 2-13). The B Complex sediments reflect mainly CCU gravels associated with the paleochannel that extends from Gable Gap to the 200 East Area. The hydraulic properties associated with the CCU gravels, as defined by the model, are as follows: porosity of 0.2 and horizontal hydraulic conductivity of 17,000 m/day (Table 2-1). Further discussion is provided in Appendix B.

2.5 Sampling and Analysis

Groundwater quality data were collected during constant-rate pumping of the treatability test to estimate the mass removal rate of site-related contaminants. Samples were collected at the 299-E33-268 extraction well at 24-hour intervals during the 3-day constant-rate test (~473 L/min [125 gpm]) and weekly during the remaining 30-day constant-rate test (~379 L/min [100 gpm]), in accordance with Table 2-2 (DOE/RL-2010-74). Groundwater samples collected from the test well were analyzed for cyanide, iodine-129, nitrate, technetium-99, tritium, and uranium. One field duplicate sample was collected for each constituent during the test to evaluate the consistency and precision of field sampling methods. The mass removed during the constant-rate test was estimated by multiplying the average sample concentration by the average pumping rate and elapsed time.

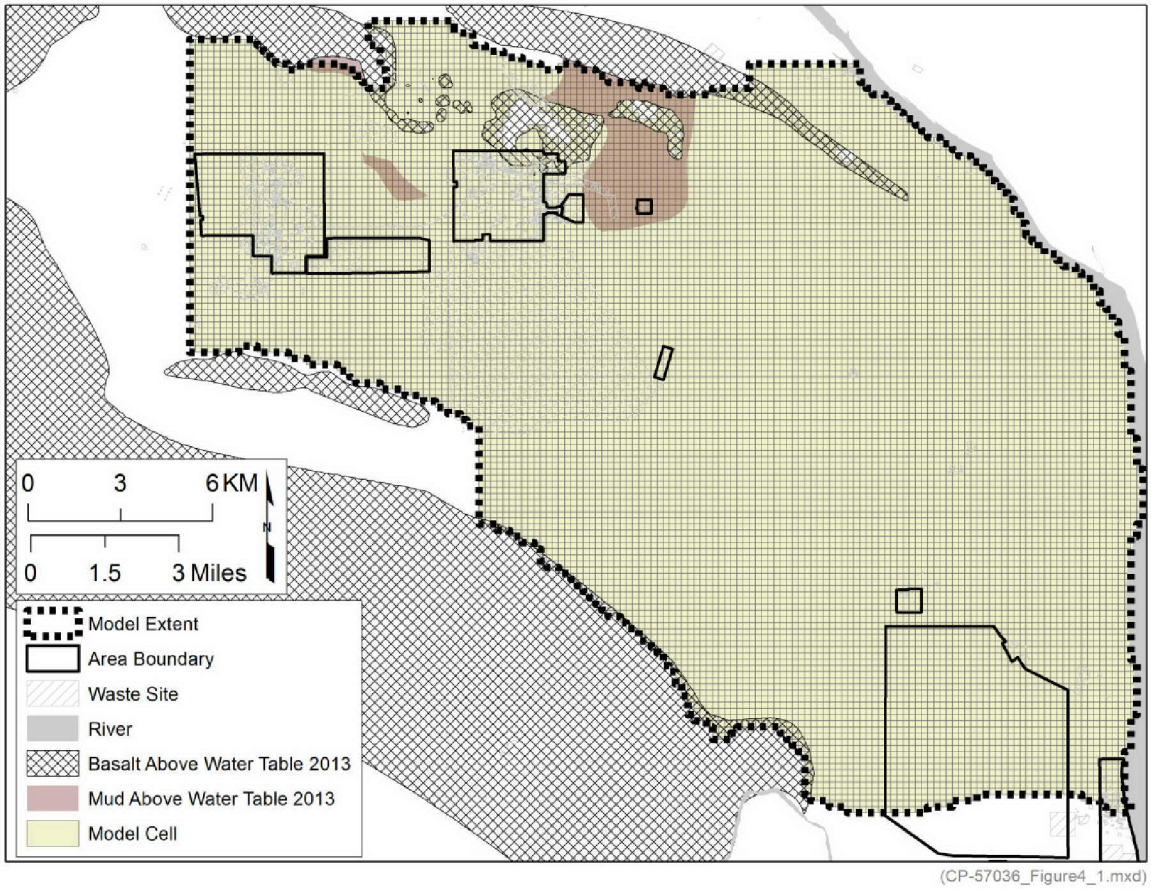


Figure 2-10. Model Domain and Model Grid for the P2R Model

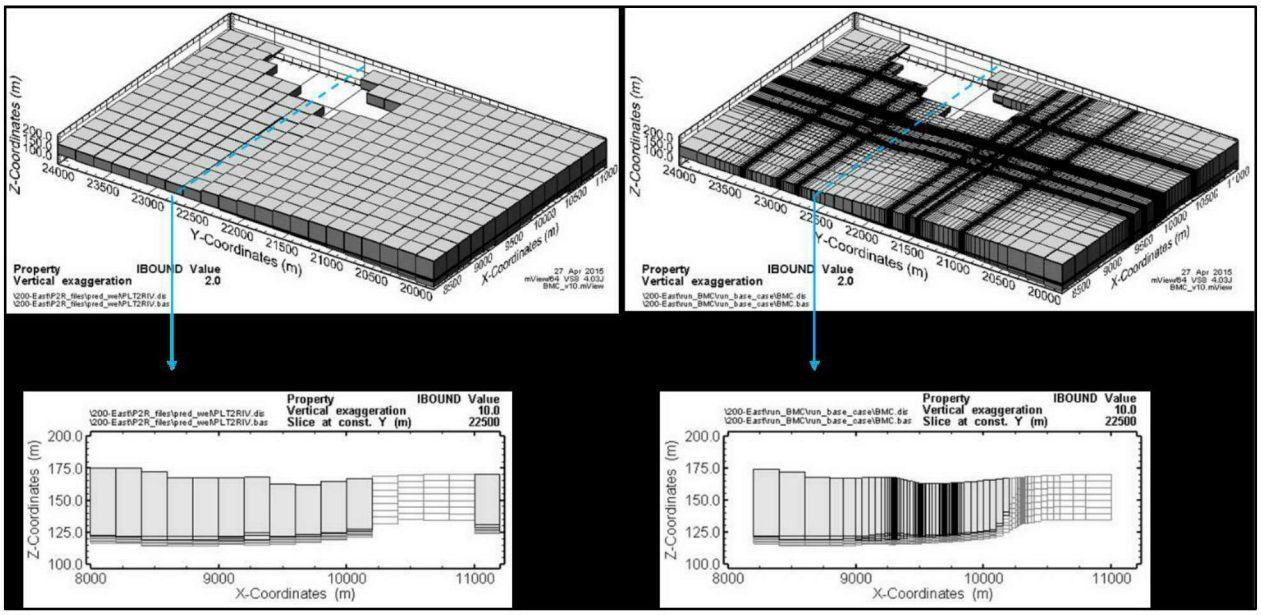


Figure 2-11. Comparison of P2R Model (left) and B Complex TMR Model (right)

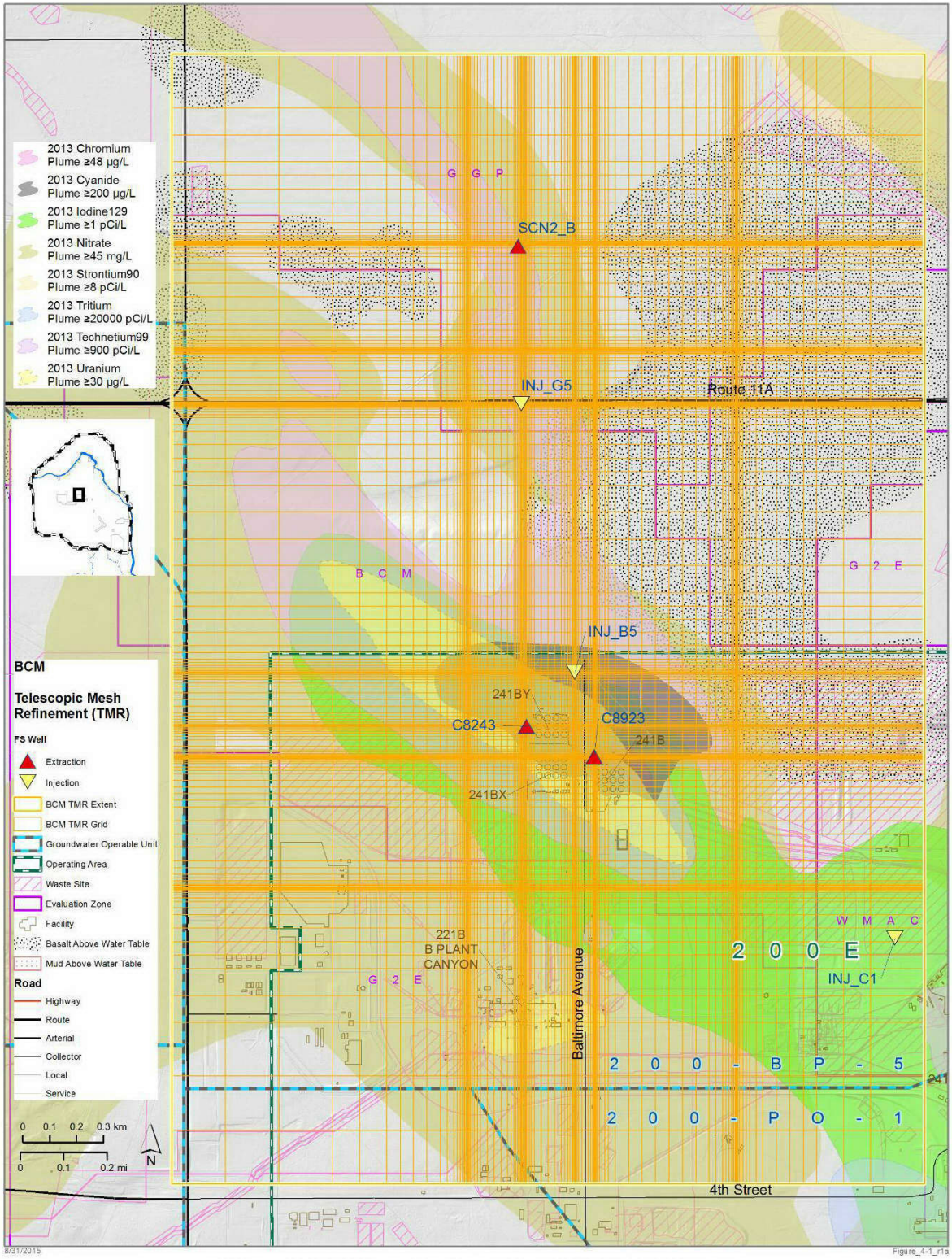
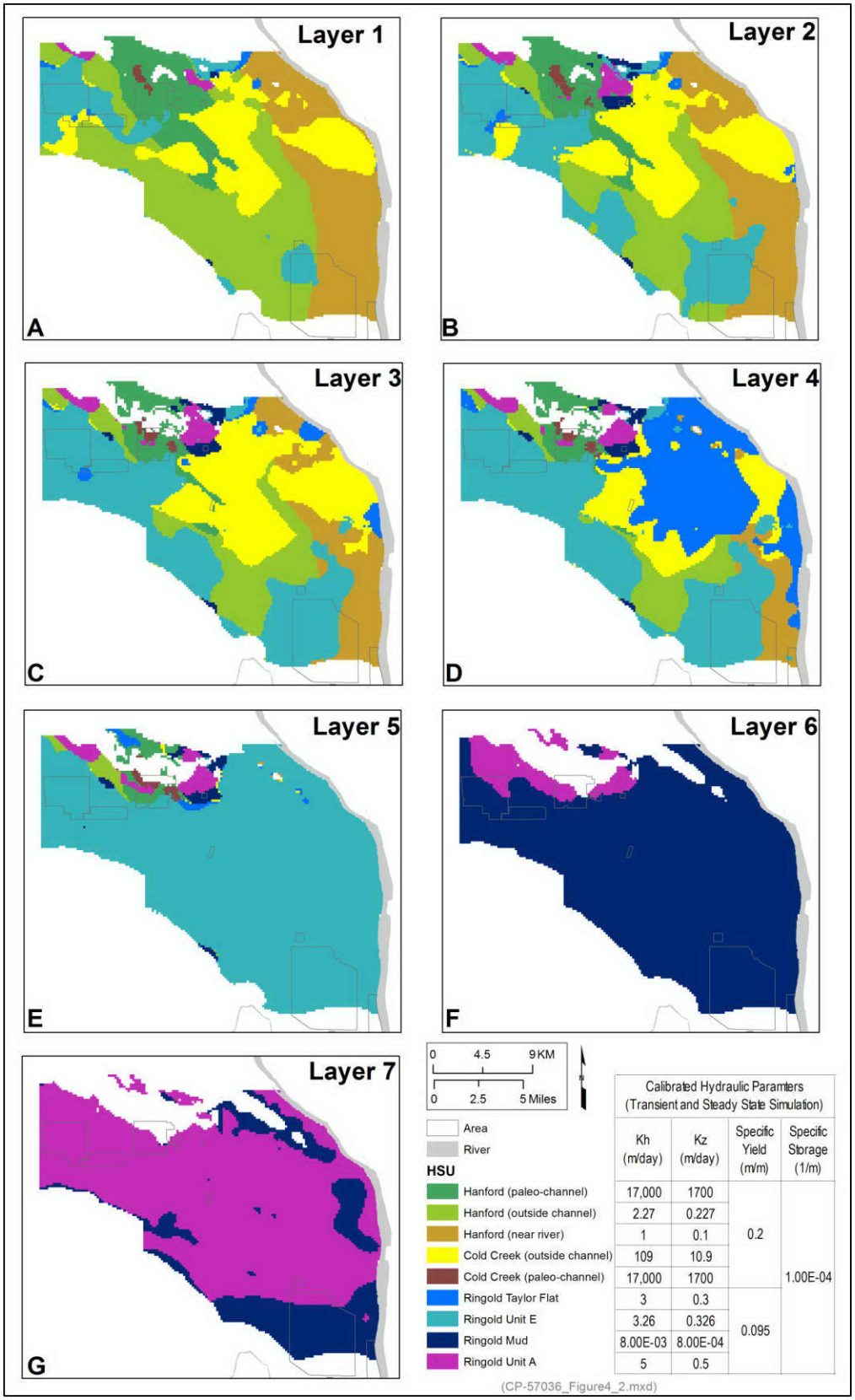


Figure 2-12. B Complex Local Scale TMR Model Extent



Calibrated Hydraulic Paramters (Transient and Steady State Simulation)

HSU	Kh (m/day)	Kz (m/day)	Specific Yield (m/m)	Specific Storage (1/m)
Hanford (paleo-channel)	17,000	1700	0.2	1.00E-04
Hanford (outside channel)	2.27	0.227		
Hanford (near river)	1	0.1		
Cold Creek (outside channel)	109	10.9		
Cold Creek (paleo-channel)	17,000	1700		
Ringold Taylor Flat	3	0.3	0.095	
Ringold Unit E	3.26	0.326		
Ringold Mud	8.00E-03	8.00E-04		
Ringold Unit A	5	0.5		

Figure 2-13. Hydrostratigraphic Unit Assignment to Model Layers with the P2R Model Domain

Table 2-1. Hydraulic Properties and Ranges Used for P2R Model

Property	Units	Hydrostratigraphic Unit	Low	High	Calibrated: Steady State and Transient Simulations
Hydraulic Conductivity	m/day	Hanford, Cold Creek, (paleo-channel)	1	37,000	17,000
		Hanford (outside paleo-channel)	0.1	19.7	2.27
		Hanford (near Columbia River)	0.9	62	1
		Cold Creek	1	400	109
		Cold Creek (paleo-channel)	1	37,000	17,000
		Ringold Taylor Flat*	1	20	3
		Ringold E	0.1	18.6	3.26
		Ringold Upper Mud	2e-4	0.03	8E-03
		Ringold A	1	8	5
Vertical Anisotropy of Hydraulic Conductivity	-/-	All	0.01	0.1	0.1
Specific Yield	m/m	Hanford and Cold Creek	0.1	0.37	0.2
		Ringold	0.05	0.11	0.095
Specific Storage	1/m	All	2.3E-05	1.2E-03	1E-04

Reference: CP-57037, *Model Package Report: Plateau to River Groundwater Transport Model Version 7.1* (Table 4-4).

* No description for this soil type is within the hydraulic properties database or the previous modeling efforts. Range of values assumed based on pumping test values from other Hanford (outside paleo-channel) and Ringold E values.

2.6 Waste Streams

All waste, including waste generated by sampling activities, was managed in accordance with DOE/RL-2003-30, *Waste Control Plan for the 200-BP-5 Operable Unit*, pursuant to 40 CFR 300.440, "National Oil and Hazardous Substances Pollution Contingency Plan," "Procedures for Planning and Implementing Off-Site Response Actions."

2.7 Data Management

The treatability test generated water level measurements, groundwater pumping rate measurements, and lab analyses of contaminant concentrations. Data collected was managed in accordance with the project-specific quality assurance project plan included in the sampling and analysis plan, which is included in DOE/RL-2010-74. The data management approach is summarized in the following paragraphs.

Table 2-2. 200-BP-5 OU Treatability Test Analytical Performance Requirements for Water Matrices—Constant-Rate Pumping Time Series Sampling

Chemical Abstracts Service or Constituent Identifier Number	Analyte	Survey or Analytical Method[a]	Water Lowest Overall Risk Based Screening Level (pCi/L)	Risk Based Screening Level Basis	Water Target Detection Limits (pCi/L)[b]	Water Precision Required (%)	Water Accuracy Required (%)[c]
14133-76-7	Technetium-99	Technetium-99 Liquid Scintillation Counter (Low Level)	900	40 CFR 141.66	15	≤20	70–130
U-233/234	Uranium-233/234	Isotopic Uranium Alpha Energy Analysis	None (20)[d]	40 CFR 141.66	1	≤20	70–130
15117-96-1	Uranium-235		None (24)[d]	40 CFR 141.66	1	≤20	70–130
U-238	Uranium-238		None (24)[d]	40 CFR 141.66	1	≤20	70–130
7440-61-1	Uranium (Total)	Kinetic Phosphorescence or EPA Method 6020	30	40 CFR 141.66	1	≤20	70–130
Sample Schedule—Samples for the above Parameters Will Be Collected on Day 1, Day 2, Day 3, and Weekly Thereafter (Week 1, Week 2, Week 3, Week 4) through Day 30, with a Final Sample Collected on the Last Day of the Test							
15046-84-1	Iodine-129	Chemical Separation Low-Energy Spectroscopy	1	40 CFR 141.66	1	≤20	70–130
10028-17-8	Tritium	Tritium Liquid Scintillation Counter (Mid-Level)	20,000	40 CFR 141.66	400	≤20	70–130
57-12-5	Cyanide	EPA Methods 9010 Total Cyanide or 335	200	40 CFR 141.62	20	≤20	80–120
14797-55-8	Nitrate	Ion Chromatography, EPA Method 300.0 or 9056	45,000	40 CFR 141.62	250	≤20	80–120

Table 2-2. 200-BP-5 OU Treatability Test Analytical Performance Requirements for Water Matrices—Constant-Rate Pumping Time Series Sampling

Chemical Abstracts Service or Constituent Identifier Number	Analyte	Survey or Analytical Method[a]	Water Lowest Overall Risk Based Screening Level (pCi/L)	Risk Based Screening Level Basis	Water Target Detection Limits (pCi/L)[b]	Water Precision Required (%)	Water Accuracy Required (%)[c]
Sample Schedule—Samples for the above Parameters Will Be Collected on Day 1 and Each Week of Testing							

References: 40 CFR 141.62, "National Primary Drinking Water Regulations," "Maximum Contaminant Levels for Inorganic Contaminants."

40 CFR 141.66, "Maximum Contaminant Levels for Radionuclides."

a. EPA methods are found in EPA/600/R-93/100, *Methods for the Determination of Inorganic Substances in Environmental Samples*.

b. Detection limits are based on optimal conditions in a standard fixed laboratory for radiological analyses. For cyanide, nitrate, and uranium, the quantitation limit is provided. The quantitation limit is 3 to 10 times the detection limit. The quantitation limit for nitrate is provided versus nitrogen in nitrate. Interferences and matrix effects may decrease sensitivity, resulting in an increase to the values shown.

c. Accuracy criteria are for associated batch laboratory control sample percent recoveries. With the exception of gamma ray energy analysis, additional analysis-specific evaluations are also performed for matrix spikes, tracers, and carriers, as appropriate to the method. Precision criteria are based on batch laboratory replicate sample analyses.

d. No maximum contaminant levels exist for uranium isotopes. Values shown in parenthesis are concentrations in water that would produce an effective dose equivalent of 4 mrem/yr if consumed at annual average rates (DOE/RL-2008-01, *Hanford Site Groundwater Monitoring Report for Fiscal Year 2007*, Table 1.0-6).

EPA = U.S. Environmental Protection Agency

Field personnel conducting the tests recorded pertinent test activities (e.g., calibrations, sample collections, and transducer installations or downloads) in bound logbooks, on data collection sheets, or directly to electronic devices. Logbook entries identified the date and time, provided detail of the activity or data collection, and included photographs when possible.

Data from each sampling event was compiled into a database, Hanford Environmental Information System, for this project. The database stores all records, including sampling notes, chain-of-custody forms, and analytical laboratory reports. In addition to paper copies of the data, laboratory analysis and field survey numerical values obtained were entered into electronic spreadsheets for further analysis.

Aquifer transmissivity and specific yield estimates obtained from the test were compared with the following values: (1) values estimated from testing performed elsewhere within the 200 East Area, (2) values determined from AQTESOLV software, and (3) values estimated with numerical model calibrations. Data collected for this test were accepted based on their comparability between aquifer-derived hydraulic parameters from AQTESOLV and P2R numerical model results. No formal data quality assessment was needed because of the comparability of the following:

- Water levels – consistency between monitoring well baseline measurements
- Hydraulic parameters – consistency between AQTESOLV and P2R numerical model results
- Analytical results – consistency between test sample results and previous results in this area, comparability between field and laboratory duplicates, and comparability in trends between contaminants sourced from sites in the immediate area within the zone of influence

2.8 Deviations from Treatability Test Plan

During the treatability test there were eight deviations from the test plan. These deviations did not have an adverse effect on the treatability test objectives. The eight deviations are as follows:

1. Because of a data logger programming issue during the step drawdown test, automated water level data collection did not begin until the test was underway at the first flow rate (189 L/min [50 gpm]). Therefore, the static water level was determined from the recovery data collected after pumping was terminated.

2. The theoretical maximum yield from the pumping well (i.e., the pumping rate correlating to 100 percent drawdown) was not estimated from the step drawdown test because the aquifer beneath the 200 East Area is highly transmissive (e.g., the maximum drawdown observed was only 4.7 percent of the total aquifer drawdown available). Therefore, it was not feasible to predict a meaningful pumping rate for 100 percent drawdown. The maximum theoretical yield is not a limiting factor on pumping.

3. The pumping rate selection for the 3-day constant-rate test used the maximum pumping rate possible (473 L/min [125 gpm]), given the extraction well's installed pump. Although the initial design called for a larger pump, potential back-pressure in the transfer line required an engineering change to a smaller pump with a maximum pumping rate of approximately 473 L/min (125 gpm).

4. More water level data than was required were collected during the constant-rate tests for each well because the start of pumping could not be timed precisely. The loggers were set to record on a 2 second frequency for 6 hours during the startup period. The 2 second frequency allowed for good resolution on the initial drawdown in the wells. This period was followed by a 5-minute frequency lasting for the remainder of the pumping phase. When pumping was terminated, the loggers were set

to record again at a 2-second frequency for 6 hours to resolve the initial rapid water level changes during recovery. This was followed by measurements at a 5-minute frequency for the remainder of the recovery period, which resulted in the collection of more than 23,000 water level measurement records from each of the wells during the tests. To reduce this data set to a reasonable size for analysis, the data were arranged to a log frequency. The initial frequency was 2 seconds for 10 records commencing at the start of pumping (or recovery). Then, the sample interval was doubled to 4 seconds for another 10 records, followed by 8 seconds for 10 records, and so on. By this method, the larger amount of measurements collected for each well was reduced to a range between 122 and 153 measurements for the pumping and recovery phases. These data were then imported into the AQTESOLV software for analysis.

5. During the 3-day constant-rate test, the Levelogger in well 299-E33-38 failed, so data from this well were not available for analysis.

6. Also during the 3-day constant-rate test, the cable on the Levelogger for 699-49-57A was damaged (apparently by rodents), so data from this well were not available for analysis.

7. Measurable drawdown during the 3-day constant-rate test was only discernible in the pumping well 299-E33-268, and in the following three observation wells because of high aquifer transmissivity: 299-E33-267 (4.5 m [15 ft] south of the pumping well), 299 E33 31 (9.2 m [30 ft] southeast of the pumping well), and 299 E33 342 (134 m [440 ft] northeast of the pumping well). Therefore, data from these four wells were used to determine large-scale aquifer hydraulic properties.

8. A large barometric pressure change occurred just as the recovery portion of the 27-day test began. Because normalization of the water level measurements to a constant barometric pressure contains some residual error, the recovery data at well 299-E33-342 (which had the lowest drawdown) was adversely affected. Because of this, hydraulic property determinations for this well were very sensitive to the period of analysis chosen, so the results for this well when analyzed by themselves were determined not to be reliable.

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3 Results and Discussion

Unconfined aquifer test results and interpretations associated with water level corrections, drawdown measurements, and hydraulic parameter calculations are discussed in Section 3.1. The refinement of the local-scale model based on the properties calculated from test results is discussed in Section 3.2. Groundwater analytical results and estimated mass removed are discussed in Section 3.3.

The following completion dates are associated with the different test components:

- Baseline water table measurements for normalization to a constant barometric pressure – August 3 to September 21, 2015
- Step drawdown test – September 30, 2015
- 3-day constant-rate pumping test – October 13 to October 16, 2015
- 27-day constant-rate test – October 22 to November 19, 2015

3.1 Data Analysis and Interpretation

The treatability test provided sufficient data to determine that a 189 L/min (50 gpm) extraction rate can be sustained in the B Complex area. The test also provided sufficient data to determine the following:

- Large-scale unconfined aquifer hydraulic parameters within the area bounded by the extraction well to well 299-E33-342 in the B Complex area (Figure 2-1)
- Mass of contaminant removal during the test

A main component of the success of this test was the ability to barometrically correct water table measurements. This correction allowed pumping-induced water level changes to be differentiated from atmospheric pressure changes as far as distant well 299-E33-342, which increased the size of the area for which larger-scale aquifer hydraulic parameters could be calculated. The following discussion describes the findings for each of the preceding bullets. The results of the step drawdown test are also provided.

3.1.1 Results for Normalization of Hydraulic Heads to a Constant Barometric Pressure

Changes in atmospheric barometric pressure can cause changes in well water if the barometric change causes an imbalance of air pressure between the well and the adjacent vadose zone at the water table. An example of this effect is shown by the blue line in Figure 3-1, which in this case, accounts for fluctuations of more than 2 cm (0.8 in.). This occurs in relatively deep wells, like those in the B Complex, because of the thick vadose zone, and in other wells where low-permeability units within the vadose zone inhibit the migration of air pressure equalization pulses. To account for the variability, the water level measurements collected for the treatability test were normalized to a constant barometric pressure using multiple regression/deconvolution (Rasmussen and Crawford, 1997; Spane, 2002).

In summary, the down-well BaroLogger pressure is removed from the LevelLogger measurements after both are converted to absolute pressure values in pounds per square inch. Next, the linear atmospheric barometric pressure effects on the absolute water levels are modeled by MRCX until model-predicted barometric effects produce a maximum goodness-of-fit with the absolute pressure effects (Figure 3-2). Removing the linear effects of atmospheric pressure changes by deconvolution results in the red line in Figure 3-1. Additional information is provided in Appendix A (ECF-200BP5-15-00124, *200-BP-5 Treatability Test: Analysis of the Step Drawdown and Constant Rate Pumping Tests at Well 299-E33-268*).

3.1.2 Results of the Step Drawdown Test

Automated water levels were collected in the pumping well (299-E33-268) during the step drawdown test at a 2-second frequency. Because of a logger programming issue, data collection did not begin until the test was underway at the first flow rate (189 L/min [50 gpm]). The data were used to calculate the drawdown associated with each pumping rate (the static water level was determined from the recovery data collected after pumping was terminated). The data were not normalized to a constant barometric pressure because of the short duration of the test. Results of the automated water level measurements collected during the step drawdown test are shown in Figure 3-3, and results of the test are shown in Table 3-1. The maximum drawdown was 10.4 cm (4.09 in.) at the 568 L/min (150 gpm) flow rate, which is 4.7 percent of the theoretical maximum drawdown of 2.2 m (7.2 ft).

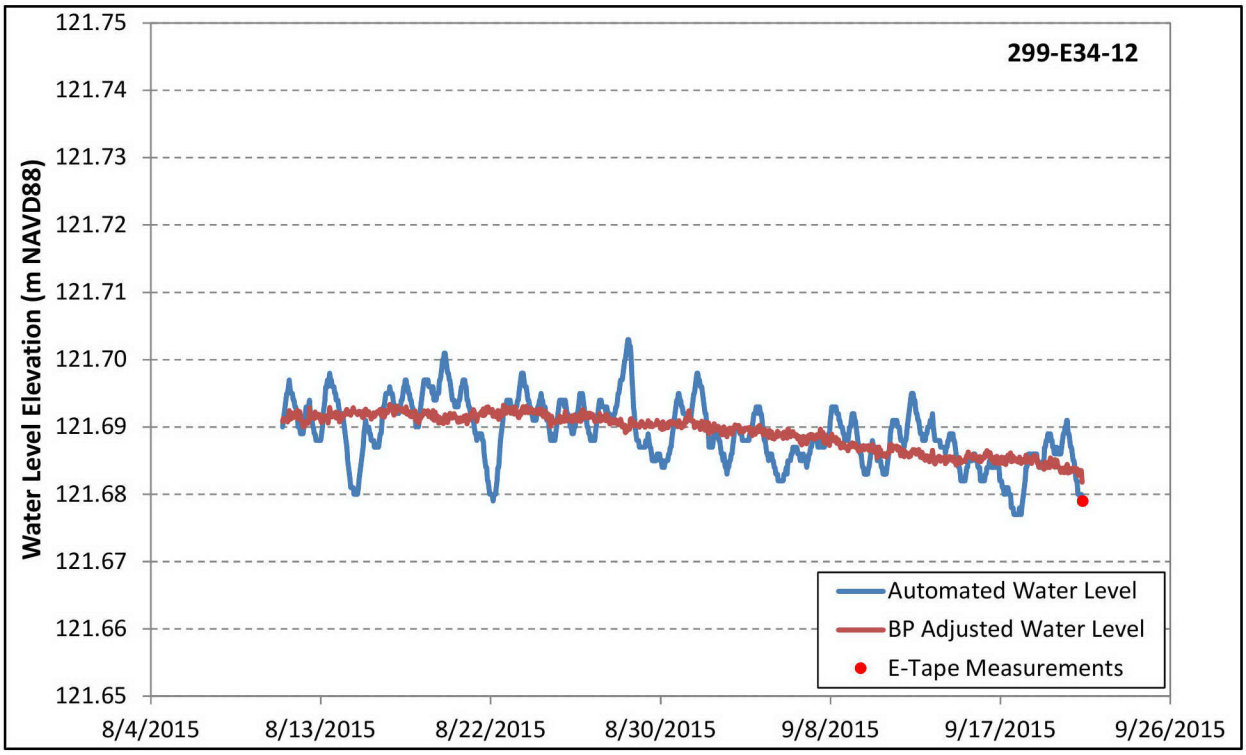


Figure 3-1. Comparison of Barometric Corrected versus Uncorrected Water Levels Collected during Baseline Water Level Measurements at Background Well 299-E34-12

As a result of the limited and stabilized drawdown during this test step, it was recommended that a pumping rate of 586 L/min [150 gpm]) be used as the optimum pumping rate for the constant-rate test. However, because of back-pressure buildup in the transfer line and limited high range pumps on hand, the maximum pumping rate for the constant-rate test was limited to approximately 473 L/min (125 gpm).

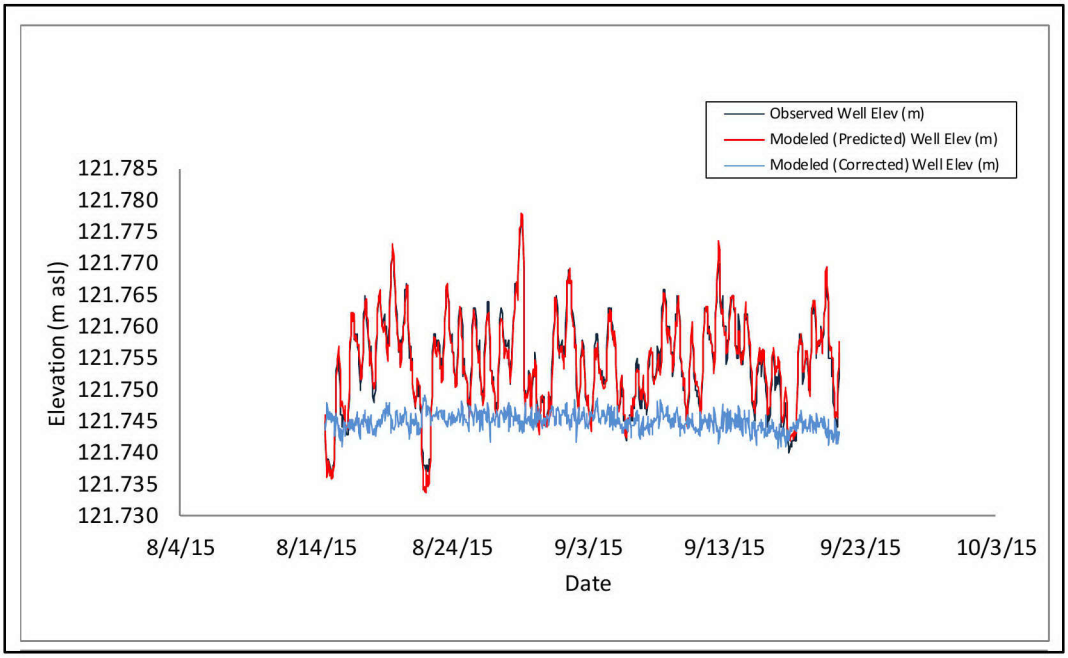


Figure 3-2. Example of MRCX Goodness-of-Fit with Absolute Pressure Effects on the Water Table and the Resulting Barometric Corrected Water Level

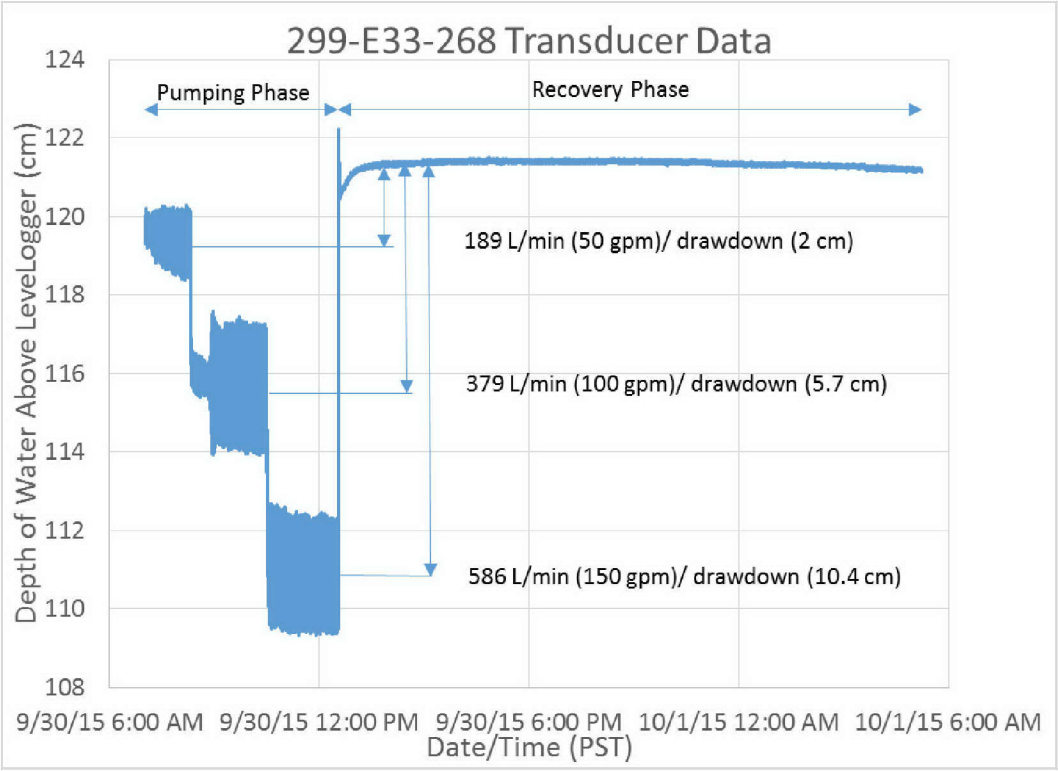


Figure 3-3. Drawdown Measurements over Time at Extraction Well 299-E33-268 for Stepped Pumping Rates of 189, 379, and 568 L/min (50, 100, and 150 gpm) and Subsequent Aquifer Recovery

Table 3-1. Results of the Step Drawdown Test

Pumping Rate (L/min [gpm])	Maximum Drawdown		Specific Capacity	
	(cm)	Percent of Total Available Drawdown*	(gpm/m)	(gpm/ft)
189 (50)	2.0	0.9%	2,500	762
379 (100)	5.7	2.6%	1,754	535
568 (150)	10.4	4.7%	1,442	440

* Total available drawdown is equal to the aquifer thickness of 2.2 m (220 cm).

3.1.3 Three-Day Constant-Rate Test

The water level drawdown measurements collected for the 3-day constant-rate discharge test were normalized to a constant barometric pressure using deconvolution, as described in Section 3.1.1. During this analysis, it was discovered that the LeveLogger in well 299-E33-38 had failed, so data from this well were not available for analysis. Further, the cable on the LeveLogger for 699-49-57A was damaged (apparently by animals), so data from this well were not available for analysis. Data for the remaining wells were examined graphically to determine whether drawdown could be discerned in each well. Drawdown was obvious in the pumping well 299-E33-268, and was discernible in only three observation wells: 299-E33-267 (4.5 m [15 ft] south of the pumping well), 299-E33-31 (9.2 m [30 ft] southeast of the pumping well), and 299-E33-342 (134 m [440 ft] northeast of the pumping well) (Figure 3-4). Data from these four wells were used to determine aquifer hydraulic properties. Charts of the automated water level measurements collected from the pumping and observation wells are provided in Appendix A.

A large amount of data was collected during the test. Because the start of pumping could not be timed precisely, the loggers were set to record on a 2-second frequency for 6 hours during the startup period. The 2-second frequency allowed for good resolution on the initial water level drawdown in the wells. This period was followed by a 5-minute frequency lasting for the remainder of the pumping phase of the test. When pumping was terminated, the loggers were set to record again at a 2-second frequency for 6 hours to resolve the initial rapid water level changes that occur during recovery. This was followed by measurements at a 5-minute frequency for the remainder of the recovery period, resulting in the collection of more than 23,000 water level measurements from each of the wells during the 3-day test. To reduce this data set to a reasonable size for analysis, the data were arranged to a log frequency. Ten records at 2-second intervals represented drawdown from the start of pumping (or recovery). Then, the measurement interval was doubled to 4 seconds for another 10 records, followed by 8 seconds for 10 records, and so on. By this method, the approximately 23,000 measurements collected for each well during the test were reduced to a range between 122 and 153 measurements for the pumping and recovery phases. These data were then imported into the AQTESOLV software for analysis.

The water levels in 299-E34-12 were used to identify temporal background trends in the water table during the 3-day test. During the 3-day test, the background water table elevation was stable, so no change was needed for water level data from the monitoring network.

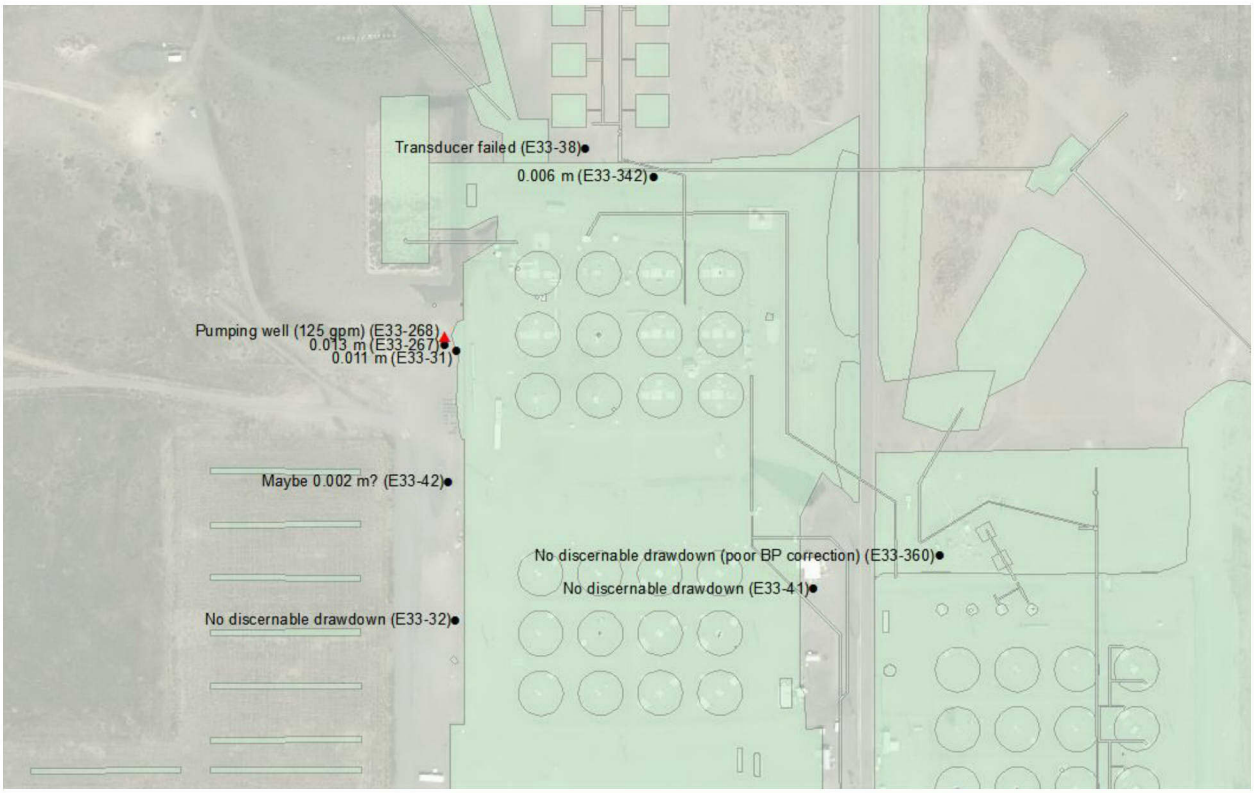


Figure 3-4. Final Drawdown Measurements for the 3-Day Constant-Rate Test at 473 L/min (125 gpm)

The pressure derivative was examined for the extraction well and the three observation wells with discernible drawdown. The pressure derivative was used to assist in determining the best time period for performing curve matching. Aquifer properties were then determined by fitting the type curves to the data using the automatic curve matching feature of AQTESOLV. The variables for each solution method were allowed to vary, as shown by the limits in Table 3-2. At the start of the 3-day test, the pumping rate varied for a few minutes until it stabilized near the planned rate of 473 L/min (125 gpm). For this reason, the period used for curve matching (i.e., the analysis window) was usually set to begin at either 0.01 day (2.4 minutes) or 0.1 day (2.4 hours) after pumping began, and the analysis window typically extended for the remaining duration of the pumping phase (3.3 days).

Curve matching using the Theis/Hantush method and the Neuman method was performed for each observation well separately, for observation wells 299-E33-267 and 299-E33-31 together (these are closest to the pumping well), and for all three observation wells together. The Moench method was applied to all four wells.

Recovery data for the 3-day test were also analyzed. Aquifer parameters calculated from the water level recovery data obtained after the termination of pumping were estimated in a manner similar to that used for the drawdown data. The recovery times were converted to Agarwal equivalent times using Equation 7 (Section 2.3.4.4). The recovery data were analyzed using the same method, except that the Moench method was not employed (because there was no active pumping).

Table 3-2. Variables and Limits Used for the Automatic Curve-Matching Feature of AQTESOLV

Variable	Theis, 1935/ Hantush, 1961a,b		Neuman, 1974		Moench, 1997	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Transmissivity (T) (m^2/d)	1	1×10^6	1	1×10^6	1	1×10^6
Storativity (S)	1×10^{-3} [a]	N/A[a]	1×10^{-5}	1×10^{-3}	1×10^{-3} [b]	1×10^{-3} [b]
Specific Yield (S_y)	N/A[a]	1.0[a]	1×10^{-3}	1.0	0.21[b]	0.21 [b]
Anisotropy Ratio (K_z/K_r)	0.001	1.0	Not used	Not used	0.01	1.0
Wellbore Skin Factor (S_w)	N/A	N/A	N/A	N/A	-5	100

References: Hantush, 1961a, "Drawdown around a Partially Penetrating Well."
Hantush, 1961b, "Aquifer Tests on Partially Penetrating Wells."
Moench, 1997, "Flow to a Well of Finite Diameter in a Homogeneous, Anisotropic Water Table Aquifer."
Neuman, 1974, "Effect of Partial Penetration on Flow in Unconfined Aquifers Considering Delayed Gravity Response."
Theis, 1935, "The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage."
a. The Theis/Hantush method uses only a single storage coefficient variable; the minimum was set to 1×10^{-3}, and the maximum was set to 1.0.
b. Storativity and specific yield were held constant at the indicated values for the Moench method.
N/A = not applicable

Charts of the fitted curves for the drawdown and recovery portions of the 3-day test are provided in Appendix A. Appendix A also contains charts of the pressure derivative for Wells 299-E33-268, 299-E33-31, 299-E33-267, and 299-E33-342 for the drawdown portion of the 3-day test.

Results of determining hydraulic properties for the drawdown and recovery portion of the 3-day test are provided in Table 3-3. Transmissivity values ranged from 34,800 to 46,900 m^2/day with an average value of 41,300 m^2/day. Hydraulic conductivity ranged from 15,800 to 21,300 m/day with an average value of 18,800 m/day. Specific yield values for several of the tests were unrealistically high. These high values may have been caused by assumptions of the analytical models not being fully met. Results that were unrealistically high were not included in calculating the range and average result, which was 0.11 to 0.31 with an average of 0.21.

3.1.4 Twenty-Seven-Day Constant-Rate Test

The water level measurements collected for the 27-day constant-rate test were normalized to a constant barometric pressure using deconvolution, as described in Section 3.1.1. It should be noted that the cable to the BaroLogger in 299-E33-38 failed during the 27-day test, so downhole barometric pressure measurements were not directly available. However, the relationship between the downhole barometric pressure and the barometric pressure measurements at meteorology Station 6 were determined by multiple linear regression on the background measurements. Convolution was used to estimate the downhole pressure from the Station 6 measurements during the 27-day test (using the same method as that described in Section 3.1). Further, the cable on the LeveLogger for 699-49-57A was damaged (apparently by animals), so data from this well were not available for analysis. Charts of the data for the remaining wells were examined to determine whether drawdown could be discerned in each well. Drawdown was obvious in the pumping well 299-E33-268, but because of the high transmissivity of the aquifer, drawdown was discernible in only three of the observation wells: 299-E33-267 (4.5 m [15 ft] south of the pumping well),

299-E33-31 (9.2 m [30 ft] southeast of the pumping well), and 299-E33-342 (134 m [440 ft] northeast of the pumping well). Data from these four wells were used to determine aquifer hydraulic properties. Charts of the automated water level measurements collected from the pumping and observation wells are provided Appendix A.

Table 3-3. Results of Determining Hydraulic Properties for the 3-Day Constant-Rate Discharge Test

Analysis Type			Results		
Wells	**Test Type**	**Solution Method**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Specific Yield**
299-E33-31	Drawdown	Theis, 1935	4.36E+04	1.98E+04	0.25
299-E33-31	Drawdown	Neuman, 1974	4.56E+04	2.07E+04	0.18
299-E33-31	Recovery	Theis, 1935	4.12E+04	1.87E+04	0.63[a]
299-E33-31	Recovery	Neuman, 1974	4.13E+04	1.88E+04	0.62[a]
299-E33-267	Drawdown	Theis, 1935	3.53E+04	1.60E+04	1.00[a]
299-E33-267	Drawdown	Neuman, 1974	4.26E+04	1.94E+04	0.23
299-E33-267	Recovery	Theis, 1935	3.48E+04	1.58E+04	1.00[a]
299-E33-267	Recovery	Neuman, 1974	3.53E+04	1.60E+04	1.00[a]
299-E33-342	Drawdown	Theis, 1935	4.22E+04	1.92E+04	0.21
299-E33-342	Drawdown	Neuman, 1974	4.20E+04	1.91E+04	0.22
299-E33-342	Recovery	Theis, 1935	3.54E+04	1.61E+04	0.11
299-E33-342	Recovery	Neuman, 1974	3.54E+04	1.61E+04	0.11
299-E33-31 and 299-E33-267	Drawdown	Theis, 1935	4.15E+04	1.89E+04	0.31
299-E33-31 and 299-E33-267	Drawdown	Neuman, 1974	3.96E+04	1.80E+04	0.45[a]
299-E33-31 and 299-E33-267	Recovery	Theis, 1935	4.27E+04	1.94E+04	0.28
299-E33-31 and 299-E33-267	Recovery	Neuman, 1974	4.25E+04	1.93E+04	0.28
E33-31, E33-267, and E33-342	Drawdown	Theis, 1935	4.37E+04	1.99E+04	0.21
E33-31, E33-267, and E33-342	Drawdown	Neuman, 1974	4.36E+04	1.98E+04	0.21
E33-31, E33-267, and E33-342	Recovery	Theis, 1935	4.69E+04	2.13E+04	0.14
E33-31, E33-267, and E33-342	Recovery	Neuman, 1974	4.68E+04	2.13E+04	0.14
All Wells	Drawdown	Moench, 1997	4.50E+04	2.05E+04	0.21[b]
		Minimum:	3.48E+04	1.58E+04	0.11
		Maximum:	4.69E+04	2.13E+04	0.31
		Average:	**4.13E+04**	**1.88E+04**	**0.21**

References: Moench, 1997, "Flow to a Well of Finite Diameter in a Homogeneous, Anisotropic Water Table Aquifer."
Neuman, 1974, "Effect of Partial Penetration on Flow in Unconfined Aquifers Considering Delayed Gravity Response."
Theis, 1935, "The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage."

a. Unrealistic specific yield value – not used in the minimum, maximum, or average determinations.
b. The specific yield for the Moench method was held constant at the average value of 0.21 determined from the other analyses.

A large amount of data was collected during the test. Because the start of pumping could not be timed precisely, the loggers were set to record on a 2-second frequency for 6 hours during the startup period. The 2-second frequency allowed for good resolution on the initial drawdown in the wells. This period was followed by a 5-minute frequency lasting for the remainder of the pumping test. When pumping was terminated, the loggers were set to record again at a 2-second frequency for 6 hours to resolve the initial rapid water level changes during recovery. This was followed by measurements at a 5-minute frequency for the remainder of the recovery period, resulting in the collection of more than 30,000 records for each well during the 27-day test. To reduce this data set to a reasonable size for analysis, the data were resampled on a log frequency. The initial frequency was 2 seconds for 10 records commencing at the start of pumping (or recovery). Then, the sample interval was doubled to 4 seconds for another 10 records, followed by 8 seconds for 10 records, and so on. By this method, the more than 30,000 measurements collected for each well during the tests were reduced to between 122 and 153 measurements during the pumping or recovery phases. These data were then imported into the AQTESOLV software for analysis.

The water levels in 299-E34-12 were used to identify temporal trends in the water table during the 27-day test. During the 27-day test, the background water table elevation declined about 0.014 m (0.046 ft). Because the rate of decline was stable, linear regression was used to identify the slope of the declining trend, and then this slope was used to detrend the water level measurements collected during the 27-day test (a comparison of the original and detrended measurements for 299-E34-12 is shown in Figures E-9 and E-10 in Appendix E of ECF-200BP5-15-00124). This was done so the background water table decline did not affect the drawdown determinations.

The pressure derivative was examined for the pumping well and the three observation wells with discernible drawdown. The pressure derivative was used to assist in determining the time period for which curve matching would be performed. Aquifer properties were then determined by fitting type curves to the data using the automatic curve matching feature of AQTESOLV. The variables were allowed to vary, and their limits are shown in Table 3-2 for each solution method. During startup of the 27-day test, the pumping rate stabilized at 379 L/min (100 gpm) more quickly than during the 3-day test, and drawdown in the wells also stabilized after about 1 day. For these reasons, the period used for curve matching typically started at 0.0001 day (8 seconds) and ended at 1 day.

Curve matching using the Theis/Hantush method and the Neuman method was performed for each observation well separately, for observation wells 299-E33-267 and 299-E33-31 together (these are closest to the pumping well), and for all three observation wells together. The Moench method was applied to all four wells.

Recovery data for the 27-day test were also analyzed. Buildup of the water level after the termination of pumping was calculated in a manner similar to that for drawdown. The recovery times were then converted to Agarwal equivalent times using Equation 7 (Section 2.3.4.4). The recovery data were analyzed in the same manner the drawdown data were analyzed, except that the Moench method was not employed (because there was no active pumping). A large barometric pressure change occurred just as the recovery portion of the 27-day test began. Normalization of the water level measurements to a constant barometric pressure contains some residual error, which adversely affected the recovery data at well 299-E33-342 (which had the lowest drawdown). Hydraulic property determinations for this well were sensitive to the period of analysis chosen, so the results for this well were determined to be unreliable.

Charts of the fitted curves for the drawdown and recovery portions of the 27-day test are provided in Appendices E and F of ECF-200BP5-15-00124, respectively. Appendix F also contains charts of the pressure derivative for wells 299-E33-268, 299-E33-31, 299-E33-267, and 299-E33-342 for the drawdown portion of the 27-day tests.

Results of the hydraulic properties calculated for the drawdown and recovery portion of the 27-day test are provided in Table 3-4. The results confirmed the properties determined during the 3-day test. Transmissivity ranged from 33,200 to 46,400 m^2/day with an average value of 40,100 m^2/day. Hydraulic conductivity ranged from 15,100 to 21,100 m/day with an average value of 18,200 m/day. Many of the specific yield determinations came out unrealistically high, so the range and average were not determined (ND). This was a consequence of curve matching to earlier data during the 3-day test. Although the transmissivity and hydraulic conductivity results of the 27-day test were similar to the results of the 3-day test, the 3-day test is considered to be the better test. The 3-day test is better because of a higher pumping rate (473 L/min [125 gpm]), which stresses the aquifer a little more than the pumping rate during the 27-day test (379 L/min [100 gpm]), and because it provides more realistic specific yield values. Thus, the average values for the 3-day test are considered to be the final results.

Table 3-4. Results of Determining Hydraulic Properties for the 27-Day Constant-Rate Discharge Test

Analysis Type			Results		
Wells	**Test Type**	**Solution Method**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Specific Yield[a]**
299-E33-31	Drawdown	Theis, 1935	4.38E+04	1.99E+04	0.38
299-E33-31	Drawdown	Neuman, 1974	4.36E+04	1.98E+04	0.38
299-E33-31	Recovery	Theis, 1935	4.19E+04	1.90E+04	0.82
299-E33-31	Recovery	Neuman, 1974	4.20E+04	1.91E+04	0.80
299-E33-267	Drawdown	Theis, 1935	3.32E+04	1.51E+04	1.00
299-E33-267	Drawdown	Neuman, 1974	3.32E+04	1.51E+04	1.00
299-E33-267	Recovery	Theis, 1935	4.18E+04	1.90E+04	1.00
299-E33-267	Recovery	Neuman, 1974	4.20E+04	1.91E+04	0.80
299-E33-342	Drawdown	Theis, 1935	4.64E+04	2.11E+04	0.36
299-E33-342	Drawdown	Neuman, 1974	4.56E+04	2.07E+04	0.37
299-E33-342	Recovery	Theis, 1935	Not reliable[b]	N/A[b]	N/A[b]
299-E33-342	Recovery	Neuman, 1974	Not reliable[b]	N/A[b]	N/A[b]
299-E33-31 and 299-E33-267	Drawdown	Theis, 1935	3.60E+04	1.64E+04	0.76
299-E33-31 and 299-E33-267	Drawdown	Neuman, 1974	3.58E+04	1.63E+04	0.77
299-E33-31 and 299-E33-267	Recovery	Theis, 1935	3.93E+04	1.79E+04	1.00
299-E33-31 and 299-E33-267	Recovery	Neuman, 1974	3.92E+04	1.78E+04	0.57
E33-31, E33-267, and E33-342	Drawdown	Theis, 1935	3.71E+04	1.69E+04	0.65
E33-31, E33-267, and E33-342	Drawdown	Neuman, 1974	3.70E+04	1.68E+04	0.65
E33-31, E33-267, and E33-342	Recovery	Theis, 1935	4.08E+04	1.85E+04	0.88
E33-31, E33-267, and E33-342	Recovery	Neuman, 1974	4.07E+04	1.85E+04	0.89

Table 3-4. Results of Determining Hydraulic Properties for the 27-Day Constant-Rate Discharge Test

Analysis Type			Results		
Wells	**Test Type**	**Solution Method**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Specific Yield[a]**
All Wells	Drawdown	Moench, 1997	4.32E+04	1.96E+04	0.21[c]
		Minimum:	3.32E+04	1.51E+04	ND
		Maximum:	4.64E+04	2.11E+04	ND
		Average:	**4.01E+04**	**1.82E+04**	ND

References: Moench, 1997, "Flow to a Well of Finite Diameter in a Homogeneous, Anisotropic Water Table Aquifer."
Neuman, 1974, "Effect of Partial Penetration on Flow in Unconfined Aquifers Considering Delayed Gravity Response."
Theis, 1935, "The Relation between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Ground-Water Storage."

a. Specific yield results were unrealistically high and are not representative of aquifer conditions.
b. Results were sensitive to the analysis window chosen because of the low observed drawdown and a large barometric pressure change that occurred during initiation of the recovery portion.
c. The specific yield for the Moench method was held constant at the average value of 0.21 determined for the 3-day test.

N/A = not applicable

ND = not determined

3.2 Numerical Model Analysis

The derived hydraulic properties from this treatability test were used to update local-scale hydrologic numerical model plume capture simulations. A local-scale TMR model, part of the P2R model, was used to update local-scale hydrologic numerical model plume capture simulations. This section discusses how the TMR model results compared favorably with the treatability test hydraulic properties, groundwater gradient and flow direction, and drawdown. As a result, the capture zone derived by the model is considered to be broadly consistent with current aquifer conditions.

The hydraulic parameters as defined for the TMR and P2R models nearly matched the large-scale hydraulic properties derived during the treatability test. CP-57037 explains that the hydraulic properties for the TMR and P2R models were obtained from experimental interpretation from PNL-10886, *Development of a Three-Dimensional Ground-Water Model of the Hanford Site Unconfined Aquifer System: FY 1995 Status Report*, and PNNL-13641, *Uncertainty Analysis Framework – Hanford Site-Wide Groundwater Flow and Transport Model*. The TMR and P2R model-derived aquifer properties were within 11 percent of the average hydraulic properties derived during the treatability test (Table 3-5). To evaluate how much difference the hydraulic parameters make in capture analysis, the model-derived and field-derived parameters were compared.

The groundwater gradient and flow direction for the local-scale TMR model and the observations from the low-gradient monitoring network water elevations were also comparable. A visual comparison of observed and simulated hydraulic gradient and flow direction is shown in Figure 3-5. The derived groundwater gradient and flow direction for the simulated model and low-gradient monitoring network are tabulated in Table 3-6. Table 3-6 demonstrates that the simulated hydraulic gradient and flow direction fit reasonably to observed data. More discussion is provided in Appendix B.

Drawdown comparisons between model simulations for the 3-day pumping test and actual observed drawdowns during the treatability test were generally within a factor of two. The unchanged hydraulic parameters from the TMR model are compared to the measured drawdown during the test, as shown in Table 3-7. By using the average hydraulic parameters defined by the aquifer test, the simulated drawdown data are even closer to the observed drawdown data (Table 3-7). Further comparisons are provided in Appendix B.

Table 3-5. Comparison of Hydraulic Properties Derived from Treatability Test Data with Model-Derived Values

Treatability Test Methods			Average Results		
Test	**Test Type**	**Solution Methods**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Specific Yield**
3-Day Constant-Rate Test	Drawdown	Theis, Neuman, Moench	**4.13E+04**	**1.88E+04**	**0.21**
27-Day Constant-Rate Test	Drawdown	Theis, Neuman, Moench	**4.01E+04**	**1.82E+04**	ND
Document Reference			**Model Calibration Values**		
CP-47631, Model Package Report: Central Plateau Groundwater Model Version 3.4, Rev. 1			3.74E+04	1.70E+04	0.2

ND = not determined

Table 3-6. Comparison of Observed and Simulated Hydraulic Gradients

Target Name	Observed Azimuth (Degree)	Simulated Azimuth (Degree)	Residual Azimuth (Degree)	Observed Magnitude (m/m)	Simulated Magnitude (m/m)	Residual Magnitude (m/m)
Target 1	135	143.42	-8.42	6.5E-06	8.21E-06	-1.71E-06
Target 2	135	130.87	4.13	7.1E-06	5.56E-06	1.54E-06

Table 3-7. Comparison of Observed and Simulated Drawdowns

	Extraction Well 299-E33-268	Monitoring Well 299-E33-267	Monitoring Well 299-E33-31	Monitoring Well 299-E33-42	Monitoring Well 299-E33-342
Model Simulated Drawdown (mm) Using Unchanged Hydraulic Parameter	31	20.7	17.7	8	7
Measured Drawdown during Test (mm)	20	13	11	2(?)	6
Model Simulated Drawdown (mm) Using Derived	28.2	18.8	16.1	7	6

Table 3-7. Comparison of Observed and Simulated Drawdowns

	Extraction Well 299-E33-268	Monitoring Well 299-E33-267	Monitoring Well 299-E33-31	Monitoring Well 299-E33-42	Monitoring Well 299-E33-342
Hydraulic Parameter from Test					
Measured Drawdown during Test (mm)	20	13	11	2(?)	6

Capture zone analyses were completed for the different pumping rates and different hydraulic properties for variability evaluations. The pumping rates evaluated included 189, 379, and 586 L/min (50, 100, and 150 gpm). The hydraulic properties included the unchanged model parameters, treatability test-derived hydraulic properties, and an average of the two. These various evaluations are provided in Appendix B. When evaluating the difference between capture zones using the various hydraulic parameters, there was little noticeable difference. Although the capture zones differed more using the various pumping rates, the difference was not significant as seen between the capture zone analysis for 189 and 379 L/min (50 and 100 gpm) (Figures 3-6 and 3-7, respectively). Figure 3-7 shows that complete capture of the BY Cribs is obtained at 100 gpm. By examination of capture zone calculations, as provided in Figure 3-8 (Todd and Mays, 1980, *Groundwater Hydrology*), the most significant parameter associated with capture zone variability at the B Complex is the groundwater gradient. Thus, if TEDF discharges decline or Columbia River stages increase, the capture zone would decrease in width. Alternatively, if Columbia River stages continue at lower than average and TEDF discharges increase, then even larger capture could be realized then depicted in Figures 3-6 and 3-7.

3.3 Contaminant Mass Removal

The mass removal rates during the constant-rate test were estimated using the following data from extraction well 299-E33-268: (1) the average sample concentration of the six contaminants (cyanide, iodine-129, nitrate, technetium-99, tritium, and uranium), (2) the average pumping rate, and (3) the elapsed time. The samples were collected and analyzed as scheduled. The analytical results from the constant-rate pumping test are presented in Table 3-8.

The 3-day test started pumping groundwater on October 13, 2015, at about 7:45 a.m. and was completed on October 16, 2015, at roughly 1:10 p.m. The test ran for 77.5 hours, and the pump rate averaged 473 L/min (125 gpm). The total contaminated groundwater removed during the 3-day test was approximately 2,200,031 L (581,250 gal). Groundwater samples for uranium and technetium-99 were collected daily at 24, 48, and 72 hours after the start of the test. The other co-contaminants (cyanide, iodine-129, nitrate, and tritium) were sampled once after 24 hours of extraction.

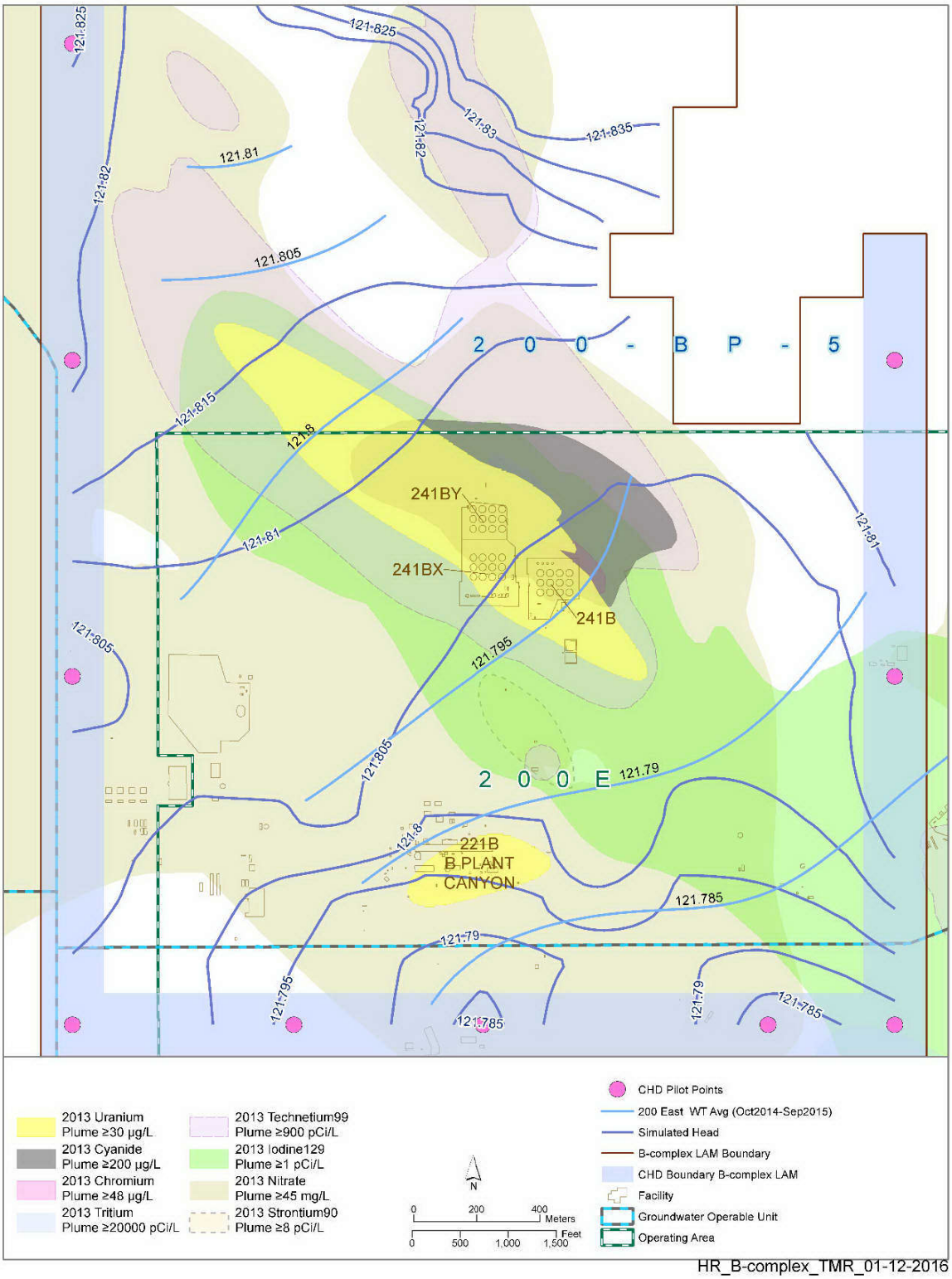


Figure 3-5. Comparison of Current Water Table Contours based on 200 East Low-Gradient Monitoring Network and Simulated Head Contours at Water Table in the Vicinity of B Complex Area

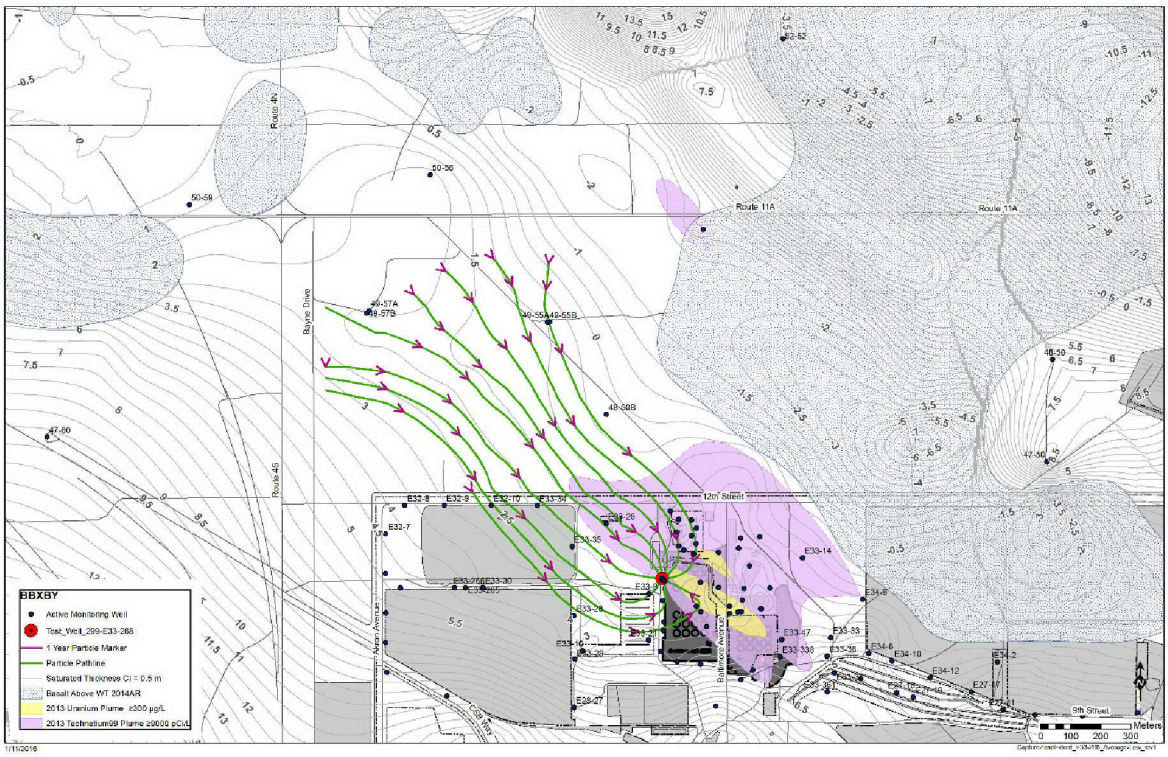


Figure 3-6. Simulated Capture Zone at 189 L/min (50 gpm) Using Average Aquifer Hydraulic Properties from Treatability Test Results

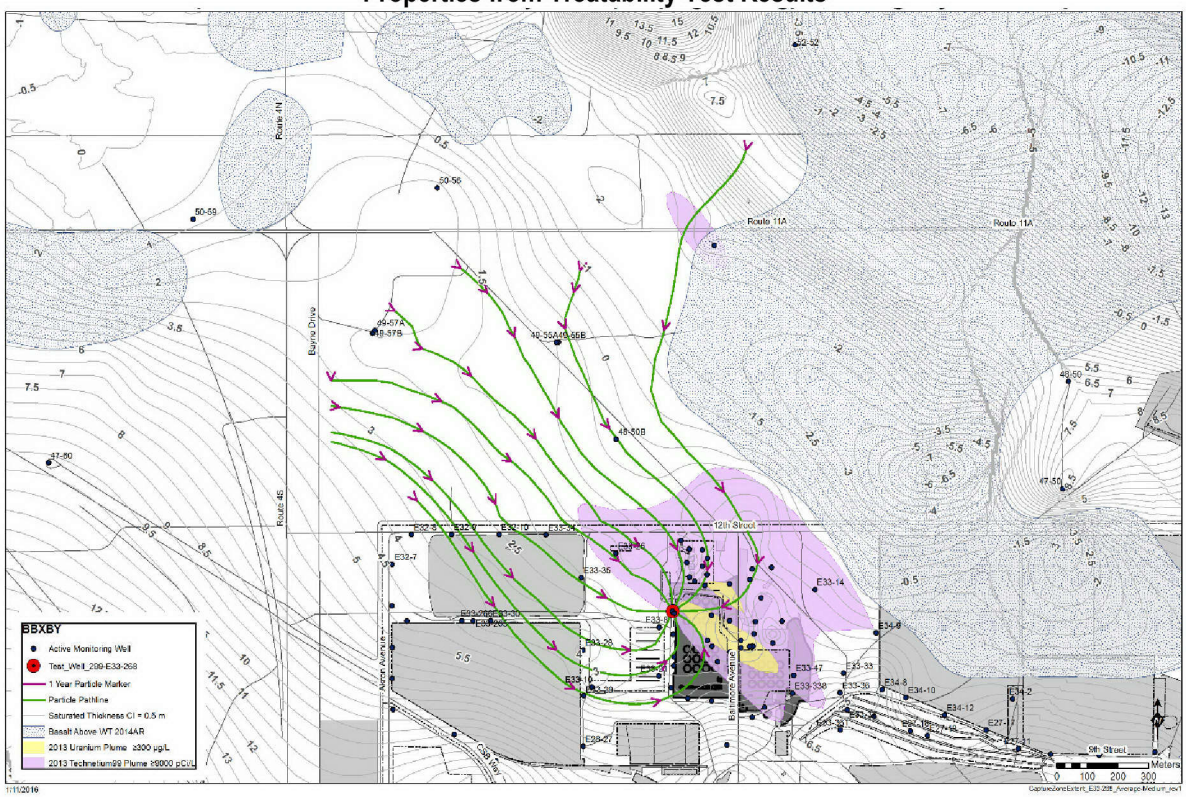
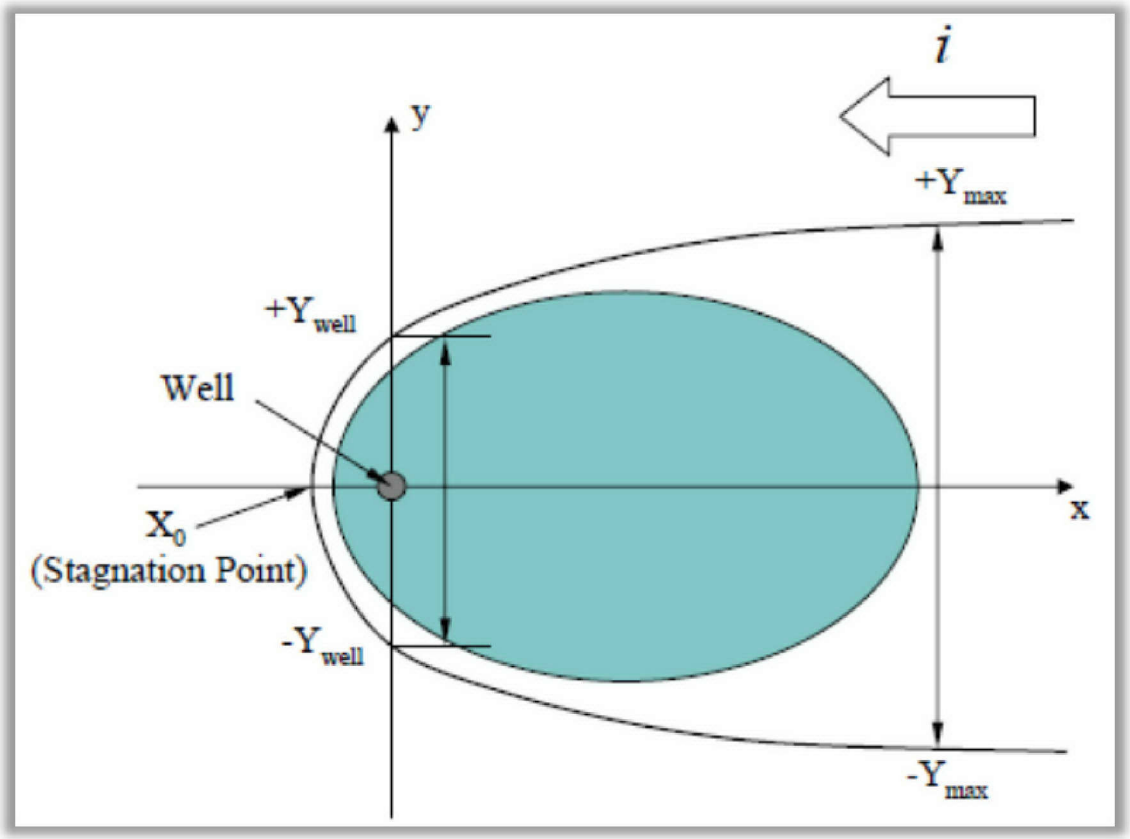


Figure 3-7. Simulated Capture Zone at 379 L/min (100 gpm) Using Average Aquifer Hydraulic Properties from Treatability Test Results



$X_0 = -Q/2\pi Ti,\ Y_{well} = \pm Q/2Ti,\ Y_{max} = \pm Q/4Ti$

Figure 3-8. Capture Equation and Associated Depiction of Defining Parameters of Capture, where *Q* is the pumping rate, *T* is the transmissivity, and *I* is the gradient

Table 3-8. Analytical Results from the 30-Day Constant-Rate Pumping Test

Date	Technetium-99 pCi/L	Uranium µg/L	Cyanide µg/L	Nitrate µg/L	Iodine-129 pCi/L	Tritium pCi/L
10/14/2015	6,230	123	363,260	258	11,000	2.89
10/14/2015	6,190	162	367,690	266	12,300	3.34
10/15/2015	6,270	119				
10/16/2015	7,070	115				
10/29/2015	7,430	130	443,000	252	12,000	1.42
10/29/2015	7,960					2.02
11/5/2015	7,940					2.62
11/5/2015	7,730	118	443,000	307	11,800	4.21
11/12/2015	7,340	147	443,000	309	12,800	1.93
11/18/2015	8,400	118	487,000	351	11,000	1.76
Average Concentration	7,256	129	424,492	351	11,000	1.76

During the 27-day test, groundwater samples for the contaminants were collected weekly (at 7, 14, 21, and 27 days) after the start of the test. The 27-day test started on October 22, 2015 at 7:30 a.m. and was completed on November 19, 2015 at 8:08 a.m. The test ran for 672.6 hours. During the test, the pump rate averaged 379 L/min (100 gpm). The total contaminated groundwater removed during the 27-day test was about 15,275,495 L (4,035,798 gal).

Contaminant concentration trends during the test appeared to vary. For example, concentrations of technetium-99 increased during the test (Figure 3-9), while uranium concentrations remained stable with two apparent out-of-trend results (Figure 3-9). Concentrations of technetium-99 co-contaminants (cyanide and nitrate) also increased during the test (Figure 3-10). All three of these contaminants are associated with the BY Cribs to the northeast of the 299-E33-268 extraction well (Figure 2-1). The elevated contamination levels associated with these three constituents appear to be associated with remnant plumes that migrated northwest from the BY Cribs prior to the 2011 groundwater flow direction change. The increases may be a combination of elevated contamination migrating back in from the northwest and recent contaminant infiltration from the vadose zone near the BY Cribs. These increased concentrations verify observed drawdown at well 299-E33-342. Iodine-129 and tritium results were similar to those of uranium and did not show an increase in concentrations during the test (Figure 3-11). This lack of an increase may indicate that there is no ongoing source near the extraction well, and only traces of the remaining dispersed plume were captured during the test. Tritium concentrations are nearly half the DWS in this area now.

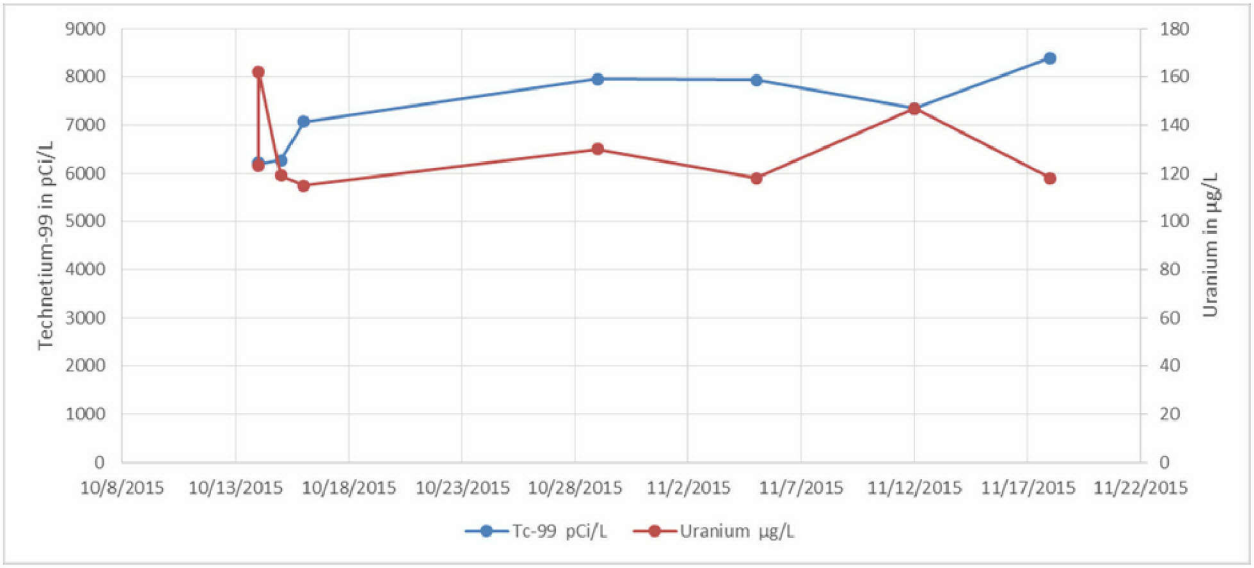


Figure 3-9. Trend Chart of Technetium-99 and Uranium Results during the 30-Day Constant-Rate Test

The rate of removal was also tracked for technetium-99 and uranium as shown in Figures 3-12 and 3-13, respectively.

Combining the average sample concentration during the test of the six contaminants as defined in Table 3-8, the average pumping rate during the test of 388.3 L/min (102.5 gpm), and the elapsed time of 45,010 minutes (750 hours, 31.26 days) provides a total mass removed in Table 3-9. The difference between the total mass in Figures 3-12 and 3-13 versus the total mass in Table 3-9 is the individual concentration for a specific time instead of an average concentration over the entire time. Table 3-9 also provides the average rate of removal for the six contaminants based on the average mass over the total duration of pumping.

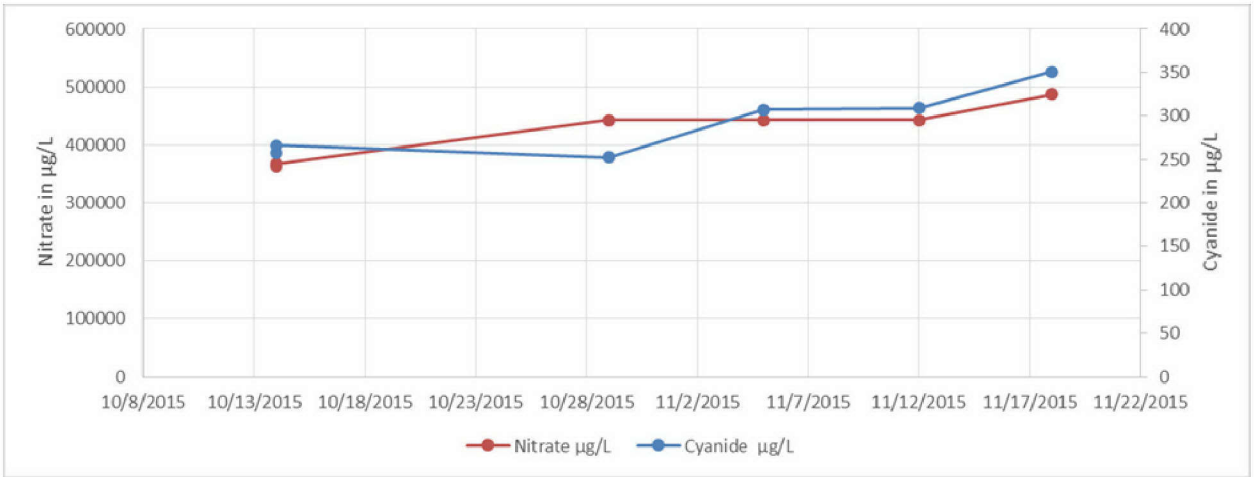


Figure 3-10. Trend Chart of Cyanide and Nitrate Concentrations during the 30-Day Constant-Rate Test

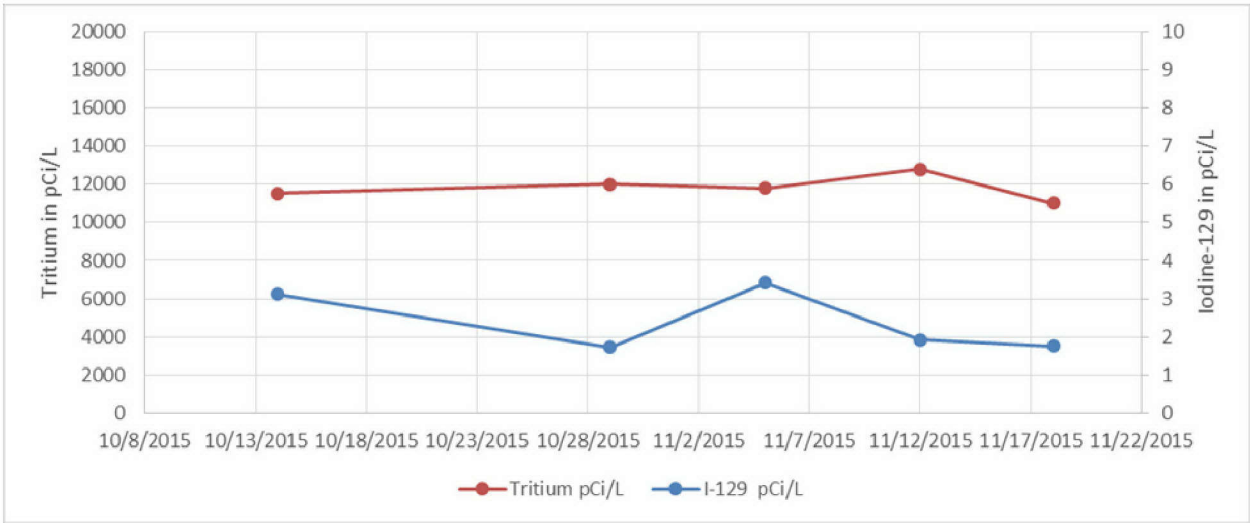


Figure 3-11. Trend Chart of Iodine-129 and Tritium Concentrations during the 30-Day Constant-Rate Test

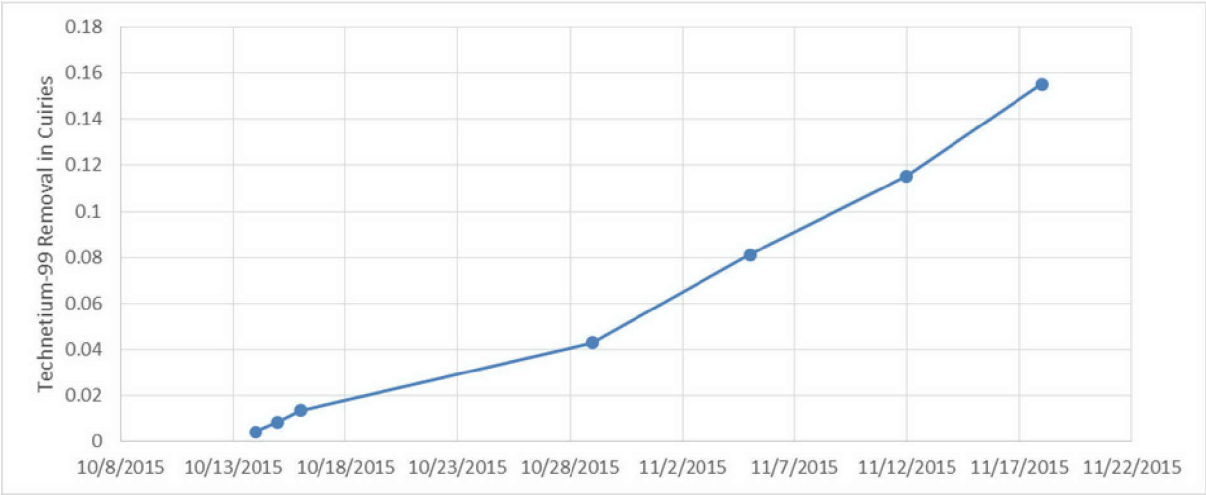


Figure 3-12. Cumulative Technetium-99 Removal during 30-Day Constant-Rate Test

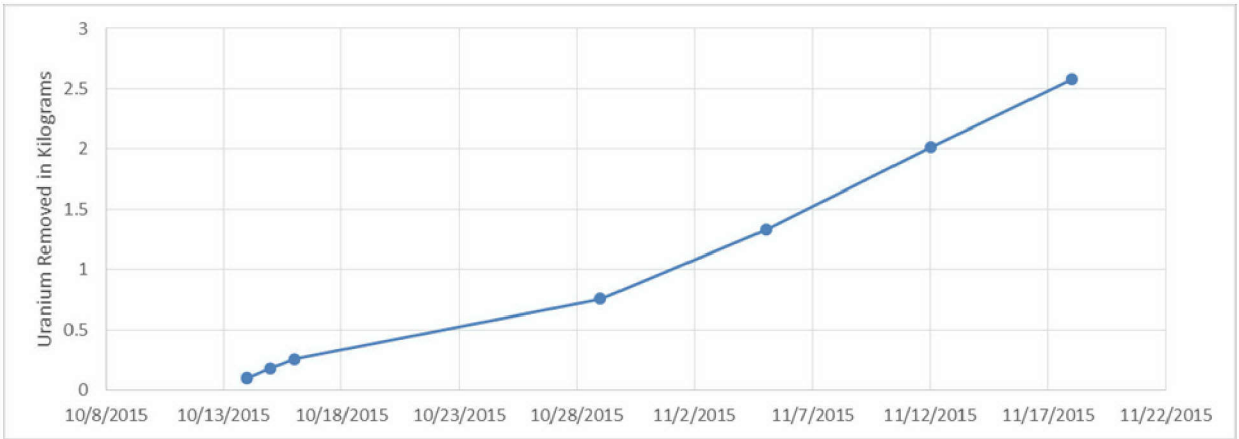


Figure 3-13. Cumulative Uranium Removal during 30-Day Constant-Rate Test

Table 3-9. Total Estimated Mass Removal and Rate of Removal

Contaminant	Average Concentration	Average Pumping Rate (L/min)	Pumping Time (Minimum)	Total Mass Removed	Average Rate of Removal
Technetium-99 pCi/L	7,256	102.6	45,010	0.13 Curies	4.06E-03 pCi/day
Uranium µg/L	129	102.6	45,010	2.25 kg	7.21E-02 µg/day
Cyanide µg/L	351	102.6	45,010	5.1 kg	1.62E-01 µg/day
Nitrate µg/L	42,492	102.6	45,010	7,419 kg	2.37E+02 µg/day
Iodine-129 pCi/L	1.76	102.6	45,010	0.44E-5 Curies	1.41E-6 pCi/day
Tritium pCi/L	11,000	102.6	45,010	0.21 Curies	6.61E-03 pCi/day

4 Conclusions

This treatability test proved that pumping rates greater than a 586 L/min (150 gpm) can be sustained in the unconfined aquifer at B Complex, capture is sufficiently wide to consider P&T as a plausible alternative in the 200-BP-5 OU FS, and treatment of uranium and technetium-99 is achieved by the 200 West Groundwater Treatment Facility.

The following three performance objectives, as required by DOE/RL-2010-74 and discussed in Section 2.1, were completed during this test:

- Objective 1 – The sustained yield of extraction well 299-E33-268 was much greater than a 586 L/min (150 gpm) pumping rate. A maximum drawdown of 10.4 cm (4.09 in.) was observed while pumping at a 568 L/min (150 gpm) (Figure 4-1). This drawdown represented 4.7 percent of the theoretical maximum drawdown of the 2.2 m (7.2 ft) unconfined aquifer thickness.

- Objective 2 – The aquifer response to sustained pumping was measured for calculation of aquifer properties (i.e., aquifer transmissivity and specific yield). Approximately 23,000 water level measurements were collected for each well during the 3-day constant-rate pumping test, resulting in drawdown measurements ranging from 6 to 13 mm at three nearby monitoring wells (Figure 3-4). Three different curve matching techniques were used to derive the hydraulic parameters using the software program AQTESOLV. The pumping rate, drawdown and associated time since pumping started, and distance from the pumping well were used as input parameters for the AQTESOLV program (Section 2.3.4). Averaging the calculation results of the three curve matching techniques derived the following hydraulic parameter values, transmissivity at 4.13E+04 m^2/day and specific yield at 0.21. The hydraulic conductivity was also determined at 1.88 E+04 m/day.

- Objective 3 – Concentrations of uranium and technetium-99 were measured from groundwater samples collected during 30 days of sustained pumping from extraction well 299-E33-268 (Section 3.3). Using the average sample concentration and average pumping rate the total mass removed from the B Complex aquifer was 0.13 curies of technetium-99 and 2.25 kg of uranium. Mass removal of co-contaminants cyanide, nitrate, iodine-129, and tritium was calculated as discussed in Section 3.3.

Although not a test performance objective, the derived hydraulic properties from this treatability test were to be used to update local-scale hydrologic numerical model plume capture simulations (Section 2.4). Model derived drawdown and observed drawdown were compared to assess the representativeness of the model. Drawdowns were similar within a factor of two. The updated capture zone analysis is shown in Figure 4-2 assuming a pumping rate of 378 L/min (100 gpm) and using average hydraulic properties derived from the pilot-scale aquifer test. The simulation indicate that a wide capture zone can be generated with a pumping rate of approximately 378 L/min (100 gpm).

Results of the field tests and numerical model simulation were presented to the Tri-Party agencies on December 17, 2015, and February 18, 2016, respectively. The meeting minutes and presentations associated with these briefings are provided in Appendices C and D, respectively. Recommendations from the test were to continue pumping at the extraction well until the action is superseded by a non-time-critical removal action.

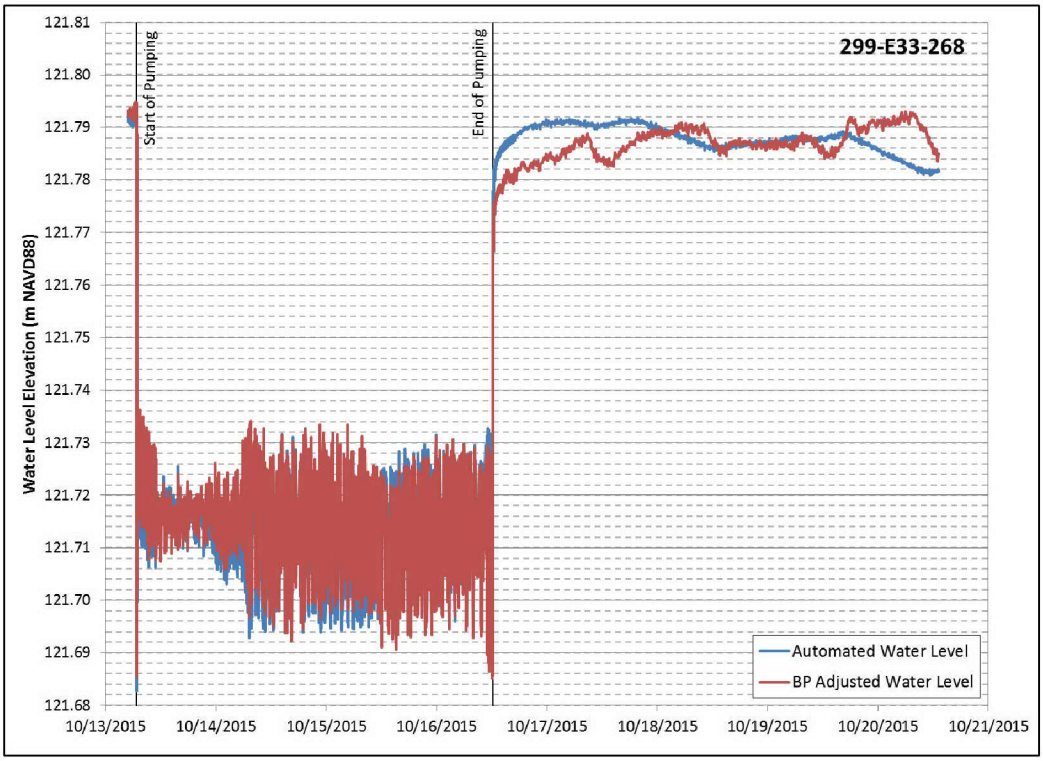


Figure 4-1. Automated Water Level Measurements Collected for Well 299-E33-268 (Pumping Well) during the 3-Day Constant-Rate Discharge Test

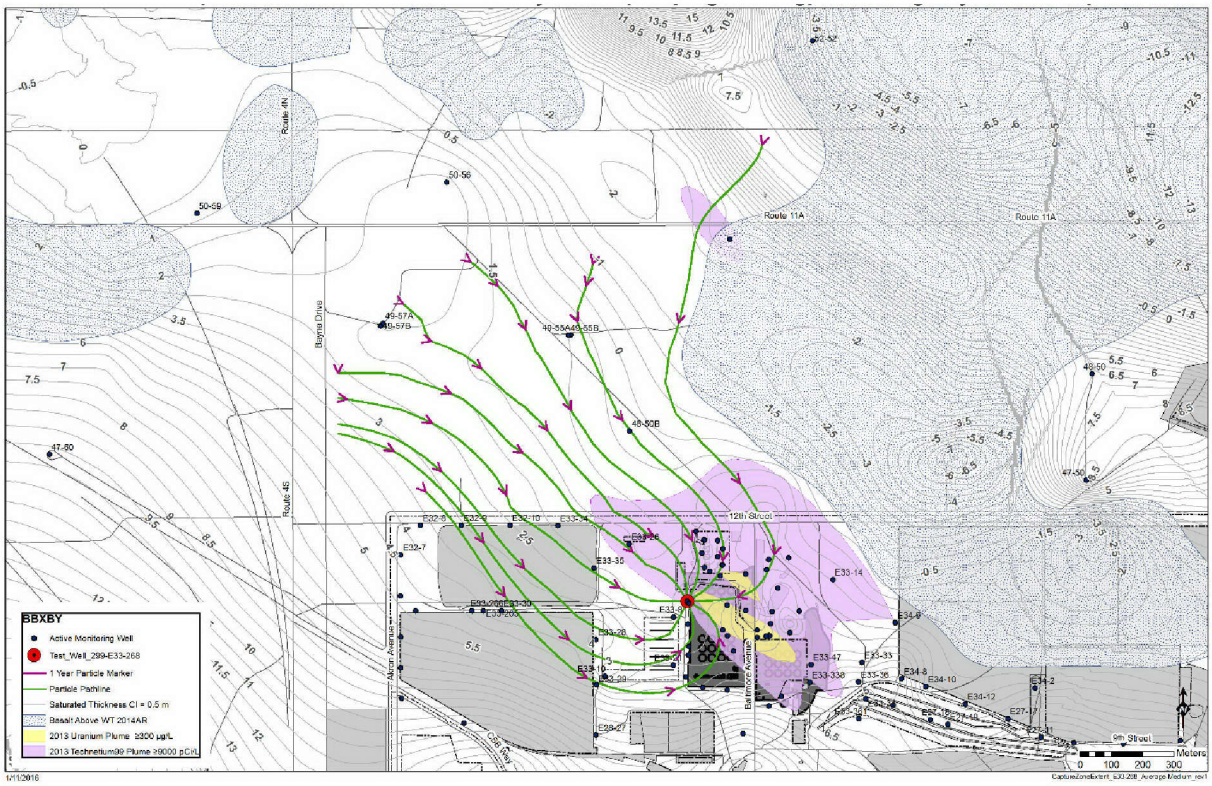


Figure 4-2. Refined Simulated Numerical Model Capture Zone at 378 L/min (100 gpm) Using Average Hydraulic Properties Derived by Treatability Test Results

5 References

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Appendix A

200-BP-5 Treatability Test Analysis of the Step Drawdown and Constant-Rate Pumping Test at Well 299-E33-268

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Plateau Remediation Company

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Terms

BRF	Barometric response function
HISI	Hanford Information Systems Inventory
MRCX	Multiple Regression Correction in Excel
PDT	Pacific Daylight Time
PSIA	Per square inch absolute
PST	Pacific Standard Time

1 Purpose

This document describes the analyses of the step drawdown and constant rate discharge tests conducted at pumping well 299-E33-268 for the 200-BP-5 treatability test (DOE/RL-2010-74, Rev. 2, *Treatability Test Plan for the 200-BP-5 Groundwater Operable Unit*). This well is located in the B Complex of the Hanford Site 200 East Area.

2 Background

From the 1940s until the 1980s, the Hanford Site produced plutonium for national defense. During that time operations used many chemical and radiological constituents which potentially can migrate to groundwater from waste sites. In the 1990s, the Hanford mission changed to environmental cleanup, including remediation of known groundwater contamination under the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*.

A treatability test was conducted in the unconfined aquifer beneath the B Tank Farm Complex in the 200-BP-5 Operable Unit between September and November 2015 to determine the practicality of operating a pump-and-treat system to remediate the uranium and technetium-99 plumes in that area (DOE/RL-2010-74, Rev. 2). The test was conducted in 4 parts: 1) collection of baseline water level measurements, 2) a 1-day step drawdown test, 3) a 3-day constant rate discharge test (at 125 gpm), and 4) a 27-day constant rate discharge test (at 100 gpm). Well 299-E33-268 was the pumping well, and there were 10 observation wells (Figure 1). Purge water was transferred via pipeline to the 200 West Groundwater Treatment Facility for treatment and subsequent injection into the aquifer.

Baseline water level measurements were collected from the pumping and observation wells for a minimum of 30 days prior to the start of the step drawdown test. The data were used to determine the water-level barometric response characteristics for each well, which allowed the water level measurements collected during the test to be corrected for fluctuations caused by barometric pressure changes. Drawdown in the pumping and observation wells was expected to be small due to the high transmissivity of the aquifer, so it was important to remove barometric effects from the data so the drawdown could be discerned.

The step drawdown test was conducted on 9/30/2015. Well 299-E33-268 was pumped at flow rates of 50 gpm (189 L/min), 100 gpm (378 L/min), and 150 gpm (568 L/min) for 2 hours each. The data were analyzed to determine the efficiency of the pumping well. The 3-day constant rate discharge test was conducted at 125 gpm (473 L/min). Pumping for this test began on 10/13/2015 at 6:44:57 AM (Pacific Standard Time [PST]) and ended on 10/16/2015 at 12:15:17 PM PST. The data were analyzed to determine aquifer properties (transmissivity, hydraulic conductivity, and specific yield). After a recovery period, the 3-day test was followed by the 27-day constant rate discharge test. Pumping for this test began on 10/22/2015 at 6:32:19 AM PST and ended on 11/19/2015 at 8:05:27 AM PST.

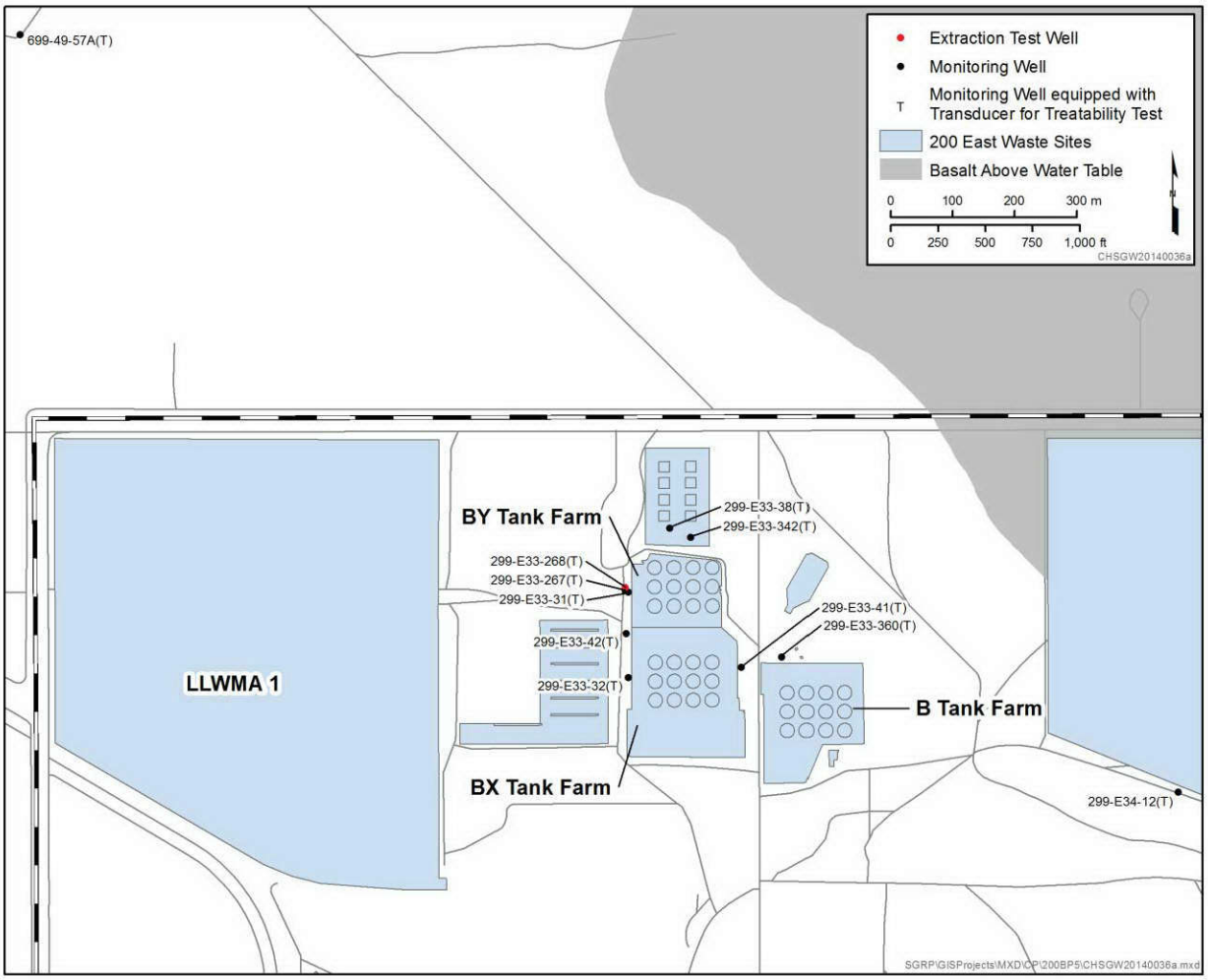

Figure 1. Well Location Map for the 200-BP-5 Treatability Test

3 Methodology

This section describes the analysis of the baseline water level data to determine barometric response characteristics, the method of normalizing the water level measurements to a constant barometric pressure, the method of analysis of the step drawdown test, and the methods used to analyze data from both the 3-day and 27-day constant rate discharge tests.

3.1 Normalization of Hydraulic Heads to a Constant Barometric Pressure

Within unconfined aquifers, changes in ambient barometric pressure can cause changes in well water level elevations if the barometric change causes an imbalance of air pressure between the well and the adjacent vadose zone at the water table. This occurs in relatively deep wells because of the thick vadose zone, and in other wells where low-permeability units within the vadose zone inhibit the migration of air pressure pulses. Barometric pressure changes introduce variability into water-level measurements in two ways: (1) barometric pressure may change during the time period in which a set of water-level measurements is collected from a well network, and (2) different wells may respond differently to barometric pressure changes. To account for these sources of variability, the water-level measurements collected for the treatability test were normalized to a constant barometric pressure using multiple regression/deconvolution ("Identifying and Removing Barometric Pressure Effects in Confined and Unconfined Aquifers" [Rasmussen and Crawford, 1997]; "Considering Barometric Pressure in Groundwater Flow Investigations" [Spane, 2002]).

Using the baseline water level data for the pumping well and each observation well, multiple regression was used to determine the quantitative relationship between barometric pressure and well water-level response (using time series data for both parameters). This relationship was then used to determine a barometric response function (BRF) describing how the well water level would change to an instantaneous unit change in barometric pressure.

The multiple regression was performed using the MRCX software developed by Pacific Northwest National Laboratory (PNNL-19775, *Guide to Using Multiple Regression in Excel [MRCX v. 1.1] for Removal of River Stage Effects from Well Water Levels*), which is based on Microsoft[1] Excel. Although this software was specifically designed for assessing river stage effects, it can also be used for barometric pressure effects because the mathematical equations are identical. The water-level measurements and barometric pressure time series were detrended (using Excel) and then input into MRCX. The regression was performed using either the "original data" or "first differences" options in MRCX, whichever provided the best results. The "original data" option corresponds to the following regression equation from Rasmussen and Crawford (1997, Equation 7):

$$h_O(t) = \beta_0 + \beta_1 t + \Delta u_0 B(t) + \Delta u_1 B(t-1) + \ldots + \Delta u_n B(t-n) \qquad \textbf{(Equation 1)}$$

where:

h_O = observed well water-level elevation (m) as a function of time t (hr)

β_0 = offset coefficient (m)

β_1 = linear trend coefficient (m/hr) (which was determined to be zero during the regression analysis because the data were detrended beforehand)

[1] The Microsoft® products identified in this calculation are either registered trademarks or trademarks of Microsoft Corporation in the United States and/or in other countries.

Δu_n = fitted barometric response coefficient (i.e., regression coefficients) for time lags of 0 to n (m/m)

B = barometric pressure measurements (m of water) as a function of time

n = maximum time lag (hr)

The "first differences" option uses an equation of the same form, except that changes in the water levels are related to changes in barometric pressure:

$$\Delta h_O(t) = \beta_0 + \beta_1 t + \Delta u_0 \Delta B(t) + \Delta u_1 \Delta B(t-1) + \ldots + \Delta u_n \Delta B(t-n) \qquad \textbf{(Equation 2)}$$

where:

Δh_O and ΔB = change in observed well water-level elevation and change in barometric pressure, respectively, between successive times

When performing the multiple regression in MRCX, the maximum time lag (n) was increased to a value at which a good fit was achieved between the predicted and measured water levels and a further increase did not substantially improve the fit. The BRF was determined by MRCX from the regression coefficients as follows (Rasmussen and Crawford, 1997, Equation 5):

$$u(\tau) = \sum_{i=0}^{\tau} \Delta u_i \qquad \textbf{(Equation 3)}$$

where:

u = water-level response (m) to an instantaneous unit change in barometric pressure as a function of the time lag, τ (hr)

The BRFs for each well used in this test are provided in Appendix A.

Deconvolution was used to normalize the water-level measurements collected for this test to a constant barometric pressure using Excel. The net change in well water-level in response to a recent history of barometric pressure changes (n + 1 hourly measurements total) was computed using the following numerical approximation of a convolution integral (Rasmussen and Crawford, 1997, Equation 4):

$$\Delta h_B(t) = \sum_{\tau=0}^{n} u(\tau) \cdot \Delta B(t-\tau) \qquad \textbf{(Equation 4)}$$

where:

Δh_B = change in well water-level elevation (m) at some time t (hr) due to changes in barometric pressure for the previous n time lags

τ = time lag (hr) between a previous hourly barometric pressure change and the associated well water-level response at the current time

ΔB = change in barometric pressure (m of water) over the previous hourly time steps

Finally, the change in well water-level elevation was added to the observed well water-level elevation (i.e., deconvolved) to produce an adjusted well water-level elevation in which barometric pressure effects had been removed (i.e., normalized to a constant barometric pressure).

It should be noted that the equations presented in Rasmussen and Crawford (1997) are written in terms of total head (i.e., the sum of hydraulic head and barometric pressure head), whereas the equations presented in this section are in terms of hydraulic head (i.e., well water-level elevation). To normalize water-level

measurements to a constant barometric pressure, well water-level response functions are needed instead of total head response functions. The use of well water-level elevations instead of total head is valid because convolution can be used on any pair of variables exhibiting a linear stress-response relationship (Olsthoorn, 2008, "Do a Bit More with Convolution").

3.2 Analysis of the Step Drawdown Test

Drawdown observed during the step-drawdown test was used to calculate the specific capacity for each flow rate (as flow rate divided by drawdown). Further, it was intended that the theoretical maximum yield of the pumping well (i.e., the pumping rate correlating to 100 percent drawdown) would be estimated. This was to be done by using the drawdown observed at multiple pumping rates to predict by regression a pumping rate associated with full drawdown (i.e., the total thickness of the aquifer, which is 2.2 m [7.2 ft]). However, the aquifer beneath the 200 East Area is so highly transmissive that the maximum drawdown observed was only 4.7% of the total drawdown available. Because of this low value, it was deemed not feasible to predict a meaningful pumping rate for 100% drawdown. Thus, the maximum theoretical yield was reported simply as being much higher than the maximum flow rate during the step-drawdown test (i.e., >>150 gpm).

3.3 Analysis of the Constant Rate Discharge Tests

Data from the 3-day and 27-day constant rate discharge tests were analyzed using the AQTESOLV[2] software. AQTESOLV allows for the display of aquifer test data, calculation of pressure derivatives, and analysis of the data to determine aquifer properties. It includes a large number of analysis methods applicable to a wide variety of situations (e.g., slug tests, pump tests, confined aquifers, unconfined aquifers, leaky confined aquifers, etc.).

The solution methods used for this analysis were Theis (1935, "The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage") as modified by Hantush (1961a, "Drawdown around a partially penetrating well") and Hantush (1961b, "Aquifer tests on partially penetrating wells"), Neuman (1974, "Effect of partial penetration on flow in unconfined aquifers considering delayed gravity response"), and Moench (1997, "Flow to a well of finite diameter in a homogeneous, anisotropic, water-table aquifer"). Pressure derivatives were calculated using the method of Spane and Wurstner (1993, "DERIV: A computer program for calculating pressure derivatives for use in hydraulic test analysis").

3.3.1 Pressure Derivatives

The pressure derivative consists of the change of drawdown water level measurements with respect to the natural logarithm of time. The shape of the resulting curve can be used diagnostically to identify test conditions not as easily identified by examining the drawdown measurements directly (e.g., wellbore storage, vadose zone gravity drainage, infinite acting radial flow conditions, recharge boundary conditions, etc.) (Spane and Wurstner [1993]).

The method of Spane and Wurstner (1993), which is implemented in the AQTESOLV software, was used to calculate pressure derivatives. The user can specify the L-spacing, which is the portion of a log cycle used in calculating the derivative. An L-spacing of 1 (the maximum allowed) was used which resulted in the most smoothing of the data. This was done because the water level measurements collected during the tests were noisy compared to the magnitude of the drawdown observed.

[2] AQTESOLV is copyrighted by HydroSOLVE, Inc., Reston, Virginia.

3.3.2 Theis (1935) / Hantush (1961a,b) Method

The method of Theis (1935) was developed for nonsteady flow to a fully penetrating well in a confined aquifer. The equations are (Freeze and Cherry, 1979, *Groundwater*):

$$s = \frac{Q}{4\pi T}\int_{u}^{\infty}\frac{e^{-u}}{u}du \qquad \textbf{(Equation 5)}$$

in which

$$u = \frac{r^2 S}{4Tt} \qquad \textbf{(Equation 6)}$$

where:

s = drawdown from static water level (length)

Q = pumping rate (length^3/time)

T = transmissivity (length^2/time)

r = radial distance from the pumping well to the observation well (length)

S = storage coefficient (unitless)

t = time (time)

The integral in Equation 5 is the exponential integral and is commonly represented as a function, $W(u)$, known as the well function. Values of the well function can be determined numerically.

Hantush (1961a,b) extended the Theis (1935) method to account for partially penetrating wells and anisotropy (vertical hydraulic conductivity can differ from the horizontal hydraulic conductivity). The equations are more complex and the reader is referred to Hantush (1961a,b) or the AQTESOLV online help for details.

Although developed for confined aquifers, the method of Theis (1935) / Hantush (1961a,b) can be used to determine hydraulic properties for unconfined aquifers if the amount of drawdown is small relative to the aquifer thickness (Freeze and Cherry, 1979). Once infinite acting radial flow conditions have been achieved during the test, straight line analysis methods can be used (e.g., Cooper and Jacob, 1946, "A generalized graphical method for evaluating formation constants and summarizing well field history"). This condition is indicated by a constant pressure derivative following the wellbore storage and gravity drainage responses (PNL-8359, 1993, *Selected Hydraulic Test Analysis Techniques for Constant-Rate Discharge Tests*). The advantage of the straight line method is that it can be easily implemented graphically. However, type curves were used for analyzing the 200-BP-5 data because these are automatically implemented in AQTESOLV.

3.3.3 Neuman (1974) Method

The method of Neuman (1974) was developed for nonsteady flow to a fully or partially penetrating well in a homogeneous, anisotropic unconfined aquifer with delayed gravity drainage from the vadose zone. The anisotropy component refers only to differences between the horizontal and vertical hydraulic conductivity; horizontal hydraulic conductivity is isotropic (i.e., constant regardless of direction). The equations are complex and the reader is referred to Neuman (1974) or the AQTESOLV online help for details.

3.3.4 Moench (1997) Method

Like Neuman (1974), the method of Moench (1997) also applies to nonsteady flow to a fully or partially penetrating well in a homogeneous, anisotropic (horizontal versus vertical hydraulic conductivity only) unconfined aquifer with delayed gravity drainage from the vadose zone. However, the method also includes wellbore storage and skin effects. Thus, drawdown in the pumping well can be included in the analyses, whereas with the other methods, only observation wells are used. The equations are complex and the reader is referred to Moench (1997) or the AQTESOLV online help for details.

3.3.5 Recovery Data

Drawdown data from constant rate discharge tests can be directly analyzed to determine hydraulic properties by application of the methods described in Sections 3.3.2, 3.3.3, and 3.3.4. To analyze recovery data using these methods, the buildup of the water level after the termination of pumping has to be expressed in terms of the Agarwal equivalent time (Agarwal, 1980, "A New Method to Account for Producing Time Effects when Drawdown Type Curves are used to Analyze Pressure Buildup and other Test Data"), as follows:

$$t_e = \frac{t \cdot t'}{t + t'} \qquad \textbf{(Equation 6)}$$

where:

t_e = Agarwal equivalent time

t = duration of pumping

t' = time since pumping terminated

4 Assumptions and Inputs

This section lists the assumptions and inputs applicable to the 200-BP-5 treatability test analyses.

4.1 Assumptions

The main assumption regarding normalizing water level measurements to a constant barometric pressure is that the response of the well water level to a barometric pressure change is linear. In other words, if the barometric pressure change is doubled, the water level response doubles; if the pressure changed is halved, the water level response is halved. Linearity allows for the method of convolution to be applied in which the known response of the water level to a unit, step change in barometric pressure is used to determine the water level response to an arbitrary time-series of barometric pressure changes using superposition.

Several assumptions apply to the aquifer test analysis methods described in Section 3. Because many of the assumptions are common to more than one method, they are listed in Table 1 and the applicable method(s) are indicated.

Table 1. Constant Rate Discharge Test Analysis Methods and Assumptions

Assumption	Theis (1935) / Hantush (1961a,b)	Neuman (1974)	Moench (1997)
Aquifer is of infinite lateral extent	X	X	X
Aquifer is of constant thickness	X	X	X
Aquifer is homogeneous	X	X	X
Aquifer slope is negligible	X	X	X
The lower boundary of the aquifer is impermeable	X	X	X
The water table is initially horizontal	X	X	X
Drawdown is small relative to the aquifer thickness	X	X	X
Aquifer is anisotropic (i.e., $K_x = K_y \neq K_z$)	X	X	X
Water is discharged instantaneously from storage	X		
Wellbore storage/skin effects are negligible	X	X	

4.2 Inputs

Input data to the test analyses consisted of the following:

- Barometric pressure measurements from Hanford meteorology stations 6 (200 East Area) and 21 (200 West Area). Data from station 6 were primarily used; data from station 21 were used only fill gaps in the station 6 data.
- Time series water level measurements from the pumping and observation wells. These data were collected using absolute pressure transducers (Model 3001 LeveLogger Gold® and Model 3001 BaroLogger Gold™ both manufactured by Solinst[3]), as opposed to vented transducers, following the recommendations in SGW-49700, 2011, *Comparison of Vented and Absolute Pressure Transducers for Water-Level Monitoring in Hanford Site Central Plateau Wells*.
- Pumping well flow rates. These data were obtained from the pump-and-treat operation organization which collects flow rate data on a very frequent basis from all operating pumping wells. These data were reduced to specific time/flow rate pairs to represent the main changes in flow rates during test startup. The reduced data input into AQTESOLV are given in Table 2 for both the 3-day and 27-day tests.
- Well location and construction characteristics. This information was obtained from as-built diagrams and survey reports and is listed in Table 3 for the pumping well (299-E33-268) and those observation wells with discernable drawdown (299-E33-31, 299-E33-267, and 299-E33-342). All of the wells fully penetrated the 2.2 m thickness aquifer.

[3] Model 3001 LeveLogger Gold® is a registered trademark and the Model 3001 BaroLogger Gold™ is a trademark of Solinst Canada, Ltd., Georgetown, Ontario, Canada.

Table 2. Pumping Rates Input into AQTESOLV for the Constant Rate Discharge Tests

Time (days)	Flow Rate (gpm)		Time (days)	Flow Rate (gpm)		Time (days)	Flow Rate (gpm)
3-Day Test							
0	164.4632568		0.006944444	123.6388168		0.180555556	124.0922227
0.000694444	156.5557505		0.013888889	123.1247823		0.222222222	123.8409323
0.001388889	140.8461151		0.020833333	123.2649743		0.263888889	123.8435286
0.002083333	142.2113698		0.027777778	123.3387348		0.305555556	123.9935702
0.002777778	137.4971085		0.034722222	123.8152012		0.347222222	124.1912576
0.003472222	134.5970764		0.041666667	124.0703861		0.388888889	124.5991547
0.004166667	131.7153727		0.048611111	124.1010817		0.430555556	124.9021388
0.004861111	128.7649473		0.055555556	123.9962428		0.472222222	124.9998716
0.005555556	126.4101067		0.097222222	123.9957854		3.229166667	0
0.00625	125.4021975		0.138888889	124.1671291			
27-Day Test							
0	126.3093109		0.000347222	131.9444427		0.00150463*	100
0.000231481	147.5578766		0.001388889	76.58275604			

* Constant flow rate from this time on.

Table 3. Well Location and Characteristics Information Input into AQTESOLV

Parameter	299-E33-268	299-E33-267	299-E33-31	299-E33-342
Easting coordinate (m)[a]	573519.25	573519.51	573524.98	573625.68
Northing coordinate (m)[a]	137498.67	137494.16	137491.439	137579.96
Inside radius of well casing (m)	0.1016[b]	0.0508	0.0508	0.0508
Radius of downhole equipment (m)	0.0381	0.0127	0.0127	0.0127
Radius of well open interval (m)	0.1016	0.0508	0.0508	0.0508
Fully penetrating?	Yes	Yes	Yes	Yes

a. North American Datum (1983) state plane, Washington south zone (4602)
b. This value was a solution parameter by the Moench (1997) method, so the final value determined by that method differs from the value entered into the AQTESOLV software.

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5 Software Applications

The software applications used for this work were MRCX, AQTESOLV, and MS Excel. Both MRCX Version 1.1 (HISI ID: 3385) and AQTESOLV Version 4.50 Professional (HISI ID: 3219) are registered in Hanford Information Systems Inventory (HISI) and are approved for use. Other than for MRCX, Excel was used as a desktop calculator and is exempt from controlled software management procedures. Both MRCX and AQTESOLV® were used within their limitations.

6 Calculations

The time-series water level measurements collected during the baseline period were analyzed using MRCX to determine BRFs for the pumping and observation wells used in this test. The baseline data were collected on a one-hour frequency, so the BRFs consist of time-varying barometric coefficients at hourly intervals. Charts of the baseline water level measurements and the BRFs are provided in Appendix A.

Automated water level measurements were collected in the pumping well (299-E33-268) during the step drawdown test at a 2-second frequency. Due to a logger programming issue, data collection did not actually begin until the test was underway at the first flow rate (50 gpm). The data were used to calculate the drawdown associated with each pumping rate (the static water level was determined from the recovery data collected after pumping was terminated). The data were not normalized to a constant barometric pressure due to the short duration of the test. Results of the step-drawdown test are provided in Section 7.

The time-series water level measurements collected for the 3-day and 27-day constant rate discharge tests were normalized to a constant barometric pressure using deconvolution, as described in Section 3.1. During this analysis, it was discovered that the LeveLogger in well 299-E33-38 had failed, so data from this well were not available for analysis. Further, the cable on the LeveLogger for 699-49-57A was damaged (apparently by animals), so data from this well were not available for analysis. Charts of the data for the remaining wells were examined to determine if drawdown could be discerned in each well. Drawdown was obvious in the pumping well, 299-E33-268, but because of the high transmissivity of the aquifer, drawdown was discernable in only 3 of the observation wells: 299-E33-267 (4.5 m [15 ft] south of the pumping well), 299-E33-31 (9.2 m [30 ft] southeast of the pumping well), and 299-E33-342 (134 m [440 ft] northeast of the pumping well). Data from these 4 wells were used to determine aquifer hydraulic properties. Charts of the automated water level measurements collected from the pumping and observation wells are provided in Appendices B and E for the 3-day and 27-day constant rate discharge tests, respectively.

Large data sets were collected during the test. Because the start of pumping could not be timed precisely, the loggers were set to record on a 2-second frequency for 6 hours during the startup period. The 2-second frequency allowed for good resolution on the initial drawdown in the wells. This period was followed by a 5-minute frequency lasting for much of the pumping phase of the test. When pumping was terminated, the loggers were set to record again at a 2-second frequency for 6 hours to resolve the initial rapid water level changes during recovery. This was followed by measurements at a 5-minute frequency for the remainder of the recovery period. This resulted in the collection of over 23,000 water level measurement records from each of the wells during the 3-day test, and over 30,000 records during the 27-day test. To reduce this data set to a reasonable size for analysis, the data were resampled on a log frequency. The initial frequency was 2 seconds for 10 records commencing at the start of pumping (or recovery). Then, the sample interval was doubled to 4 seconds for another 10 records, followed by 8 seconds for 10 records, etc. By this method, the approximately 20,000 to 30,000 measurements collected for each well

during the tests were reduced to between 122 and 153 measurements during either the pumping or recovery phases. These data were then imported into the AQTESOLV software for analysis.

The water levels in 299-E34-12 were used to identify temporal trends in the water table during both the 3-day and 27-day tests. During the 3-day test, the background water table elevation was stable, but it declined about 0.014 m during the 27-day test. Because the rate of decline was stable, linear regression was used to identify the slope of the declining trend and then this slope was used to detrend all the water level measurements collected during the 27-day test (a comparison of the original and detrended measurements for 299-E34-12 is shown in Figures E-9 and E-10 in Appendix E). This was done so the background water table decline did not affect the drawdown determinations.

It should be noted that the cable to the BaroLogger in 299-E33-32 failed during the 27-day test, so downhole barometric pressure measurements were not directly available. However, the relationship between the downhole barometric pressure and the barometric pressure measurements at meteorology station 6 were determined by multiple linear regression on the background measurements, and then convolution was used to estimate the downhole pressure from the station 6 measurements during the 27-day test (using the same method described Section 3.1).

The pressure derivative was examined for the pumping well and the 3 observation wells with discernable drawdown. The pressure derivative was used to assist in determining the time period for which curve matching would be performed. Aquifer properties were then determined by fitting of type curves to the data using the automatic curve matching feature of AQTESOLV. The variables allowed to vary and their limits are shown in Table 4 for each solution method. At the start of the 3-day test, the pumping rate varied for a few minutes until it stabilized near the planned rate of 125 gpm. For this reason, the period used for curve matching (i.e., the analysis window) was usually set to begin at either 0.01 days (2.4 minutes) or 0.1 days (2.4 hours) after pumping began, and the analysis window typically extended the duration of the pumping phase (3.3 days). During startup of the 27-day test, the pumping rate stabilized at 100 gpm more quickly and drawdown in the wells had stabilized after about 1 day. For these reasons, the period used for curve matching typically started at 0.0001 days (8 seconds) and ended at 1 day.

Table 4. Variables and Limits used for the Automatic Curve Matching Feature of AQTESOLV

Variable	Theis (1935) / Hantush (1961a,b)		Neuman (1974)		Moench (1997)	
	Min	Max	Min	Max	Min	Max
Transmissivity (T) (m^2/d)	1	1×10^6	1	1×10^6	1	1×10^6
Storativity (S)	1×10^{-3} [a]	n/a [a]	1×10^{-5}	1×10^{-3}	1×10^{-3} [b]	1×10^{-3} [b]
Specific Yield (S_y)	n/a [a]	1.0 [a]	1×10^{-3}	1.0	0.21 [b]	0.21 [b]
Anisotropy Ratio (K_z/K_r)	0.001	1.0	Not used	Not used	0.01	1.0
Wellbore Skin Factor (S_w)	n/a	n/a	n/a	n/a	-5	100

a. The Theis (1935) / Hantush (1961a,b) method uses only a single storage coefficient variable; the minimum was set to 1×10^{-3} and the maximum was set to 1.0.
b. Storativity and specific yield were held constant at the indicated values for the Moench (1997) method.

Curve matching using the Theis (1935) / Hantush (1961a,b) method and the Neuman (1974) method was performed for each observation well separately, for observation wells 299-E33-267 and 299-E33-31 together (these are closest to the pumping well), and for all three observation wells together. The Moench (1997) method was applied to all 4 wells.

Recovery data for the 3-day and 27-day tests were also analyzed. Buildup of the water level after the termination of pumping was calculated in a similar manner as for drawdown. The recovery times were then converted to Agarwal equivalent times using Equation 6. The recovery data were analyzed in the same manner as for the drawdown data, except that the method of Moench (1997) was not employed (because there was no active pumping). A large barometric pressure change occurred just as the recovery portion of the 27-day test began. Because normalization of the water level measurements to a constant barometric pressure contains some residual error, the recovery data at well 299-E33-342 (which had the lowest drawdown) was adversely affected. Because of this, hydraulic property determinations for this well were very sensitive to the period of analysis chosen, so the results for this well when analyzed by itself were determined not to be reliable.

Charts of the fitted curves for the drawdown and recovery portions of the 3-day test are provided in Appendices C and D, respectively. Charts of the fitted curves for the drawdown and recovery portions of the 27-day test are provided in Appendices F and G, respectively. Appendices C and F also contain charts of the pressure derivative for wells 299-E33-268, 299-E33-31, 299-E33-267, and 299-E33-342 for the drawdown portion of the 3-day and 27-day tests, respectively.

7 Results

The automated water level measurements collected during the step-drawdown test are shown in Figure 2, and results of the test are shown in Table 5. The maximum drawdown was 0.104 m (10.4 cm) at the 150 gpm flow rate, which is only 4.7 % of the theoretical maximum drawdown of 2.2 m (220 cm). Thus, drawdown was not a limiting factor on pumping, and the theoretical maximum yield is greater than 150 gpm. Specific capacity ranged from a high of 2,500 gpm/m (762 gpm/ft) at the 50 gpm flow rate to a low of 1,442 gpm/m (440 gpm/ft) at the 150 gpm flow rate. These specific capacity values are quite high. For comparison, the pump-and-treat extraction well in the 200 West Area with the highest specific capacity is 299-W14-22 with a value of 45.9 gpm/m (13.7 gpm/ft) at a flow rate of approximately 100 gpm.

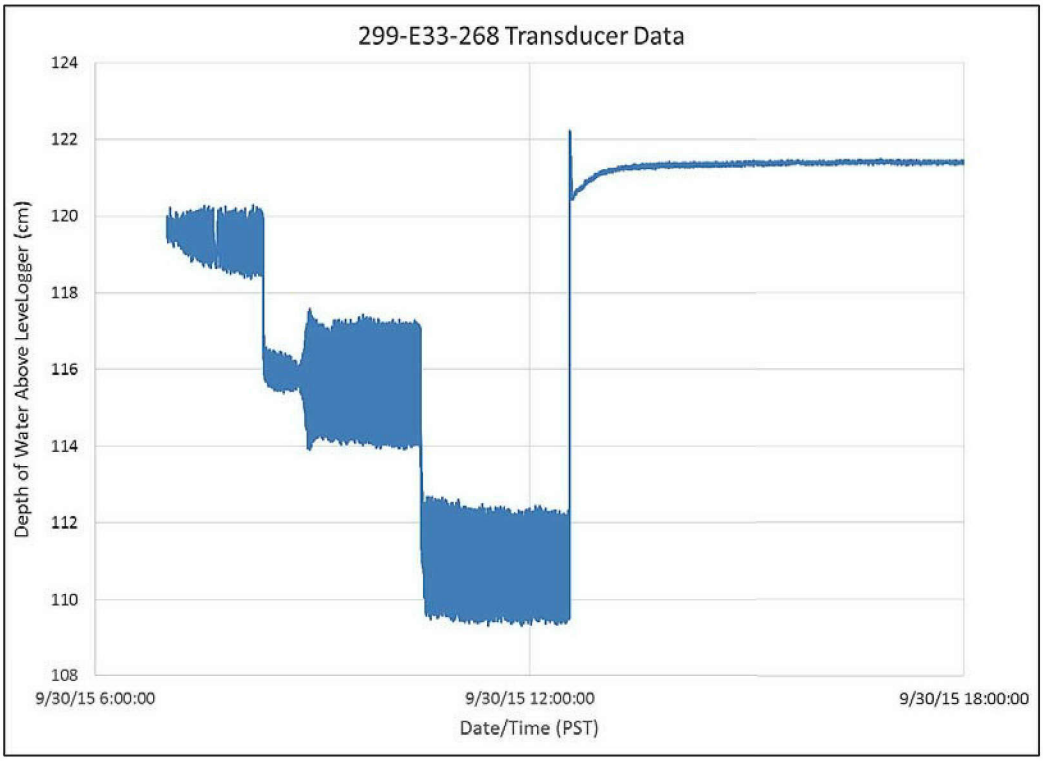

Figure 2. Automated Water Level Measurements Collected in Pumping Well 299-E33-268 during the Step-Drawdown Test

Table 5. Results of the Step-Drawdown Test

Pumping Rate (gpm)	Drawdown		Specific Capacity	
	cm	Percent of Total Available Drawdown*	gpm/m	gpm/ft
50	2.0	0.9 %	2,500	762
100	5.7	2.6 %	1,754	535
150	10.4	4.7 %	1,442	440

* Total available drawdown is equal to the aquifer thickness of 2.2 m (220 cm).

Results of determining hydraulic properties for the drawdown and recovery portion of the 3-day test are provided in Table 6. Transmissivity ranged from 34,800 to 46,900 m^2/day with an average value of 41,300 m^2/day. Hydraulic conductivity ranged from 15,800 to 21,300 m/day with an average value of 18,800 m/day. Specific yield values for several of the tests were unrealistically high. This may be caused by assumptions of the analytical models not being fully met. Those results that were unrealistically high were not included in calculating the range and average result, which was 0.11 to 0.31 with an average of 0.21.

Table 6. Results of Determining Hydraulic Properties for the 3-Day Constant Rate Discharge Test

Analysis Type			Results		
Wells	**Test Type**	**Solution Method**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Specific Yield**
299-E33-31	Drawdown	Theis (1935)	4.36E+04	1.98E+04	0.25
299-E33-31	Drawdown	Neuman (1974)	4.56E+04	2.07E+04	0.18
299-E33-31	Recovery	Theis (1935)	4.12E+04	1.87E+04	0.63[a]
299-E33-31	Recovery	Neuman (1974)	4.13E+04	1.88E+04	0.62[a]
299-E33-267	Drawdown	Theis (1935)	3.53E+04	1.60E+04	1.00[a]
299-E33-267	Drawdown	Neuman (1974)	4.26E+04	1.94E+04	0.23
299-E33-267	Recovery	Theis (1935)	3.48E+04	1.58E+04	1.00[a]
299-E33-267	Recovery	Neuman (1974)	3.53E+04	1.60E+04	1.00[a]
299-E33-342	Drawdown	Theis (1935)	4.22E+04	1.92E+04	0.21
299-E33-342	Drawdown	Neuman (1974)	4.20E+04	1.91E+04	0.22
299-E33-342	Recovery	Theis (1935)	3.54E+04	1.61E+04	0.11
299-E33-342	Recovery	Neuman (1974)	3.54E+04	1.61E+04	0.11
299-E33-31 & 299-E33-267	Drawdown	Theis (1935)	4.15E+04	1.89E+04	0.31
299-E33-31 & 299-E33-267	Drawdown	Neuman (1974)	3.96E+04	1.80E+04	0.45[a]
299-E33-31 & 299-E33-267	Recovery	Theis (1935)	4.27E+04	1.94E+04	0.28
299-E33-31 & 299-E33-267	Recovery	Neuman (1974)	4.25E+04	1.93E+04	0.28
E33-31, E33-267, & E33-342	Drawdown	Theis (1935)	4.37E+04	1.99E+04	0.21
E33-31, E33-267, & E33-342	Drawdown	Neuman (1974)	4.36E+04	1.98E+04	0.21
E33-31, E33-267, & E33-342	Recovery	Theis (1935)	4.69E+04	2.13E+04	0.14
E33-31, E33-267, & E33-342	Recovery	Neuman (1974)	4.68E+04	2.13E+04	0.14
All Wells	Drawdown	Moench (1997)	4.50E+04	2.05E+04	0.21[b]
		Minimum:	3.48E+04	1.58E+04	0.11
		Maximum:	4.69E+04	2.13E+04	0.31
		Average:	**4.13E+04**	**1.88E+04**	**0.21**

a. Unrealistic specific yield value – not used in the minimum, maximum, or average determinations.
b. The specific yield for the Moench (1997) method was held constant at the average value of 0.21 determined from the other analyses.

Results of determining hydraulic properties for the drawdown and recovery portion of the 27-day test are provided in Table 7. The results confirmed the properties determined during the 3-day test. Transmissivity ranged from 33,200 to 46,400 m^2/day with an average value of 40,100 m^2/day. Hydraulic conductivity ranged from 15,100 to 21,100 m/day with an average value of 18,200 m/day. Many of the specific yield determinations came out unrealistically high, so the range and average was not determined. This was a consequence of curve matching to earlier data than during the 3-day test. Although the transmissivity and hydraulic conductivity results of the 27-day test were similar to the results of the 3-day test, the 3-day test is considered to be the better test because of a higher pumping rate (125 gpm) which stressed the aquifer a little more than the pumping rate during the 27-day test (100 gpm), as well as more realistic specific yield values. Thus, the average values for the 3-day test are considered to be the final results.

Table 7. Results of Determining Hydraulic Properties for the 27-Day Constant Rate Discharge Test

Analysis Type			Results		
Wells	**Test Type**	**Solution Method**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Specific Yield[a]**
299-E33-31	Drawdown	Theis (1935)	4.38E+04	1.99E+04	0.38
299-E33-31	Drawdown	Neuman (1974)	4.36E+04	1.98E+04	0.38
299-E33-31	Recovery	Theis (1935)	4.19E+04	1.90E+04	0.82
299-E33-31	Recovery	Neuman (1974)	4.20E+04	1.91E+04	0.80
299-E33-267	Drawdown	Theis (1935)	3.32E+04	1.51E+04	1.00
299-E33-267	Drawdown	Neuman (1974)	3.32E+04	1.51E+04	1.00
299-E33-267	Recovery	Theis (1935)	4.18E+04	1.90E+04	1.00
299-E33-267	Recovery	Neuman (1974)	4.20E+04	1.91E+04	0.80
299-E33-342	Drawdown	Theis (1935)	4.64E+04	2.11E+04	0.36
299-E33-342	Drawdown	Neuman (1974)	4.56E+04	2.07E+04	0.37
299-E33-342	Recovery	Theis (1935)	Not reliable[b]	n/a[b]	n/a[b]
299-E33-342	Recovery	Neuman (1974)	Not reliable[b]	n/a[b]	n/a[b]
299-E33-31 & 299-E33-267	Drawdown	Theis (1935)	3.60E+04	1.64E+04	0.76
299-E33-31 & 299-E33-267	Drawdown	Neuman (1974)	3.58E+04	1.63E+04	0.77
299-E33-31 & 299-E33-267	Recovery	Theis (1935)	3.93E+04	1.79E+04	1.00
299-E33-31 & 299-E33-267	Recovery	Neuman (1974)	3.92E+04	1.78E+04	0.57
E33-31, E33-267, & E33-342	Drawdown	Theis (1935)	3.71E+04	1.69E+04	0.65
E33-31, E33-267, & E33-342	Drawdown	Neuman (1974)	3.70E+04	1.68E+04	0.65
E33-31, E33-267, & E33-342	Recovery	Theis (1935)	4.08E+04	1.85E+04	0.88
E33-31, E33-267, & E33-342	Recovery	Neuman (1974)	4.07E+04	1.85E+04	0.89

Table 7. Results of Determining Hydraulic Properties for the 27-Day Constant Rate Discharge Test

Analysis Type			Results		
Wells	**Test Type**	**Solution Method**	**Transmissivity (m^2/day)**	**Hydraulic Conductivity (m/day)**	**Specific Yield[a]**
All Wells	Drawdown	Moench (1997)	4.32E+04	1.96E+04	0.21[c]
		Minimum:	3.32E+04	1.51E+04	ND
		Maximum:	4.64E+04	2.11E+04	ND
		Average:	**4.01E+04**	**1.82E+04**	ND

a. The specific yield results were unrealistically high and are not representative of aquifer conditions.
b. Results were very sensitive to the analysis window chosen due to the low observed drawdown and a large barometric pressure change that occurred during initiation of the recovery portion.
c. The specific yield for the Moench (1997) method was held constant at the average value of 0.21 determined for the 3-day test.

ND = not determined

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Appendix A
Baseline Data Analysis and Barometric Response Functions

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This appendix provides charts of the barometric response functions generated using the MRCX software. This is followed by charts of the baseline water level measurements and the measurements normalized to a constant barometric pressure by the deconvolution technique described in Section 3.1. A portion of one of the Excel spreadsheets used for performing the deconvolution is provided as an example.

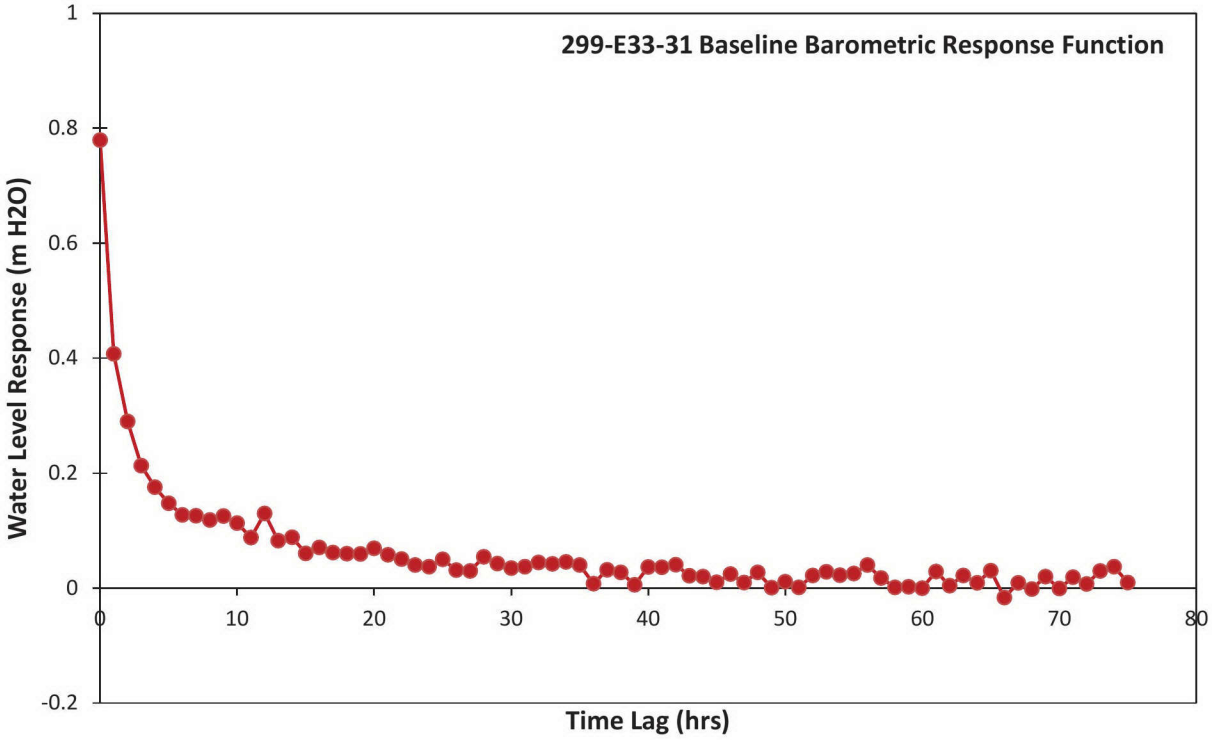

Figure A-1. Barometric Response Function for 299-E33-31.

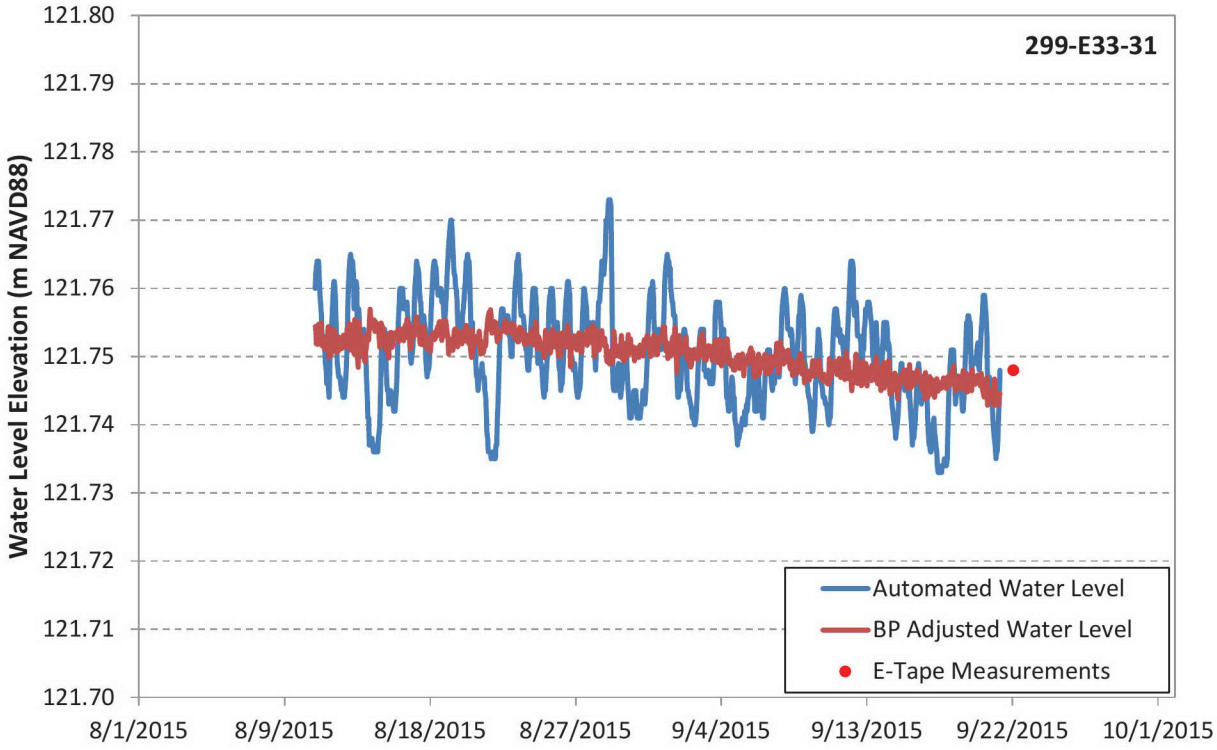

Figure A-2. Baseline Water Level Measurements for 299-E33-31.

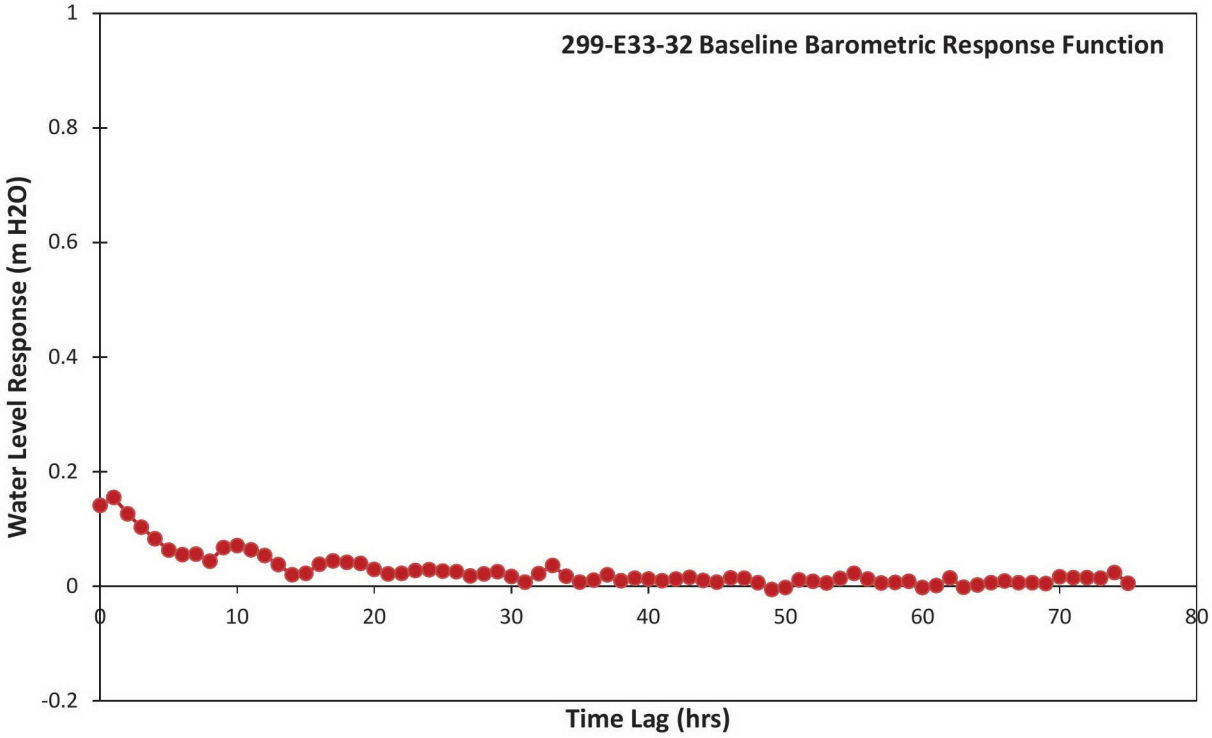

Figure A-3. Barometric Response Function for 299-E33-32.

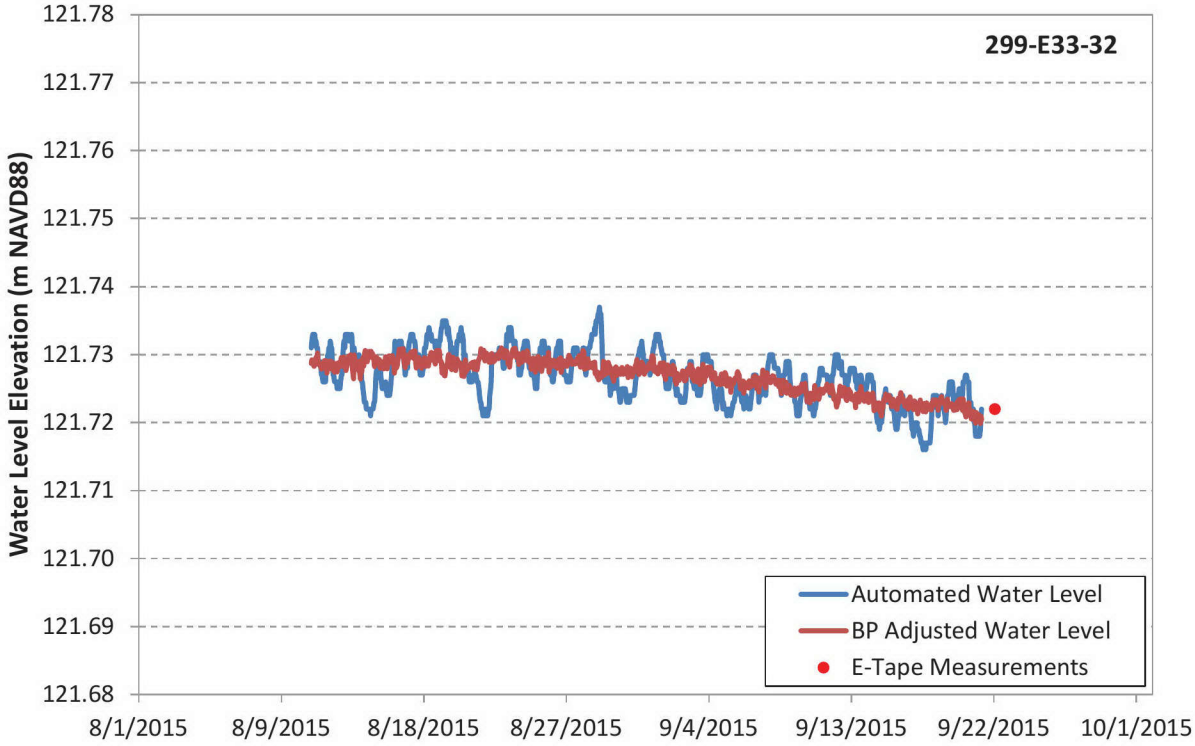

Figure A-4. Baseline Water Level Measurements for 299-E33-32.

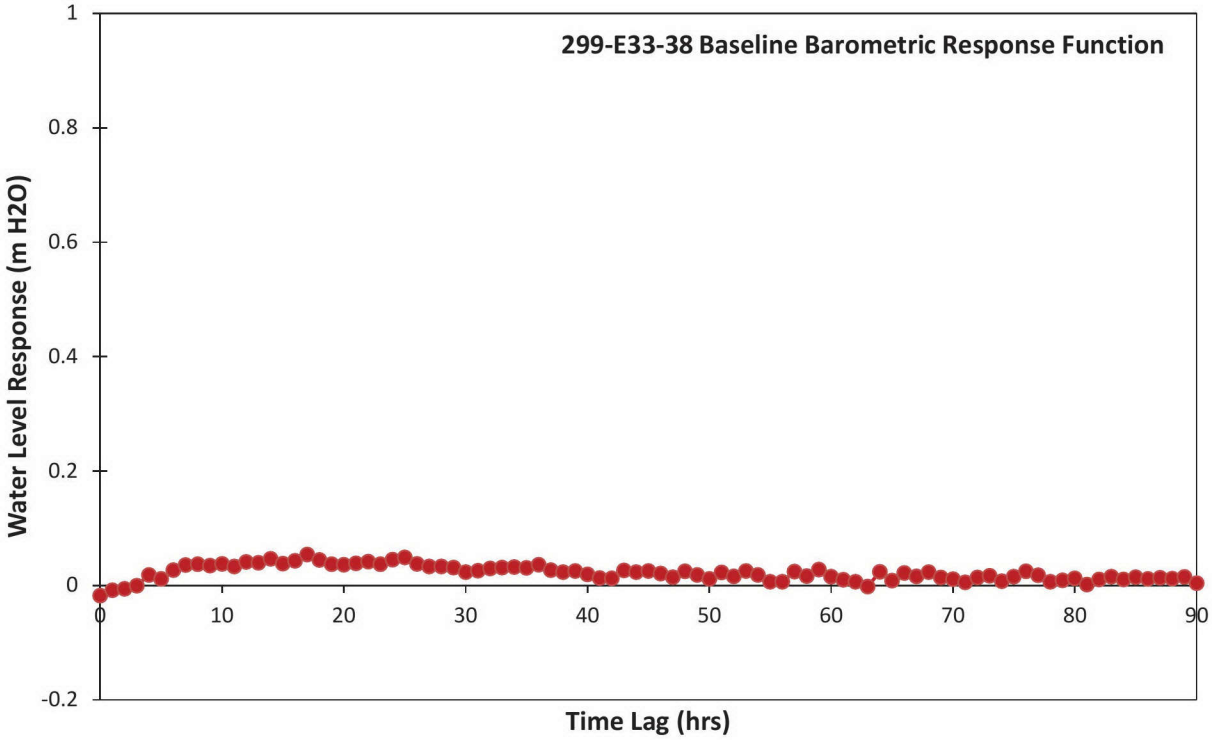

Figure A-5. Barometric Response Function for 299-E33-38.

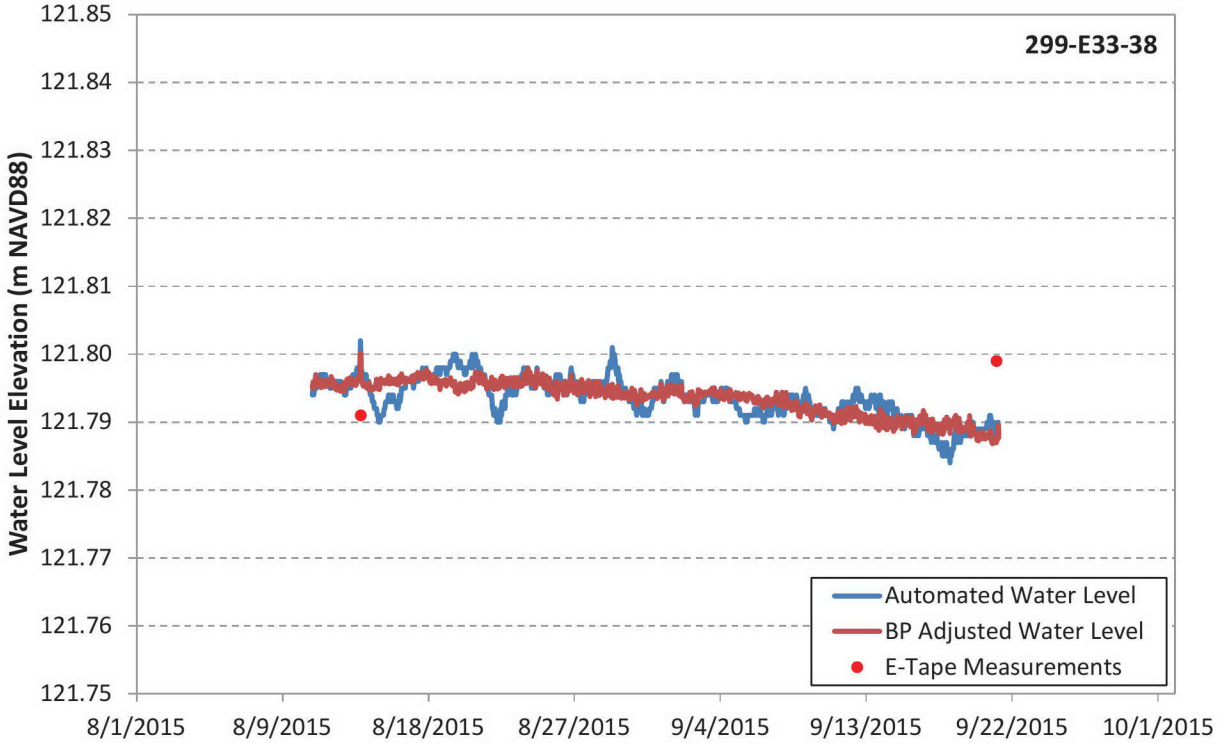

Figure A-6. Baseline Water Level Measurements for 299-E33-38.

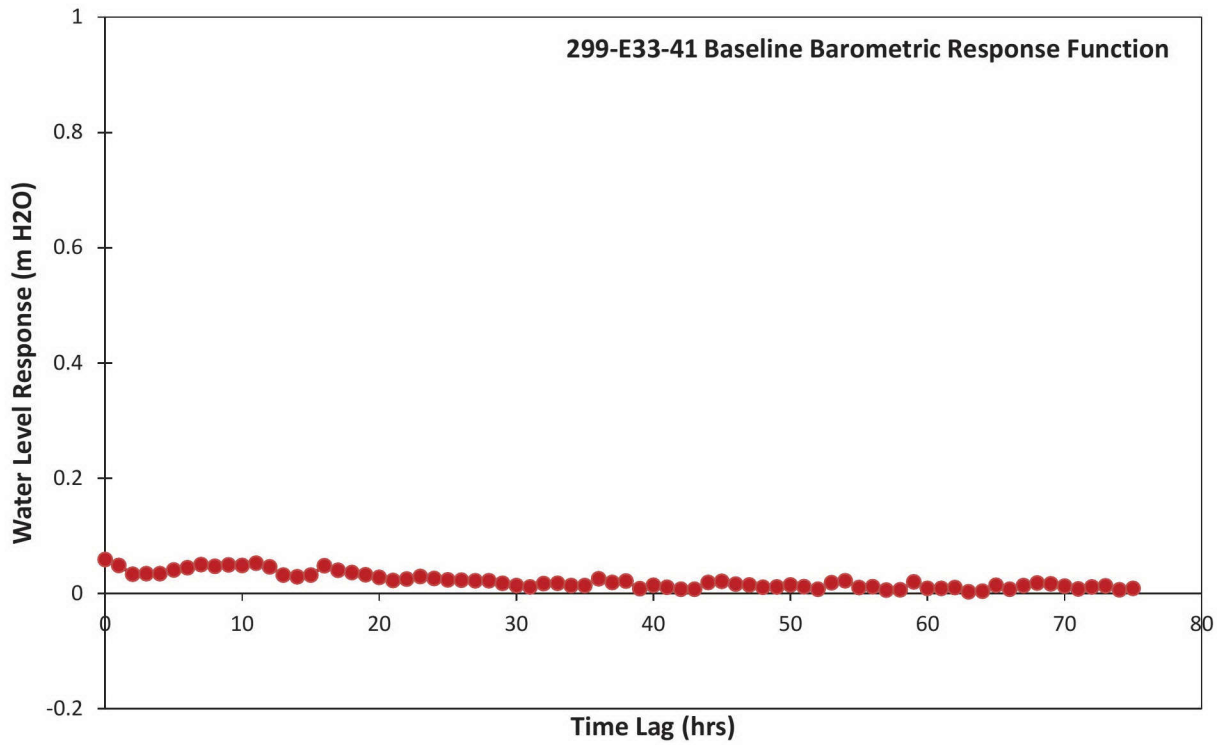

Figure A-7. Barometric Response Function for 299-E33-41.

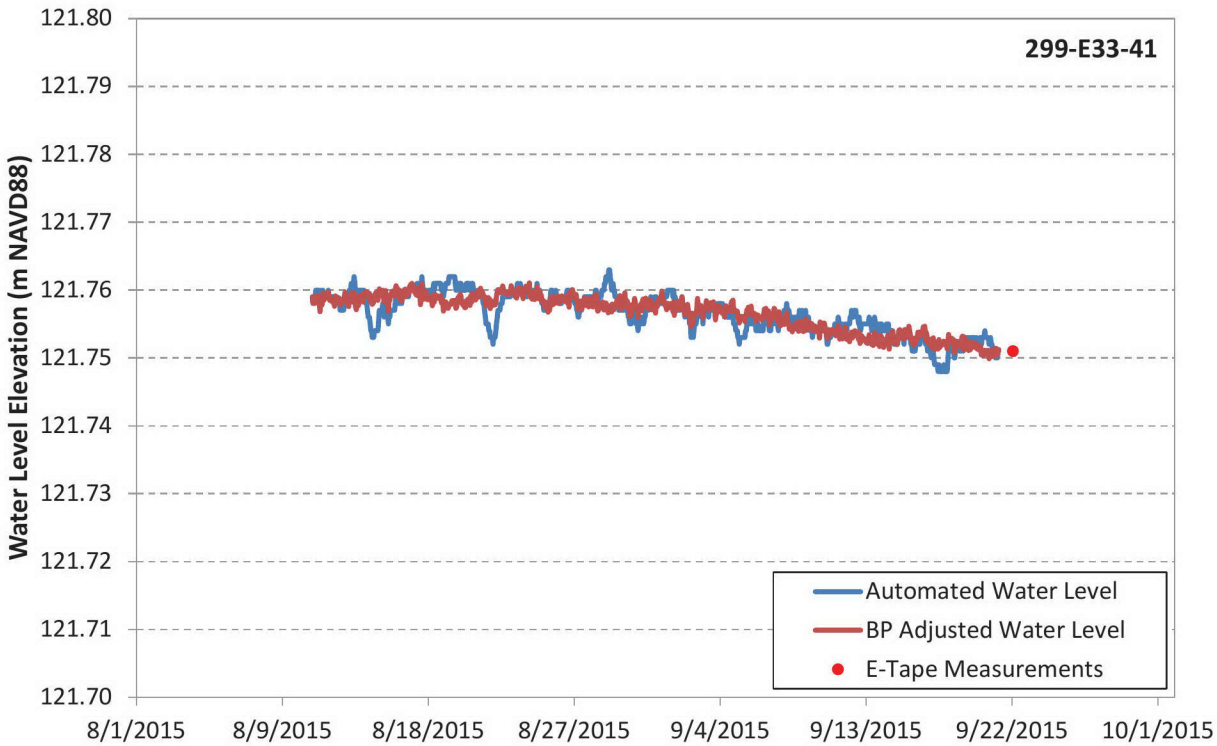

Figure A-8. Baseline Water Level Measurements for 299-E33-41.

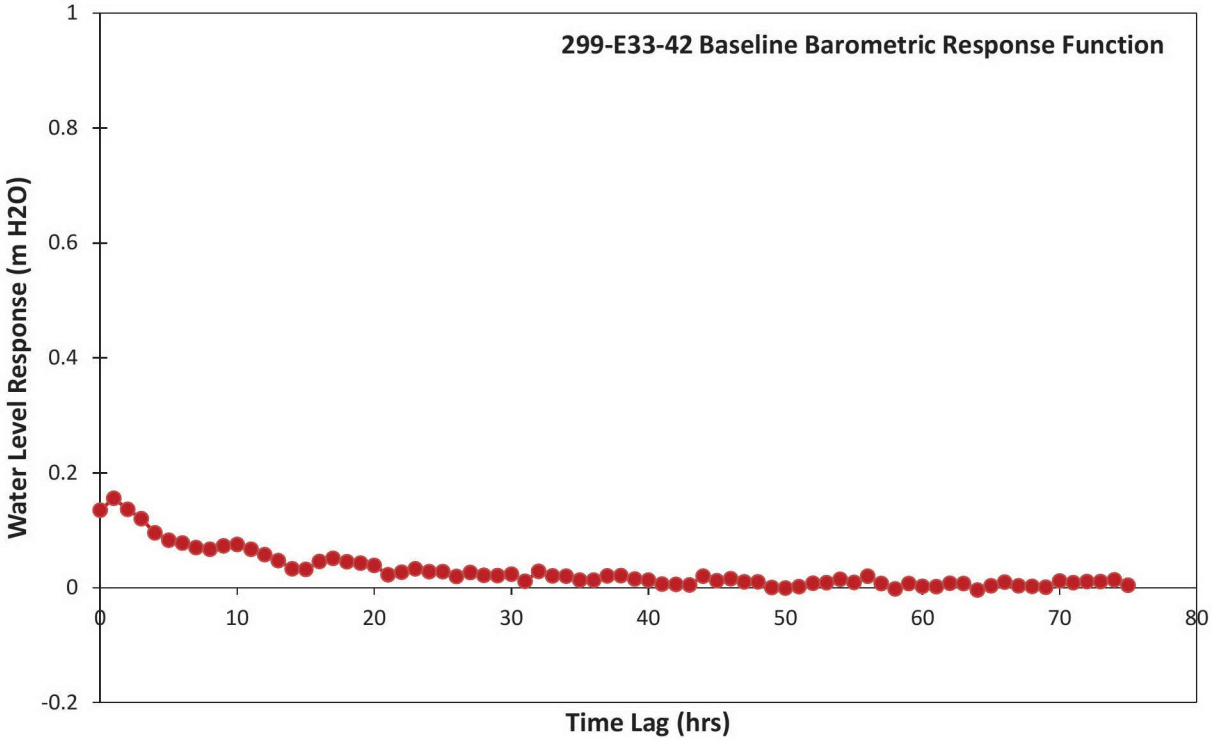

Figure A-9. Barometric Response Function for 299-E33-42.

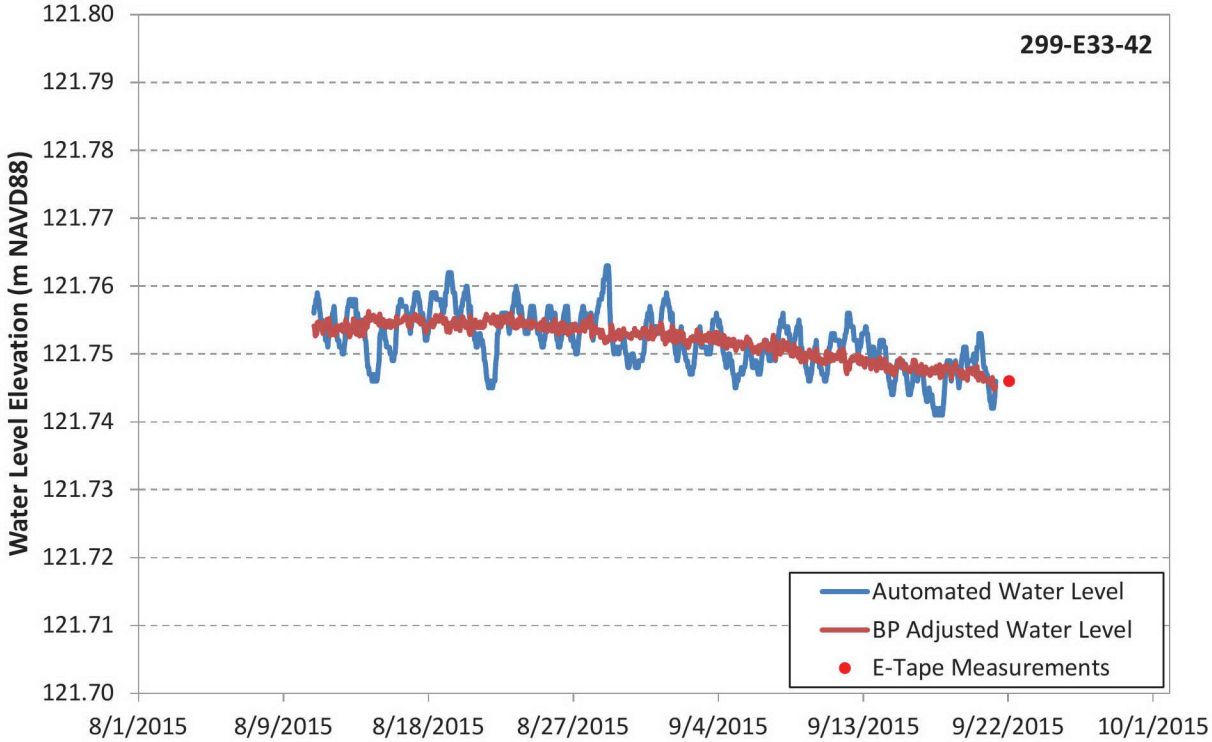

Figure A-10. Baseline Water Level Measurements for 299-E33-42.

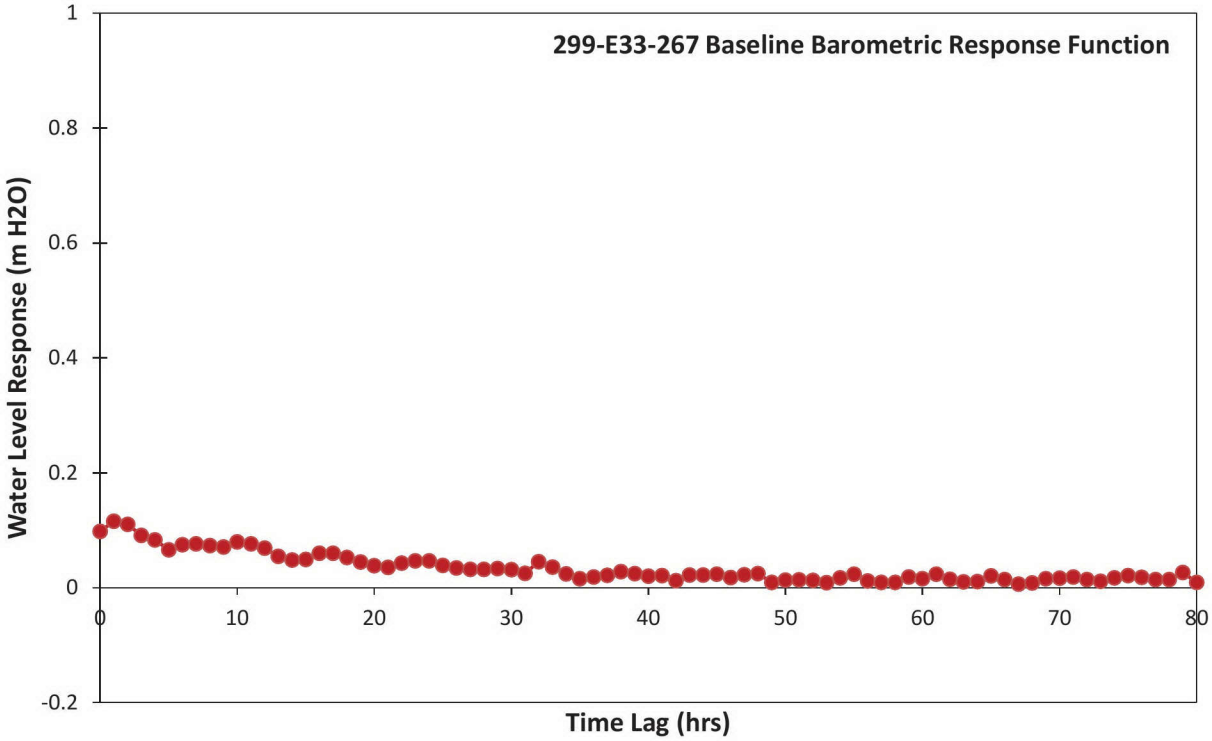

Figure A-11. Barometric Response Function for 299-E33-267.

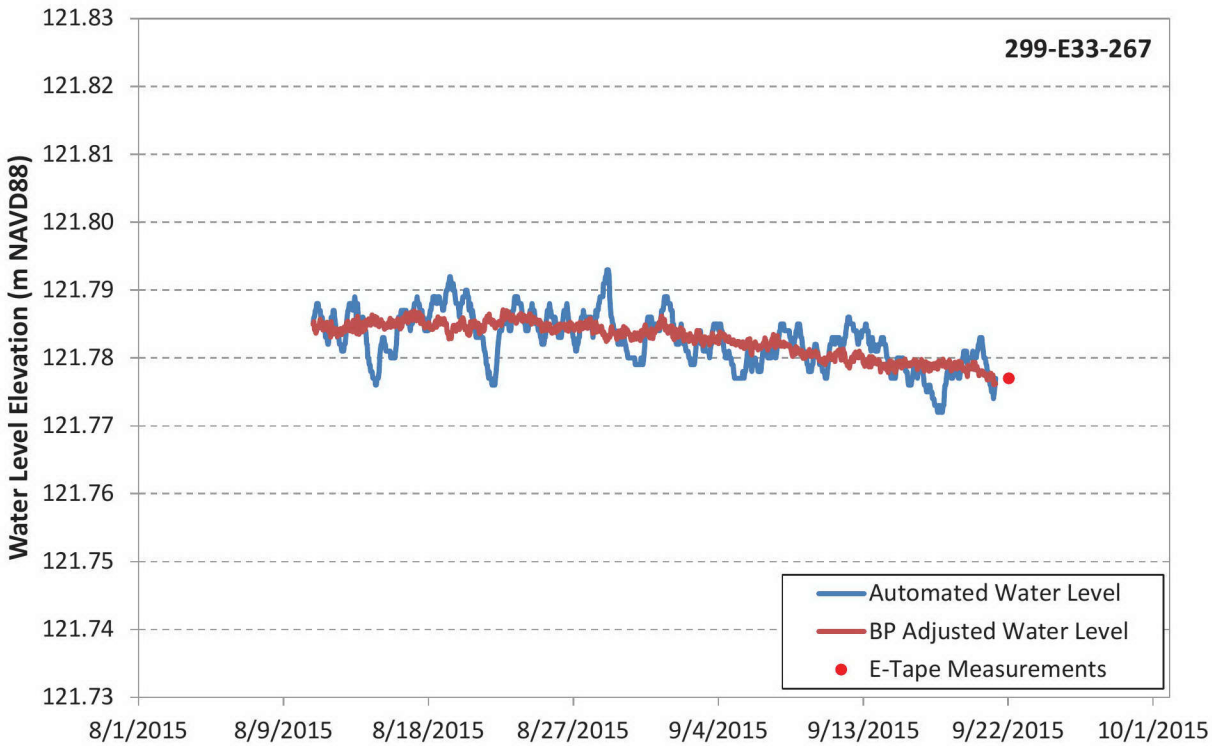

Figure A-12. Baseline Water Level Measurements for 299-E33-267.

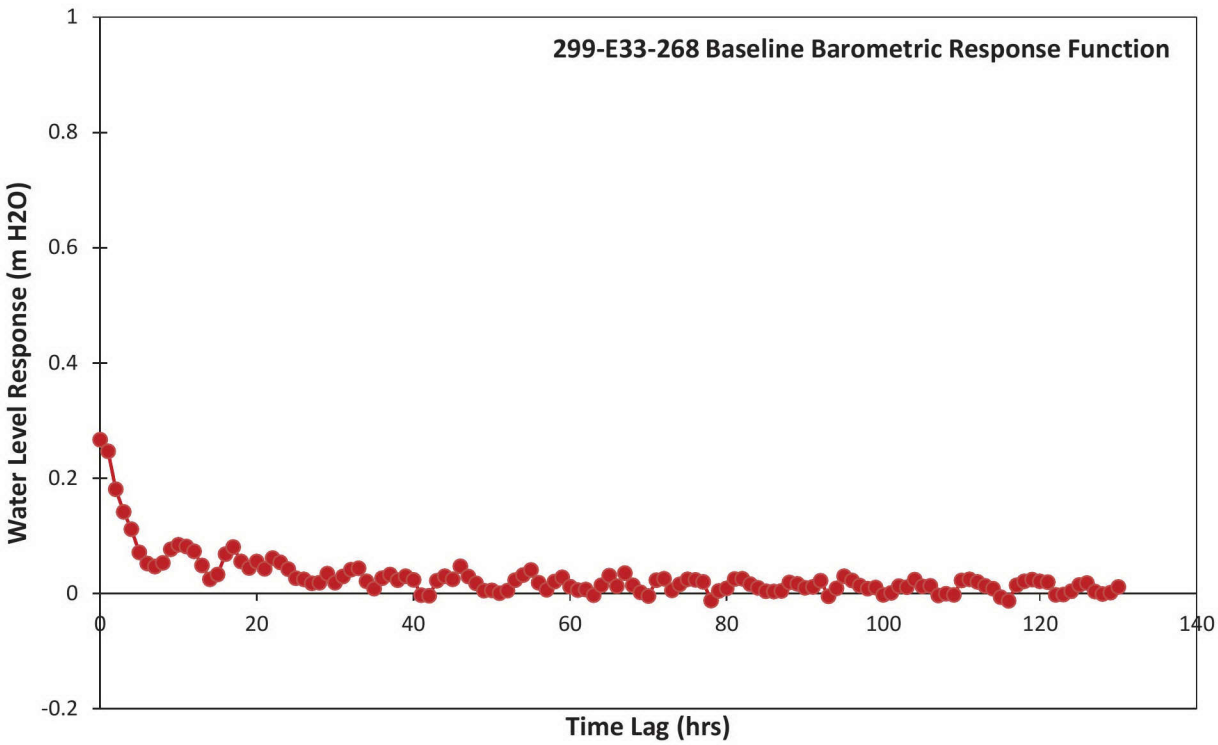

Figure A-13. Barometric Response Function for 299-E33-268.

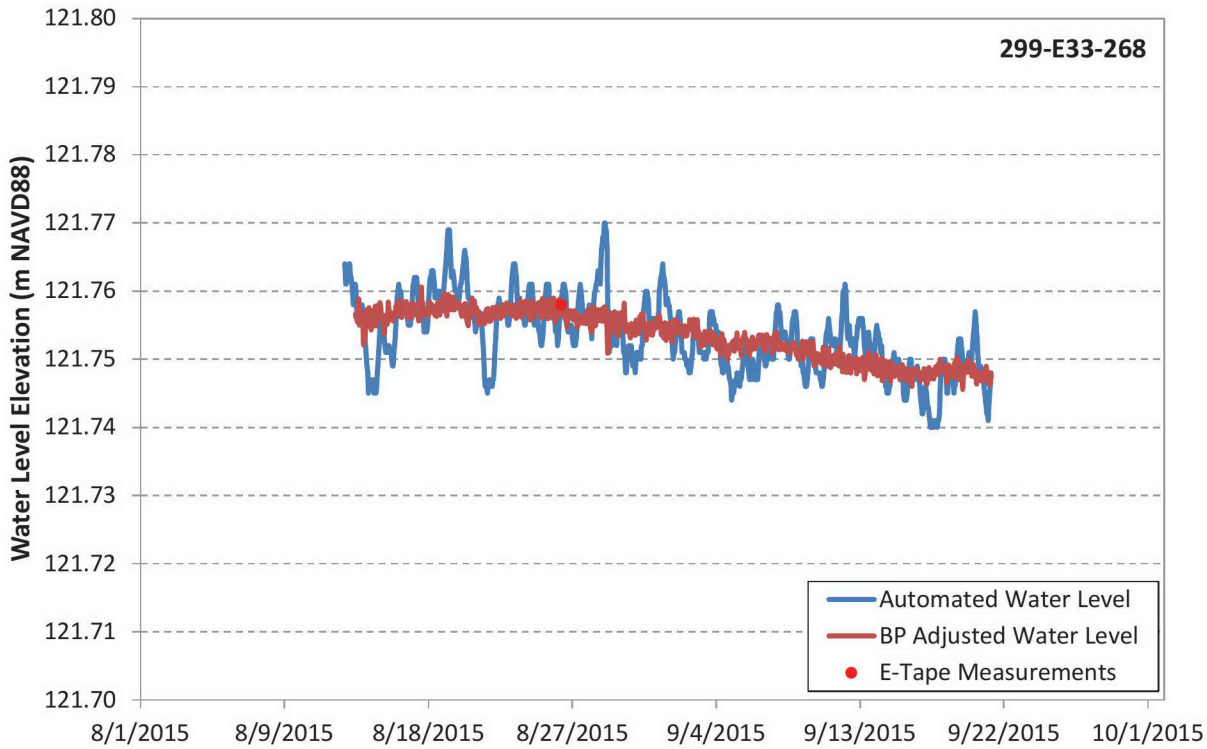

Figure A-14. Baseline Water Level Measurements for 299-E33-268.

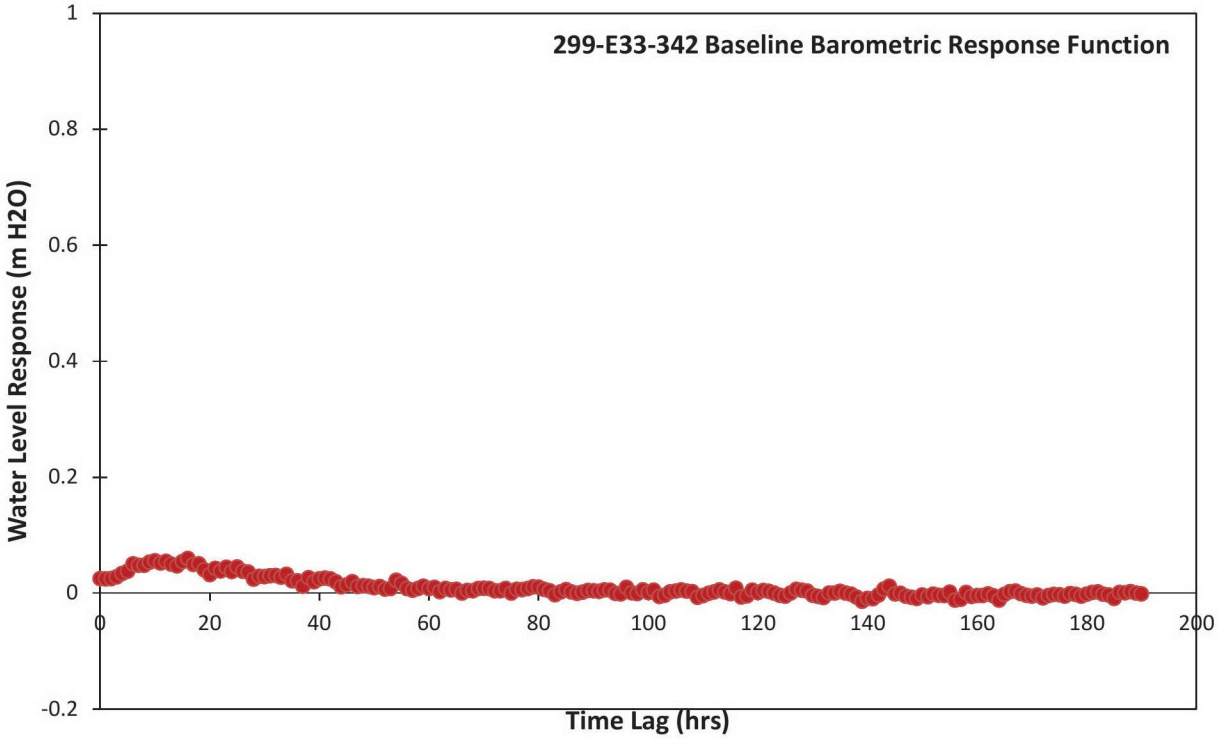

Figure A-15. Barometric Response Function for 299-E33-342.

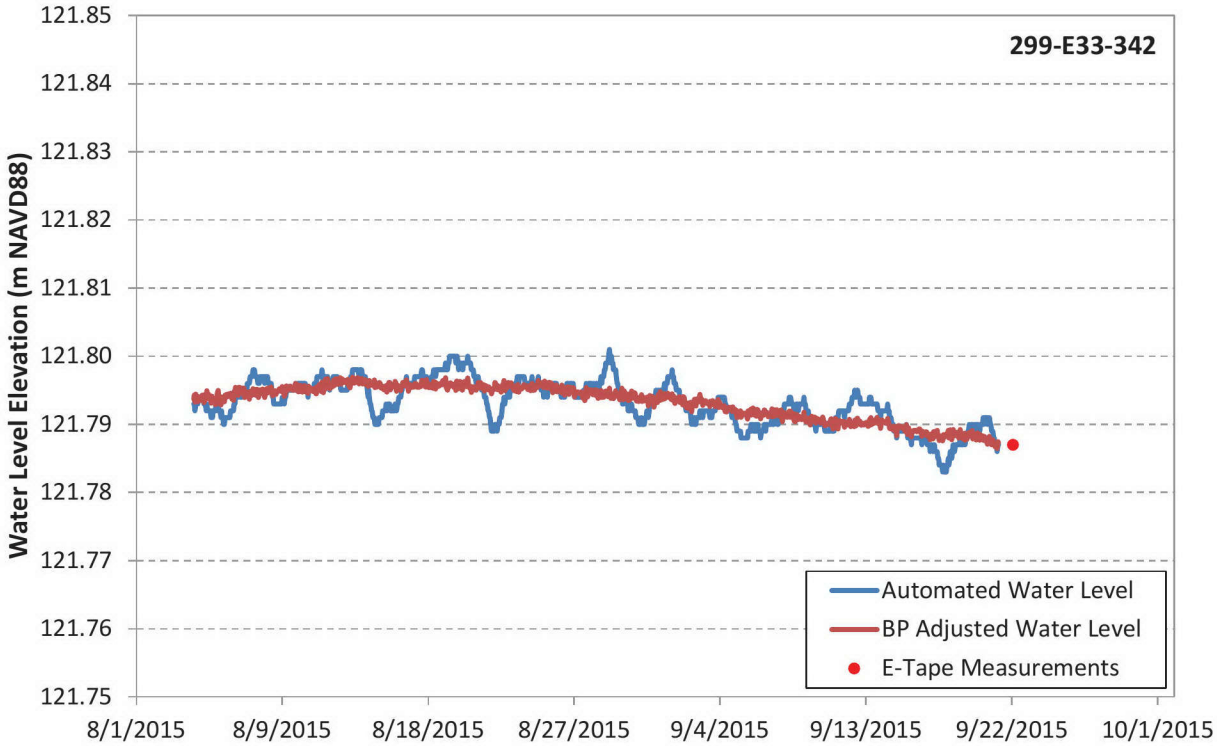

Figure A-16. Baseline Water Level Measurements for 299-E33-342.

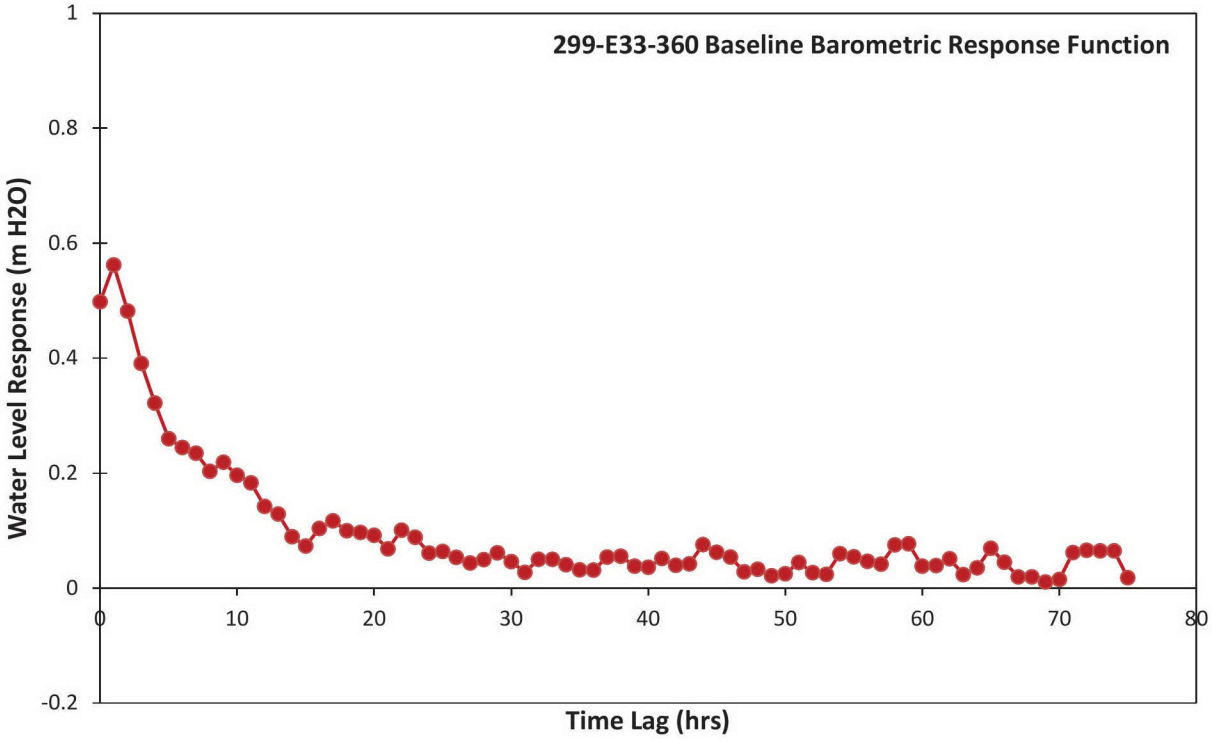

Figure A-17. Barometric Response Function for 299-E33-360.

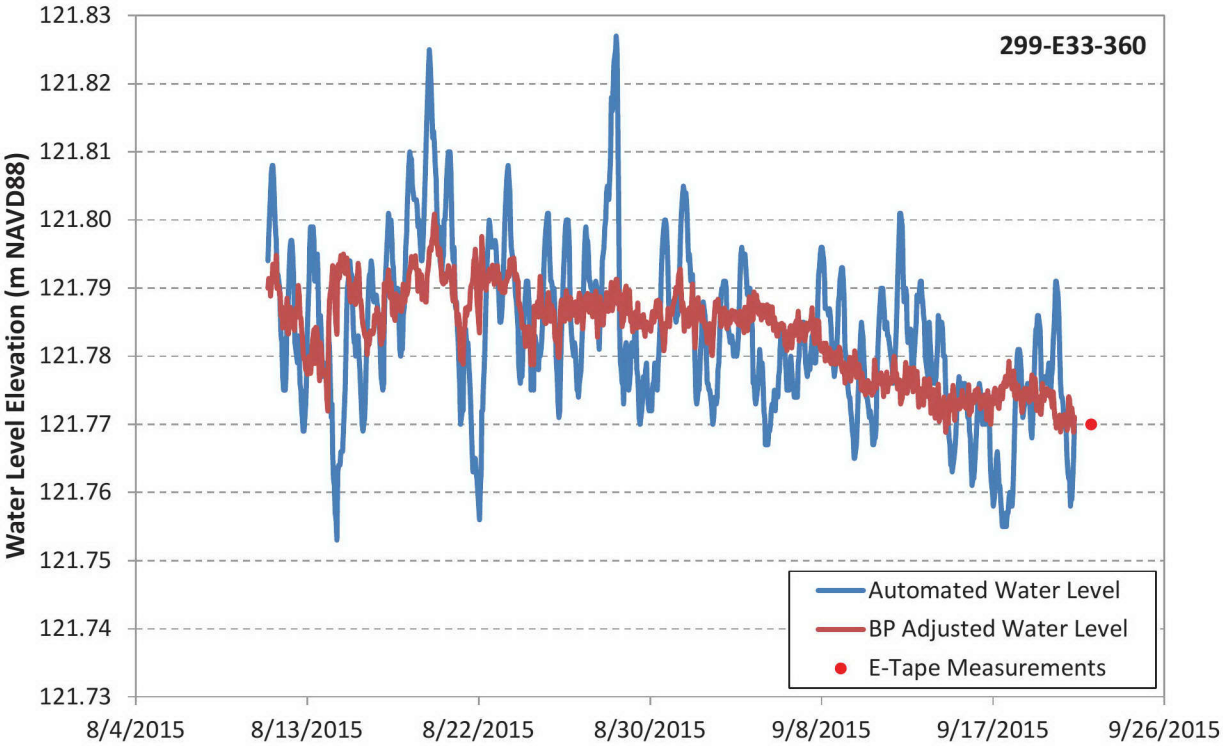

Figure A-18. Baseline Water Level Measurements for 299-E33-360.

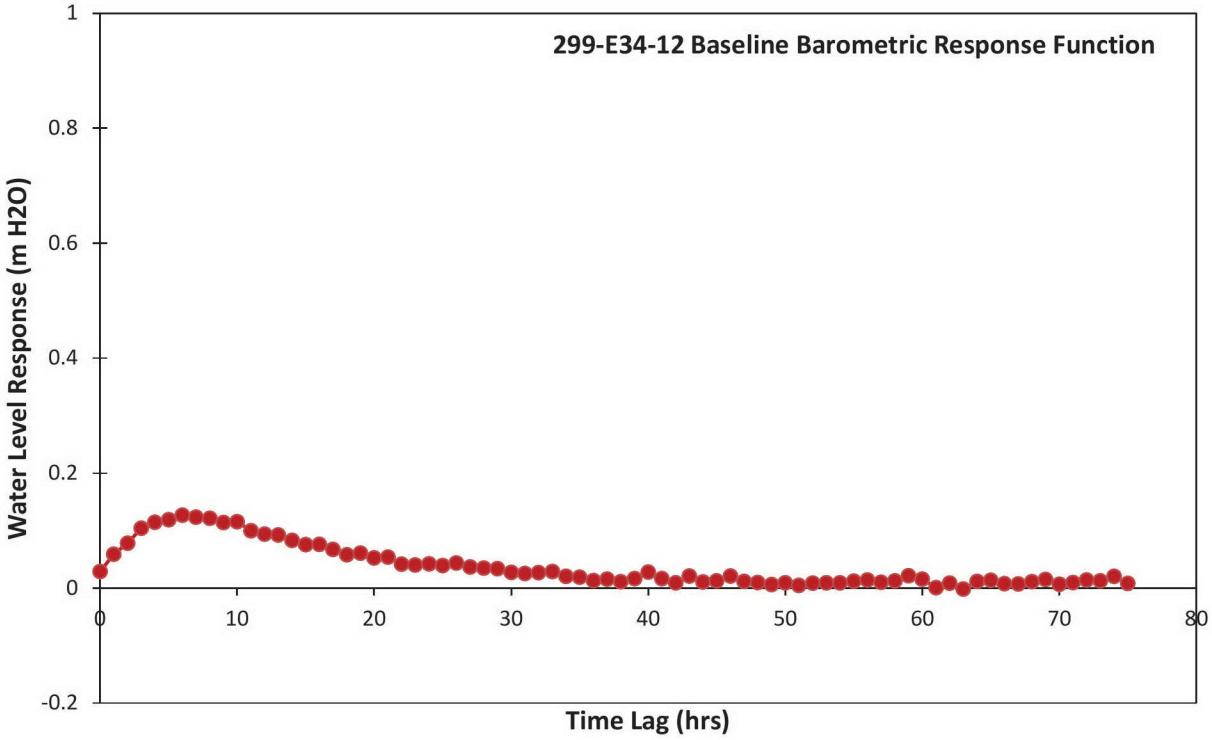

Figure A-19. Barometric Response Function for 299-E34-12.

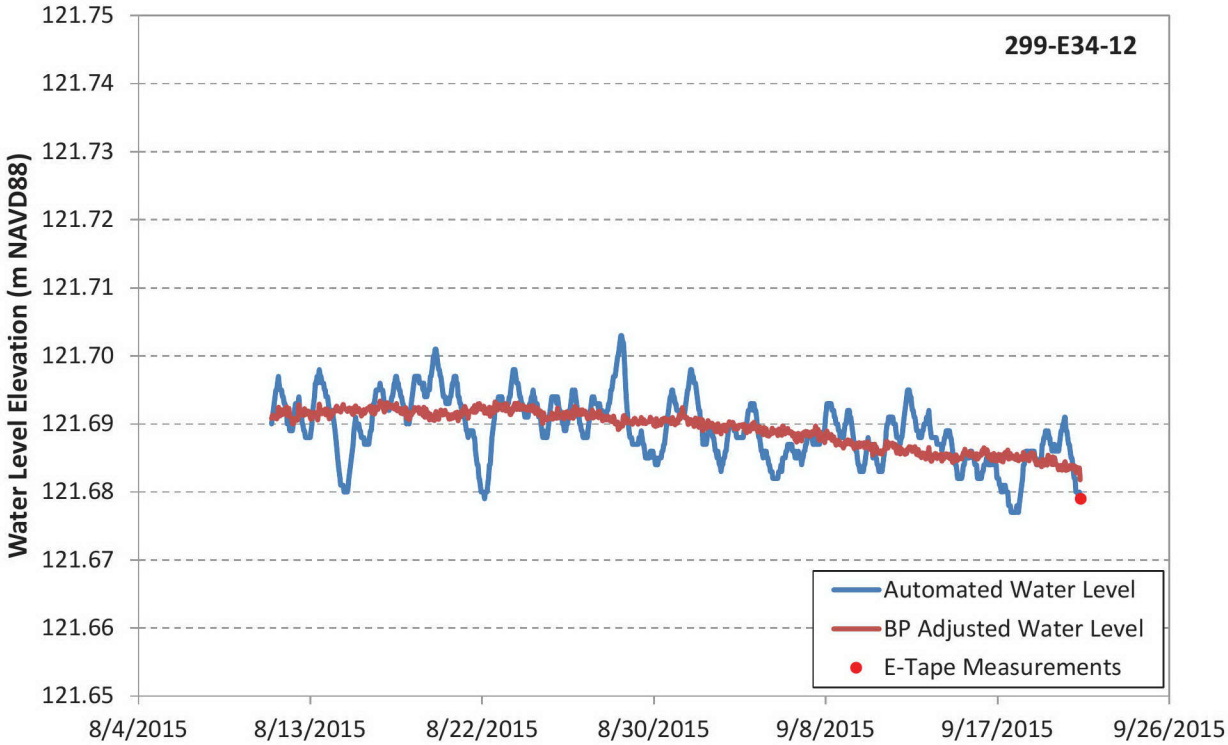

Figure A-20. Baseline Water Level Measurements for 299-E34-12.

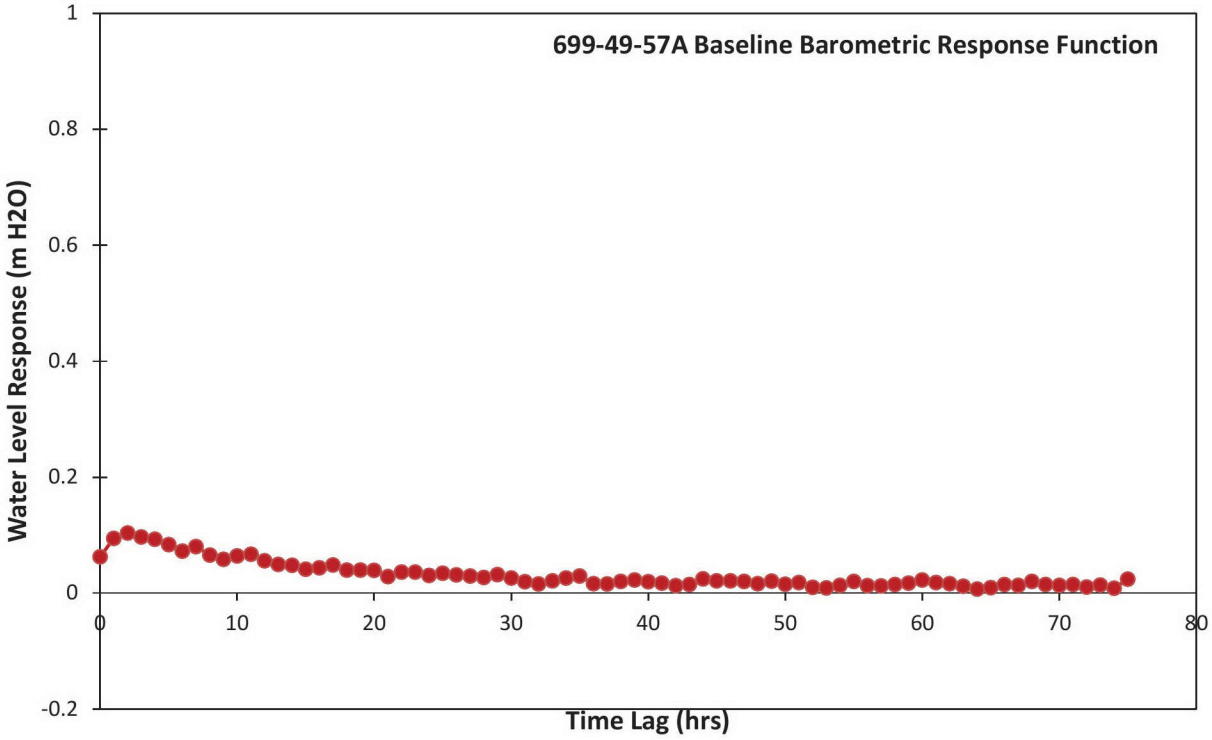

Figure A-21. Barometric Response Function for 699-49-57A.

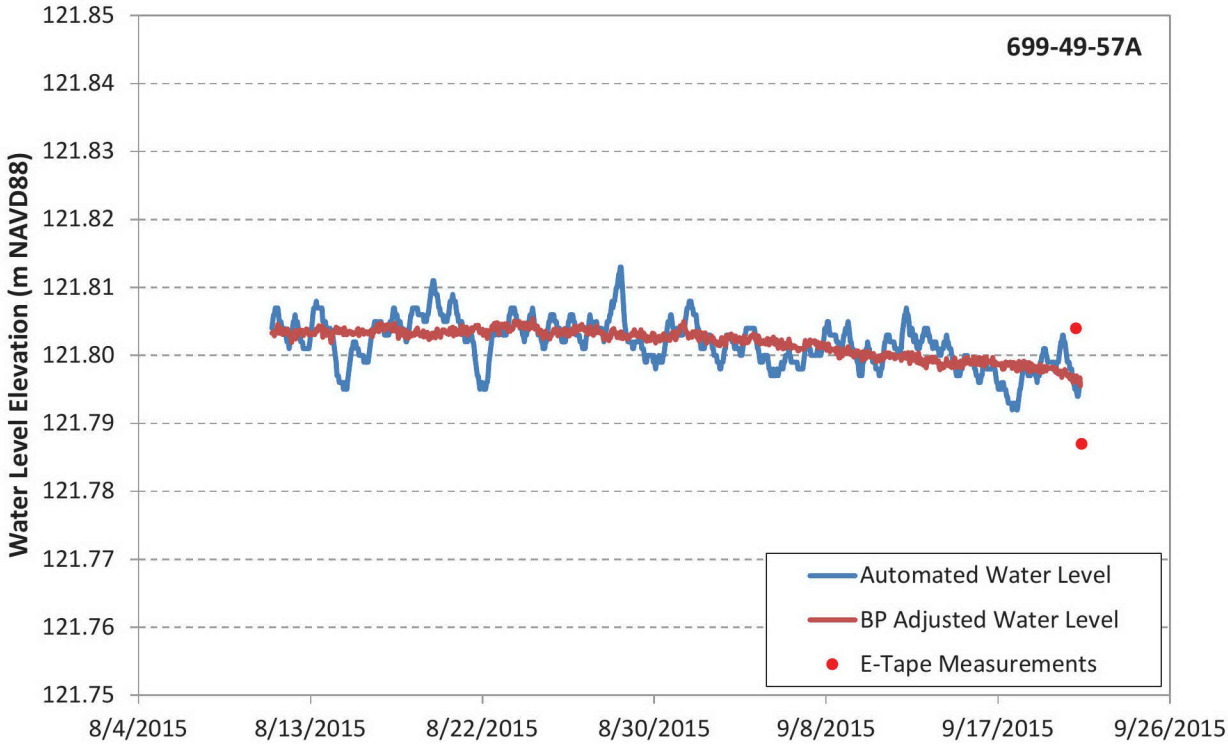

Figure A-22. Baseline Water Level Measurements for 699-49-57A.

The portion of the spreadsheet below shows how the data logger files are processed to convert the units of measurement from centimeters to pounds per square inch absolute (PSIA). This is followed by a graphic showing the formulas used. The timestamps are converted from Pacific Daylight Time (PDT) to Pacific Standard Time (PST) by subtracting 1/24th of a day. This example is the BaroLogger file for the baseline monitoring data collected from 299-E33-31. LeveLogger files are processed in the same manner.

Serial_number:										
1052634										
Project ID:										
BP-5 Treatabiliy est						Altitude Compensation Factor:		1.21	m per 1000 m elevation	
Location:						Unadjusted Zero Point:		950	pressure as cm H2O	
299-E33-31 Baro						Altitude Setting:		0	m elevation	
LEVEL						Adjusted Zero Point:		950	pressure as cm H2O	
UNIT: cm										
Offset: 0.000000 cm				Water Column to Pressure Conversion Factor:				0.70307	m H2O per psia	
Altitude: 0.000000 m										
TEMPERATURE										
UNIT: Deg C										
Date	Time	Date/Time (PST)	ms	LEVEL	TEMPERATURE		psia	in-Hg	m-H2O	
8/11/2015	14:00:00	8/11/15 13:00	0	63.58	17.967		14.41649	29.35197	10.1358	
8/11/2015	15:00:00	8/11/15 14:00	0	62.97	17.947		14.40781	29.3343	10.1297	
8/11/2015	16:00:00	8/11/15 15:00	0	62.31	17.947		14.39842	29.31519	10.1231	
8/11/2015	17:00:00	8/11/15 16:00	0	61.64	17.952		14.38889	29.29579	10.1164	

Serial_number:									
1052634									
Project ID:									
BP-5 Treatabiliy est						Altitude Compensation Factor:	1.21	m per 1000 m elevation
Location:						Unadjusted Zero Point:	950	pressure as cm H2O
299-E33-31 Baro						Altitude Setting:	0	m elevation
LEVEL						Adjusted Zero Point:	=I5-I6/1000*I	pressure as cm H2O
UNIT: cm								
Offset: 0.000000 cm				Water Column to Pressure Conversion Factor:			0.70307	m H2O per psia
Altitude: 0.000000 m								
TEMPERATURE								
UNIT: Deg C								
Date	Time	Date/Time (PST)	ms	LEVEL	TEMPERATURE	psia	in-Hg	m-H2O
42227	0.583333333333333	=A14+B14-1/24	0	63.58	17.967	=(E14+$I$7)/100/$I$9	=H14*2.036	=H14*$I$9
42227	0.625	=A15+B15-1/24	0	62.97	17.947	=(E15+$I$7)/100/$I$9	=H15*2.036	=H15*$I$9
42227	0.666666666666667	=A16+B16-1/24	0	62.31	17.947	=(E16+$I$7)/100/$I$9	=H16*2.036	=H16*$I$9
42227	0.708333333333333	=A17+B17-1/24	0	61.64	17.952	=(E17+$I$7)/100/$I$9	=H17*2.036	=H17*$I$9

The graphic below shows a portion of a spreadsheet used to normalize the water level measurements to a constant barometric pressure. Column B contains the timestamp for the barometric pressure data, and column C contains the change in barometric pressure between hourly timesteps. Column E contains the automated water level elevations. The deconvolution is performed in column F in which the previous *n* hourly barometric pressure changes are multiplied by the BRF coefficients one element at a time and then summed (*n* is the number of coefficients in the BRF) by an array formula. This provides the change in the water level caused by barometric pressure fluctuations, which is removed (by addition in the formula due to sign conventions) from the measurement.

	A	B	C	D	E	F
1	**Water-Level Barometric Pressure Response for 299-E33-31**					
2	Deconvolved Transducer Data (i.e., Normalized to a Constant Barometric Pressure)					
3						
4		***Deconvolved Using Station #6 BP Measurements***				
5			Station #6			BP Normalized
6			Change in		Absolute x-ducer	Absolute x-ducer
7			Barometric Pres.		Water Level Elev.	Water Level Elev.
8		DATE_TIME_PST	(m H2O)		(m NAVD88)	(m NAVD88)
9		8/7/15 23:00	0.00020719			
10		8/8/15 0:00	0.00324597			
11		8/8/15 1:00	-0.001761112			
12		8/8/15 2:00	0.003280502			
13		8/8/15 3:00	0.000621569			
14		8/8/15 4:00	0.002279086			
15		8/8/15 5:00	0.002693465			
16		8/8/15 6:00	0.004834424			
17		8/8/15 7:00	0.000517974			
18		8/8/15 8:00	0.006181156			
19		8/8/15 9:00	-0.004938019			
20		8/8/15 10:00	-0.005801309			
21		8/8/15 11:00	-0.0079768			
22		8/8/15 12:00	-0.001208606			
23		8/8/15 13:00	-0.001622985			
24		8/8/15 14:00	-0.00583584			
25		8/8/15 15:00	-0.003073312			
26		8/8/15 16:00	-0.004143792			
27		8/8/15 17:00	0.001761112			
28		8/8/15 18:00	-0.000138126			
29		8/8/15 19:00	0.005594119			
30		8/8/15 20:00	0.008563837			

30		8/8/15 20:00	0.008563837			
31		8/8/15 21:00	0.005455993			
32		8/8/15 22:00	0.009565253			
33		8/8/15 23:00	0.008701963			
34		8/9/15 0:00	0.006595536			
35		8/9/15 1:00	0.003315034			
36		8/9/15 2:00	0.005076145			
37		8/9/15 3:00	0.005214272			
38		8/9/15 4:00	0.001381264			
39		8/9/15 5:00	0.00669913			
40		8/9/15 6:00	0.001657517			
41		8/9/15 7:00	0.006112093			
42		8/9/15 8:00	0.000414379			
43		8/9/15 9:00	0.004558171			
44		8/9/15 10:00	-0.004489108			
45		8/9/15 11:00	0.002140959			
46		8/9/15 12:00	-0.005904904			

	A	B	C	D	E	F
47		8/9/15 13:00	-0.003280502			
48		8/9/15 14:00	-0.006353814			
49		8/9/15 15:00	-0.010532138			
50		8/9/15 16:00	0.00193377			
51		8/9/15 17:00	-0.003591286			
52		8/9/15 18:00	-0.007458826			
53		8/9/15 19:00	-0.002486275			
54		8/9/15 20:00	0.004765361			
55		8/9/15 21:00	0.004938019			
56		8/9/15 22:00	0.00107048			
57		8/9/15 23:00	-0.001035948			
58		8/10/15 0:00	-0.005594119			
59		8/10/15 1:00	-0.000794227			
60		8/10/15 2:00	0.006077562			
61		8/10/15 3:00	-0.001208606			
62		8/10/15 4:00	0.001795643			
63		8/10/15 5:00	0.001864706			
64		8/10/15 6:00	0.001553922			
65		8/10/15 7:00	-3.45316E-05			

66		8/10/15 8:00	0.003556755			
67		8/10/15 9:00	0.00172658			
68		8/10/15 10:00	-0.00107048			
69		8/10/15 11:00	-0.007009915			
70		8/10/15 12:00	-0.009012748			
71		8/10/15 13:00	-0.003867539			
72		8/10/15 14:00	0.001381264			
73		8/10/15 15:00	0.005628651			
74		8/10/15 16:00	-0.015850004			
75		8/10/15 17:00	-0.002210022			
76		8/10/15 18:00	-0.001415796			
77		8/10/15 19:00	0.013501856			
78		8/10/15 20:00	-0.001381264			
79		8/10/15 21:00	0.00324597			
80		8/10/15 22:00	0.004385513			
81		8/10/15 23:00	-0.003971134			
82		8/11/15 0:00	0.002417212			
83		8/11/15 1:00	0.009254469			
84		8/11/15 2:00	-0.006561004			
85		8/11/15 3:00	0.00669913			
86		8/11/15 4:00	0.000828758			
87		8/11/15 5:00	0.003625818			
88		8/11/15 6:00	0.005525056			
89		8/11/15 7:00	0.002831591			
90		8/11/15 8:00	-0.0006561			
91		8/11/15 9:00	0.001139543			
92		8/11/15 10:00	-0.005628651			

	A	B	C	D	E	F
93		8/11/15 11:00	-0.006975383			
94		8/11/15 12:00	-0.006319283			
95		8/11/15 13:00	-0.007009915		121.76	121.7543926
96		8/11/15 14:00	-0.008183989		121.762	121.7544074
97		8/11/15 15:00	-0.011671681		121.763	121.7518648

Below is the same spreadsheet with formulas displayed.

	A	B	C	D	E	F
1	**Water-Level Barometric Pressure Response for 299-E33-31**					
2	Deconvolved Transducer Data (i.e., Normalized to a Constant Barometric Pressure)					
3						
4		***Deconvolved Using Station #6 BP Measurements***				
5			Station #6			BP Normalized
6			Change in		Absolute x-ducer	Absolute x-ducer
7			Barometric Pres.		Water Level Elev.	Water Level Elev.
8		DATE_TIME_PST	(m H2O)		(m NAVD88)	(m NAVD88)
9		=TransducerData!O326	=TransducerData!Q326			
10		=TransducerData!O327	=TransducerData!Q327			
11		=TransducerData!O328	=TransducerData!Q328			
12		=TransducerData!O329	=TransducerData!Q329			
13		=TransducerData!O330	=TransducerData!Q330			
14		=TransducerData!O331	=TransducerData!Q331			
15		=TransducerData!O332	=TransducerData!Q332			
16		=TransducerData!O333	=TransducerData!Q333			
17		=TransducerData!O334	=TransducerData!Q334			
18		=TransducerData!O335	=TransducerData!Q335			
19		=TransducerData!O336	=TransducerData!Q336			
20		=TransducerData!O337	=TransducerData!Q337			
21		=TransducerData!O338	=TransducerData!Q338			
22		=TransducerData!O339	=TransducerData!Q339			
23		=TransducerData!O340	=TransducerData!Q340			
24		=TransducerData!O341	=TransducerData!Q341			
25		=TransducerData!O342	=TransducerData!Q342			
26		=TransducerData!O343	=TransducerData!Q343			
27		=TransducerData!O344	=TransducerData!Q344			
28		=TransducerData!O345	=TransducerData!Q345			
29		=TransducerData!O346	=TransducerData!Q346			
30		=TransducerData!O347	=TransducerData!Q347			
31		=TransducerData!O348	=TransducerData!Q348			
32		=TransducerData!O349	=TransducerData!Q349			
33		=TransducerData!O350	=TransducerData!Q350			
34		=TransducerData!O351	=TransducerData!Q351			
35		=TransducerData!O352	=TransducerData!Q352			
36		=TransducerData!O353	=TransducerData!Q353			
37		=TransducerData!O354	=TransducerData!Q354			
38		=TransducerData!O355	=TransducerData!Q355			
39		=TransducerData!O356	=TransducerData!Q356			
40		=TransducerData!O357	=TransducerData!Q357			
41		=TransducerData!O358	=TransducerData!Q358			
42		=TransducerData!O359	=TransducerData!Q359			
43		=TransducerData!O360	=TransducerData!Q360			
44		=TransducerData!O361	=TransducerData!Q361			
45		=TransducerData!O362	=TransducerData!Q362			
46		=TransducerData!O363	=TransducerData!Q363			
47		=TransducerData!O364	=TransducerData!Q364			
48		=TransducerData!O365	=TransducerData!Q365			
49		=TransducerData!O366	=TransducerData!Q366			
50		=TransducerData!O367	=TransducerData!Q367			
51		=TransducerData!O368	=TransducerData!Q368			
52		=TransducerData!O369	=TransducerData!Q369			
53		=TransducerData!O370	=TransducerData!Q370			
54		=TransducerData!O371	=TransducerData!Q371			
55		=TransducerData!O372	=TransducerData!Q372			

56		=TransducerData!O373	=TransducerData!Q373			
57		=TransducerData!O374	=TransducerData!Q374			
58		=TransducerData!O375	=TransducerData!Q375			
59		=TransducerData!O376	=TransducerData!Q376			
60		=TransducerData!O377	=TransducerData!Q377			
61		=TransducerData!O378	=TransducerData!Q378			
62		=TransducerData!O379	=TransducerData!Q379			
63		=TransducerData!O380	=TransducerData!Q380			

	A	B	C	D	E	F
64		=TransducerData!O381	=TransducerData!Q381			
65		=TransducerData!O382	=TransducerData!Q382			
66		=TransducerData!O383	=TransducerData!Q383			
67		=TransducerData!O384	=TransducerData!Q384			
68		=TransducerData!O385	=TransducerData!Q385			
69		=TransducerData!O386	=TransducerData!Q386			
70		=TransducerData!O387	=TransducerData!Q387			
71		=TransducerData!O388	=TransducerData!Q388			
72		=TransducerData!O389	=TransducerData!Q389			
73		=TransducerData!O390	=TransducerData!Q390			
74		=TransducerData!O391	=TransducerData!Q391			
75		=TransducerData!O392	=TransducerData!Q392			
76		=TransducerData!O393	=TransducerData!Q393			
77		=TransducerData!O394	=TransducerData!Q394			
78		=TransducerData!O395	=TransducerData!Q395			
79		=TransducerData!O396	=TransducerData!Q396			
80		=TransducerData!O397	=TransducerData!Q397			
81		=TransducerData!O398	=TransducerData!Q398			
82		=TransducerData!O399	=TransducerData!Q399			
83		=TransducerData!O400	=TransducerData!Q400			
84		=TransducerData!O401	=TransducerData!Q401			
85		=TransducerData!O402	=TransducerData!Q402			
86		=TransducerData!O403	=TransducerData!Q403			
87		=TransducerData!O404	=TransducerData!Q404			
88		=TransducerData!O405	=TransducerData!Q405			
89		=TransducerData!O406	=TransducerData!Q406			
90		=TransducerData!O407	=TransducerData!Q407			
91		=TransducerData!O408	=TransducerData!Q408			
92		=TransducerData!O409	=TransducerData!Q409			
93		=TransducerData!O410	=TransducerData!Q410			
94		=TransducerData!O411	=TransducerData!Q411			
95		=TransducerData!O412	=TransducerData!Q412		=TransducerData!L12	=E95+SUM(C20:C95*TransducerData!$V$12:$V$87)
96		=TransducerData!O413	=TransducerData!Q413		=TransducerData!L13	=E96+SUM(C21:C96*TransducerData!$V$12:$V$87)
97		=TransducerData!O414	=TransducerData!Q414		=TransducerData!L14	=E97+SUM(C22:C97*TransducerData!$V$12:$V$87)

Appendix B
Automated Water Level Measurements for the 3-Day Constant Rate Discharge Test

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Charts of the automated water level measurements collected during the 3-day test are shown in Figures B-1 through B-9. The pumping well, 299-E33-268, is shown first (Figure B-1) and then the observation wells are shown in order of increasing distance from the pumping well (Figures B-2 to B-9). Drawdown was discernable in the pumping well and in 299-E33-267, 299-E33-31, and 299-E33-342. Some drawdown may also have occurred at 299-E33-42, but this could not be confirmed because the amount of apparent drawdown (0.002 m) is about the same as the remaining error when the water levels are normalized to a constant barometric pressure as can be seen in the post pumping measurements (10/17/2015 to 10/20/2015 in Figure B-4). For this reason, 299-E33-42 was not included in the hydraulic property determinations.

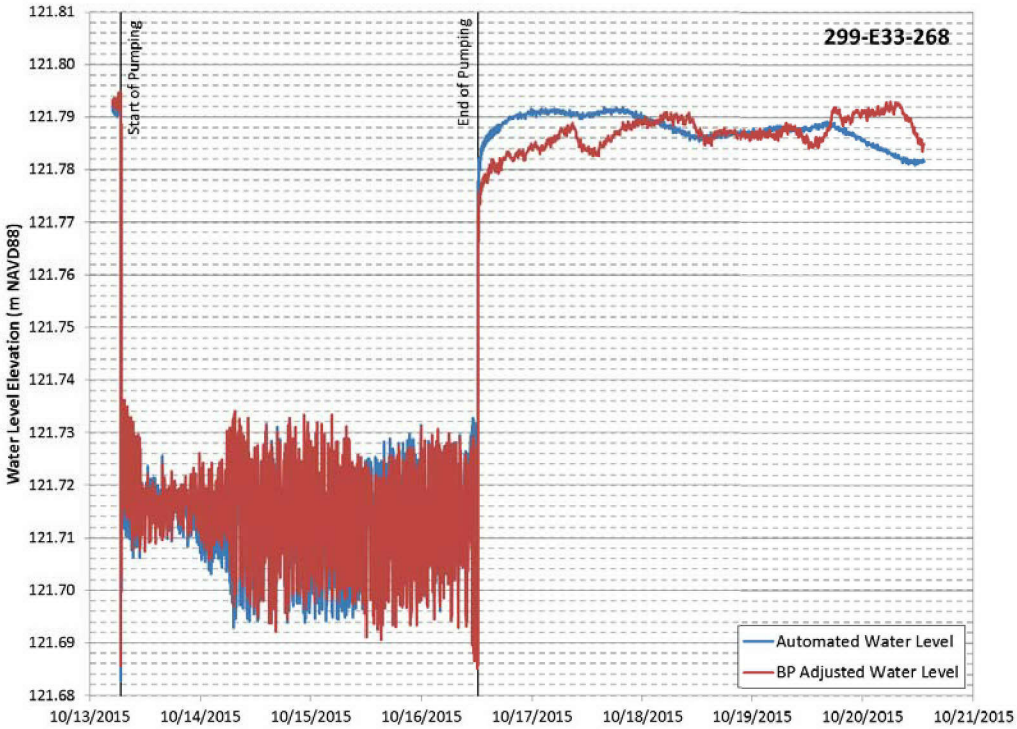

Figure B-1. Automated Water Level Measurements Collected for Well 299-E33-268 (Pumping Well) during the 3-Day Constant Rate Discharge Test

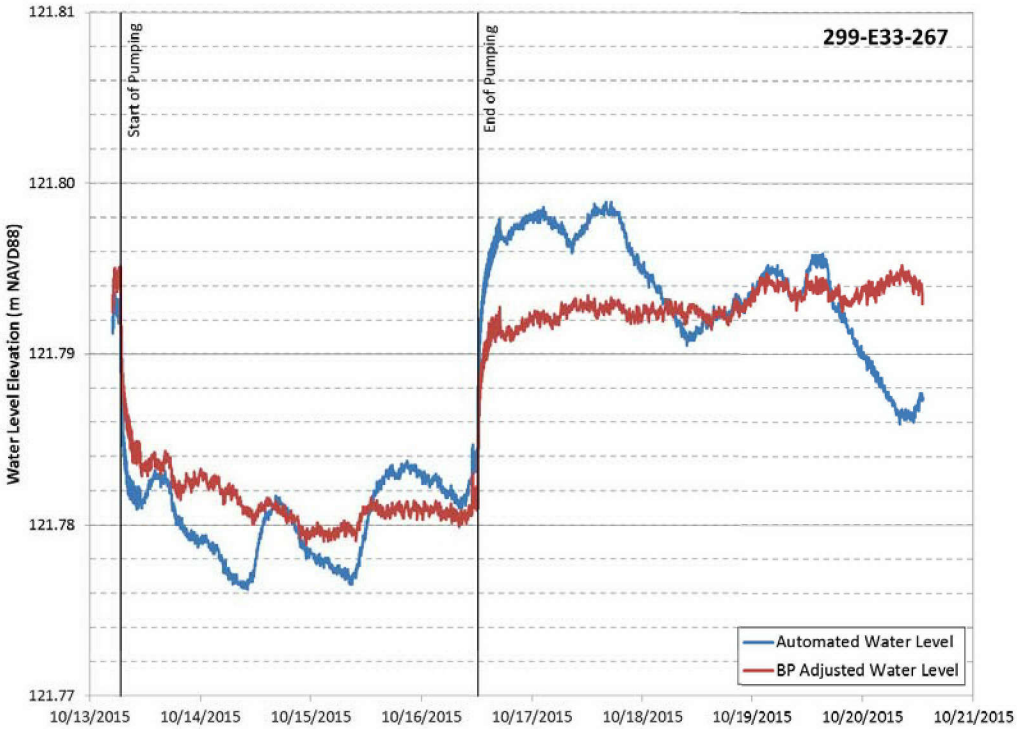

Figure B-2. Automated Water Level Measurements Collected for Well 299-E33-267 (4.5 m [15 ft] South of the Pumping Well) during the 3-Day Constant Rate Discharge Test

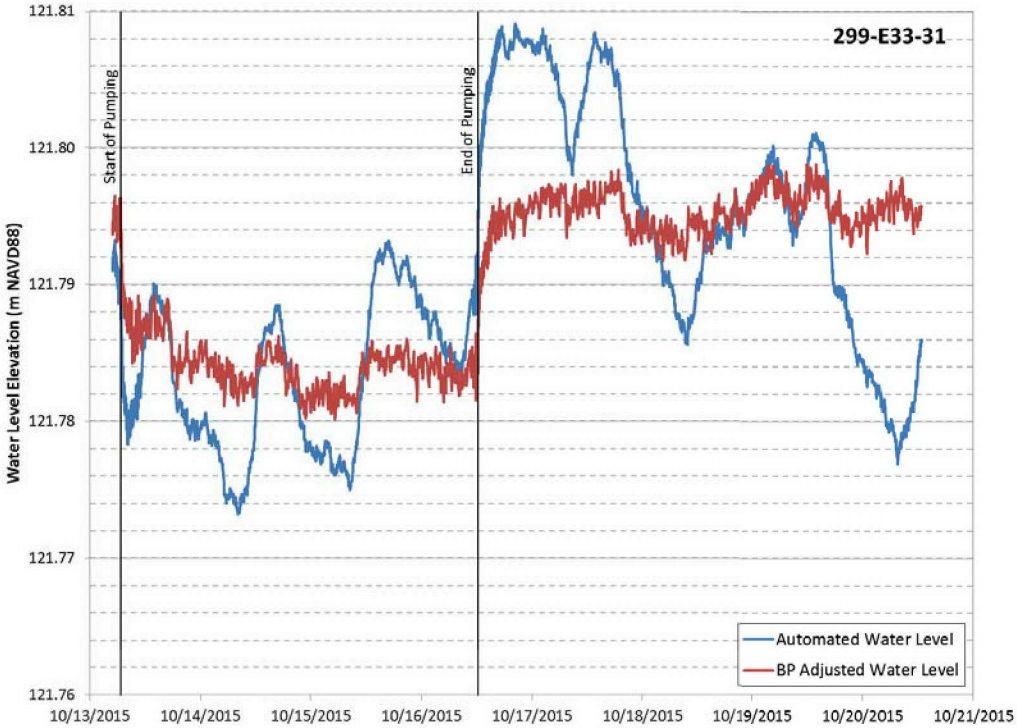

Figure B-3. Automated Water Level Measurements Collected for Well 299-E33-31 (9.2 m [30 ft] South-Southeast of the Pumping Well) during the 3-Day Constant Rate Discharge Test

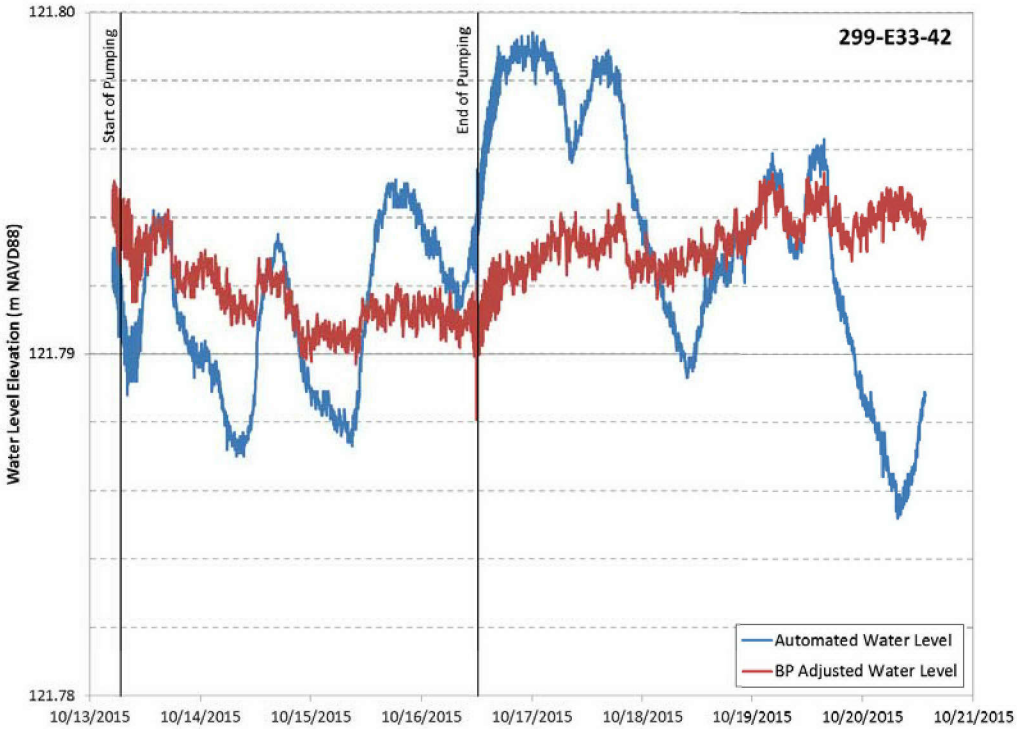

Figure B-4. Automated Water Level Measurements Collected for Well 299-E33-42 (74 m [240 ft] South of the Pumping Well) during the 3-Day Constant Rate Discharge Test

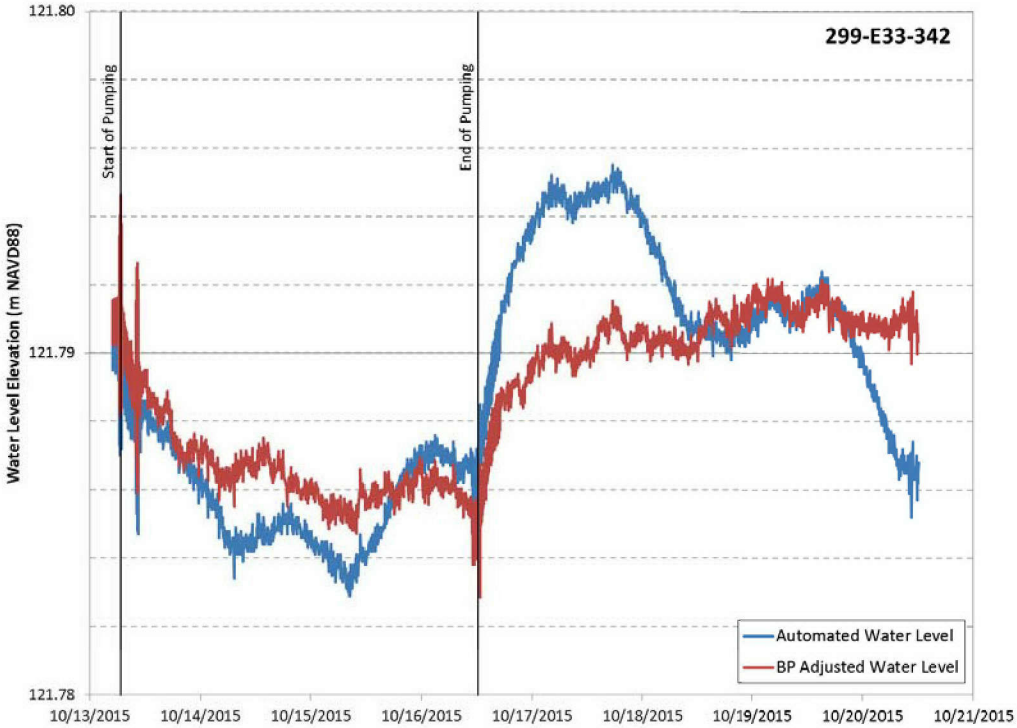

Figure B-5. Automated Water Level Measurements Collected for Well 299-E33-342 (134 m [440 ft] Northeast of the Pumping Well) during the 3-Day Constant Rate Discharge Test

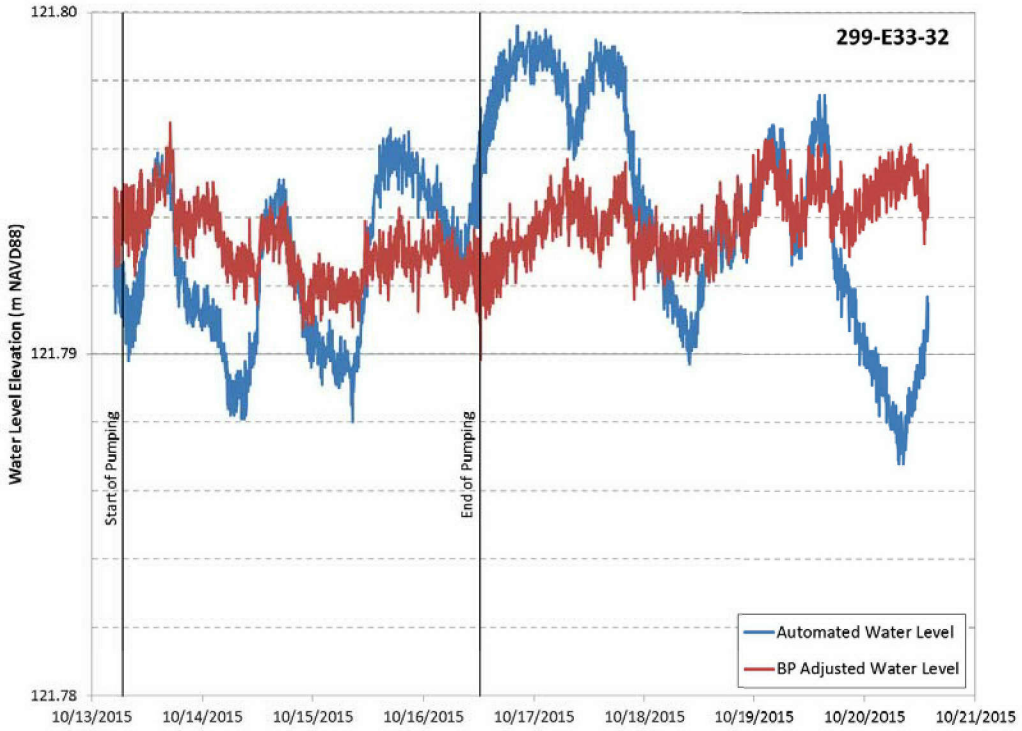

Figure B-6. Automated Water Level Measurements Collected for Well 299-E33-32 (145 m [479 ft] South of the Pumping Well) during the 3-Day Constant Rate Discharge Test

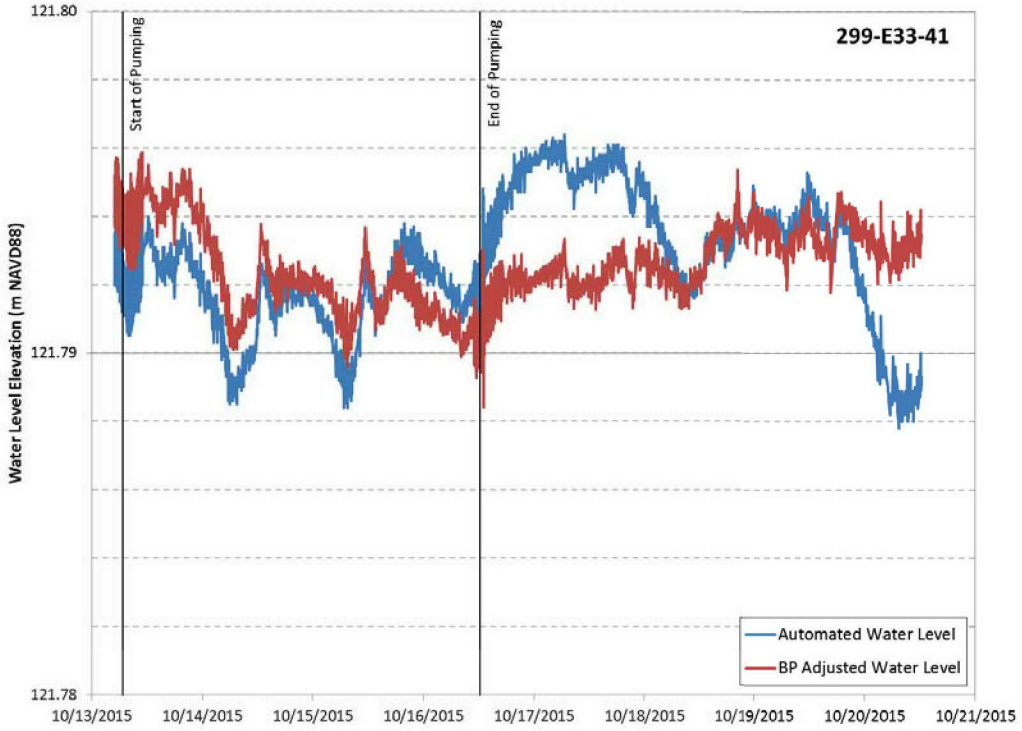

Figure B-7. Automated Water Level Measurements Collected for Well 299-E33-41 (228 m [748 ft] Southeast of the Pumping Well) during the 3-Day Constant Rate Discharge Test

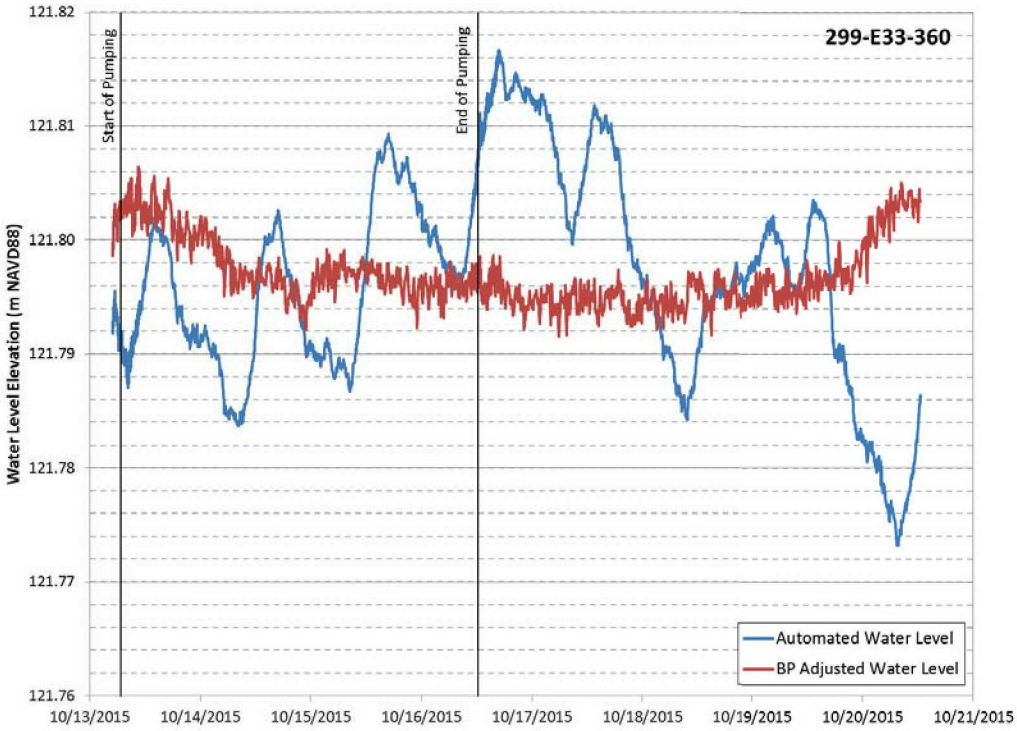

Figure B-8. Automated Water Level Measurements Collected for Well 299-E33-360 (276 m [906 ft] East-Southeast of the Pumping Well) during the 3-Day Constant Rate Discharge Test

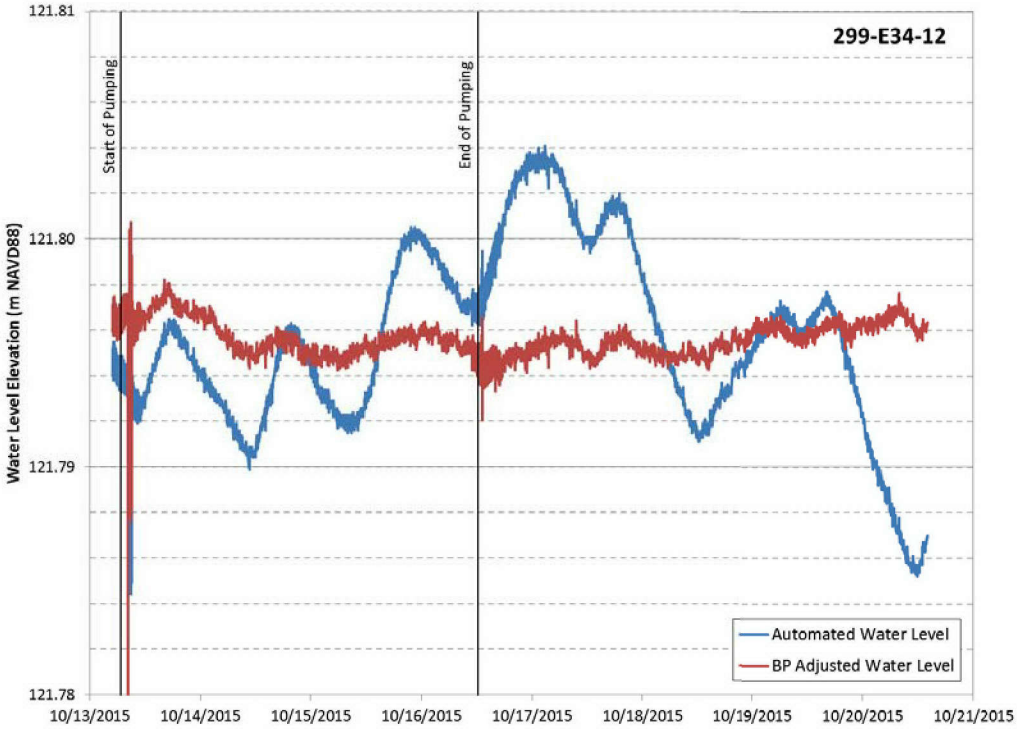

Figure B-9. Automated Water Level Measurements Collected for Well 299-E34-12 (951 m [3,120 ft] East-Southeast of the Pumping Well) during the 3-Day Constant Rate Discharge Test

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Appendix C
AQTESOLV Results for the 3-Day Constant Rate Discharge Test - Drawdown

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This appendix provides charts of the curves matched to the drawdown data from the 3-day constant rate discharge test conducted between 10/13/2015 and 10/16/2015. The pumping well was 299-E33-268 and drawdown was observed in wells 299-E33-31, 299-E33-267, and 299-E33-342. Pressure derivatives for these 4 wells are also provided.

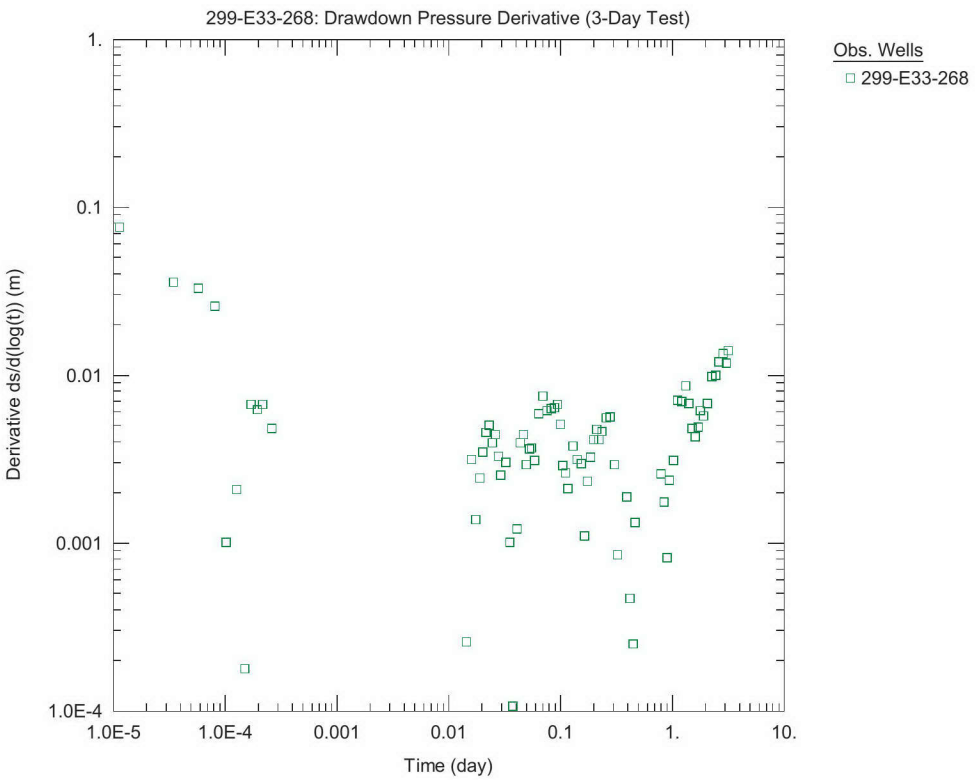

Figure C-1. AQTESOLV Pressure Derivative for Drawdown at 299-E33-268 (Pumping Well).

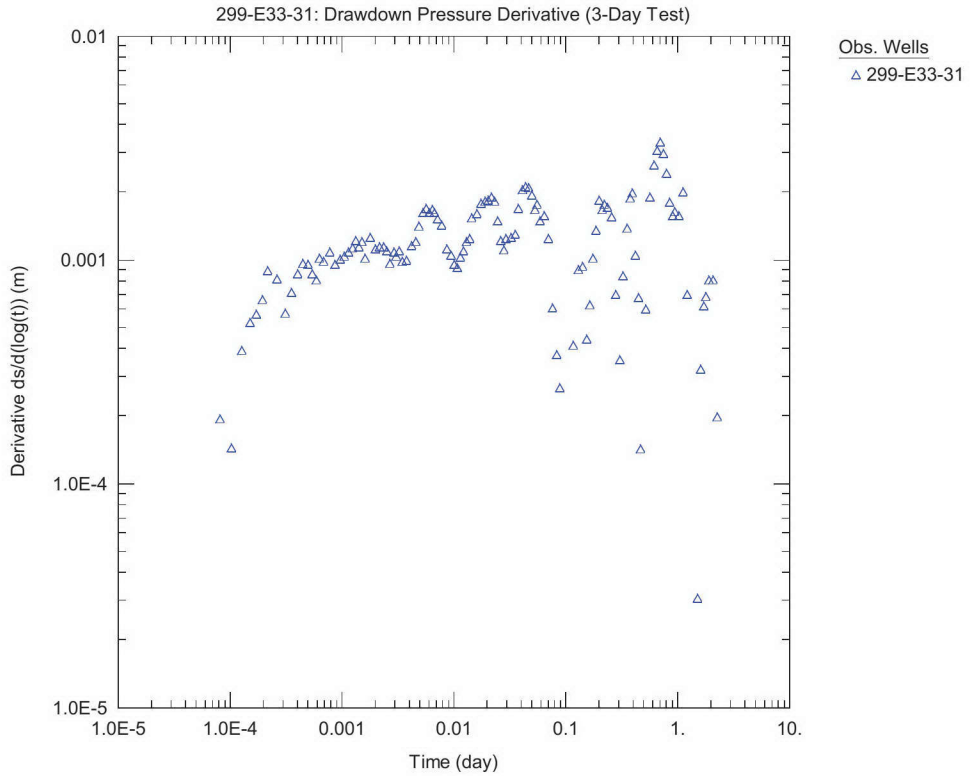

Figure C-2. AQTESOLV Pressure Derivative for Drawdown at 299-E33-31

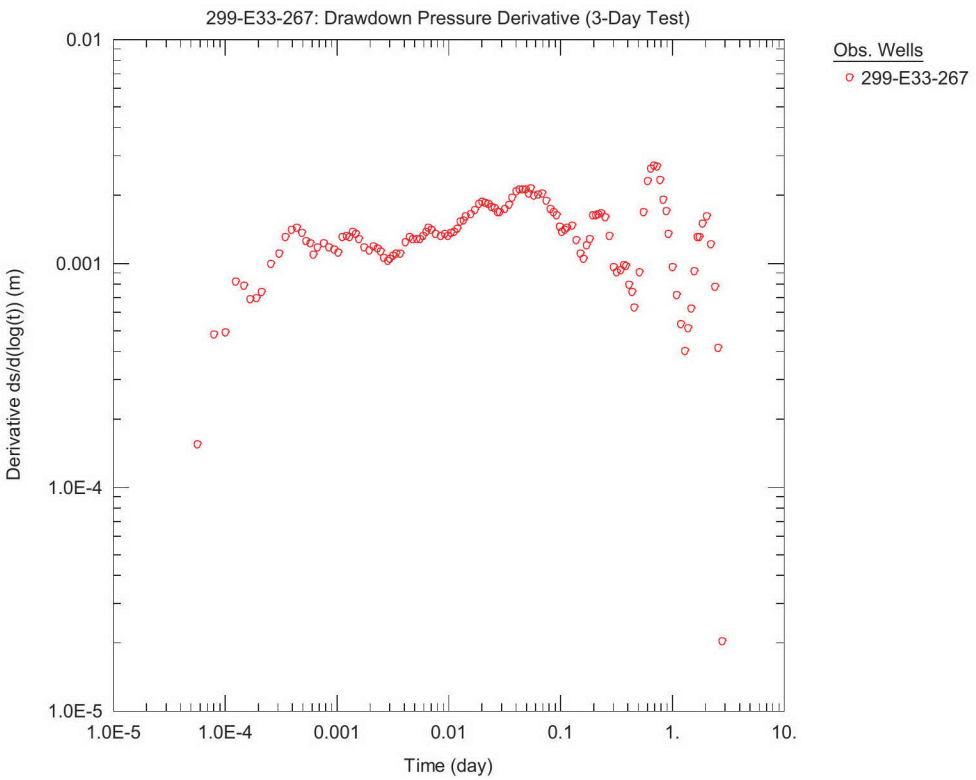

Figure C-3. AQTESOLV Pressure Derivative for Drawdown at 299-E33-267.

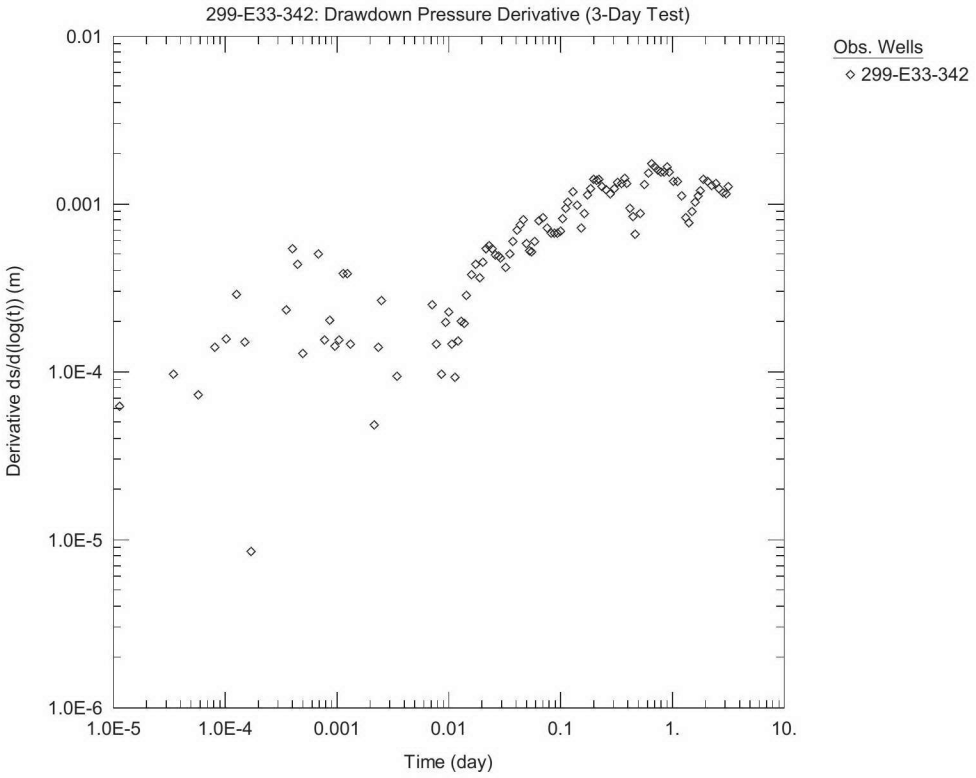

Figure C-4. AQTESOLV Pressure Derivative for Drawdown at 299-E33-342.

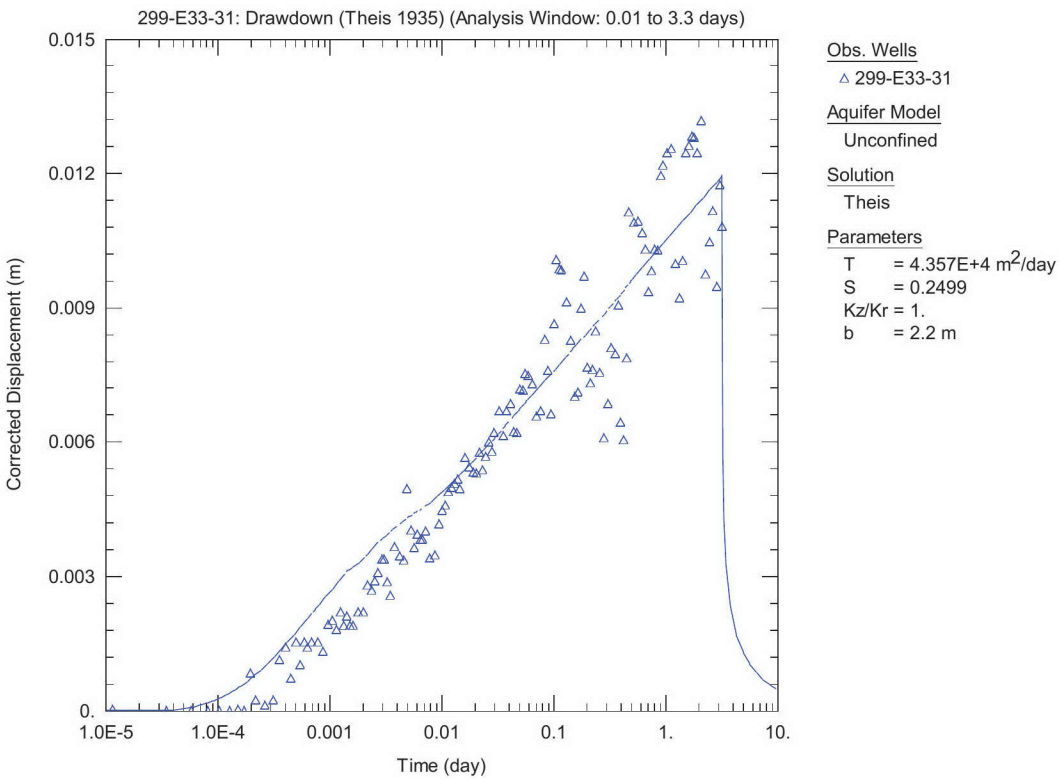

Figure C-5. AQTESOLV Results for Drawdown at 299-E33-31 by the Theis (1935)/Hantush (1961a,b) Method.

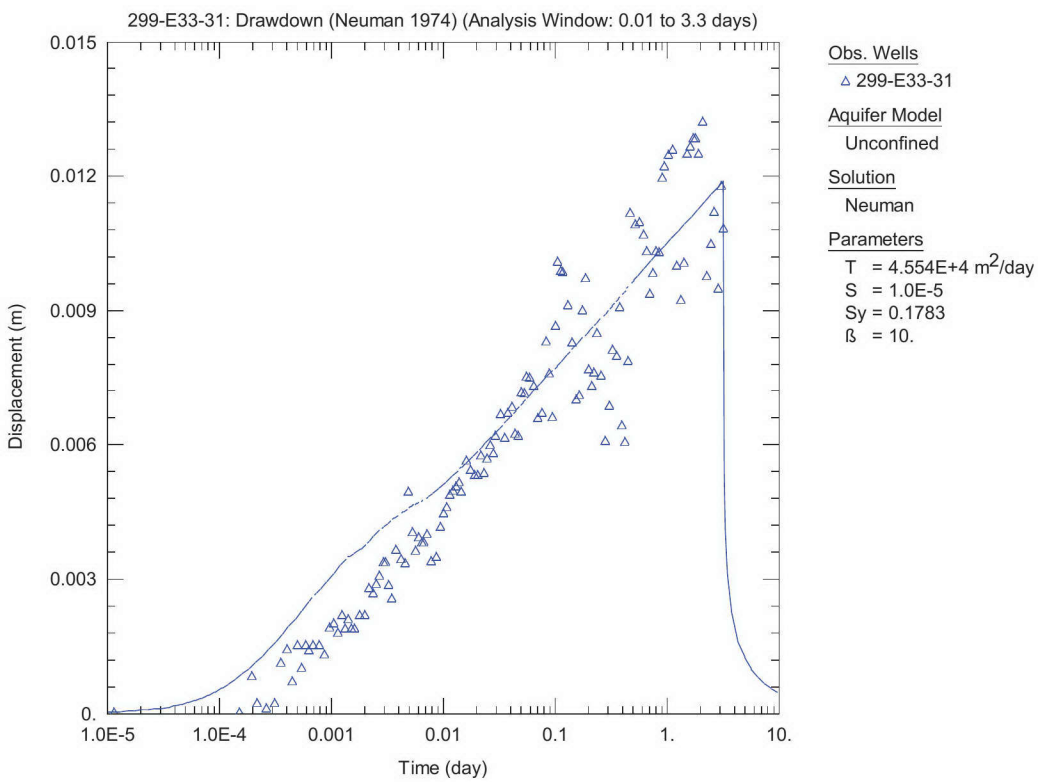

Figure C-6. AQTESOLV Results for Drawdown at 299-E33-31 by the Neuman (1974) Method.

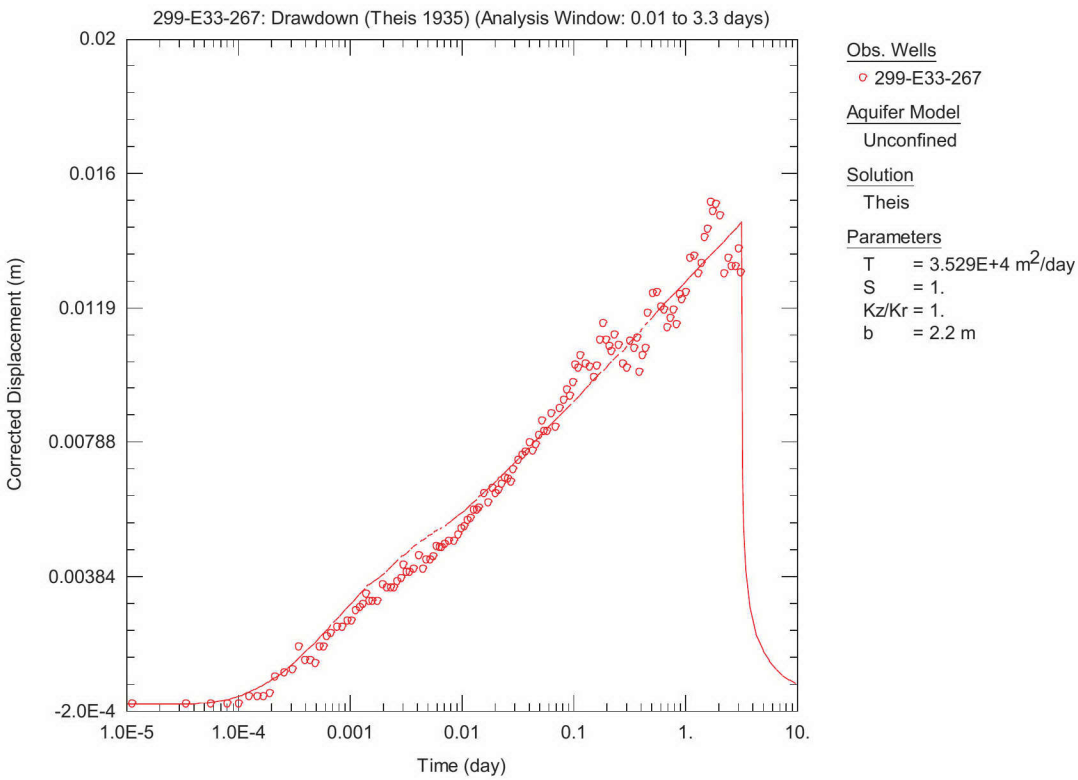

Figure C-7. AQTESOLV Results for Drawdown at 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

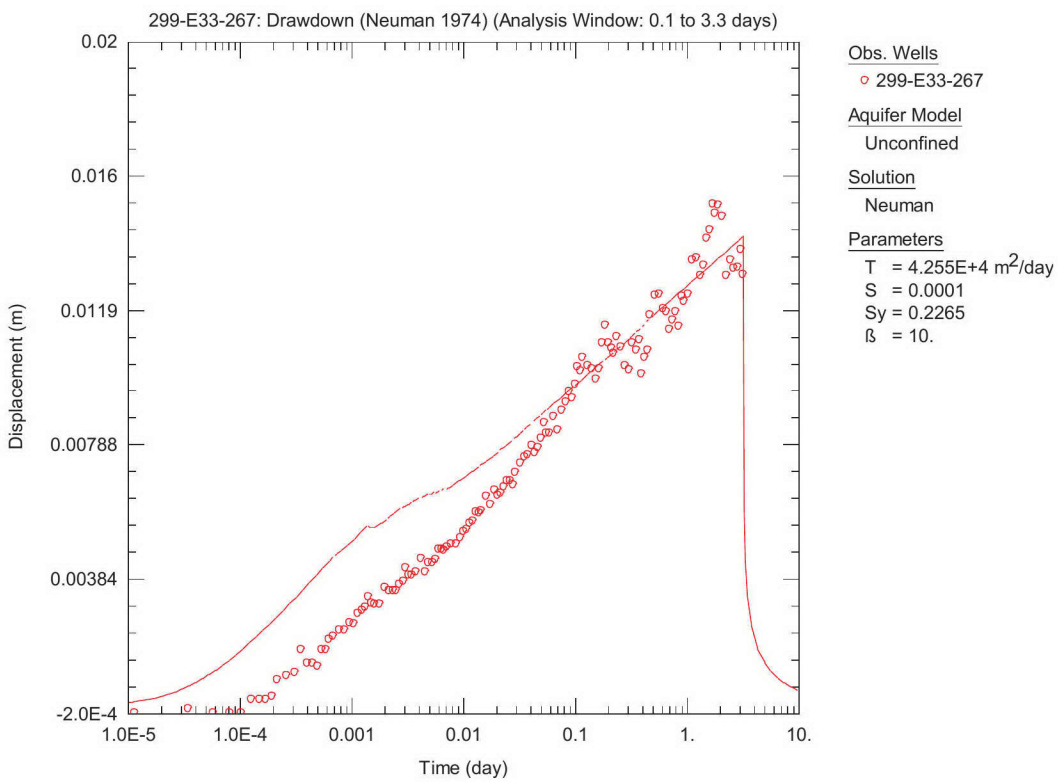

Figure C-8. AQTESOLV Results for Drawdown at 299-E33-267 by the Neuman (1974) Method.

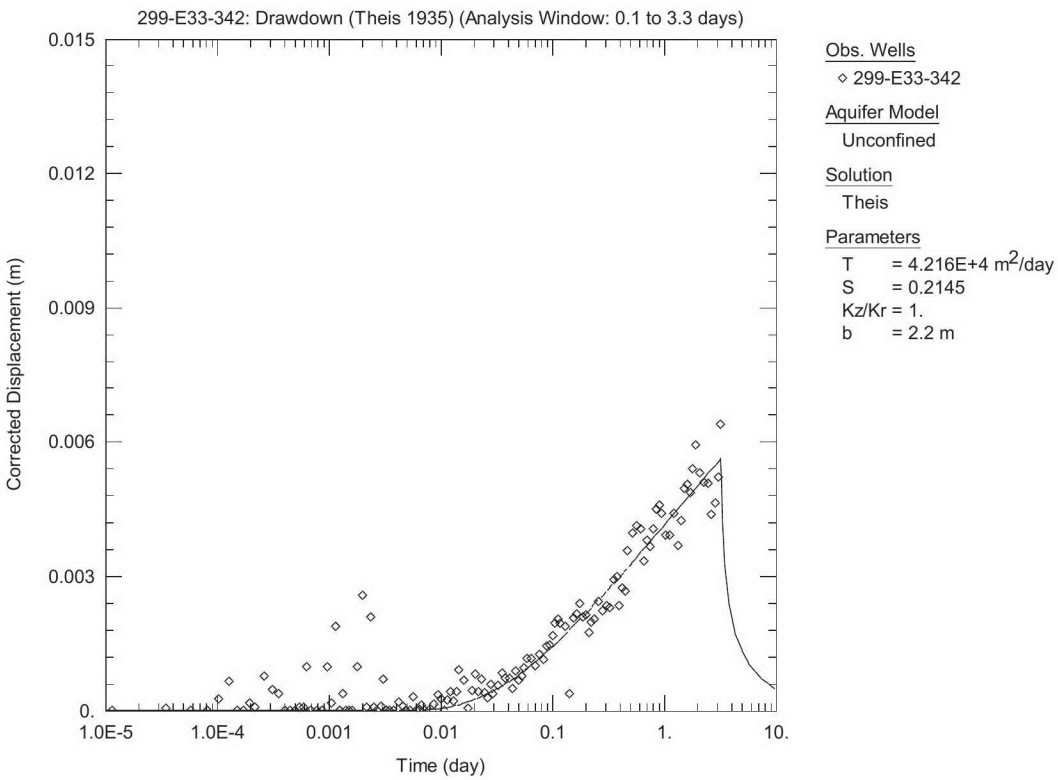

Figure C-9. AQTESOLV Results for Drawdown at 299-E33-342 by the Theis (1935)/Hantush (1961a,b) Method.

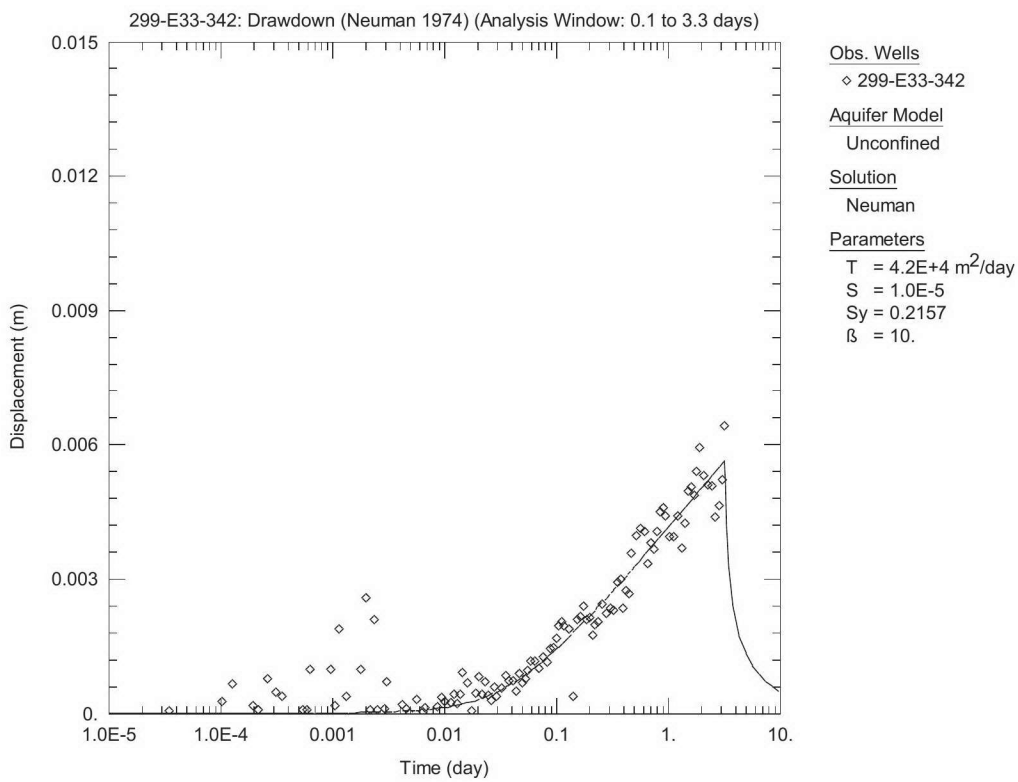

Figure C-10. AQTESOLV Results for Drawdown at 299-E33-342 by the Neuman (1974) Method.

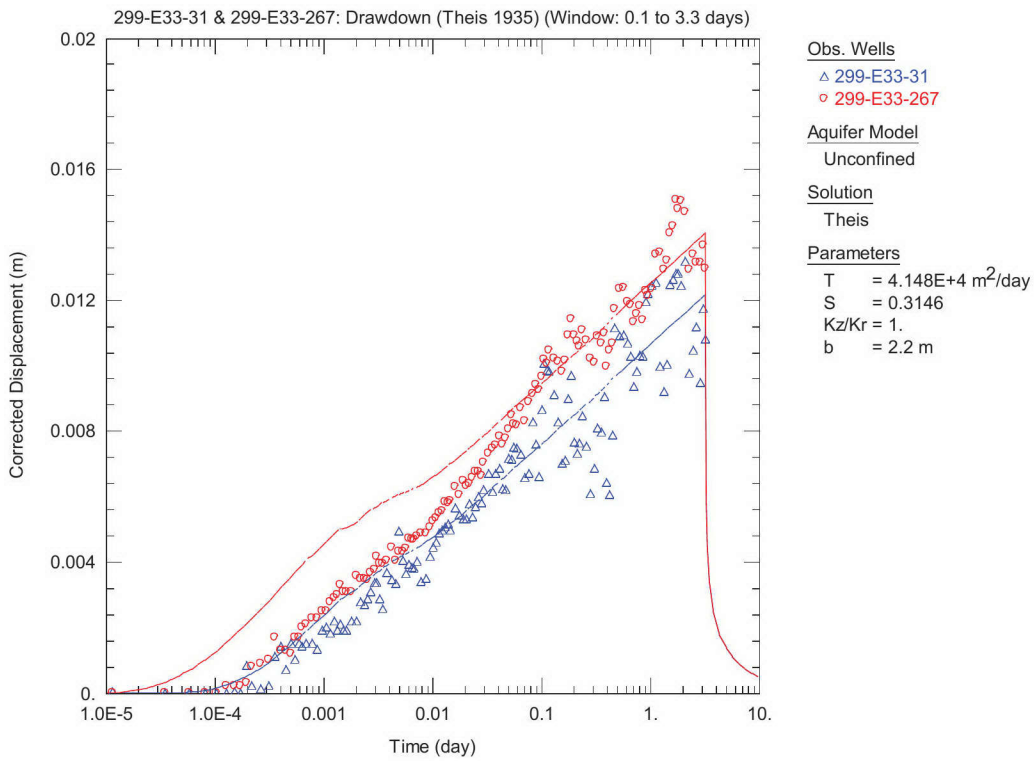

Figure C-11. AQTESOLV Results for Drawdown at 299-E33-31 and 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

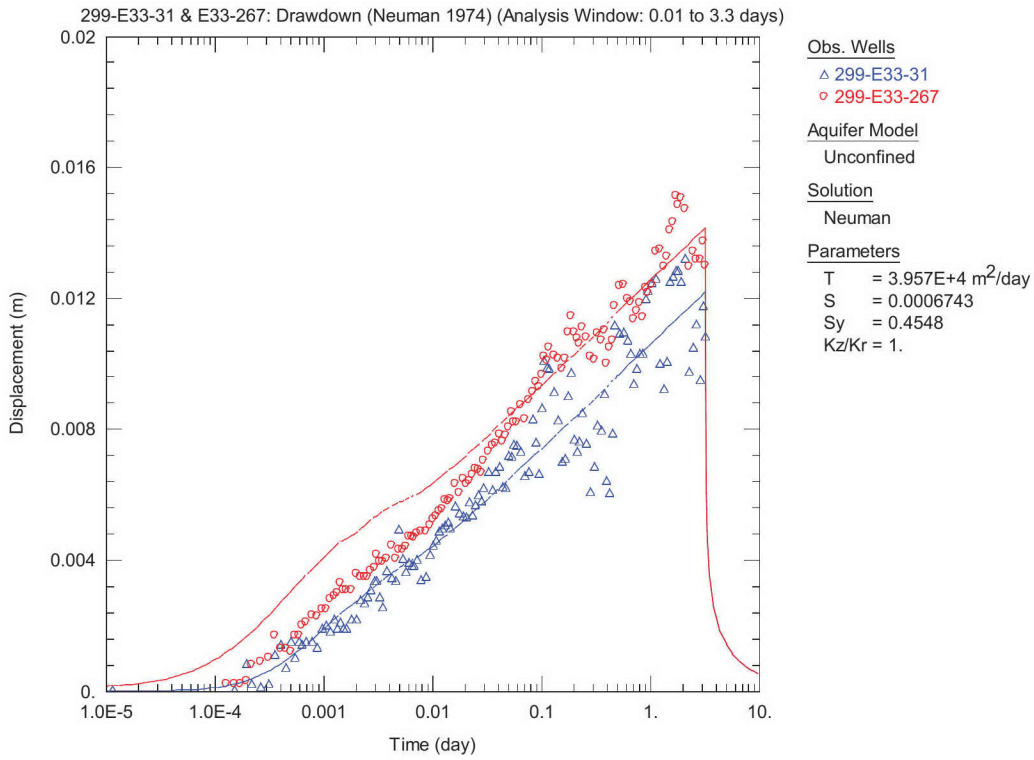

Figure C-12. AQTESOLV Results for Drawdown at 299-E33-31 and 299-E33-267 by the Neuman (1974) Method.

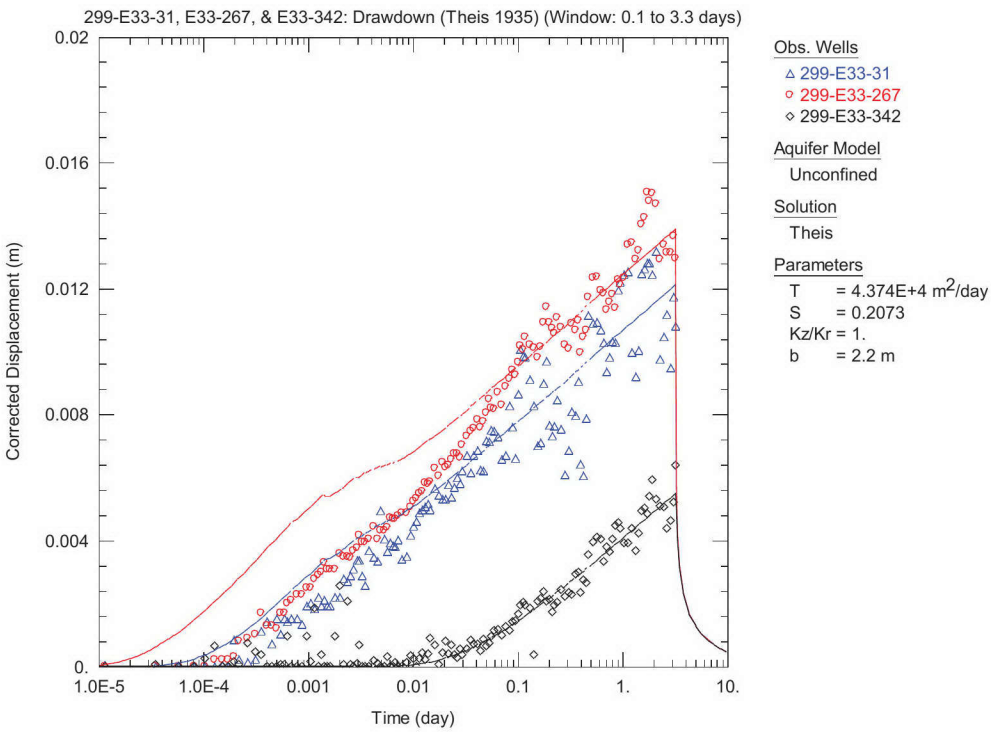

Figure C-13. AQTESOLV Results for Drawdown at 299-E33-31, 299-E33-267, and 299-E33-342 by the Theis (1935)/Hantush (1961a,b) Method.

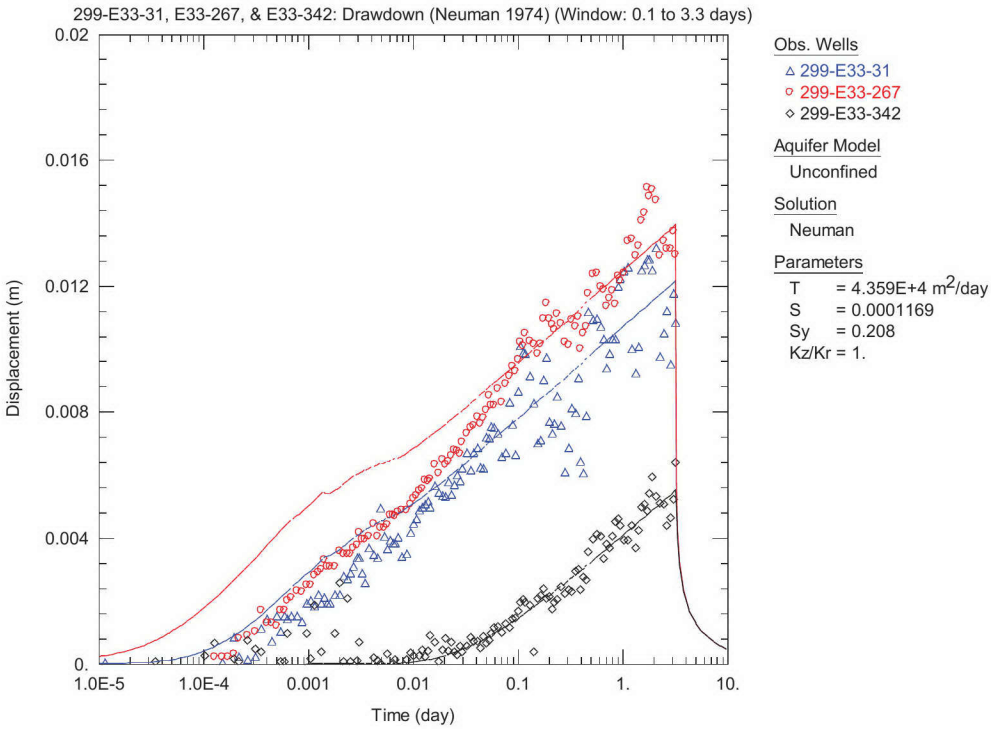

Figure C-14. AQTESOLV Results for Drawdown at 299-E33-31, 299-E33-267, and 299-E33-342 by the Neuman (1974) Method.

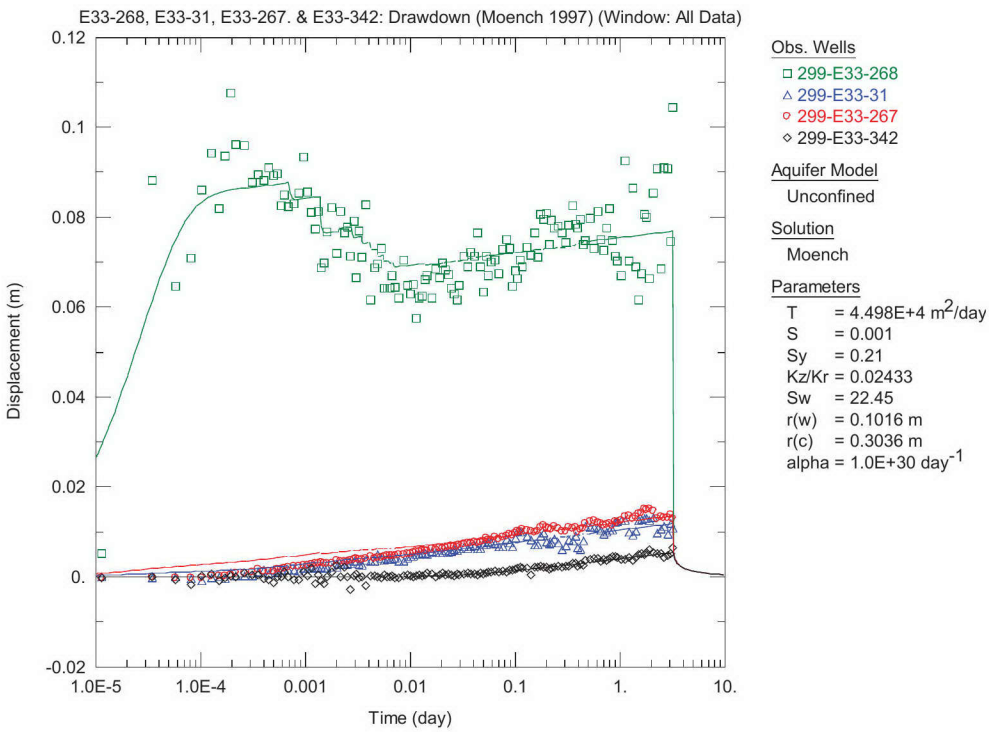

Figure C-15. AQTESOLV Results for Drawdown at Pumping Well 299-E33-268 and Observation Wells 299-E33-31, 299-E33-267, and 299-E33-342 by the Moench (1997) Method.

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Appendix D
AQTESOLV Results for the 3-Day Constant Rate Discharge Test - Recovery

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This appendix provides the curves matched to the recovery data from the 3-day constant rate discharge test conducted between 10/13/2015 and 10/16/2015. The pumping well was 299-E33-268 and because drawdown was observed in wells 299-E33-31, 299-E33-267, and 299-E33-342, these wells were analyzed for buildup.

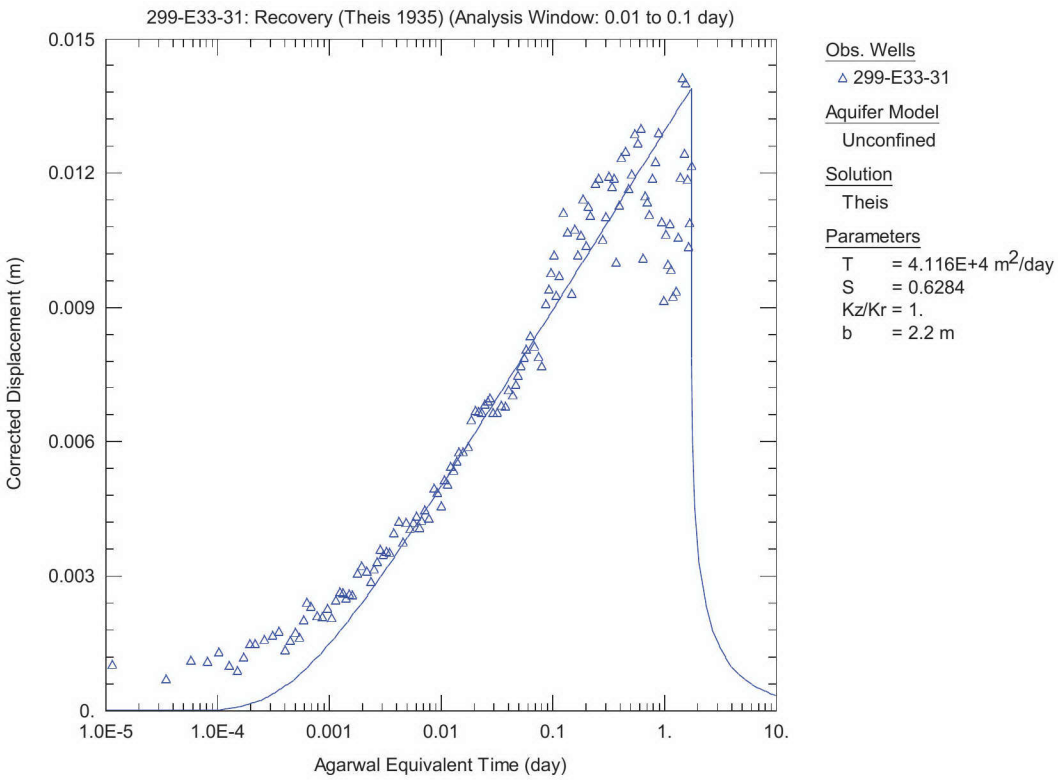

Figure D-1. AQTESOLV Results for Recovery at 299-E33-31 by the Theis (1935)/Hantush (1961a,b) Method.

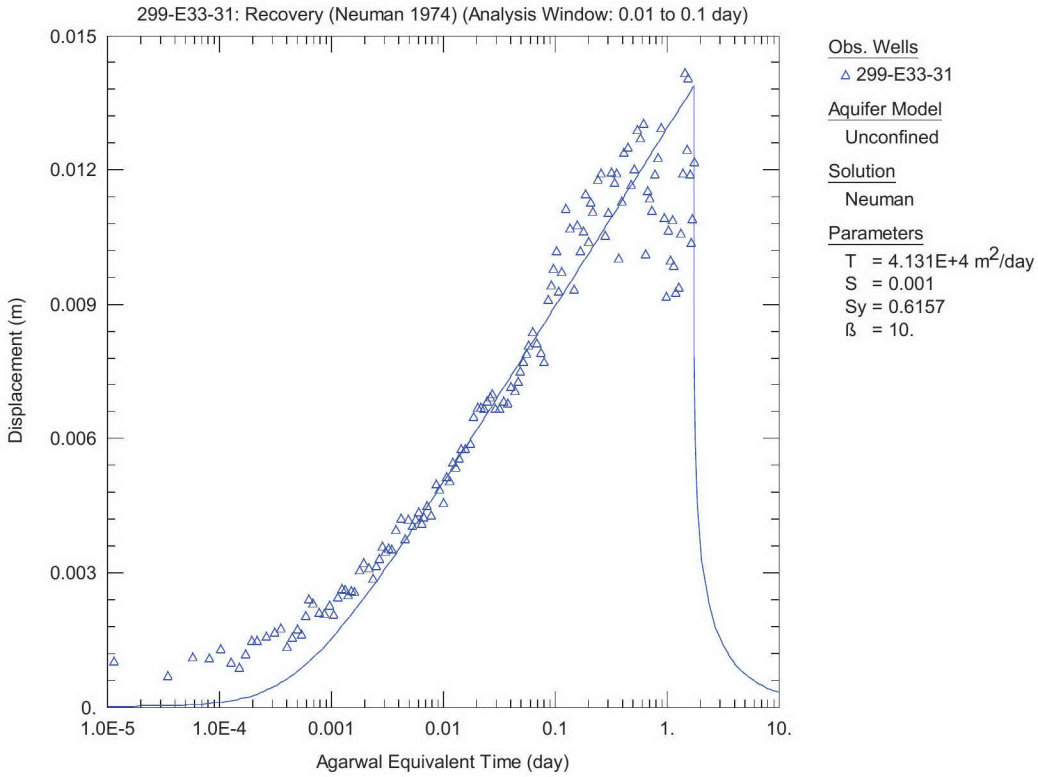

Figure D-2. AQTESOLV Results for Recovery at 299-E33-31 by the Neuman (1974) Method.

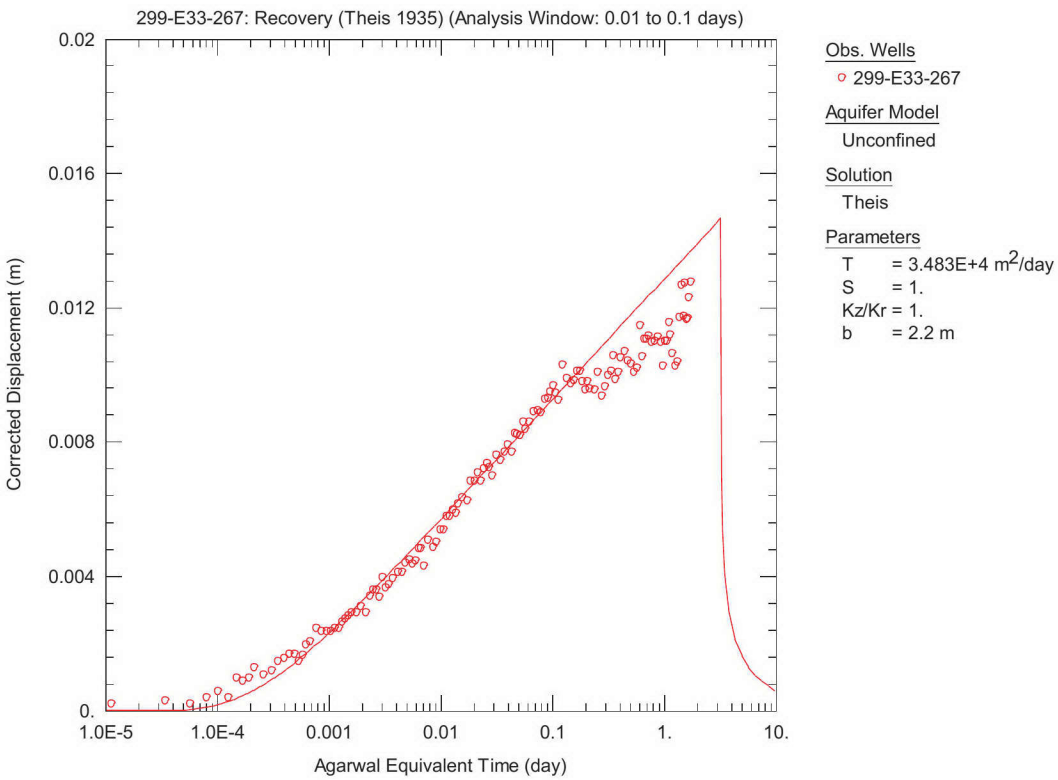

Figure D-3. AQTESOLV Results for Recovery at 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

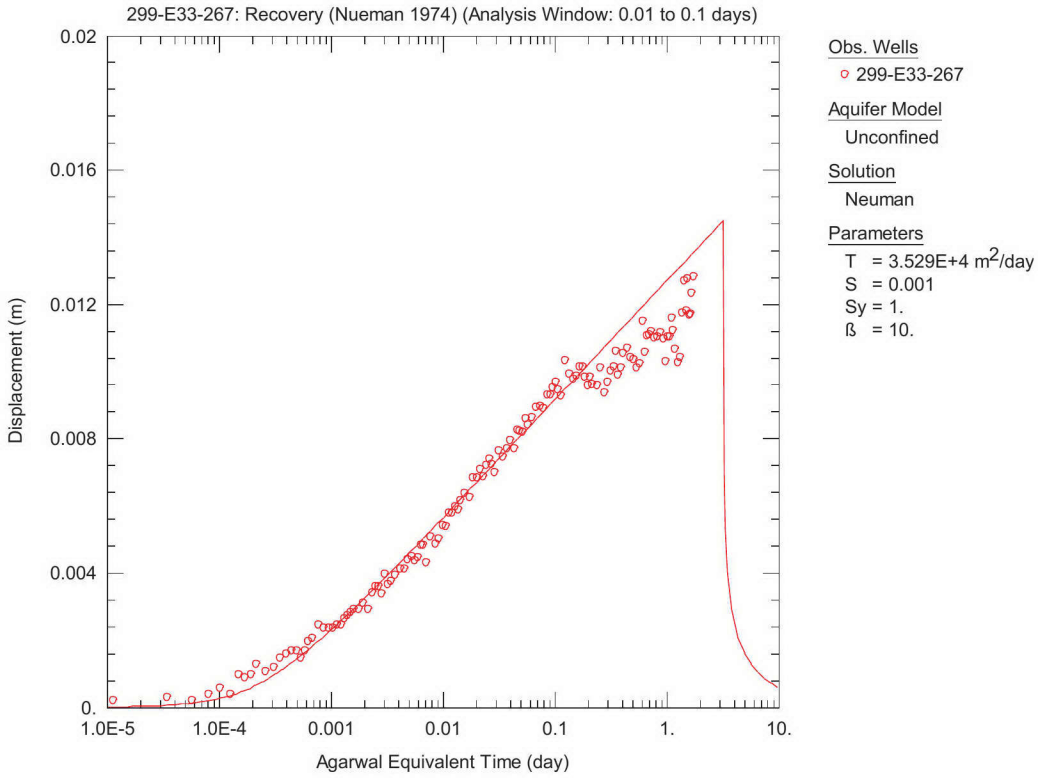

Figure D-4. AQTESOLV Results for Recovery at 299-E33-267 by the Neuman (1974) Method.

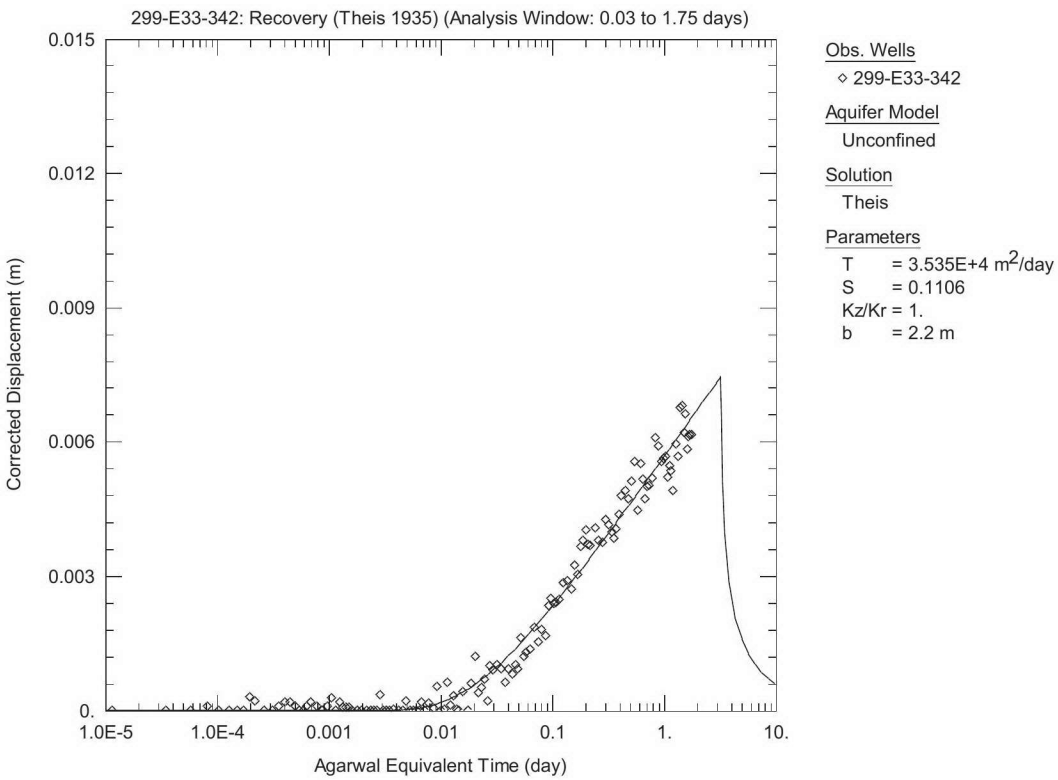

Figure D-5. AQTESOLV Results for Recovery at 299-E33-342 by the Theis (1935)/Hantush (1961a,b) Method.

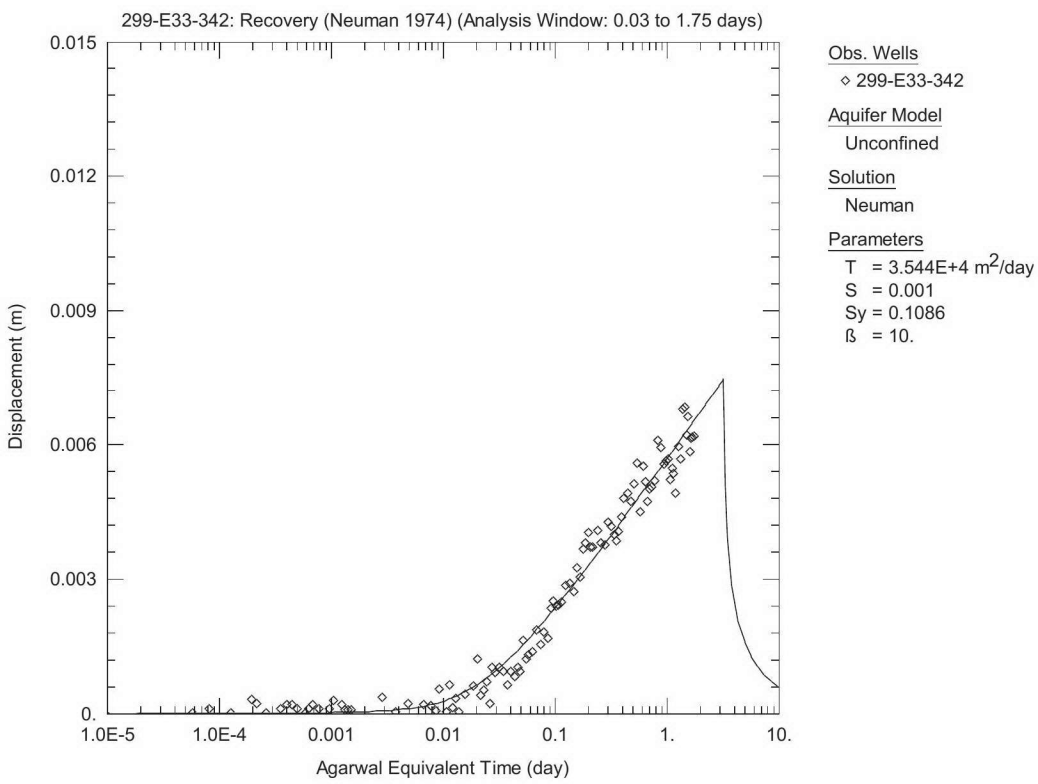

Figure D-6. AQTESOLV Results for Recovery at 299-E33-342 by the Neuman (1974) Method.

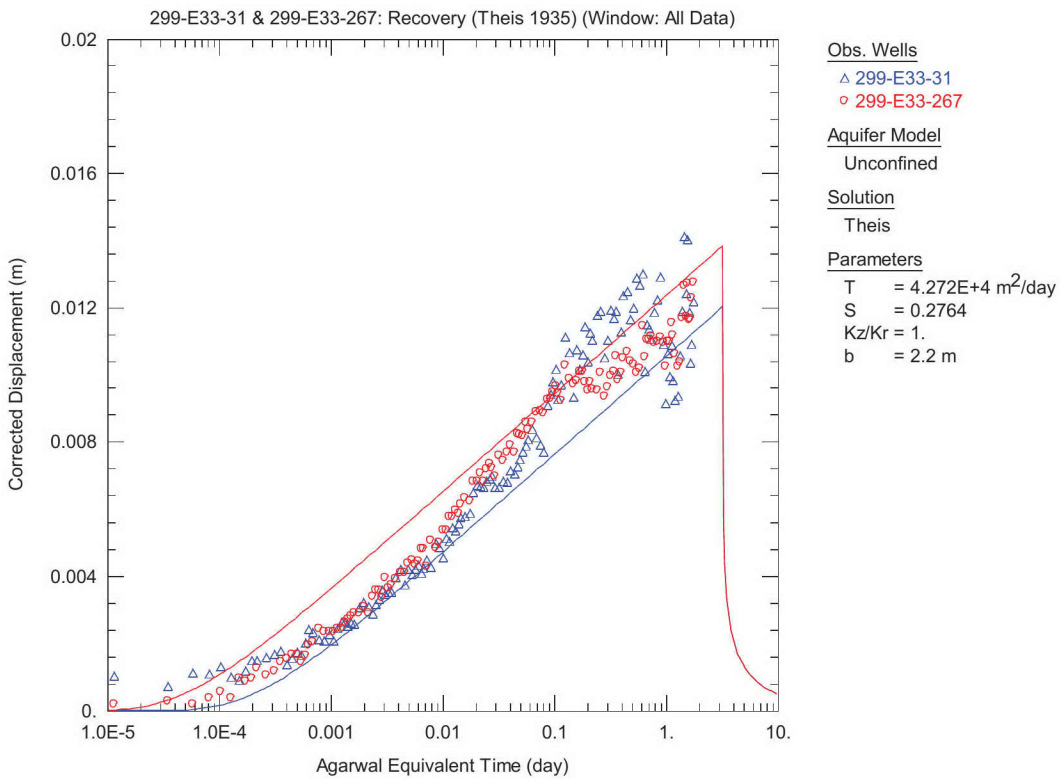

Figure D-7. AQTESOLV Results for Recovery at 299-E33-31 and 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

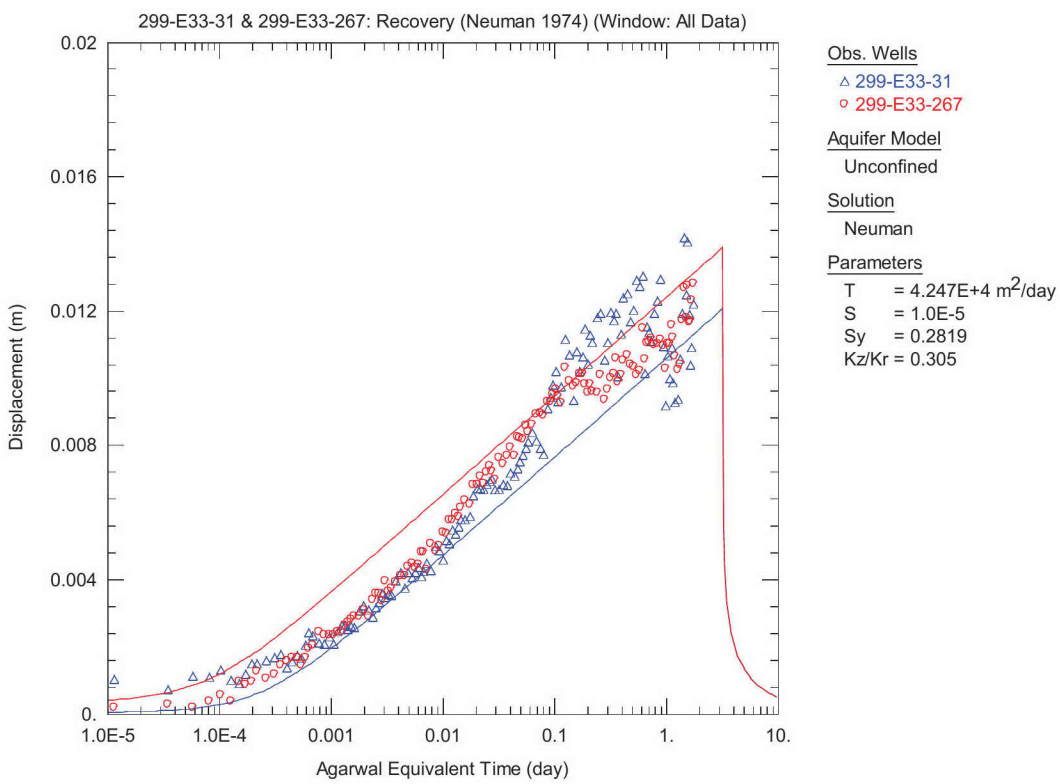

Figure D-8. AQTESOLV Results for Recovery at 299-E33-31 and 299-E33-267 by the Neuman (1974) Method.

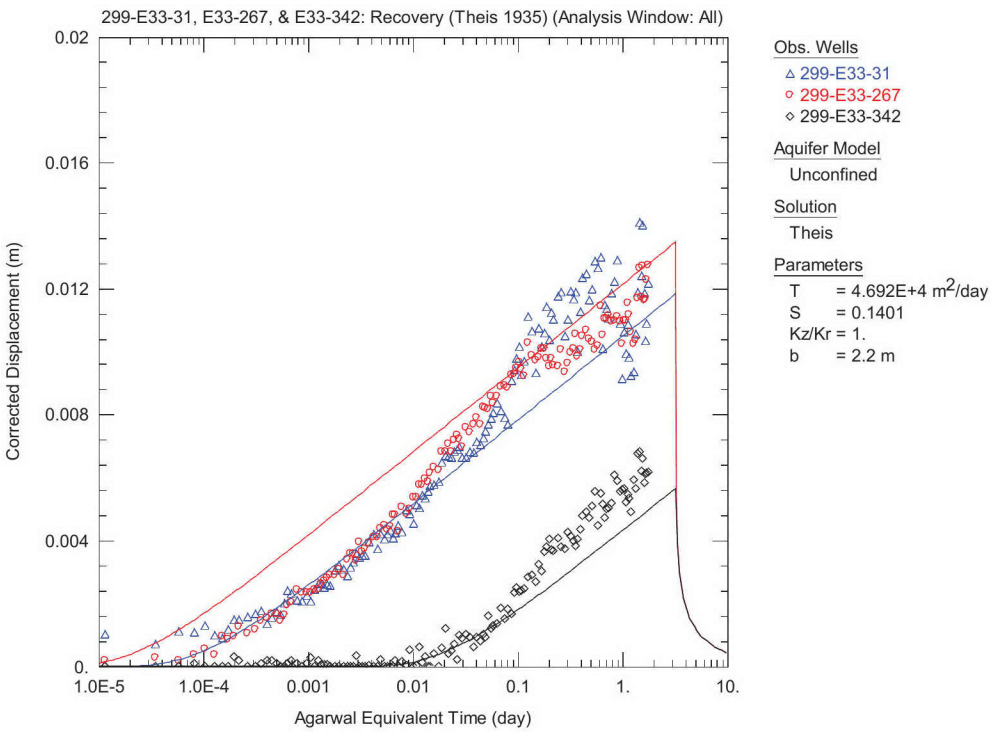

Figure D-9. AQTESOLV Results for Recovery at 299-E33-31, 299-E33-267, and 299-E33-342 by the Theis (1935)/Hantush (1961a,b) Method.

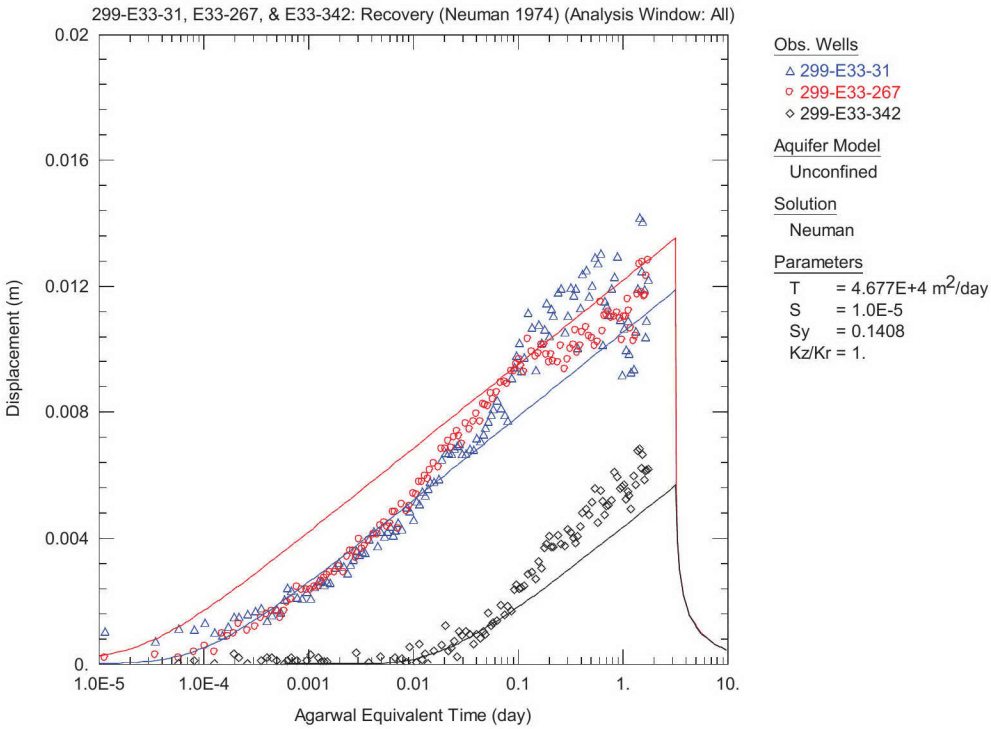

Figure D-10. AQTESOLV Results for Recovery at 299-E33-31, 299-E33-267, and 299-E33-342 by the Neuman (1974) Method.

Appendix E
Automated Water Level Measurements for the 27-Day Constant Rate Discharge Test

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Charts of the automated water level measurements collected during the 27-day test are shown in Figures E-1 through E-10. The pumping well, 299-E33-268, is shown first (Figure E-1) and then the observation wells are shown in order of increasing distance from the pumping well (Figures E-2 to E-10). Two charts are provided for 299-E34-12. The first (Figure E-9) shows the unmodified water level in the well during the test period. The water level exhibits a declining trend during this time. This is the background trend of the water table because 299-E34-12 is 951 m (3,120 ft) from the pumping well and did not experience any drawdown during the test. Because the background water table declined during the test, it was important to remove that decline from the measurements so it would not affect the drawdown determinations. After the measurements from 299-E34-12 were normalized to a constant barometric pressure, a line was fit to the data by linear regression. The slope of the line was then used to detrend all the measurements for all the wells before data analysis. The detrended measurements for 299-E34-12 are shown in Figure E-10, and all the other figures (i.e., E-1 to E-8) show the detrended data for the remaining wells.

Like for the 3-day test, drawdown was discernable in the pumping well and in 299-E33-267, 299-E33-31, and 299-E33-342 (pumping was resumed after the recovery period, hence the resumption of drawdown on the charts on 11/20/2015). Some drawdown may also have occurred at 299-E33-42, but this could not be confirmed because the amount of apparent drawdown (0.001 to 0.002 m) is about the same as the remaining error when the water levels are normalized to a constant barometric pressure. For this reason, 299-E33-42 was not included in the hydraulic property determinations.

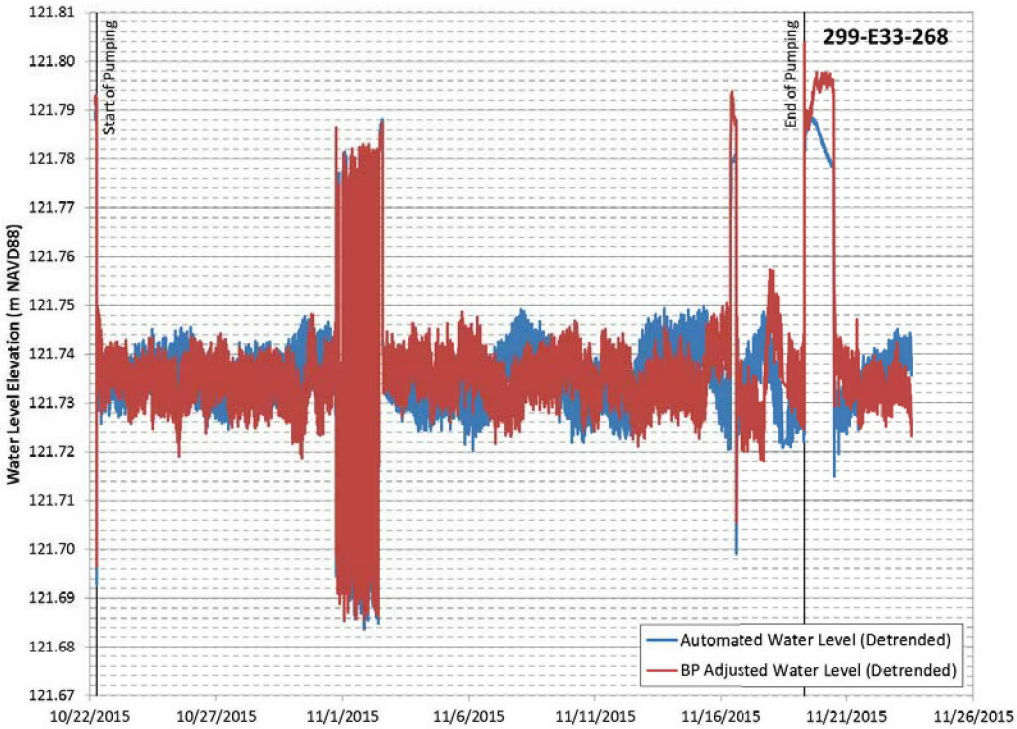

Figure E-1. Automated Water Level Measurements Collected for Well 299-E33-268 (Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

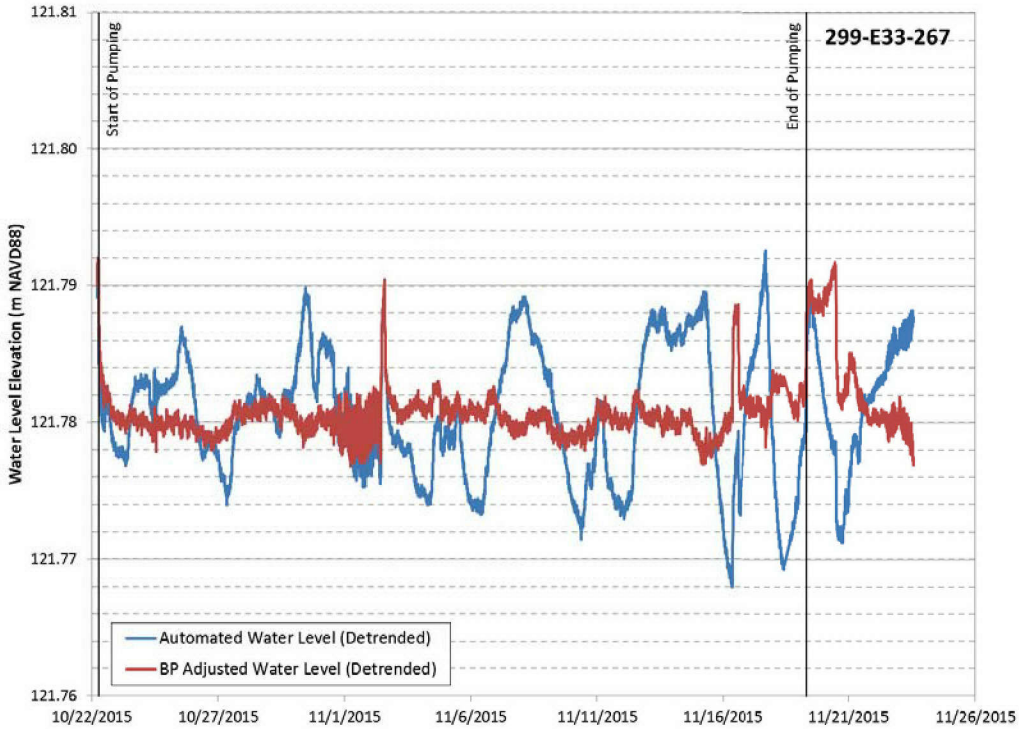

Figure E-2. Automated Water Level Measurements Collected for Well 299-E33-267 (4.5 m [15 ft] South of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

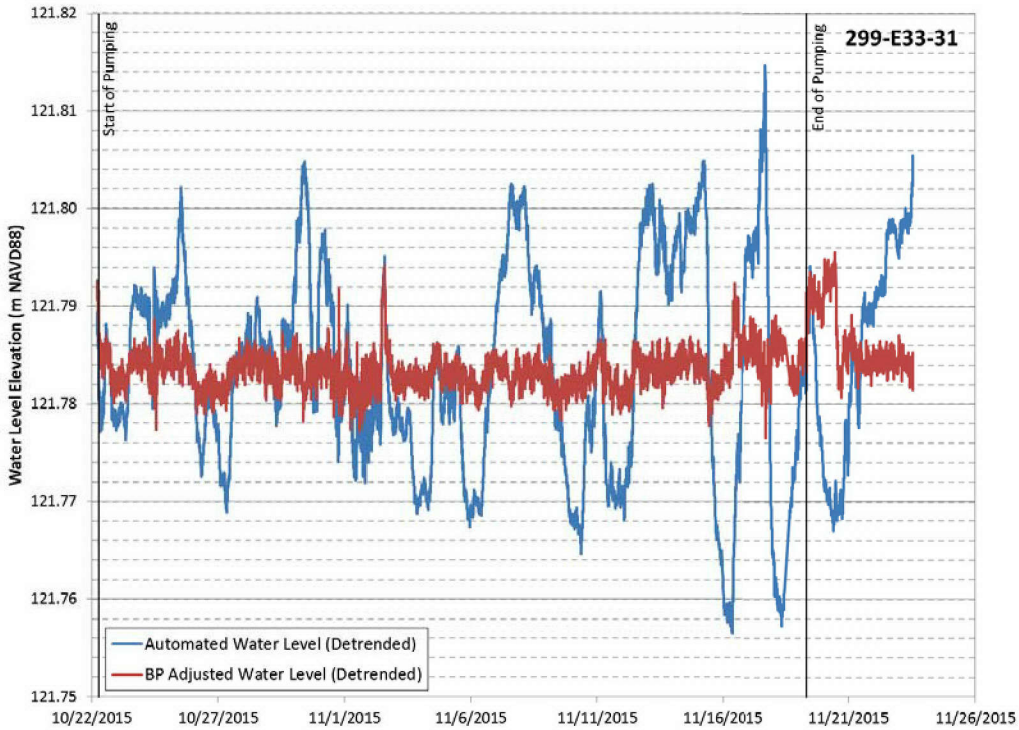

Figure E-3. Automated Water Level Measurements Collected for Well 299-E33-31 (9.2 m [30 ft] South-Southeast of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

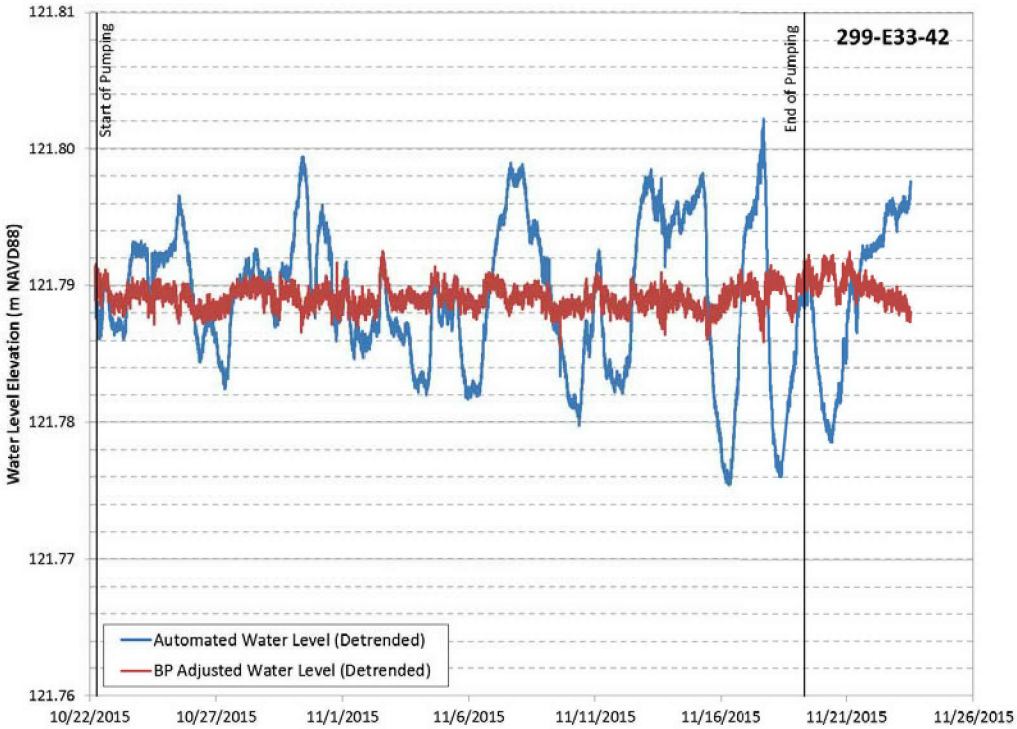

Figure E-4. Automated Water Level Measurements Collected for Well 299-E33-42 (74 m [240 ft] South of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

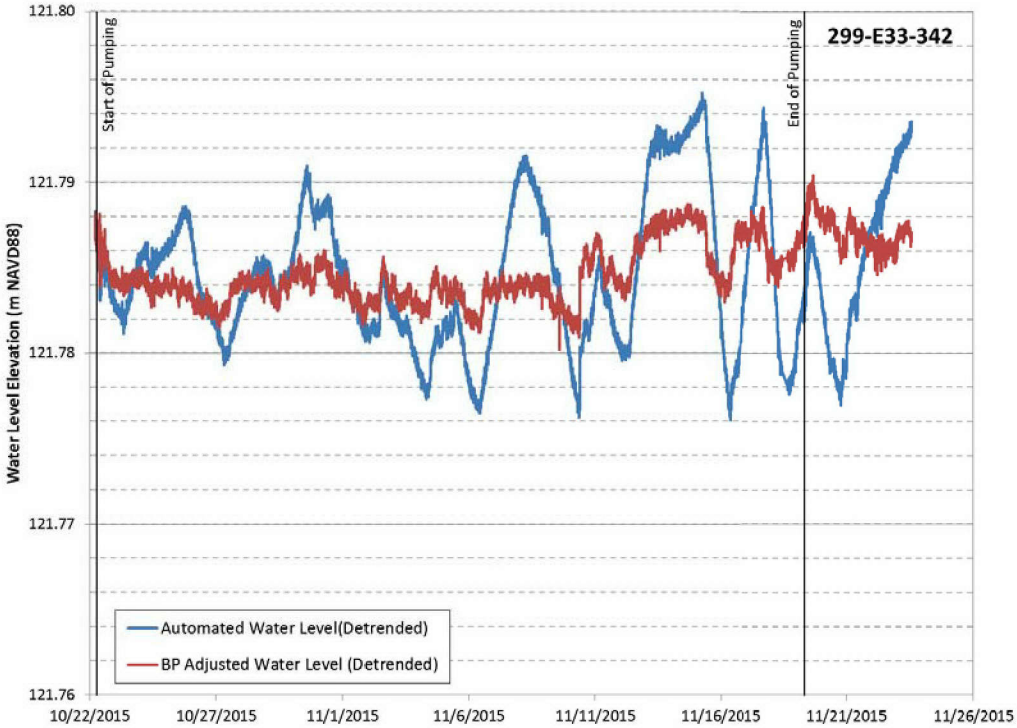

Figure E-5. Automated Water Level Measurements Collected for Well 299-E33-342 (134 m [440 ft] Northeast of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

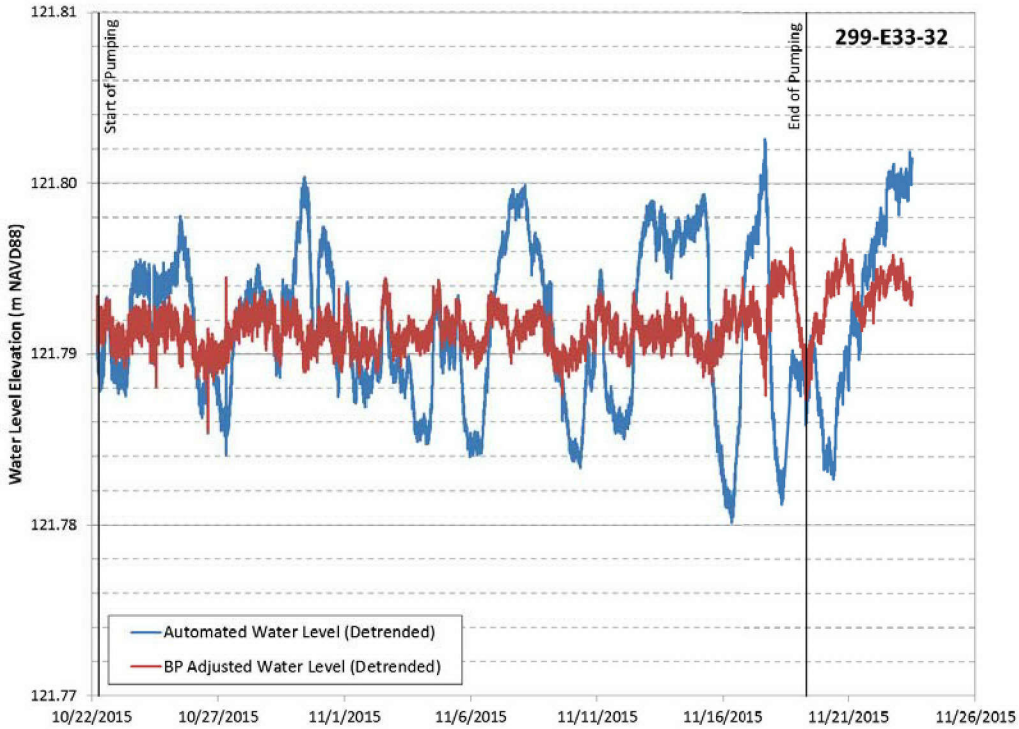

Figure E-6. Automated Water Level Measurements Collected for Well 299-E33-32 (145 m [476 ft] South of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

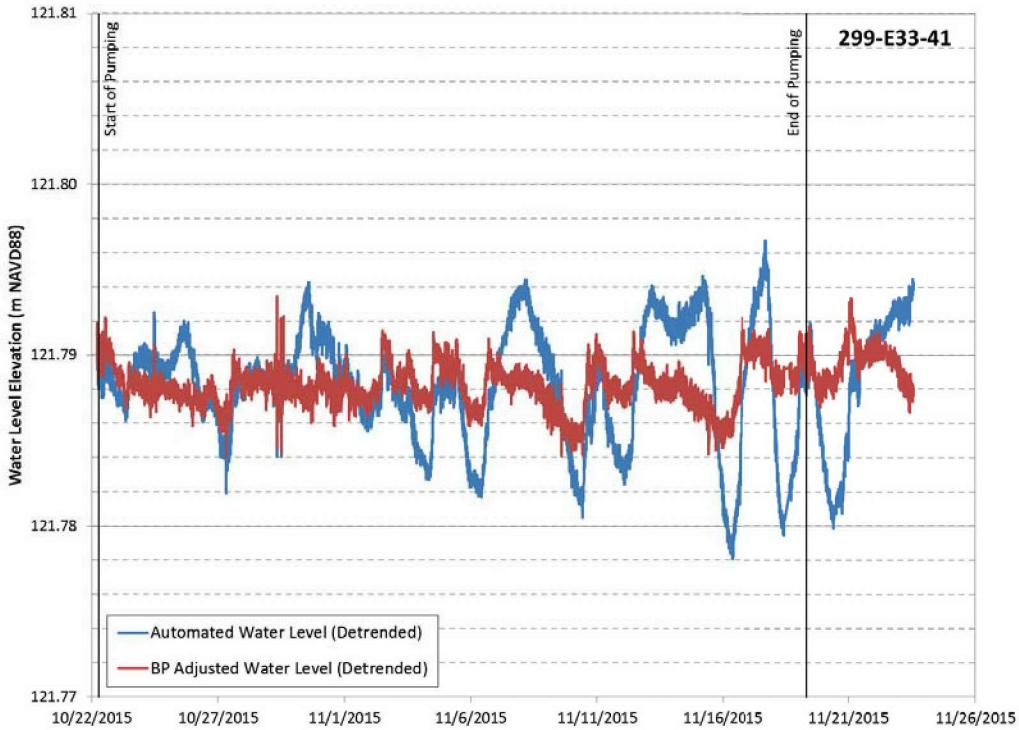

Figure E-7. Automated Water Level Measurements Collected for Well 299-E33-41 (228 m [748 ft] Southeast of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

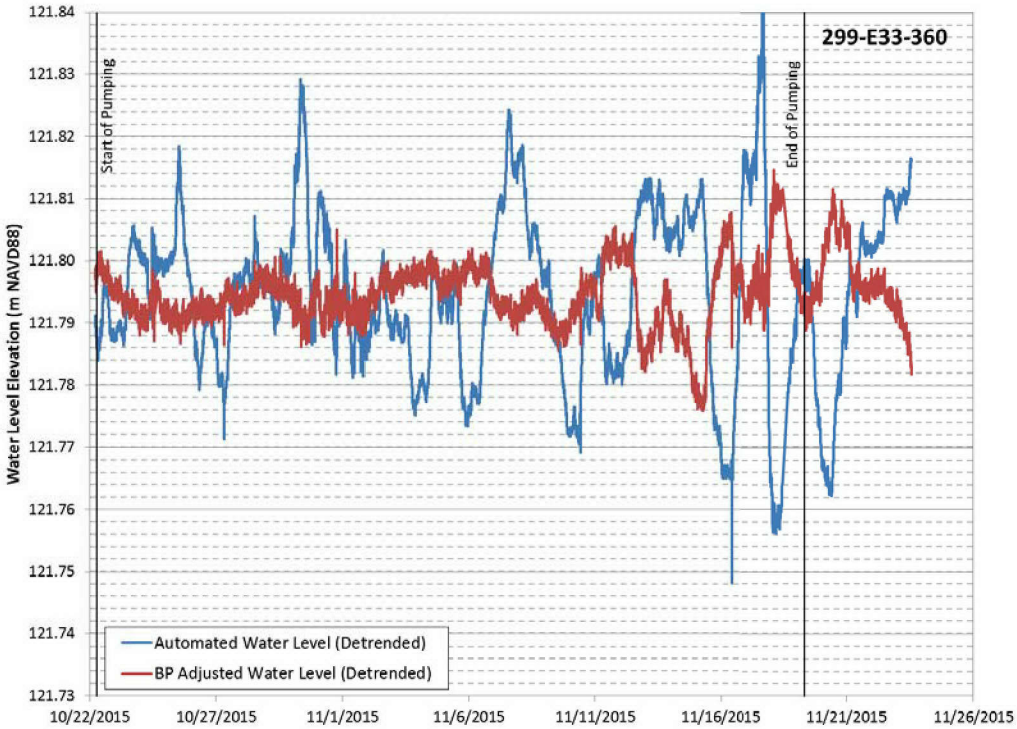

Figure E-8. Automated Water Level Measurements Collected for Well 299-E33-360 (276 m [906 ft] East-Southeast of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

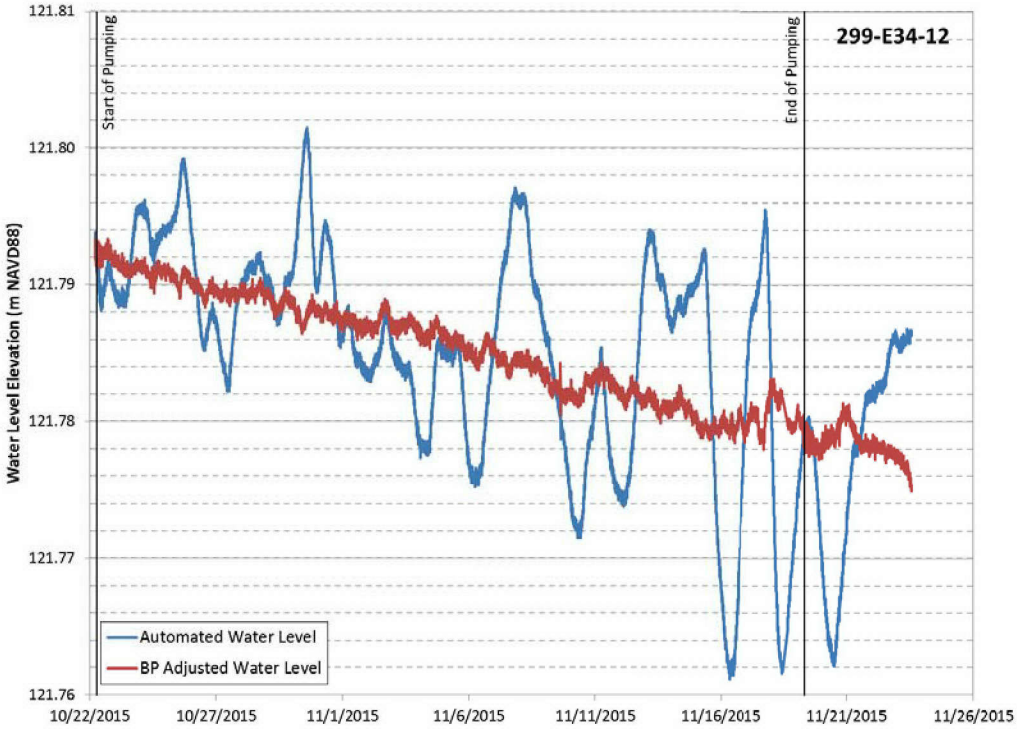

Figure E-9. Automated Water Level Measurements Collected for Well 299-E34-12 (951 m [3,120 ft] East-Southeast of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Original Data)

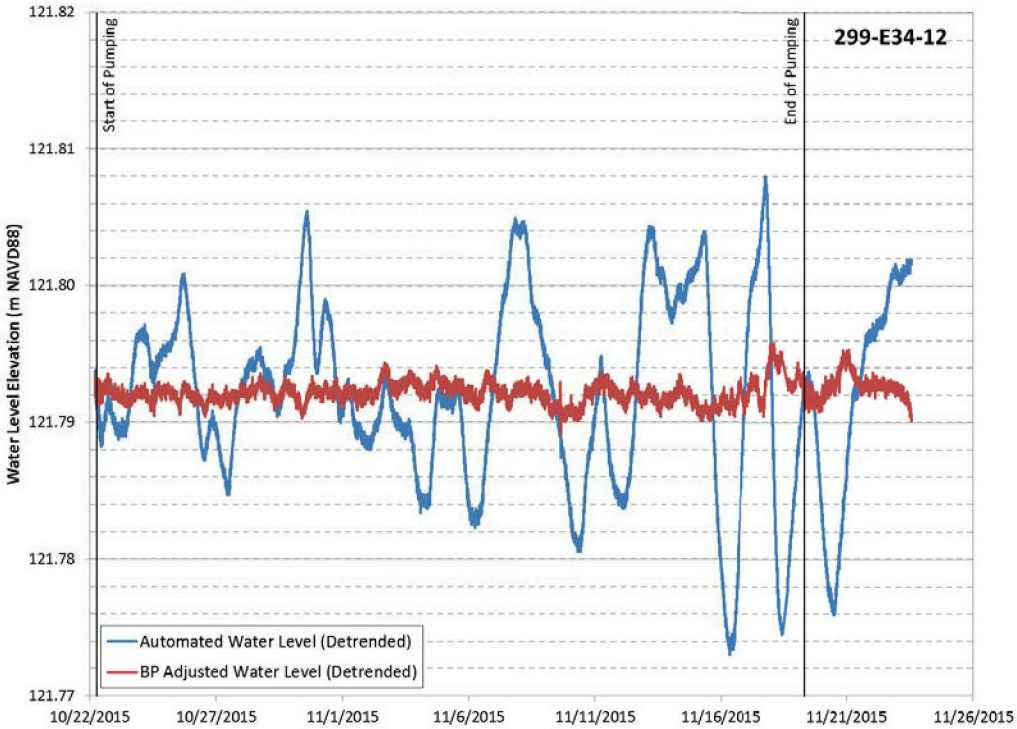

Figure E-10. Automated Water Level Measurements Collected for Well 299-E34-12 (951 m [3,120 ft] East-Southeast of the Pumping Well) during the 27-Day Constant Rate Discharge Test (Detrended)

Appendix F
AQTESOLV Results for the 27-Day Constant Rate Discharge Test - Drawdown

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This appendix provides the curves matched to the drawdown data from the 27-day constant rate discharge test conducted between 10/22/2015 and 11/18/2015. The pumping well was 299-E33-268 and drawdown was observed in observation wells 299-E33-31, 299-E33-267, and 299-E33-342. Pressure derivatives for these 4 wells are also provided.

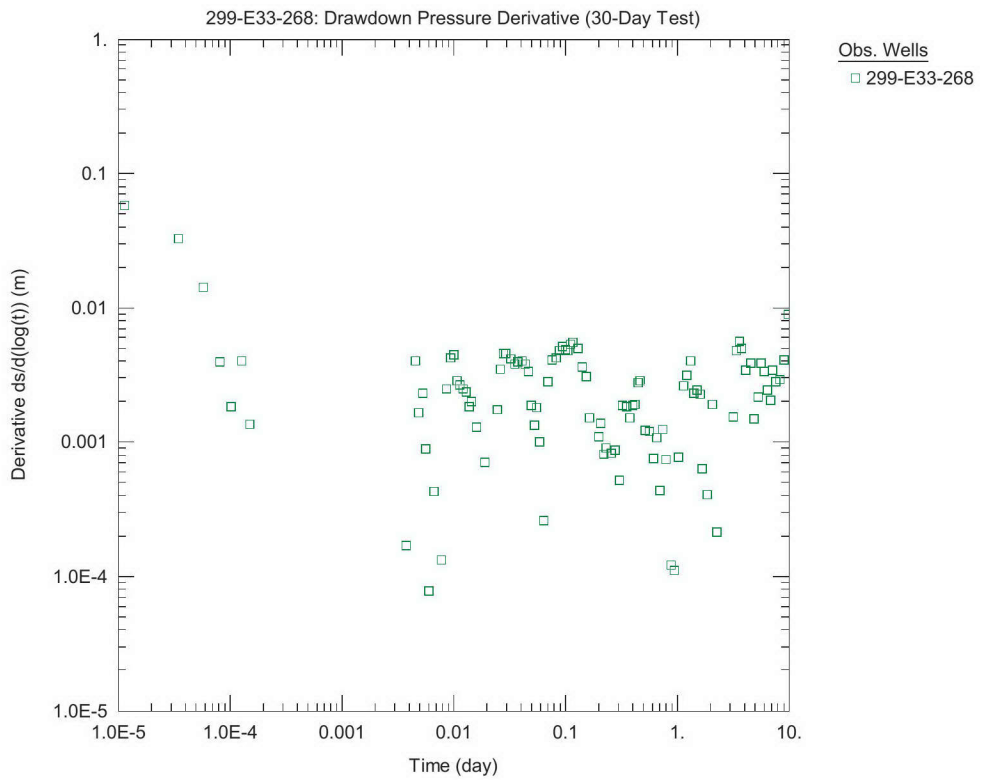

Figure F-1. AQTESOLV Pressure Derivative for Drawdown at 299-E33-268 (Pumping Well).

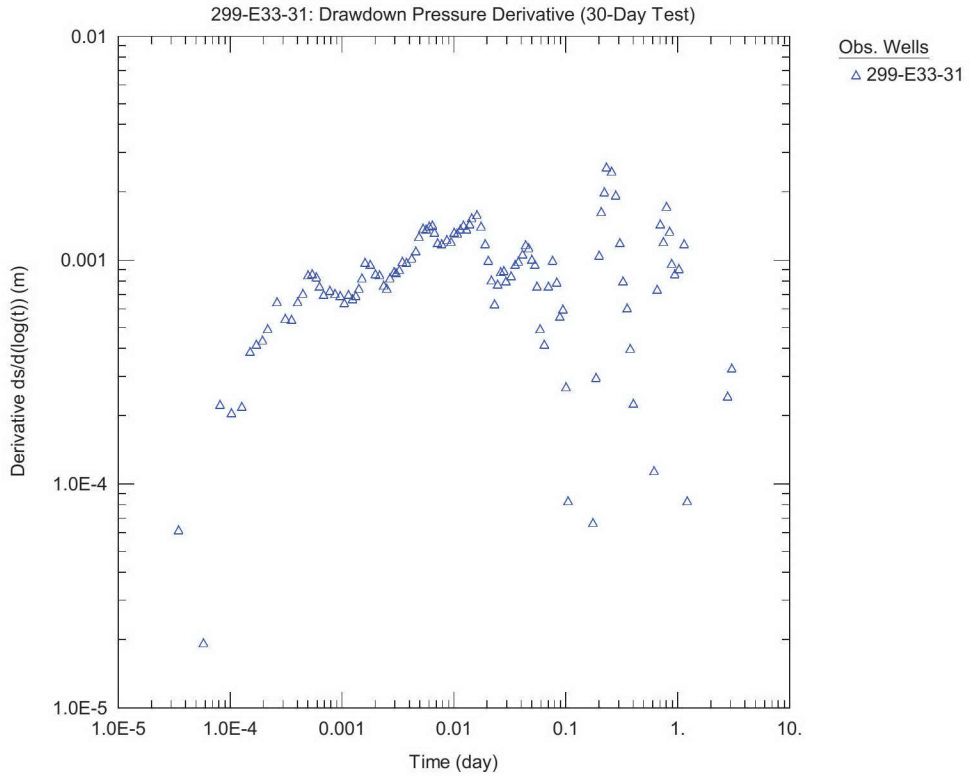

Figure F-2. AQTESOLV Pressure Derivative for Drawdown at 299-E33-31.

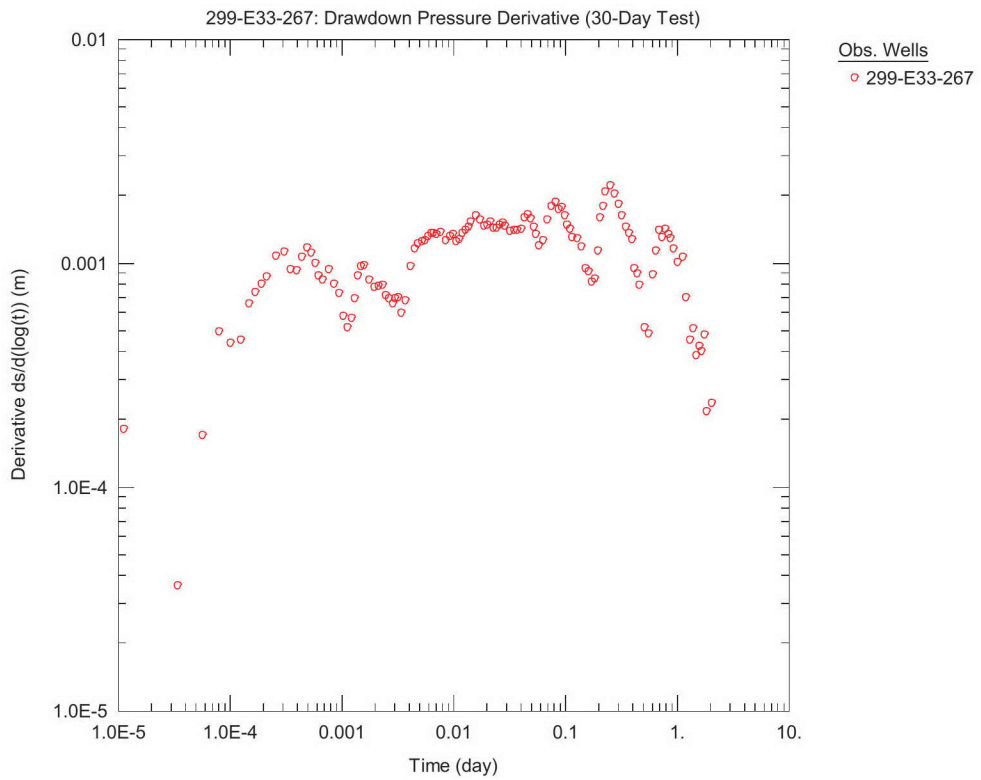

Figure F-3. AQTESOLV Pressure Derivative for Drawdown at 299-E33-267.

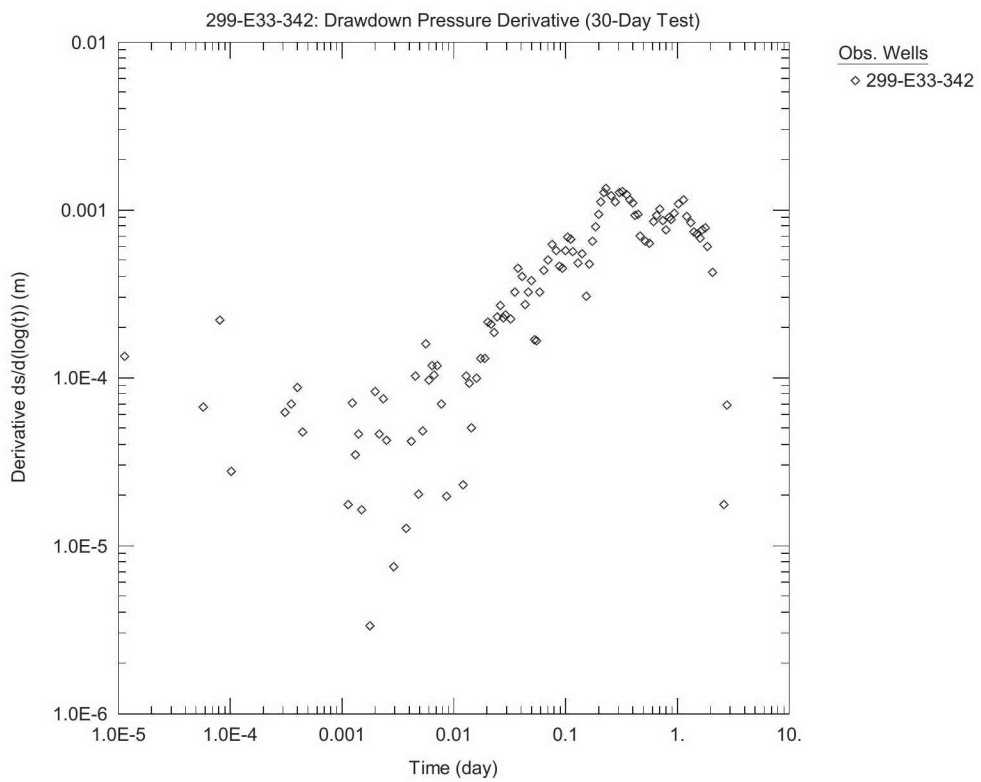

Figure F-4. AQTESOLV Pressure Derivative for Drawdown at 299-E33-342.

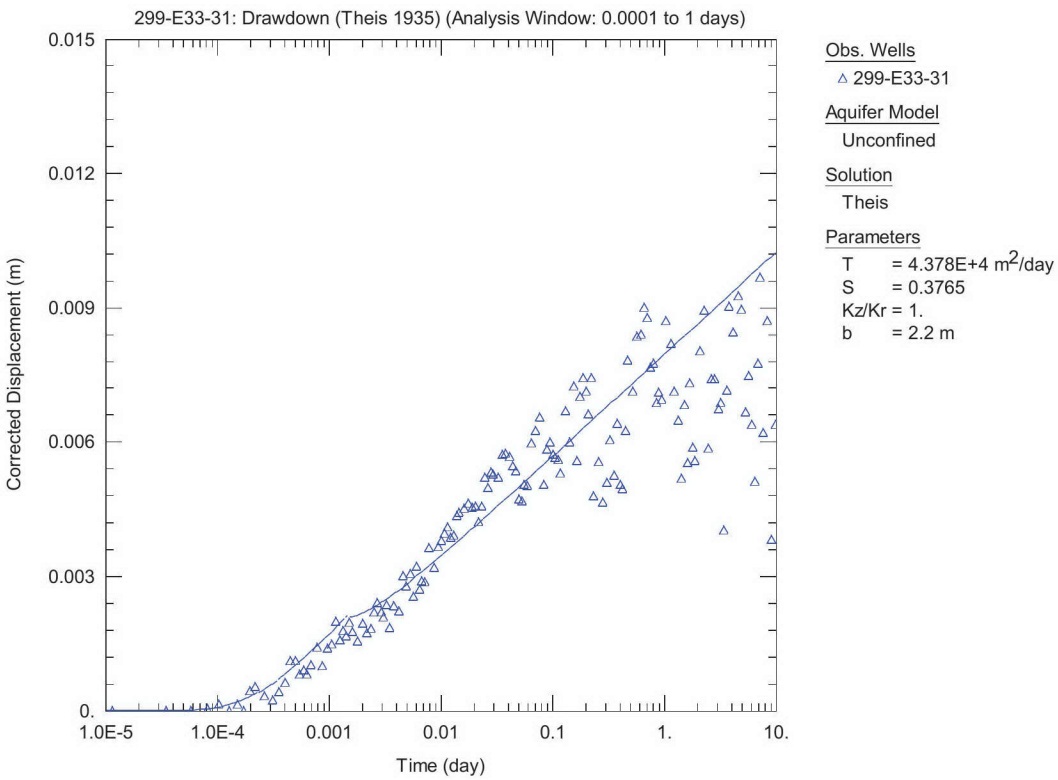

Figure F-5. AQTESOLV Results for Drawdown at 299-E33-31 by the Theis (1935)/Hantush (1961a,b) Method.

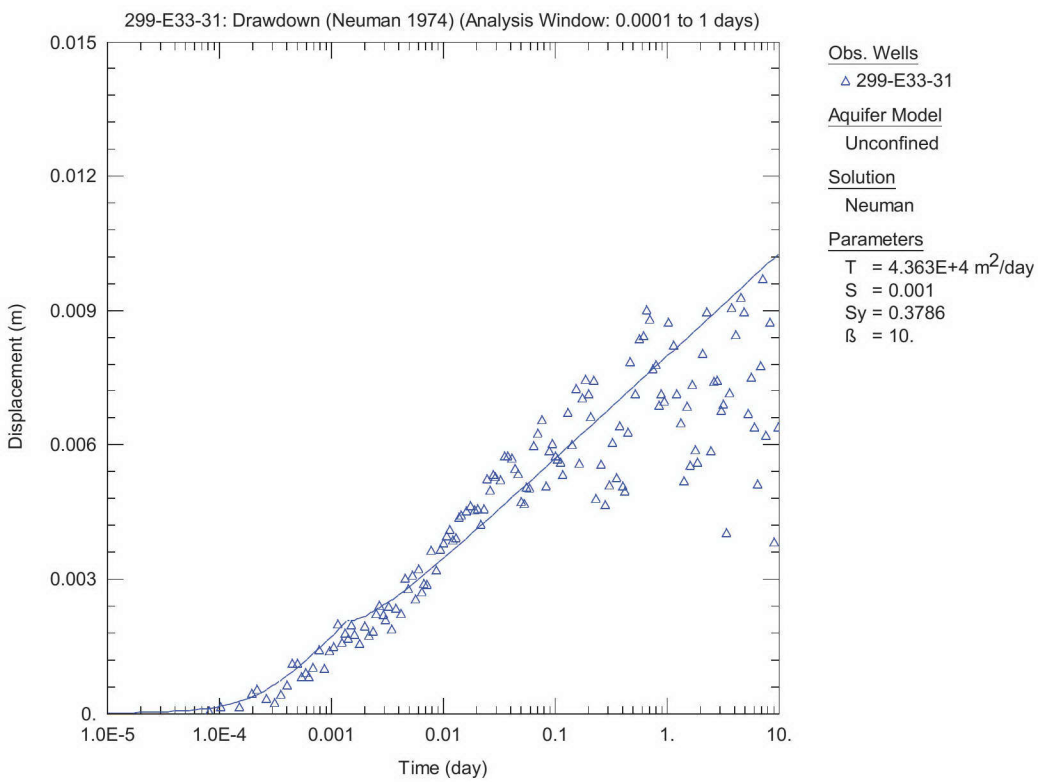

Figure F-6. AQTESOLV Results for Drawdown at 299-E33-31 by the Neuman (1974) Method.

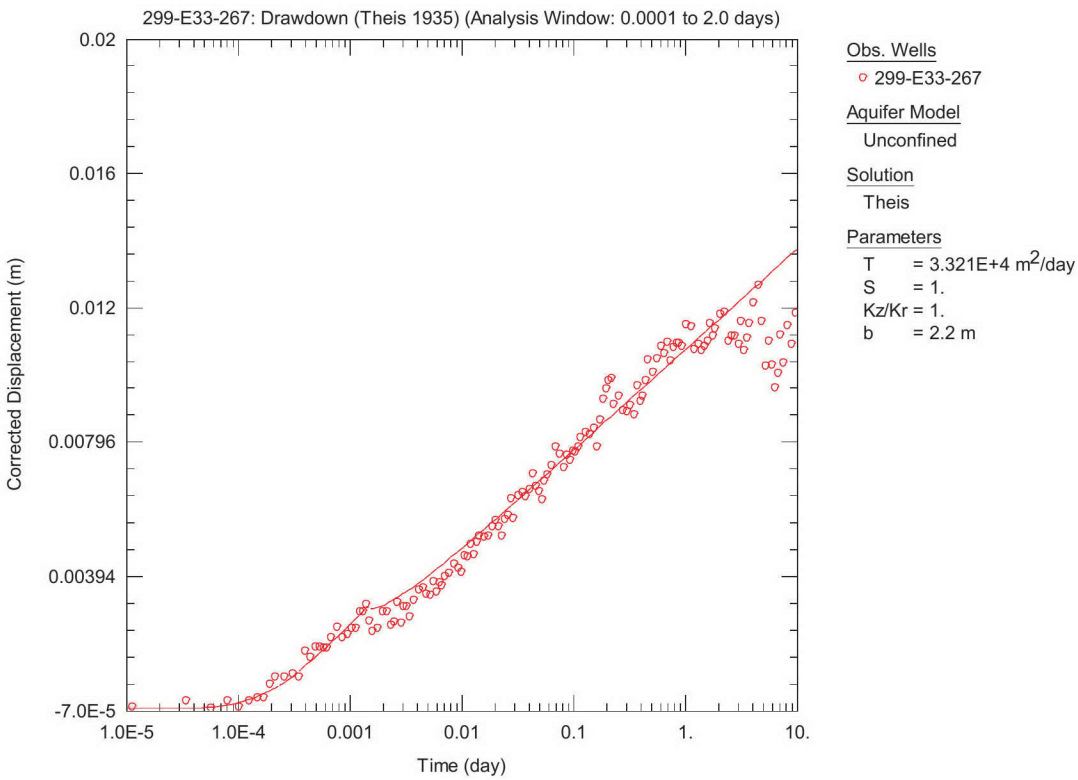

Figure F-7. AQTESOLV Results for Drawdown at 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

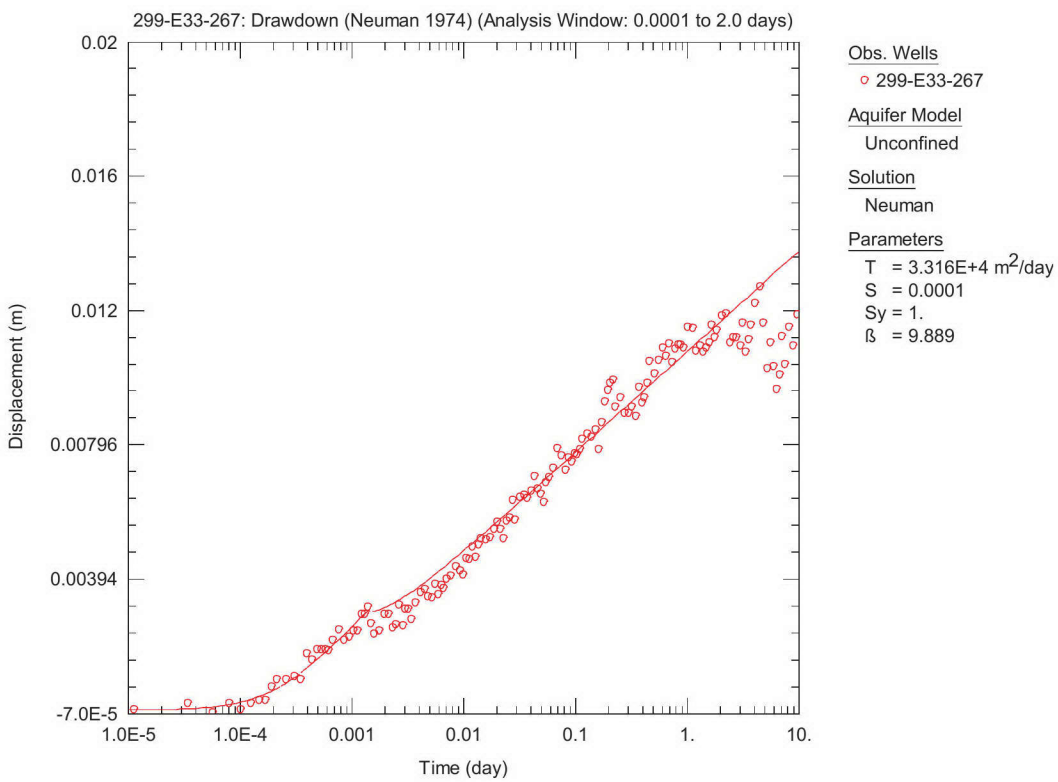

Figure F-8. AQTESOLV Results for Drawdown at 299-E33-267 by the Neuman (1974) Method.

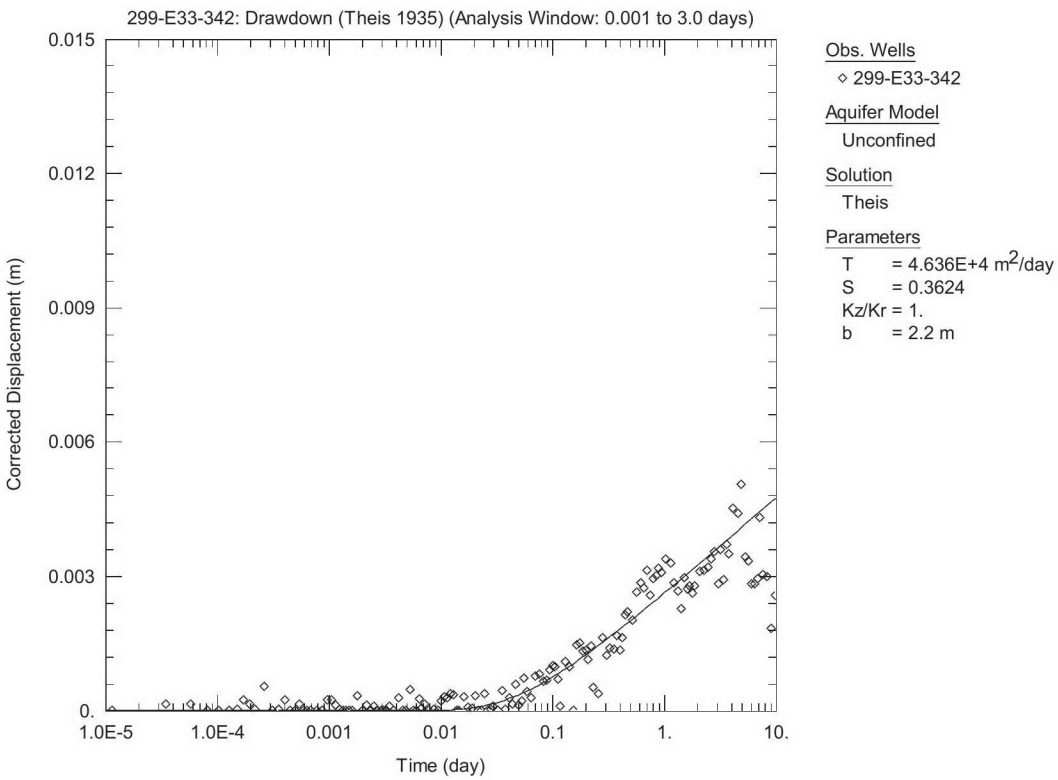

Figure F-9. AQTESOLV Results for Drawdown at 299-E33-342 by the Theis (1935)/Hantush (1961a,b) Method.

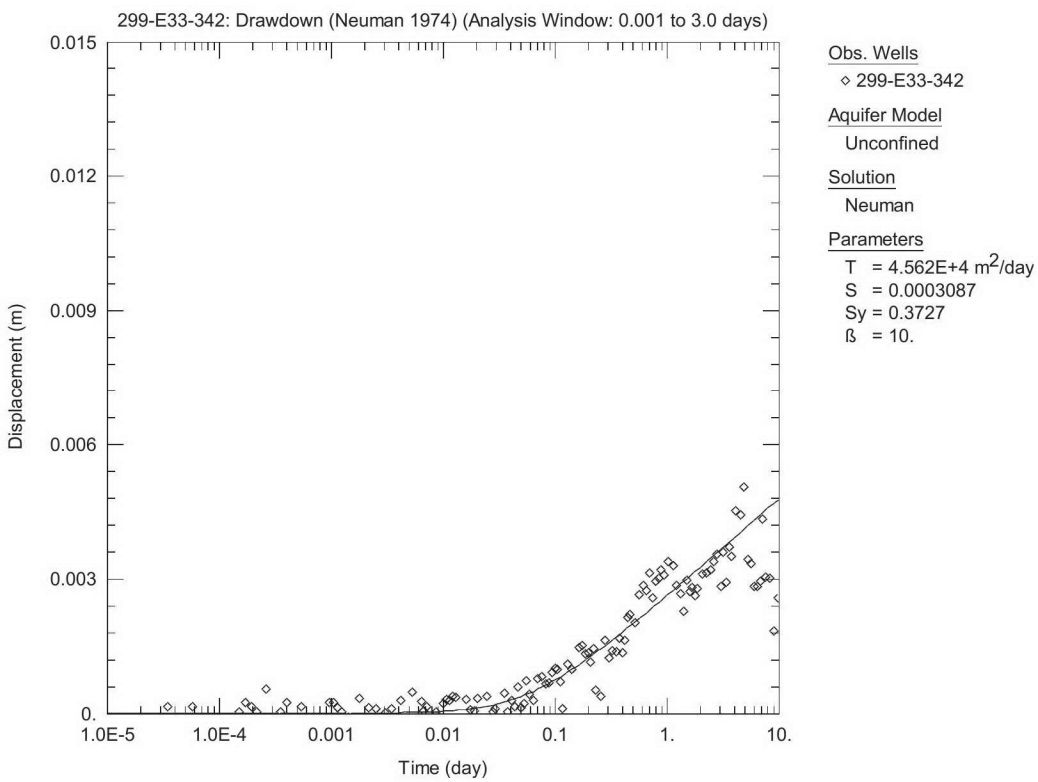

Figure F-10. AQTESOLV Results for Drawdown at 299-E33-342 by the Neuman (1974) Method.

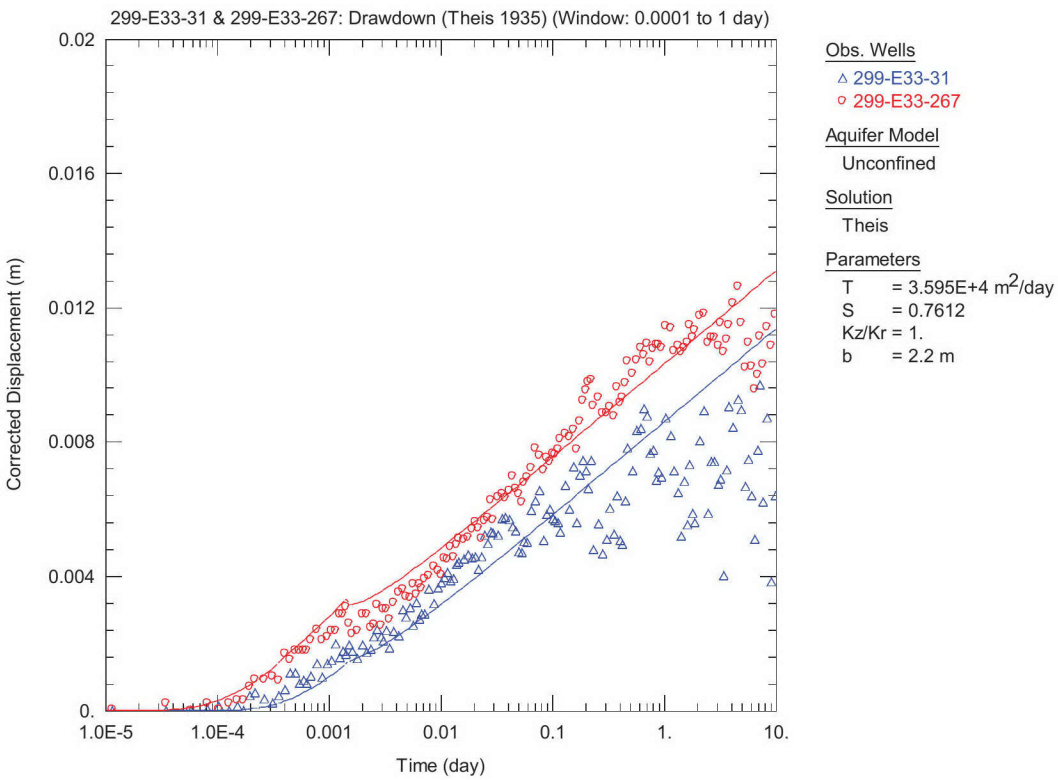

Figure F-11. AQTESOLV Results for Drawdown at 299-E33-31 and 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

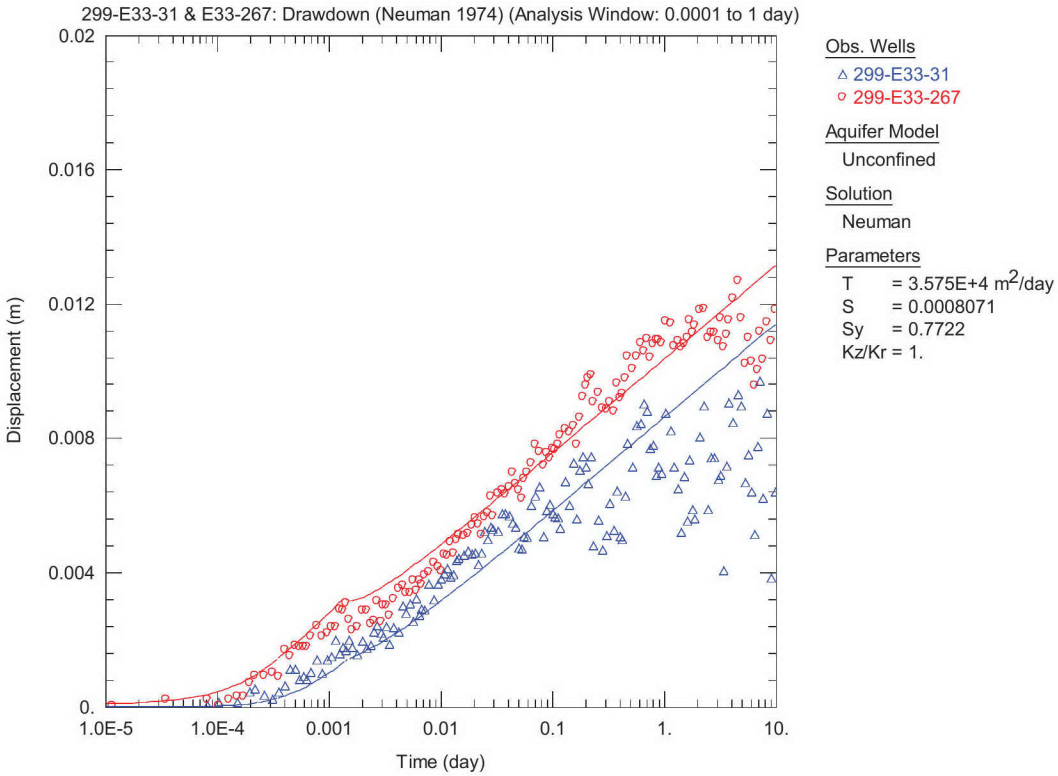

Figure F-12. AQTESOLV Results for Drawdown at 299-E33-31 and 299-E33-267 by the Neuman (1974) Method.

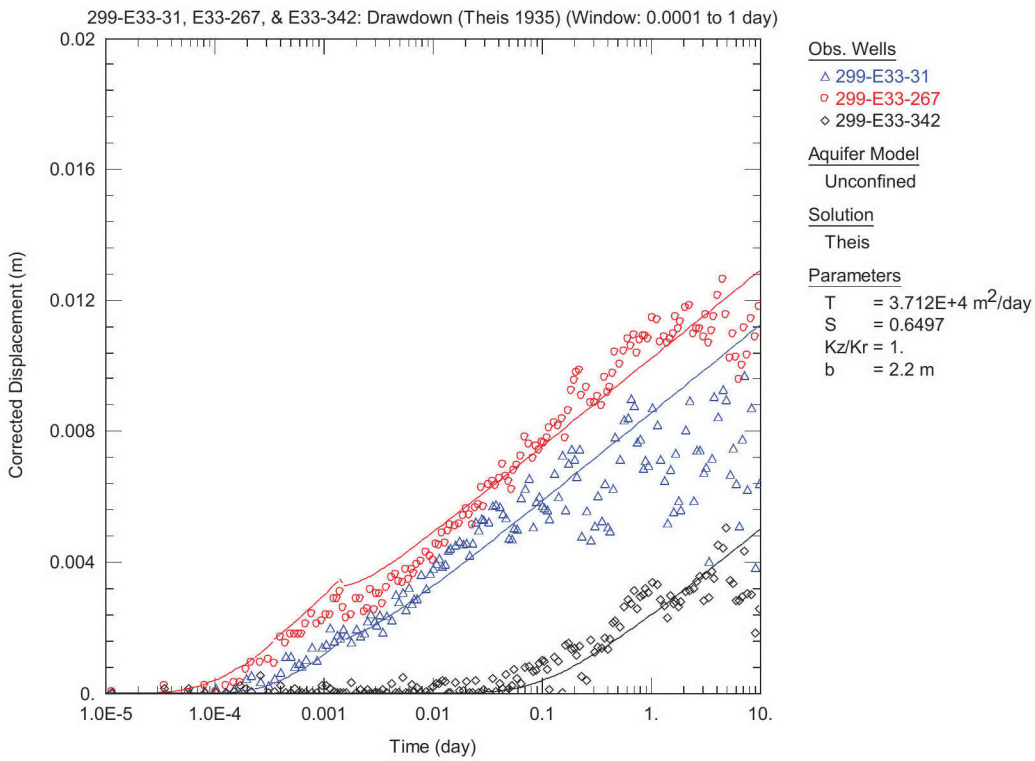

Figure F-13. AQTESOLV Results for Drawdown at 299-E33-31, 299-E33-267, and 299-E33-342 by the Theis (1935)/Hantush (1961a,b) Method.

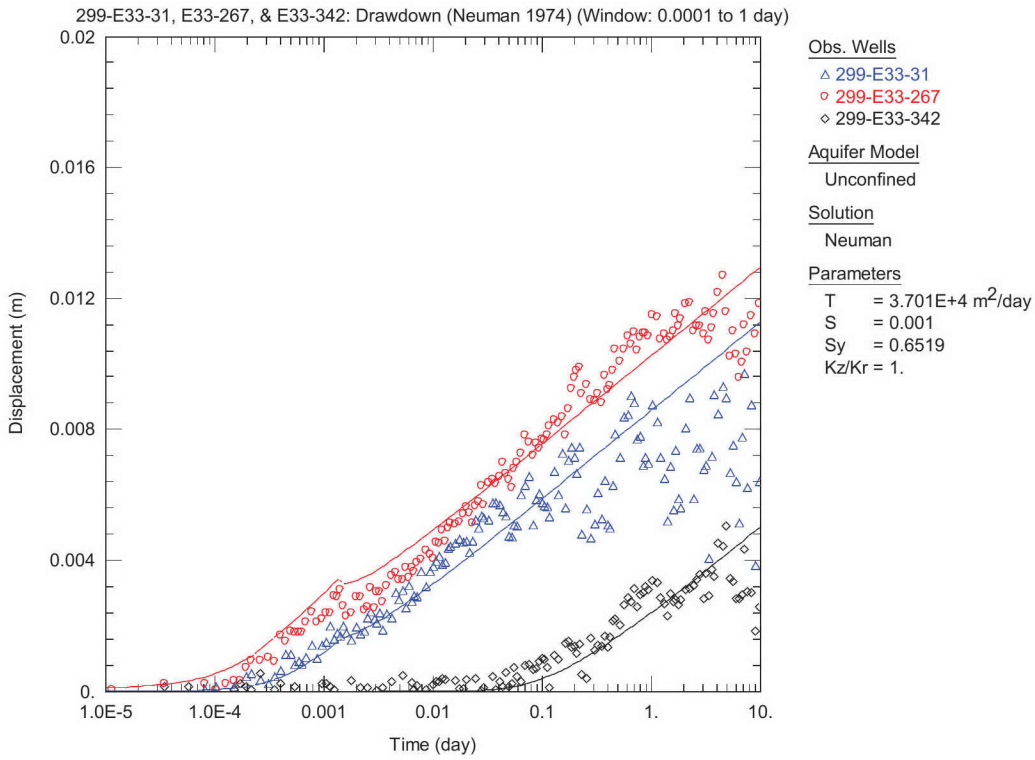

Figure F-14. AQTESOLV Results for Drawdown at 299-E33-31, 299-E33-267, and 299-E33-342 by the Neuman (1974) Method.

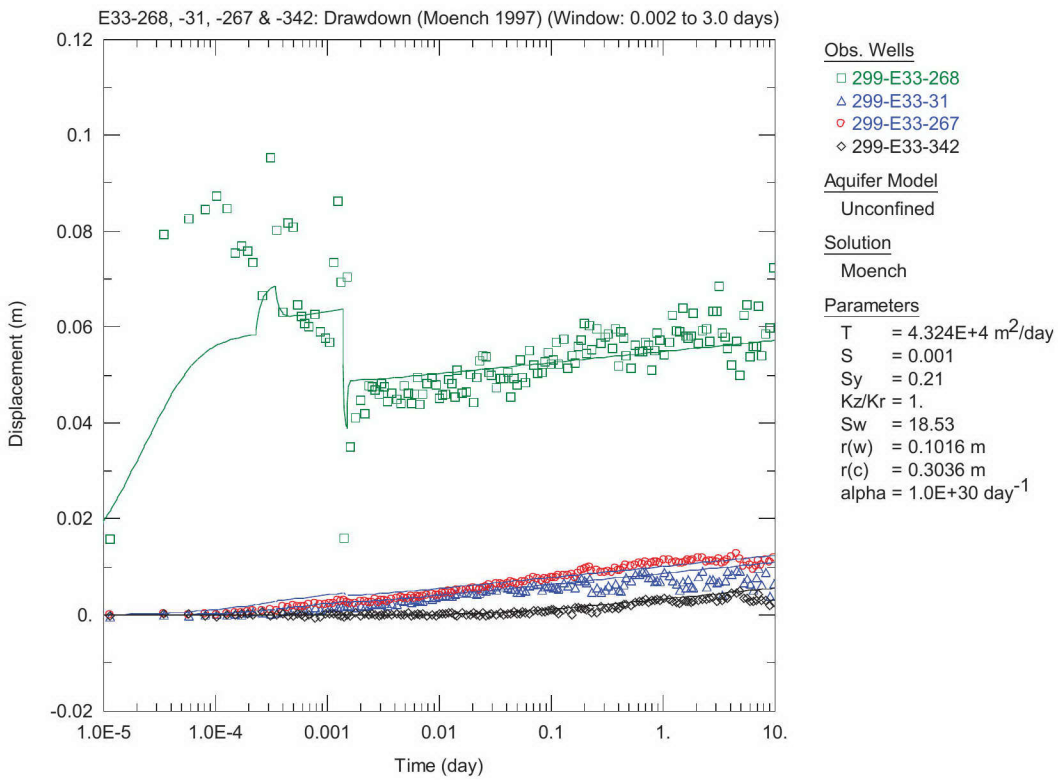

Figure F-15. AQTESOLV Results for Drawdown at Pumping Well 299-E33-268 and Observation Wells 299-E33-31, 299-E33-267, and 299-E33-342 by the Moench (1997) Method.

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Appendix G
AQTESOLV Results for the 27-Day Constant Rate Discharge Test - Recovery

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This appendix provides the curves matched to the recovery data from the 27-day constant rate discharge test conducted between 10/22/2015 and 11/18/2015. Because drawdown was observed in observation wells 299-E33-31, 299-E33-267, and 299-E33-342, these wells were analyzed for buildup.

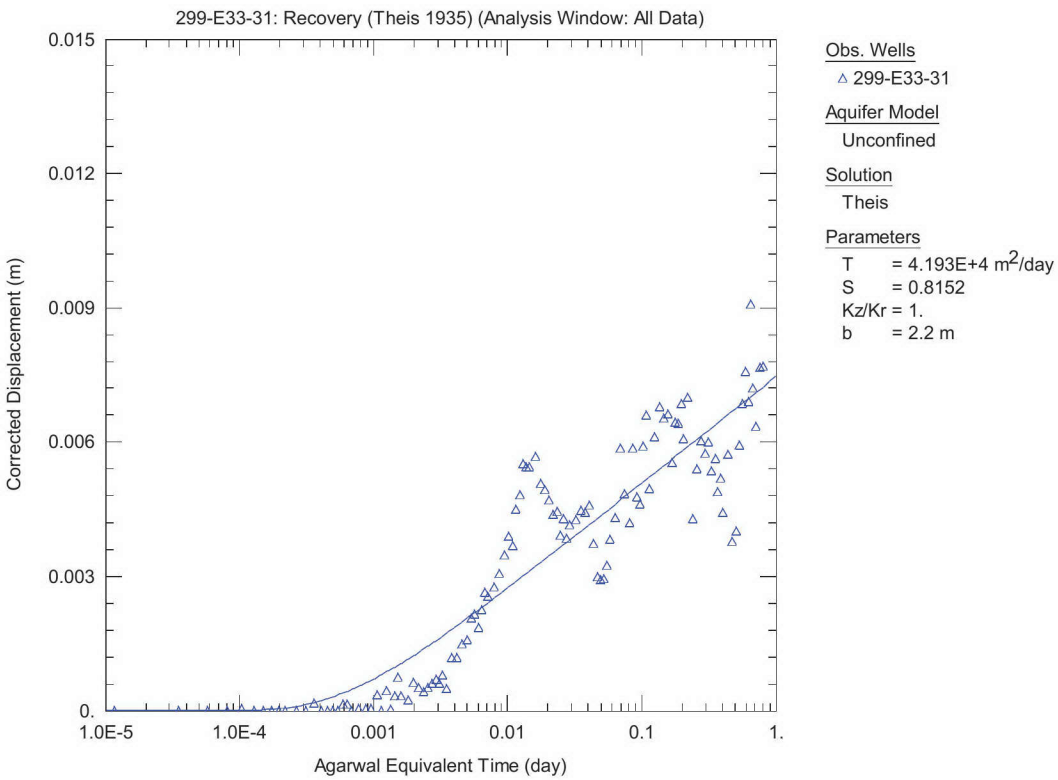

Figure G-1. AQTESOLV Results for Recovery at 299-E33-31 by the Theis (1935)/Hantush (1961a,b) Method.

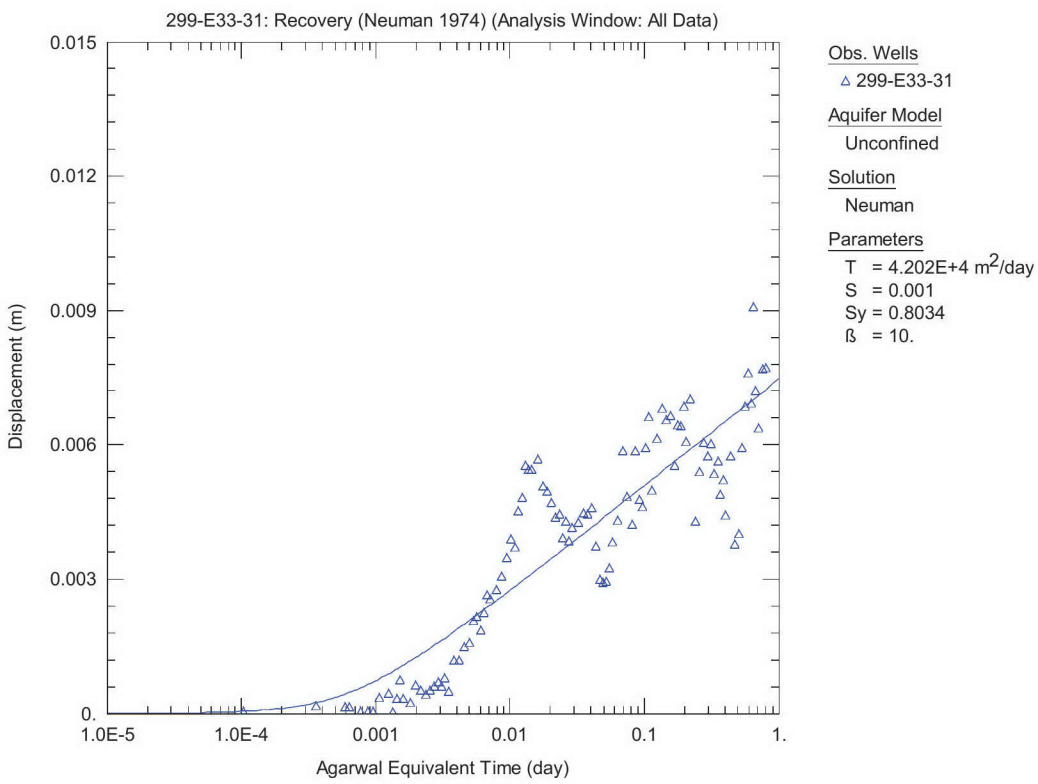

Figure G-2. AQTESOLV Results for Recovery at 299-E33-31 by the Neuman (1974) Method.

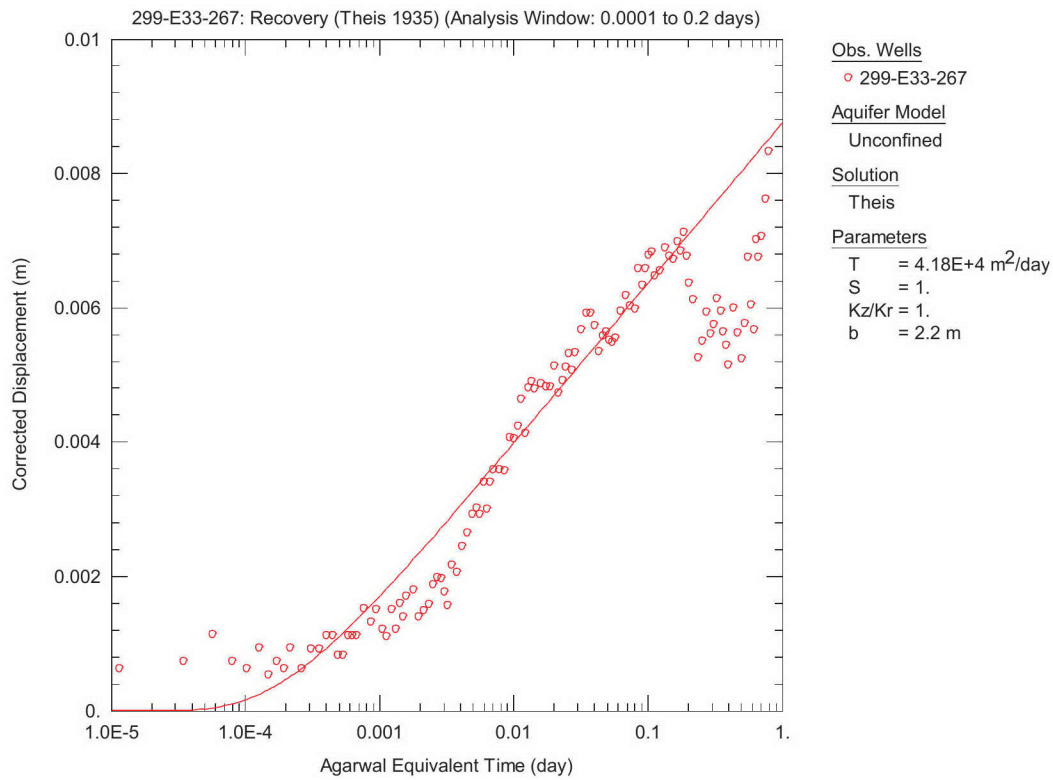

Figure G-3. AQTESOLV Results for Recovery at 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

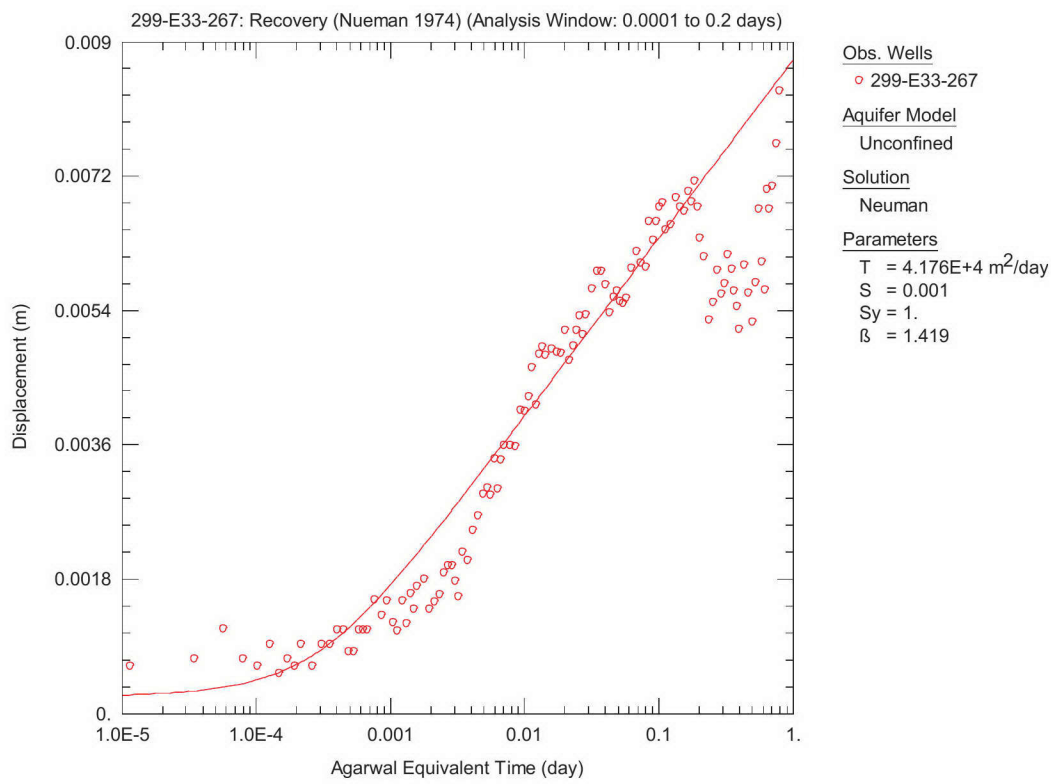

Figure G-4. AQTESOLV Results for Recovery at 299-E33-267 by the Neuman (1974) Method.

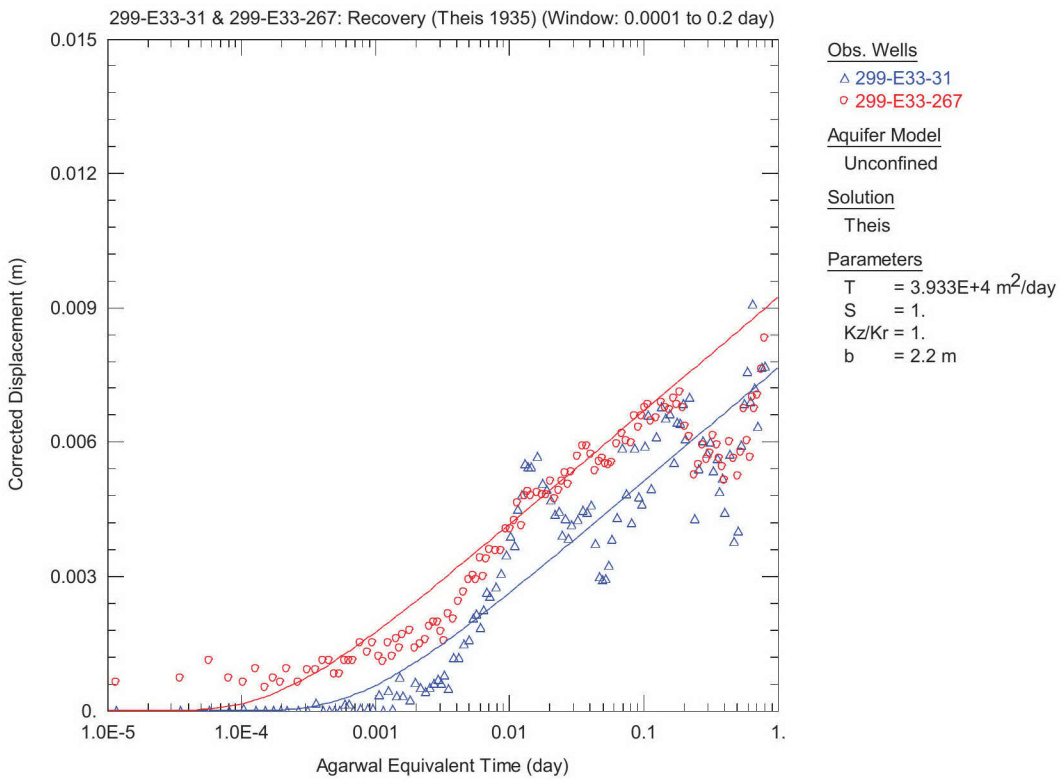

Figure G-5. AQTESOLV Results for Recovery at 299-E33-31 and 299-E33-267 by the Theis (1935)/Hantush (1961a,b) Method.

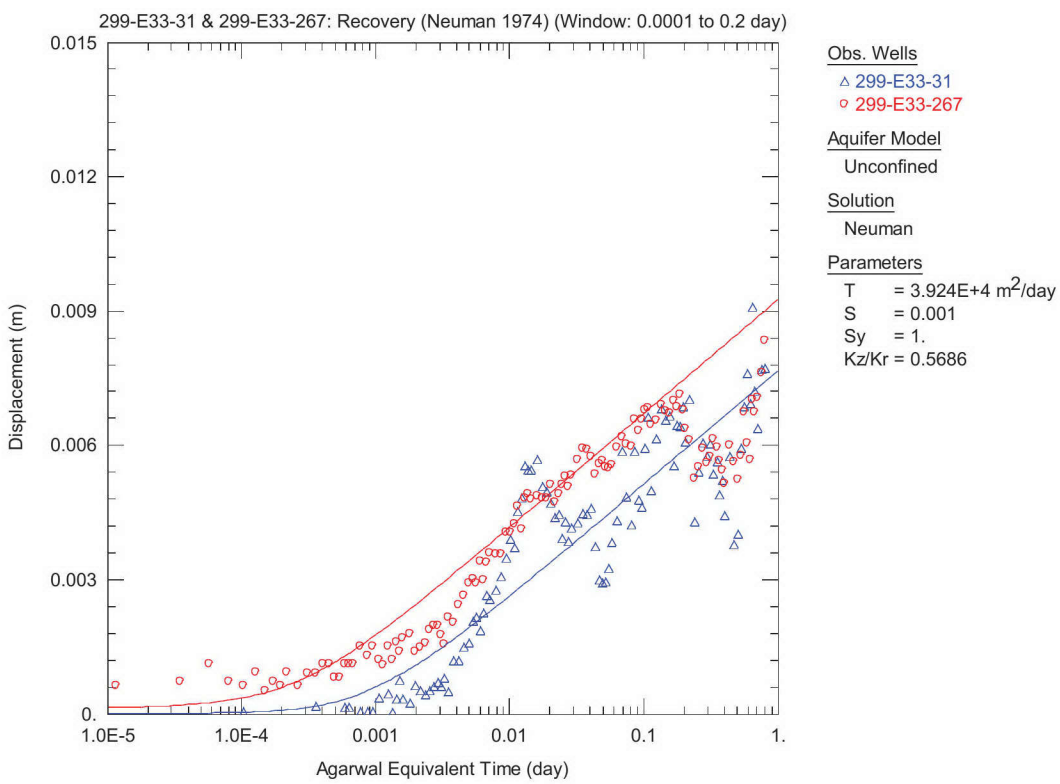

Figure G-6. AQTESOLV Results for Recovery at 299-E33-31 and 299-E33-267 by the Neuman (1974) Method.

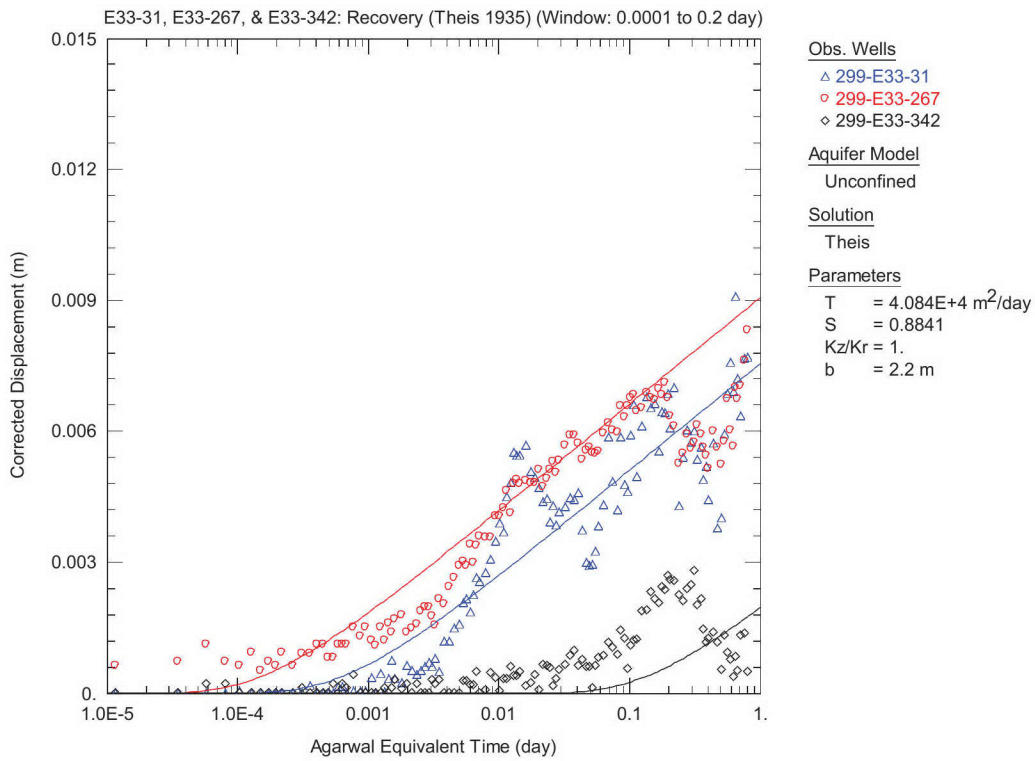

Figure G-7. AQTESOLV Results for Recovery at 299-E33-31, 299-E33-267, and 299-E33-342 by the Theis (1935)/Hantush (1961a,b) Method.

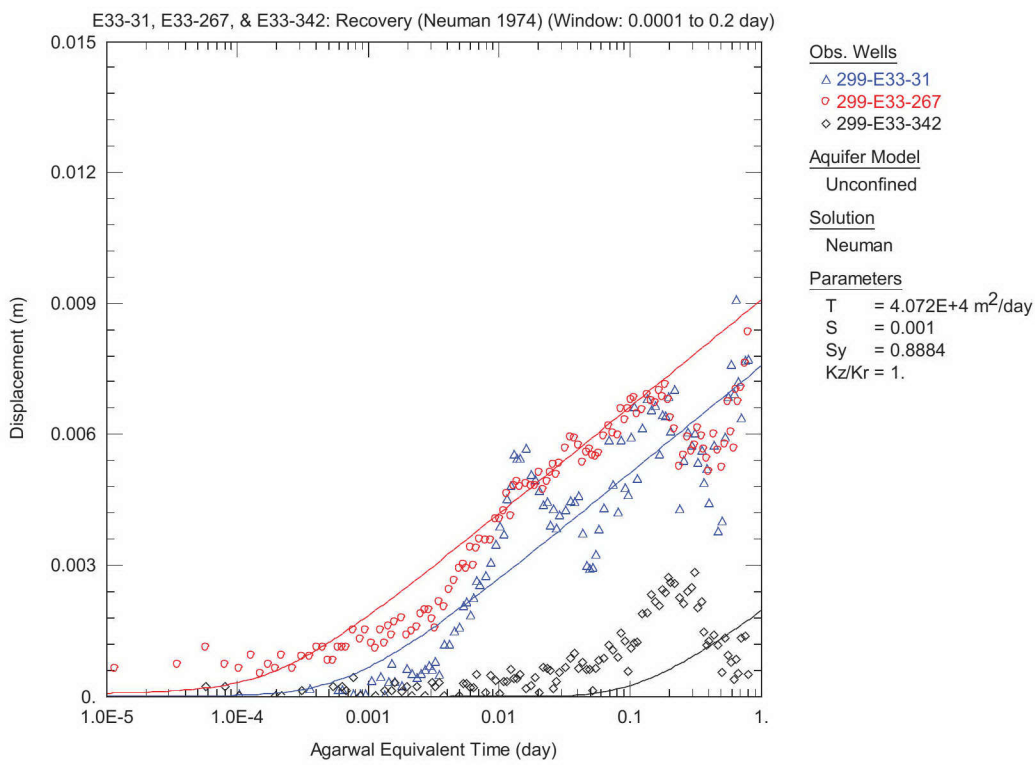

Figure G-8. AQTESOLV Results for Recovery at 299-E33-31, 299-E33-267, and 299-E33-342 by the Neuman (1974) Method.

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Appendix B

200-BP-5 Treatability Test Technical Support Capture Zone Analysis

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APRIL 2016

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200-BP-5 Treatability Test Technical Support Capture Zone Analysis

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

P.O. Box 1600
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From: Greg Ruskauff <GRuskauff@intera.com>
Sent: Wednesday, January 20, 2016 12:27 PM
To: Nichols, William E
Subject: ECF

Follow Up Flag: Follow up
Flag Status: Flagged

Categories: CHPRC

The B complex ECF is nearly done – as senior reviewer I agreed the methodology and results were fine. There were a few editorial items I found that Helal is fixing. I can sign the form and FAX I suppose, but can you sign for me?

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Environmental Calculation File

200-BP-5 Treatability Test Technical Support Capture Zone Analysis

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Terms

BMC	B-Complex TMR model
CHD	constant head (the time-variant specified-head package of MODFLOW used to simulate specified head boundaries that can change within or between stress periods)
ECF	environmental calculation file
FS	Feasibility Study
F&T	fate and transport
HFB	horizontal flow barrier (the horizontal flow barrier package of MODFLOW used to simulate barriers to flow by reducing the conductance between individual pairs of cells)
HISI	Hanford Information System Inventory (database)
P2R	Plateau to River (model)
P&T	pump-and-treat
REC	remediation evaluation case
RI	Remedial Investigation
TEDF	Treated Effluent Disposal Facility
TMR	telescopic mesh refinement

1 Purpose

A local area submodel of the Plateau-to-River (P2R) Model was developed with telescopic mesh refinement (TMR) and used to simulate drawdowns and capture zones of extraction wells in the vicinity of the B-Complex for different P&T scenarios. The drawdown and capture zone analyses were performed to ensure that the P&T remedial actions under consideration are hydraulically feasible.

A pumping test was carried out in well 299-E33-268 to evaluate the hydraulic properties of the Hanford and Cold Creek formations in the vicinity of the B-complex. Drawdown equilibrated after only 3 days due to the high transmissivity of the aquifer. The test analysis resulted in minimum, average, and maximum estimates of hydraulic conductivity and specific yield.

The purpose of this environmental calculation file (ECF) is to evaluate the drawdowns simulated with the TMR model by comparison to the drawdowns observed in the 3-day pumping test, and subsequently evaluate drawdowns and capture zones assuming 5 years of pumping in well 299-E33-268. The drawdown analyses performed for the 3-day pumping test are carried out through comparison to drawdown in well 299-E33-268 as well as drawdowns in a number of observation wells located inside and around the B-Complex. Three parameter sets of hydraulic conductivity and specific yield are used corresponding to the minimum, average, and maximum values derived from the pumping test. The same parameter sets are then used to evaluate drawdowns and capture zones for a 5-year pumping period and assuming three different scenarios corresponding to low, medium, and high pumping rate.

2 Background

A detailed description of the site background is provided in Chapter 3 of DOE/RL-2009-127, Draft A.

3 Methodology

The methodology for developing a TMR MODFLOW model is outlined in Leake and Claar (1999). The basic concept consists of using a numerical model with a relatively large domain and extracting simulated outputs from that model to develop the model inputs for a model with a relatively smaller domain where more detailed model discretization is desired. The boundary conditions for the sub-domain model are extracted from simulated results of the larger model. This method provides consistency between the larger domain and the sub-domain and allows the model to be used more efficiently for investigating local scale issues (Leake and Claar, 1999).

Calculations are performed using the TMR model extracted from the P2R numerical F&T model as described in ECF-200BP5-15-0009, *Evaluation of Plume Capture and Hydraulic Performance for B-Complex Vicinity Submodel for 200-BP-5 and 200-PO-1 Operable Units Feasibility Study Evaluation of Remedial Alternatives.* Both the P2R and the B-Complex TMR models are implemented in MODFLOW to calculate groundwater flow. The TMR model spans the B-Complex and Gable Gab evaluation areas of the P2R Model. In general, an investigated scenario is simulated with the P2R Model and the calculated hydraulic heads are mapped on the TMR model boundaries to create the boundary conditions for the TMR. Similarly, initial hydraulic heads for the TMR model are extracted from the parent P2R simulation. Flow properties are extracted from the P2R Model and mapped onto the corresponding TMR model grid blocks. As discussed in Section 7, the P2R Model corresponding to the no-action scenario was used to parent all of the TMR simulations. Accordingly, flow properties were changed in the TMR model variants alone without re-running the parent P2R Model. A comparison of this approach to TMR models that were derived from P2R Model variants that take into account pumping scenarios as well as modified flow properties is also discussed in Section 7.

4 Assumptions and Inputs

4.1 Model Domain

The spatial discretization of the TMR Model is selected to provide as accurate a representation as possible of the drawdown and capture zone while allowing the model to produce results in a reasonable time. To this end, variable horizontal gridding was applied, with model nodes separated by 2 m in the vicinity of preliminary extraction and injection well locations and extending as far as 200 m elsewhere. Figure 4-1 shows the TMR grid. Layer elevations from the P2R Model were then interpolated bi-linearly on the TMR grid. Figure 4-2 shows a comparison between the parent P2R Model and the TMR model.

4.2 Simulation Periods

The simulations with the TMR model comprise two groups: (1) simulations carried out for comparison to the 3-day pumping test, and (2) simulations carried out for the evaluation of the 5-year pumping scenario. The simulated timeframes are selected accordingly.

Simulating the 3-day pumping test was performed by first computing a steady-state period to be sure there are no artificial transient effects. A 3 day transient stress period is then simulated with the test pumping rate, and then another transient period is simulated to represent the recovery phase after pumping stopped.

The 5-year pumping scenario was simulated by first computing a steady-state stress period. Each subsequent year is simulated with 8 transient stress periods, each simulated with 6 time steps corresponding to two-month increments.

4.3 Processes Simulated and Limitations to the Simulation

The MODFLOW/MT3DMS family of numerical groundwater simulators estimates groundwater flow and fate and transport based using packages that represent certain processes occurring in nature. For this simulation the processes and corresponding simulation packages are shown in Table 4-1. The table includes any limitations that the implementation of the particular package in MODFLOW/MT3DMS may impose on the model.

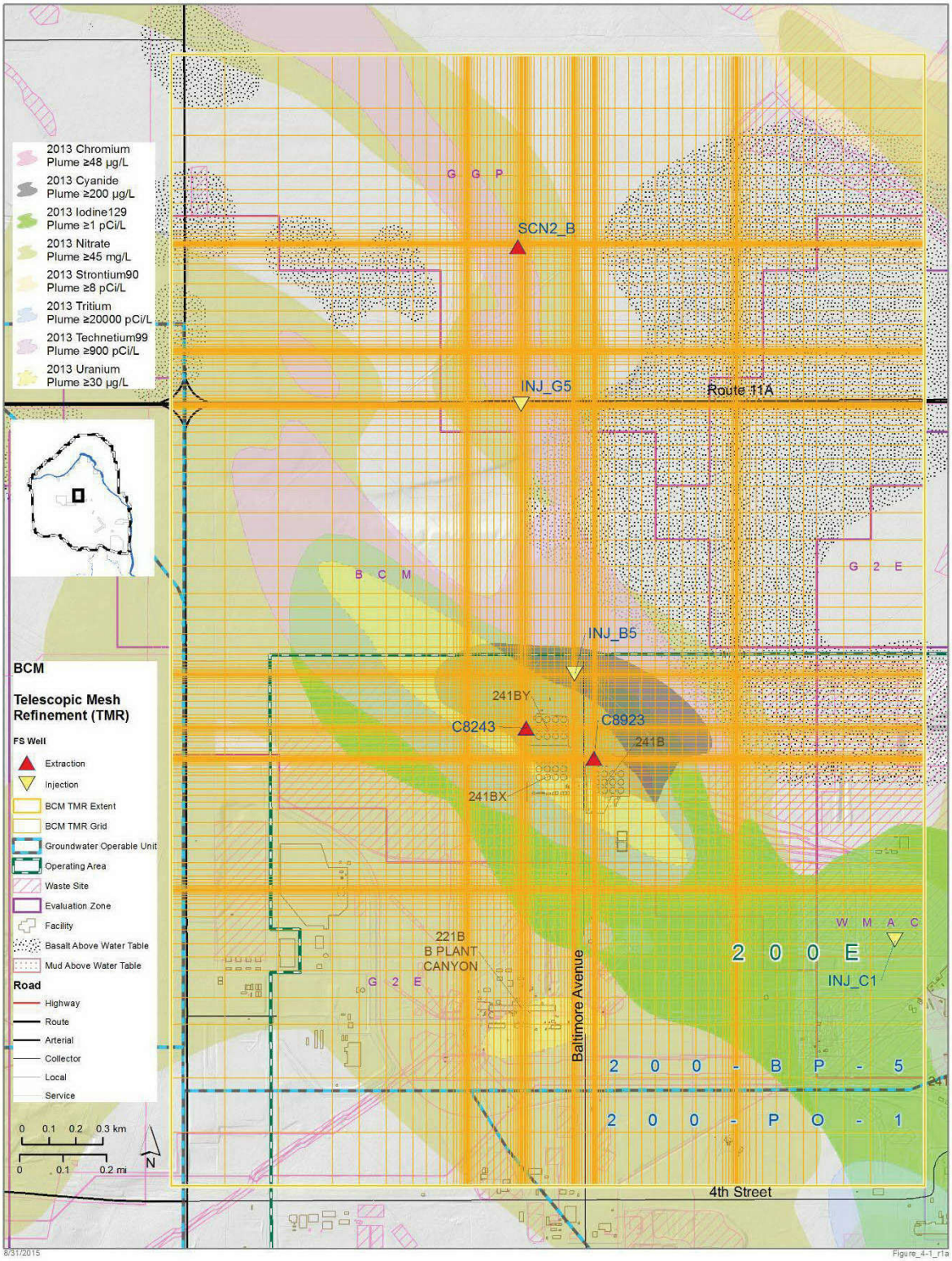


Figure 4-1. B-Complex TMR Model Extent

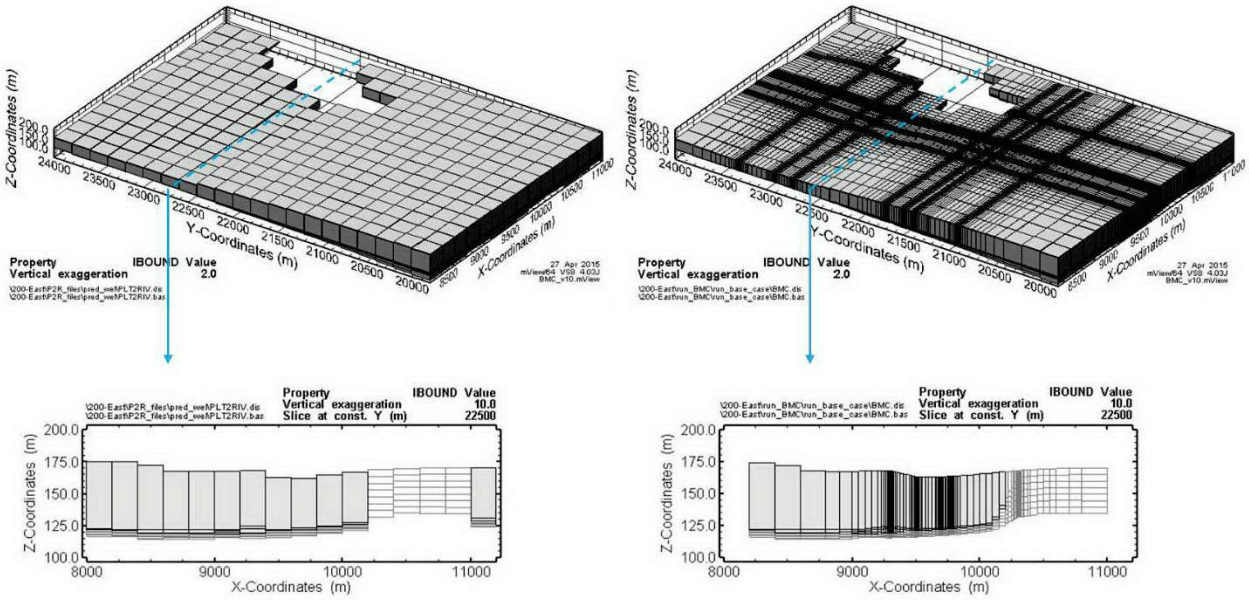


Figure 4-2 Comparison between P2R Model (left) and B-Complex TMR Model Mesh (right)

Table 4-1. Groundwater Processes, Simulated Packages, and Limitations for the P2R Model

Groundwater Process		MODFLOW/MT3DMS Package	Limitations (if any)
Groundwater Flow	Recharge	Recharge Package	Considered recharge that arrives at the groundwater
	Columbia River	River Package	
	Injection/Extraction	Well Package	No multiwell interaction
	Head at model boundaries	CHD package	Assessment of remedial alternatives that effect flow of water should be sufficiently far from boundaries as to not significantly influence flow through the CHD boundaries
	May Junction Fault	HFB Package	

4.4 Hydrostratigraphy of the Unconfined Aquifer

The geologic representation for the model is derived from the Hanford South Geoframework Model (HSGM) (ECF-Hanford-13-0029, *Development of the Hanford South Geologic Framework Model, Hanford Site, Washington*). The HSU definitions presented in ECF-Hanford-13-0029 include the Hanford and Cold Creek formations and the Ringold formation with the Taylor Flat, Unit E, Upper Mud, and Unit A members of that formation. Seven model layers are used to represent the seven HSUs are defined in the HSGM. Assignment of a numerical cell to an HSU is not dependent on model layer. The details regarding the assignment of HSUs to model layers are recorded in CP-57037, *Plateau to River Groundwater Transport Model Package Report*. The hydraulic properties of the HSUs in the P2R Model were estimated through model calibration as described in CP-57037.

The assignment of the HSUs in the B-Complex TMR was carried out by identifying and mapping the HSUs from the P2R Model onto the TMR grid for each layer. The HSUs per model layer in the TMR are shown in Figure 4-3. In the largest part of the model, the Hanford and Cold Creek formations corresponding to the paleo-channel lie directly above the basalt. Ringold Unit A is present below the Hanford/Cold Creek formation in the south, whereas Ringold Unit E and Ringold mud HSU's are only locally present at the south corners of the model. The hydraulic properties were then assigned to each HSU in the TMR using the values from the P2R Model calibration as shown in Figure 4-3. Furthermore, Figure 4-4 shows cross-sections of horizontal hydraulic conductivity in the west-east direction for Y = 21,000 and Y = 23,000 m, and in the north-south direction for X = 9,000 and X = 10,300 m. White cells with gray edges denote inactive cells of the basalt. It is indicated that the hydrostratigraphy in the TMR model domain is dominated by the high-permeability Hanford/Cold Creek formation (K = 17,000 m/d). Bottom elevations of the Hanford/Cold Creek formation range approximately between 110 and 120 m in the central part of the model. The north-south cross-sections indicate that the Hanford/Cold Creek formation dips in the northernmost part of the model, and in the south where it contacts the underlying Ringold units. Bottom elevations are somewhat higher in the north, where the thickness of the Hanford/Cold Creek formation decreases.

4.5 Boundary Conditions

The boundary conditions for the numerical model represent interactions with the aquifer by water external to the model. These include water infiltrating through the vadose zone that becomes recharge, movement to and from the Columbia River, liquid discharges from waste sites, and extraction and injection at well locations. Figure 4-5 illustrates the locations and types of boundary conditions used to construct the P2R Model. The details of each of these boundary conditions are discussed below.

4.5.1 Upper Boundary (Recharge)

The recharge boundary condition represents water that from the top surface of the model infiltrates through the vadose zone until reaching the saturated zone. This water can originate naturally or by anthropogenic sources such as waste site discharge. Each of these types of sources of recharge was included in the model using the MODFLOW Recharge package which represents recharge as a specified flux (i.e., second-type or Neumann) boundary condition.

Natural Recharge

The natural component of recharge includes water originating as precipitation and infiltration through the vadose zone that ultimately reaches the saturated zone as recharge.

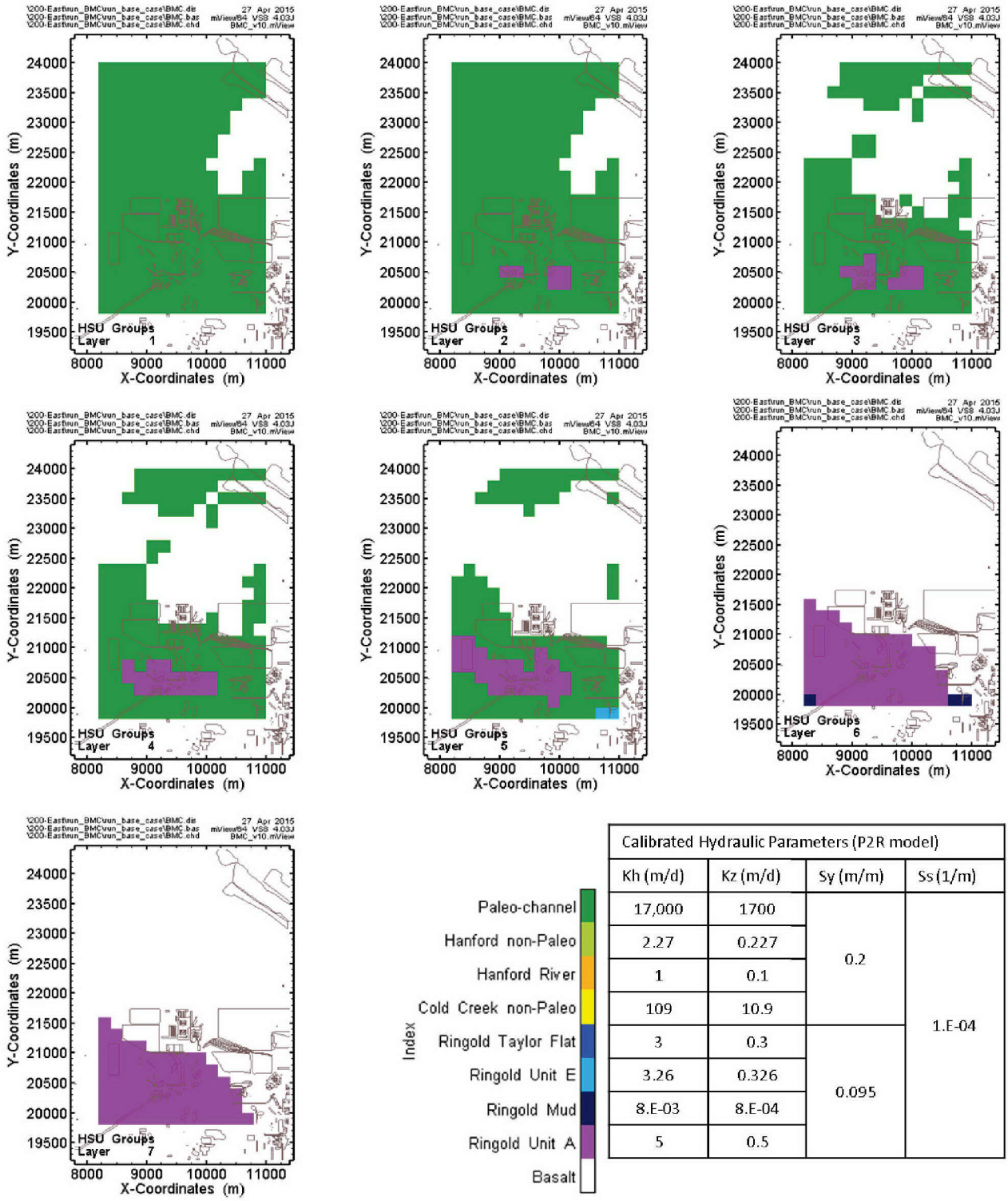
Anthropogenic Recharge

The anthropogenic component of recharge includes fluxes from surface water discharge due to operations at the Hanford Site, including the Treated Effluent Disposal Facility (TEDF).

The upper boundary conditions for the TMR model are extracted for each stress period from the P2R Model. Coordinates from the P2R Model grid faces coincide with grid faces in the finer TMR mesh, so that recharge values from the P2R Model are essentially mapped onto the first layer of the TMR grid. Figure 4-6 shows an example of recharge mapped from the P2R to the BMC TMR for the first stress period of the transient simulation.

4.5.2 Lower Boundary

The base of the numerical model (bottom of model layer 7) is simulated as a no-flow boundary.



Calibrated Hydraulic Parameters (P2R model)			
Kh (m/d)	Kz (m/d)	Sy (m/m)	Ss (1/m)
17,000	1700	0.2	1.E-04
2.27	0.227		
1	0.1		
109	10.9		
3	0.3	0.095	
3.26	0.326		
8.E-03	8.E-04		
5	0.5		

Figure 4-3. Hydrostratigraphic Units (HSUs) in the B-Complex TMR Model Layers

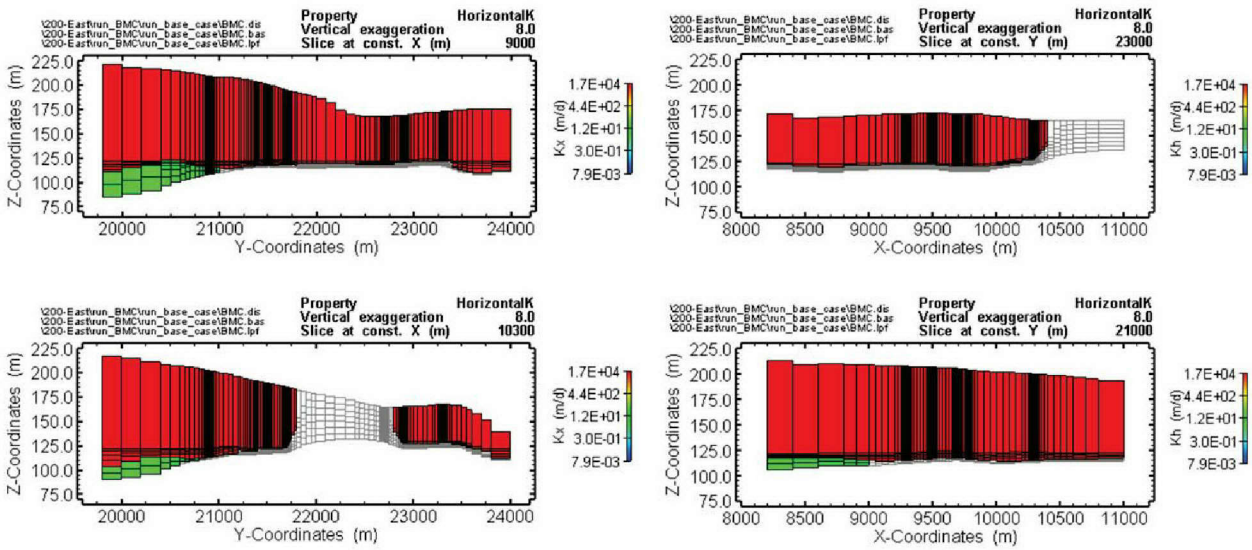


Figure 4-4. Cross-sections of Hydraulic Permeability in the B-Complex TMR Model (left: constant X; right: constant Y)

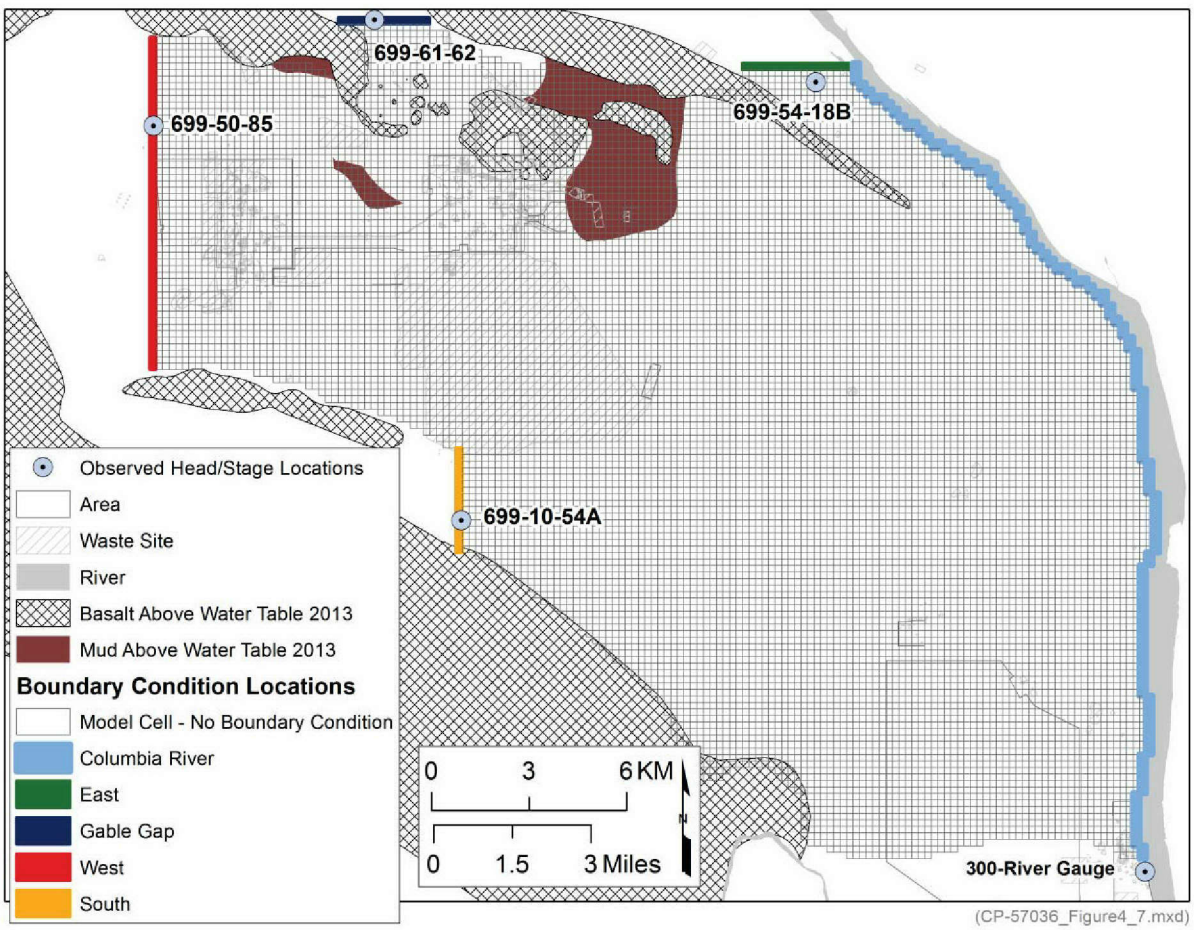


Figure 4-5. Boundary Condition Locations used for the P2R Model

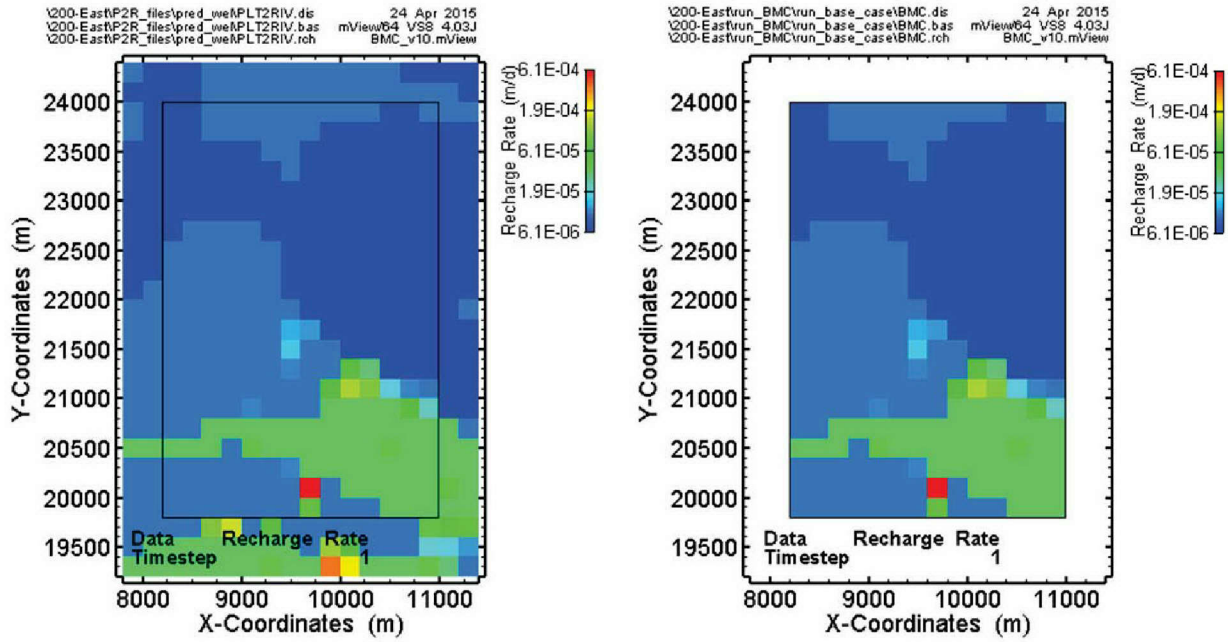


Figure 4-6. Recharge Interpolation from the P2R Model Grid onto the TMR Grid for the First Stress Period of the Transient Simulation

4.5.3 Lateral Boundaries

Lateral boundaries in the P2R Model are assigned one of the following types:

- Specified head boundaries;
- No-flow boundaries;
- Mountain-front inflow boundaries;
- General head boundaries (Columbia River).

The lateral boundary conditions for the TMR model are extracted from the P2R Model and mapped onto the TMR grid.

First, nodes that need to be inactive in the TMR were identified by mapping the P2R properties onto the TMR grid for each layer as explained in Section 4.4 (i.e. basalt above groundwater). Boundary nodes belonging to the basalt were assigned no-flow boundaries.

The remaining active boundary nodes were assigned specified head boundary conditions. For this, heads simulated with the parent P2R Model were mapped onto the active TMR nodes along the lateral boundaries of the TMR grid for each of the 51 stress periods and for each model layer. An example is shown in Figure 4-7. The boundary heads were then written out as time-dependent specified head boundaries using the CHD package of MODFLOW.

Mountain-front inflow boundaries and general head boundaries associated with the Columbia River are not present in the B-Complex TMR domain.

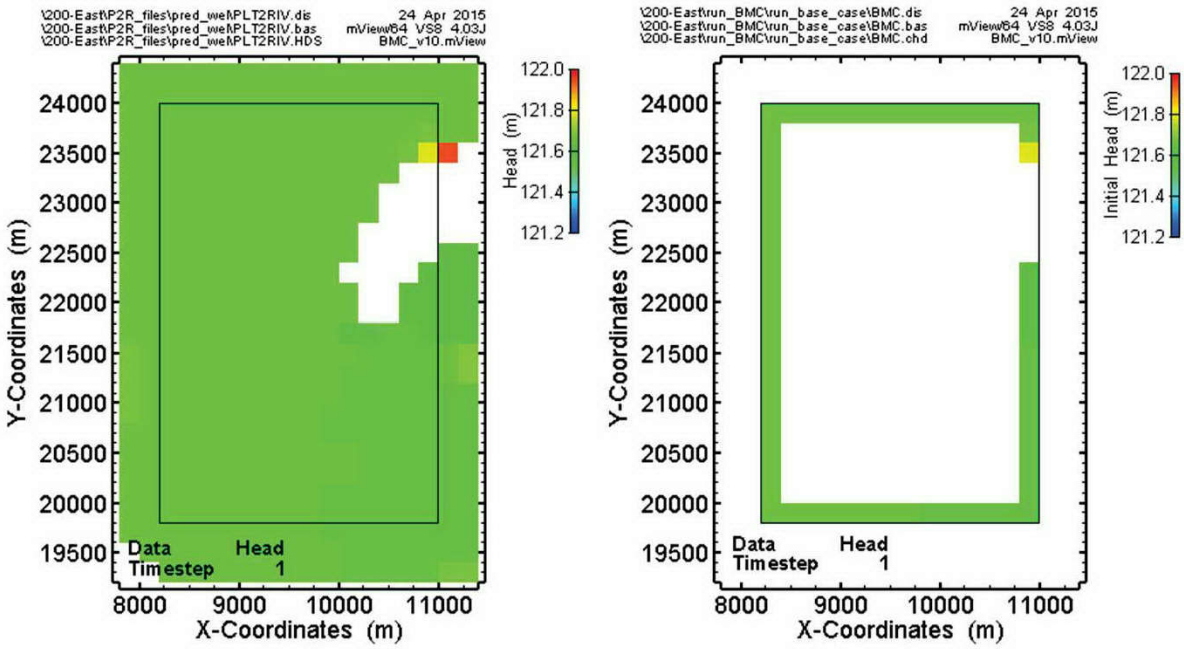


Figure 4-7. Interpolation of Heads from the P2R to the TMR Grid Boundaries for the First Stress Period of the Transient Simulation

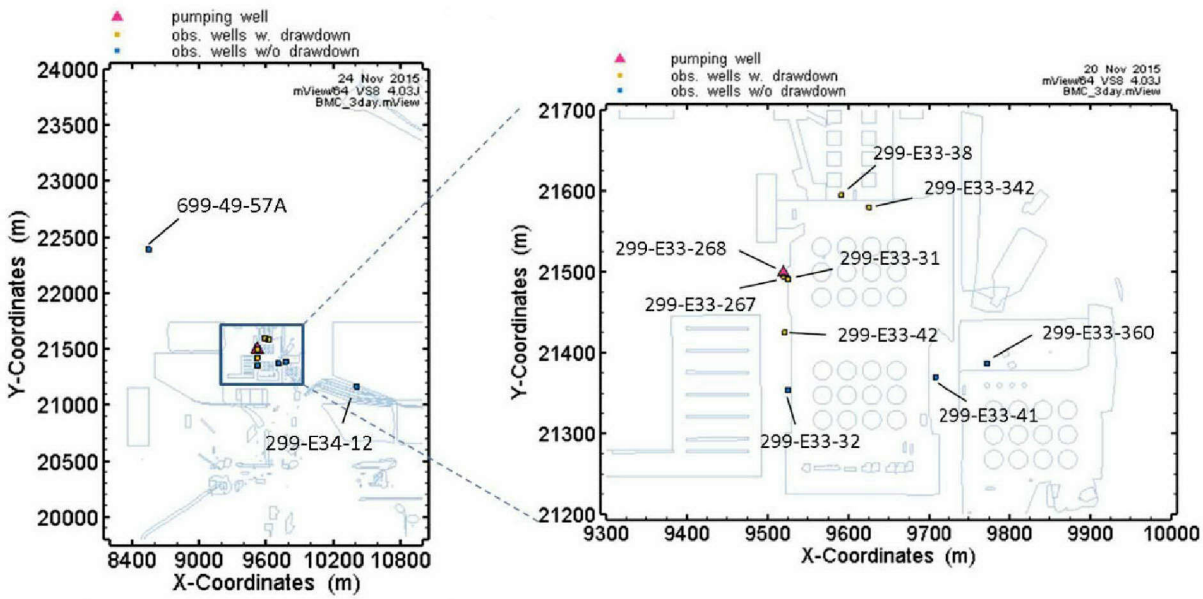
4.5.4 Pumping and Observation Wells

Pumping in well 299-E33-268 is modeled using the Modified Multi-Node Well Package (MNW2). Additional well locations were used to evaluate drawdowns during the 3-day pumping test and the 5-year pumping scenarios. The locations of the wells and drawdowns measured at the end of the 3-day pumping test are shown in Figure 4-8. Drawdown was measured in observation wells marked in yellow, whereas observation wells marked in blue did not indicate any measurable drawdown.

4.5.5 Initial Hydraulic Head Distribution

The initial hydraulic head distribution was determined using a steady state stress period at the beginning of the simulation where boundary conditions assignments matched the first transient simulation period.

As with boundary conditions, the initial conditions are extracted from the node values in the P2R Model.



Well	299-E33-268	299-E33-267	299-E33-E31	299-E33-42	299-E33-38	299-E33-342
Distance from 299-E33-268 (m)	0	4.52	9.23	74.31	119.8	133.92
Drawdown (m)	0.02	0.013	0.011	0.002	0.006	0.006

Figure 4-8. Pumping and Observation Well Locations and Measured Drawdown

5 Software Applications

Software used to perform this calculation are approved, managed, and used in compliance with the CH2M Hill Plateau Remediation Company (CHPRC) requirements of PRC-PRO-IRM-309, *Controlled Software Management*.

5.1 Exempt Software

Microsoft Excel®[1] is site-licensed software used as "flat file" spreadsheets that are wholly incorporated into this calculation and verified during the technical review of this report, and is therefore rated as exempt software (PRC-PRO-IRM-309, Section 1.3, Exemptions). Excel® spreadsheets were used to tabulate average monthly and long-term hydraulic head and river stage data for model input, and chart modeling results produced by MODFLOW-2000 and MT3DMS-MST.

[1] Excel is a registered trademarks of Microsoft Corporation in the United States and other countries.

5.2 Approved Software

MODFLOW-2000-MST is an approved calculation software (CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*). PEST, ArcGIS®[2], and Groundwater Vistas™[3] are approved support software (CHPRC-00258).

5.2.1 MODFLOW-2000-MST

- Software Title: MODFLOW-2000-MST
- Software Version: CHPRC Build 6 (executable "(mf2k-mst-chprc06dp.exe"), double precision compilation
- Hanford Information System Inventory (HISI) Identification Number: 2517 (Safety Software, Level C)
- Authorized Workstation type and property number: Personal Computer, PSC-Lithium and Personal Computer, ID tag KXGVD
- Authorized Users: H Rashid and A Papafotiou
- Software Vendor Documents:
    - Harbaugh et al. (2000), *MODFLOW-2000, the U.S. Geological Survey modular ground-water model -- User guide to modularization concepts and the Ground-Water Flow Process*
    - SSPA (2012a), *Documentation for: MODFLOW-2000-SSPA Build 006 Modifications and options added to MODFLOW-2000*
- CHPRC Software Control Documents:
    - CHPRC-00257, *MODFLOW and Related Codes Functional Requirements Document*
    - CHPRC-00258, *MODFLOW and Related Codes Software Management Plan*
    - CHPRC-00259, *MODFLOW and Related Codes Software Test Plan*
    - CHPRC-00260, *MODFLOW and Related Codes Requirements Traceability Matrix*
    - CHPRC-00261, *MODFLOW and Related Codes Acceptance Test Report*

5.2.2 MODFLOW & Related Codes Support Software

CHPRC-00257 distinguishes calculational software from supporting software because these two groups of software are classified and graded differently. The basis for the difference is that calculational software, including MODFLOW-2000-MST, calculate results that will be used to support decision-making and as such, constitute safety software graded to level C. In contrast, supporting software includes graphical interfaces, visualization, and input preparation support but not calculation of results that directly support

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[2] ArcGIS is a registered trademark of ESRI in the United States and other countries.

[3] Groundwater Vistas is a trademark of Environmental Simulation, Inc.

decision-making, and are therefore not rated as safety software. The support software items identified in CHPRC-00258 and used in this calculation were:

- **MODPATH**: USGS version of MODPATH version 6.0 (mp6x64.exe) was used for capture zone analysis.
- **Groundwater Vistas®:** (*Guide to Using Groundwater Vistas* [Rumbaugh and Rumbaugh, 2007].) Used graphical tools for model input/output review. Groundwater Vistas™ was used in pre-processing some input files.
- **mView:** Used for developing the TMR model, interpolating information from the P2R Model, and generating MODFLOW input. Provided post-processing tools including extraction and visualization of simulated heads, flows, and pathlines.
- **ArcGIS®[4]:** (The ESRI Guide to GIS Analysis, Volume 1: Geographic Patterns and Relationships [Mitchell, 1999].) Provided visualization tool for assessing simulated plume distributions, identifying extraction/injection well coordinates and mapping auxiliary data. ArcGIS® was used in pre- and post-processing simulation results.
- **PEST**: ([Doherty, 2007]) Used for automated calibration. Pre- and post-processing utilities distributed with the support software PEST were used to facilitate efficient simulation execution.
- **ARANZ LeapFrog-Hydro®**: Used to assign model layers based on current interpretation of geologic units present within the model domain.
- **Microsoft Excel®:** Developed model input files and used to calculate average monthly and daily hydraulic head and river stage estimates.

5.3 Software Installation and Checkout

Safety Software (MODFLOW-2000-MST and MT3DMS-MST) was checked out and installed in accordance with procedures specified in CHPRC-00259. Executable files were obtained from the Software Owner, installation tests identified in CHPRC-00259 were performed and confirmed, and Software Installation and Checkout Forms were completed and approved for installations used to perform model runs reported in this calculation. A copy of the Software Installation and Checkout Forms for the authorized users and authorized workstations for software used that requires this documentation are provided in Attachment A to this ECF.

5.4 Statement of Valid Software Application

The preparers of this calculation attest that the software identified above, and used for the calculations described in this calculation, is appropriate for the application and used within the range of intended uses for which it was tested and accepted by CHPRC. Because MODFLOW-2000-MST is graded as Level C software, use of this software is logged in the HISI under the corresponding entries (Identification Numbers 2517 and 2518). These software items were used within the limitations identified in CHPRC-00257. Installations of the software are operating correctly, as demonstrated by installation testing performed on the workstations mentioned above and documented in the Software Installation and Checkout Form (Attachment A).

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[4] ArcGIS® is a registered trademark of ESRI Corporation.

6 Calculation

The pumping test was carried out in well 299-E33-268 to measure drawdowns and estimate hydraulic properties of the Hanford/Cold Creek formation. The test lasted 3 days and resulted in estimated minimum, average, and maximum values of hydraulic conductivity and specific yield. Based on the previous analyses performed with the B-Complex TMR model (ECF-200BP5-15-0009), different pumping rates are considered for a pumping period of 3 to 5 years for this well. This section describes how the 3-day pumping test and the 5-years pumping scenarios were implemented in the numerical simulations carried out with the B-Complex TMR model, with the specific objective of comparing simulated to measured drawdowns, and evaluating capture zones by means of particle tracking.

6.1 Transient Simulations

The transient simulations are split into two groups depending on the purpose of the model, namely: (1) the simulations carried out for comparison to the 3-day pumping test, and (2) the simulations carried out for the evaluation of the 5-year pumping scenarios.

The simulations used for the comparison to the 3-day pumping test are implemented in the B-Complex TMR by assigning the corresponding pumping rate of 125 GPM in well 299-E33-268 between September 01 and September 03 2015 (see also Section 4.2). Four different sets of hydraulic conductivity and specific yield are used in different simulation variants, corresponding to the unchanged parameters of the P2R and TMR model, and the minimum, average, and maximum values estimated with the pumping test (Table 6-1). Moreover, an additional simulation is performed using hydraulic conductivity fitted to drawdown in well 299-E33-268 by trial-and-error. As the 3 day pumping period was too short to create a capture zone or affect hydraulic heads at the boundaries of the TMR, the P2R Model corresponding to no-pumping (i.e. no remediation actions implemented) was used to parent the daughter TMR model.

The simulations carried out to evaluate the 5-year pumping scenarios are implemented by assigning a pumping rate in well 299-E33-268 between January 1, 2016 and December 31, 2020 (see also Section 4.2). Similarly to the 3-day pumping test simulations, four sets of hydraulic conductivity and specific yield are implemented corresponding to the unchanged TMR parameters, and the average, minimum, and maximum values estimated with the pumping test (Table 6-1). For each parameter set, three scenarios are simulated corresponding to a pumping rate of 50, 100, and 150 GPM in well 299-E33-268. For 3-day pumping test simulations and drawdown analysis on 5-year pumping scenarios, the TMR model has been derived from both pumping and no-pumping runs of the P2R Model to allow comparison and evaluation of the hydraulic head boundary effects. Particle tracking analysis on 5-year pumping scenarios was first carried out with the TMR model derived from the no-pumping P2R simulation. Moreover, the TMR model was then calibrated to fit the gradient (i.e., magnitude and direction) in the vicinity of the B-complex. The calibrated flow model was used for the particle tracking analysis. The details of the calibration process is described in Section 6.1.1.

Table 6-1. Parameter Sets used in the Numerical Simulations

Parameter Set	Hydraulic Conductivity (m/d)	Specific Yield (-)
Unchanged TMR values	17,000	0.20
Average values	18,800	0.21
Minimum values	15,800	0.11
Maximum values	21,300	0.31

6.1.1 Flow Model Calibration

The CHD boundary conditions of the B-complex TMR were calibrated to match the current interpretation of the water table surface in the vicinity of the B-complex area (Figure 6-1). The gradient of the water table surface (i.e., magnitude and direction) in the vicinity of B-complex was calculated from the current interpretation of the water table surface and used as the primary calibration targets in the calibration setup. Though the main goal for the calibration was to match the water table gradient in the vicinity of B-complex, a few heads along the interpreted contour lines of the water table were also used as the calibration targets so that there were enough targets within the model domain for overall consistency. The PEST (Doherty, 2007) parameter estimation software was used to facilitate estimates of CHD boundary conditions along with manual adjustments. The following steps were followed to construct and run the PEST model for B-complex TMR:

1. All the MODFLOW model files are same as the base B-complex TMR model (derived from no pumping scenario of P2R Model) except the CHD package.
2. The CHD boundary condition was parameterized by points interpolated over the model grid via ordinary kriging. This approach is termed the “pilot point” method of parameterization (Doherty, 2003).
3. Pilot points are chosen such a way so that there is always at least 2 pilot points and a maximum of 5 pilot points along a row/column for each layer. Moreover, pilot points are distributed spatially so that at least 2-3 points are available for interpolation within the correlation scale range (range). A total of 16 pilot points (i.e., PEST adjustable parameters) were finalized to be used in the PEST framework for calibrating CHD boundary conditions. For any layer, if a pilot point falls into an inactive cell the point is removed from the calculation. For example, all the 16 pilot points in layer 1 were used to calculate CHD boundary condition as all of them fall into active CHD boundary cells. On the other hand, only 5 pilot points in Layer 7 were used to calculate CHD boundary as 11 other pilot points fall into the inactive cells.
4. A zonation file for each model layer was created using the Groundwater Vistas software where CHD boundary cells were assigned to one zone and rest of the model cells were assigned to another zone.
5. The PEST groundwater utility PPK2FAC was used to generate kriging factors from the pilot points at each layer for all the CHD boundary cells. A spherical variogram with a correlation range of 1,000 m was used to characterize spatial variability of CHD boundary conditions. The PEST groundwater utility FAC2REAL was used to calculate CHD at each boundary cell based on the pilot point values and kriging factors generated by PPK2FAC program. A Fortran code (dochd.exe) was used to read the FAC2REAL generated CHD boundary condition and write in MODFLOW CHD package format.
6. PEST was used to get a calibrated model which fits the observation targets reasonably. Some of the PEST estimated parameters were manually adjusted for conceptual reasonableness.

The location of the pilot points that were used to calculate CHD boundary condition are shown in Figure 6-1. Figure 6-1 also shows the current interpretation of the water table surface contours and the hydraulic gradient network locations which were used as observation targets to calibrate the model. A comparison between current interpretation of water table contour and simulated water table contour is shown in Figure 6-2. The comparison between observed and simulated hydraulic gradient (i.e., magnitude and direction) is tabulated in Table 6-2. Table 6-2 clearly shows that the simulated hydraulic gradient fits

reasonably to observed data. Calibrated CHD boundary condition was used for all the stress periods in the flow model for particle tracking analysis.

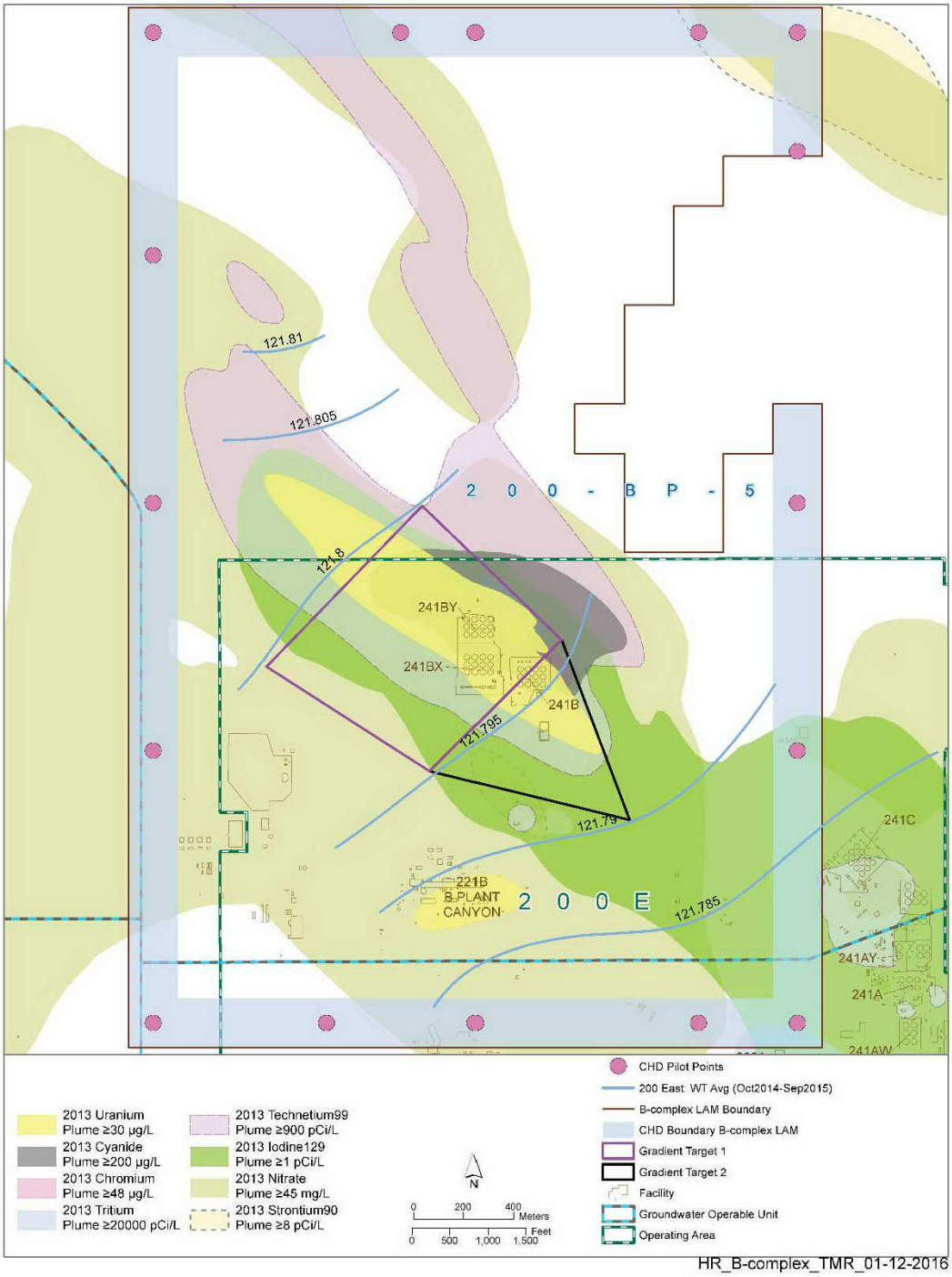

Figure 6-1. Pilot Point Locations, Current Interpretation of Water Table, and Calibration Targets within B-Complex TMR Model

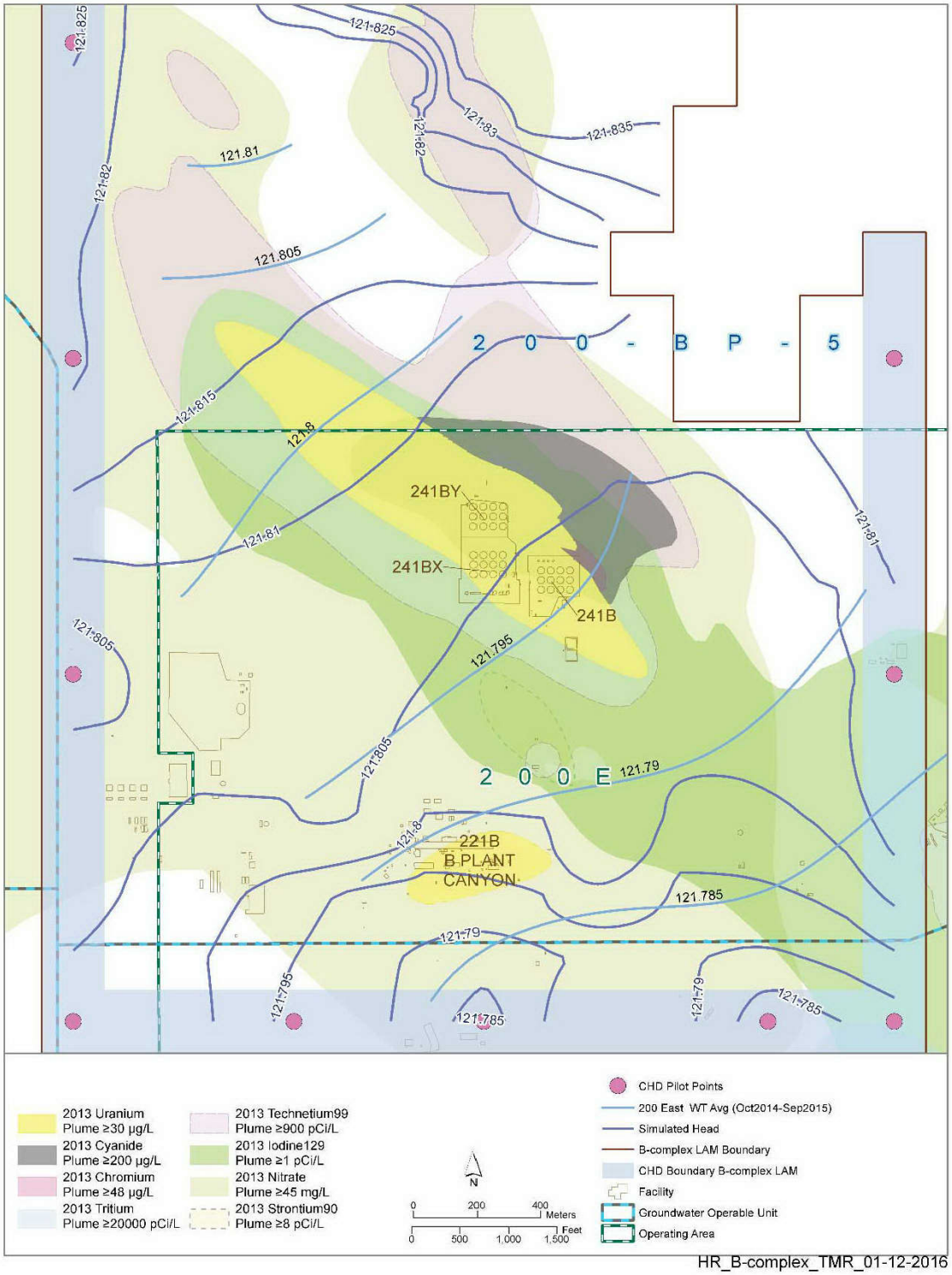

Figure 6-2. Comparison between Current Interpretation of Water Table Contours and Simulated Head Contours at Water Table in the Vicinity of B-Complex Area

Table 6-2. Comparison between Observed and Simulated Hydraulic Gradient

Target Name	Observed Azimuth (Degree)	Simulated Azimuth (Degree)	Residual Azimuth (Degree)	Observed Magnitude (m/m)	Simulated Magnitude (m/m)	Residual Magnitude (m/m)
Target 1	135.00	143.42	-8.42	6.5E-06	8.21E-06	-1.71E-06
Target 2	135.00	130.87	4.13	7.1E-06	5.56E-06	1.54E-06

6.2 Particle Tracking

Particle tracking algorithms allow the estimation of pathlines for a given velocity field in an aquifer by appropriate interpolation of the velocity vectors. Each pathline is therein constructed as a series of locations of a particle at different times. When the calculation of particle locations is carried out with *forward tracking*, particles are released at specified locations (i.e. contaminant sources) and then tracked downgradient for a time frame specified by the user (i.e. until the end time of the flow simulation). On the other hand, *backward tracking* allows to identify the origin of particles that end up at locations specified by the user at selected times. Both methods are available in MODPATH and result in a pathline file that includes all discrete locations of every particle after each time step. It is thus possible to post-process this output and estimate all traveled distances and travel times associated with any location selected in an aquifer.

The transient hydraulic simulations carried out with the B-Complex TMR provide hydraulic heads and cell-to-cell flows across the model domain. In the simulations of the 3-day pumping test, no capture zone was formed due to the short time of pumping. In the case of the 5-year pumping scenarios, hydraulic heads and cell-to-cell flows simulated with the calibrated flow model are subsequently used as input for MODPATH simulations in order to delineate the capture zone of well 299-E33-268. For this, particles are released at the well location at the end of the 5-year pumping period, and tracked backwards.

7 Results/Conclusions

This section presents the results of all numerical simulations carried out with the B-Complex TMR model for the pumping test and capture zone evaluation. In Section 7.1, the metrics used to evaluate and compare numerical simulations are presented. Section 7.2 presents the results from the 3-day pumping test simulations. Section 7.3 presents the results from the capture zone analysis of the TMR model based on 5-year pumping scenarios.

7.1 Comparison and Evaluation Metrics

The following presents the comparison and evaluation metrics used for the 3-day pumping test simulations (Section 7.1.1) and for the 5-year pumping scenarios (Section 7.1.2).

7.1.1 3-day Pumping Test

The simulations for the 3-day pumping test are evaluated by means of drawdown analysis. To calculate drawdown at the pumping and observation well locations, an additional simulation is carried out using the parameter set and hydraulic head boundaries from each scenario but at the same time deactivating the

pumping well. Consequently, the head difference between the original scenario simulation (with wells) and the additional simulation (without wells) is calculated to filter out head changes related to the transient boundary condition and thus obtain the local "net" changes at the well locations due to water extraction and injection. The time-histories of calculated drawdown are then compared to the maximum drawdown measured after 3 days of testing at the corresponding locations (Figure 7-1, left). Time on the horizontal axis corresponds to days after the beginning of the pumping test. Measured drawdowns are thus assigned to $t = 3$ days for comparison to the simulation. The well locations and values of measured drawdowns are shown in Figure 4-8.

7.1.2 5-year Pumping Scenarios

The simulations for the 5-year pumping scenarios are evaluated by means of drawdown analysis as well as capture zone analysis.

Drawdowns are calculated in a similar manner as done for the 3-day pumping test simulations. In this case, time on the horizontal axis corresponds to time from the beginning of the simulation, thus pumping takes place between $t = 3$ years and $t = 8$ years (Figure 7-1, right).

Pathlines and travel times are always calculated for particles backtracked from the location of the extraction well. The capture zone maps were created using Groundwater Vistas to preprocess the pathlines into ArcGIS® format. The distance between two arrows of particle pathlines (Figure 7-9) denote the distance traveled by the particle in a year.

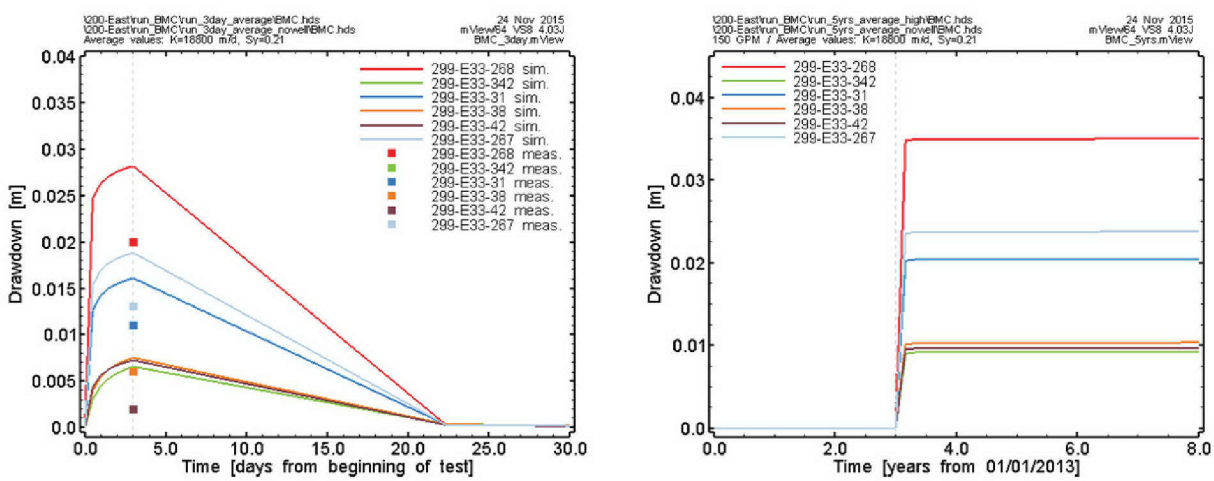

Figure 7-1. Examples of Time-histories of Drawdown Calculated at Selected Well Locations for the 3-day Pumping Test (left) and the 5-year Pumping Scenario (right)

7.2 3-day Pumping Test Simulations

This section provides the drawdown analyses performed for the 3-day pumping test simulations. First, a simulation is carried out with the unchanged parameters of the TMR and parent P2R Model (Section 7.2.1). Subsequently, the average, minimum, and maximum parameter estimates are used (Sections 7.2.2, 7.2.3, and 7.2.4, respectively) to simulate the test. Finally, an additional simulation is carried out using a hydraulic conductivity value hand-fitted to match the drawdowns measured closest to the pumping well (Section 7.2.5).

7.2.1 Unchanged TMR Parameters

The drawdowns simulated with the original TMR model parameters are compared to the measured drawdowns in Figure 7-2 (left figure shows time-histories from wells with measured drawdown, right figure shows wells with zero measured drawdown). Simulated drawdown in pumping well 299-E33-268 reaches 31 mm after 3 days (compared to 20 mm measured drawdown). Simulated drawdown in observation wells 299-E33-267 and 299-E33-31, both located within 10 meters distance from the pumping well, reaches 20.7 mm and 17.7 mm, respectively (compared to 13 mm and 11 mm measured drawdown, respectively). It is indicated that the deviation between simulated and measured drawdown in these three wells is systematic (i.e. similar difference in drawdown between wells 299-E33-268 and 299-E33-267 both in simulation and measurement). On the other hand, drawdowns in the more remote observation wells with distances between 74 and 134 m from pumping well indicate a different pattern (i.e. drawdowns in wells 299-E33-38 and 299-E33-42 are almost identical in the simulation but differ in the measurement). Finally, simulated drawdowns in wells where measured drawdown was zero (distances between 144 and 277 m from pumping well) are below 5 mm (Figure 7-2, right).

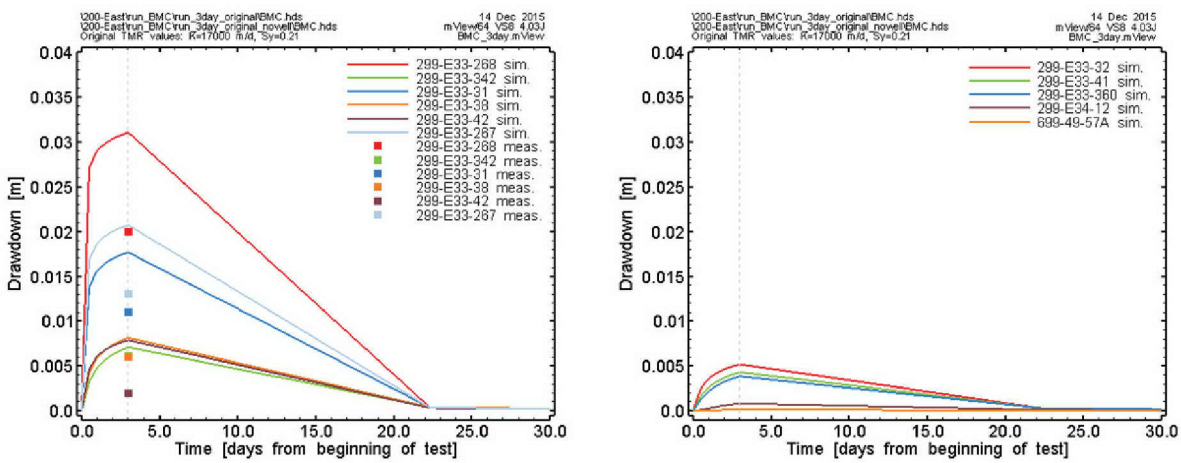

Figure 7-2. Comparison between Measured Drawdown and Calculated Drawdown with the Original TMR Parameters; Drawdown Time-history in Wells with (left) and without (right) Measurable Drawdown

7.2.2 Average Parameters

The drawdowns simulated with the average estimates of parameters are compared to the measured drawdowns in Figure 7-3. Overall, the drawdown comparison is similar as that presented for the unchanged TMR model parameters. In this case, simulated drawdown in pumping well 299-E33-268 is decreased to 28.2 mm due to the higher hydraulic conductivity. Drawdowns in observation wells 299-E33-267 and 299-E33-31 are accordingly decreased to 18.8 mm and 16.1 mm, respectively. Changes in simulated drawdown compared to the previous simulation are negligible in the rest of the observation wells.

To further clarify the differences between simulated and measured drawdowns at the different well locations, different cross-plots of residuals are constructed, as shown in Figure 7-4. The cross-plot between residuals and distance from the pumping well (Figure 7-4, top right) does not indicate any distinguishable correlation or reliable spatial pattern. However, the residual value is biased on the amount of drawdown, i.e. wells close to the pumping location may result in higher residual even though the agreement between model and measurement is qualitatively better compared to more remote locations where the drawdown is

smaller. Residuals are therefore normalized with the corresponding simulated drawdown and then plotted once more with distance (Figure 7-4, bottom left). Normalized residual equal to one indicates maximum relative deviation, which occurs in observation wells with some simulated drawdown but zero measured drawdown. Normalized residual equal to zero indicates agreement between model and measurement. It is shown that a correlation exists between normalized residual and distance from pumping well 299-E33-268, except for wells 299-E33-38 and 299-E33-342 which are both located in the northeast of 299-E33-268. The cross-plot between normalized residuals and measured drawdown (Figure 7-4, bottom right) indicates a similar effect. Higher drawdowns (i.e. closer to the pumping well) relate to lower residuals, whereas wells 299-E33-38 and 299-E33-42 result in outliers. Despite the limited number of data points, this behavior could indicate a structural feature of the Hanford/Cold Creek formation with hydraulic conductivity varying towards the northeast; an effect which is not accounted for the in the TMR model that assumes uniform parameters for each formation across the model domain. Alternatively, it is the lowest values of drawdown that show this behavior which also may due to the amount of measurement error relative to the size of the measurement itself.

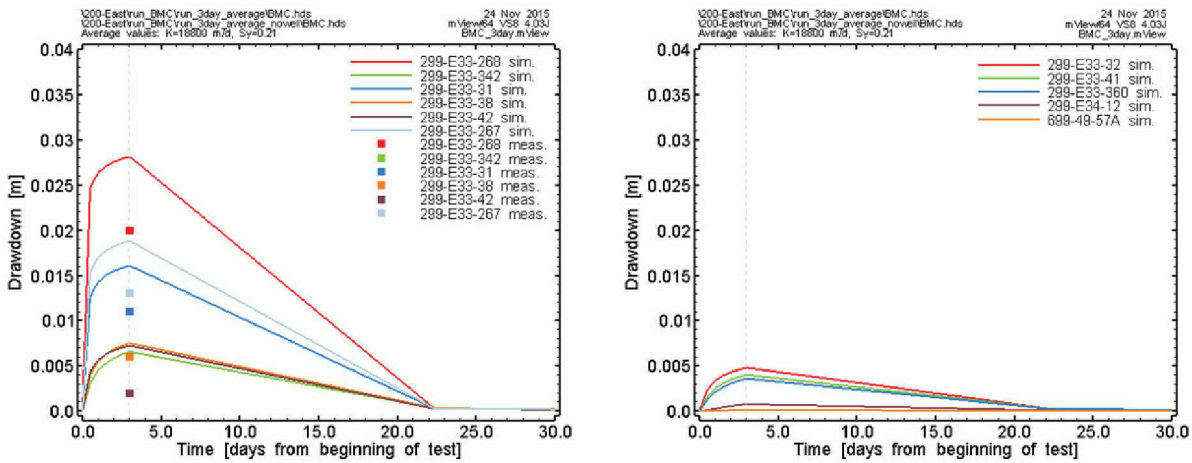

Figure 7-3. Comparison between Measured Drawdown and Calculated Drawdown with the Average Parameters; Drawdown Time-history in Wells with (left) and without (right) Measurable Drawdown

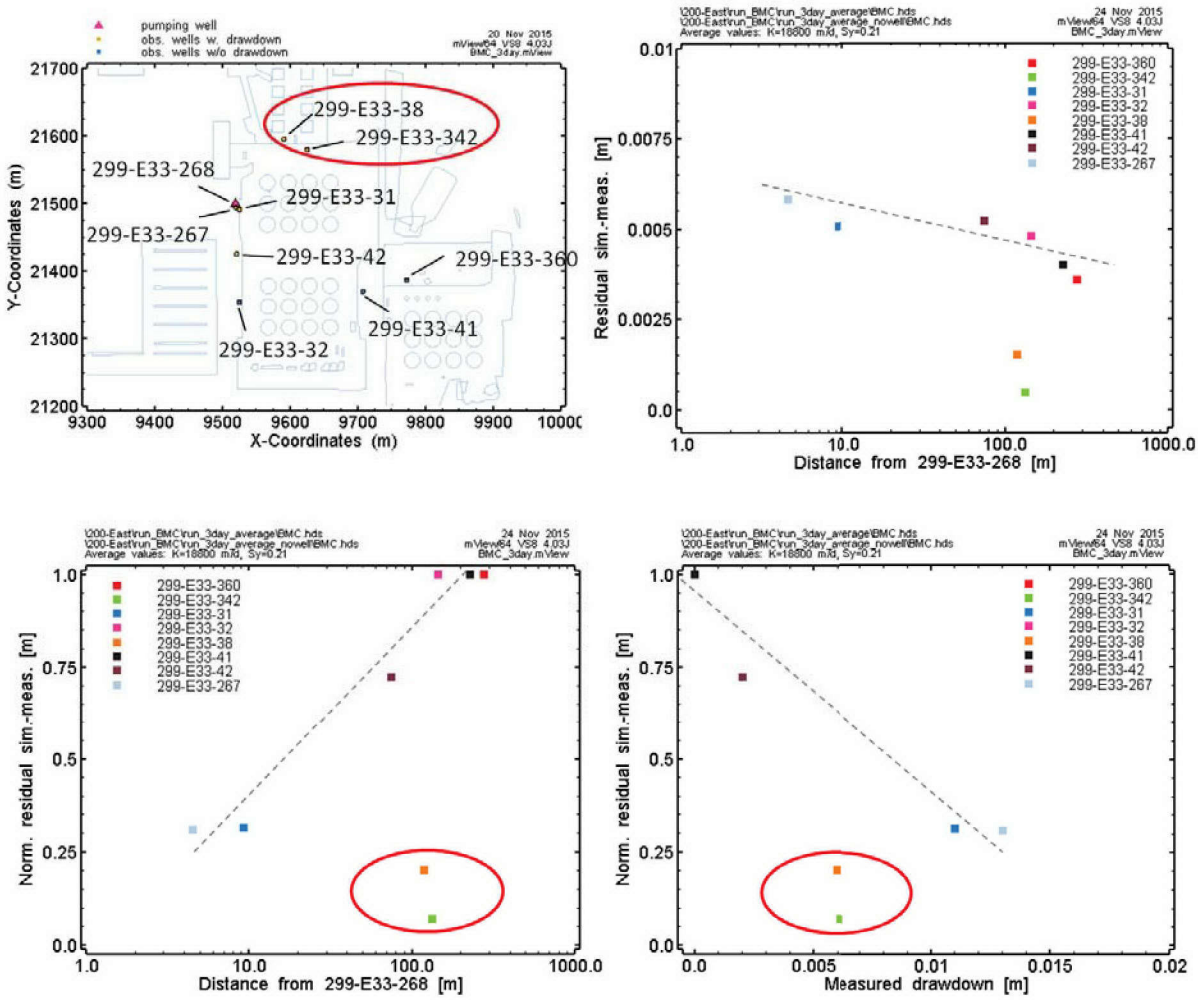

Figure 7-4. Analysis of Residuals between Measured and Calculated Drawdown with the Average Parameters: Absolute Residuals vs Distance (top right); Normalized Residuals vs Distance (bottom left); and Normalized Residuals vs Measured Drawdown (bottom right)

7.2.3 Minimum Parameters

The drawdowns simulated with the minimum estimates of parameters are compared to the measured drawdowns in Figure 7-5. In general, this simulation results in the highest deviation from the measured values. Simulated drawdown in pumping well 299-E33-268 is increased to 34.1 mm due to the lower hydraulic conductivity. Drawdowns in observation wells 299-E33-267 and 299-E33-31 are increased to 23.0 mm and 19.7 mm, respectively. Simulated drawdowns in wells with zero measured drawdown are below 6 mm (Figure 7-5, right).

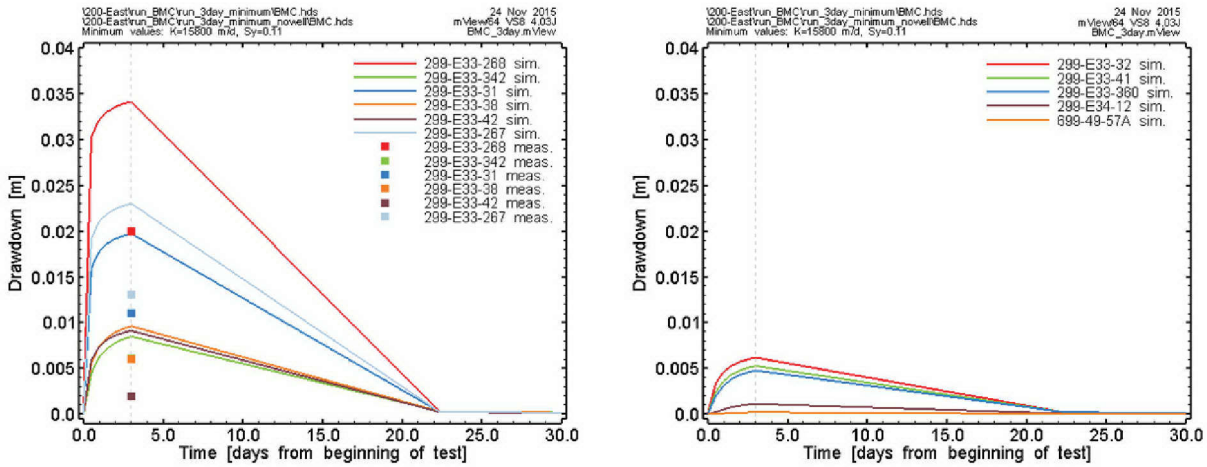

Figure 7-5. Comparison between Measured Drawdown and Calculated Drawdown with the Minimum Parameters; Drawdown Time-history in Wells with (left) and without (right) Measurable Drawdown

7.2.4 Maximum Parameters

The drawdowns simulated with the maximum estimates of parameters are compared to the measured drawdowns in Figure 7-6. It is indicated that the increased permeability results in lower drawdowns and therefore also in less deviation from the measured values. Simulated drawdowns in wells 299-E33-268, 299-E33-267, and 299-E33-31 are 24.6, 16.3, and 14.0 mm, respectively. Simulated drawdowns in wells with zero measured drawdown are below 4 mm (Figure 7-6, right).

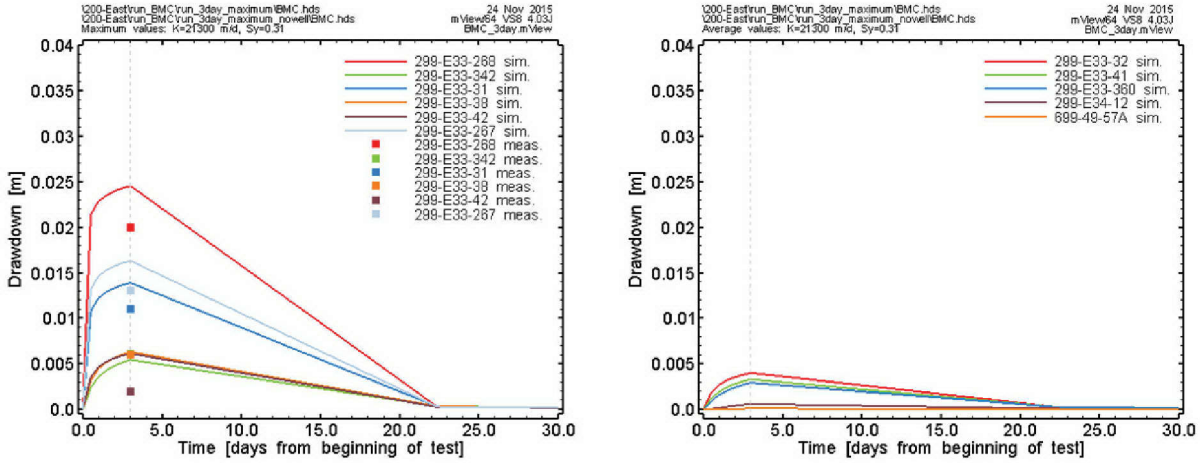

Figure 7-6. Comparison between Measured Drawdown and Calculated Drawdown with the Maximum Parameters. Drawdown Time-history in Wells with (left) and without (right) Measurable Drawdown

7.2.5 Fitted Hydraulic Conductivity

In this simulation, the hydraulic conductivity of the Hanford/Cold Creek formation is increased stepwise until the simulated maximum drawdown in well 299-E33-268 matches the measured value. It is emphasized here that this is not a systematic parameter fit, but rather a simple trial-and-error fit always assuming an anisotropy factor of 10. The horizontal hydraulic conductivity value found through this fitting procedure

was 26,200 m/d. The resulting drawdowns are compared to the measured values in Figure 7-7. It is indicated that reasonable agreement is achieved for wells 299-E33-268, 299-E33-267, and 299-E33-31, whereas some deviations are observed for the rest of the wells. This is may be due to some heterogeneity of the Hanford/Cold Creek formation (possibly to the northeast as indicated by the residual analysis) that is not accounted for in the model.

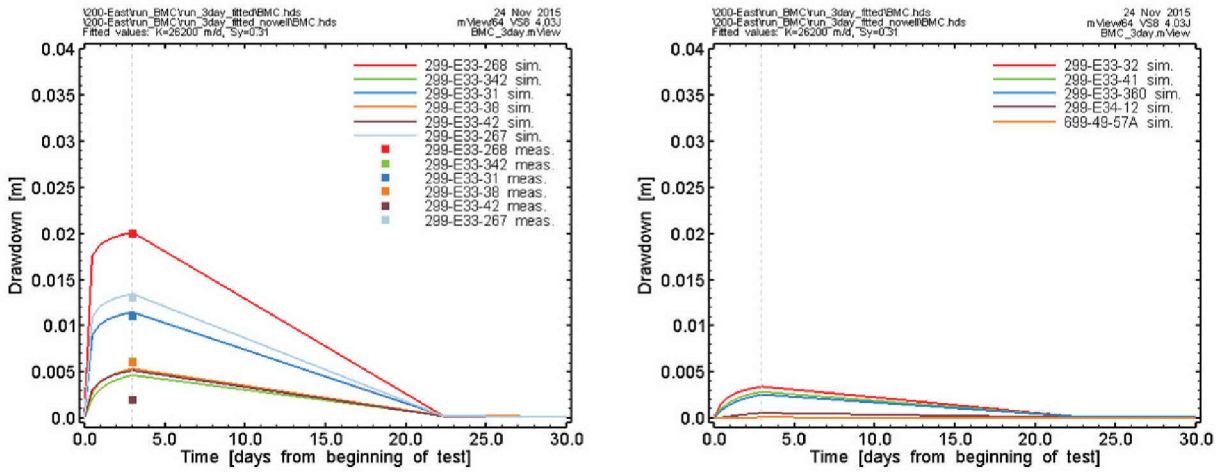

Figure 7-7. Comparison between Measured Drawdown and Calculated Drawdown with Fitted Permeability: Drawdown Time-history in Wells with (left) and without (right) Measurable Drawdown

7.3 5-years Pumping Simulations

The results of the 5-years pumping simulations will be presented in the following. The TMR model is used to evaluate drawdowns and capture zones using the unchanged TMR parameters in Section 7.3.1, and the estimated average, minimum, and maximum parameters in Sections 7.3.2, 7.3.3, and 7.3.4, respectively.

7.3.1 Unchanged TMR Parameters

The TMR model with unchanged parameters is used to simulate the 5-year pumping scenario for the three pumping rates considered (50, 100, and 150 GPM).

Drawdown analysis

Figure 7-8 shows the drawdowns simulated in pumping well 299-E33-268 and in the observation wells nearest to 299-E33-268. Similarly to the 3-day pumping test simulations, maximum drawdowns are reached very quickly after the onset of pumping (i.e. within one time step) due to the high hydraulic conductivity of the Hanford/Cold Creek formation. In well 299-E33-268 the drawdown reaches 12.8, 25.7, and 38.8 mm for 50, 100, and 150 GPM, respectively. Consistently with the 3-day pumping test analyses, the observation wells with the highest drawdown are 299-E33-267 and 299-E33-31, followed by 299-E33-38, 299-E33-42, and 299-E33-342.

Capture zone analysis

Capture zones simulated after 5 years of pumping with 50, 100, and 150 GPM are shown in Figure 7-9, Figure 7-10, and Figure 7-11, respectively. In general, hydraulic heads do not show significant differences between the three variants. As indicated by the drawdown analysis, head differences for increasing pumping rates lie within a range of 26 mm in the vicinity of the pumping well. On the other hand, the shape and width of the capture zone change. The capture zone for 100 and 150 GPM has similar width and travel

length whereas the capture zone for 50 GPM is significantly narrower. In addition, the capture zone with 150 GPM pumping rate also extends to the south-east side of the model domain.

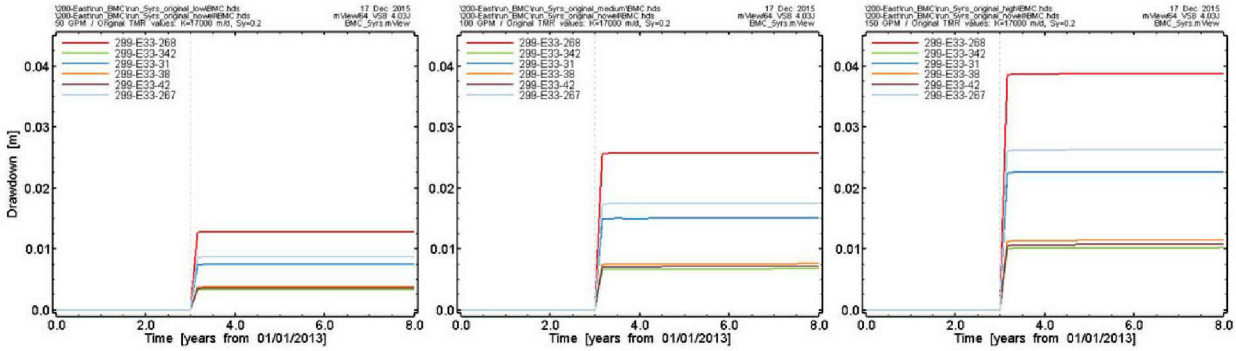

Figure 7-8. Comparison between Drawdowns Simulated with the TMR model with Unchanged Parameters and Pumping Rate of 50 (left), 100 (middle), and 150 GPM (right).

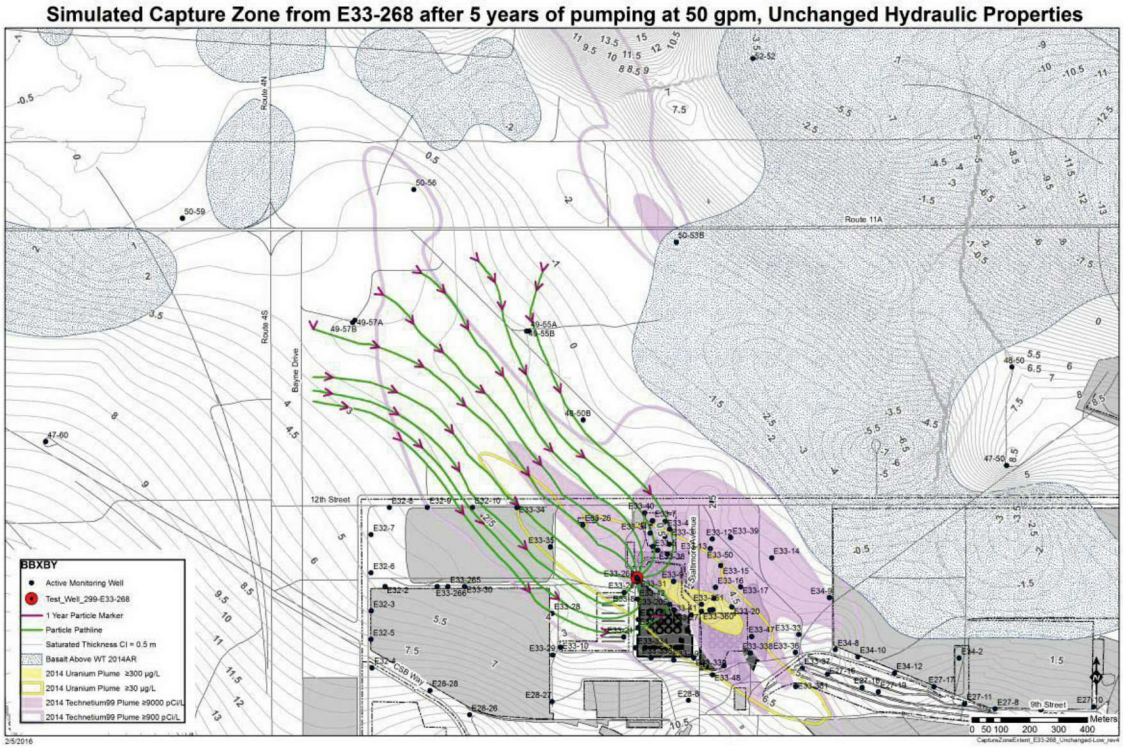

Figure 7-9. Predicted Hydraulic Capture Zone at 1-year Intervals for Unchanged Hydraulic Properties with 50 GPM Pumping (backward particle track)

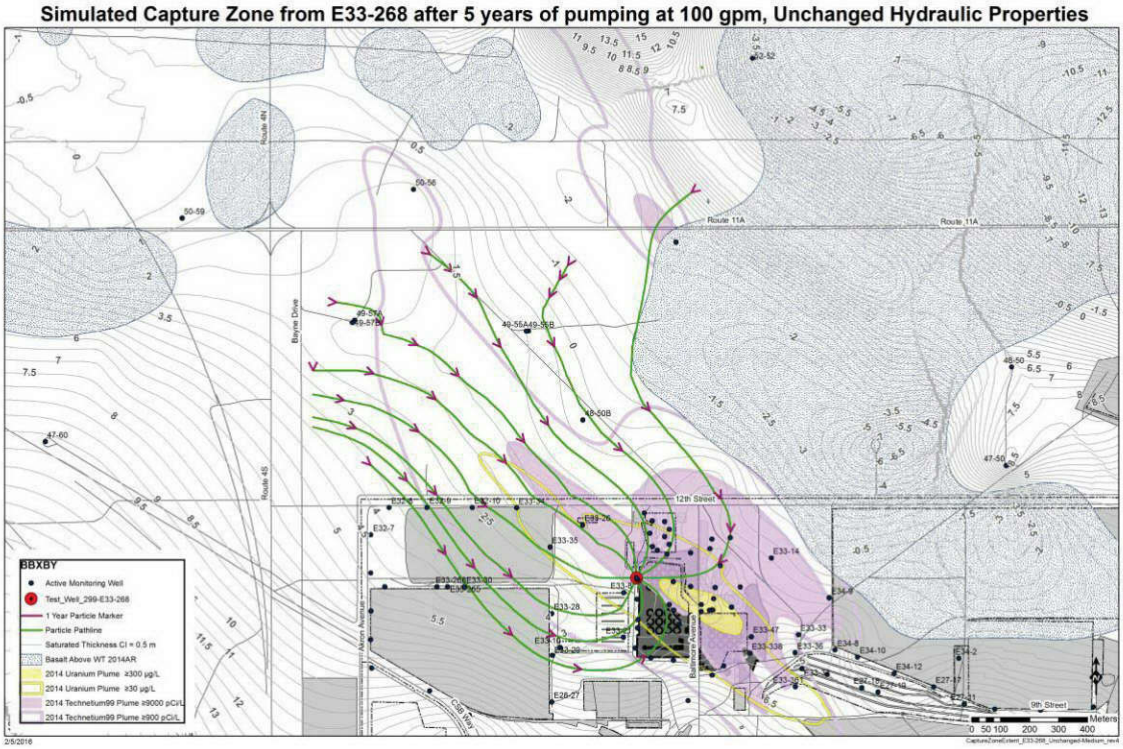

Figure 7-10. Predicted Hydraulic Capture Zone at 1-year Intervals for Unchanged Hydraulic Properties with 100 GPM Pumping (backward particle track)

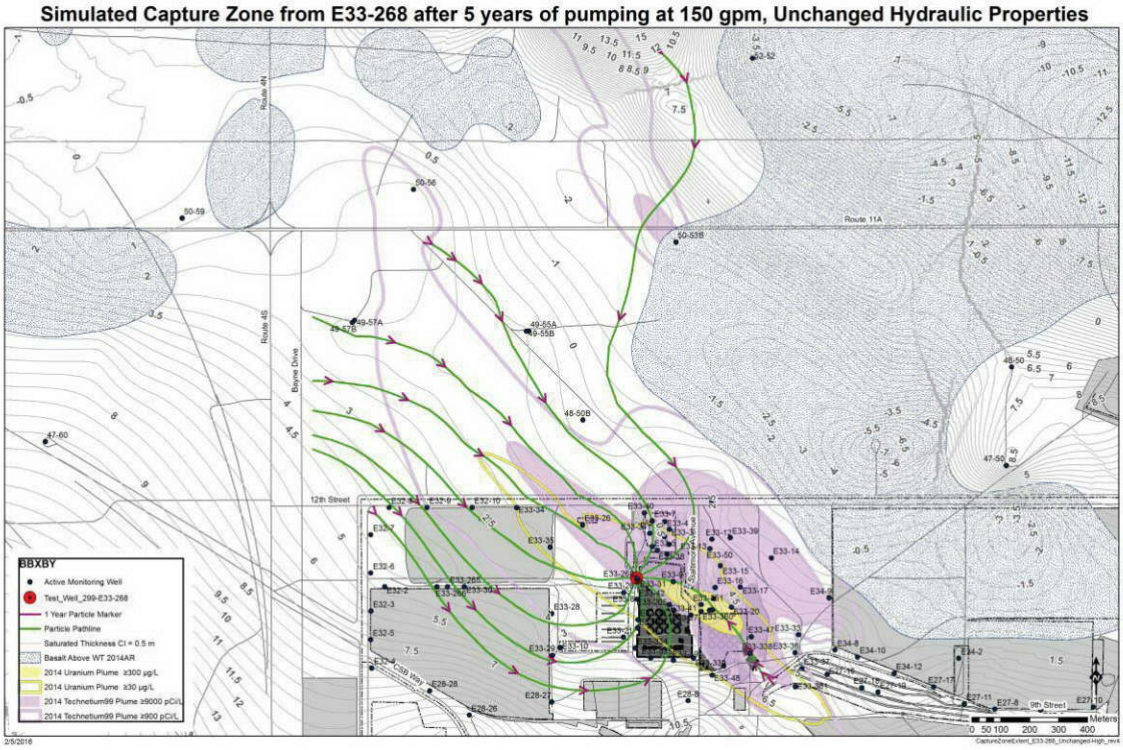

Figure 7-11. Predicted Hydraulic Capture Zone at 1-year Intervals for Unchanged Hydraulic Properties with 150 GPM Pumping (backward particle track)

7.3.2 Average Parameters

The input parameters are changed in the TMR model to the average estimates from the 3-day pumping test. The model is then used to simulate the 5-year pumping scenario for the three pumping rates.

Drawdown analysis

Figure 7-12 shows the drawdowns simulated in pumping well 299-E33-268 and in the observation wells nearest to 299-E33-268. Overall, the spatial and temporal evolution of drawdowns is similar to those from the TMR simulations with the unchanged model parameters. Drawdowns are however somewhat lower in this case due to the higher hydraulic conductivity. Drawdowns in well 299-E33-268 reach 11.6, 23.2, and 35.0 mm for 50, 100, and 150 GPM, respectively. Similarly to the previous, the observation wells with the highest drawdown are 299-E33-267 and 299-E33-31, followed by 299-E33-38, 299-E33-42, and 299-E33-342.

Capture zone analysis

The capture zones simulated after 5 years of pumping with 50, 100, and 150 GPM are shown in Figure 7-13, Figure 7-14, and Figure 7-15, respectively. Similarly to the simulations with the unchanged parameters, hydraulic heads vary up to approximately 24 mm for the three pumping rates used. The evolution of capture zones is also very similar. It is expected because the hydraulic conductivity for unchanged and average condition is very similar (17,000 m/d and 18,800 m/d).

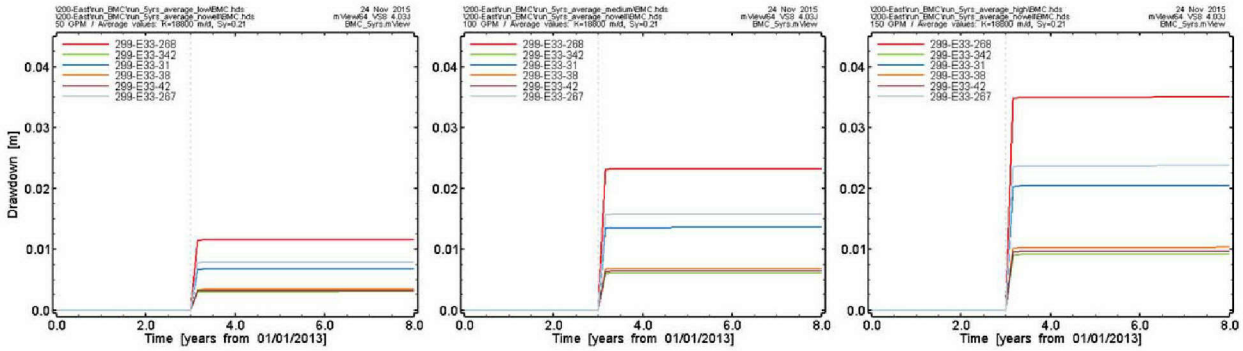

Figure 7-12. Comparison between Drawdowns Simulated with the TMR Model with the Average Parameters and Pumping Rate of 50 (left), 100 (middle), and 150 GPM (right)

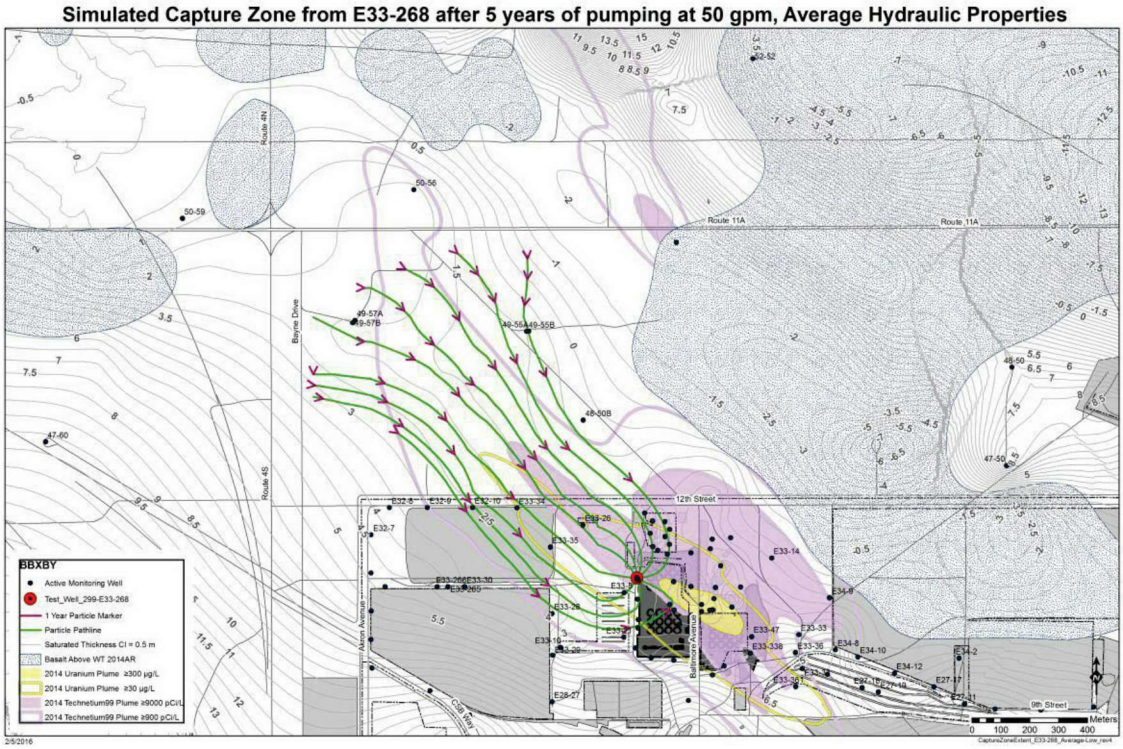

Figure 7-13. Predicted Hydraulic Capture Zone at 1-year Intervals for Average Hydraulic Properties with 50 GPM Pumping (backward particle track)

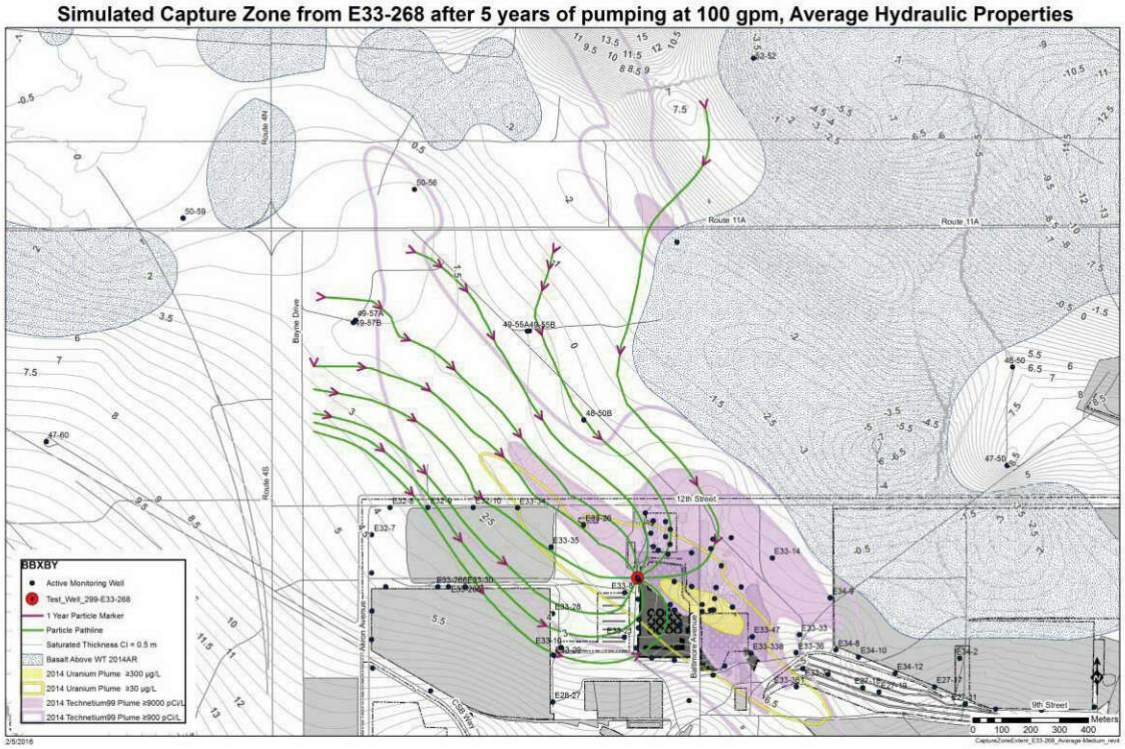

Figure 7-14. Predicted Hydraulic Capture Zone at 1-year Intervals for Average Hydraulic Properties with 100 GPM Pumping (backward particle track)

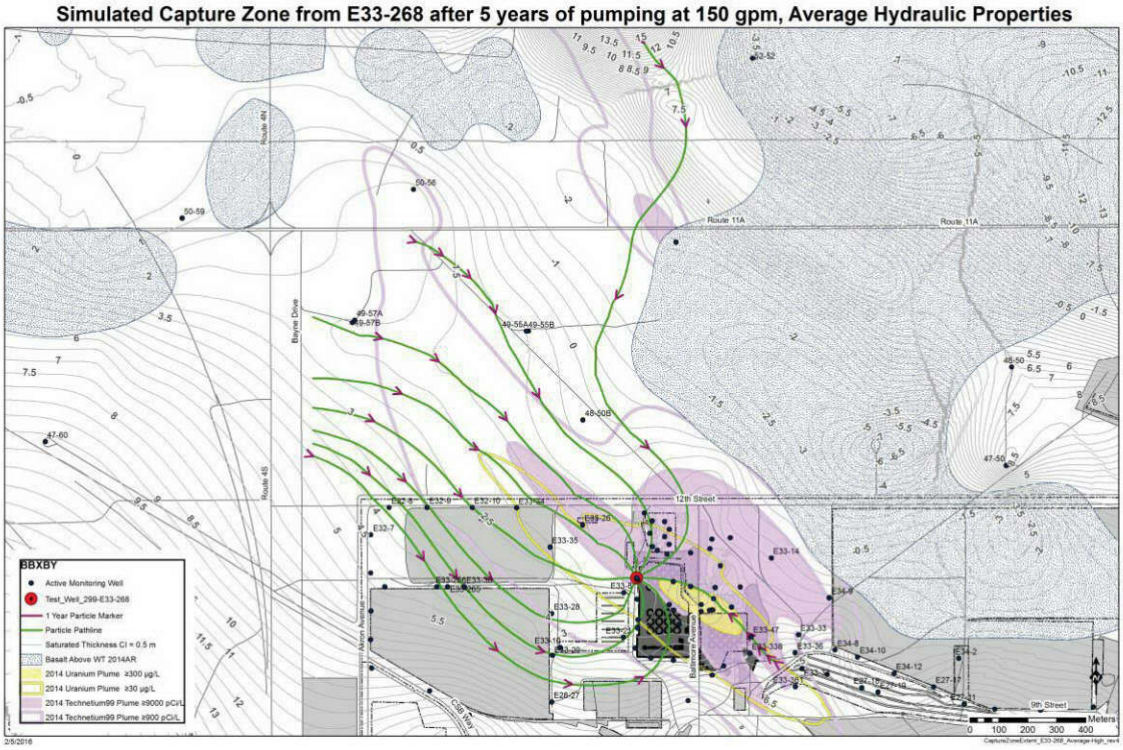

Figure 7-15. Predicted Hydraulic Capture Zone at 1-year Intervals for Average Hydraulic Properties with 150 GPM Pumping (backward particle track)

7.3.3 Minimum Parameters

The input parameters in the TMR model are now changed to the minimum estimates from the 3-day pumping test, and the 5-year pumping scenario is simulated for the three pumping rates.

Drawdown analysis

Figure 7-16 shows the drawdowns simulated in pumping well 299-E33-268 and in the observation wells nearest to 299-E33-268. It is indicated that the minimum estimate of hydraulic conductivity results in the highest estimates of drawdown in the pumping and observation wells. Drawdown in well 299-E33-268 reaches 13.8, 27.7, and 41.8 mm for 50, 100, and 150 GPM, respectively.

Capture zone analysis

The capture zones simulated after 5 years of pumping with 50, 100, and 150 GPM are shown in Figure 7-17, Figure 7-18, and Figure 7-19, respectively. As indicated by the drawdown analysis, head differences for increasing pumping rates lie within a range of 28.0 mm in the vicinity of the pumping well, which is slightly increased compared to the previous variants. Typically, the capture zone for same pumping rate with a lower hydraulic conductivity (i.e., lower transmissivity) should be wider than the capture zone with higher hydraulic conductivity. As expected, the capture zones are wider than the capture zones for unchanged and average parameter condition. However, the travel length is shorter compared to unchanged average parameter condition.

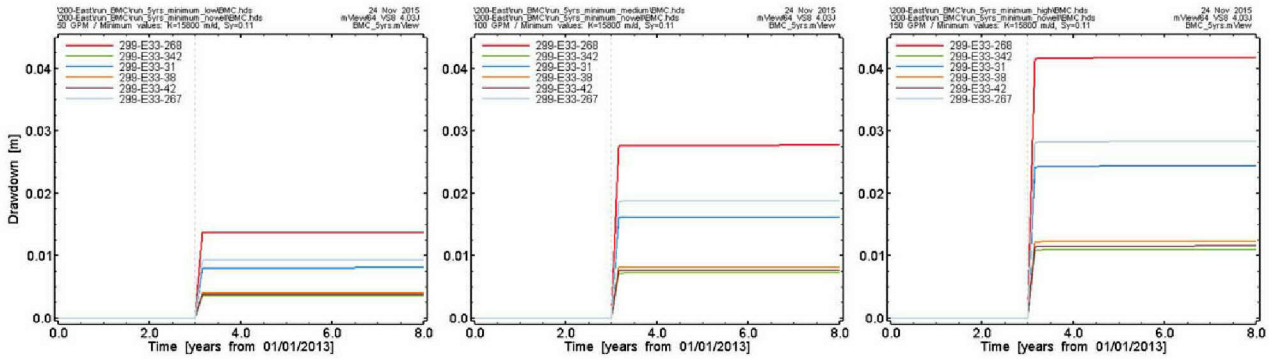

Figure 7-16. Comparison between Drawdowns Simulated with the TMR model with the Minimum Parameters and Pumping Rate of 50 (left), 100 (middle), and 150 GPM (right)

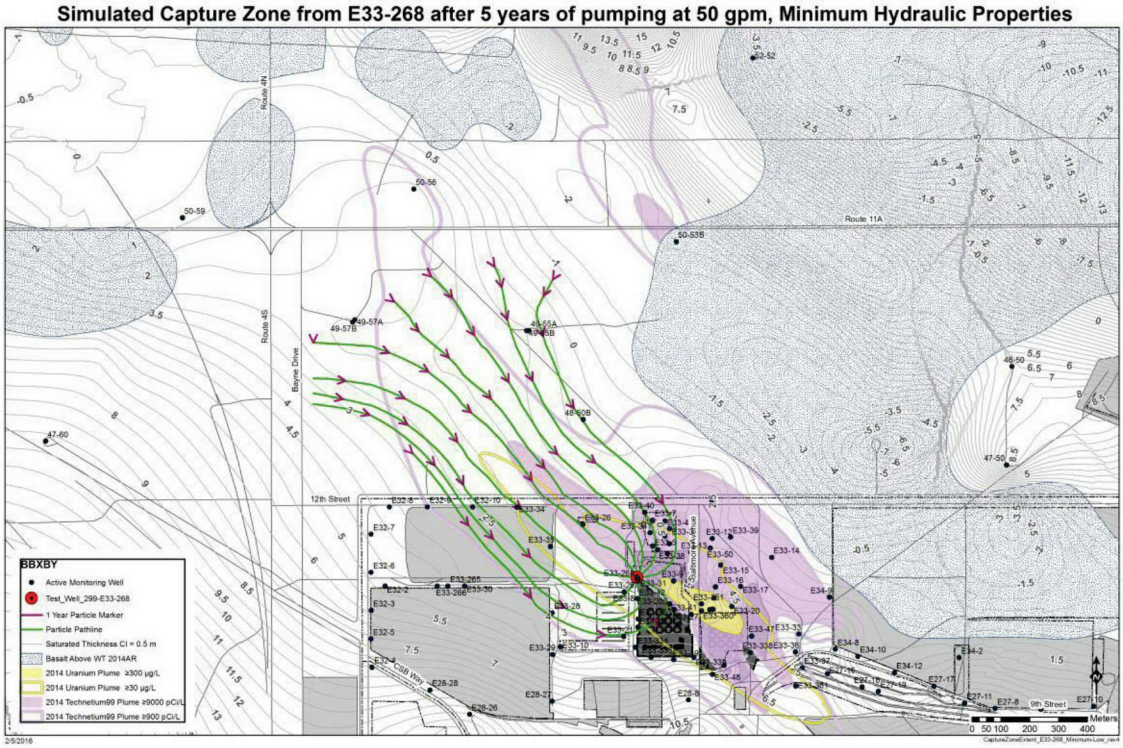

Figure 7-17. Predicted Hydraulic Capture Zone at 1-year Intervals for Minimum Hydraulic Properties with 50 GPM Pumping (backward particle track)

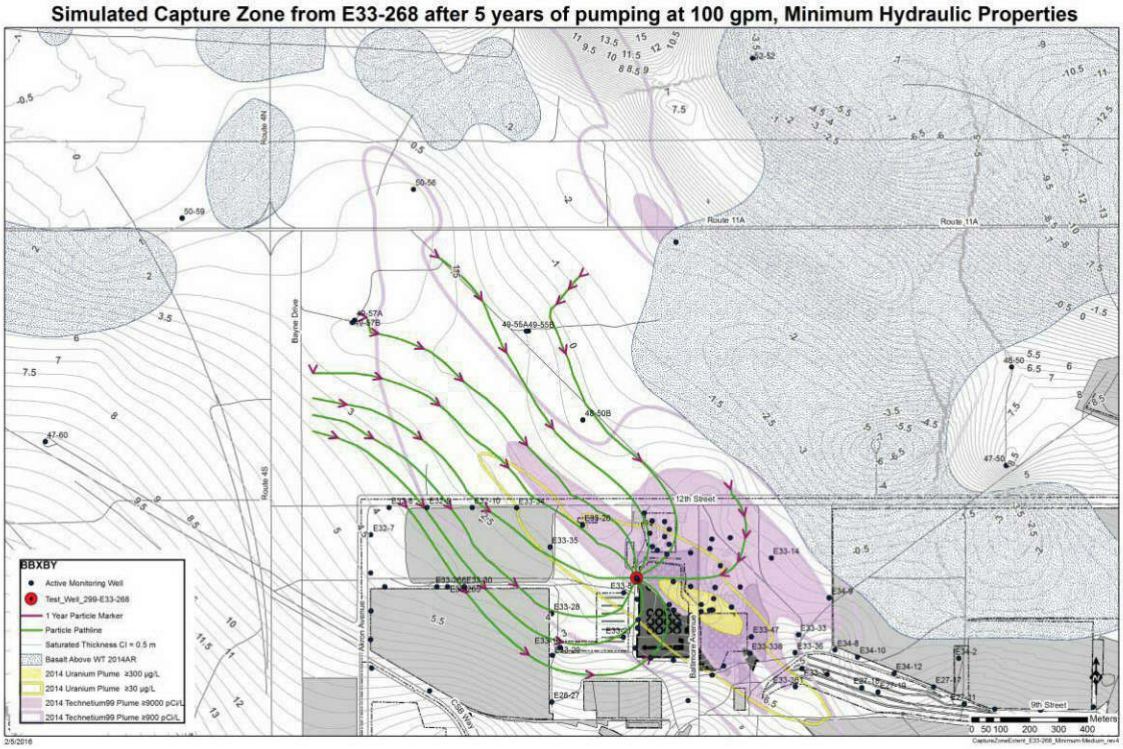

Figure 7-18. Predicted Hydraulic Capture Zone at 1-year Intervals for Minimum Hydraulic Properties with 100 GPM Pumping (backward particle track)

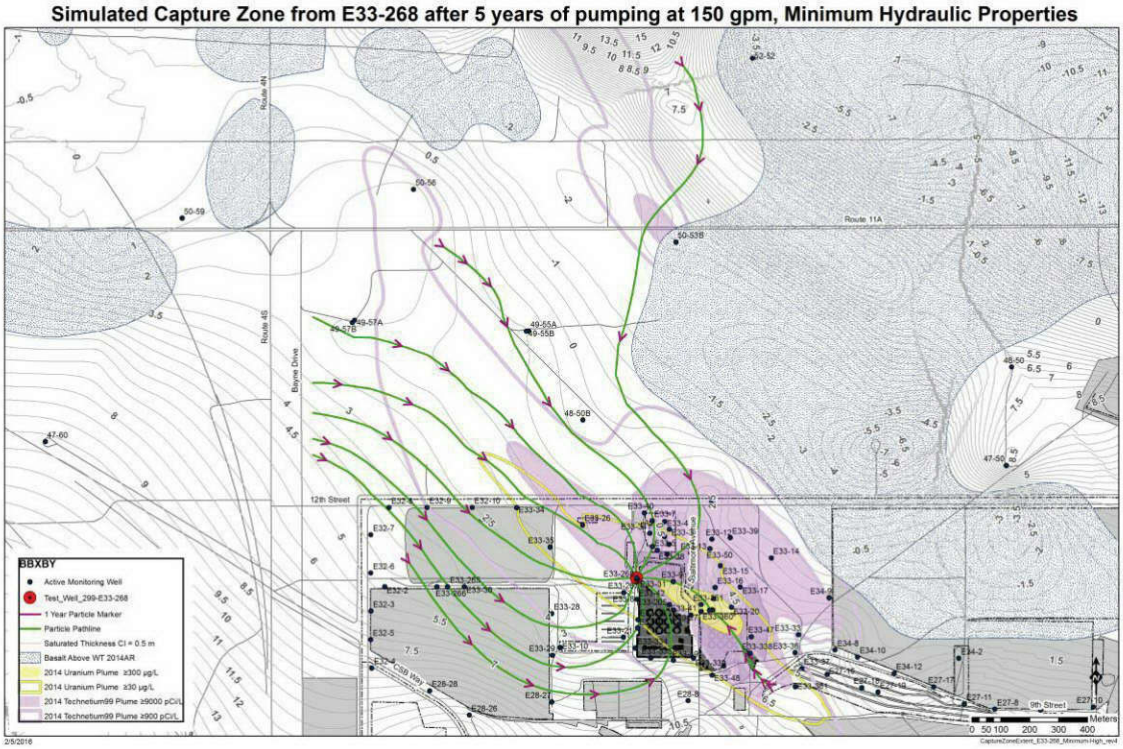

Figure 7-19. Predicted Hydraulic Capture Zone at 1-year Intervals for Minimum Hydraulic Properties with 150 GPM Pumping (backward particle track)

7.3.4 Maximum Parameters

The input parameters in the TMR model are now changed to the maximum estimates from the 3-day pumping test, and the 5-year pumping scenario is simulated for the same pumping rates.

Drawdown analysis

Figure 7-20 shows the drawdowns simulated in pumping well 299-E33-268 and in the observation wells nearest to 299-E33-268. In this case, the lowest drawdowns are observed among the simulation variants due to the maximum hydraulic conductivity value. Drawdown in well 299-E33-268 reaches 10.2, 20.5, and 30.9 mm for 50, 100, and 150 GPM, respectively.

Capture zone analysis

The capture zones simulated after 5 years of pumping with 50, 100, and 150 GPM are shown in Figure 7-21, Figure 7-22, and Figure 7-23, respectively. Due to the higher conductivity value, the hydraulic head change observed when increasing the pumping rate does not exceed approximately 21 mm. Similarly to the previous, the capture zone is narrower than the capture zone for unchanged, average and minimum condition.

Inspection of the 5-year drawdown and capture zones over the suite of considered hydraulic properties shows little difference in capture zone for a given pumping rate. This is due to the modest variation (17,000 in the initial model to the 21,300 m/d maximum) in hydraulic conductivity.

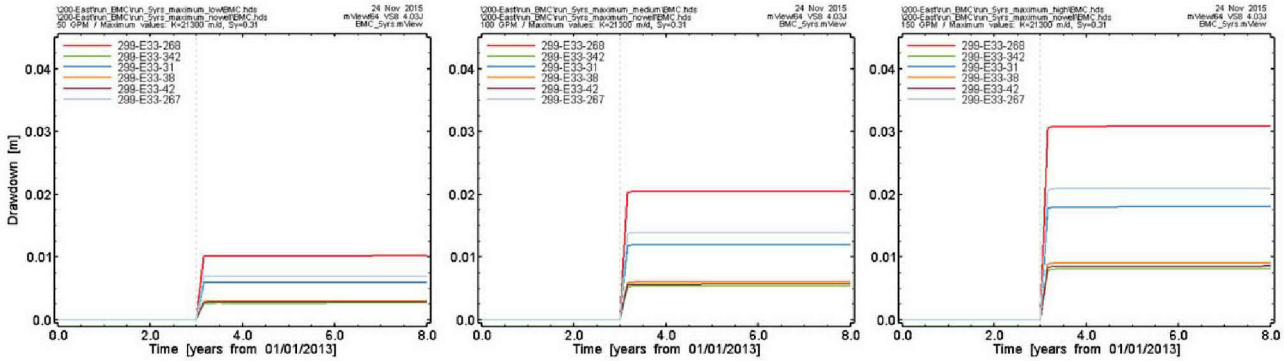

Figure 7-20. Comparison between Drawdowns Simulated with the TMR Model with the Maximum Parameters and Pumping Rate of 50 (left), 100 (middle), and 150 GPM (right)

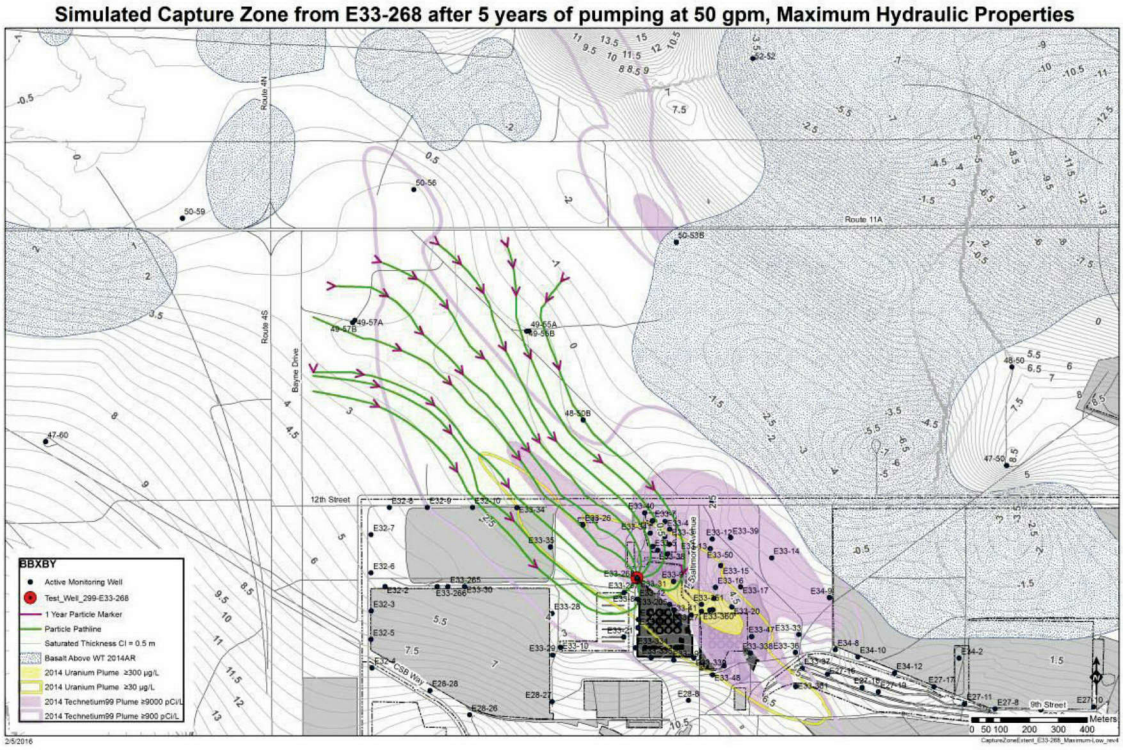

Figure 7-21. Predicted Hydraulic Capture Zone at 1-year Intervals for Maximum Hydraulic Properties with 50 GPM Pumping (backward particle track)

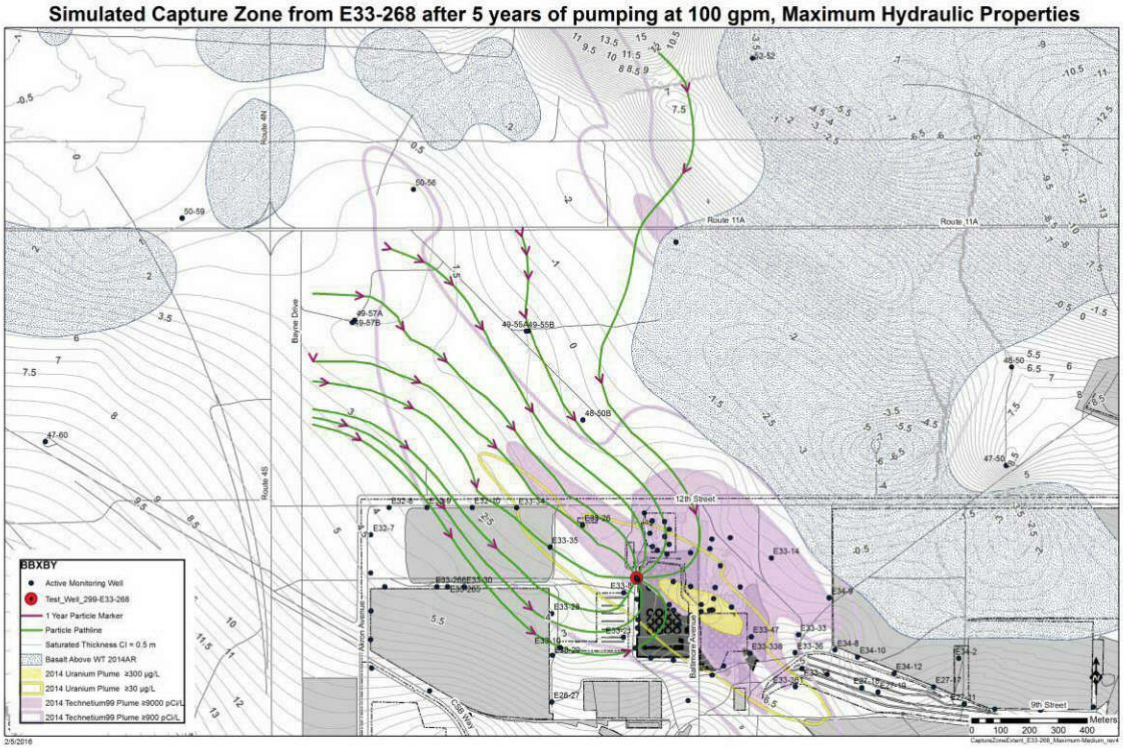

Figure 7-22. Predicted Hydraulic Capture Zone at 1-year Intervals for Maximum Hydraulic Properties with 100 GPM Pumping (backward particle track)

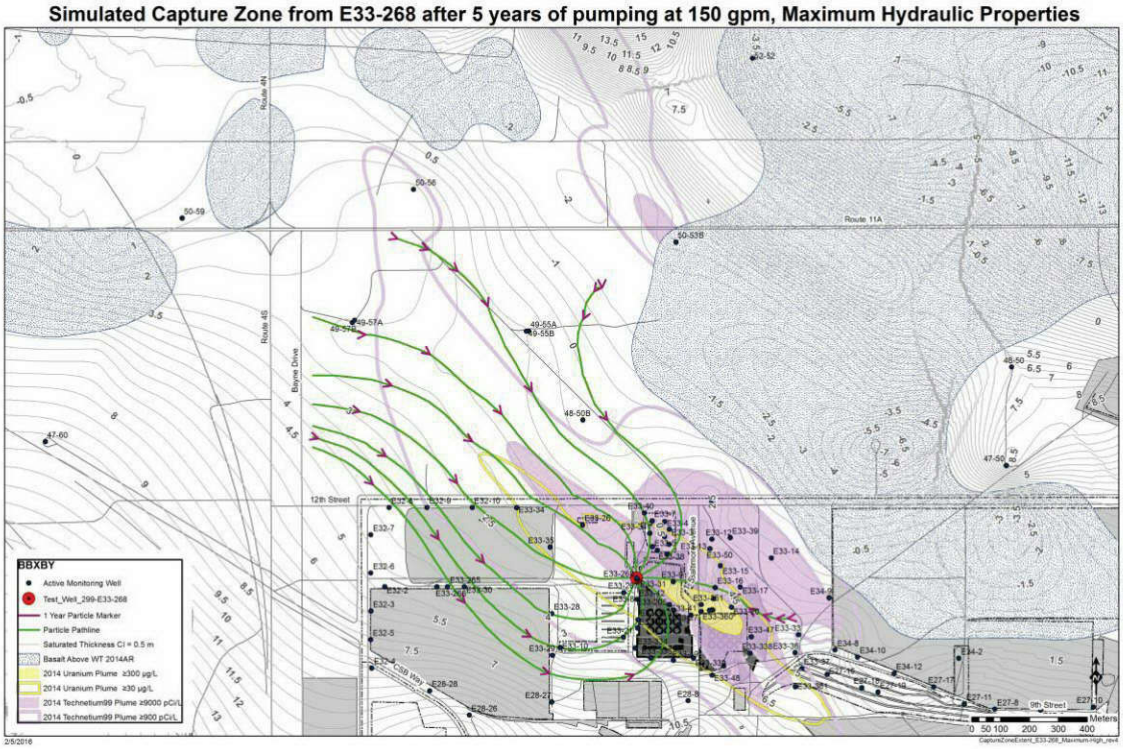

Figure 7-23. Predicted Hydraulic Capture Zone at 1-year Intervals for Maximum Hydraulic Properties with 150 GPM Pumping (backward particle track)

8 References

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Attachment A

Software Installation and Checkout Form

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:

Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:

Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 6

EXECUTABLE INFORMATION:

2. Executable Name (include path):

Following executable files in directory: [redacted]

MD5 Signature (unique ID)	Executable File Name
C3B75ADEBC7F41F15F006A0A3AED2D21	mf2k-chprc06dp.exe
C3141B0D41E084601DC2C8EB746B189F	mf2k-chprc06sp.exe
4F9E3D4A5ECF0360C8247C4279FE25F1	mf2k-mst-chprc06dp.exe
0E38BD210A582EF42CC79145C14F8E69	mf2k-mst-chprc06sp.exe
EE4D6CE61E07E0218F81822CE54499DE	modpath-mst-chprc06dp.exe
F83D1B16B26887A8C9579373D919DF4F	modpath-mst-chprc06sp.exe
D3337D49ED0AAA92E6FE6A6EB027647A	mt3d-mst-chprc06dp.exe
E6A66025170D441389642CC0A7B59749	mt3d-mst-chprc06sp.exe

3. Executable Size (bytes): MD5 signatures listed above uniquely identify executable files

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

WC95463; Dell Latitude Laptop

5. Operating System (include version number):

Windows 7 Enterprise Service Pack 1

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

Lenovo Thinkpad W540 (PSC-Lithium)

7. Operating System (include version number):

Windows 8.1 Pro

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]6\test

10. Procedure(s):

CHPRC-00259 Rev 2, MODFLOW and Related Codes Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

MF-ITC-1 and MT-ITC-1 inputs

13. Output Files:

MF-ITC-1 and MT-ITC-1 outputs

Page 1 of 2 A-6005-149 (REV 0)

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: MODFLOW and Related Codes — Software Version No.: Bld 6

14. Test Cases:

MF-ITC-1 (both standard and NST versions of MODFLOW)- run for single & double precision
MT-ITC-1 - run for single and double precision

15. Test Case Results:

All tests returned identical results as base cases

16. Test Performed By: H Rashid

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update): Installation approved, noted in HISI entry. -WEN

Prepared By:

19. _____ Software Owner (Signature) — WE Nichols Print — _____ Date

20. Test Personnel:

Sign	Print	Date
S.M. Hafakur Rashid	H Rashid	10/17/2014
	N/R (CHPRC-00259 Rev 2)	

Approved By:

21. _____ Software SME (Signature) — _____ Print — _____ Date

Page 2 of 2 — A-6005-149 (REV 0)

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:

Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:

Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 6

EXECUTABLE INFORMATION:

2. Executable Name (include path):

Following executable files in directory: [redacted]

MD5 Signature (unique ID)	Executable File Name
C3B75ADEBC7F41F15F006A0A3AED2D21	mf2k-chprc06dp.exe
C3141B0D41E084601DC2C8EB746B189F	mf2k-chprc06sp.exe
4F9E3D4A5ECF0360C8247C4279FE25F1	mf2k-mst-chprc06dp.exe
0E38BD210A582EF42CC79145C14F8E69	mf2k-mst-chprc06sp.exe
D3337D49ED0AAA92E6FE6A6EB027647A	mt3d-mst-chprc06dp.exe
E6A66025170D441389642CC0A7B59749	mt3d-mst-chprc06sp.exe

3. Executable Size (bytes): MD5 signatures listed above uniquely identify executable files

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

WC95463; Dell Latitude Laptop

5. Operating System (include version number):

Windows 7 Enterprise Service Pack 1

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

KXGVD; Dell Vostro 430

7. Operating System (include version number):

Windows 7 Professional Service Pack 1

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]

10. Procedure(s):

CHPRC-00259 Rev 2, MODFLOW and Related Codes Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

MF-ITC-1 and MT-ITC-1 inputs

13. Output Files:

MF-ITC-1 and MT-ITC-1 outputs

Page 1 of 2 A-6005-149 (REV 0)

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: MODFLOW and Related Codes Software Version No.: Bld 6

14. Test Cases:

MF-ITC-1 (both standard and MST versions of MODFLOW)- run for single & double precision
MT-ITC-1 - run for single and double precision

15. Test Case Results:

FC: no differences encountered

16. Test Performed By: Alexandros Papafotiou

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update): Installation Approved and recorded in HISI Entry 2517 (MODFLOW) and 2518 (MT3DMS

Prepared By:

19.	WE Nichols	
Software Owner (Signature)	Print	Date

20. Test Personnel:

	Alexandros Papafotiou	02/05/2015
Sign	Print	Date
Sign	Print	Date
	N/R (CHPRC-00259 Rev 2)	
Sign	Print	Date

Approved By:

21.		
Software SME (Signature)	Print	Date

Page 2 of 2 A-6005-149 (REV 0)

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Appendix C

12/17/15 Tri-Party Briefing Meeting Minutes and Presentation

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MEETING MINUTES

200-BP-5 OU Treatability Test Update

Attendees:

Alaa Aly (CHPRC)
Craig Arola (CHPRC)
Damon Delistray (Ecology) – phone
Dennis Faulk (EPA)
Jim Hanson (DOE/RL)
Tim Mullin (Ecology)
John McDonald (CHPRC)
Beth Rochette (Ecology)
Greg Thomas (CHPRC)
Kim Welsch (Ecology)

CC:

From: Greg Thomas

Date: December 17, 2016

This meeting was held in 2420 Stevens Center, Richland, room number 224, from 14:30 to 16:00 Pacific Standard Time on December 17, 2015. A summary of the discussion follows.

Objective/Purpose:

The purpose of this meeting was to present the preliminary results of the 200-BP-5 Treatability Test for the 200-BP-5 Groundwater Operable Unit as described DOE/RL-2010-74, Rev 2 to the Washington Department of Ecology (Ecology) and EPA.

Discussion:

- Greg Thomas (CHPRC) and John McDonald (CHPRC) presented a summary of the 200-BP-5 Treatability Test (see attached SGW-59590-VA)
- The presentation included the following key points:
    1) Test included defining aquifer hydraulic parameters and estimates of mass removal.
    2) The estimated mass removed from well 299-E33-268 during the 30-day constant rate test for contaminants were:
        - Uranium: 2.2 Kg
        - Technetium-99: 0.12 Ci.
        - Nitrate: 7559 Kg
        - Iodine-129: 4.67E-05 Ci

- Cyanide: 5.13 Kg

3) Also a total of 4.577 million gallons were extracted from this well in the 30-days

- Two conclusions were presented:
  1) The treatability test proved a sustainable yield of greater than 50 gpm can be maintained in the thin aquifer at the B Complex. Sustained yield of much greater than 150 gpm could be potentially be achieved for well 299-E33-268.
  2) Average hydraulic parameters derived for the unconfined aquifer were as follows:
     - Transmissivity: 41,300 m2/day
     - Specific Yield: 0.21
     - Hydraulic Conductivity: 18,800 m/day
- A path forward was presented to continue to pump up to 100 gpm with treatment at the 200 West Groundwater Treatment Facility to assess mass removal over time with continued measurements of COC concentrations until a non-time-critical removal action for B-Complex is in place. During the presentation on Slide 13, Dennis Faulk (EPA) asked what flow capacity the pipeline from 200 East to the 200 West P&T could accommodate. Jim Hanson (DOE) asked CHPRC to evaluate the total flow of the pipeline and provide that flow capacity. Jim also stated that the limitation for sending groundwater for treatment from the 200 East Area to the 200 West P&T will most likely be limited by nitrate concentrations in the B Complex groundwater and not the overall capacity of the pipeline installed for the treatability test.
- Regarding Slide 13, Damon Delistray (Ecology) noted that the MTCA Method value listed for Nitrate in the table is incorrect.
- On Slide 14, Kim Welsch (Ecology) asked what the minimum flow rate needed is to prevent the pipeline from freezing. Greg Thomas (CHPRC) stated that is was on the order of to 70 to 75 gpm below 0 degrees F.

Actions:

1. DOE/RL requested CHPRC provide a pipeline liquid flow capacity for the pipeline installed for the treatability test extending from the B Complex to the 200 West P&T to address the question by EPA.
   a. Response: CHPRC Engineering calculated a maximum flow rate of 225 gpm for the current pipeline and pump configuration installed and used for the treatability test.
2. DOE/RL requested that CHPRC correct the Nitrate MTCA Method B value in the table on Slide 13 and send the presentation back out to the group.
   a. Response: The nitrate value in the presentation has been corrected and a revised presentation attached.

200-BP-5 OU Treatability Test

12/17/15 Tri-Party Briefing

Author Greg Thomas

DOE/RL-2015-75, Draft A
APRIL 2016

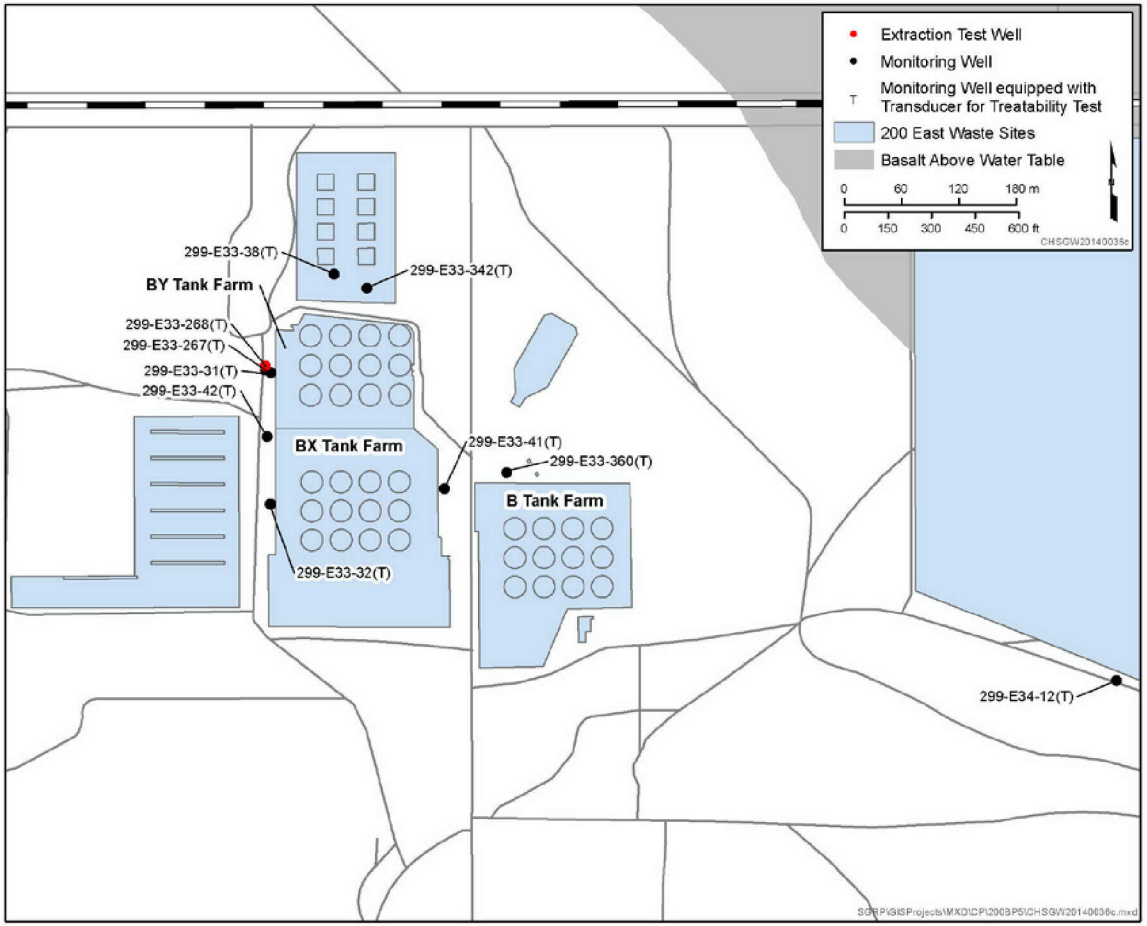
ch2m

U.S. DEPARTMENT OF ENERGY

200-BP-5 OU Treatability Test - Agenda

This presentation provides information for the Tri-Party briefing of the 200-BP-5 Treatability Test performed from August to November of 2015

- Purpose
- Scope
- Approach/Analysis
- Results
- Conclusions
- Recommendations



C-4

DOE/RL-2015-75, Draft A
APRIL 2016

200-BP-5 OU Treatability Test - Purpose

The purpose of the treatability test was to evaluate whether a 189 L/min (50 gpm) pumping rate can be sustained in the unconfined aquifer in the area of the uranium and technetium-99 groundwater plumes near the B Tank Farm. Additionally, the test will be used to support alternative development for the 200-BP-5/200-PO-1 Feasibility Study, by determining the practicality of operating a pump-and-treat system to remediate the uranium and technetium-99 plumes in this area.

200-BP-5 OU Treatability Test - Scope

Testing included 4 phases:

1) 30-day baseline barometric and water level measurement: August 11 through September 21, 2015.

2) Step drawdown test using pumping rates of 50, 100, and 150 gpm to assess optimum sustainable yield: September 29, 2015

3) 3-day constant rate pumping test (125 gpm) for estimation of aquifer hydraulic properties: October 13 to October 16, 2015

4) 30-day constant rate discharge test (100 gpm) to determine mass removal rates and sustainable yield: October 13 through October 16, 2015 and October 22 to November 19, 2015.

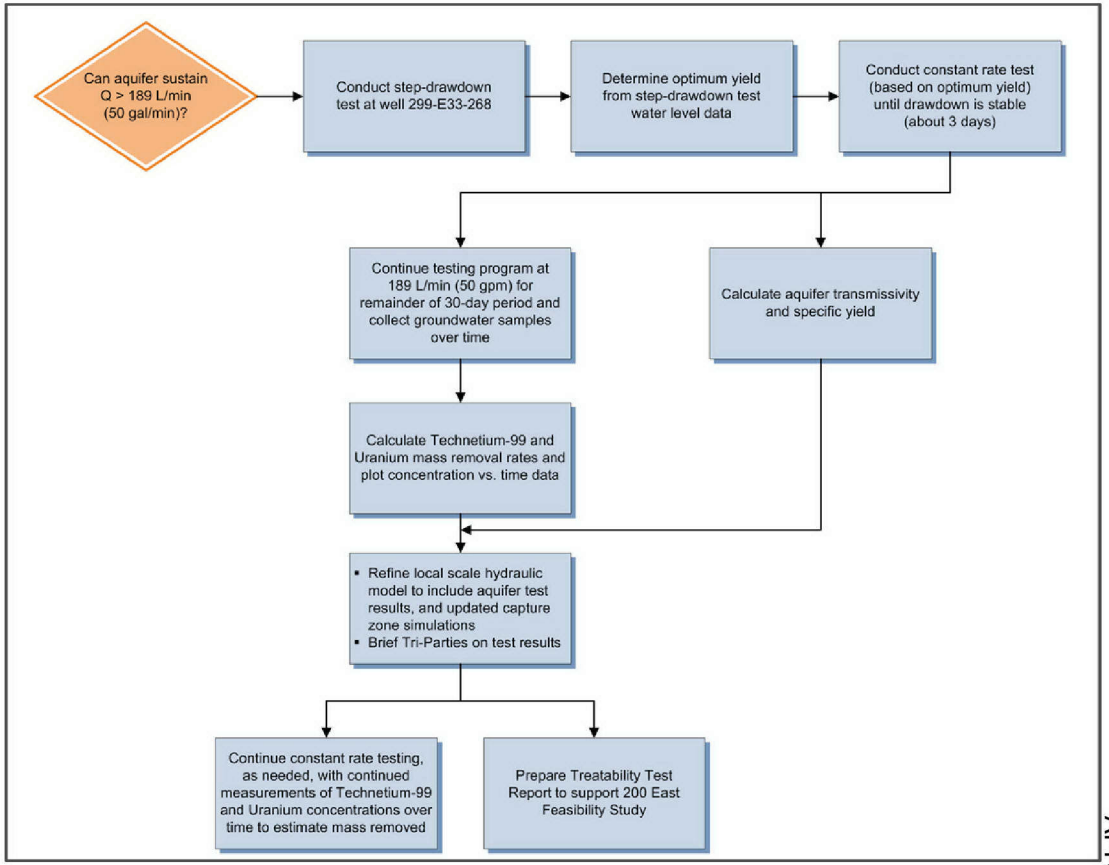


Figure 4-6 DOE/RL-2010-74, Rev. 2

C-6

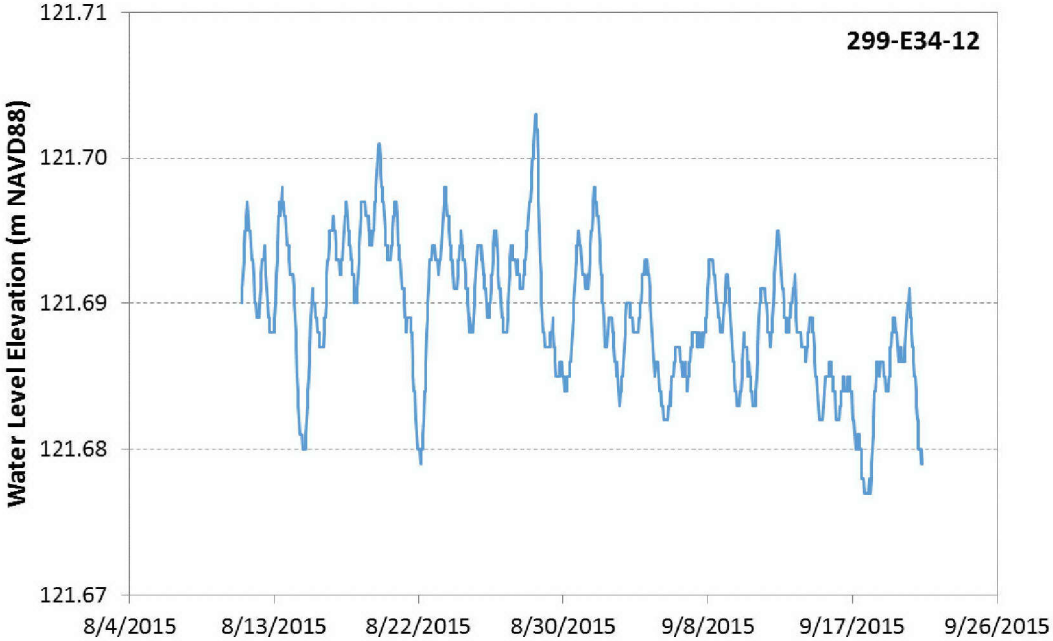
DOE/RL-2015-75, Draft A
APRIL 2016

200-BP-5 OU Treatability Test – Approach/Analysis – Baseline Water Level

Baseline Water Level

Collect 30 days of water and barometric pressure data

- Example of uncorrected level logger measurements at background well 299-E34-12



200-BP-5 OU Treatability Test – Approach/Analysis – Step Drawdown Test

Perform Test: Measure flow rate using a flowmeter and drawdown with transducers

Process Data: correct for barometric pressure fluctuations

Determine: Optimum yield/well performance (e.g., drawdown over aquifer thickness)

200-BP-5 OU Treatability Test – Approach/Analysis – 3-Day Constant Pumping Rate Test

Three step approach to 3-day constant rate test for estimation of aquifer hydraulic properties for refinement of the predictive capability of the numerical hydrologic model

Perform Test: Measure flow rate using a flowmeter and drawdown with transducers

Process Data: Correct water level by removal of barometric effects

Determine aquifer properties using AQTESOLV program (e.g., tansmissivity, specific yield, and hydraulic conductivity)

200-BP-5 Treatability Test

AQTESOLV Input Parameters

This spreadsheet documents the parameters input into AQTESOLV for analyzing drawdown data from the 200-BP-5 treatability test.

Parameter	Value	Units
Aquifer Saturated Thickness:	2.2	m
299-E33-268 (Pumping Well):		
Inside Radius of Well Casing:	0.1016	m
Radius of Downhole Equipment:	0.0381	m
Radius of well:	0.1016	m
Pumping Rate:	125	gpm
299-E33-31 (9.2 m south-southeast):		
Inside Radius of Well Casing:	0.0508	m
Radius of Downhole Equipment:	0.0127	m
Radius of well:	0.0508	m
299-E33-267 (4.5 m South):		
Inside Radius of Well Casing:	0.0508	m
Radius of Downhole Equipment:	0.0127	m
Radius of well:	0.0508	m
299-E33-342 (134 m northeast):		
Inside Radius of Well Casing:	0.0508	m
Radius of Downhole Equipment:	0.0127	m
Radius of well:	0.0508	m

200-BP-5 OU Treatability Test – Approach/Analysis – 30-Day Constant Pumping Rate Test

Three step approach to 30-day constant rate test for estimation of contaminant mass removal

1) Measure extracted water flow rate using a flowmeter
2) Collect groundwater samples for uranium, technetium-99, nitrate, iodine-129, and cyanide at the following frequency: 1, 2, and 3 days of pumping and weekly thereafter.
3) Calculate mass removed

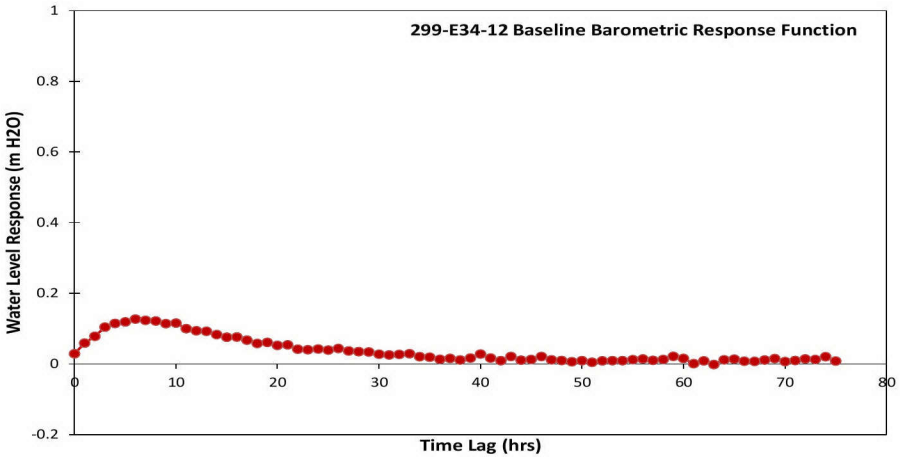
200-BP-5 OU Treatability Test – Result – Correction of Baseline Water Level

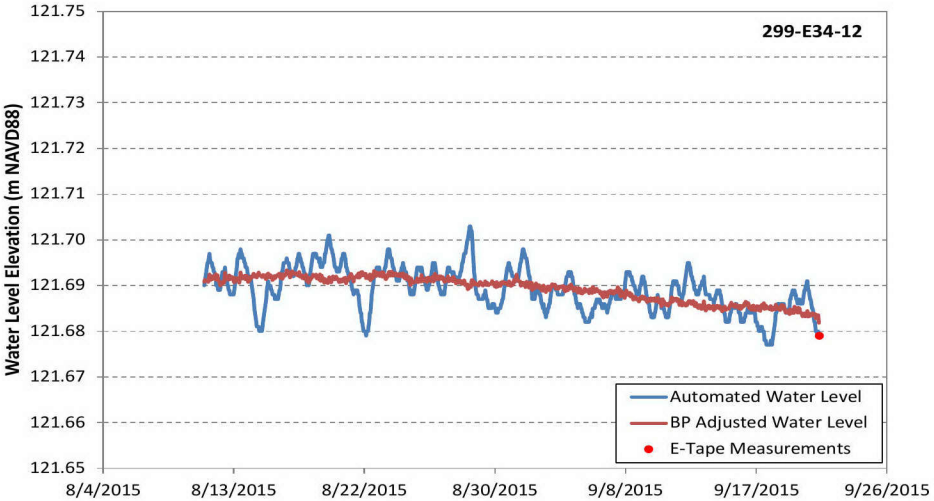
Example of:

Barometric Response Function (BRF) for well 299-E34-12 determined from baseline data(collected from August 11 through September 21, 2015)

Background water level elevation after correction for barometric effects by deconvolution (Rasmussen, T.C. and L.A. Crawford, 1997, "Identifying and Removing Barometric Pressure Effects in Confined and Unconfined Aquifers," *Ground Water* 35[3]:502-511).

- Blue: uncorrected water level
- Red: corrected water level

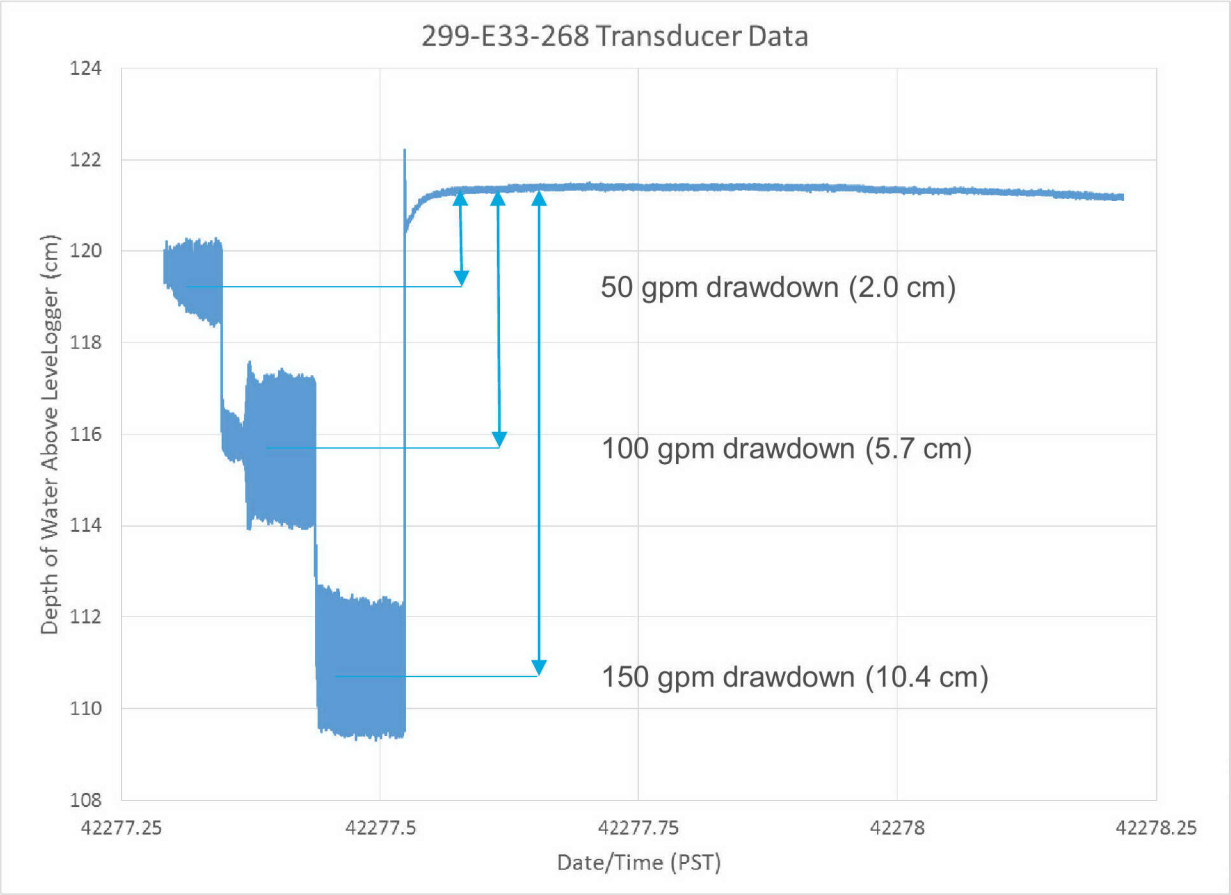




200-BP-5 OU Treatability Test – Results – Step Drawdown Test

Sustainable yield for well 299-E33-268 was >>150 gpm.

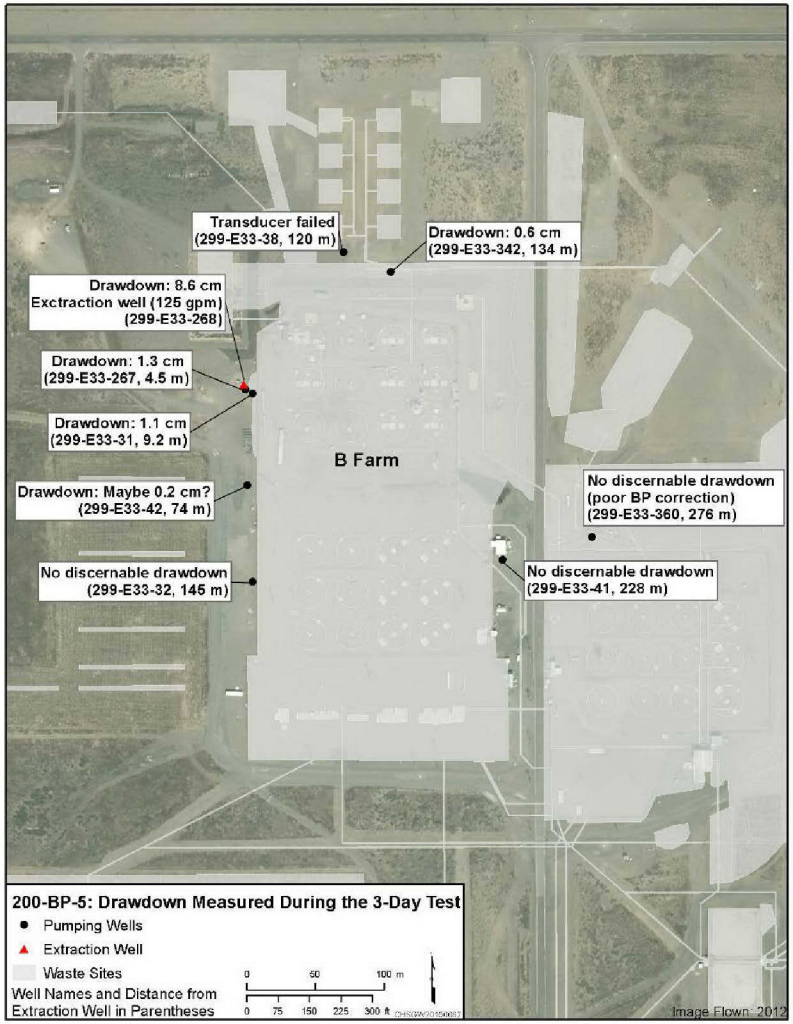
Selected maximum pump rate for constant rate test at ~125 gpm



200-BP-5 OU Treatability Test – Results – 3-Day Constant Rate Test

Measured drawdown during the 3-day, 125 gpm, constant rate test was observed at 4 wells:

Well	Well Tye	Drawdown in Centimeters	Distance from Extraction Well in Meters
299-E33-268	Extraction	8.6	0
299-E33-267	Monitoring	1.3	4.5
299-E33-31	Monitoring	1.1	9.2
299-E33-342	Monitoring	0.6	134
299-E33-42	Monitoring	0.2	74



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200-BP-5 OU Treatability Test – Results – 3-Day Constant Rate Test

Estimated aquifer hydraulic properties were derived in AQTESOLV using drawdown and recovery water level measurements by various methods (Theis, Neuman, Moench). The average value of these methods produced the following:

Transmissivity: 41,300 m^2/day

Specific Yield: 0.21

Hydraulic Conductivity: 18,800 m/day

Analysis Type			Results			
Wells	Test Type	Solution Method	Transmissivity (m2/d)	Hydraulic Conductivity (m/d)	Specific Yield	
299-E33-31	Drawdown	Theis (1935)	4.36E+04	1.98E+04	0.25	
299-E33-31	Drawdown	Neuman (1974)	4.56E+04	2.07E+04	0.18	
299-E33-31	Recovery	Theis (1935)	4.12E+04	1.87E+04	0.63	Unrealistic specific yield
299-E33-31	Recovery	Neuman (1974)	4.13E+04	1.88E+04	0.62	Unrealistic specific yield
299-E33-267	Drawdown	Theis (1935)	3.53E+04	1.60E+04	1.00	Unrealistic specific yield
299-E33-267	Drawdown	Neuman (1974)	4.26E+04	1.94E+04	0.23	
299-E33-267	Recovery	Theis (1935)	3.48E+04	1.58E+04	1.00	Unrealistic specific yield
299-E33-267	Recovery	Neuman (1974)	3.53E+04	1.60E+04	1.00	Unrealistic specific yield
299-E33-342	Drawdown	Theis (1935)	4.22E+04	1.92E+04	0.21	
299-E33-342	Drawdown	Neuman (1974)	4.20E+04	1.91E+04	0.22	
299-E33-342	Recovery	Theis (1935)	3.54E+04	1.61E+04	0.11	
299-E33-342	Recovery	Neuman (1974)	3.54E+04	1.61E+04	0.11	
299-E33-31 & E33-267	Drawdown	Theis (1935)	4.15E+04	1.89E+04	0.31	
299-E33-31 & E33-267	Drawdown	Neuman (1974)	3.96E+04	1.80E+04	0.45	Unrealistic specific yield
299-E33-31 & E33-267	Recovery	Theis (1935)	4.27E+04	1.94E+04	0.28	
299-E33-31 & E33-267	Recovery	Neuman (1974)	4.25E+04	1.93E+04	0.28	
299-E33-31, E33-267, & E33-342	Drawdown	Theis (1935)	4.37E+04	1.99E+04	0.21	
299-E33-31, E33-267, & E33-342	Drawdown	Neuman (1974)	4.36E+04	1.98E+04	0.21	
299-E33-31, E33-267, & E33-342	Recovery	Theis (1935)	4.69E+04	2.13E+04	0.14	
299-E33-31, E33-267, & E33-342	Recovery	Neuman (1974)	4.68E+04	2.13E+04	0.14	
299-E33-268, E33-31, E33-267, & E33-342	Drawdown	Moench (1997)	4.56E+04	2.05E+04	0.21	Specific yield held constant at 0.21
		Minimum:	3.48E+04	1.58E+04	0.11	
		Maximum:	4.69E+04	2.13E+04	0.31	
		Average:	**4.13E+04**	**1.88E+04**	**0.21**	

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DOE/RL-2015-75, Draft A
APRIL 2016

200-BP-5 OU Treatability Test – Approach/Analysis – 30-Day Test

The estimated mass removal from well 299-E33-268 during the 30-day:

- Uranium: 2.2 Kg
- Technetium-99: 0.12 Ci
- Nitrate: 7559 Kg
- Iodine-129: 4.67E-05 Ci
- Cyanide: 5.13 Kg

Total estimated water removed during 30-day test was:

- 4,576,772 gallons
- 17,323,084 liters

Contaminant	Number of Samples[a]	Concentration Range[b]	Average Concentration[b]	Federal Drinking Water Standard[bc]	Model Toxic Control Act Method B Cleanup Levels Non-Carcinogens at HQ = 1	Liters Removed[d]	Estimated Mass Removed from Well 299-E33-268 During 30 Day Test[e]
Uranium[f]	7	115 - 162	127.07	30	48	17,323,084	2.20
Tc-99[g]	5	6,190 - 7,960	7,016	900		17,323,084	0.12
Nitrate[f]	5	363,260 - 487,300	436,355	45,000	113,600	17,323,084	7559.01
I-129[g]	3	1.42 - 4.21	2.75	1		17,323,084	4.76E-05
Cyanide[f]	5	252 - 351	296.2	200	4.8	17,323,084	5.13

a - any duplicate samples collected are averaged with the main sample and counted as one sample

b - measurement in ug/L for nonrad and pCi/L for rad

c - Federal DWS from 40 CFR 141, "National Primary Drinking Water Regulations," with iodine-129 and technetium 99 values from EPA 816 F 00 002, Implementation Guidance for Radionuclides

d - total gallons removed from well 299-E33-268 (4,576,772)

e - measurement in Kg for non rads and curies for rads

f - 1 duplicate collected/analyzed

g - 3 duplicates collected/analyzed

200-BP-5 OU Treatability Test – Conclusions

- Treatability test proved a sustainable yield of greater than 50 gpm can be maintained in the thin aquifer at the B Complex. Sustained yield >>150 gpm for well 299-E33-268
- Hydraulic parameters of interest were derived as follows:
  - Transmissivity: 41,300 m^2/day
  - Specific Yield: 0.21
  - Hydraulic Conductivity: 18,800 m/d

200-BP-5 OU Treatability Test – Recommendations

- Continue pumping at ~100 gpm with treatment at the 200 West Groundwater Treatment Facility
- Further assess mass removal rates with continued measurements of COC concentrations from well 299-E33-268 (i.e., conveyance pipeline sample valve port)
- Transition into a non-time-critical removal action for B-Complex.

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Appendix D

2/18/16 Tri-Party Briefing Meeting Minutes and Presentation

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MEETING MINUTES

200-BP-5 OU Treatability Test Update

Attendees:

See attached sign-in sheet

From: Craig Arola
Date: February 18, 2016

This meeting was held in 2420 Stevens Center, Richland, room number 308, from 11:00 to 12:30 Pacific Standard Time on February 18, 2016. A summary of the discussion follows.

Objective/Purpose:

The purpose of the meeting was to present analysis of the 200-BP-5 Treatability Test, focusing on numerical modeling of the predicted capture zone from the test well (299-E33-268) using hydraulic parameters calculated from field-scale aquifer testing. The treatability test was described in the DOE/RL-2010-74, Rev 2, *Treatability Test Plan for the 200-BP-5 Groundwater Operable Unit*. This meeting was the second of two meetings presenting test results and analysis to the Washington Department of Ecology (Ecology) and EPA. The first meeting was held on December 17, 2015, and summarized the results of aquifer testing (step-drawdown and constant rate) including calculated hydraulic parameters.

Discussion:

- CHPRC presented CHPRC-02833-VA Rev.0, *Numerical Model Hydraulic Analysis of the 200-BP-5 Treatability Test* (document attached).
- The presentation included the following key points:
    1) The numerical analysis approach used a sub-domain, focusing on the B Complex Area, of the groundwater flow and transport model that was developed to support the 200-BP-5 Remedial Investigation (RI) (Slides 3 and 4)
    2) The model simulations used a range of hydraulic conductivity values derived from the analysis of the treatability test results (as presented in the December 17, 2015 presentation) (Slides 7 and 8)
    3) Flow directions and hydraulic gradient simulated using the B Complex Area sub-domain matched reasonably well with field observations (hydraulic gradients and flow directions) based on water level measurements in the B Complex area (Slide 11).
    4) Model simulations of drawdown in the well at 125 gpm were similar to drawdown observed during aquifer testing. The modeled drawdown values were generally higher than observed values, but the difference was at the millimeter scale.

5) Model simulations indicated that the width of the capture zone from Well 299-E33-268 is more sensitive to the pumping rate than hydraulic conductivities calculated from aquifer tests.

6) A treatability test report is currently being drafted for RL review.

- Regarding Slide 11, Ecology expressed concern about the ability to measure millimeter changes in water levels. DOE and CHPRC explained the development of the low gradient network and the key features of the network (e.g., gyroscopic surveys, using the same e-tape and same person to measure water levels in a well for consistency, and barometric pressure corrections). Ecology requested a document that describes the low gradient network and development of 200 East water table maps.

- Regarding Slide 11, Ecology asked for an explanation of how differences in flow direction could impact the capture zone analyses. CHPRC staff responded that as long as the differences between simulated and calculated flow directions are within about 15 degrees, there is limited impact on the model results.

- At the conclusion of the presentation, Ecology expressed skepticism that one well could capture an area as large as the model simulations indicate. CHPRC responded that continued operation of the extraction well will provide additional information on the capture zone development and size and that the simulation was consistent with drawdown observations during the aquifer test. Drawdown was observed in a well approximately 300 meters away from the extraction well during aquifer testing.

- At the conclusion of the presentation, Ecology asked about how heterogeneous the paleochannel in the B Complex is. CHPRC responded that the treatability test provided the first detailed information about the channel heterogeneity from a pumping test. Some heterogeneity was revealed, but hydraulic conductivity results from analysis of aquifer testing did not show a wide range. CHPRC also stated that pumping tests in the Gable Gap revealed similar results. Ecology requested an electronic copy or link to the Gable Gap tests.

- Ecology, CHPRC, and DOE discussed that a non-time critical removal action (NTCRA) for groundwater contamination beneath the B Complex is moving forward. An EE/CA has been drafted (the preferred alternative is continued extraction), and will be followed by an Action Memorandum (AM) to authorize the removal action.

Actions:

1. Ecology requested an electronic copy of, or a link to the following three documents:

    a. The most recent quarterly groundwater monitoring report for WMA C (SGW-59423, http://pdw.hanford.gov/arpir/pdf.cfm?accession=0078460H)

    b. A document describing the low gradient monitoring network and the low gradient water table maps for 200 East (SGW-58828, http://pdw.hanford.gov/arpir/pdf.cfm?accession=0079727H)

    c. Document summarizing historic pumping tests conducted on sediments in the Gable Gap similar to those near B Complex (HW-60601, http://pdw.hanford.gov/arpir/pdf.cfm?accession=D196029475)

200-BP-5 Treatability Test Capture Zone update
2/18/2016

Name	Organization	Phone Number
Craig Arola	CHPRC	376-2366
Noel Smith-Jackson	ecology	372-7926
Greg Thomas	CHPRC	373-3907
John P. McDonald	CHPRC	373-3727
Jerry Yokel		272-937
Curt Witreich		
~~Jeff Wilson~~	~~ECOLOGY~~	~~372-7882~~
Nina Menard	ECY	372-7941
Maria Skoska	ECY	372-7891
Tim Mullin	Ecology	509-372-7970
Beth Rochette	Ecology	509-372-7922
ZELMA JACKSON	ECY	509-372-7910
Jim Hanson	DOE-RL	509-373-9068
Damon Delistry (phone)	ECY	
Alaa Aly	CHPRC	

Numerical Model Hydraulic Analysis of the 200-BP-5 Treatability Test

February 1, 2016

CHPRC-02833-VA Rev. 0

DOE/RL-2015-75, Draft A
APRIL 2016

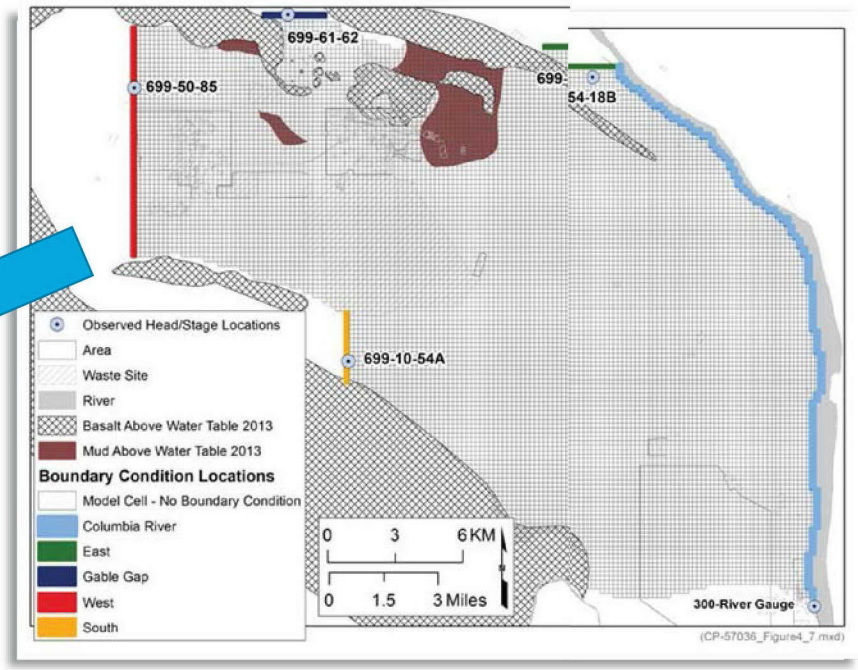
Topics

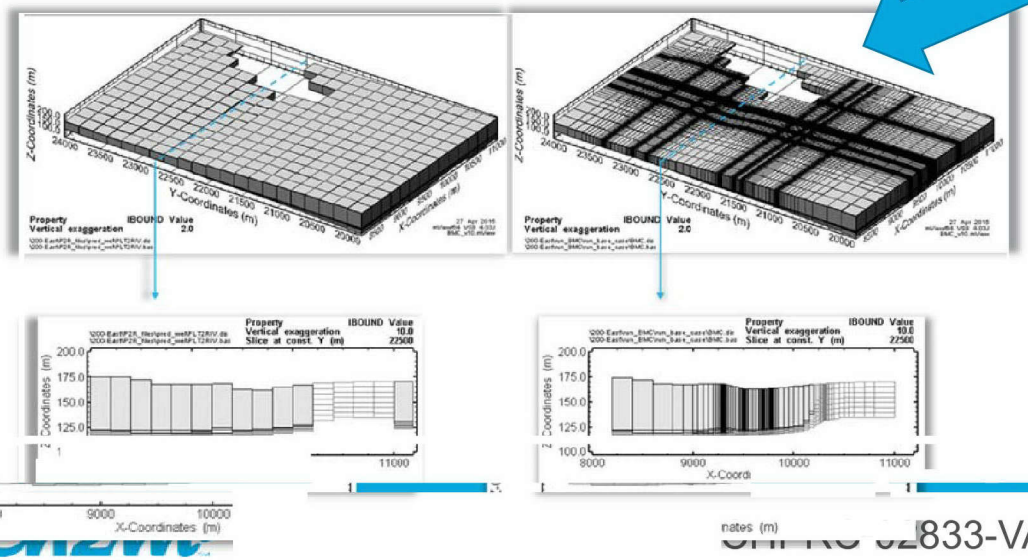
- Introduction to numerical modeling approach
- Review general capture zone analysis approach
- Review pumping-test property estimates
- Discuss numerical model drawdown analysis approach and results
- Capture zone approach and results
- Summary and conclusions

Modeling Approach - Telescopic Mesh Refinement

- Technique to create a sub model (child) using the properties and boundary conditions from a larger (parent) model
  - Usually to improve accuracy for smaller scale features
- Parent model is P2R developed for the BP-5/PO-1 RI/FS

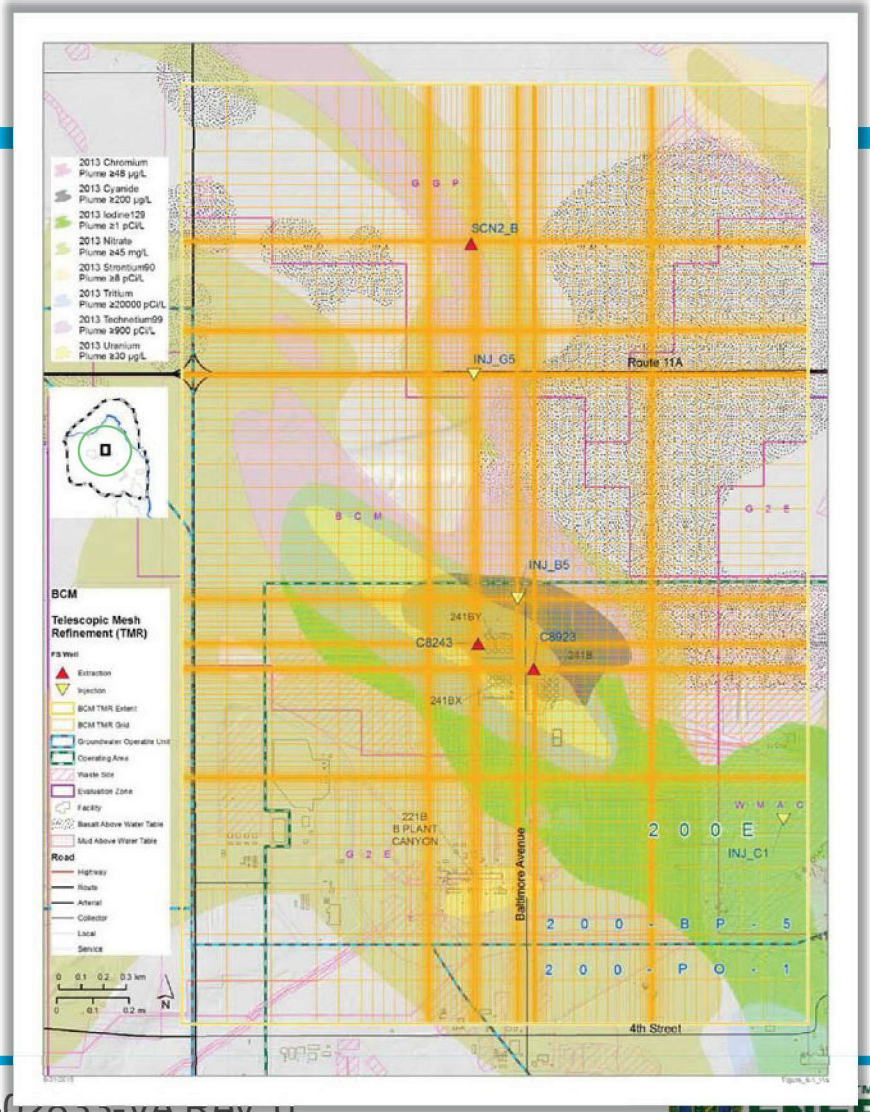
P2R Domain





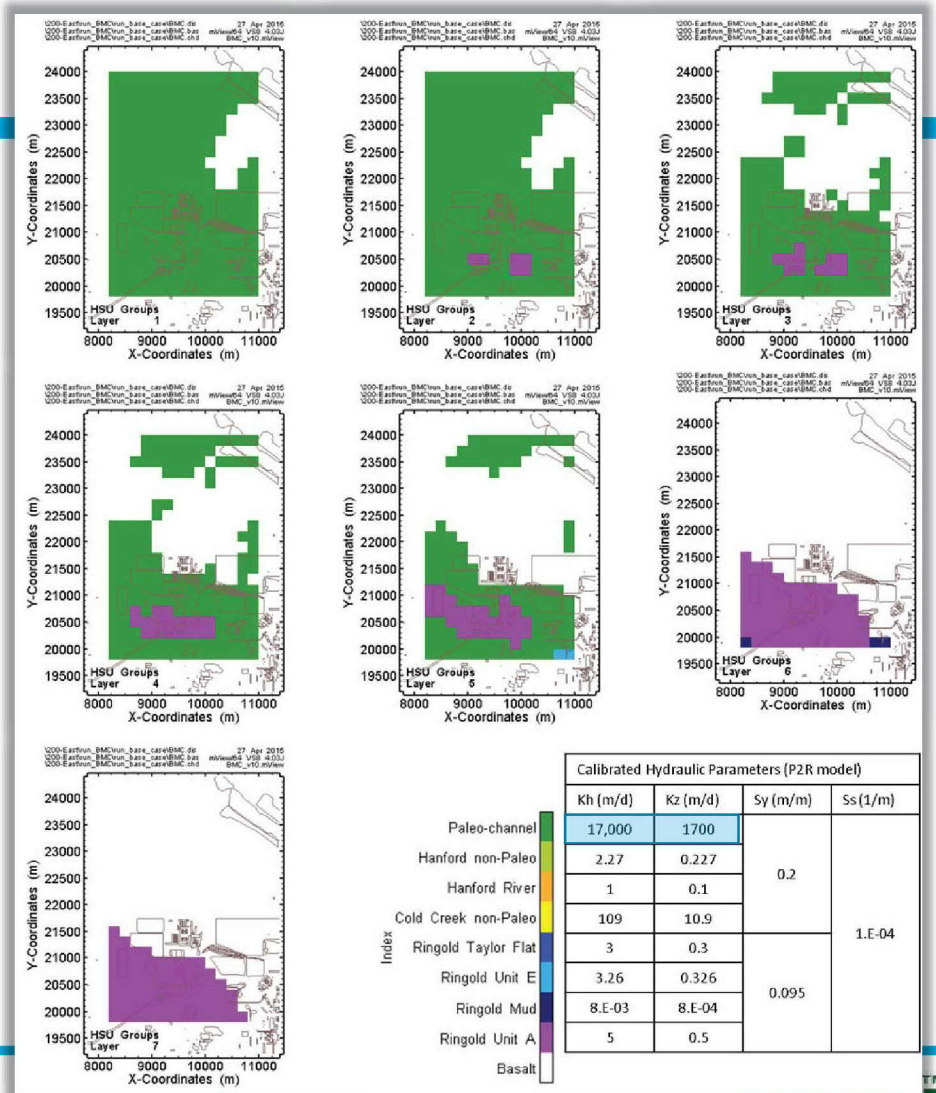
B Complex TMR Model

- 120 columns, 176 rows, 7 layers
- Grid spacing from 200 to 2 m, changing by factor of 2
- Boundary conditions interpolated from P2R model



TMR Hydraulic Conductivity

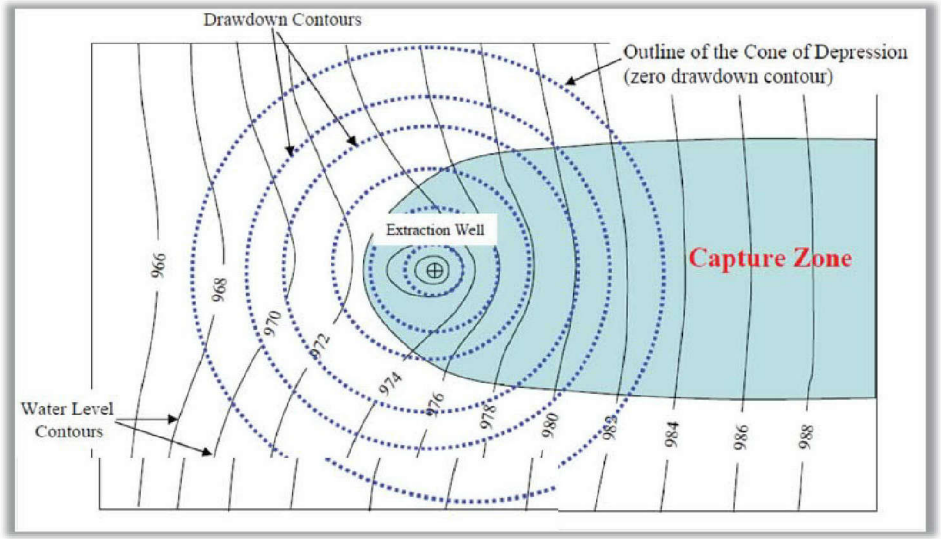
- Same as P2R parent
- Paleochannel (Cold Creek and Hanford formations) for saturated sediment under B Complex
  - K is 17,000 m/d
  - S_s is 10^{-4} 1/m
  - S_y is 0.2



Calibrated Hydraulic Parameters (P2R model)			
Kh (m/d)	Kz (m/d)	Sy (m/m)	Ss (1/m)
17,000	1700	0.2	1.E-04
2.27	0.227		
1	0.1		
109	10.9		
3	0.3	0.095	
3.26	0.326		
8.E-03	8.E-04		
5	0.5		

EPA's Approach for Performing Capture Zone Analysis

- "A Systematic Approach for Evaluation of Capture Zones at Pump and Treat Systems", EPA 600R-08-003, January, 2008.
  - Interpret water levels and hydraulic gradient
  - Gather hydraulic conductivity data
  - Capture zone width analytic computation, can include drawdown calculations
  - Numerical modeling simulating water levels in conjunction with particle tracking
- Drawdown is superimposed on the potential field to reflect pumping influence (principle of superposition) and associated capture zone



200-BP-5 OU Treatability Test – Results from 3-Day Constant-Rate Test

- Estimated aquifer hydraulic properties were with AQTESOLV using drawdown and recovery water level measurements by various methods (Theis, Neuman, Moench). T
- The average values of these methods are as follows:
  - Transmissivity: 41,300 m^2/day
  - Specific Yield: 0.21
  - Hydraulic Conductivity: 18,800 m/day

Analysis Type		
Wells	Test Type	Solution Method
299-E33-31	Drawdown	Theis (1935)
299-E33-31	Drawdown	Neuman (1974)
299-E33-31	Recovery	Theis (1935)
299-E33-31	Recovery	Neuman (1974)
299-E33-267	Drawdown	Theis (1935)
299-E33-267	Drawdown	Neuman (1974)
299-E33-267	Recovery	Theis (1935)
299-E33-267	Recovery	Neuman (1974)
299-E33-342	Drawdown	Theis (1935)
299-E33-342	Drawdown	Neuman (1974)
299-E33-342	Recovery	Theis (1935)
299-E33-342	Recovery	Neuman (1974)
299-E33-31 & E33-267	Drawdown	Theis (1935)
299-E33-31 & E33-267	Drawdown	Neuman (1974)
299-E33-31 & E33-267	Recovery	Theis (1935)
299-E33-31 & E33-267	Recovery	Neuman (1974)
299-E33-31, E33-267, & E33-342	Drawdown	Theis (1935)
299-E33-31, E33-267, & E33-342	Drawdown	Neuman (1974)
299-E33-31, E33-267, & E33-342	Recovery	Theis (1935)
299-E33-31, E33-267, & E33-342	Recovery	Neuman (1974)
299-E33-268, E33-31, E33-267, & E33-342	Drawdown	Moench (1997)

TMR Drawdown Analysis Approach

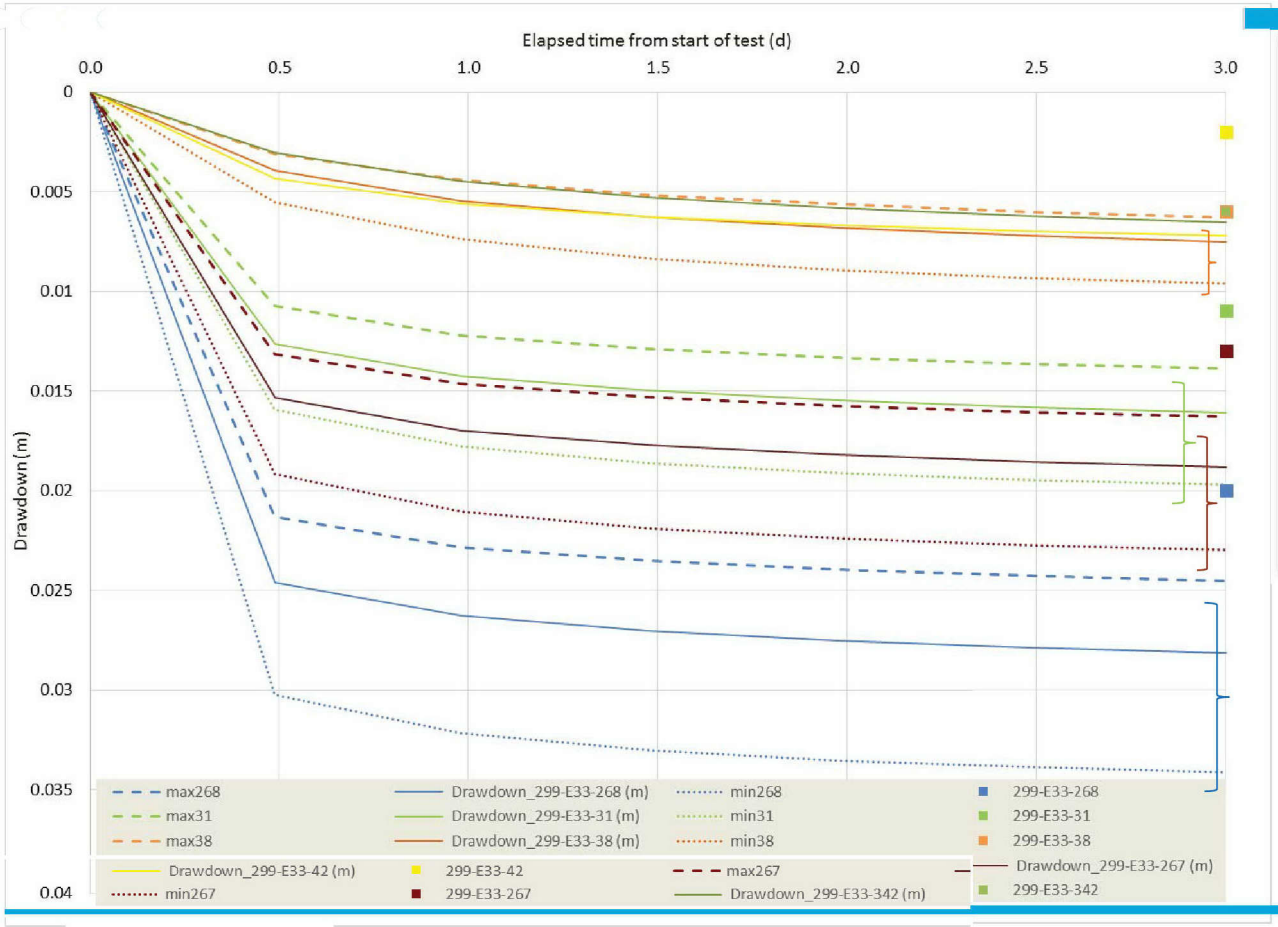
- Simulate 3 day test to test TMR and data consistency for capture zone analysis by:
  - Specifying pumping rate
  - Specifying test-estimated hydraulic parameters (minimum, average, maximum K and S_y)
    - K = 15,800 m/d, S_y = 0.11
    - K = 18,800 m/d, S_y = 0.21
    - K = 21,300 m/d, S_y = 0.31
  - Simulating 3 days of pumping
  - Comparing computed to measured drawdown

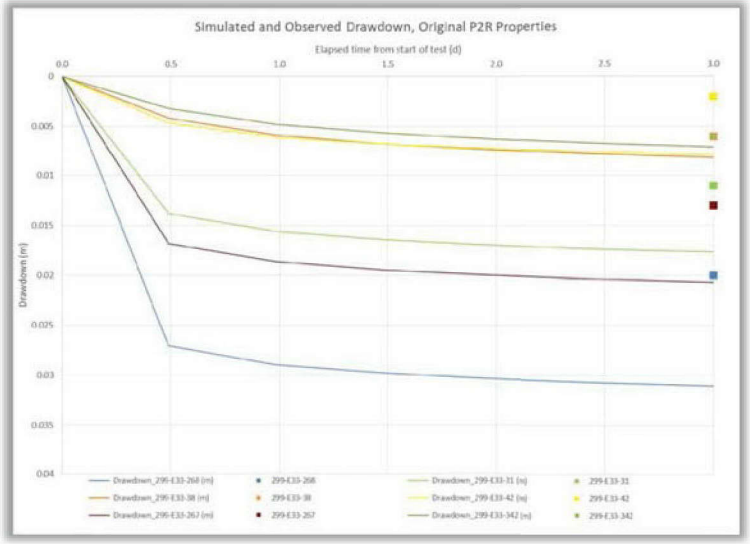
Model Parameters

Saturated thickness → Specific storage/yield → Hydraulic conductivity

Variability

3-Day Test Observed and Simulated Drawdown

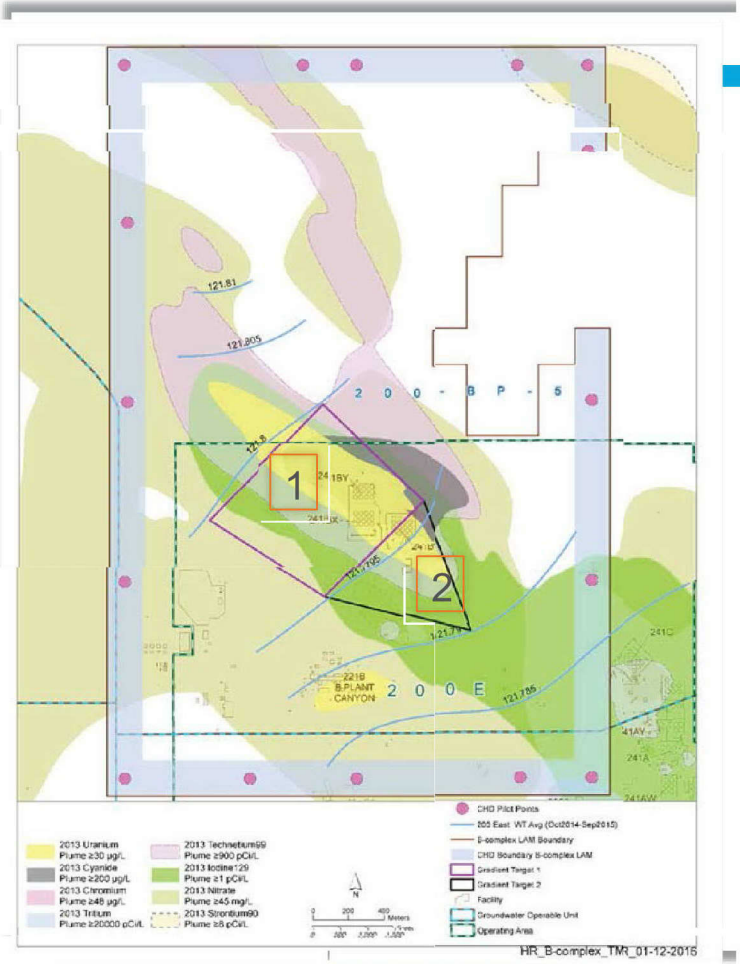




- Drawdown computed with maximum, average, minimum properties
  - shown for wells 299-E33-268, 299-E33-267, 299-E33-31, 299-E33-38
- Data and P2R TMR computed agree with drawdown over the range of properties

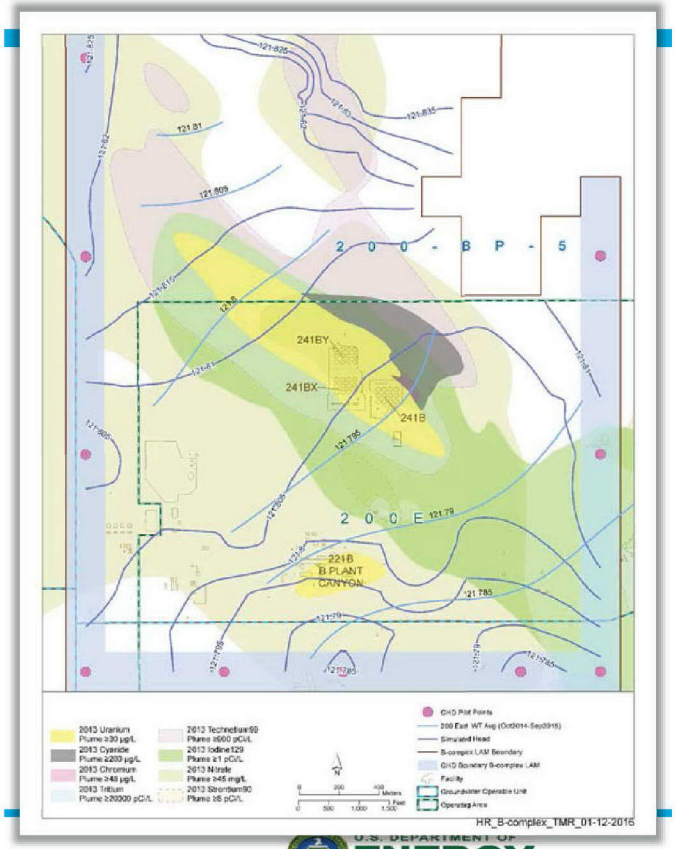
TMR Boundary Conditions

- Drawdown reasonably represented by P2R TMR model
  - Part of capture zone analysis
- Boundary conditions developed using 2011 data
  - Extrapolated forward in time
  - Local gradients depend on TEDF discharge, which are annual averages
- Actual groundwater flow direction is more northwest-southeast than extrapolated conditions
  - Need to adjust represent recent observations
  - This affects capture zone direction

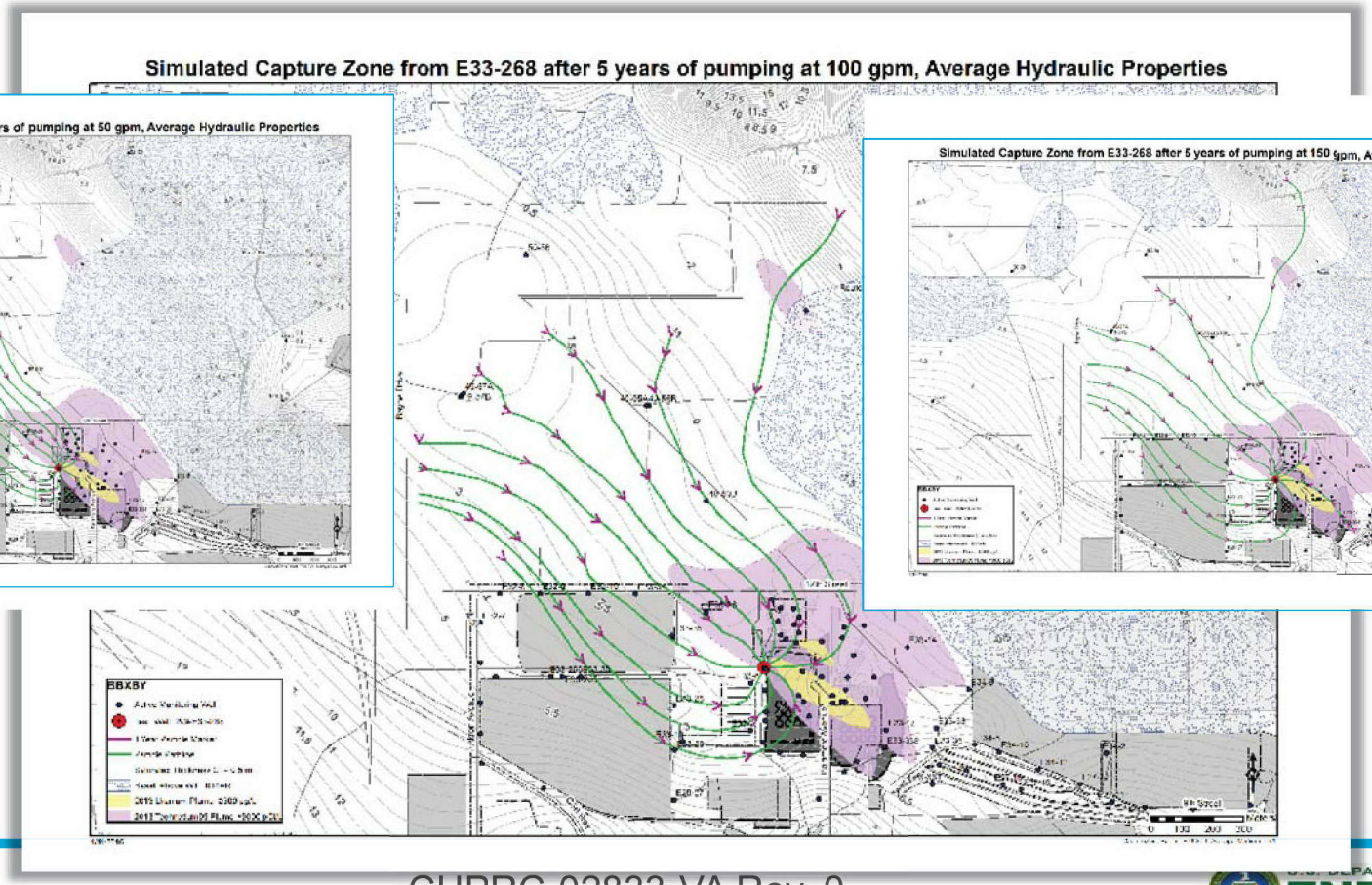


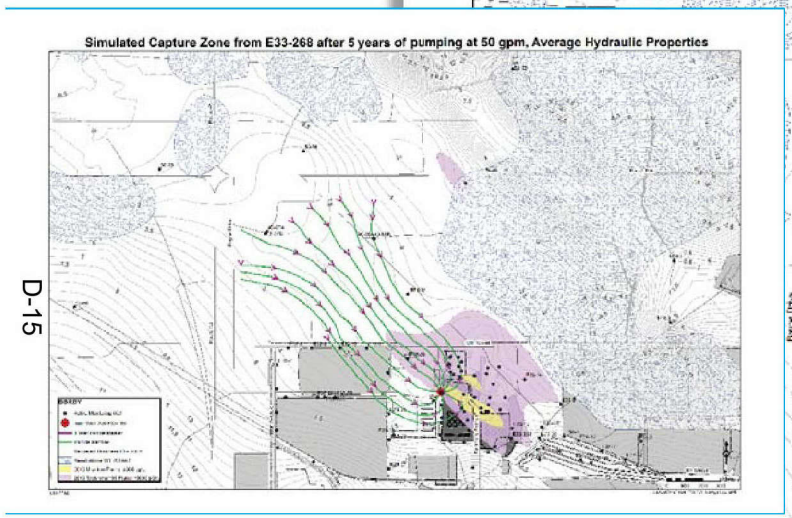
TMR Boundary Condition Adjustment Results

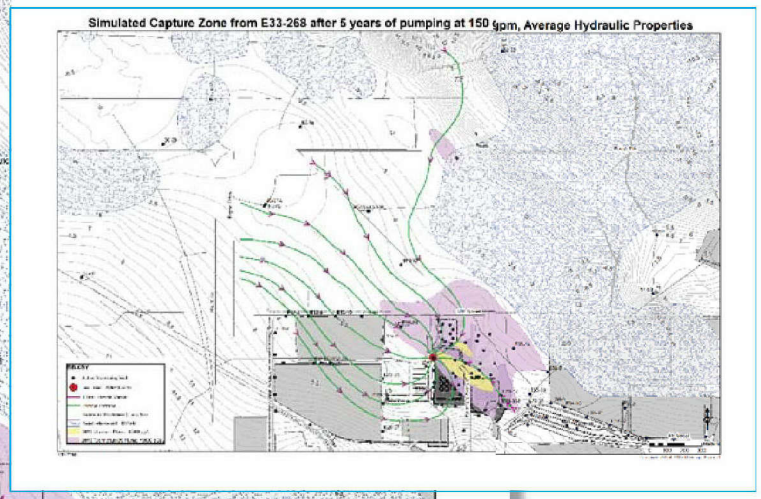
- Adjust boundary conditions mathematically to match mapped surface
  - "calibration"
  - No changes to properties
  - No changes to geologic structure
  - Unchanging over time
- Hydraulic gradient:
  - Target 1: 6.5 x 10^{-6} estimated vs. simulated 8.2 x 10^{-6}
  - Target 2: 7.1 x 10^{-6} estimated vs. simulated 5.6 x 10^{-6}
- Flow direction:
  - Target 1: 135^0 estimated vs. 132^0 simulated
  - Target 2: 135^0 estimated vs. 130^0 simulated



5 Year Capture Zones –Average Properties, 50, 100, 150 gpm

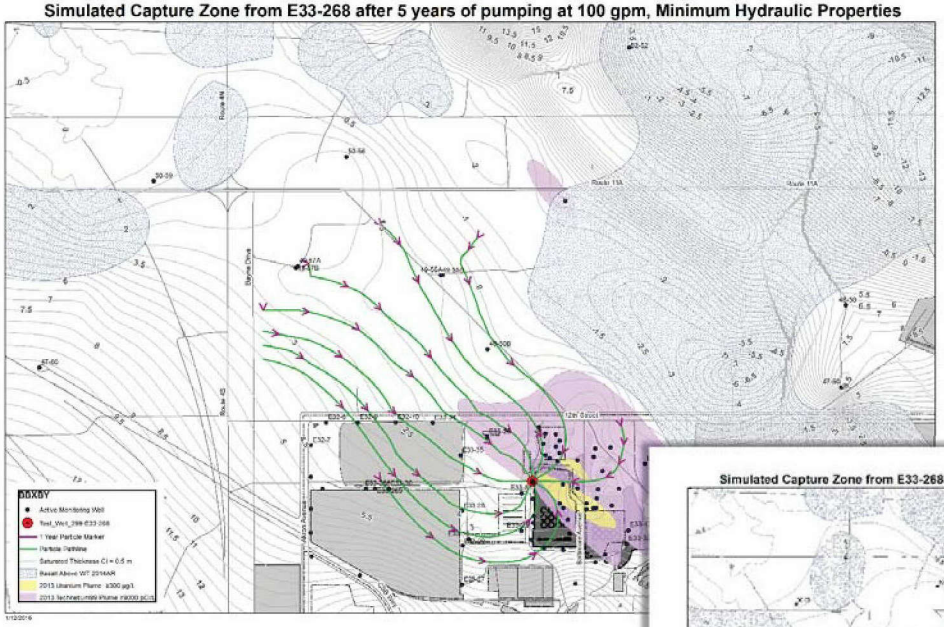




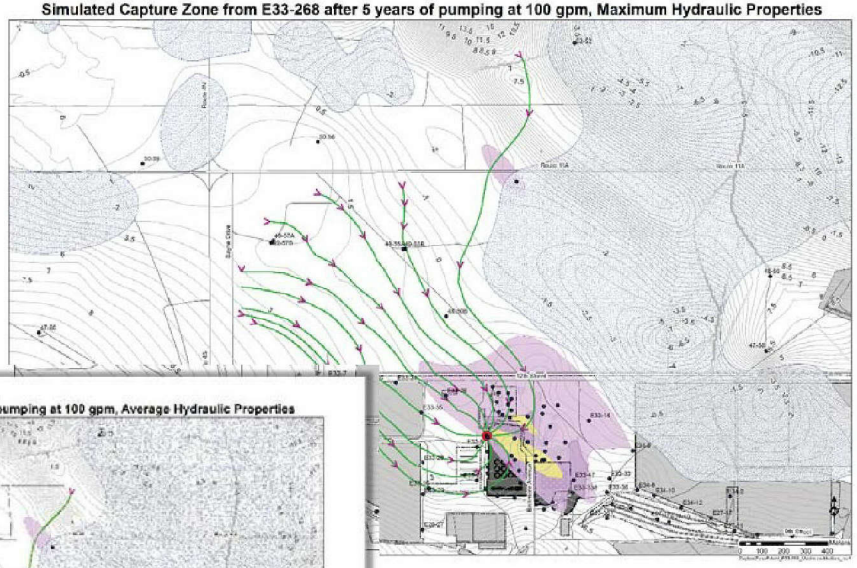


Hydraulic Property Effects on Capture Zone

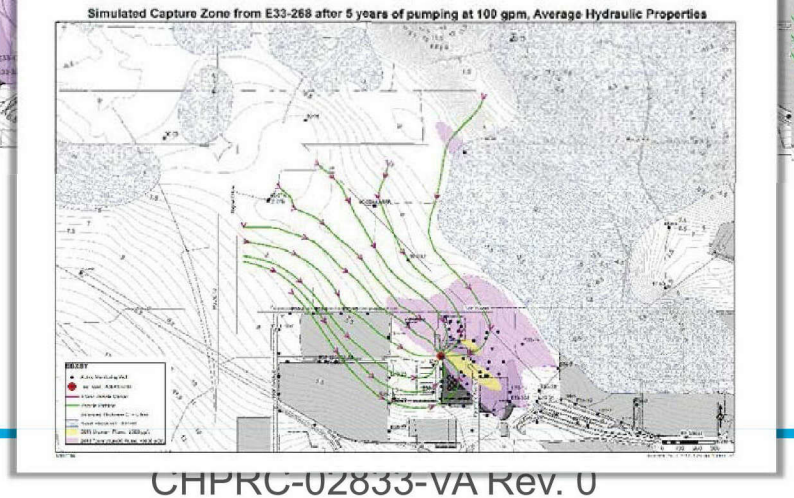
Simulated Capture Zone from E33-268 after 5 years of pumping at 100 gpm, Minimum Hydraulic Properties



Simulated Capture Zone from E33-268 after 5 years of pumping at 100 gpm, Maximum Hydraulic Properties



Simulated Capture Zone from E33-268 after 5 years of pumping at 100 gpm, Average Hydraulic Properties



Reasonableness Check

- Steady-state capture zone in an isotropic, homogeneous, 2D, confined aquifer
  - High transmissivity means short time for equilibration
  - Drawdown is so minimal (20 mm in pumping well) saturated thickness essentially doesn't change

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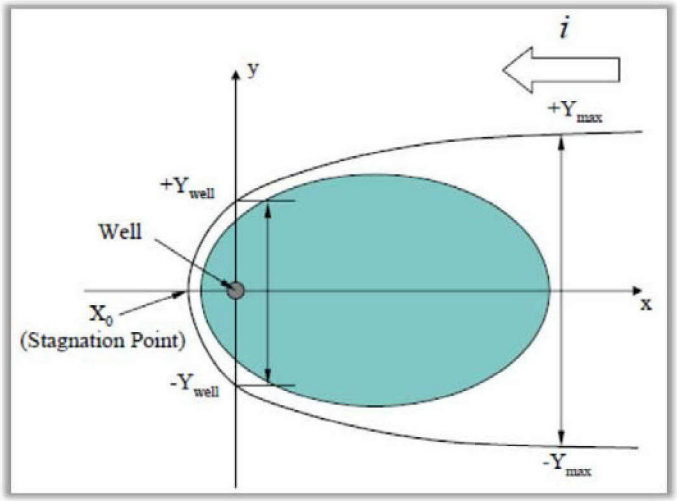
$$Y_{\max} = 100 \frac{gal}{\min} \frac{1440 \min}{1 day} \frac{0.003785 m^3}{1 gal} \Big/ 2*(18{,}880 m/d*1.5 m)*6.5x10^{-6} = 1{,}480\ m$$



$$X_0 = -Q/2\pi Ti \quad ; \quad Y_{\max} = \pm Q/2Ti \quad ; \quad Y_{well} = \pm Q/4Ti$$

Todd, D.K., 1980, *Groundwater hydrology*, 2d ed., New York: John Wiley.

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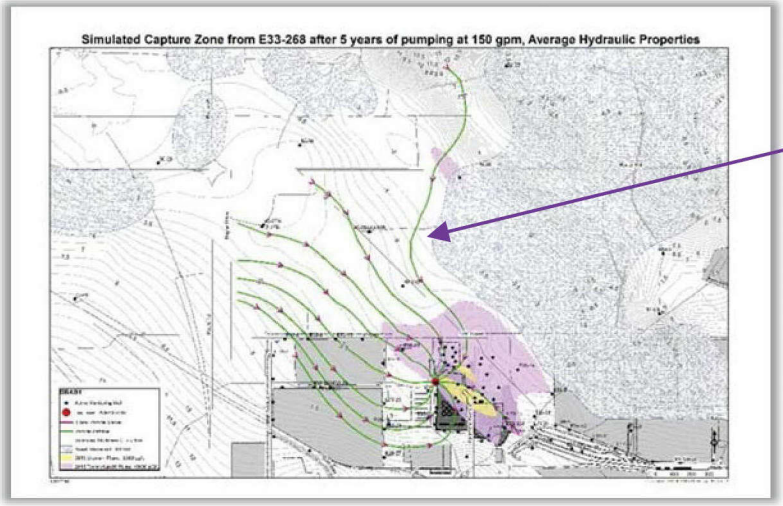
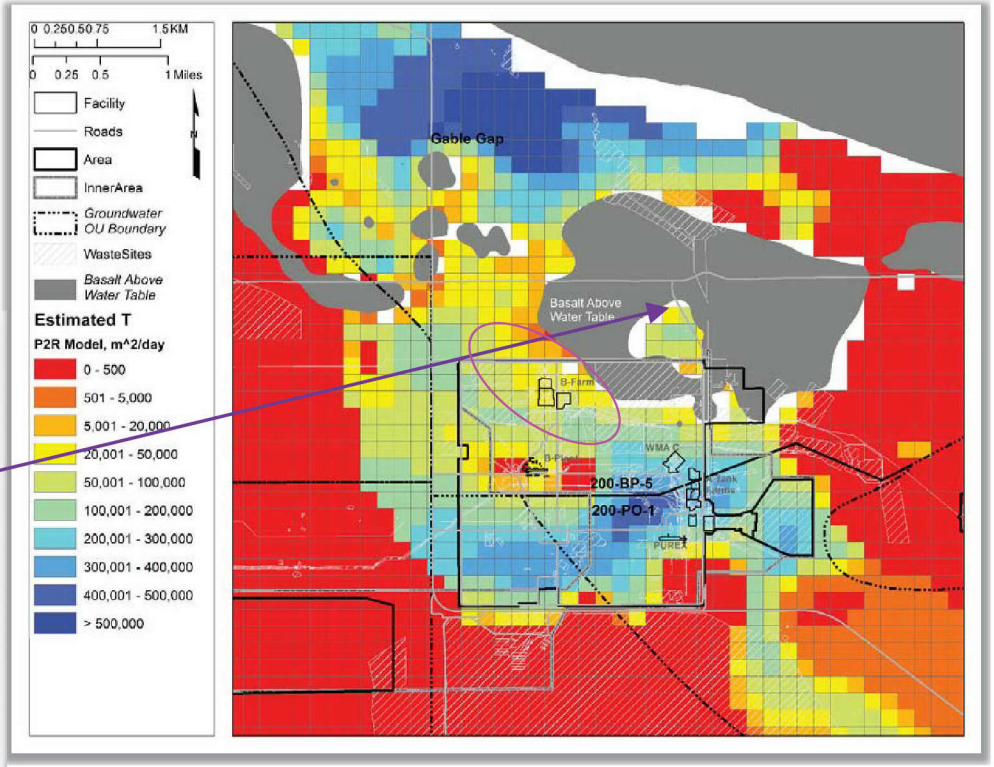
Non-Ideal Factors: *aka* Reality

- Non-idealities:
  - Basalt subcrop to the northeast
  - Inferred transmissivity heterogeneity based on structure
- Capture zone width reduced from ideal case





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Summary

1. TMR computed capture zone width is less than analytically-estimated size due to geologic factors
2. Differences in capture zone width from hydraulic property values are minor for a given pumping rate
   - Uncertainty in hydraulic conductivity from test interpretation has little influence
3. Model agreement with drawdown data using test-estimated properties increases confidence in TMR computed capture zone size
4. Delivering the test report to DOE on February 16, 2016

Conclusions

1. Pumping test analysis further substantiates high hydraulic conductivity in the area
   - Suggested by large-scale model calibration
   - Confirms the conceptual model of the high-hydraulic conductivity area in 200 East
2. The P2R model (created in 2013) has hydraulic properties broadly consistent with the pumping-test properties
   - TMR gives drawdown consistent with field data
   - Large-scale model calibration allowed effective inference of hydrogeologic properties