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Field Test Report: Preliminary Aquifer Test Characterization Results for Well 299-W15-225: Supporting Phase I of the 200-ZP-1 Groundwater Operable Unit Remedial Design

FA Spane
DR Newcomer

September 2009

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Pacific Northwest National Laboratory
Richland, Washington 99352

Abstract

A number of remedial action programs have been implemented on the Hanford Site that employ pump-and-treat well systems to control and treat contaminated groundwater as part of their remediation strategy. Predictive modeling and optimization of the design of large-scale pump-and-treat systems (particularly within thick unconfined aquifers), however, require additional hydrologic characterization information that is not commonly available at most extensively contaminated groundwater sites. To meet these objectives, the acquisition of large-scale hydraulic and storage properties and the vertical distribution profile of aquifer hydraulic conductivity are particularly critical in accurately modeling the performance of the pump-and-treat system. The addition of newly constructed extraction wells to a pump-and-treat system affords the opportunity to acquire both local hydraulic property versus depth profile information as well as large-scale aquifer characterization information. This hydraulic characterization information can be obtained both during well construction (i.e., selective well-depth characterization) and/or following construction of wells designed with long well-screen completions.

This report examines the hydrologic test results for both local vertical profile characterization and large-scale hydrologic tests associated with a new extraction well (well 299-W15-225) that was constructed during FY2009 for inclusion within the future 200-West Area Groundwater Treatment System that is scheduled to go on-line at the end of FY2011. To facilitate the analysis of the large-scale hydrologic test performed at newly constructed extraction well 299-W15-225 (C7017; also referred to as EW-1 in some planning documents), the existing 200-ZP-1 interim pump-and-treat system was completely shut-down ~1 month before the performance of the large-scale hydrologic test. Specifically, this report 1) applies recently developed methods for removing barometric pressure fluctuations from well water-level measurements to enhance the detection of hydrologic test and pump-and-treat system effects at selected monitor wells, 2) analyzes the barometric-corrected well water-level responses for a preliminary determination of large-scale hydraulic properties, and 3) provides an assessment of the vertical distribution of hydraulic conductivity in the vicinity of newly constructed extraction well 299-W15-225. The hydrologic characterization approach presented in this report is expected to have universal application for meeting the characterization needs at other remedial action sites located within unconfined and confined aquifer systems.

Summary

A final Record of Decision (EPA et al. 2008) for the 200-ZP-1 groundwater operable unit was signed by the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE), and the Washington Department of Ecology on September 30, 2008. The final selected remedy for this groundwater operable unit (OU) is a combination of pump-and-treat, monitored natural attenuation, flow-path control, and institutional controls. While interim pump-and-treat operations have been ongoing since 1994 within the 200-ZP-1 OU, the focus to date has been simply controlling the high concentration portion of the carbon tetrachloride plume (>2,000 μg/L). The interim pump-and-treat system was designed to treat water at pumping rates as high as 500 gpm. A new full-scale 200-West Area Groundwater Treatment Facility is currently being designed. This new facility will be placed in operation by December 31, 2011, and is being designed to treat water at pumping rates as high as 2,500 gpm. The new facility will treat the eight contaminants of concern identified in the final Record of Decision (EPA et al. 2008), including carbon tetrachloride, trichloroethylene, total chromium, hexavalent chromium, technetium-99, iodine-129, tritium, and nitrate.

The 200-West Area Groundwater Treatment Facility may have as many as 20 new extraction wells and 17 injection wells installed to support final pump-and-treat operations. The first of these new extraction wells to be installed was well 299-W15-225, which was constructed between February and June 2009. This well is located to the southwest of the 241-TX-TY Tank Farm. An evaluation was performed to identify hydrologic test methods that could be implemented at the new extraction well that would significantly improve the level of hydraulic property characterization within this portion of the 200-ZP-1 OU. The general objective for acquiring detailed hydraulic property information from the new extraction well 299-W15-225 was to improve and optimize the design and operation of the new 200-West Area Groundwater Treatment Facility, as described in U.S. Department of Energy/Richland Operations (DOE/RL 2008). Specific objectives of the hydrologic characterization tests conducted at the newly constructed extraction well 299-W15-225 were to determine the lateral and vertical distribution of aquifer hydraulic properties and to assess the lateral extent or *area-of-influence* of the new extraction well, 299-W15-225. This type of aquifer test characterization information is important for the detailed modeling of contaminant capture and the optimum design of pump-and-treat systems (i.e., future extraction well siting and completion).

To meet these program objectives, three hydrologic test methods that were originally identified in Spane and Newcomer (2009a) were implemented as part of the well 299-W15-225 field test characterization program. These characterization methods were designed to provide detailed lateral and vertical aquifer hydraulic property information within and surrounding the well 299-W15-225 site location. These three hydrologic tests included:

- Detailed test/depth-interval slug-test characterization during the drilling of well 299-W15-225
- Dynamic electromagnetic flowmeter survey within the completed well 299-W15-225
- Constant-rate pumping test of well 299-W15-225 and monitoring the large-scale areal response within surrounding and neighboring monitor wells.

In concert with these three identified hydrologic test methods, two step-drawdown tests and an intervening extensive well-development phase were also performed as part of the overall well characterization program. These additional well test activities were not designed directly for acquiring

aquifer property characterization information, but rather were used to assess the efficacy of extended well-development on well production performance and to assess an optimum pumping rate for the subsequent constant-rate pumping test.

Of these test methods, the constant-rate pumping test and recovery provides the best opportunity for obtaining detailed, large-scale information for a wide range of hydrologic properties (i.e., transmissivity, hydraulic conductivity, vertical and horizontal anisotropy, and storativity). Many of these properties cannot be reliably estimated using standard single-well tests or hydrologic tests of short duration. This acquisition of large-scale hydrologic characterization information is particularly important for improving the design of the remediation system, particularly as it relates to siting of additional pump-and-treat system extraction wells using numerical groundwater flow and contaminant capture models. An inherent element in analyzing large-scale hydrologic test response results is the quantification and removal of temporal barometric pressure effects on well water-level response. As demonstrated in Spane (1999, 2002, 2008a) and Spane and Thorne (2000), removing barometric pressure effects is necessary for any quantitative, detailed analysis of multi-well, constant-rate pumping tests conducted within the general 200-West Area of the Hanford Site.

The following results were obtained from the well 299-W15-225 field test characterization:

1. Barometric pressure effects impose a significant extraneous impact on monitored well water-level measurements, which are used to monitor aquifer conditions and relative performance/impact of the 200-ZP-1 OU pump-and-treat system. Barometric response patterns for the nearby monitor wells examined as part of this investigation indicate very similar time-lag characteristics and exhibit time-lag dependence ranging between ~130 and 180 hours. Barometric pressure effects within well water-level responses were successfully removed with a *universal* correction procedure that used a universal multiple-regression deconvolution technique. The corrected well water-level responses facilitated detailed analysis of hydrologic tests conducted at well 299-W15-225.

2. Slug test characterization during well construction provided discrete hydraulic property vs. depth information for two test/depth intervals within the upper-section of the unconfined aquifer. The average hydraulic property estimates for these two zones are very similar (i.e., 4.6 and 5.7 m/day), and are slightly higher than the geometric mean value (2.2 m/day) calculated for other surrounding monitor well slug tested intervals.

3. The electromagnetic borehole flowmeter survey provided detailed characterization information concerning the relative vertical distribution of hydraulic properties within the unconfined aquifer at well 299-W15-225. The relative hydraulic property profile, while variable, indicated that the highest permeability intervals occur within the middle and lower sections of the unconfined aquifer.

4. Two step-drawdown tests were conducted for selecting an optimum pumping rate for the following constant-rate pumping test and for assessing whether an intervening extensive well-development program had any discernable effect on extraction well performance. The results of the step-drawdown test comparison indicate that well 299-W15-225 is highly efficient (well efficiencies between 88 and 97%) over the pumping rates observed, and that the extraction well performance increased ~5% following implementing the extensive well development program.

5. Water-levels were monitored at 22 surrounding well locations during the 3-day constant-rate pumping test conducted at well 299-W15-225. Hydrologic responses associated with the 3-day

pumping test were observed over well distances of ≥690 m from the pumped well location. This indicates that well 299-W15-225 will impose a hydrologic *area of influence* of greater than 690 m at similar pumping rates (i.e., ~568 lpm) and over extended pumping periods commonly employed for extraction wells within the 200-ZP-1 OU pump-and-treat system.

6. Hydrologic test analysis results for the 3-day constant-rate pumping test were limited in this report to a composite multi-well analysis for the pumped well and near-field wells 299-W15-40 and 299-W15-44. The composite multi-well analysis indicated the following best-estimate aquifer property values: T = 438 m^2/day; K = 7.91 m/day (based on an aquifer thickness of 55.4 m); K_D = 0.1; S = 9.7E-4; and S_y = 0.096. The calculated aquifer hydraulic properties for the near-field monitor well/well 299-W15-225 analysis fall within the upper-range of similarly derived, large-scale values determined for the adjacent area.

In conclusion, due to the level of success demonstrated for this field test characterization, it is recommended that the hydrologic characterization methods used at well 299-W15-225 be considered for possible use at other selected ZP-1 extraction well locations. These characterization methods would be most relevant for areas where numerical modeling uncertainty can be significantly reduced by acquisition of large-scale and vertically-distributed hydrologic characterization information.

Acronyms

CHPRC	CH2M Hill Plateau Remediation Company
COC	contaminant of concern
DOE/RL	U.S. Department of Energy/Richland Operations
EBF	electromagnetic borehole flowmeter
FY	fiscal year
LED	light-emitting diode
MSL	mean sea level
OU	operable unit
PDT	Pacific Daylight Time
PNNL	Pacific Northwest National Laboratory
WMA	Waste Management Area
UHF	ultra-high frequency
USB	universal serial bus

Nomenclature

b	=	aquifer thickness; L
C_D	=	slug test damping parameter; dimensionless
D_a	=	vertical pneumatic diffusivity of the vadose zone; L^2/T
E	=	well efficiency; dimensionless
Δh_w	=	change in well water-level elevation due to atmospheric pressure change; L
K_{avg}	=	average horizontal hydraulic conductivity; L/T
K_D	=	vertical anisotropy (K_v/K_h); dimensionless
K_h	=	hydraulic conductivity in the horizontal direction; L/T
K_i	=	horizontal hydraulic conductivity of the *i*th layer; L/T
K_v	=	hydraulic conductivity in the vertical direction; L/T
L	=	test interval or well-screen length; L
L_e	=	effective well water-column length; L
ΔP_a	=	change in atmospheric pressure; F/L^2
Q	=	pumping rate; L^3/T
r_c	=	radius of well casing; L
r_o	=	radial distance from pumped well to monitor well location; L
r_w	=	radius of well; L
R_e	=	effective test radius parameter; L
s	=	drawdown; L
s'	=	corrected drawdown due to aquifer dewatering; L
s_w	=	total well drawdown; L
s_D	=	dimensionless drawdown
S	=	storativity; dimensionless
S_y	=	specific yield; dimensionless
T	=	transmissivity; L^2/T
t	=	time; T
t_s	=	dimensionless time with respect to the S
t_y	=	dimensionless time with respect to the S_y
Z_D	=	dimensionless depth within the aquifer, equal to z/b
Z	=	aquifer depth below water table; L
β	=	dimensionless unconfined aquifer parameter, equal to $K_D\, r^2/b^2$
σ	=	dimensionless unconfined aquifer parameter, equal to S/S_y

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1.0 Introduction

A number of programs have been implemented on the Hanford Site that use the pumping and treatment of contaminated groundwater as part of their remediation strategy (e.g., DOE/RL 2000). CH2M Hill Plateau Remediation Company (CHPRC) is currently assessing aquifer characterization needs to optimize pump-and-treat remedial strategies (e.g., siting of new extraction well locations) in the 200-ZP-1 Operable Unit (OU). As part of this assessment, CHPRC is focusing on hydrologic characterization opportunities that may be available for planned and newly constructed pump-and-treat extraction wells that will be supporting the new 200-West Area Groundwater Treatment Facility. This new facility will be placed in operation by December 31, 2011, and is being designed to treat water at pumping rates as high as 2,500 gpm. The new facility will treat the eight contaminants of concern identified in the final Record of Decision (EPA et al. 2008), including carbon tetrachloride, trichloroethylene, total chromium, hexavalent chromium, technetium-99, iodine-129, tritium, and nitrate. The 200-West Area Groundwater Treatment Facility may have as many as 20 new extraction wells and 17 injection wells installed to support final pump-and-treat operations. The first of these new extraction wells to be installed was well 299-W15-225, which was constructed between February and June 2009. This well is located near the southwest corner of the 241-TX-TY Tank Farm.

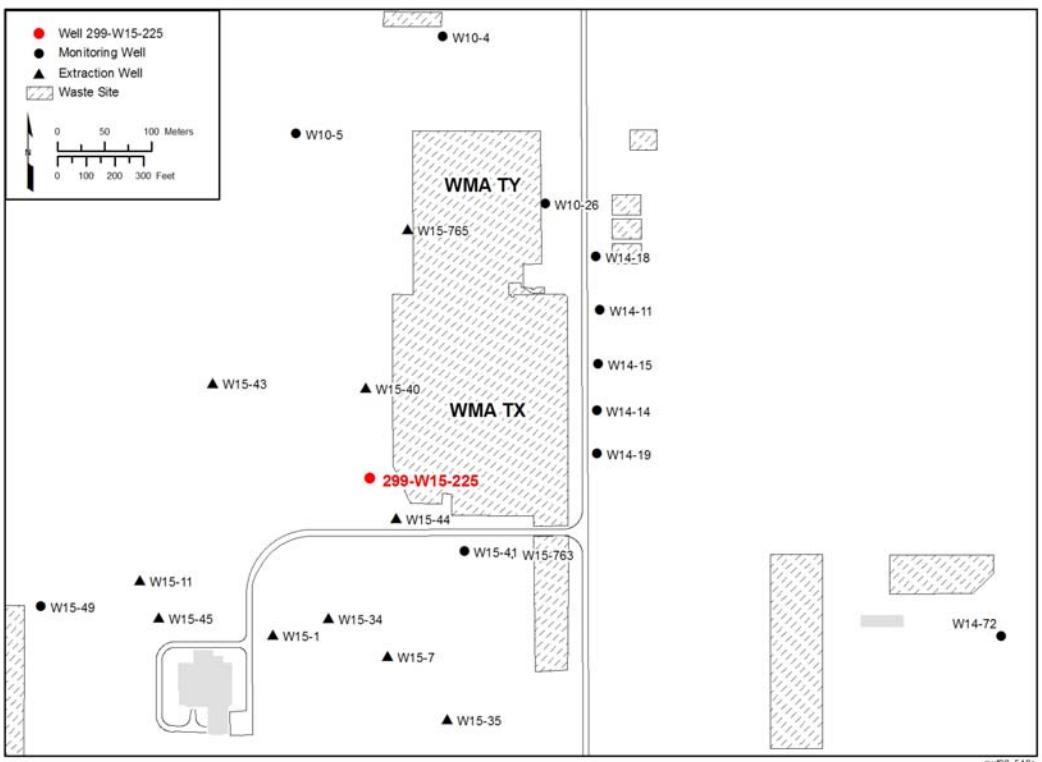


Figure 1.1. Location Map Showing New Well 299-W15-225, Adjacent WMA TX-TY Tank Farm Area, and Surrounding Well Sites

As reported in Spane and Newcomer (2009a), meetings were held on November 21 and December 1, 2008, with staff and consultants of CHPRC and Pacific Northwest National Laboratory (PNNL) to help identify specific hydrologic tests that would provide needed characterization information to support optimization of the pump-and-treat system. Based on these meeting discussions, it was decided to focus on hydrologic test methods that could be readily applied at a new, to-be-constructed ZP-1 extraction well location (i.e., 299-W15-225; see Figure 1.1 for location). The general objective for acquiring detailed hydrologic property information from the new extraction well 299-W15-225 (C7017; also referred to as EW-1 in some planning documents) was to improve and optimize the design and operation of the 200-West Area Groundwater Treatment Facility, as described in U.S. Department of Energy/Richland Operations (DOE/RL 2009). Specific objectives of the hydrologic characterization tests conducted at the newly constructed extraction well 299-W15-225 were to determine the lateral and vertical distribution of aquifer hydraulic properties and to assess the lateral extent or *area-of-influence* of the new extraction well, 299-W15-225. This type of aquifer test characterization information is important for the detailed modeling of contaminant capture and the optimum design of pump-and-treat systems (i.e., future extraction well siting and completion).

To meet these program objectives, three hydrologic test characterization methods were identified in Spane and Newcomer (2009a) and CHPRC (2009) to provide detailed lateral and vertical aquifer hydraulic property information. These three hydrologic tests included:

- Detailed test/depth-interval slug-test characterization during the drilling of 299-W15-225
- Dynamic electromagnetic borehole flowmeter survey within the completed new well 299-W15-225
- Constant-rate pumping test of well 299-W15-225 and monitoring the large-scale areal response within surrounding and neighboring monitor wells.

Of these test methods, the constant-rate pumping test and recovery provides an opportunity for obtaining detailed, large-scale information for a wide range of hydrologic properties (i.e., transmissivity, hydraulic conductivity, anisotropy, and storativity/specific yield). Many of these properties cannot be reliably estimated using standard single-well tests or hydrologic tests of short duration. This acquisition of large-scale hydrologic characterization information is particularly important for improving the design of the remediation system, particularly as it relates to siting of additional pump-and-treat system extraction wells using numerical groundwater flow and contaminant capture models. A key element in analyzing large-scale hydrologic test response results is to quantify and remove temporal barometric pressure effects on well water-level response. As demonstrated in Spane (1999, 2002, 2008b) and Spane and Thorne (2000), it is necessary to remove barometric effects for any quantitative, detailed analysis of multi-well constant-rate pumping tests conducted within the general 200-West Area of the Hanford Site.

This report discusses hydrologic characterization tests that were conducted during the construction and immediately following completion of ZP-1 extraction well 299-W15-225 during FY2009. This report section describes the general hydrogeologic setting and pertinent details concerning the construction of extraction well 299-W15-225. Section 2.0 provides a general discussion concerning the performance and analysis of hydrologic test characterization methods conducted at well 299-W15-225. Section 3.0 describes the relative effects of barometric pressure fluctuations and their removal from monitor well water levels used in this investigation. Analysis results for hydrologic tests conducted in well 299-W15-225 are given in Section 4.0. Conclusions and recommendations for subsequent test characterization activities are presented in Section 5.0, followed by the references cited in the text in Section 6.0.

Appendices of additional characterization information are also provided (A—borehole geology log description; B—baseline well water-level versus barometric pressure response plots; C—multiple-regression coefficient analysis; D—barometric-corrected baseline well water-level response plots; and

E—summary of electromagnetic borehole flowmeter [EBF] survey test data). Also, a list of the scientific nomenclature used throughout this report is provided on page xi.

It should be noted that a significant hydrologic test data set was collected for 22 wells monitored during the course of the constant-rate pumping tests conducted at well 299-W15-225. This report only provides limited quantitative analysis results for the constant-rate pumping test responses observed at near-field monitor wells located within 100 m of test well 299-W15-225 (i.e., 299-W15-40, and 299-W15-44). This is due to the short-duration of time available from test performance (i.e., June 29 to July 2, 2009), and preliminary results reporting requirements for the end of FY2009. A significant amount of large-scale hydraulic characterization information can be realized by subsequent test analysis of available far-field well test response (i.e., for wells >100 m from well 299-W15-225) and incorporation of vertically-distributed, multi-layer analysis approaches that would be implemented by incorporating the results of the dynamic EBF test survey results.

1.1 Hydrogeologic Setting

Figure 1.2 shows a generalized east-west geologic cross section of sediments in the vicinity of well 299-W15-225 (across the boundary of the WMA TX Tank Farm). As noted in Spane (2008b) and Spane and Thorne (2000), the uppermost aquifer in this general 200-West Area is unconfined and lies within Ringold Unit E. This hydrogeologic unit is reported by Lindsey (1995) to be composed of gravel, with a fine-sand matrix, and contains local sand and silt beds. These sediments are partially to well-indurated and have variable amounts of secondary mineralization. The uppermost aquifer is underlain by a lacustrine mud unit referred to as the Ringold Lower Mud. This mud unit separates the uppermost aquifer from a locally confined aquifer within the underlying Ringold Unit A gravel (basal Ringold), which lies above the basalt bedrock. Other confined aquifers are present within the deeper basalt formations. The mud unit that separates the uppermost unconfined aquifer from the underlying Ringold Unit A gravel is continuous over most of the Hanford Site, but is missing just north of the 200-West Area and in several small areas to the east of the 200-West Area. As indicated in the geologic borehole log included in Appendix A, the Ringold Lower Mud was encountered over a depth interval of 125.1 and 139.6 m bgs (410.5 and 458 ft). The Ringold Unit A gravel was encountered immediately below the Ringold Lower Mud and continued to the bottom of the borehole, which was terminated at a depth of 141.7 m bgs (465 ft). Figure 1.3 shows a fence diagram showing sedimentary relationships across the WMA TX-TY and adjacent WMA T Tank Farm Areas as reported in Reidel and Chamness (2007).

Figure 1.4 shows the general long-term aquifer water-level decline exhibited within monitor well 299-W14-14 located along the eastern boundary of the WMA TX Tank Farm Area. This pattern is representative of other long-term water-level responses exhibited at other monitor well locations in the surrounding area. As indicated in the figure, well 299-W14-14 exhibited a consistent well water-level decline pattern of ~0.35 m/year for the approximately 10-year period. This decline trend is identical to the historical trend exhibited in the WMA T Tank Farm Area located immediately to the north of WMA TX-TY, as reported in Spane (2008b). The overall decline in the unconfined aquifer water-table elevation is consistent with the decrease and cessation of wastewater disposal activities during this period within the 200-West Area and initiation of ZP-1 extraction well pumping to the south of WMA TX-TY, as discussed in Spane and Thorne (2000).

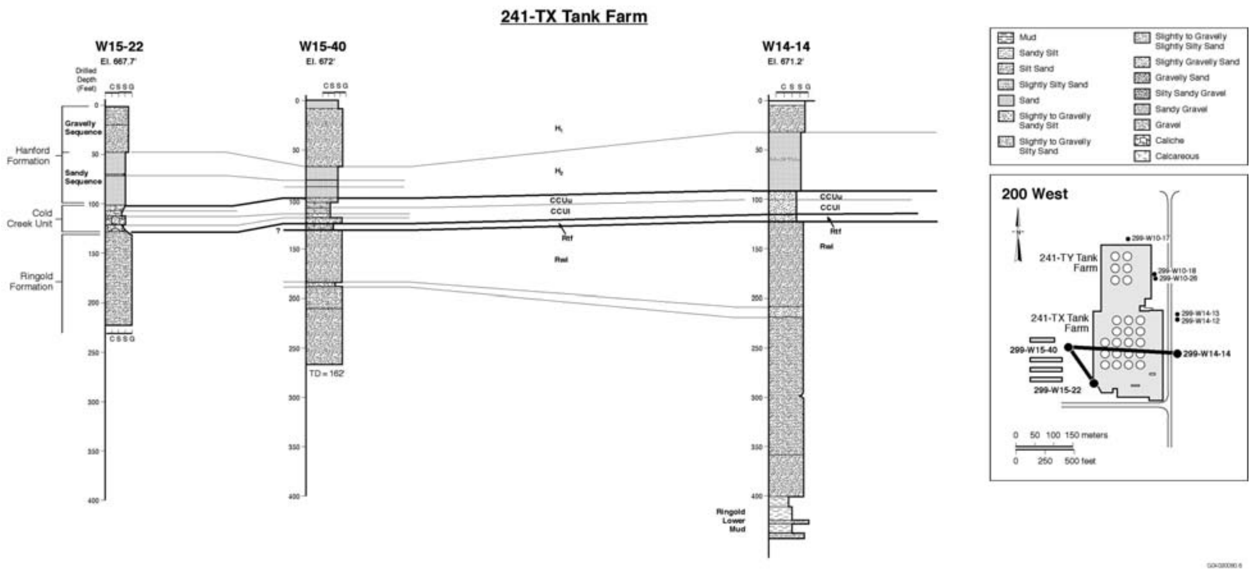


Figure 1.2. Generalized East-West Geologic Cross-Section across WMA TX Tank Farm Area (taken from Reidel and Chamness 2007)

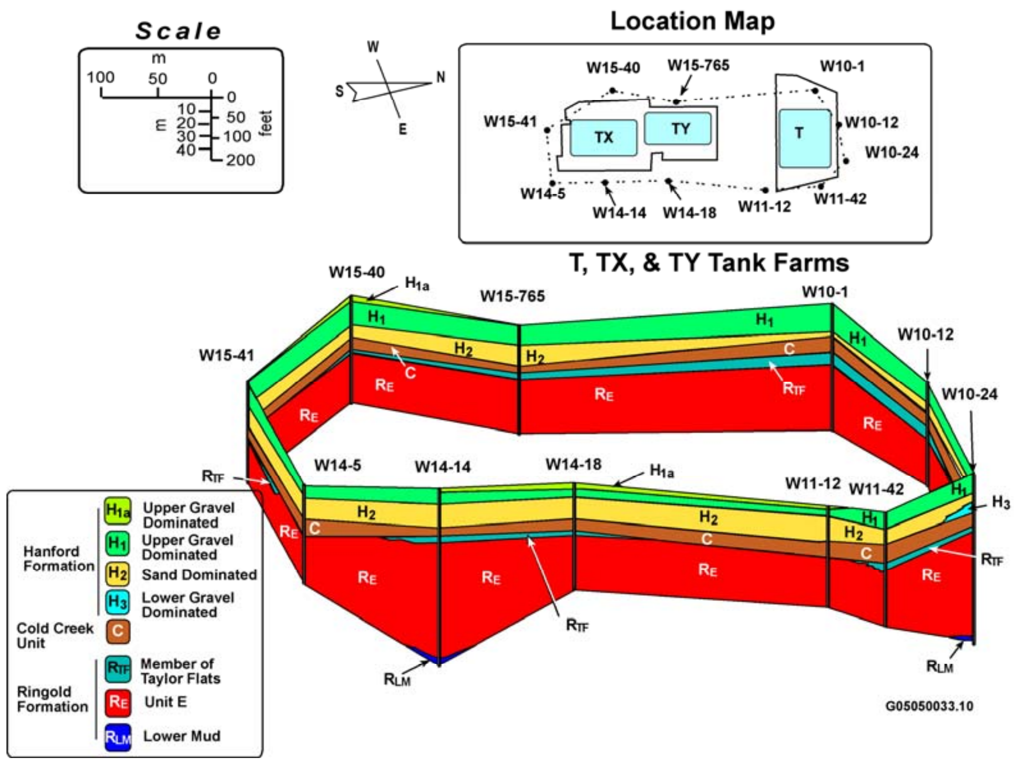


Figure 1.3. Geologic Fence Diagram of the Adjacent WMA TX –TY and T Tank Farm Areas (taken from Reidel and Chamness 2007)

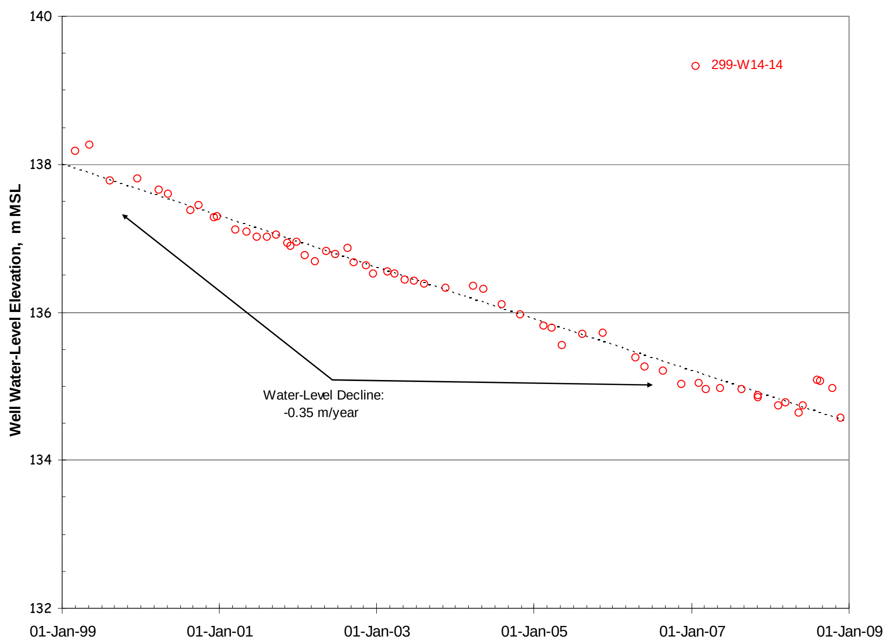


Figure 1.4. Long-Term Well Water-Level Elevation Decline Recorded at Monitor Well 299-W14-14

1.2 Available Hydraulic Characterization Information

Spane and Newcomer (2009a) provide a summary review of available well information and recently conducted hydrologic characterization tests that were performed for wells in the vicinity of the TX-TY Tank Farm. Table 1.1 lists pertinent well completion and distance/location information for various monitor and extraction wells as it relates to the newly constructed extraction well 299-W15-225. Spane and Newcomer (2009a) analyzed available hydraulic-property (hydraulic-conductivity) information for hydrologic tests previously conducted within the TX-TY Tank Farm area from FY 1999 to FY 2005. As discussed in their report, 12 well sites in the vicinity of extraction well 299-W15-225 have reported slug-test characterization results. In addition, three well site locations were reported to have had short-duration (i.e., 213 to 285 minutes) constant-rate pumping tests, one of which (299-W14-15) was a multi-well test that used nearby observation wells (299-W14-13 and 299-W14-14). The single- and multi-well hydraulic-conductivity estimates obtained from the pumping tests compare favorably with the single-well slug tests conducted at these well site locations, as noted in Spane and Newcomer (2009a).

Figure 1.5 shows a histogram distribution of hydraulic conductivity values for slug tests conducted within the top (i.e., upper 10 meters) of the unconfined aquifer. These tests are reflective of the Ringold Formation gravel unit E. As shown in the figure, the histogram distribution appears to conform to a log-normal distribution with a hydraulic conductivity range between 0.07 and 19.9 m/day and a geometric mean of 2.20 m/day. These hydraulic-conductivity values compare favorably to the range (0.05 to 64.1 m/day) and geometric mean (3.43 m/day) previously reported for slug-test characterization performed for all wells within the entire 200-West Area (Spane and Newcomer 2008).

Table 1.1. Pertinent Survey and Completion Information for Wells in the Vicinity of Well 299-W15-225 (modified from Spane and Newcomer 2009a)

Wells in the Vicinity of Well 299-W15-225	NAD83 (91) Horizontal Coordinate Survey		NAVD(88) Elevation Survey	Well-Screen Elevation, m MSL (Top – Bottom)	Radial Distance from Well 299-W15-225, m
	North, m	East, m	Brass Cap, m MSL		
299-W10-4	136578.08	566734.64	205.26	147.33 – 130.56	475.54
299-W10-5	136474.83	566578.60	204.97	151.62 – 137.90	374.31
299-W10-26	136400.93	566843.40	204.67	138.50 – 127.80	346.33
299-W14-11	136287.62	566901.69	204.38	124.59 – 121.54	302.82
299-W14-14	136181.33	566898.39	204.62	138.47 – 127.79	251.79
299-W14-15	136231.04	566899.66	204.58	137.58 – 126.95	271.45
299-W14-18	136344.43	566897.44	204.26	137.78 – 127.11	336.41
299-W14-19	136135.32	566898.63	204.90	136.76 – 126.09	242.82
299-W14-72	135941.28	567328.44	215.67	89.48 – 84.90	691.80
299-W15-1*	135942.94	566554.31	206.11	148.18 – 123.79	195.28
299-W15-7*	135920.20	566675.88	203.33	147.84 – 96.62	189.59
299-W15-11*	136000.72	566412.30	207.35	151.56 – 116.80	267.77
299-W15-34*	135960.44	566613.41	204.91	140.79 – 125.46	154.78
299-W15-35*	135853.07	566739.26	202.88	140.03 – 124.77	268.64
299-W15-40*	136205.29	566652.49	205.06	138.61 – 127.90	96.53
299-W15-41	136031.99	566757.58	202.79	136.96 – 132.38	126.41
299-W15-43*	136210.34	566490.12	206.78	137.76 – 127.09	195.51
299-W15-44*	136066.82	566685.02	204.17	138.24 – 127.57	50.40
299-W15-45*	135961.16	566432.94	206.79	135.70 – 120.44	268.58
299-W15-49	135972.91	566307.20	208.38	136.50 – 125.83	375.53
299-W15-225	136108.88	566657.25	NA	NA	0.00
299-W15-763	136029.05	566809.18	202.18	137.62 – 126.93	171.62
299-W15-765*	136373.06	566697.02	204.51	137.44 – 126.77	267.16

* existing interim ROD 200-ZP-1 extraction well
NA: not available; new well survey not completed.

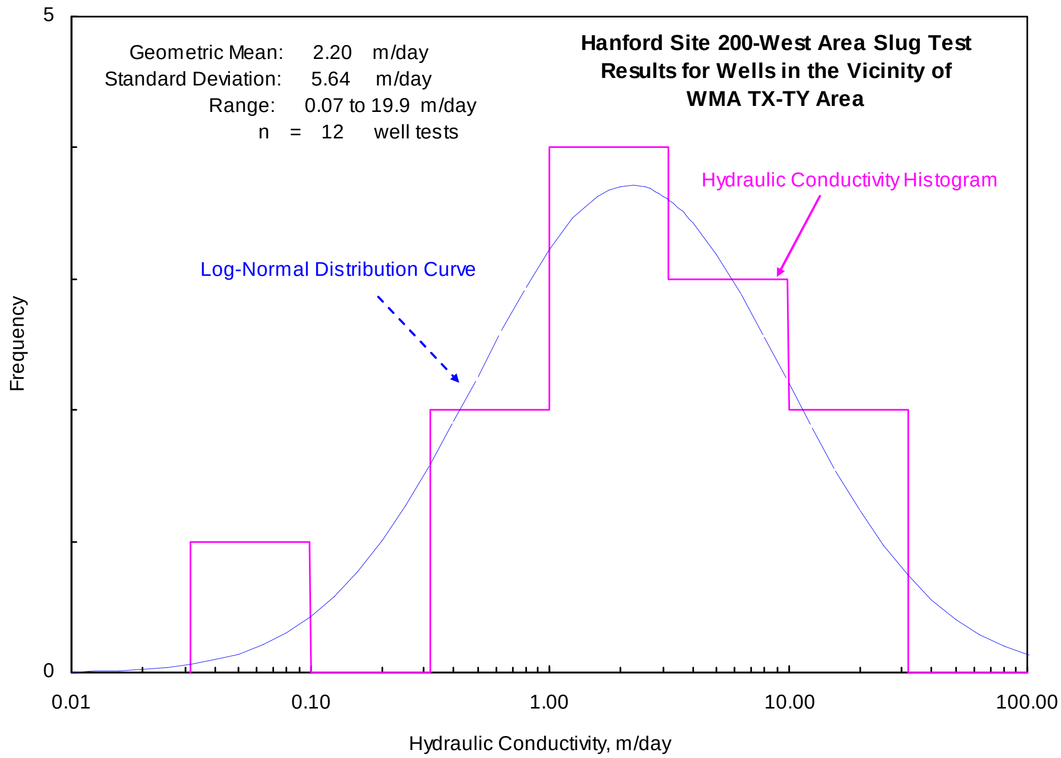


Figure 1.5. Hydraulic Conductivity Histogram for Recently Tested Wells in the Vicinity of TX-TY Tank Farm (adapted from Spane and Newcomer, 2009a)

1.3 Well 299-W15-225 Construction and Completion Description

Drilling of well 299-W15-225 was initiated on January 30, 2009, and continued until reaching a total borehole depth of 141.7 m bgs, on May 25, 2009. The well was completed over the period May 25 to June 16, 2009. Specific details concerning the well completion are shown in Figure 1.6. Of hydrologic test importance are the two separate well-screen sections: a 6.1-m 0.102-cm (0.040-in.) slot well screen completed over the depth interval 74.7 to 80.8 m bgs; and a 39.6-m 0.140-cm (0.055-in.) slot well screen was completed over the depth interval 83.9 to 123.5 m bgs. A description of the geologic material encountered during drilling and within the well-screened interval is presented in Appendix A. Table 1.2 summarizes the schedule of salient well activities as they relate to hydrologic testing performed at well 299-W15-225.

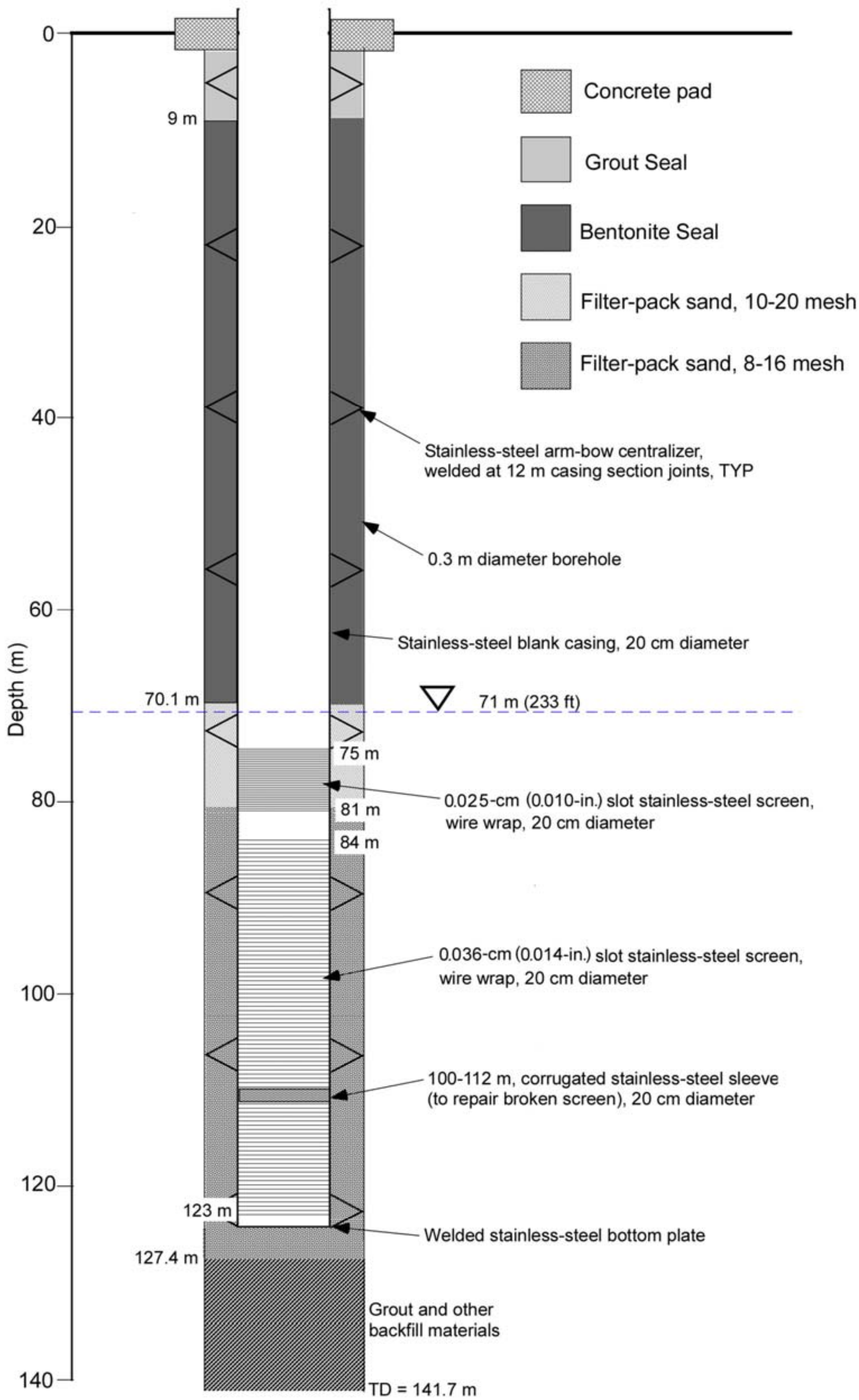


Figure 1.6. Well 299-W15-225 Completion As-Built Diagram

Table 1.2. Well 299-W15-225 Activity and Testing Summary

Calendar Date	Well Test/ Activity	Comments
1/30/2009	Well Drilling	Well drilling initiated by Blue Star Drilling Company
3/9/2009	Drill-and-Test Slug Test Characterization	Ten slug tests conducted for test/depth interval 74.5 to 75.6 m bg (Zone 1)
3/23/2009	Drill-and-Test Slug Test Characterization	Eight slug tests conducted for test/depth interval 75.7 to 78.3 m bgs (Zone 2)
3/26/2009	ZP-1 Extraction Wells Shutdown	Pumping at surrounding ZP-1 extraction wells terminated to facilitate hydrologic testing and baseline monitoring activities associated with well 299-W15-225 hydrologic characterization
5/4/2009	Distant ZP-1 Extraction Wells Re-started	Pumping resumed at distant ZP-1 extraction wells 299-W15-6, -W15-36, -W15-46, and –W15-47
5/5/2009	Well Construction	TD depth of 141.7 m bgs reached
5/12 - 6/16/2009	Well Completion and Initial Well Development	
6/1/2009	Distant ZP-1 Extraction Wells Shutdown	Pumping terminated at distant ZP-1 extraction wells 299-W15-6, -W15-36, -W15-46, and –W15-47
6/17/2009	Step-Drawdown Test 1	Four, 2-hr steps conducted at 107.9, 230.2, 347.1, and 461.1 liters per minute
6/18 - 6/26/2009	Extensive Well Development Activities	
6/28/2009	Step-Drawdown Test 2	Five, 2-hr steps conducted at 126.8, 230.5, 353.2, 459.2, and 569.3 liters per minute
6/29 - 7/2/2009	Constant-Rate Pumping Test	3-day pumping test conducted at 591.2 liters per minute
7/2 - 9/2009	Constant-Rate Pumping Test Recovery Monitoring	
7/10/2009	Ambient EBF Survey	
7/13/2009	Dynamic EBF Survey	
7/14 - 15/2009	Pneumatic Slug Test Characterization	Seven slug tests conducted for completed well test/depth interval 83.9 to 123.5 m bgs (Zone 3)
7/15 - 16/2009	Pneumatic Slug Test Characterization	Six slug tests conducted for completed well test/depth interval 74.7 to 123.5 m bgs (Zone 4)

2.0 Well 299-W15-225 Hydrologic Test Characterization Methods

Based on results of an aquifer characterization review and assessment for this study, Spane and Newcomer (2009a) and CHPRC (2009) identified three hydrologic test characterization methods for well 299-W15-225 during the drilling/construction phase and following its well completion. The three recommended test methods included:

- progressive test/depth interval slug test characterization during borehole drilling
- ambient and dynamic EBF surveys within the completed well-screen section
- a constant-rate pumping and recovery test of well 299-W15-225, and monitoring the areal drawdown/recovery response within surrounding and neighboring monitor wells.

The objective of detailed test/depth-interval slug-test characterization was to provide local-scale hydraulic property characterization of selected test/depth intervals within the penetrated unconfined aquifer. Since this characterization is conducted during the active drilling phase, it was implemented before the other two identified hydrologic tests. The discrete aquifer hydraulic conductivity distribution information obtained with this method is particularly useful for assessing the hydrogeologic controls of aquifer contamination/depth levels, selecting the well-screen completion design, and refining hydraulic-property characterization results obtained with the dynamic EBF flowmeter survey and areal, large-scale constant-rate pumping tests. In addition to detailed test/depth-interval slug-test characterization, pneumatic slug tests of the two well-screen sections following well completion were also performed. This test method provided identical aquifer hydraulic property information, but over considerably larger, aquifer test-interval sections. These pneumatic slug tests are useful for more general analysis of the constant-rate pumping test and EBF flowmeter survey results.

The focus of the dynamic EBF flowmeter survey was to provide a more continuous characterization of the *relative* hydrologic conductivity versus depth profile within the completed well 299-W15-225 well-screen section. Local to intermediate-scale hydraulic property information is derived using this method, and when combined with slug and/or pumping test-derived hydraulic property determinations, an *absolute* hydraulic-conductivity profile of the well-screened interval within the aquifer can be derived.

The principal objective of the constant-rate pumping test was to generate an areal hydrologic response that could be monitored at surrounding, variably-distant, monitoring well locations. Analysis of this imposed hydrologic response provides the opportunity of acquiring intermediate- to large-scale aquifer hydraulic and storage property information. This type of information is especially relevant for numerical modeling of contaminant transport and optimization of pump-and-treat systems, particularly when it can be constrained by depth-derived hydrologic information obtained by other hydrologic test methods (e.g., depth-interval slug-test characterization).

In concert with these three identified hydrologic test methods, two step-drawdown tests and an extensive well-development phase between the two step-drawdown tests activities were also performed as part of the overall well characterization program. These additional well test activities were not designed directly for acquiring aquifer property characterization information, but rather to be used to assess the efficacy of extended well-development on well production performance and for assessing an optimum pumping rate for the subsequent constant-rate pumping test.

The following is taken largely from Spane (2008a) and Spane and Newcomer (2009a) and provides a general discussion of the identified three hydrologic test characterization methods and additional well-test activities, as well as their relevance for acquiring information that can be used for numerical modeling needs within the study area (i.e., improving contaminant transport and capture and optimizing pump-and-treat strategies). A description of the performance and analysis of the individual tests initiated at well 299-W15-225 is presented in Section 4.

All field tests were conducted in accordance with standard hydrologic procedures identified in Spane and Newcomer (2009a) and SGW-40266-Rev 0 (CHPRC 2009). Pertinent test information was recorded in field test notebooks and/or test specific field data sheets during testing. All field notes, test data sheets, and test data files will be copied and transferred directly to CHPRC for archival purposes.

2.1 Slug Testing

As noted previously, detailed test/depth-interval slug-test characterization provides discrete aquifer hydraulic conductivity versus depth information that is useful for assessing hydrogeologic controls of contamination depth profile levels within the unconfined aquifer. As discussed in Spane and Newcomer (2008, 2009a), well 299-W14-11, located immediately east of the TX-TY Tank Farm, was previously characterized using this slug testing method during the course of test-well drilling. No hydraulic test characterization, however, was performed within the upper ~7 meters of the unconfined aquifer, which contains the highest ^{99}Tc contaminant levels at the well 299-W14-11 location. Because of the lack of hydraulic test characterization, no quantitative assessment of subsurface hydrogeologic controls on contamination depth levels was possible for this location. Based on this assessment, it was recommended by Spane and Newcomer (2009a) that a detailed slug-test-interval characterization be performed at the new extraction well 299-W15-225, specifically within the upper, middle, and lower sections of the unconfined aquifer. However as will be discussed, slug testing planned for the middle and lower sections of the unconfined aquifer were curtailed because of difficulties encountered while preparing the upper test/depth interval for slug test characterization (i.e., due to retraction of the outer drill casing). As a result, no discrete aquifer hydraulic property information for the lower and middle sections of the unconfined aquifer was obtained using this test method. As a complementing/replacement characterization activity, pneumatic slug-test characterization was performed over the well-screen sections of the completed well. The pneumatic slug tests were performed over much-longer test/depth intervals. As a result, the pneumatic slug tests provide more general hydraulic characterization information representing larger composite lower and middle sections of the unconfined aquifer. A description of slug testing during progressive borehole drilling and pneumatic slug-testing in the final, completed well is provided in the following sections.

2.1.1 Progressive Drill-and-Test Borehole Characterization

General guidance for the performance of slug tests is contained in the PNNL procedures manual PNL-MA-567, AT-6 (PNNL 1993). Briefly stated, slug tests are initiated by applying an instantaneous stress and monitoring the pressure recovery response (i.e., well water-level recovery) back to pre-test conditions. The recovery time and response pattern of the recovery can provide detailed local information concerning the hydraulic properties of the surrounding test formation, the presence of complicating, non-formation conditions (e.g., well skin), and the applicable conceptual model (e.g., homogeneous vs. heterogeneous aquifer).

Slug tests are commonly implemented mechanically by rapidly immersing or removing a submerged slugging rod of known displacement or by pneumatically depressing the well water-column using compressed air (Spane et al. 1996). Generally, mechanically induced slug tests provide more test control; however, pneumatically conducted tests provided distinct advantages for test intervals exhibiting higher transmissivity conditions. Because of the expected lower transmissivity conditions, Spane and Newcomer (2009a) recommended that slug tests conducted progressively during well 299-W15-225 drilling be performed mechanically using slugging rods. The slug tests were conducted using slugging rods having two different displacement volumes (i.e., 0.0055 m^3 and 0.0110 m^3), which theoretically impart an applied stress level of 0.68 m for the low-stress tests, and 1.36 m for the high-stress tests within the 0.10-m (4-in.) I.D. well test system. Multiple slug tests were performed for each stress level to assess test reproducibility. As noted in Spane and Newcomer (2008 and 2009a), the comparison of normalized slug-test responses is useful to evaluate stress-dependent, non-linear test well conditions. Evidence of stress dependence for tests within low to intermediate permeability formations such as the Ringold Formation may indicate the effectiveness of well development and the presence of near-well heterogeneities and dynamic skin conditions, as noted in Butler et al. (1996). Dynamic skin conditions refer to the non-repeatability of test responses conducted at a particular stress level. This non-repeatability of test response is commonly associated with changing formational conditions near the well caused by incomplete well development. As described in Butler (1998), hydraulic-property characterization results obtained from wells exhibiting stress dependence should be viewed with caution, with more credence given to test responses exhibiting less-lagged response characteristics (e.g., tests conducted at lower stress levels). Conversely, wells exhibiting repeatable slug-test responses at different stress levels indicate a stable or static formation condition surrounding the well and suggest that the well is in good hydraulic communication with the surrounding formation, and the test interval has been effectively developed.

Slug testing was implemented when the approximate targeted test/depth intervals within the upper part of the unconfined aquifer were reached during drilling. To prepare the test zone for slug-test characterization, an inflatable packer attached to a 3.1-m length of 0.076-cm (0.030-in.) slot temporary-well-screen (0.102 m I.D.) test assembly was lowered to the bottom of the borehole, as indicated in the general slug-test configuration shown in Figure 2.1. The outer 0.324-m O.D. drill casing was then retracted a prescribed length, exposing a well-screen section of ~1 to 3 m to the surrounding formation. The packer was then inflated within the drill casing, effectively isolating the exposed well-screen/test interval section from the overlying annulus between the outer drill casing and the inner test-tubing string. While the packer was inflated, test/depth interval isolation was verified by adding ~20 liters of de-ionized water down the annular space between the riser tubing and the drill casing before beginning the testing sequence. After the packer seal was verified and pre-test baseline pressure conditions were stabilized for ~10 to 15 minutes, then slug testing was initiated. Individual slug tests were allowed to reach full recovery, followed by ~10 to 15 minutes of stable pre-test conditions, before starting the next slug test within the characterization sequence. A Druck, Inc. or Keller PSI strain-gauge, pressure transducer, with ranges of 0- to 34.5-kPa (0- to 5-psig), 0- to 69-kPa (0- to 10-psig), or 0- to 138-kPa (0- to 20-psig), was installed below the fluid-column surface within the riser tubing or well-screen section to monitor the downhole test-interval pressure responses. Pressure-transducer measurements were recorded with a Campbell Scientific, Inc. model CR-10 data logger.

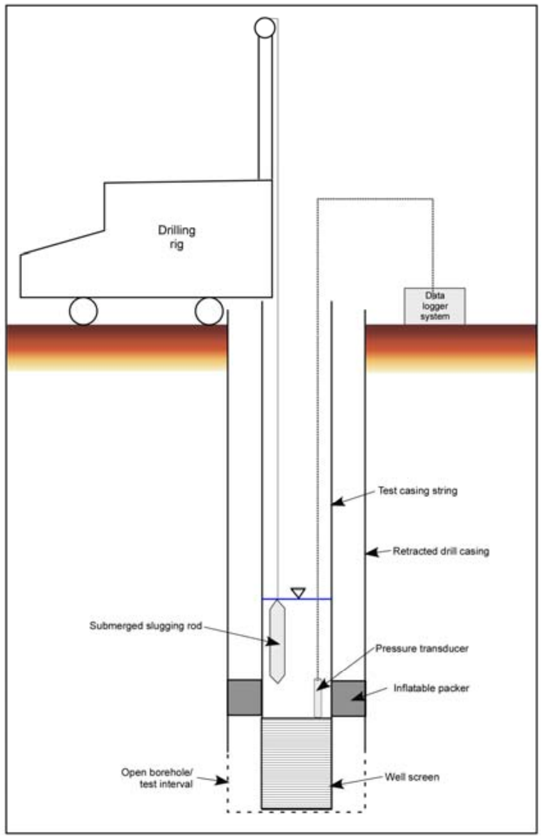


Figure 2.1. General Mechanical Slug-Test Configuration During Progressive Borehole Drilling of Well 299-W15-225 (modified from Spane and Newcomer 2009a)

2.1.2 Pneumatic Slug Tests within Completed Well

After well 299-W15-225 was completed and developed, pneumatic slug testing was performed on the two sections of the well screen shown in the well as-built in Figure 1.6. Two pneumatic slug test/depth interval characterizations were performed: individual testing of the lower well screen and composite testing of both the lower and upper-well screens together. The lower well screen (83.9 to 123.5 m bgs) is located within the middle and lower sections of the unconfined aquifer. When combined with the overlying well-screen section (74.7 to 80.8 m bgs), over 80% of the unconfined aquifer thickness is penetrated by the composite well-screen section.

To prepare for pneumatic slug testing of the lower well screen, a packer assembly connected to a 0.102-m I.D. test tubing string was lowered to the blank section of well casing shown in Figure 1.6 that separates upper and lower well screens (between 80.8 and 83.9 m bgs). This general test deployment is shown in Figure 2.2. For pneumatic slug testing of the entire or composite well-screen section, the packer/test tubing assembly was placed immediately above the upper well-screen section, which was located ~5 m below the static water-table conditions during the time of testing.

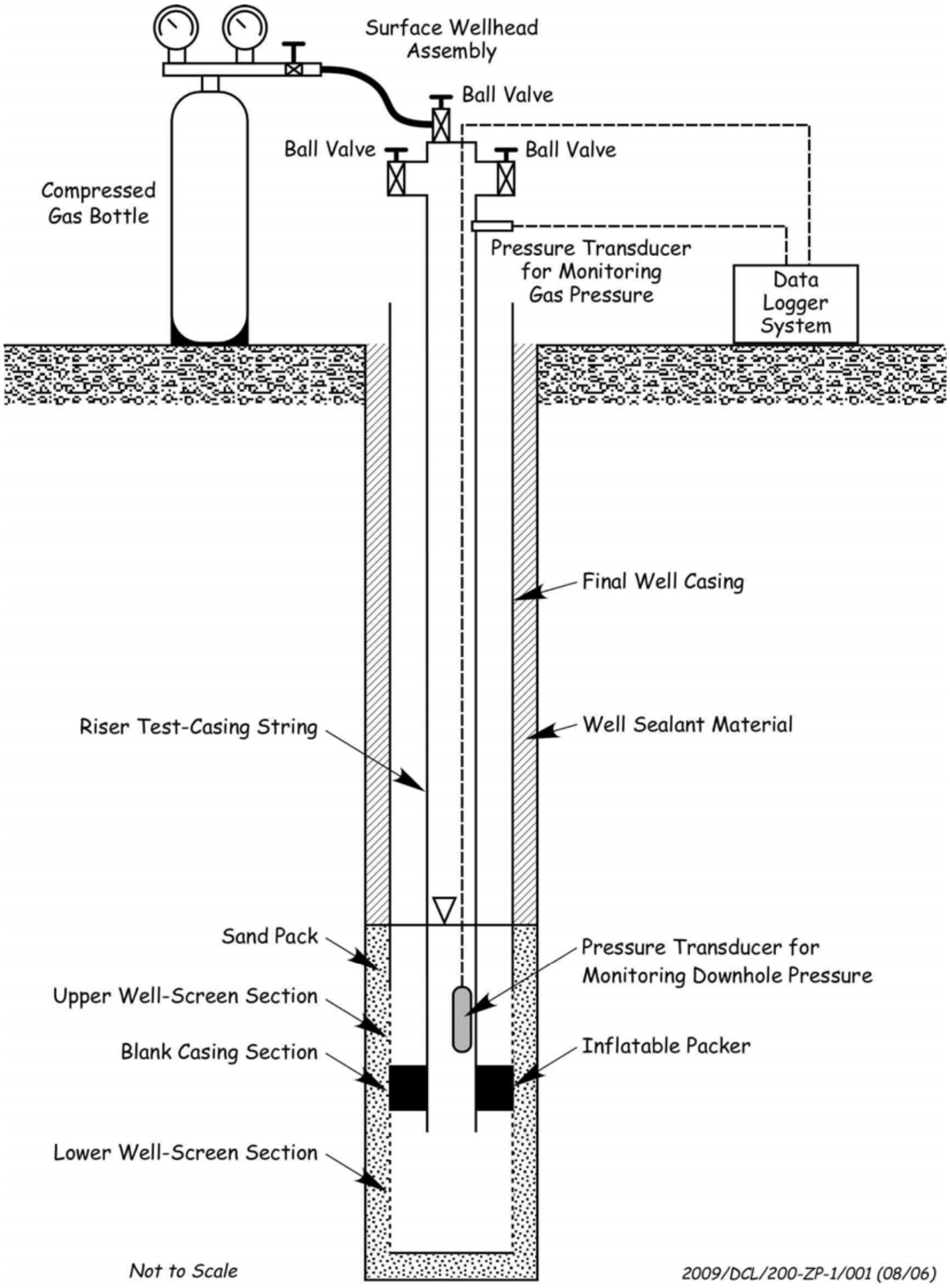


Figure 2.2. General Pneumatic Slug-Test Configuration for Well-Screen Intervals within the Final, Completed Well 299-W15-225

Pneumatic slug tests required the use of a wellhead-manifold assembly at the surface for sealing the test-tubing string (Figure 2.2). The wellhead assembly is also needed to administer the compressed gas (nitrogen) for pneumatically depressing the fluid column at the prescribed stress levels. Design features of the wellhead assembly include:

- a sealed, pass-through connection through the top of the manifold to allow passage of the downhole pressure transducer and cable
- an outside pressure transducer probe connection that allows direct measurement of the gas pressure within the test casing below the surface seal
- a compressed gas line connection and valve to introduce compressed gas directly to the inside of the test-casing string
- surface wellhead ball valves for rapidly releasing the compressed gas from the test-casing string at the time of slug-test initiation.

Compressed gas pressure was controlled by a pressure regulator at the gas bottle and monitored with a strain-gauge, 0- to 69-kPa (0- to 10-psig) pressure transducer installed at the outside connection on the wellhead assembly. A low-pressure gauge range (e.g., 207 kPa [30 psi]) on the inflation line side of the regulator was required to monitor and control the prescribed stress levels. Downhole pressure responses within the test interval section were monitored with a strain-gauge, 0- to 69-kPa (0- to 10-psig) pressure transducer installed within the riser test-casing tubing.

After installing the packer/test-tubing and surface wellhead assemblies, the packer was inflated within the 0.203 I.D. blank well casing, effectively isolating the exposed well-screen/test-interval section from the overlying annulus between the well casing/upper screen and the inner riser tubing. While the packer was inflated, test/depth interval isolation was verified by adding ~20 liters of de-ionized water down the annular space between the riser tubing and the well casing before beginning the testing sequence. After the packer seal was verified, compressed gas was slowly introduced to the inside of the test-casing string until the prescribed stress-level pressure was reached. As soon as pressure conditions within the riser test-casing string stabilized for ~10 to 15 minutes, then slug testing was initiated.

Pneumatic slug tests were initiated by quickly opening the surface ball valves and monitoring the associated slug-test recovery pressure response with the downhole pressure transducer/datalogger system until pre-test pressure conditions were reached. A series of three to four different, stress-level slug tests were performed for each of the two well-screen test characterizations. This was accomplished by applying different compressed gas pressures within the pressure range of ~7 to 35 kPa (~1 to 5 psi). Individual slug tests were allowed to reach full recovery, followed by ~10 to 15 minutes of stable pre-test conditions, before starting the next pneumatic slug test within the characterization sequence.

2.1.3 Analytical Methods

The following discussion pertaining to slug-test response and analysis is taken primarily from Spane and Newcomer (2008, 2009a). Slug-test analysis is dependent on the well water-level response characteristics following slug-test initiation. As shown in Figure 2.3 and discussed in Butler (1998), water levels within a test well can respond in one of three ways to the instantaneously applied stress of a slug test. These response model patterns are 1) an over-damped response, where the water levels recover in an exponentially decreasing recovery pattern, 2) an underdamped response, where the slug-test response oscillates above and below the initial static, with decreasing peak amplitudes with time, and 3) critically-damped, where the slug-test behavior exhibits characteristics that are transitional to the over- and under-damped response patterns. Factors that control the type of slug-test response model that are exhibited within a well include a number of aquifer properties (hydraulic conductivity) and well-dimension characteristics (well-screen length, well-casing radius, well-radius, aquifer thickness, fluid-column length) and can be expressed by the response damping parameter, C_D, which Butler (1998) reports for unconfined aquifer tests as:

$$C_D = (g/L_e)^{1/2}\, r_c^{2} \ln (R_e/r_w)/(2\,K\,L) \qquad (2.1)$$

where
- g = acceleration due to gravity
- L_e = effective well water-column length
- r_c = well casing radius; i.e., radius of well water-column that is active during testing
- R_e = effective test radius parameter; as defined by Bouwer and Rice (1976)
- r_w = well radius
- K = hydraulic conductivity of test interval
- L = well-screen length.

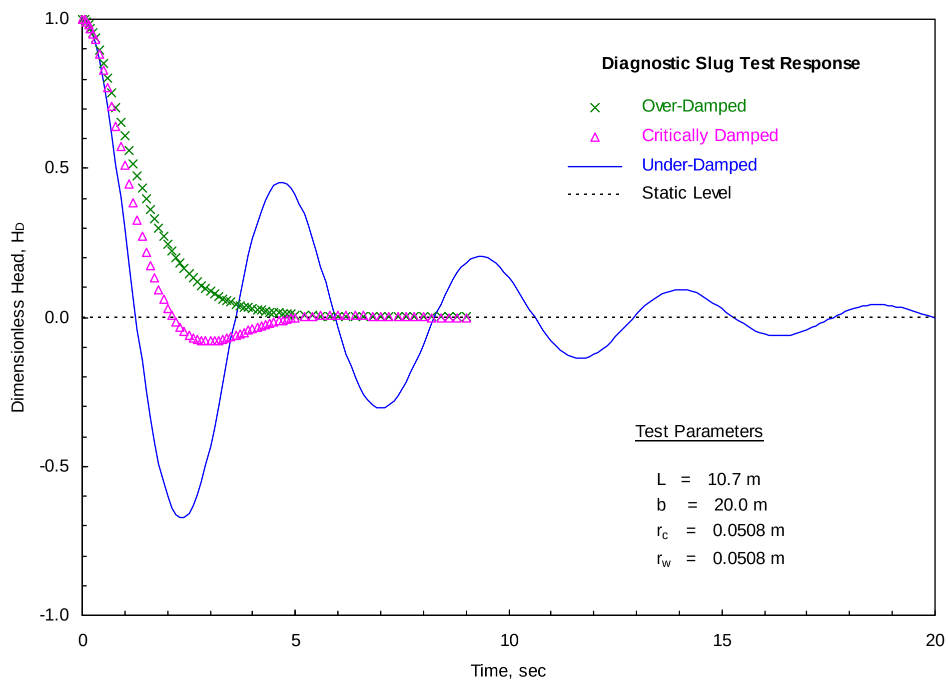


Figure 2.3. Diagnostic Slug-Test Response Patterns (adapted from Spane and Newcomer 2008)

Given the multitude of possible combinations of aquifer properties, well-casing dimensions, and test interval lengths, no universal C_D value ranges can be provided that describe slug test response conditions. However, for the assumed test system dimensions anticipated for testing at new extraction well 299-W15-225 during drilling, the following general guidelines on slug test response prediction are provided:

- C_D >3 = over-damped response
- C_D 1 - 3 = critically-damped response
- C_D <1 = under-damped response.

An over-damped test response generally occurs within stress wells monitoring test formations of low to moderately high hydraulic conductivity (e.g., Ringold Formation) and are indicative of test conditions where frictional forces (i.e., resistance of groundwater flow from the test interval to the well) are predominant over test-system inertial forces. Based on test responses exhibited for slug tests conducted within nearby wells (listed in Spane and Newcomer 2009a), slug tests conducted within new extraction well 299-W15-225 (with test interval lengths of ≤ 5 m) were expected to exhibit over-damped response characteristics. Figure 2.4 shows predicted slug-test recovery as a function of hydraulic conductivity (K range: 1 to 25 m/day; 3.05-m test interval) for test intervals exhibiting over-damped response characteristics for general ZP-1 test well/interval conditions. The test predictions shown in the figure are based on responses occurring within a test system casing I.D. = 0.102 m (i.e., dimension of the testing string for the packer/well-screen assembly). As indicated in the figure, test intervals having hydraulic-conductivity values of approximately 25 m/day or less should be readily resolved for tests exhibiting over-damped slug-test behavior. For over-damped slug tests, two different methods are commonly used for the slug-test analysis: the semiempirical, straight-line analysis method described in Bouwer and Rice (1976) and Bouwer (1989, 1996), and the type-curve-matching method for unconfined aquifers presented in Butler (1998). A detailed description of over-damped slug-test analysis methods is presented in Spane and Newcomer (2008).

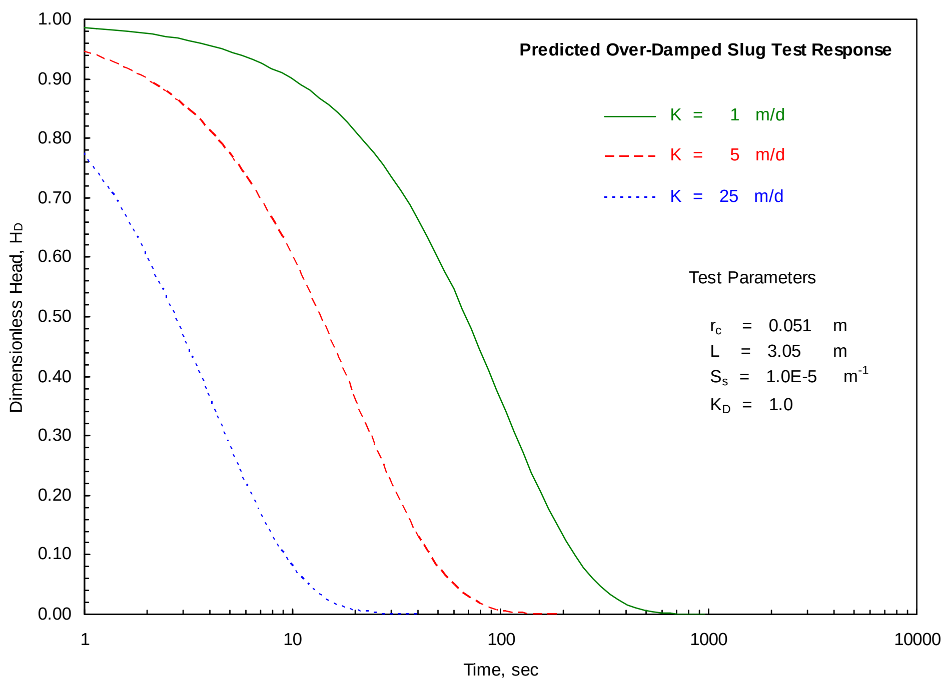


Figure 2.4. Over-Damped Slug-Test Response as a Function of Hydraulic Conductivity

As noted above, slug tests exhibiting under-damped or critically damped behavior are not anticipated for test/depth-interval characterizations conducted at well 299-W15-225 during drilling. However because of the significantly larger test screen length (and correspondingly higher test interval transmissivity), under-damped or critically damped slug test behavior was expected for pneumatic tests conducted within completed well 299-W15-225. Under-damped test-response patterns are exhibited within stress wells where inertial forces are predominant over formation frictional forces. This commonly occurs in wells with extremely long fluid columns (i.e., large water mass within the well column) and/or that penetrate highly permeable aquifers. Tests exhibiting under-damped behavior should be conducted with very small stress levels compared to the test-interval section, i.e., $H_o << L$, as originally noted in Van der Kamp (1976) and restated in Butler (1998). Figure 2.5 shows predicted under-damped slug-test response characteristics as a function of hydraulic conductivity (K range: 10 to 50 m/day) for the given well 299-W15-225 well completion characteristics.

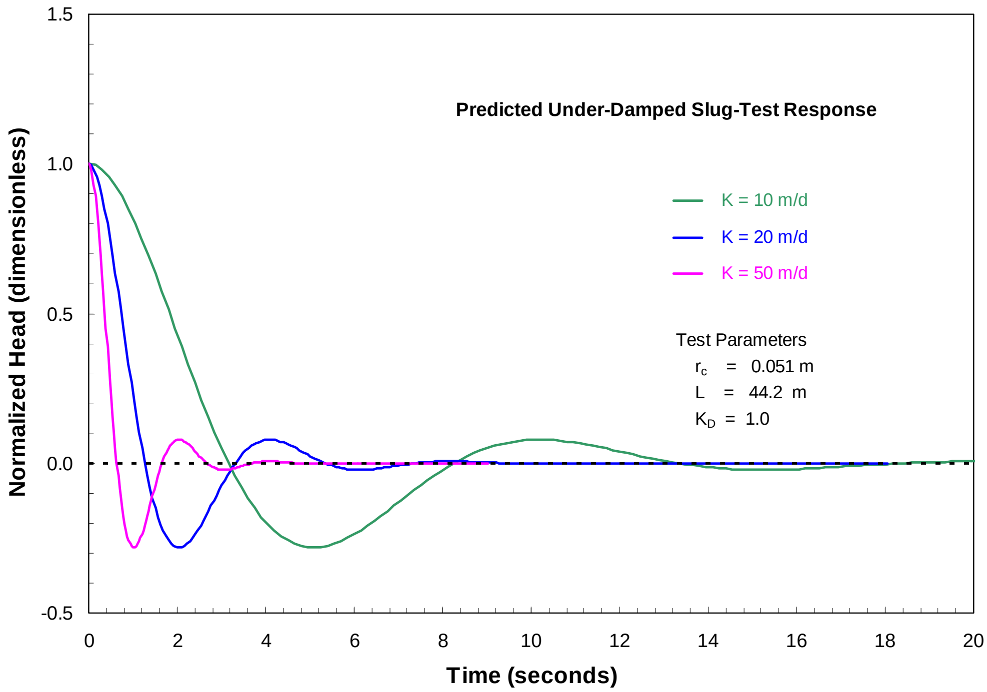


Figure 2.5. Under-Damped Slug-Test Response as a Function of Hydraulic Conductivity

As noted in Spane and Newcomer (2008), slug tests exhibiting under-damped or critically-damped response characteristics cannot be analyzed quantitatively using the Bouwer and Rice or type-curve analysis methods. Methods that can be employed for analyzing unconfined aquifer tests exhibiting high permeability characteristics include methods described in Springer and Gelhar (1991), Butler (1998), McElwee and Zenner (1998), McElwee (2001), Butler and Garnett (2000), and Zurbuchen et al. (2002). Because of the ease provided by a spreadsheet-based approach, the test analysis method presented in Butler and Garnett (2000) was used for well 299-W15-225 tests exhibiting high permeability oscillatory response characteristics, i.e., under- or critically damped (i.e., Zone 3 and Zone 4).

2.2 Dynamic Electromagnetic Flowmeter Survey

EBF surveys are effective for accurately measuring the vertical groundwater-flow distribution in wells under ambient (static) and dynamic (e.g., pumping-induced) test conditions. As noted in Spane (2008a), dynamic EBF surveys provide direct measurements of groundwater in-flow along the saturated well screen during a constant-rate pumping test. The various measured inflow rates vs. depth are directly related to the vertical profile of hydraulic conductivity outside the well screen within the surrounding aquifer formation. This type of characterization information is particularly important for designing and deploying *in situ* treatment technologies within heterogeneous aquifer systems. To correct the dynamic flowmeter survey results for natural, in-well vertical flow conditions, an ambient (i.e., non-pumping) EBF survey is normally conducted before the dynamic flowmeter test. A detailed description of EBF instrumentation and application of surveys for site characterization is presented in Spane and Newcomer (2008).

A review of available hydrologic test-well characterization information indicates that no dynamic EBF flowmeter surveys have been conducted within wells in the vicinity of well 299-W15-225. A number of dynamic flowmeter surveys, however, have been successfully completed at other Hanford Site locations, e.g., 300 Area and 100-D Area, to provide detailed hydraulic-conductivity vs. depth-profile information (e.g., Newcomer, 2009). Examples of using EBF survey information to develop vertical depth profiles of hydraulic conductivity and geostatistical realizations within the surrounding aquifer materials at other, non-Hanford Site locations are also presented in Vermeul et al. (2004) and Li et al. (2008).

The theory that governs the operation of the EBF is Faraday's Law of Induction, which states that the voltage induced by a conductor moving orthogonally through a magnetic field is directly proportional to the velocity of the conductor moving through the field. For EBF surveys, flowing water is the conductor, an electromagnet generates a magnetic field, and the electrodes within the flowmeter are used to measure the induced voltage. For sign convention, upward flow represents a positive voltage signal, and downward flow represents a negative voltage signal. A more detailed description of the EBF instrument system and field test applications are provided in Molz et al. (1994) and Young et al. (1998). A schematic depiction of the field, well-test design is shown in Figure 2.6. The EBF probe consisted of an electromagnet and two electrodes 180 degrees apart inside a hollow cylinder. The inside diameter of the hollow cylinder was 2.5 cm (1 in.), and the outside diameter of the probe cylinder was just under 5.1 cm (2.0 inches). The probe was connected to an electronics box at the surface with a jacketed cable. The electronics attached to the electrodes transmit a voltage signal directly proportional to the velocity of water acting as the conductor. Computer software was used to record the voltage signal and convert the signal to a flow-rate measurement. The EBF probe used for the well 299-W15-225 survey is manufactured by Quantum Engineering Corporation and is capable of measuring flow ranging from 0.04 to 40 L/min (0.01 to 10.6 gpm).

For the EBF surveys performed in well 299-W15-225, an inflatable packer was used to minimize bypass flow between the probe and the stainless steel wire-wrap well screen (Figure 2.6). The inflatable packer consists of a rubber sleeve attached to a stainless steel assembly and is sealed with hose clamps. The EBF probe cylinder was mounted inside the stainless steel assembly. The packer and all fittings were checked for gas leaks at the surface before starting the flowmeter survey. At each prescribed depth, the inflation of the packer was controlled with compressed nitrogen gas, a regulator, and inflation tubing. Flow conditions in the well were allowed to re-establish for several minutes because of disturbances caused by movement of the packer/probe assembly. After recording the flow measurement, the packer was deflated using a vented valve. The probe was raised very slowly to the next depth, and the measurement procedure was repeated.

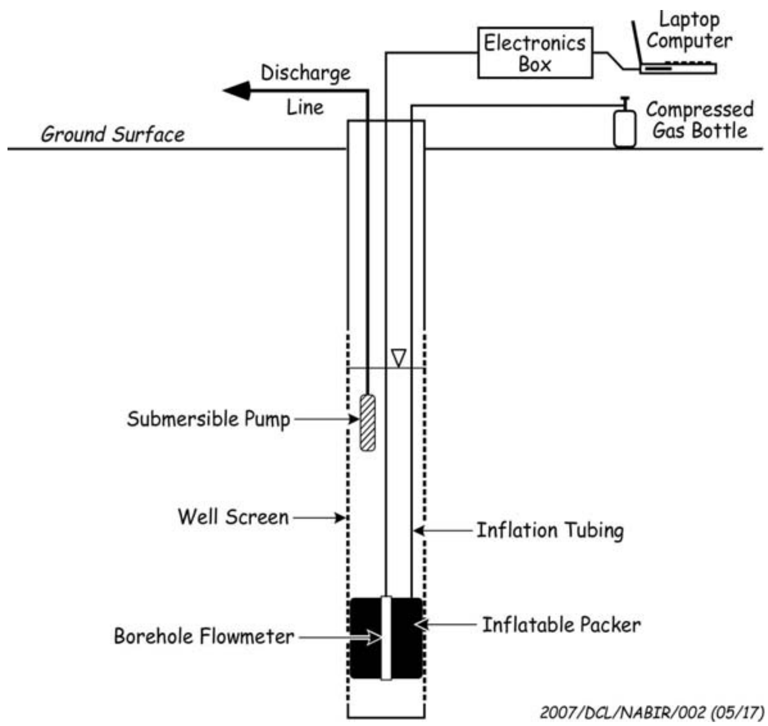


Figure 2.6. General Electromagnetic Borehole Flowmeter Survey Configuration (taken from Spane and Newcomer 2009a)

In addition to the inflatable packer system, a 0.203-m (8-in.) O.D. rubber gasket was attached to the bottom of the packer assembly. For each individual measurement depth, vertical flow was measured with the packer system fully inflated and measured with the packer system un-inflated (i.e., rubber gasket seal only). The purpose of these repeated measurements at each depth was to 1) verify capture of the dynamic profile in case the inflatable packer began to leak or fail and 2) account for any potential over-range problems with the EBF instrument at the upper end of the flow range. Vertical flow measured at higher flow ranges with only the gasket providing the seal (i.e., packer un-inflated) was not expected to over-range the instrument because of a greater proportion of bypass flow around the seal.

Both ambient (i.e., static) and dynamic (i.e., pump-induced) flowmeter tests were performed in well 299-W15-225. The ambient and dynamic flowmeter measurements were acquired every ~1.5 m over the well-screen section. Flowmeter measurements were acquired within a blank section of casing and at one of the well-screen solid joints to correct the flow measurements for bypass flow between the EBF probe packer system and the well screen. All flowmeter measurements were referenced to the top of the outer protective casing.

During the dynamic flowmeter tests, groundwater was pumped from the well and discharged to a portable tank. The discharge rate was held constant during the dynamic test. The well was pumped ~30 minutes to allow flow conditions to reach near-equilibrium before recording the EBF measurements. The discharge rate was measured and recorded periodically with a calibrated in-line flowmeter. After near-equilibrium conditions were established, electromagnetic borehole flowmeter measurements were made in succession from bottom to top of the saturated well-screen section. Zero flow point measurements taken with the EBF probe in a container of water at the surface and within the saturated blank casing above the top of the well screen provided a reference for the survey measurements.

For EBF survey test analysis, it is assumed that the aquifer within the well-screen section is composed of a series of horizontal layers, possessing layer-specific hydraulic properties. As discussed in Newcomer (2009), under ambient-flow conditions (i.e., non-pumping), the difference between two successive well-screen depth measurements is the portion of ambient flow, Δq_i, entering the well screen between depths where the flow measurements were taken. These two depths are assumed to bound interval *i* (*I = 1,2,…,n*). The portion of flow, ΔQ_i, entering the well screen between these successive depths under pump-induced conditions is calculated in the same manner. Ambient-flow survey-profile information is used to correct dynamic flowmeter survey results for background natural vertical-gradient conditions.

The analytical method used for calculating the vertical distribution of relative hydraulic conductivity from dynamic EBF surveys is summarized in Molz et al. (1989) and Boman et al. (1997). Briefly stated, assuming that a constant pumping rate and pseudo-steady-state conditions are reached during pumping, the normalized relative hydraulic conductivity, K_r, for each *i*th interval within the aquifer can be calculated as follows:

$$K_r = \frac{K_i}{K_{avg}} = \frac{(\Delta Q_i - \Delta q_i)/\Delta z_i}{\sum_i (\Delta Q_i - \Delta q_i)/\sum z_i}; \quad i = 1,2,...,n \qquad (2.2)$$

where K_i = absolute horizontal hydraulic conductivity of the *i*th layer

K_{avg} = average horizontal hydraulic conductivity

ΔQ_i = difference in EBF flow measurements at the top and bottom of the *i*th interval under pumping conditions

Δq_i = difference in EBF flow measurements at the top and bottom of the *i*th interval under ambient conditions

Δz_i = *i*th interval thickness.

As indicated in Equation (2.2), the normalized relative hydraulic-conductivity value can be determined directly from measuring specific depth inflow rates as it relates to total flow pumped from the entire test interval. An absolute or actual hydraulic-conductivity-value depth profile (i.e., K_i versus depth), however, can be developed if an estimate of K_{avg} has been determined from a standard hydrologic test method (e.g., constant-rate pumping test). This can be derived by calculating the dimensional values of K_i for each *i*th depth interval by multiplying the net dynamic flowmeter test discharge result relationship (indicated in Equation 2.2) by the previously determined K_{avg} value.

It should be noted that the analysis method presented previously is strictly valid for EBF surveys conducted within fully penetrating confined aquifer wells. For EBF surveys conducted within partially penetrating unconfined aquifer wells, adverse boundary effects associated with flow convergence (i.e., non-horizontal flow) at the water table and at the base of the well screen are possible. However, because new well 299-W15-225 was completed at a distance (e.g., 5 to 10 m) below the water table, no significant water-table boundary effects are expected for flowmeter measurements obtained at the top of the well screen. Any apparent flow convergence effects that occur at the base (or top) of the well screen can be accounted for by taking into account the well/aquifer penetration relationship. For these reasons, the K_r relationship expressed in Equation (2.2) is considered valid for determining the vertical distribution of hydraulic conductivity with depth within the unconfined aquifer at well 299-W15-225. Additionally, any groundwater-flow bypass that may occur within the sandpack outside the well screen is considered to be minor and relatively uniform for the purpose of dynamic EBF testing analysis. Non-uniform sandpack flow during testing is difficult to quantify and remains an unknown for the test. However, the fact that head loss for groundwater flow through the well screen would be significantly lower than through the outside annular sandpack suggests that this factor may be relatively unimportant except where unknown heterogeneities may occur within the sandpack.

2.3 Step-Drawdown Pumping Tests

Step drawdown tests are normally conducted to assess well/aquifer-loss performance and for guidance in selecting an optimum pumping rate for a subsequent, longer-duration, constant-rate pumping test. The test is conducted as a series of sequential, short-duration constant-rate pumping tests, with each step conducted of uniform duration and at progressively higher pumping rates. As discussed in Spane and Newcomer (2009a), a minimum of three steps is required, and four or more steps are generally preferred. For unconfined aquifer step-drawdown tests (and constant-rate pumping tests), drawdown at the pumped well should be limited to no more than 25% of the pre-test saturated aquifer thickness.

For well 299-W15-225, two separate step-drawdown tests, which were separated by a program of extensive well development, were conducted. The purpose of the extensive well development was to improve well production capabilities for the newly constructed extraction well 299-W15-225. Comparing results obtained from the performance of the first and second step-drawdown test provided the basis for assessing the impact of the implemented extensive well-development activities. Based on anticipated hydraulic properties within the general area (Section 1.2), the first step-drawdown test was designed with four step-discharge rates of ~113.5, 227, 340.5, and 454 liters per minute (30, 60, 90, and 120 gallons per minute) for the individual pumping steps (i.e., 30-gpm step increments). Each individual step increment was conducted for a duration of 2 hours. After monitoring recovery following termination of the first step-drawdown test, extensive well-development activities were implemented within the completed well-screen sections over a 9-day period. Well development activities included air-lift pumping, surging, and over-pumping using a high-capacity turbine pump. Following completion and recovery of the well-development activities, a second step-drawdown test was initiated. The second step-drawdown test used approximately the same four discharge rates as used during the first test, and an added fifth step was conducted at ~567 liters per minute (150 gallons per minute).

Well loss at new well 299-W15-225 was assessed by comparing discharge, Q, and the drawdown/pumping-rate ratio, s_w/Q, (i.e., drawdown/discharge). Using the standard head-loss analysis plot procedure originally described by Jacob (1946) and Rorabaugh (1953), a non-linear, increasing s_w/Q vs. Q pattern is indicative of turbulent well-loss conditions, while a constant, linear relationship vs. Q indicates that well losses exhibited during pumping are laminar in nature.

Jacob (1946) presented the following well loss/drawdown relationship used to assess well-discharge performance:

$$s_w = \mathrm{BQ} + \mathrm{CQ}^2 \qquad (2.3)$$

where BQ = laminar aquifer head loss, and CQ^2 = turbulent well head loss.

As shown in Figure 2.7, a linear-regression slope fit through the step-drawdown test data provides coefficients for the head loss equation (2.3), with the intercept value equal to coefficient B, and the linear-regression slope equivalent to coefficient C. It should be noted that the laminar aquifer head loss, BQ, includes the effects of true formational aquifer characteristics (i.e., head loss due to hydraulic properties) and those attributable to well-skin effects (i.e., damage associated with drilling/well construction process).

The well efficiency, E, or percentage of the observed drawdown within the well not attributed to turbulent well loss components can be calculated based on the following relationship provided in Roscoe Moss (1990):

$$E = 100/(1 + CQ/B) \qquad (2.4)$$

where equation parameters were previously defined.

Equations 2.3 and 2.4 were used to correct for pumping well 299-W15-225 drawdown during the 3-day constant-rate pumping test and to also assess the hydrologic impact of extensive well-development activities implemented at the pumping well location, respectively.

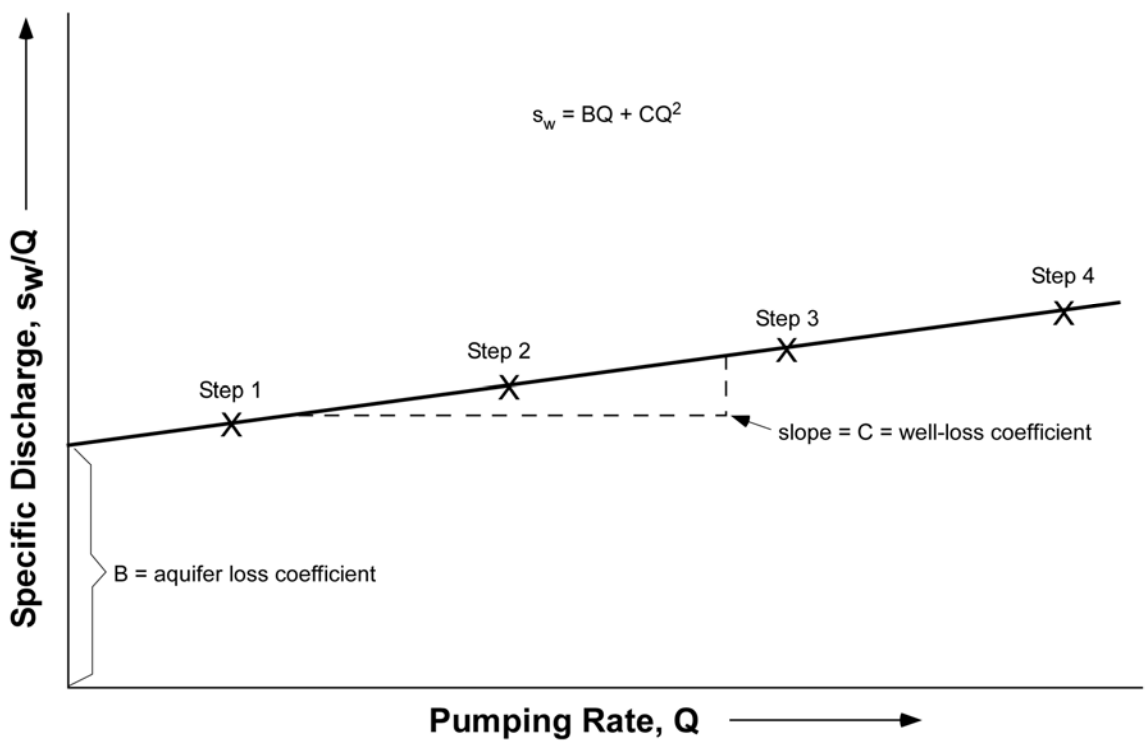


Figure 2.7. Specific Drawdown Plot Relationships for Calculating Formation Loss (B) and Well Loss (C) Coefficients from Step-Drawdown Test Data

2.4 Constant-Rate Pumping Test

During constant-rate pumping tests, groundwater is extracted from the aquifer and regulated to maintain a constant, uniform rate. The pressure response within the pumped well is monitored during the active withdrawal (drawdown) phase and during the subsequent recovery (build-up) period following termination of pumping. The analysis of the drawdown and recovery pressure response within the pumped well and surrounding monitor wells (i.e., multi-well tests) provides a means for estimating hydraulic and storage properties of the aquifer as well as for discerning formational and non-formational flow conditions (e.g., wellbore storage, skin effects, presence of boundaries). Guidance for the performance of constant-rate pumping tests is contained in the PNNL procedures manual PNL-MA-567, AT-7 (PNNL 1993). Additional test performance guidelines specific to well 299-W15-225 are provided in Spane and Newcomer (2009a). An excellent reference for measuring, conducting, and analyzing multi-well constant-rate pumping tests is presented in Kruseman and de Ridder (2000). Examples of multi-well constant-rate pumping tests performed on the Hanford Site are presented in Spane et al. (2001a, 2001b, and 2002) and Spane (2008b).

The extraction of groundwater at a constant-rate from well 299-W15-225 will cause associated drawdown pressure responses to be imposed within an aquifer that are a function of the pumping rate, distance from the point of pumping, and surrounding aquifer hydraulic and storage properties. The collection of drawdown and subsequent recovery data versus time (i.e., since pumping initiated and stopped, respectively) at the pumped well and various surrounding monitor well locations provides the analysis basis for determining aquifer hydraulic and storage properties. It should be noted that an inherent assumption in constant-rate pumping test analysis is that the observed well water-level responses are caused solely by the imposed hydrologic stress (i.e., due to pumping at new well 299-W15-225). External man-induced stresses (i.e., from surrounding ZP-1 pump-and-treat extraction wells) as well as natural stresses such as barometric pressure fluctuations, however, also impose discernable impacts on well water-level measurements and may significantly mask water-level responses within more distant monitoring well locations. To enhance the successful performance of a multi-well constant-rate pumping test at new well 299-W15-225, efforts were implemented to minimize the extraneous effects from surrounding ZP-1 extraction wells and to remove the effects of barometric pressure fluctuations, as discussed in Section 3.

After monitoring the recovery following completion of the second step-drawdown test, a 3-day constant-rate pumping test was initiated at well 299-W15-225. The pumping rate selected for the constant-rate test was be based on results obtained during the step-drawdown test. The ~567 liters per minute (150 gallons per minute) pumping rate selected for the 3-day constant-rate test was based on 1) specific drawdown/discharge characteristics exhibited during the two step-drawdown tests, 2) pumping equipment characteristics, and 3) the limitation of drawdown to less than 25% of the aquifer thickness at the extraction well location, as identified in Spane and Newcomer (2009a). A recovery period of 6 days was monitored at the stress well and surrounding monitor well locations following termination of the 3-day constant-rate pumping test.

It should be noted that a significant hydrologic test data set was collected for 22 wells monitored during the course of the constant-rate pumping tests conducted at well 299-W15-225. This current report only provides limited quantitative analysis results for the constant-rate pumping test responses observed at the pumped well and near-field monitor wells located within 100 m of test well 299-W15-225 (i.e., 299-W15-40, and 299-W15-44). This is due to the short-duration of time available from test performance (i.e., June 29 to July 2, 2009) and preliminary result reporting requirements for the end of FY2009. A significant amount of large-scale hydraulic characterization information can be realized by subsequent test analysis of available far-field well test response (i.e., for wells >100 m from well 299-W15-225) and incorporation of vertically distributed, multi-layer analysis approaches that would be implemented by incorporating the results of the dynamic EBF test survey results.

The analysis approach is based on type-curve matching methods (i.e., Neuman 1972, 1974, 1975) that are commonly used to analyze standard pumping test responses. These approaches, however, do not account for wellbore storage effects either at the pumped well or observation well locations. To account for wellbore storage effects, type curves were generated using the WTAQ3 computer program described by Moench (1997). WTAQ3 can be used to generate pumping test-type curves that represent a wide range of test and aquifer conditions, including partially penetrating wells, confined or unconfined aquifer models, and wellbore storage at both the stress (pump) and observation (monitor) well locations. The type-curve generation program also allows for non-instantaneous release (drainage-delay factor) of water from the unsaturated zone. The shape of the unconfined aquifer pumping test-type curves used in the individual well response analysis is sensitive to a number of hydrologic parameters, including radial distance from the pumping well location, r_o, vertical anisotropy, K_D (i.e., K_v/K_h), and the storativity/specific yield ratio ($\sigma = S/S_y$).

It should be noted that for thin aquifers where drawdown represents a significant percentage of the total saturated thickness, corrections for dewatering the unconfined aquifer are required to account for the decrease in associated aquifer transmissivity before applying type-curve analysis. Jacob (1963) provided an equation to correct drawdown data obtained for pumping tests within thin unconfined aquifers. The corrected drawdown, s', which accounts for aquifer dewatering, can be calculated using the following relationship:

$$s' = s - \left(\frac{s^2}{2b} \right) \tag{2.5}$$

where equation parameters were previously defined.

Since the unconfined aquifer within the general area is relatively thick (i.e., ~55 m), and the observed areal drawdown at the various surrounding monitor well locations was relatively small (i.e., ≤ 0.1 m), an associated aquifer dewatering correction for the constant-rate pumping test was not needed (e.g., for $s \leq 0.1$ m; $s^2/2b \leq 0.0001$ m).

3.0 Barometric Effects

The following discussion of barometric effects on well water-level measurements is taken largely from Spane and Newcomer (2008, 2009a). Briefly stated, barometric-pressure fluctuations can have a discernible overwhelming impact on well water-level measurements obtained during hydrologic tests for aquifer property characterization. Although the pressure transducers commonly used in hydrologic testing are vented to *correct* the well readings for changes in barometric pressure, barometric fluctuations can also cause actual changes to the water-level elevation within a well that do not represent actual surrounding aquifer conditions. This response effect is commonly ascribed to confined aquifers; however, wells completed within unconfined aquifers may also exhibit associated responses to barometric changes (Weeks 1979; Rasmussen and Crawford 1997). Water levels in unconfined aquifers typically exhibit variable time-lagged responses to barometric fluctuations. This time-lag response is caused by the time required for the barometric pressure change to be transmitted from land surface to the water table through the vadose zone, as compared to the instantaneous transmission of barometric pressure through the open well.

To determine the significance of barometric effects and enable their removal from well water-level measurements taken during the course of hydrologic testing at well 299-W15-225, Spane and Newcomer (2009a) recommended that an extended baseline monitoring period (e.g., 30 days) be implemented and observed at all selected monitor well locations (see Figure 1.1) before starting the step-drawdown and constant-rate pumping tests at well 299-W15-225. Collecting an extended record of well water-levels and associated barometric pressure readings during this extended baseline monitoring period enables barometric response functions to be developed for each of the wells selected for monitoring during the hydrologic test characterization. The development of the barometric response functions provides the means for removing barometric pressure fluctuation effects from well water-level measurements collected during the drawdown and recovery phases for the 3-day constant-rate pumping test conducted at well 299-W15-225. Detailed hydrologic test analysis of the imposed hydrologic test response for the various monitor well locations would not be possible without removing the barometric pressure effects. This is particularly the case for more distant monitoring wells (i.e., >100 m) from the extraction well where temporal barometric pressure fluctuations may have a significantly greater impact on well water-levels than the hydrologic response produced by pumping. A detailed description of the barometric removal process is presented in Rasmussen and Crawford (1997) and Spane (1999, 2002). Examples of its application for barometric-pressure removal from similar areal hydrologic test characterization assessments associated with neighboring ZP-1 extraction well locations are provided in Spane and Thorne (2000) and Spane (2008b).

Briefly stated, the barometric correction of well water-level measurements provides a measurement of the water-table in the vicinity of the monitor well. Removal of barometric effects depends on the diagnostic response model exhibited by the well/ aquifer system with different removal methods recommended for confined and unconfined aquifers, as well as for those exhibiting composite model-response behavior. As noted in Spane (1999), removing barometric fluctuations from hydrologic test data requires the following steps:

1. Collect test site atmospheric pressure values and associated aquifer formation pressure values for a pre- or post-test baseline period, during which no other extraneous stresses are imposed on the well/aquifer system.

2. Perform diagnostic barometric response analysis of the baseline well data record using the multiple-regression convolution method described by Rasmussen and Crawford (1997) to distinguish between aquifer or composite well-/aquifer-model behavior.

3. Remove barometric induced changes from the test data record using the multiple-regression deconvolution technique.

It should be noted that operating the surrounding ZP-1 pump-and-treat system represents a dynamic, extraneous stress, which would conflict with the Step 1 requirement. To minimize the effect of surrounding extraction well effects, the ZP-1 pump-and-treat system was shut down on March 26, 2009. Four of the more distant ZP-1 extraction wells (i.e., >475 m from well 299-W15-225) were restarted on May 4, 2009, under the assumption that the drawdown effects imposed by these distant extraction well locations would not have any discernable impact on well water-levels monitored as part of the well 299-W15-225 test characterization. However, as will be discussed in Section 3.3, during the barometric analysis and correction process, it was apparent that associated well water-level responses were detectable in the surrounding vicinity of well 299-W15-225 that could be attributable to these four distant ZP-1 extraction wells. As a consequence, pumping at these four distant ZP-1 extraction wells was terminated on June 1, 2009.

3.1 Baseline Well Water-Level Response

To facilitate the barometric pressure removal process, baseline water-level responses were monitored for the monitor wells selected to assess the areal hydrologic impact imposed by the 3-day constant-rate pumping test at well 299-W15-225, as listed in Table 1.1. These wells are part of two Hanford Site well water-level monitoring networks: the Hanford Site monitoring network and the 200-ZP-1 Pump-and-Treat Operations well system. All water-level data obtained from these listed wells were collected and maintained either by the CHPRC Technical Reporting Group or by the 200-ZP-1 Pump-and-Treat Operations Group during the period of investigation. For monitor wells maintained by the CHPRC Technical Reporting Group, water-level responses were measured at regular intervals (e.g., frequency = 10 minutes) using an automated measurement station that records the pressure of the overlying well water column above a submerged, in-well pressure transducer, which is connected to a surface datalogger. The pressure transducers are vented to the atmosphere, which is used as a reference for calculating a differential pressure that is reflective of only changes in the well fluid-column height above the submerged, in-well transducer. The in-well fluid-column height measurements were converted to water-level elevations, expressed in m above mean sea level (MSL), using the reference surface well control elevation datum and the measured pressure depth setting. Manual depth-to-water measurements were taken periodically at selected well sites as a field check of the well water-level measurements and pressure transducer performance. Specific pressure recording and transmittal equipment used in these wells included:

- Drück PDCR 1830-8388 submersible vented pressure transducer; 5 or 10 psi range
- Campbell Scientific Inc. CR800 series datalogger
- Radio Frequency modem and ultra high frequency (UHF) transceiver and omni-directional antenna.

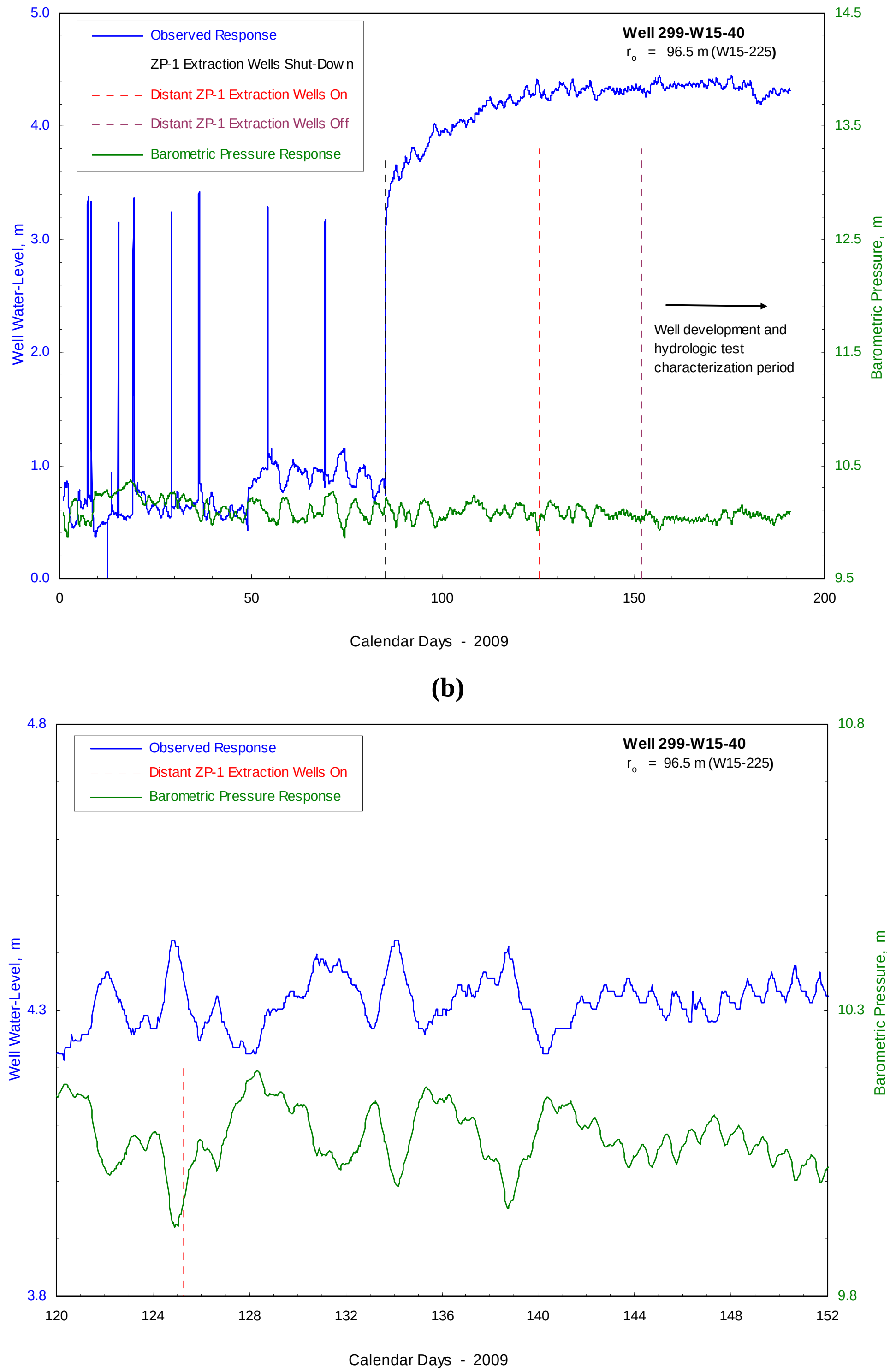
Barometric pressures were also monitored by PNNL during the course of the investigation at neighboring wells 299-W11-41 and 299-W11-47, located approximately 630 m from well 299-W15-225. These site barometric pressure measurements were the basis for removing the adverse impact of barometric pressure fluctuations on well water-level measurements. The barometric pressures were measured with a Vaisala barometric pressure transducer (Model # PTB101B) and recorded on a Campbell Scientific Inc. CR10X series datalogger

All of monitored water-level measurements obtained from indicated ZP-1 extraction wells shown in Figure 1.1 were maintained and recorded at the well site locations by the 200-ZP-1 Pump-and-Treat Operations Group. These wells are not part of the site-wide monitor well network and were designed primarily to monitor operational performance of the individual ZP-1 pump-and-treat extraction wells. The pressure transducers installed at these ZP-1 extraction well sites are connected to the pump/flow control panel at each well head. The control panel has a visual readout display (light-emitting diode [LED]) on top of the panel and is wired with dual universal serial bus (USB) dataloggers connected within the panel. The pressure transducer readings are expressed as a fluid-column height above the pressure transducer setting. These pressure readings were not converted to a water-level elevation because of uncertainties in the actual pressured transducer depth setting below the reference surface elevation datum.

Figure 3.1(a, b) and Figure 3.2(a, b) compare the observed 2009 calendar year, hourly water-level response with the barometric pressure for a near-field extraction well (299-W15-40; distance = 96.5 m from well 299-W15-225) and a more distant monitor well location (299-W14-14; distance = 251.8 m from well 299-W15-225), respectively. Also indicated in the figures are specific times of events that might be expected to produce discernable well water-level responses, such as terminating or restarting pumping at surrounding ZP-1 extraction wells and initiating hydrologic testing activities at well 299-W15-225. It should be noted that the vertical scale for the near-field extraction well (Figure 3.1a) is greater in comparison to that used for the far-field well site (Figure 3.2a) to accommodate for the larger recovery water-level responses associated with termination of pumping at this extraction well site.

The predominant water-level response at near-field extraction well 299-W15-40 (Figure 3.1a) is associated with termination of pumping activities that occurred at this well site on calendar day 85 (March 26, 2009). Also evident in Figure 3.1(a) are the temporal, short-term recovery water-level responses before calendar day 85 that are attributed to temporary terminations and restarting of pumping at the extraction well location. The general, inverse relationship of the well water level and barometric pressure is more evident for the 32-day plot between calendar day 120 and 152 (April 30 and June 1, 2009). This time period was used for the barometric analysis and was selected based on its observed low water-level trend pattern characteristics and absence of potential impacting hydrologic events (e.g., before the shut-down of distant ZP-1 extraction well locations and the initiation of hydrologic testing activities at well 299-W15-225).

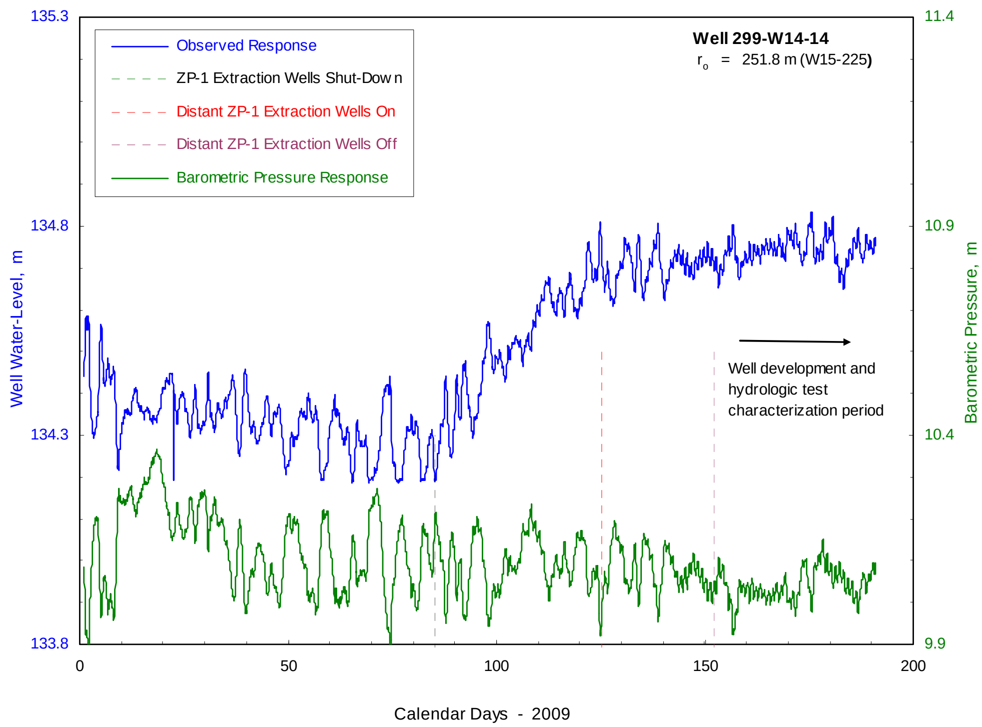
(a)



(b)

Figure 3.1. Observed Well 299-W15-40 Water-Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

(a)



(b)

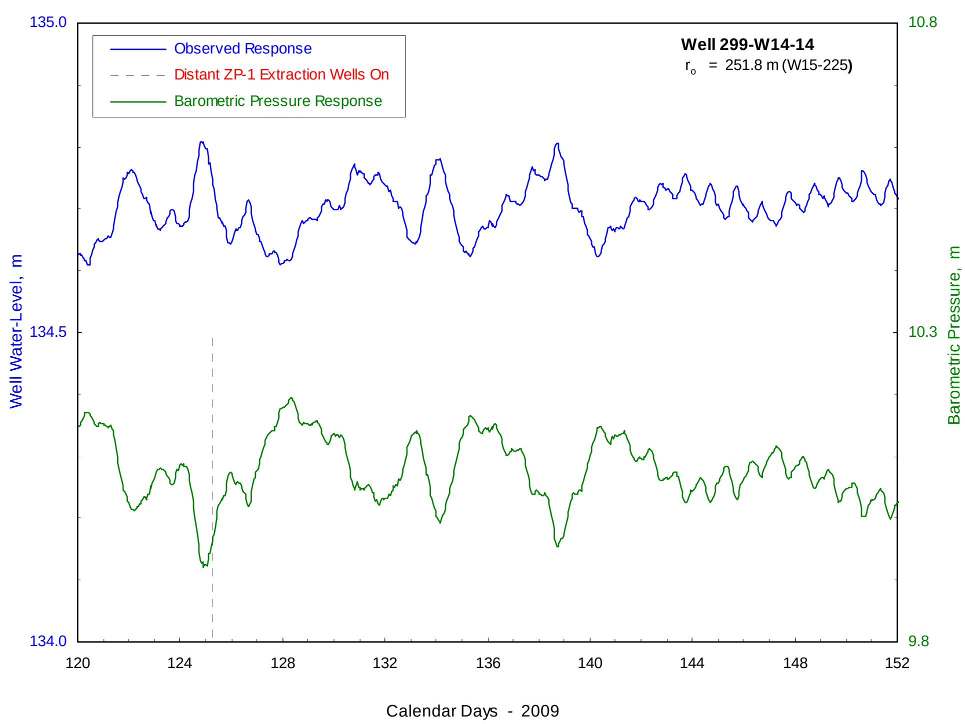


Figure 3.2. Observed Well 299-W14-14 Water-Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

The observed large-scale, areal hydrologic impacts associated with long-term, operational activities of the surrounding ZP-1 pump-and-treat system is more evident within the observed water-level response shown in Figure 3.2(a) for the more distant, far-field monitor well 299-W14-14 location. These long-term, well water-level response patterns, however, are masked to a degree by the temporal, short-term fluctuations in barometric pressure. Figure 3.2(b) shows the same 32-day time-period plot of observed well water level versus barometric pressure for well 299-W14-14. As shown, a nearly identical, apparent inverse response relationship is indicated as was exhibited at near-field extraction well 299-W15-40 for well water level and barometric pressure (Figure 3.1b). Appendix B presents additional baseline well water-level versus barometric pressure plots for selected monitor wells listed in Table 1.1 and shown in Figure 1.1.

3.2 Barometric Response Analysis

A number of methods are available (i.e., time and frequency-domain) that have been shown to be effective in removing the effects of barometric pressure fluctuations from well water-level measurements. A detailed comparison and discussion of a number of these removal methods is presented in Spane (1999, 2002) and will not be repeated in this report. Because of the relative-ease and dependable removal capability, the multiple-regression deconvolution technique was selected for use in removing barometric pressure effects from the selected wells in the vicinity of well 299-W15-225 monitored during this study. Multiple-regression deconvolution techniques have been shown in a number of previous Hanford Site reports to be effective in removing barometric effects, particularly well investigations within the 200-West Area (e.g., Spane and Thorne 2000; Spane 2008b). To implement the removal procedure, the 32-day well water-level versus barometric response data set for the calendar year 2009 time period of 120 to 152 days (April 30 and June 1, 2009) was selected (see Figure 3.1b and Figure 3.2b). As noted previously, this time period was selected based on its observed low water-level trend pattern characteristics and the absence of potential impacting hydrologic events (e.g., before the distant ZP-1 extraction well locations were shut down, and the hydrologic testing activities at well 299-W15-225 were initiated).

The 32-day baseline water-level response records for selected wells in the vicinity of the well 299-W15-225 were analyzed using the multiple-regression convolution technique described in Rasmussen and Crawford (1997) and Spane (1999). Figure 3.3 shows the well water-level/barometric response patterns obtained from the multiple-regression analysis for selected near-field and far-field well locations surrounding well 299-W15-225. The plots shown have been smoothed using a 5-point central moving-average function. Although some scatter or "noise" is evident in the plots, generally the barometric response patterns obtained for the wells shown exhibit nearly identical time-delay response behavior. This suggests that vadose zone pneumatic transmission characteristics are relatively similar for the immediate areas surrounding the respective TX-TY wells shown for distances up to ~690 m from newly constructed extraction well 299-W15-225. The wells generally exhibit a barometric time-lag dependence ranging between ~130 and ~180 hours. The exhibited time-lag range is similar to well time-lag response characteristics exhibited at other surrounding 200-West Area sites (e.g., Spane 2008b). This relatively large barometric time-lag dependence is attributed to the presence of lower permeability sedimentary units within the vadose zone (e.g., Cold Creek Unit) that retard the vertical transmission of barometric pressure fluctuations from ground level to the water-table surface (see Figure 1.3 for subsurface geologic depiction).

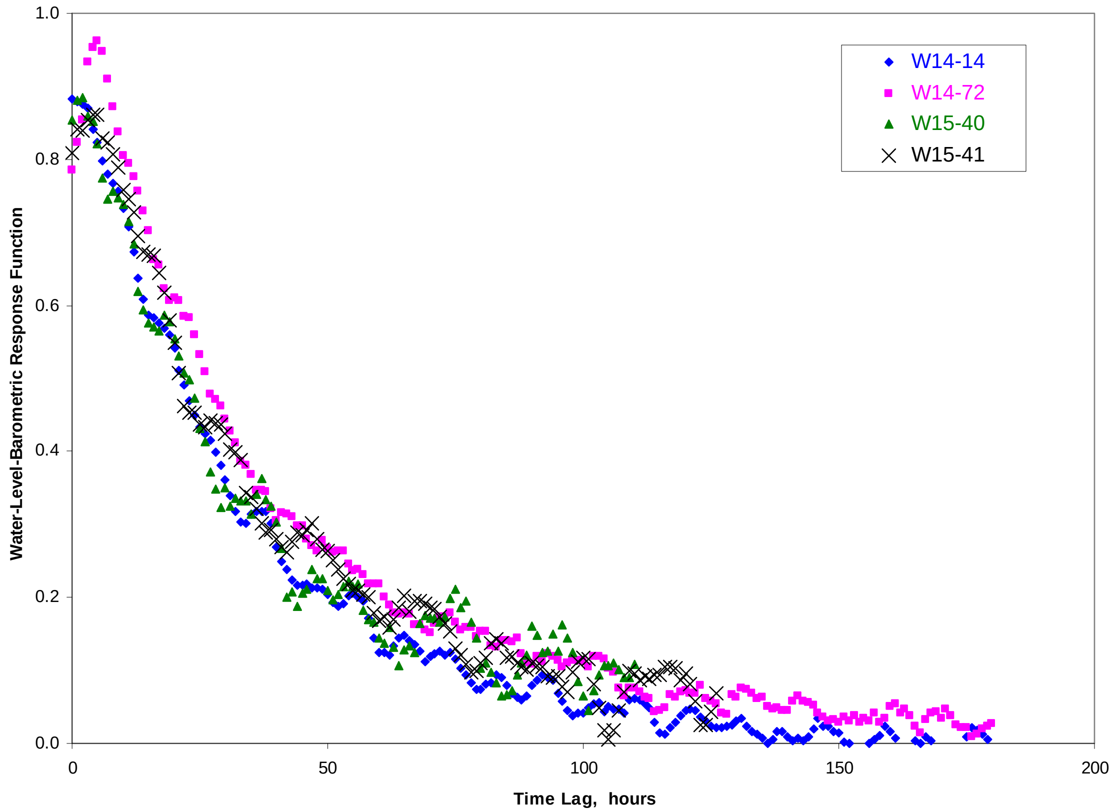


Figure 3.3. Water-Level Barometric Response Patterns for Selected Wells in the Vicinity of Well 299-W15-225

3.3 Corrected Baseline Well Water-Level Response

The “noise” or scatter exhibited by some of the well response plots shown in Figure 3.3, is attributed to the differing pressure instrument resolution/sensitivity characteristics. These instrument noise effects tend to be random and do not contribute to the overall efficiency of removing barometric pressure effects from well water-level response records. Because of the overall similarity exhibited by the individual well water-level barometric response patterns shown in Figure 3.3, the time-lag response characteristics of well 299-W14-14 were selected for universal removal application of barometric pressure effects at all monitor well locations. The use of a universal time-lag application provided better correction results (in comparison to using individual well time-lag characteristics) for well water-level responses, particularly for well exhibiting “noisy” barometric response patterns. A listing of the hourly, time-lag regression coefficients for well 299-W14-14 that were used in the universal barometric correction is presented in Appendix C.

To demonstrate the efficiency of the barometric pressure removal procedure, the observed water levels for near-field well W15-40 and far-field well 14-14 (previously shown in Figure 3.1a,b and Figure 3.2a,b, respectively) were corrected using the previously described multiple-regression barometric correction procedure. Figure 3.4 (a) and Figure 3.5 (a) shows the hourly observed and corrected well water-level responses for well 299-W15-40 and well 299-W14-14, respectively, during the baseline period of calendar days 80 to 191 (March 21 to July 9, 2009). As shown in the figure, barometric pressure fluctuations were effectively corrected and removed from the observed well water-level measurements. Many of the surrounding operational ZP-1 pump-and-treat system activities that were previously masked by temporal barometric pressure fluctuations are now clearly evident in the barometric-corrected water level response.

Figure 3.4 (b) and Figure 3.5 (b) show the hourly observed and corrected well water-level responses for well 299-W15-40 and well 299-W14-14, respectively, during the baseline period of calendar days 167 to 191 (June 16 to July 9, 2009). This time period encompasses the active hydrologic testing activities associated at newly constructed well 299-W15-225. As shown in the figure, barometric pressure fluctuations were effectively corrected and removed from the observed well water-level measurements. Many of the hydrologic testing activities conducted at well 299-W15-225 (e.g., step-drawdown tests, extensive well development activities, and the 3-day constant-rate pumping test) that were significantly masked by barometric pressure effects are now clearly exhibited in the barometric-corrected water level response. A comparison of observed and corrected baseline hourly well water-level response for other selected wells in the vicinity of well 299-W15-225 is presented in Appendix D.

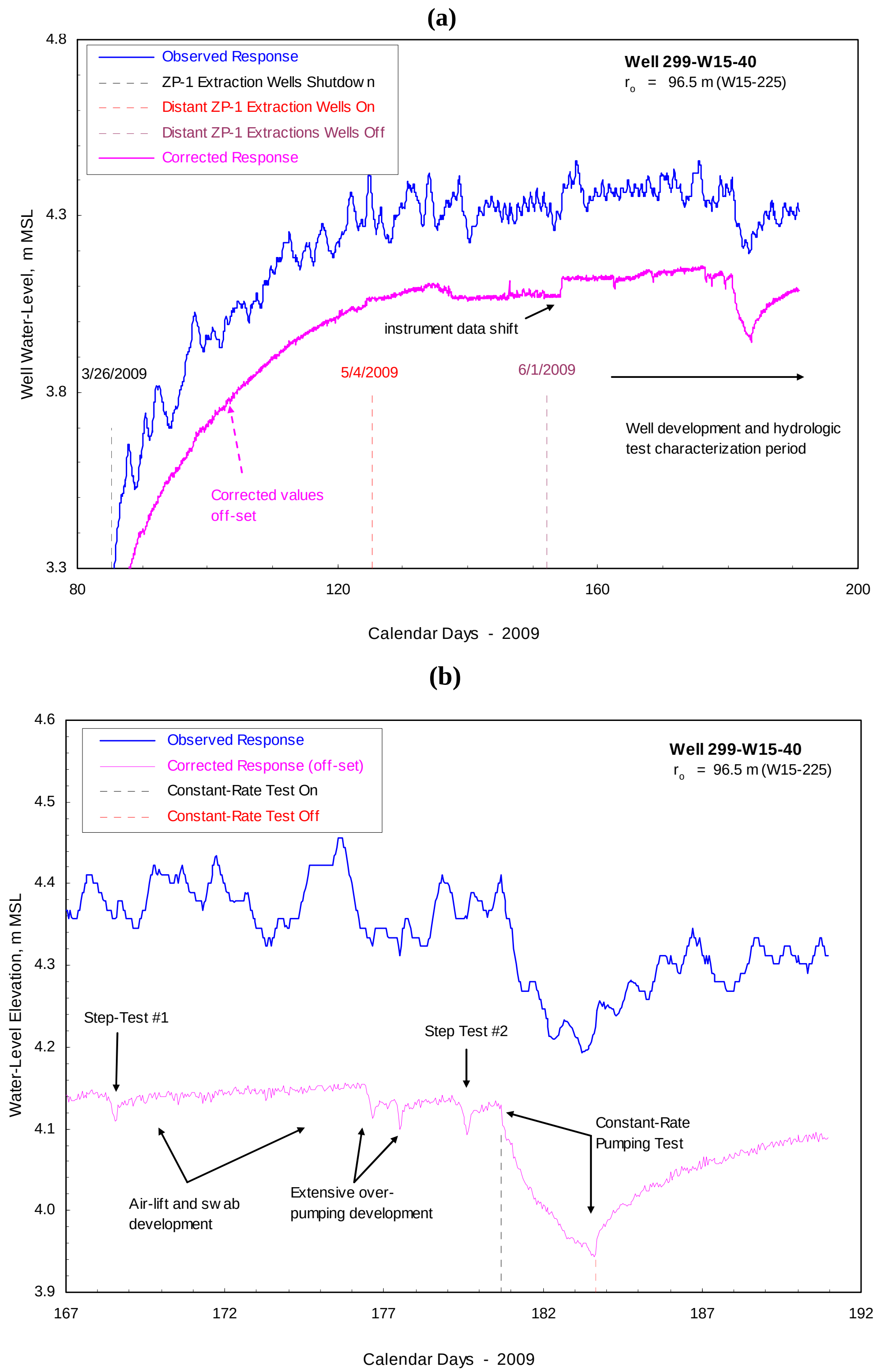
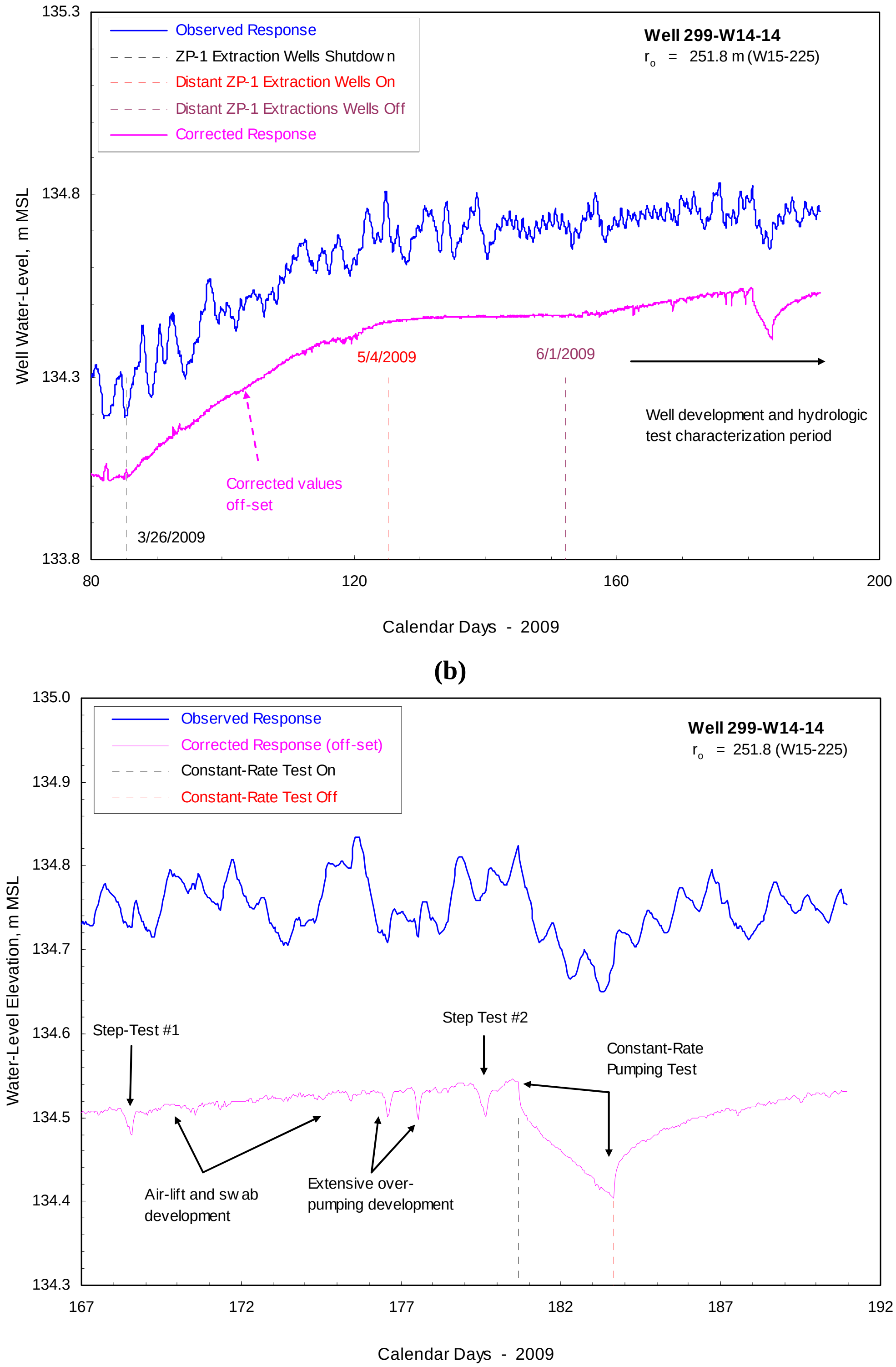


Figure 3.4. Observed and Corrected Baseline Well 299-W15-40 Water-Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time Period

(a)



(b)

Figure 3.5. Observed and Corrected Baseline Well 299-W14-14 Water-Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time Period

4.0 Hydrologic Test Analysis Results

The following provides a discussion of the preliminary results obtained for a hydrologic field-testing characterization program conducted at recently constructed well 299-W15-225. An *in-progress* summary of tests performed and preliminary analysis results were reported recently in Spane and Newcomer (2009b). The results contained herein represent a more comprehensive discussion of the characterization tests conducted at well 299-W15-225 based on the test recommendation identified in Spane and Newcomer (2009a). Based on these test recommendations, the following hydrologic test characterization program was initiated at well 299-W15-225:

- progressive test/depth interval slug test characterization during borehole drilling
- pneumatic slug test characterization of the completed well-screen section
- ambient and dynamic EBF surveys within the completed well-screen section
- step-drawdown testing
- a 3-day constant-rate pumping and recovery test of well 299-W15-225 (with associated detailed monitoring of the areal drawdown/recovery response within surrounding and neighboring wells).

The objective of each of these hydrologic test characterization elements is discussed in Section 2.0. All field tests were conducted in accordance with standard hydrologic procedures identified in Spane and Newcomer (2009a), and SGW-40266-Rev 0 (CHPRC 2009). Pertinent test information was recorded in field test notebooks and/or test-specific field data sheets during testing. All field notes, test data sheets, and test data file copies will be transferred directly to CHPRC for archival purposes.

The following discussion describes the performance and analysis of the various hydrologic tests identified above that were conducted at well 299-W15-225.

4.1 Slug Tests

The following discussion presents pertinent information describing slug-testing activities and analysis results for well 299-W15-225. Slug test characterizations were performed for two shallow test/depth intervals within the upper unconfined aquifer during borehole drilling and for two well-screen test sections after final well completion. As discussed in Section 2.1, the slug tests conducted during drilling were initiated mechanically by rapidly inserting (slug-injection) or removing (slug-withdrawal) a slugging rod of known volume into/from the temporary test-system fluid-column. Slug tests were performed pneumatically for the two slug test/well-screen characterizations performed after the final well completion. As discussed in Section 2.1, these slug tests were initiated pneumatically by rapidly releasing compressed gas used to depress the well water-column within the packer/test tubing system. Up to four different compressed gas pressures were applied to impose different stress levels on the two well-screen test sections. Table 4.1 presents pertinent slug-test characteristic information for selected test/depth intervals at well 299-W15-225.

Table 4.1. Slug-Test Characteristics for Selected Test/Depth Intervals at Well 299-W15-225

Test Well	Test Zone	Test Information: Test Date	Test Information: Number of Slug Tests	Test Information: Depth-to-Water, m bgs	Test Information: Test/Depth Interval(a) m bgs	Diagnostic Slug-Test Response Model	Hydrogeologic Unit Tested
299-W15-225	Zone 1(b)	3/9/09	10	70.87	74.5 - 75.6 (1.1)	Homogeneous Formation/ Exponential-Decay (over-damped)	Ringold Formation
	Zone 2(b)	3/23/09	8	70.87	75.7 - 78.3 (2.6)	Elastic Formation/ Exponential-Decay (over-damped)	Ringold Formation
	Zone 3(c)	7/14/09 to 7/15/09	7	69.63	83.9 - 123.5 (38.1)(d)	Homogeneous Formation/ Oscillatory (under-damped)	Ringold Formation
	Zone 4(c)	7/15/09 to 7/16/09	6	69.54	74.7 - 123.5 (44.2)(e)	Homogeneous Formation/ Oscillatory (under-damped)	Ringold Formation

(a) Estimated test-interval length (m) listed in parentheses.
(b) Mechanical slug tests performed during borehole advancement.
(c) Pneumatic slug tests conducted within completed well-screen section.
(d) Note: 1.5 m of corrugated sleeve at 110.2 to 111.7 m bgs subtracted from test/depth interval.
(e) Note: 3.1 m of blank casing at 80.8 to 83.9 m bgs and 1.5 m of corrugated sleeve at 110.2 to 111.7 m bgs for a total of 4.6 m of blank section subtracted from test/depth interval.

The diagnostic slug-test response model identified for the various test/depth intervals ranged from over-damped (exponential-decay) homogeneous/elastic to under-damped (oscillatory) homogeneous formation responses (Table 4.1). This range in response model behavior exhibited is directly related to the transmissivity of the interval tested. Standard type-curve and Bouwer and Rice methods were used to analyze tests exhibiting over-damped slug-test behavior, while the High-K method was used to analyze tests indicating under-damped test conditions. These analytical methods are described in Section 2.1.3. Table 4.2 summarizes the slug-test analysis results for each test/depth interval and the applicable analysis method used. The borehole geology log is presented in Appendix A, which can be referred to for a geologic description of the respective well test zone/depth intervals. Details concerning the performance and analysis of slug tests conducted at each test/depth interval are discussed in the following report sections.

Table 4.2. Slug Test Analysis Results for Well 299-W15-225

Test Well	Test Zone	Type-Curve Analysis Method: Hydraulic Conductivity, K_h[a] m/day	Type-Curve Analysis Method: Specific Storage, S_s m^{-1}	Bouwer and Rice Method: Hydraulic Conductivity, K_h[a] m/day	High-K Method: Hydraulic Conductivity, K_h[a] m/day
299-W15-225	Zone 1[b]	4.51 - 6.12 (5.21)	1.0E-6 to 5.0E-4	4.92 - 6.28 (5.65)	NA
	Zone 2[b]	4.41 - 5.10 (4.60)	5.0E-5 to 1.5E-4	4.13 - 4.94 (4.36)	NA
	Zone 3[c]	NA	NA	NA	15.9 - 24.2 (20.0)
	Zone 4[c]	NA	NA	NA	15.0 - 16.9 (16.1)

NA = not applicable.
Note: Number in parentheses is the average value for all tests.
(a) Assumed to be uniform within the well-screen test section.
(b) Mechanical slug tests performed during borehole advancement.
(c) Pneumatic slug tests conducted within completed well-screen section.

4.1.1 Zone 1 (Depth Interval: 74.5 to 75.6 m)

After reaching a drill depth of 76.3 m bgs, the bottom 0.6 m of the borehole filled in with sediment slough. The packer/well-screen assembly was lowered to the bottom of the borehole at a depth of 75.7 m bgs, and the 0.324 m O.D. drill casing was retracted 1.4 m (i.e., from 75.9 to 74.5 m bgs), producing a test/depth interval for Zone 1 of 74.5 to 75.6 m bgs. (Note: the projected test/depth interval is reflective of 0.1 m of sediment infill inside the temporary 0.203 m I.D. well-screen test assembly that occurred during groundwater sampling activities performed immediately before slug testing). The test tubing above the well-screen (where slug-test responses occurred) was 0.102 m I.D. The inflatable packer mounted above the temporary well-screen test assembly was set at a depth of 70.8 to 71.5 m bgs. The inflated packer provided a seal between the test tubing string and the outer drill casing, which effectively isolated the overlying annulus from the underlying test/depth interval. The borehole geologic description of Zone 1 test/depth interval listed in Appendix A indicates a test section composed primarily of a silty sandy gravel unit within the Ringold Formation, which is composed of 60% gravel, 20% sand, and 20% silt. At the time of testing, the top of the well-screen test interval was located ~3.6 m below the aquifer water-table surface.

A series of five slug-injection and five slug-withdrawal tests (four low-stress and six high-stress tests) were conducted between 1102 hours and 1330 hours PST, March 9, 2009. The slug tests were conducted with two different sized slugging rods that were partially submerged in the water column. These partially submerged slug rods imparted a theoretical applied stress level of ~0.2 to ~0.5 m for the low-stress tests and ~0.4 to ~1.0 m for the high-stress tests within the 0.102-m I.D. test-tubing string. The slug rods were not fully submerged because of an inadvertent depth error for the attaching slug-rod cable. For slug withdrawal tests, the imparted stress and associated test response occurred with the 0.102 m I.D. and the underlying, larger-diameter. well-screen/tubing-string attachment. This caused the applied stresses for slug withdrawal tests to be ~$^1/_2$ that applied to the slug-injection tests, whose responses occurred only within the overlying 0.102 m I.D. tubing test string. Because of the complexities imposed by varying the test system diameter, slug withdrawal test results were not analyzed for Zone 1. The hydraulic property test characterization results are only reflective of slug-injection tests. Downhole test-interval response pressures during testing were monitored with a 0- to 69-kPa (0- to 10-psig) pressure transducer for the first six slug tests. During the sixth slug test, the pressure transducer showed erratic behavior, causing abrupt decreasing shifts in the test response data. The transducer was replaced with a 0- to 138-kPa (0- to 20-psig) pressure transducer for the remaining four tests. The transducers were set at a depth of ~73 m bgs, and the static depth-to-water for the test interval measured before testing was 70.87 m bgs.

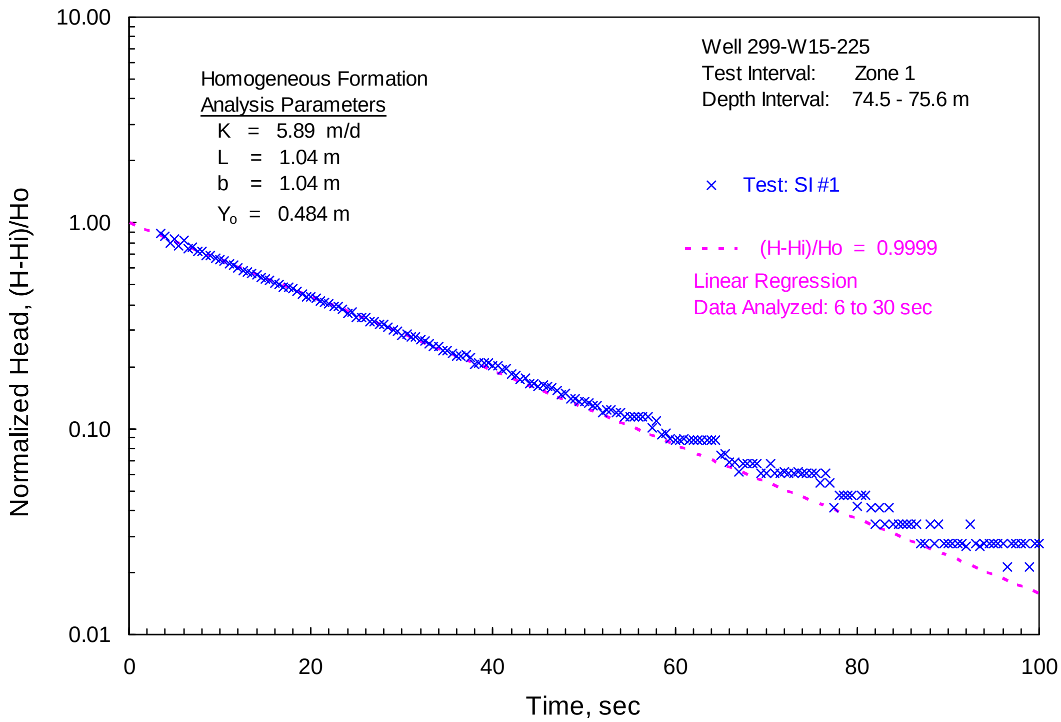
All slug-injection tests exhibited over-damped (exponential-decay response) homogeneous formation behavior, which is indicative of low-to-moderate permeability test zone conditions. A comparison of the normalized, high and low stress, slug-injection test responses indicates only a slight delay for high-stress level test responses. Slug tests exhibiting over-damped response behavior can be analyzed quantitatively with homogeneous formation analysis approaches, as described in Butler (1998). For the homogeneous formation analysis, the standard type-curve method provided K estimates ranging from 4.92 to 6.48 m/d (average of 5.65 m/d). This compares favorably to a slightly lower K range of 4.51 to 6.12 m/d (average of 5.21 m/d) using the Bouwer and Rice analysis method. Selected examples of the test-analysis plots for the Zone 1 test/depth interval are presented in Figure 4.1.

4.1.2 Zone 2 (Depth Interval: 75.7 to 78.3 m)

After reaching a drill depth of 78.8 m bgs, the bottom 0.3 m of the borehole filled in with sediment slough. The packer/well-screen assembly was lowered to the bottom of the borehole at a depth of 78.5 m, and the 0.324 m O.D. drill casing was retracted 2.9 m, producing a test/depth interval for Zone 2 of 75.7 to 78.3 m bgs. (Note: the projected test/depth interval is reflective of 0.2 m of sediment infill inside the temporary 0.203 m I.D. well-screen test assembly that occurred during drill-casing retraction activities.)

As during Zone 1 testing, the test tubing above the well-screen (where slug-test responses occurred) for Zone 2 slug test characterization was 0.102 m I.D. The inflatable packer mounted above the temporary well-screen test assembly was set at a depth of 73.5 to 74.3 m bgs. The inflated packer provided a seal between the test tubing string and the outer drill casing, which effectively isolated the overlying annulus from the underlying test/depth interval. The borehole geologic description of Zone 2 test/depth interval listed in Appendix A indicates a test section composed primarily of a silty sandy gravel unit within the Ringold Formation, which is composed of 60% gravel and ranges from 10 to 30% sand and 10 to 30% silt. At the time of testing, the top of the well-screen test interval was located ~4.8 m below the aquifer water-table surface.

A series of four slug-injection and four slug-withdrawal tests (four low-stress and four high-stress tests) were conducted between 1025 hours and 1222 hours PST, March 23, 2009. Data for one of the high-stress slug-withdrawal tests were lost due to an inadvertent over-writing of the data on the datalogger. The slug tests were conducted with two different-sized, and fully submerged slugging rods. The two slugging rod displacement volumes were 0.0055 m^3 and 0.0110 m^3. These slugging-rod volumes produced a theoretically applied stress level of 0.68 m for the low-stress tests and 1.36 m for the high-stress tests within the 0.102 m I.D. test tubing string. Downhole test-interval test-response pressures were monitored with a 0- to 34.5-kPa (0- to 5-psig) pressure transducer set at a depth of ~73 m bgs. The static depth-to-water for the test interval measured before testing was 70.87 m bgs.



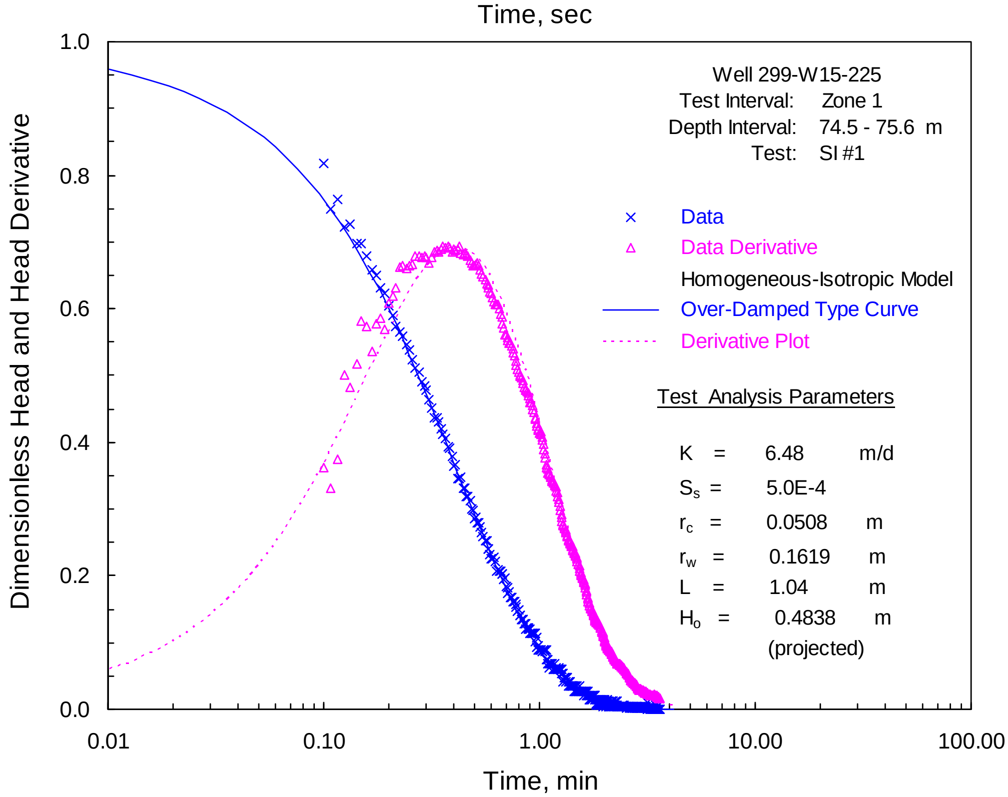


Figure 4.1. Selected Slug-Test Analysis Plots for Zone 1; Depth Interval: 74.5 to 75.6 m (Bouwer and Rice method [top] and type-curve method [bottom])

Most of the slug tests exhibited over-damped (exponential-decay response) elastic formation behavior, which is indicative of low-to-moderate permeability test zone conditions. A comparison of the normalized, high and low stress, slug-injection test responses indicates nearly identical test responses, which indicates predominately linear test-response behavior. It should be noted that the two high-stress slug-injection tests exhibited a slight departure in test-response behavior at a time equivalent to ~80% normalized recovery. The source of the slight departure is unknown, and as a result these tests were not included in the test zone characterization results.

The slug-test responses for each individual slug test indicate an elastic (concave upward) response displayed on the Bouwer and Rice analysis plot. An example showing this type of response is presented in Figure 4.2. This elastic type of test response requires that the normalized head data segment between 0.3 and 0.2 be used when using the Bouwer and Rice (1976) analysis method (Butler 1996, 1998). The elastic Bouwer and Rice slug test analyses provided K estimates ranging from 4.13 to 4.94 m/d (average of 4.36 m/d). This range compares very favorably to the K range of 4.41 to 5.10 m/d (average of 4.60 m/d) obtained with the standard type-curve analysis method. The calculated average hydraulic properties for Zone 2 are very similar to those calculated for the immediately overlying Zone 1. This suggests rather the presence of uniform hydrogeologic property conditions extending over this combined test aquifer section within the Ringold Formation. Selected examples of the test-analysis plots for the Zone 2 test/depth interval are presented in Figure 4.2.

4.1.3 Zone 3 (Lower Completed Well-Screen Section; Depth Interval: 83.9 to 123.5 m)

Following well completion and performance of the step-drawdown and constant-rate pumping tests, pneumatic slug tests were conducted for the lower well-screen section shown in Figure 1.6. The well-screen interval of 83.9 to 123.5 m bgs represents a composite of well-screen sections that includes a blank ~1.5-m section of corrugated sleeve used to remediate a break in the lower well screen located at a depth of 110.2 to 111.7 m bgs. The total length of the open well-screen section within this test/depth interval is 38.1 m. The borehole geology log for this long well-screen interval (in Appendix A) indicates variable sedimentary conditions and consists predominantly of silty sandy gravel, with minor amounts of gravelly sand and gravelly silty sand. At the time of testing, the top of the lower well-screen was located ~14 m below the aquifer water-table surface. The test results reflect sedimentary deposits of the Ringold Formation above the Ringold Lower Mud unit and are reflective of conditions within the middle and lower-sections of the unconfined aquifer.

A series of seven pneumatic slug tests were conducted at various stress levels between 1500 hours PST, July 14, 2009, and 1127 hours PST, July 15, 2009. The pneumatic slug tests were conducted by pressurizing the inside of the 0.102-m I.D. test tubing system used to set the packer assembly. The applied stress (compressed nitrogen) pressures ranged from 3.5 to 33.8 kPa (0.5 to 4.9 psi), which depressed the fluid column within the test tubing string, ranging from 0.3 to 3.4 m for individual tests. During test initiation, the pressure was rapidly released by instantly opening the ball valves at the wellhead surface manifold. The inflatable packer was set within the ~3-m blank section of casing above the top of the lower well screen, at a depth of 80.8 and 81.4 m bgs. The inflated packer provided a seal between the test tubing string and the outer well-screen/casing. This packer seal isolated the overlying annulus from the underlying lower screen. During the pneumatic slug tests, the inflatable packer was pressurized to ~410 kPa (~60 psi). The integrity of the packer seal was checked by adding several liters of de-ionized water down the annulus and monitoring for any communicative downhole pressure responses below the packer. The integrity tests indicated that the packer provided test-zone isolation during the performance of the pneumatic tests. The static depth-to-water measured for the test interval before starting the pneumatic slug tests was 69.63 m bgs.

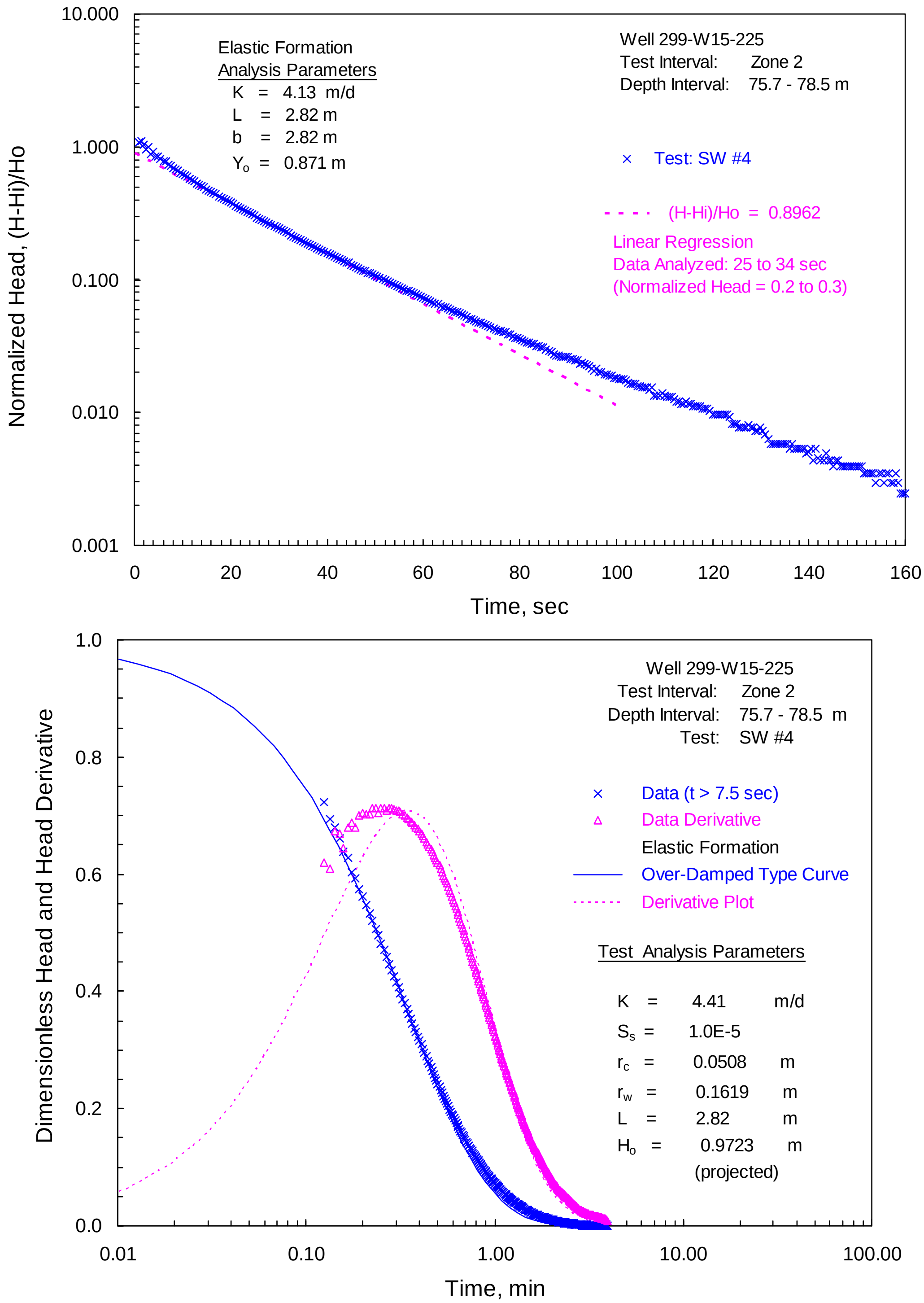


Figure 4.2. Selected Slug-Test Analysis Plots for Zone 2; Depth Interval: 75.7 to 78.5 m (Bouwer and Rice method [top] and type-curve method [bottom])

The slug tests exhibited under-damped (oscillatory-type response) formation behavior, which is indicative of moderately high permeability test-zone conditions. A comparison of the normalized slug tests of various stress levels indicates slight stress dependence, which indicates a slight, non-linear test behavior. The test responses were analyzed using the High-K analysis method discussed in Section 2.1.3. The higher stress tests generally exhibited slightly lower amplitude and less noise in the oscillatory test responses in comparison to the lower stress tests (Figure 4.3). Results obtained using the High-K analysis method provided a K estimate range of 15.9 to 24.2 m/day, with an average of 20.0 m/day for the Zone 3 lower well-screen section. A selected example of a High-K analysis for Zone 3 test is shown in Figure 4.4.

4.1.4 Zone 4 (Composite Completed Well-Screen Section; Depth Interval: 74.7 to 123.5 m)

After slug test characterization of the lower well screen was completed, pneumatic slug tests were conducted for the composite upper and lower well-screen sections, as shown in Figure 1.6. The well-screen interval of 74.7 to 123.5 m bgs represents a composite of well-screen sections that includes a blank ~1.5-m section of corrugated sleeve used to remediate a break in the lower well screen located at a depth of 110.2 to 111.7 m bgs as well as a ~3 m blank well casing section between 80.8 and 83.9 m bgs. The total length of the open well-screen section within this test/depth interval is 44.2 m. The borehole geology log for this long well-screen interval (in Appendix A) indicates variable sedimentary conditions and consists predominantly of silty sandy gravel with minor amounts of gravelly sand and gravelly silty sand. At the time of testing, the top of the upper well-screen was located ~5 m below the aquifer water-table surface. The test results reflect sedimentary deposits of the Ringold Formation above the Ringold Lower Mud unit and are reflective of conditions throughout most of the unconfined aquifer, except for the upper 5 m of the aquifer.

A series of six pneumatic slug tests at various stress levels were conducted between 1326 hours PST, July 15, 2009, and 0732 hours PST, July 16, 2009. The pneumatic slug tests were conducted by pressurizing the inside of the 0.102-m I.D. test tubing system used to set the packer assembly. The applied stress (compressed nitrogen) pressures ranged from 9.0 to 37.3 kPa (1.3 to 5.4 psi), which depressed the fluid column within the riser casing, ranging from 1.1 to 3.5 m for individual tests. During test initiation, the pressure was rapidly released by instantly opening the ball valves at the wellhead surface manifold. The inflatable packer was set within the blank section of casing above the top of the upper well screen at a depth of 73.2 and 73.8 m bgs. The inflated packer provided a seal between the test tubing string and the outer well-screen/casing. This packer seal isolated the overlying annulus from the underlying lower screen. During the pneumatic slug tests, the inflatable packer was pressurized to ~410 kPa (~60 psi). The integrity of the packer seal was checked by adding several liters of de-ionized water down the annulus and monitoring for any communicative downhole pressure responses below the packer. The integrity tests indicated that the packer provided test zone isolation during the performance of the pneumatic tests. The static depth-to-water measured for the test interval before starting the pneumatic slug tests was 69.54 m bgs.

The slug tests exhibited under-damped (oscillatory-type response) formation behavior, which is indicative of moderately high permeability test zone conditions. A comparison of the normalized slug tests of various stress levels indicates nearly identical test response patterns, which indicates linear test behavior. The test responses were analyzed using the High-K analysis method discussed in Section 2.1.3. Results obtained using the High-K analysis method provided a K estimate range of 15.0 to 16.9 m/day, with an average of 16.1 m/day for the Zone 4 lower well-screen section. A selected example of a High-K analysis for Zone 3 test is shown in Figure 4.5.

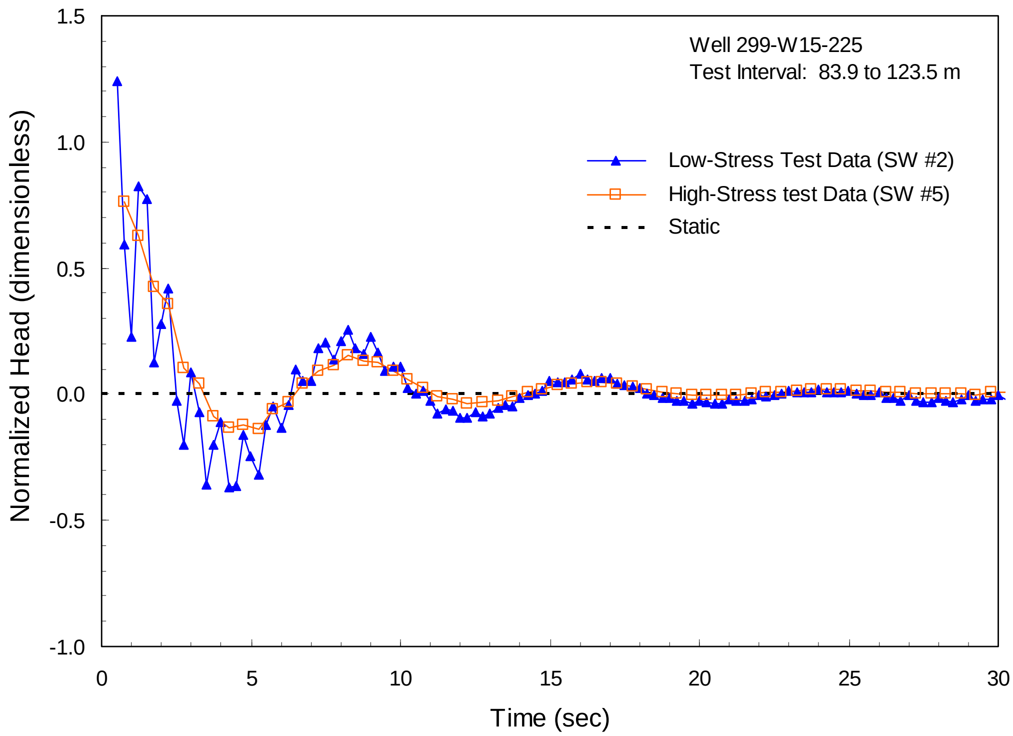


Figure 4.3. Comparison of Low- and High-Stress Under-Damped Slug-Test Responses for Zone 3

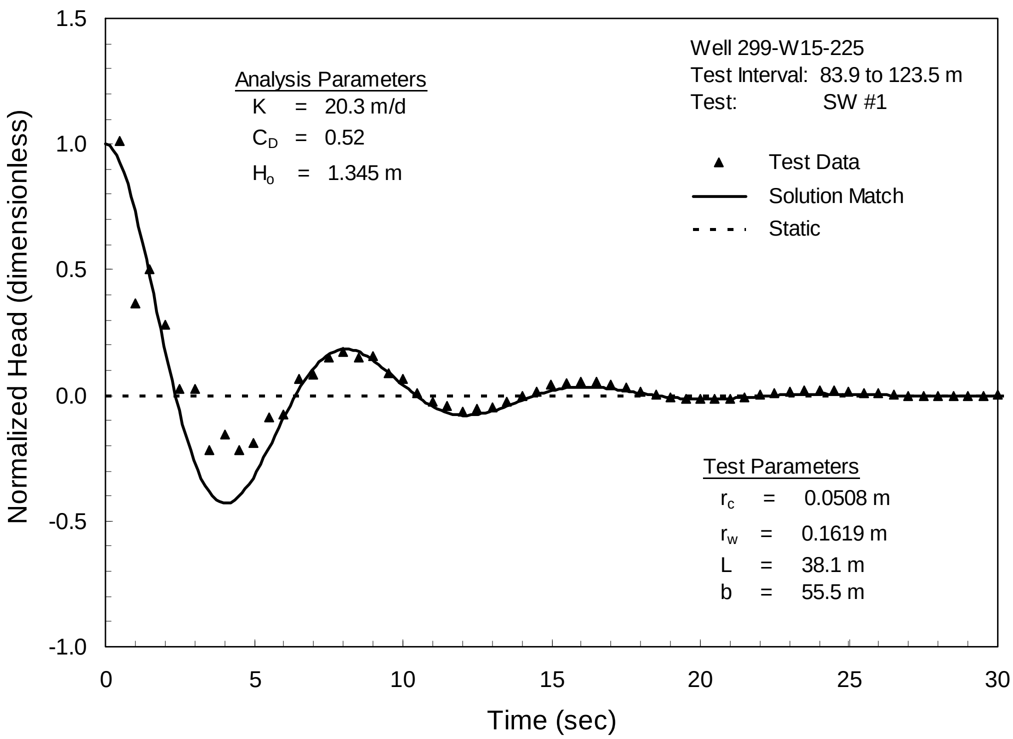


Figure 4.4. Selected High-K, Under-Damped Slug-Test Analysis Example for Zone 3

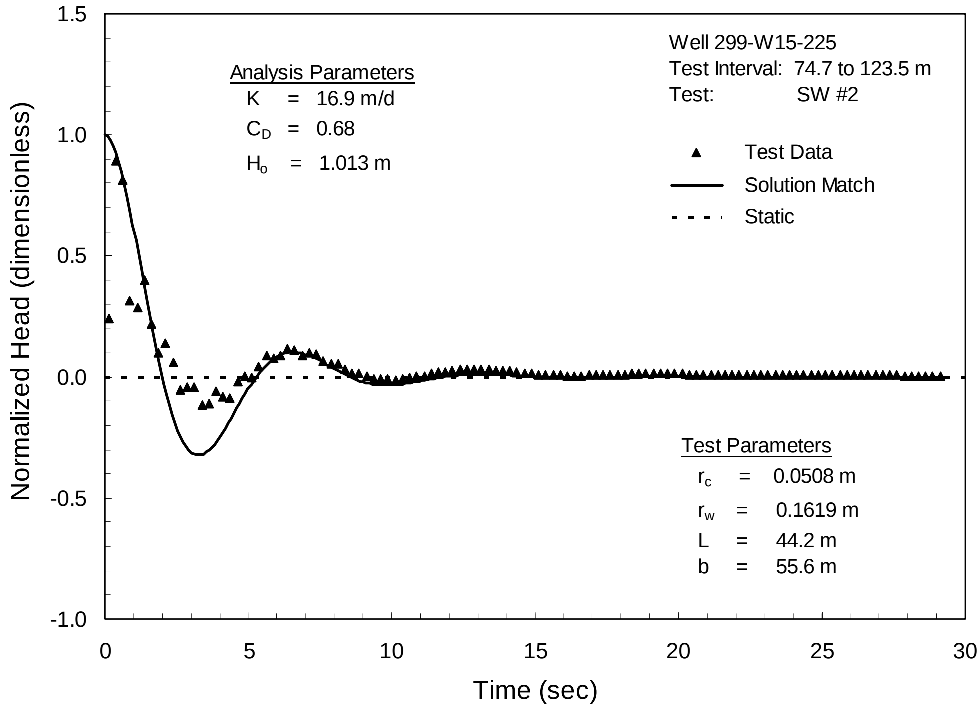


Figure 4.5. Selected High-K, Under-Damped Slug-Test Analysis Example for Zone 4

4.2 Dynamic Electromagnetic Flowmeter Survey

The following section describes the EBF surveys and analysis results conducted for well 299-W15-225. The surveys were performed in the final completed well-screen section following well development and performance of the step-drawdown and constant-rate pumping tests. A summary of pertinent information pertaining to the EBF survey is provided in Table 4.3. Detailed well-construction information for well 299-W15-225 (as it relates to the performance of the EBF survey) and a summary of the EBF analysis data are provided in Figure 1.6 and Appendix E, respectively.

Table 4.3. Summary of EBF Survey Information for Well 299-W15-225

Type of EBF Survey	EBF Survey Date	Depth/Test Interval m bgs	Static/Pump-Induced Depth-to-Water m bgs	Average Discharge Rate Lpm[(a)]	Hydrogeologic Unit Tested
Ambient	7/10/09	74.7 to 123.5 (44.2)[(b)]	69.65/NA	0	Ringold Formation
Dynamic	7/13/09	74.7 to 123.5 (44.2)[(b)]	69.66/69.80	36.2	Ringold Formation

(a) Liters-per-minute.
(b) Open well-screen length over the indicated test/depth interval (see Figure 1.6 for construction details).

As discussed in Section 1.3 and shown in Figure 1.6, well 299-W15-225 is completed with two well screen sections: a 39.6-m-long section of 0.140-cm (0.055-in.) slot screen over the depth interval 83.9 to 123.5 m bgs, and a 6.1-m section of 0.102-cm (0.040-in.) slot screen over the depth of 74.7 to 80.8 m bgs.

The well completion includes a 3.1-m long section of blank casing situated between the two well screen sections, and an ~1.5 m blank corrugated sleeve occurs over the depth interval 110.2 to 111.7 m bgs. Six blank well-screen joints occur at evenly spaced depth intervals of 6.1 m from a depth of 86.9 to 117.4 m bgs within the lower well-screen section. No blank well-screen joints occur in the upper-section of well screen. The well is completed with blank well casing from the top of the upper well screen to land surface. These blank casing sections provide a means of calibrating the EBF survey at various depth locations within the well completion.

Ambient and dynamic flowmeter surveys were conducted on July 10 and July 13, 2009, respectively. For each survey, the vertical flow was measured at ~1.5-m intervals in a direct succession from bottom to top within the completed well screen. The surveys were performed in accordance with survey procedures and methods discussed in Section 2.2. Due to EBF cable-depth limitations, the lowest measurement survey depth was at 118.0 m bgs. The uppermost survey measurement occurred at a depth of 73.8 m bgs within the blank casing above the top well-screen section. Vertical flow within the bottom 5.5 m of the well-screen section (i.e., between 118.0 and 123.5 m depth) was examined as a composite measurement depth location for the EBF analyses. Because vertical no-flow calibration measurements could not be measured directly within the well-screen sump section at the bottom of the well, zero-reference flow measurements were taken within a blank test section of 0.203-m I.D. casing at land surface before and after EBF testing. Zero-flow EBF instrument calibrations were also available within the blank casing immediately above the top of the well screen during the ambient survey. These zero-reference flow measurements were consistently within ~5% of agreement. Vertical flow calibrations were also performed within the ~3-m-long section of blank casing at a depth of 82.9 m bgs and at the 93.0-m depth screen joint to account for bypass flow between the inflatable packer/rubber gasket seal assembly and the surrounding well screen.

Following the ambient survey, the intake of a 2-Hp Sub Drive 100 submersible pump (model #25SD154) was installed to a depth of 71.9 m bgs using a 0.025-m I.D. test-tubing string. A digital inline flowmeter was installed in the discharge line at the surface for measuring the discharge flow rate, and a gate valve was used to control flow. During the dynamic survey, the in-well flow rate measured with the EBF within the blank well casing above the top of the well-screen section was 32.7 L/min. This flow rate is ~10% lower than the average constant discharge rate of 36.2 L/min measured with the surface, in-line digital flowmeter. This flow measurement discrepancy is within the maximum range of error (i.e., up to ~10%) reported for the EBF flow measurements.

For each individual EBF depth-flow measurement, vertical flow was measured both with the packer system fully inflated and not inflated (i.e., rubber gasket seal only). No packer bypass failures were observed during the course of the dynamic EBF survey. It should be noted, however, that while the packer was inflated for uppermost depth-flow measurements (i.e., 74.7 to 79.9 m bgs), including the measurement within the blank well casing immediately above the top well screen, the instrument over-ranged because of a malfunction in the electronics box. Vertical flow measured at these same depths with only the gasket providing the seal (i.e., packer un-inflated) did not over-range the instrument, however, because of a greater proportion of bypass flow around the seal. Inflated packer vertical flow measurements for these few measurement depth locations was estimated based on the inflated vs. non-inflated EBF probe measurement established for underlying measurement-depth locations. The average calculated flow ratio for inflated versus non-inflated measurements was established as a correction ratio of 3.04:1.

Ambient and dynamic vertical flow profile results are shown in Figure 4.6. The ambient vertical flow profile indicates downward flow ranging from ~0.5 to ~1.0 L/min over the two separate well-screen sections. The measured net flow profile (i.e., induced minus ambient flow) indicates that the largest change (increase) in flow contribution was at 113.4 to 118.0 m bgs near the bottom of the well screen and at 99.7 to 102.7 m bgs within the central part of the lower well-screen section. Net flow contribution at depth intervals of 74.7 to 99.7 m bgs and 102.7 to 113.4 m bgs were generally similar as indicated by the similar slope of the flow profile at these depths. The corrugated sleeve and blank casing sections did not contribute to the flow profile as shown by the zero net change in flow at the depths of these blank sections (i.e., between 110.2 and 111.7 m bgs and between 80.8 and 83.9 m bgs, respectively).

Data from the net profile shown in Figure 4.6 were used to calculate the normalized hydraulic conductivity distribution with the two well-screen sections. The profile of normalized hydraulic conductivity, presented in Figure 4.7 indicates that relative K ranged from 0.002 to 0.19, with the highest relative K values occurring at depths of ~100 to 101 m bgs and ~116 to 118 m bgs. A composite well-screen length of 44.2 m, which does not include the corrugated sleeve and blank casing sections, was used to calculate the normalized hydraulic conductivity values. As a result, no relative K values were assigned to these blank sections of the well screen.

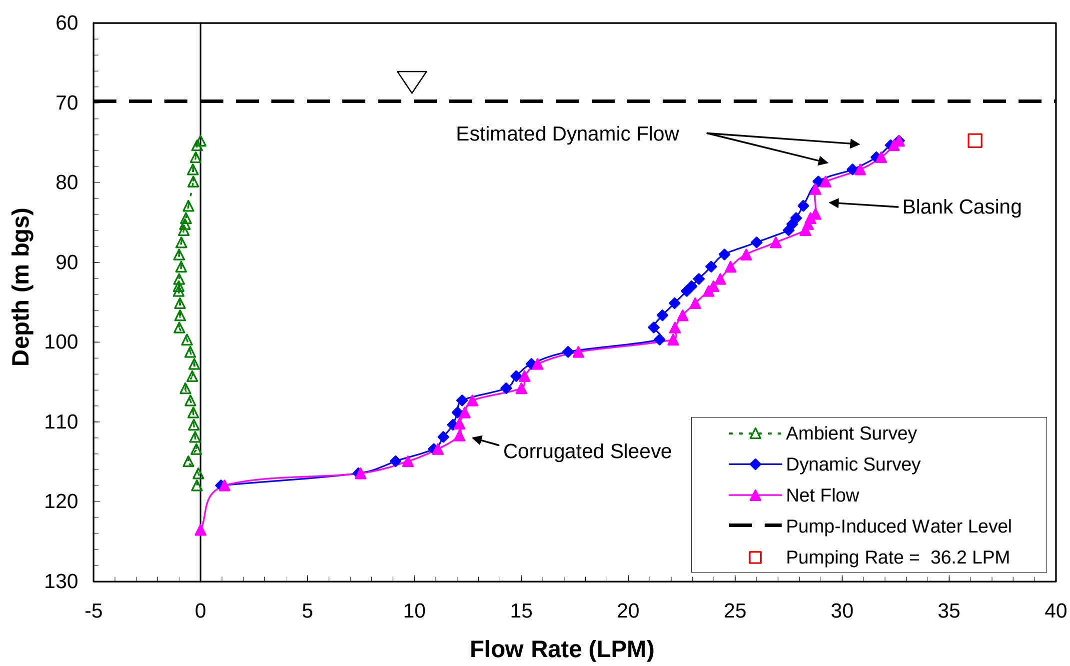


Figure 4.6. Ambient and Dynamic Vertical Flow Profiles for Well 299-W15-225

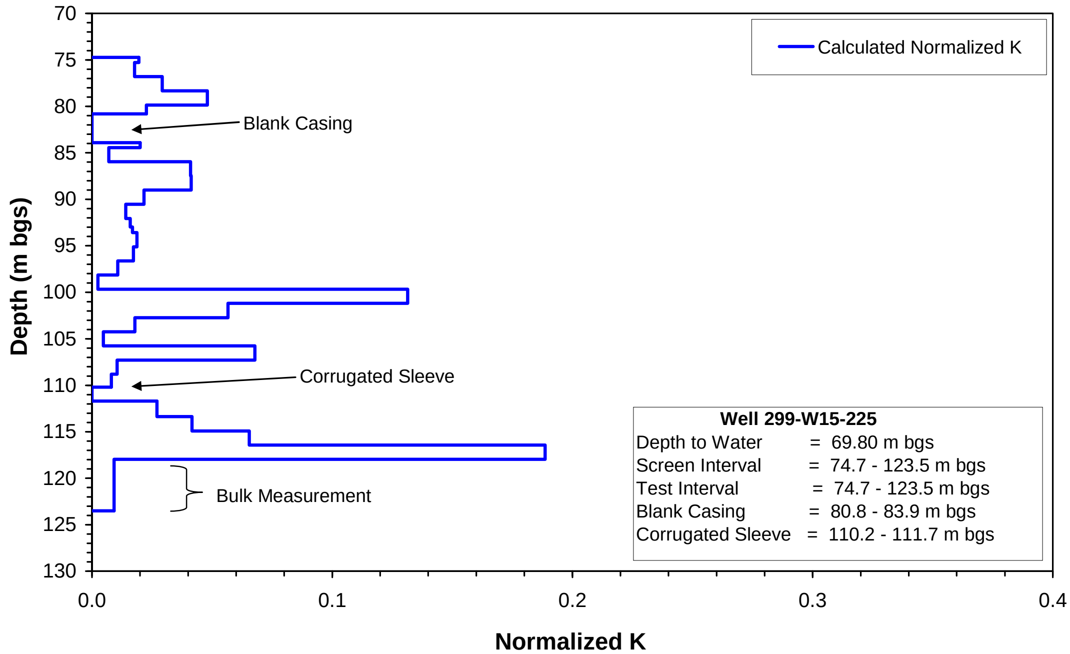


Figure 4.7. Calculated Relative Hydraulic Conductivity Profile for Well 299-W15-225

4.3 Step-Drawdown Testing

As discussed in Section 2.3, step-drawdown testing is normally performed to assess well performance and for guidance in selecting an optimum pumping rate for a subsequent, longer-duration, constant-rate pumping test. Two separate step-drawdown tests were conducted during the characterization conducted at well 299-W15-225. The two step-drawdown tests were separated by a program of extensive well development. The purpose of the extensive well development was to improve well production capabilities for the newly constructed extraction well 299-W15-225. Comparison of results obtained from the performance of the first and second step-drawdown test provided the basis for assessing the impact of the implemented extensive well-development activities. A description of the step-drawdown tests and a preliminary assessment of the efficacy of the extensive well development on well 299-W15-225 is provided in the following report sections.

4.3.1 Step-Drawdown Test 1

An initial step-drawdown test was conducted at well 299-W15-225 between 0701 and 1500 hours, PDT, on June 17, 2009. Four 2-hour pumping steps were employed during the course of performing the step-drawdown test at planned pumping rates of ~113.5, 227, 340.5, and 454 liters per minute (30, 60, 90, and 120 gallons per minute). A 50-HP Crown submersible pump (Model 5 CH225 STD) that was provided by the Blue Star well-drilling company and employed for initial well development activities was used to perform the step-drawdown test. The subsurface pump intake was set at a depth of 119.8 m bgs and was not equipped with a downhole foot/check valve. The absence of a foot/check valve within the downhole pumping assembly produces flow back of pumped groundwater back into the well column when the pumping is terminated. This impacts recovery water-levels within the pumped well during early-stages of recovery following completion of the pumping test. Surface discharge rates were monitored with two in-line surface flowmeters (Great Plains Industries, Inc, Industrial Grade, 0.051 m

I.D., Digital Turbine Flowmeter, and a 0.051 m I.D., McCrometer Totalizer Flowmeter), and surface discharge rates were regulated using an in-line surface flow valve. Groundwater produced during testing was discharged to temporary surface storage tanks, which allowed settling of any produced suspended material before pumping and ultimate discharge of the produced groundwater to the ZP-1 pump-and-treat groundwater disposal system. Water levels were measured within well 299-W15-225 during testing with an In-Situ, Inc., 20 psi pressure transducer that was installed within an in-well 0.025 m I.D., access stilling-well. The pressure transducer readings were recorded on a Hermit 3000 datalogger system. The surrounding monitor and the ZP-1 extraction well water-levels were maintained and collected during testing using the Hanford network data systems discussed in Section 3.1.

Figure 4.8 shows the observed drawdown associated with actual indicated step pumping rates used during the course of conducting the first step-drawdown test. The test information obtained during the course of the step-drawdown test was used in the head-loss analysis plot shown in Figure 4.9, using the analysis methods discussed in Section 2.3. As indicated by the linear-regression fit, laminar flow conditions are indicated for the step-drawdown test, both within the well and surrounding aquifer. Based on the head-loss regression analysis, an aquifer loss coefficient, B, of 0.0041 m, and a relatively low well loss coefficient, C, of 1.27E-6 m/lpm^2 are indicated for the test.

Figure 4.10 shows the predicted drawdown versus head-loss component plot (i.e., aquifer loss, well loss, and total head loss) for this well, based on the head-loss analysis results indicated in Figure 4.9. As indicated in the figure, drawdown associated with well loss is relatively minor and secondary in comparison to drawdown associated with aquifer loss. It should be recognized that information presented in Figure 4.10 is extended significantly beyond the actual pumping rates used during Step-Drawdown Test 1. This would only be valid if the same flow regime characteristics are operative at the higher projected pumping rates (i.e., linear aquifer system response and laminar flow conditions). If this extension is valid, then a pumping rate vs. drawdown relationship can be selected that best meets the ZP-1 pump-and-treat operational needs.

Figure 4.11 shows the well efficiency relationship based on the step-drawdown information provided in Figure 4.9 and Figure 4.10. A relatively high well efficiency is indicated for the pumping rate range used during the step-drawdown test (i.e., Q = 107.9 to 461.1 lpm and E = 97 to 88 %, respectively). At higher predicted pumping rates, well efficiency declines because of the increasing significance of well loss at the higher pumping rates as indicated in Figure 4.10.

4.3.2 Step-Drawdown Test 2

The second well 299-W15-225 step-drawdown test was separated from the first step-drawdown test by a program of extensive well development. The purpose of the extensive well development was to improve well production capabilities for the newly constructed well. Comparing results obtained from the performance of the first and second step-drawdown test provided the basis for assessing the impact of the implemented extensive well-development activities.

The second step-drawdown test was conducted at well 299-W15-225 between 0713 and 1720 hours, PDT, on June 28, 2009. Five 2-hour pumping steps were employed during the course of performing the step-drawdown test at the same four planned pumping rates used during Step-Drawdown Test 1 and an additional fifth step at a pumping rate of ~568 liters per minute (150 gallons per minute). A 20-HP Grundfos pump (Model 150S200-9) was used to perform this step-drawdown test. The subsurface pump intake was set at a depth of 118.2 m bgs and (unlike Step-Drawdown Test 1) was equipped with a downhole foot/check valve. The presence of the foot/check valve within the downhole pumping assembly eliminated the possibility of pumped groundwater flowing back into the well column when the pumping was terminated. The same surface-flow measurement and control equipment and downhole pressure measuring equipment were used during testing as was employed during Step-Drawdown Test 1. Groundwater produced during testing was discharged to temporary surface storage tanks, which allowed any produced suspended material to settle before pumping and ultimate discharge of the produced groundwater to the ZP-1 pump-and-treat groundwater disposal system. Surrounding monitor and ZP-1 extraction well water-levels were maintained and collected during testing using the Hanford network data systems discussed in Section 3.1.

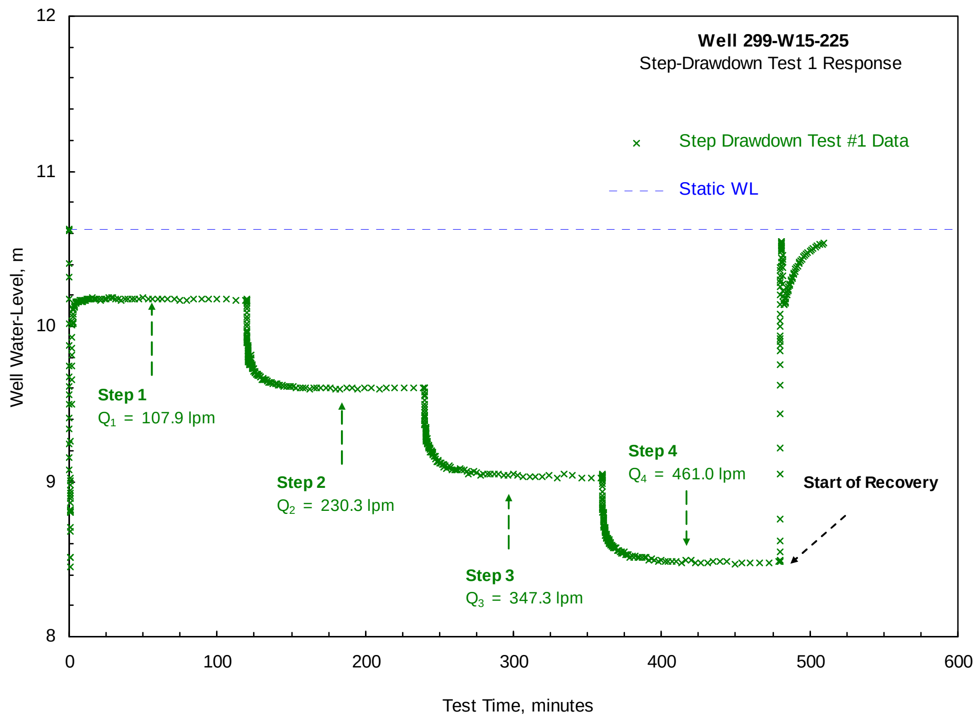


Figure 4.8. Pertinent Test Information and Observed Well 299-W15-225 Water-Level Response During and Following Step-Drawdown Test 1

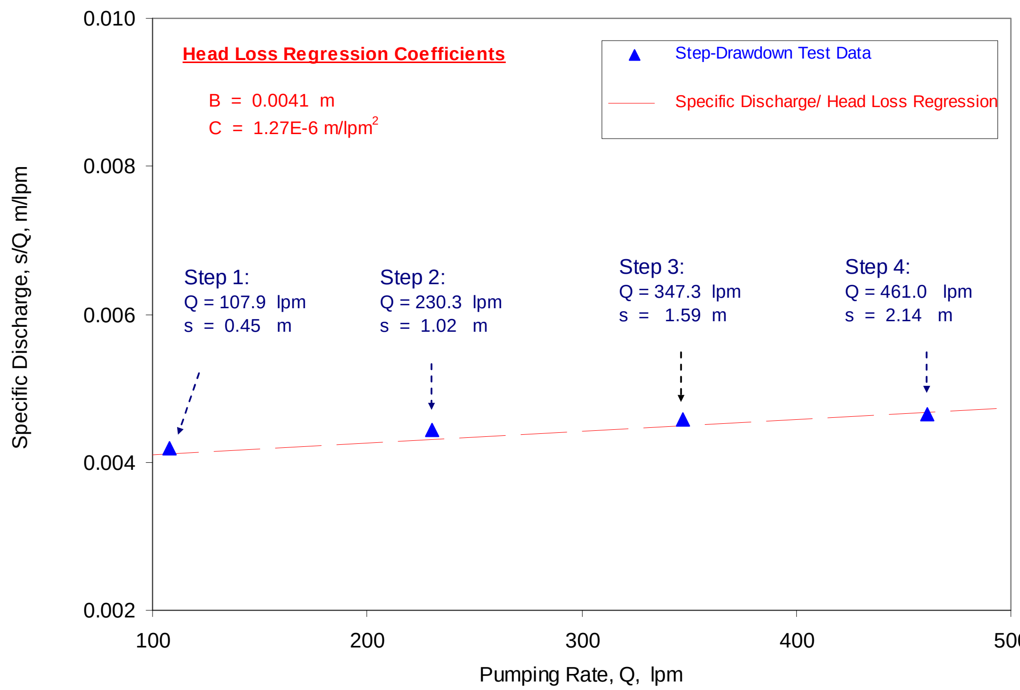


Figure 4.9. Specific Discharge/Head Loss Regression Analysis for Well 299-W15-225: Step-Drawdown Test 1

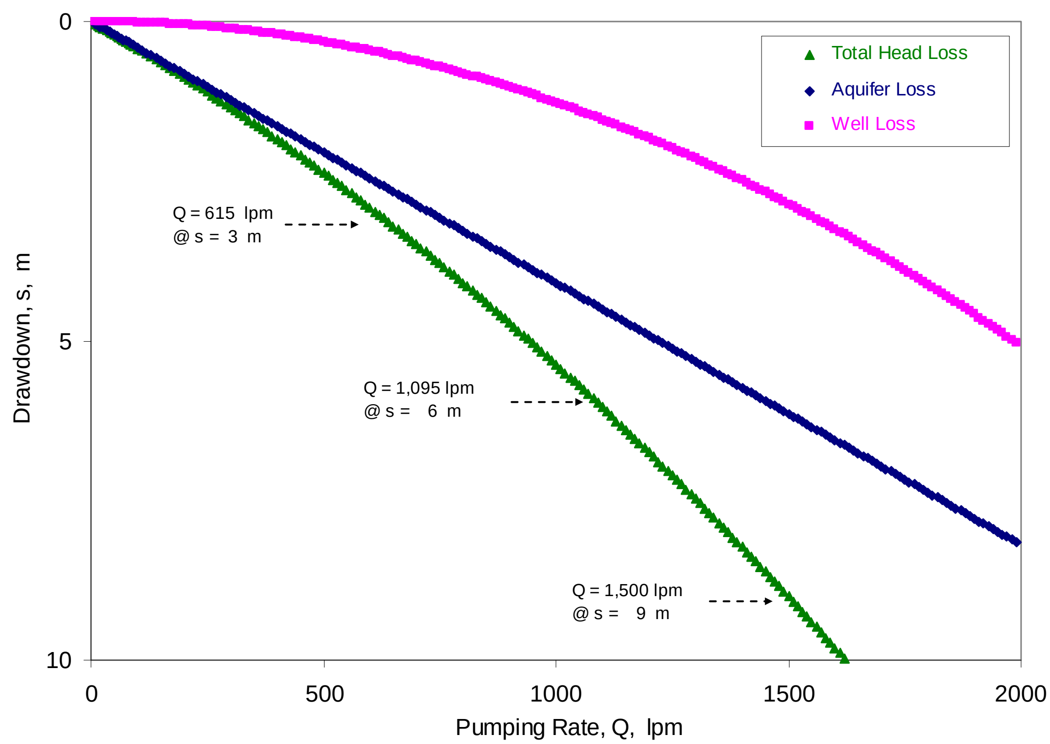


Figure 4.10. Drawdown Versus Head Loss Plot for Well 299-W15-225

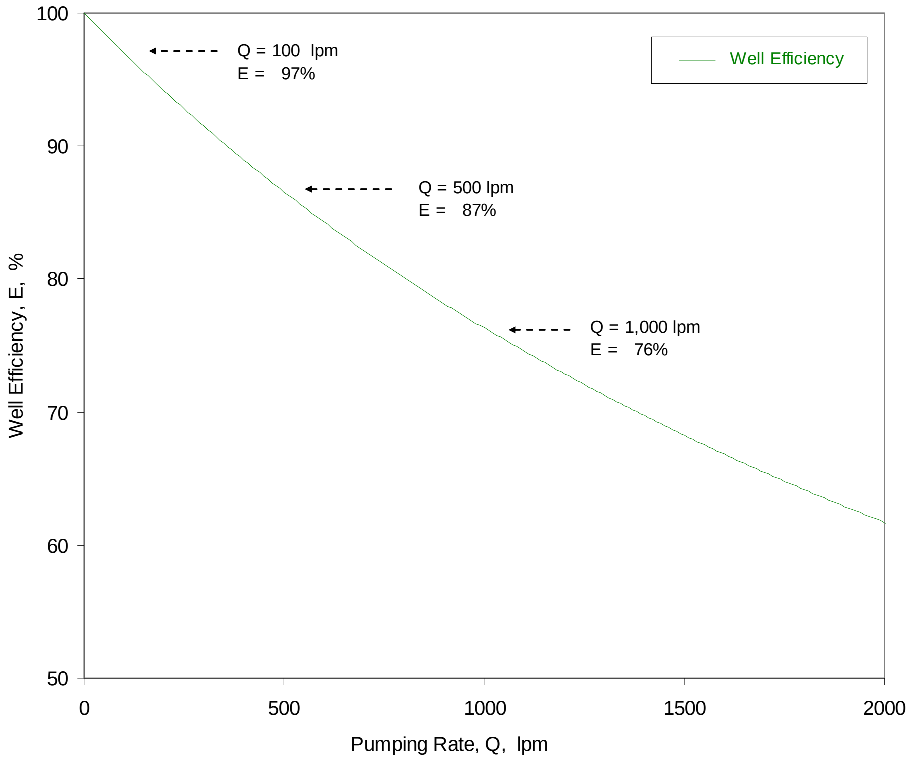


Figure 4.11. Well Efficiency Plot for Well 299-W15-225 Step-Drawdown Test 1

Figure 4.12 shows the observed drawdown and associated step pumping rates used during the course of conducting the second step-drawdown test. As was done for the first step-drawdown test, the test information obtained during the course of the second test was used to also calculate the head-loss analysis relationships after implementing the extensive well development activities. Figure 4.13 shows a comparison of the two step-drawdown test head-loss relationships. As is shown, a very slight reduction in aquifer and well loss coefficient components is indicated for Step-Drawdown Test 2 (i.e., Test 2 in comparison to Test 1 results: aquifer loss coefficient, B = 0.0039 m < 0.0041 m; well loss coefficient, C = 1.23E-6 m/lpm^2 < 1.27E-6 m/lpm^2 are indicated).

Similarly, a comparison of calculated well efficiencies is provided in Figure 4.14 for the two step-drawdown tests. As indicated in the figure, a nearly identical relatively high well efficiency is indicated for the pumping rate range used during the step-drawdown test. Based on the head-loss comparison and well-efficiency comparisons presented in Figure 4.13 and Figure 4.14, respectively, a slight improvement of ~ 5 percent in well production/drawdown characteristics is assigned to the extensive well development activities that were implemented between Step-Drawdown Tests 1 and 2.

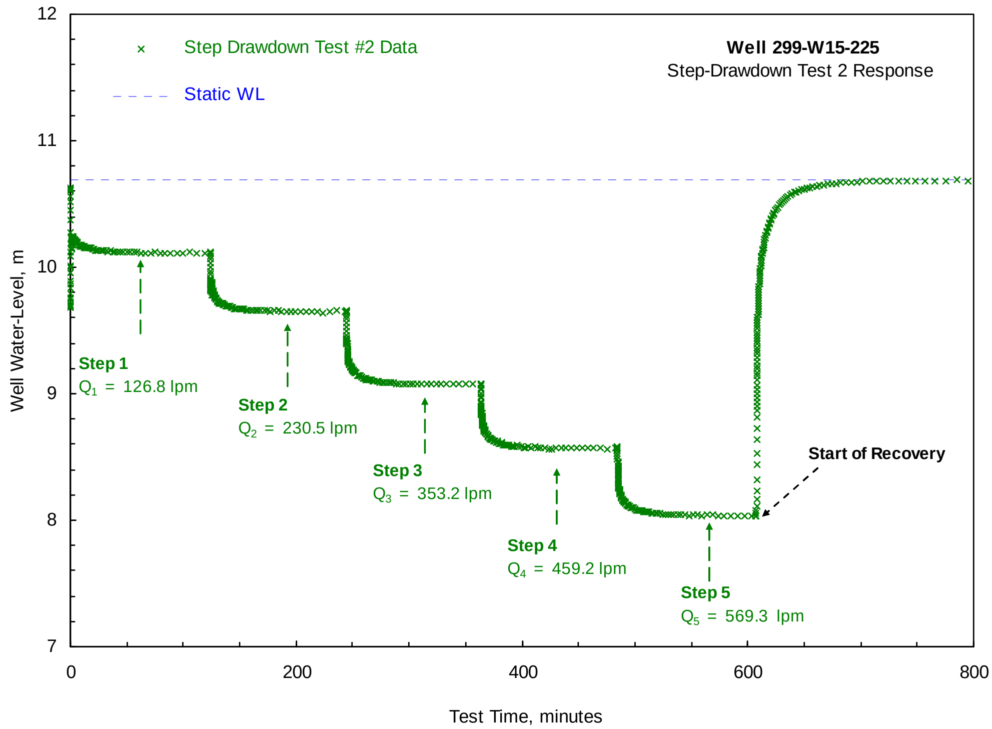


Figure 4.12. Pertinent Test Information and Observed Well 299-W15-225 Water-Level Response During and Following Step-Drawdown Test 2

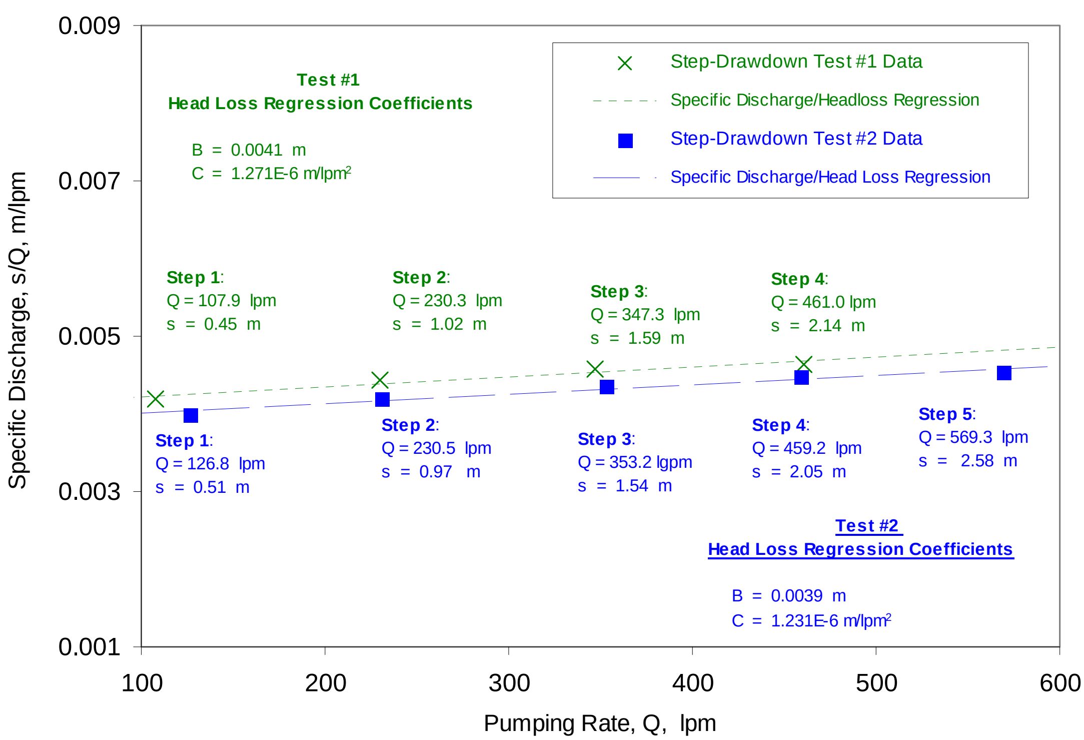


Figure 4.13. Head Loss Regression Analysis Comparison for Well 299-W15-225: Step-Drawdown Tests 1 and 2

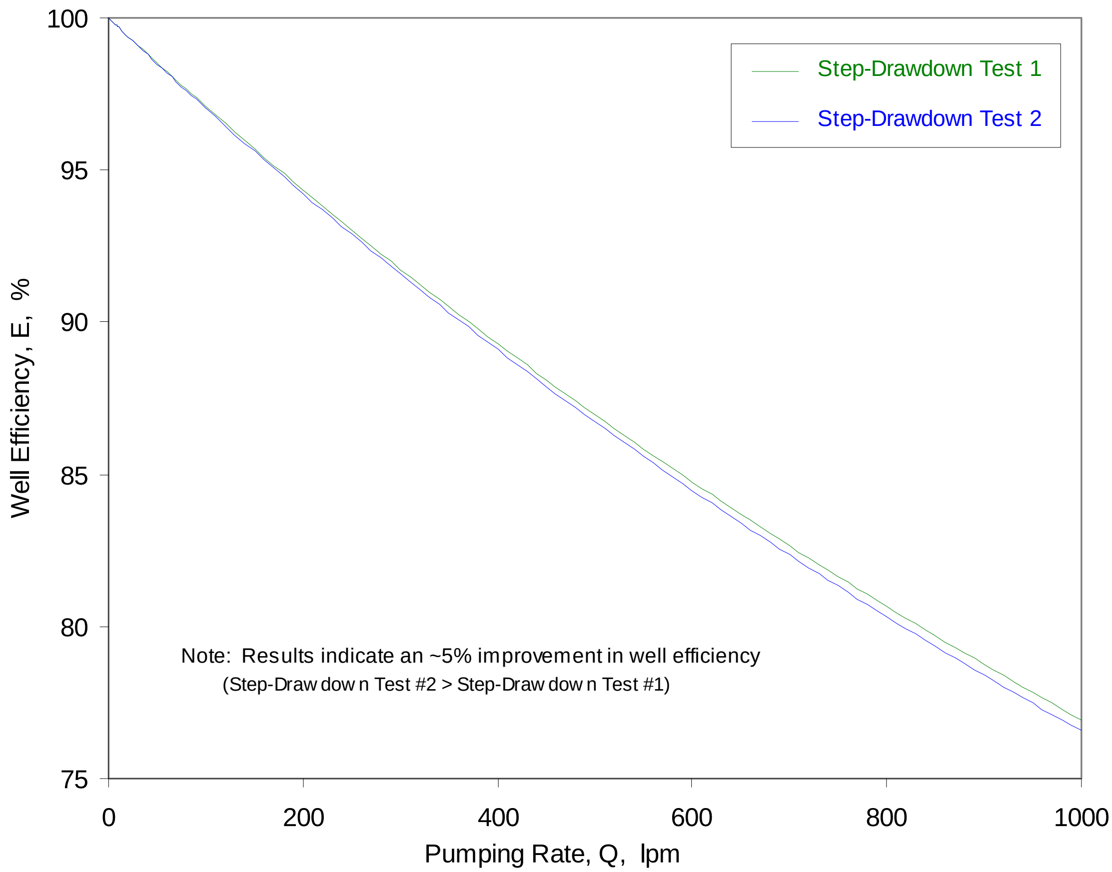


Figure 4.14. Well Efficient Analysis Comparison for Well 299-W15-225: Step-Drawdown Tests 1 and 2

4.4 Constant-Rate Pumping Test

As discussed in Section 2.4, the constant-rate pumping test provides the opportunity to determine large-scale hydraulic characterization property information over the inter-well distances monitored. Surrounding wells monitored during the course of this test were located at distances from the pumped well 299-W15-225 from 50 to 690 m (Table 1.1). As discussed in Section 3.0, because the areal hydrologic responses associated with the constant-rate test were relatively small, and the masking effects of temporal barometric pressure fluctuations were evident during testing, monitor well water-level responses were corrected for barometric effects to facilitate hydrologic test analysis. In addition, extraneous imposed hydrologic stresses within the general area were minimized by shutting down the surrounding ZP-1 pump-and-treat extraction well system, as recommended in Spane and Newcomer (2009a). Because of prescribed program reporting requirements for the well 299-W15-225 characterization program, this report only provides a preliminary quantitative analysis for the constant-rate pumping test responses observed at near-field monitor wells located within 100 m of test well 299-W15-225 (i.e., 299-W15-40, and 299-W15-44). As noted previously, a considerable data set for monitor well water-levels were collected during the constant-rate test that can be analyzed for more large-scale areal characterization information across the area.

Following completion and recovery of Step-Drawdown Test 2, an ~3-day constant-rate pumping test was conducted at well 299-W15-225 between 1654 hours, PDT, June 29, 2009, and 1658 hours, PDT, July 2, 2009. Except for the period of flow-rate regulation that occurred during the initial 5 minutes of the pumping test, pumping rates remained relatively uniform during the course of the 3-day test, varying only ~7.0 liters per minute and averaging 591.2 liters per minute for the duration of the test. The 20-HP Grundfos pump (Model 150S200-9) that was used during Step-Drawdown Test 2 was also used to perform the constant-rate test. The subsurface pump intake was set at a depth of 118.1 m bgs, and was equipped with a downhole foot/check valve. The presence of the foot/check valve within the downhole pumping assembly eliminated the possibility of pumped groundwater flowing back into the well column when the pumping was terminated. A flow-back condition into the well column would adversely affect recovery water-level measurements within the pumped well. Surface discharge rates were monitored with two in-line surface flowmeters (Great Plains Industries, Inc, Industrial Grade, 0.051 m I.D., Digital Turbine Flowmeter, and a 0.051 m I.D., McCrometer Totalizer Flowmeter), and surface discharge rates were regulated using an in-line surface flow valve. Groundwater produced during testing was discharged to temporary surface storage tanks, which allowed settling of any produced suspended material before pumping and ultimate discharge of the produced groundwater to the ZP-1 pump-and-treat groundwater disposal system. Water levels were measured within well 299-W15-225 during testing with an In-Situ, Inc., 20 psi pressure transducer, which was installed within an in-well 0.025 m I.D., access stilling-well. The pressure transducer readings were recorded on a Hermit 3000 datalogger system. The surrounding monitor and the ZP-1 extraction well water-levels were maintained and collected during testing with the Hanford network data systems discussed in Section 3.1. Recovery water-level measurements were monitored at all well locations identified in Table 1.1 until July 9, 2009, as part of this hydrologic test characterization.

Examples of observed and barometric-corrected well responses for selected monitor well locations during the period of constant-rate pumping and the subsequent recovery period are shown in Figures 3.4 and 3.5 and in Appendix D. The barometric-corrected drawdown well response is the basis for the constant-rate pumping test analysis for the monitor well locations since the corrected recovery data exhibited essentially identical well response characteristics.

A simultaneous composite test analysis of the corrected drawdown response calculated for the two near-field well sites 299-W15-40 and 299-W15-44 was performed in concert with the corrected recovery response exhibited at pumping well 299-W15-225. The recovery response data for well 299-W15-225 was used in the analysis because of the drawdown variability that occurred during the early-stages of the pumping test due to flow-rate adjustments. Essentially identical intermediate and late-time water-level behavior was exhibited for corrected drawdown and recovery response at the pumped well. The drawdown/recovery responses at the pumped well were corrected for well loss effects calculated for the average discharge rate observed during the test (591.2 liters per minute) and the well loss relationship established during the second step-drawdown test (shown in Figure 4.13).

To facilitate the composite analysis process, the automated analytical pumping test type-curve program ANIAQX (HydraLogic 1989) was used as an initial screening tool. These initial analysis parameters served as input to the WTAQ analytical model (described in Section 2.4), which was used in the finalized composite analysis. The ANIAQX program does not account for a number of well complexities (i.e., wellbore storage, well skin) that can be considered in the WTAQ model or lend itself to rapid parameter manipulation and test data/type-curve matching. It should be noted, however, that the finalized WTAQ model solutions were essentially identical to that determined with the ANIAQX model.

A finalized, best-match WTAQ composite analysis for the three wells is shown in Figure 4.15. As indicated, simulated WTAQ test responses for the respective wells were generated based on the following aquifer properties: T = 438 m^2/day; K = 7.91 m/day (based on an aquifer thickness of 55.4 m); K_D = 0.1; S = 9.7E-4; and S_y = 0.096. The analysis for these near-field well locations is considered to be robust for T and K. Similar type-curve matches could be realized for S_y values ranging between 0.08 and 0.13. The analysis appears least sensitive for K_D. This lack of sensitivity may be attributed, in part, to the fact that the pumping well nearly fully penetrates the unconfined aquifer, while the near-field monitor wells are completed only in the upper ~12% of the aquifer. The calculated aquifer hydraulic properties for the near-field monitor well/well 299-W15-225 analysis fall within the upper-range of similarly derived, large-scale values determined for the adjacent area. For the more extensive WMA T Tank Farm Area characterization, Spane (2008b) reported large-scale analysis results as follows: T = 300 to 475 m^2/day; K = 6.11 to 9.69 m/day (geometric mean = 8.01 m/day).

It should be noted again that this report only provides limited quantitative analysis results for the constant-rate pumping test responses observed at near-field monitor wells located within 100 m of test well 299-W15-225 (i.e., 299-W15-40, and 299-W15-44). A significant amount of large-scale hydraulic characterization information can be realized by subsequent test analysis of available far-field well test response (i.e., for wells >100 m from well 299-W15-225) and incorporation of vertically-distributed, multi-layer analysis approaches that would be implemented by incorporating the results of the dynamic EBF test survey results.

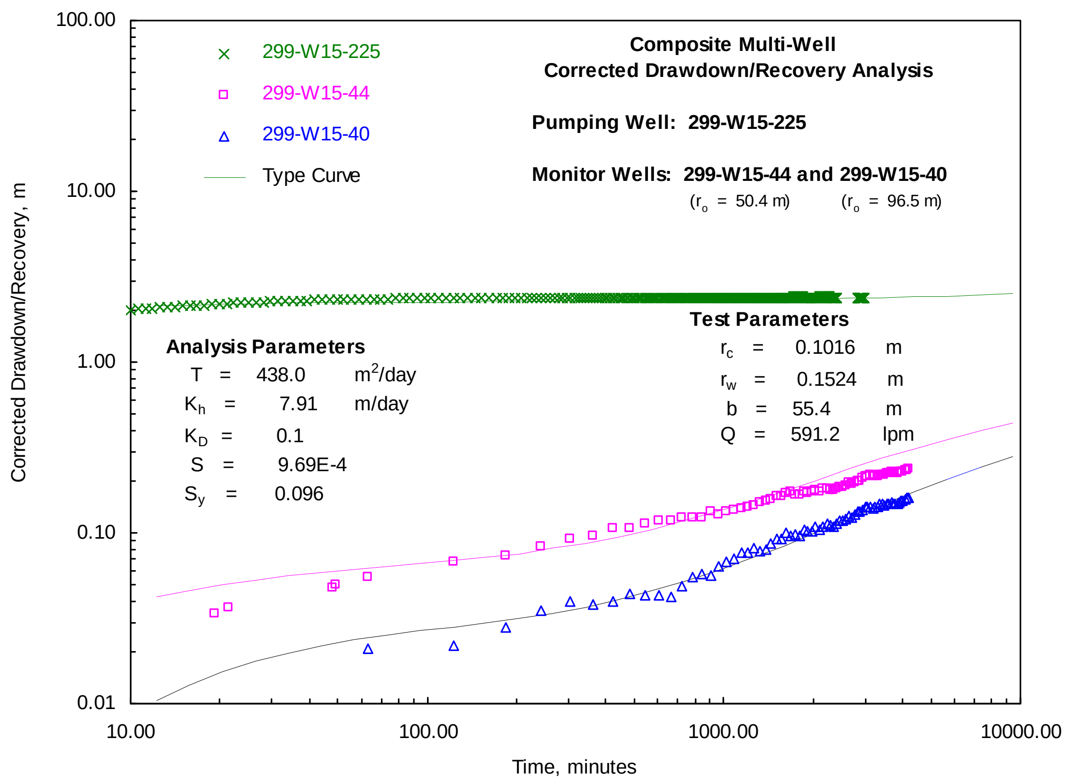


Figure 4.15. Composite Multi-Well Corrected Drawdown/Recovery Analysis: Wells 299-W15-225, 299-W15-40, and 299-W15-44

4.5 Software Quality Assurance (QA)

The WTAQ3 software (version 3 of the WTAQ program) used for calculations described in this report was developed by the U. S. Geological Survey and is documented in Barlow and Moench (1999). The program calculates hydraulic-head drawdowns in an aquifer that result from pumping at a well. The calculations are based on published equations of groundwater flow. Quality assurance of the program calculations is based on verification by hand calculating the equations. This program is “safety software” under the provisions of 10 CFR 830 and DOE Order 414.1C because the results may be used in decisions related to provide protection from existing or future radiological hazards. The software is “acquired” and has low potential impact in its application for this report because the results may be used in regulatory permitting or to plan for potential radiological releases. The major risk is that drawdowns in new pump-and-treat extraction wells may be greater or less than those predicted. The corrective action in this case is to adjust pumping rates or possibly install additional extraction wells. The predicted drawdowns will be verified through onsite pumping operations. The software is maintained by the U. S. Geological Survey and errors or software bugs can be reported to Paul Barlow, U.S. Geological Survey, 10 Bearfoot Road, Northborough, MA 01532.

The automated analytical pumping test type-curve program ANIAQX Version 2.5 (HydraLogic 1989) was used only for initial screening to narrow the range of input parameters for the WTAQ3 program. Therefore, calculations performed with the ANIAQX program had no impact on the results presented in this report.

5.0 Conclusions and Recommendations

Preliminary analysis results for hydrologic tests conducted at newly constructed extraction well 299-W15-225 indicate that detailed large-scale vertical and lateral hydraulic property information was obtained for the general area surrounding well 299-W15-225 as part of this field test characterization. Specific findings pertaining to the various hydrologic test elements and characterization activities are summarized below.

5.1 Barometric Pressure Analysis

1. Barometric pressure effects impose a significant extraneous impact on observed well water-level measurements that are used to monitor aquifer conditions and relative performance/impact of the 200-ZP-1 OU pump-and-treat system. Removing barometric pressure fluctuations using the multiple-regression deconvolution technique significantly improves the ability to detect and analyze hydrologic stresses (e.g., 0.01 m) conducted either as part of imposed specific hydrologic tests or by general operational pump-and-treat system activities.

2. The barometric response pattern for monitor wells examined as part of this investigation indicate very similar time-lag characteristics and exhibit time-lag dependence ranging between ~130 and 180 hours. Well water-level responses were successfully removed with a *universal* correction procedure based on time-lag characteristics exhibited at monitor well 299-W14-14.

5.2 Slug Test Characterization

3. Slug test characterization was conducted at well 299-W15-225 for the purpose of providing discrete hydraulic property vs. depth information within the unconfined aquifer. Two test/depth intervals were successfully characterized (Zone 1 and 2) within the upper-section of the unconfined aquifer during active borehole drilling/advancement. The average hydraulic property estimates for these two zones are very similar (4.6 and 5.7 m/day) and are slightly higher than the cited geometric mean value (2.2 m/day) calculated for other surrounding monitor well slug test results, as reported in Spane and Newcomer (2009a). This characterization method was abandoned during the course of drilling well 299-W15-225 because of well construction risk concerns and difficulties in retracting the drill casing for test zone exposure.

4. To compensate for the lack of vertical, aquifer-depth, slug test characterization information that would be obtained during borehole drilling, pneumatic slug tests were implemented within the two long well-screen sections within well 299-W15-225 after final well completion. Because of the extremely long, well-screen completions (and associated higher test interval transmissivity), these slug tests provided less quantitative hydraulic property information. The two test zone characterizations (Zone 3 and 4), however, do indicate that the lower screen section (which penetrates the middle and lower sections of the unconfined aquifer) possess higher hydraulic properties than the overlying well-screen section.

5.3 Dynamic Electromagnetic Flowmeter Survey

5. The EBF survey provided detailed characterization information concerning the relative vertical distribution of hydraulic properties within the unconfined aquifer at well 299-W15-225. The relative hydraulic property profile, while variable, indicated that the highest permeability intervals occurred within the middle and lower sections of the unconfined aquifer. The relative hydraulic property distribution obtained from the EBF survey can be quantified (i.e., to absolute hydraulic conductivity vs. depth) by using the constant-rate pumping test results obtained from the composite, near-field well analysis. This type of hydraulic property characterization is particularly useful as input for more complex numerical model simulations (i.e., using heterogeneous, multi-layer approaches) of contaminant capture in the vicinity of well 299-W15-225.

5.4 Step-Drawdown Test Characterization

6. Two step-drawdown tests were conducted at well 299-W15-225 as part of the general well/aquifer characterization investigation. The step-drawdown tests were implemented to select an optimum pumping rate for the following 3-day constant-rate pumping test and for assessing whether an intervening extensive well-development program had any discernable effect on extraction well performance. The results of the step-drawdown test comparison indicate that well 299-W15-225 is highly efficient (well efficiencies between 88 and 97%) over the pumping rates observed, and that the extraction well performance increased ~5% after implementing the extensive well development program.

5.5 Constant-Rate Pumping Test

7. A 3-day constant-rate pumping test was conducted at well 299-W15-225 at an average pumping rate of 591.2 lpm (156.2 gpm). Water-level responses were monitored in the pumped well and within 22 surrounding well locations during the pumping test and during the following ~6-day recovery period. A cursory examination of barometric-corrected well water-level responses indicates that the 3-day pumping test imposed a large-scale areal hydrologic response within the surrounding unconfined aquifer. Hydrologic responses associated with the 3-day pumping test were observed over well distances of $\geq$690 m from the pumped well location. This indicates that well 299-W15-225 will impose a hydrologic *area-of-influence* even greater than 690 m at these pumping rates and over extended pumping periods commonly employed for extraction wells within the 200-ZP-1 OU pump-and-treat system.

8. Hydrologic test analysis results for the constant-rate pumping test were limited in this report to a composite multi-well analysis for the pumped well and near-field wells 299-W15-40 and 299-W15-44. The composite multi-well analysis indicated the following best-estimate aquifer property values: T = 438 m^2/day; K = 7.91 m/day (based on an aquifer thickness of 55.4 m); K_D = 0.1; S = 9.7E-4; and S_y = 0.096. The analysis for these near-field well locations is considered to be robust for T and K. Similar type-curve matches could be realized for S_y values ranging between 0.08 and 0.13. The analysis appears least sensitive for K_D. This lack of sensitivity may be attributed, in part, to the fact that the pumping well nearly fully penetrates the

unconfined aquifer, while the near-field monitor wells are completed only in the upper ~12% of the aquifer.

9. The calculated aquifer hydraulic properties for the near-field monitor well/well 299-W15-225 analysis fall within the upper-range of similarly derived, large-scale values determined for the adjacent area. For the more extensive WMA T Tank Farm Area characterization, Spane (2008b) reported large-scale analysis results as follows: T = 300 to 475 m^2/day; K = 6.11 to 9.69 m/day (geometric mean = 8.01 m/day).

5.6 Recommendations

Because of the large hydrologic data set collected during the course of the constant-rate pumping test (i.e., for 22 surrounding wells), additional hydraulic property information can be derived from subsequent hydrologic test analysis. In particular, the following follow-on hydrologic test analysis elements are recommended:

1. Far-field individual and composite well test analysis (i.e., for wells >100 m from well 299-W15-225). This will provide larger-scale, inter-well information >100 m from the extraction well 299-W15-225 location. In addition, targeted multi-well grouping analyses can provide information concerning horizontal anisotropy within the unconfined aquifer.

2. Quantification of the EBF survey results to obtain an absolute hydraulic conductivity versus depth profile for the well 299-W15-225 location. This can be realized using the composite near-field well analysis presented in this report.

3. Application of more complex, heterogeneous, multi-layer analysis of selected monitor well test responses. Based on the results of 1 and 2, selected multi-well data sets can be re-analyzed using the vertical permeability profile structure described by the dynamic EBF test survey results. This analysis will indicate whether homogeneous or heterogeneous formation approaches are best-suited for modeling performance of the 200-ZP-1 OU pump-and-treat system.

While the constant-rate pumping test has and can provide extensive hydraulic property characterization information for the general area, it should be realized that it is still only a limited test. Larger scale information can be obtained (i.e., more reflective of ZP-1 pump-and-treat system operations) and hydrologic parameter analysis uncertainty can be significantly reduced by performing a constant-rate pumping test of longer duration (e.g., 2 to 4 weeks). An extended constant-rate pumping test can be realized without significant expenditure of additional characterization costs by performing the extended test within the existing 200-ZP-1 operational framework and relying on the existing, surrounding monitor well networks. To implement an extended constant-rate pumping test at well 299-W15-225, existing ZP-1 extraction wells would have to be shut down ~2 to 3 months before start-up of well 299-W15-225. Well 299-W15-225 would then be placed on-line and pumped continuously for the prescribed 2- to 4-week period. Following this 2- to 4-week constant-rate pumping period, the other ZP-1 extraction wells could be placed back on-line. No additional well monitoring would be required outside the existing monitoring well networks.

In conclusion, due to the level of success demonstrated for this field test characterization, it is recommended that some of the characterization methods used at well 299-W15-225 be considered for possible use at other selected ZP-1 extraction well locations. These types of test characterizations would be most relevant for areas where numerical modeling uncertainty can be significantly reduced by acquiring large-scale and vertically distributed hydrologic characterization information.

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Appendix A

Selected Borehole Geology Log Information for Well 299-W15-225; Depth Interval: 60.96 to 141.7 m bgs (200 to 465 ft)

Appendix A: Selected Borehole Geology Log Information for Well 299-W15-225; Depth Interval: 60.96 to 141.7 m bgs (200 to 465 ft)

BOREHOLE LOG

Page 6 of 12
Date: start: 02/19/09 finish: 03/04/09

Well ID: C7017 | Well Name: 299-W15-225 | Location: 20 m W of TX farms

Project: ZP-1 Pump + Treat | Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
200	G.S.				See pg. 1: down-hole
				199 – 219: sandy silty Gravel (smG):	hammer w/air rotary
				gravel 45% silt 45% sand 10%;	
				gravel up to 2" mostly felsic	archive @ 200'
				(60%) sub-rnd; sand fine to	add 150 gal water
205	G.S.			coarse, sub-rnd, mostly mafic;	at 200-202 to flush
				matrix brown (7.5YR 4/2), damp	borehole
				no rxn HCl	
				→ gravel inc to 55% silt 35 sand 10%	archive @ 205'
				→ sand inc to 20%; 60% gravel; 20% silt	*casing much harder to
210	G.S.			219-223: silty sandy GRAVEL (msG)	drive after 203'
				gravel 55% sand 25% silt 15%, gravel up	
				to 4" mostly basaltic (60%), sub-rnd;	archive @ 210'
				sand fine to coarse, moist	
				223-239: sandy GRAVEL (sG)	
215	G.S.			gravel 65%; sand 30%, silt 5%; no rxn	
	BIYCV9 BIYCW0 BIYCW1 BIYCW2	BIYD08		to HCl	archive @ 215'
				→ 227' bgs: mod cemented, no rxn to HCl	
	S.S.			→ Moisture increase slightly @ 229' bgs	Flushed ~250 gals down
	Full Recovery			→ Very moist @ 232.5' bgs	hole to clean out @ 218'
220		G.S.		→ Felsic inc to 60%, 40% mafic	
				→ 234' bgs cobbles up to 6"	Cable tool rig w/drive barrel
				→ 236' poorly cemented, rusty brown when moist	
				→ 238' large cobbles up to 8"	Split spoon 218.7'–221.2'
					Grab: B1YD08
225	G.S.				archive from s.s. clean out
	BIYCW3 BIYCW4 BIYCW5 BIYCW6	BIYD09			archive @ 225'
	S.S.				228.7'-231.2': Split Spoon
230	Full Recovery	G.S.			archive @ 230'
		① 3/3/09			BIYCW3, BIYCW4, BIYCW5,
					BIYCW6, (BIYD09 grab) chem
		▼			Water table @ 233' bgs
235	G.S.				archive @ 235'

Reported By: S. Sexton | Reviewed By: L. D. Walker

Title: Geologist | Title: Geologist

Signature: [signature] for S. Sexton | Date: 3/4/09 | Signature: [signature] | Date: 8/4/09

A-6003-642 (03/03)

BOREHOLE LOG

Start: 03/04/09
Date: finish: 3-30-09

Well ID: C7017	Well Name: 299-W15-225	Location: 20m W of TX Farms
Project: ZP-1 Pump + treat		Reference Measuring Point: Ground surface

Depth (Ft.)	Sample: Type No.	Sample: Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
240	G.S.			239-261 : silty sandy GRAVEL (msG)	cable tool rig w/ 10" drive
				gravel 60%, sand 20%, silt 20%; 60%	barrel
				felsic, 40% mafic, sub-rnd, pr cemented,	
				max cobble 4", no rxn HCl	archive @ 240' bgs
				~~→ increase silt to 25~~ 3/4/09	
245	G.S.	water sample		→ decrease silt to 10% @ 248'	archive @ 245'
	B1YD74	B1YCW7, B1YCW8, B1YCW9, B1YCX0, B1YCX1		→ increase silt to 20% @ 255'	
				decrease silt @ 260'	Water sample interval: 244.5'-248.5'
				increase sand @ 260'	Correlate grab @ 248.5'
				→ max gravel size decrease to ~3" @ 259'	
				@ 3/24/09 ~~260~~ @ 3/24/09	
250	G.S.			~~261 : sandy silty GRAVEL (smG)~~	archive @ 250'
				261-262: silty GRAVEL (mG)	
				gravel 60%, sand 10%, silt 30%	
				sand is vf. to med. grained,	
255	G.S.			262-265: sandy GRAVEL (sG)	archive @ 255'
				gravel 60%, sand 30%, silt 10%,	added 5 gal water
				sand f. to v. crse grained, subang.; gravel	added 1 gal water
				is 40% basalt, 60% felsics, subrnd to rnd	added 3 gal H_2O
				→ max gravel size increase to 8" @ 263'	
260	G.S.			~~→ silt gravel lens from 265' to 266'~~ @ 3/25/09	added 20 gal H_2O
				265-270: silty sandy GRAVEL (msG)	archive @ 260' bgs
				gravel 50%, sand 30%, silt 20%	sieve analysis grab @ 260'
				sand is vf. to f. grained, gravel ~~to~~ @ 3/25/09 same	
				as above	
265	G.S.			→ increase gravel to 60% @ 269'	archive @ 265' bgs
				→ increase silt to 20% @ 267'	sieve analysis grab @ 265'
				7/2-2.5Y (lightgray) when dry	
270	G.S.			270-316 Silty Sandy Gravel (msG)	archive and sieve grab @ 270'
		Water Sample		60% G w. rnd f. pebbs to L. cobbs. Dom. Qtz.	
				cobbs are w. rnd, pebbs are sub ang-ang.	
	B1YD75 G.S.			30% m-f. sand qtz ofeldspathic	Grab sample @ 272.5'-273'
				10-15% silt 2.5Y 7/2 + 7.5YR 4/3 (gray/brown	for chemical analysis.
275				mottling.) ~~w/ carbonate stringers~~ AL 3-26-09	
				•270.5: silt increase to 60% 7.5YR 4/3 brown.	Water Sample collection
				•Clasts w/ carbonate rhinds Strong rxn w/HCl	271-273' bgs: B1YCX3, B1YCX4
				•271.5: Silt decreas to 20% 7.5YR 4/3 brown	B1YCX5, B1YCX6, B1YCY0, B1YCY1
					B1YCY2, B1YCY8, B1YCX2 FB

Reported By: J. Thoolin / A. Lanter	Reviewed By: L.D. Walker
Title: Geologist / Geologist	Title: Geologist
Signature: [signature] Date: 3/30/09	Signature: [signature] Date: 8/4/09

A-6003-642 (03/03)

BOREHOLE LOG

Date: starting 3/30/09 Finish: 4/22/09

Well ID: C7017 | Well Name: 299-W15-225 | Location: 20 m. W. of TX Tank Farm

Project: 200-ZP-1 OU Pump + Treat | Reference Measuring Point: Ground Surface.

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description (Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl)	Comments (Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level)
275	G.S.				archive and sieve analysis grab @ 275'
				276': silty Gravel lense	
				276.5': loose sandy Gravel	add 60 gal water
				278': return to silty sandy Gravel	
280	G.S.			270 → 316': Silty Sandy GRAVEL	archive and sieve grab @ 280'
					Begin drilling w/ air rot. rig @ 280'
285	G.S.				archive + sieve grab @ 285'
290	G.S.	B1YD76, B1YD88 (Soil Grab)			archive + sieve grab @ 290'
					G.S. @ 295': B1YD76, B1YD88
295	G.S.	Water Sample			archive + sieve grab @ 295'
					Water sample: 295'–296', B1YCY3, B1YCY4, B1YCY5, B1YCY6
300	G.S.			300': increase sand% to 40%; gravel 50% silt 10%	archive + sieve grab @ 300'
305	G.S.				archive + sieve grab @ 305'
310	G.S.				archive + sieve grab @ 310'
	@ upper Geochem				

Reported By: J. Throolin | Reviewed By: L. D. Walker

Title: Geologist | Title: Geologist

Signature: [signature] Date: 4/22/09 | Signature: [signature] Date: 8/4/09

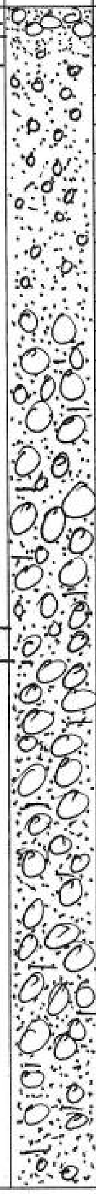
A-6003-642 (03/03)

BOREHOLE LOG

Page 9 of 12
Start: 4/22/09
Date: Finish: 4/23/09

Well ID: C7017 | Well Name: 299-W15-225 | Location: 20 m. W. of TX Farms

Project: 200-ZP-1 OU Pump + Treat | Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
315	G.S.	B1YD77 Water Sample		316-329: ~~sand (S)~~ gravelly SAND (S) JD 4/22/09, vf - m. grained, brown pr. sorted; saturated, 80% qtz./feld, 20% basalt/other, gravel is predominately felsic, 80% ~~gravel~~ sand, 20% gravel, no rxn to HCl JD 4/22/09	Air Rot. 12" Threaded casing Grab sample: B1YD77 @ 314.5 Archive + sieve grab @ 315 Water sample: 315'-316'; B1YD20, B1YD21, B1YD22, B1YD23, B1YD62
320	G.S.				Archive + sieve grab @ 320
				324-353: silty sand GRAVEL (msG) gravel 40%, sand 50%, silt 10% pr. sorted, saturated, gravel is subrnd., no rxn to HCl	
325	G.S.				Archive + sieve grab @ 325
330	G.S.				Archive + sieve grab @ 330
335	G.S.	B1YD78 Water Sample			Grab sample @ 335': B1YD78 Archive + sieve grab @ 335 Water sample 335-336': B1YD24, B1YD25, B1YD26, B1YD27, B1YD63
340	G.S.				Archive + sieve grab @ 340
345	G.S.				Archive + Sieve grab @ 345
				349: decrease gravel % to 30%, sand 50%, silt 20%	
350	G.S.				Archive + Sieve grab @ 350
				353 - : gravelly silt SAND (gmS) gravel 20%, silt 20%, sand 60% (see pg 10) →	

Reported By: J. Troolin | Reviewed By: L.D. Walker

Title: Geologist | Title: Geologist

Signature: [signature] Date: 4/23/09 | Signature: [signature] Date: 8/4/09

A-6003-642 (03/03)

BOREHOLE LOG

Page 10 of 12
Start: 4/23/09
Date: Finish: 4/28/09

Well ID: C7017	Well Name: 299-W15-225	Location: 20 m. W. of TX tank farm
Project: 200-ZP-1 OU Pump+Treat Wells		Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample: Type No.	Sample: Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
355	G.S.	B1YD79 Water Sample		353- : gravelly silty SAND (gmS)	Air Rotary 12" Threaded Casing
				(description continued from pg 9)	
				sand is vf-m grained, mod. sorted, saturated,	Archive + Sieve grab @ 355'
				70% qtz/felds, 30% basalt/other, gravel is	Grab for chemical analysis @ 355'
				predominately felsic, no rxn to HCl	Water sample: 355-356'
360	G.S.				B1YD28, B1YD29, B1YD30,
					B1YD31, B1YD64
					Archive + sieve grab @ 360'
365	G.S.				Archive + sieve grab @ 365'
				366-367: increase in gravel	
370	G.S.				Archive + sieve grab @ 370'
375	G.S. B1Y080	Water Sample			Archive + sieve grab @ 375'
					Grab for chemical analysis @ 375.5'
					Water sample: 375-376'
				376-405: silty sandy GRAVEL (msG)	B1YD32, B1YD33, B1YD34,
				silt 10%, sand 30%, gravel 60%	B1YD35, B1YD65
380	G.S.			pr. sorted, gravel chips up to 3 inches,	
				80% felsic, 20% basalt/other	archive + sieve grab @ 380'
385	G.S.				archive + sieve grab @ 385'
390	G.S.				archive + sieve grab @ 390'
				390: increase sand % to 50%, silt 20%,	
				gravel 30%	
				393: return to 60% gravel, sand 30%, silt 10%	

Reported By: J. Throolin	Reviewed By: L.D. Walker
Title: Geologist	Title: Geologist
Signature: [signature] Date: 4/28/09	Signature: [signature] Date: 8/4/09

A-6003-642 (03/03)

BOREHOLE LOG

Start: 4/28/09 Date: Finish: 5/4/09

Well ID: C7017 | Well Name: 299-W15-225 | Location: 20 m. W. of TX tank farm

Project: 200-ZP-1 OU Monitoring Wells | Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
395	G.S.	B1YD81 Water sample			Air rotary-12" Thread casing
					Grab for chemical analysis @395'
					Archive + sieve grab @ 39.5'
					Water sample: 395-396':
400	G.S.				B1YD36, B1YD37, B1YD38,
					B1YD39, B1YD66
					Archive + sieve grab @ 400'
				404: Increase sand % to 40%, gravel 40%	
405	G.S.			silt 20%	Archive + sieve grab @ 405'
410	G.S.				Archive + sieve grab @ 410'
	G.S.			410.5-458: clay (M)	Archive grab @ 411'
				lt. brown, wet, no rxn to HCl, high	
				plasticity, small percentage of silt (5%)	
		B1YD82		(Ringold Lower Mud)	
415	G.S.				Archive grab @ 415'
					Downsize casing to 8" @ 415.5'
420	G.S.				Archive grab @ 420'
425	G.S.				Archive grab @ 425'
430	G.S.			430: slight increase in silt	Archive grab @ 430'

Reported By: J. Threolin | Reviewed By: L.D. Walker

Title: Geologist | Title: Geologist

Signature: [signature] Date: 5/4/09 | Signature: [signature] Date: 8/4/09

A-6003-642 (03/03)

BOREHOLE LOG					Page 12 of 12 Date: Start: 5/4/09 Finish: 5/5/09
Well ID: C7017			Well Name: 299-W15-225	Location: 20m. W. of TX tank farm	
Project: 200-ZP-1 OU Pump+Treat Wells				Reference Measuring Point: Ground Surface	

Depth (Ft.)	Sample Type No.	Sample Blows Recovery	Graphic Log	Sample Description: Group Name, Grain Size Distribution, Soil Classification, Color, Moisture Content, Sorting, Angularity, Mineralogy, Max Particle Size, Reaction to HCl	Comments: Depth of Casing, Drilling Method, Method of Driving Sampling Tool, Sampler Size, Water Level
435	G.S.			435: increase in silt content; 50% silt, 50% clay; very hard, w. cemented when silty; change in color to predominately greenish gray, occasionally rusty brown in color	Air rotary - 8" threaded casing Archive grab @ 435'
440	G.S.				Archive grab @ 440'
445	G.S.				Archive grab @ 445' Open hole drilling from 446'-465'
450	G.S.				Archive grab @ 450'
455					Archive grab @ 455'
	G.S.				Archive grab @ 458'
460	G.S.			458-465: sandy GRAVEL (sG) 50% sand, 50% gravel, sand is brown with a slight green tint, vf-med grained sand, well sorted sand matrix, gravels are sub rnd, 50% felsic, 50% basalt/other	Archive grab @ 460' Grab for chemical analysis @ 462'
	B1YD83	Water Sample			Water sample: 461'-465'; HEIS # B1YD44, B1YD45, B1YD46, B1YD47, B1YD68
465	G.S.		TD@ 465'	Total Depth (TD) = 465'	Archive @ 465'
470					

Reported By: J. Throolin		Reviewed By: L. D. Walker	
Title: Geologist		Title: Geologist	
Signature: [signature]	Date: 5/5/09	Signature: [signature]	Date: 8/4/09

A-6003-642 (03/03)

Appendix B

Selected Well Plots of Observed Water-Level versus Barometric Pressure Response in the Vicinity of WMA TX-TY

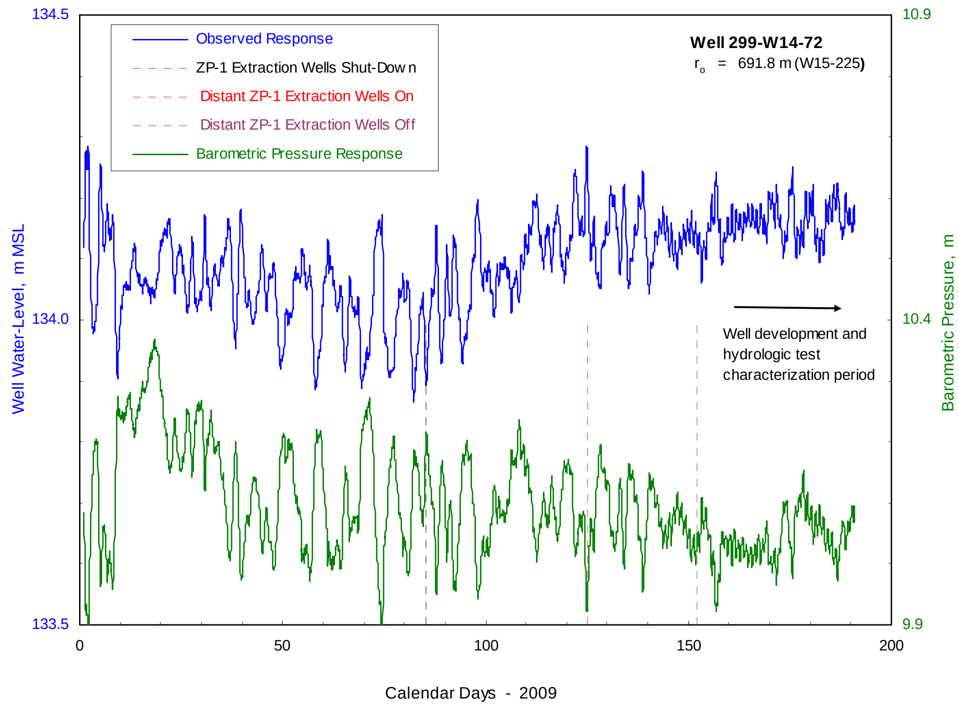
Appendix B: Selected Well Plots of Observed Water-Level versus Barometric Pressure Response in the Vicinity of WMA TX-TY

B.1 Observed Well 299-W14-72 Water Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

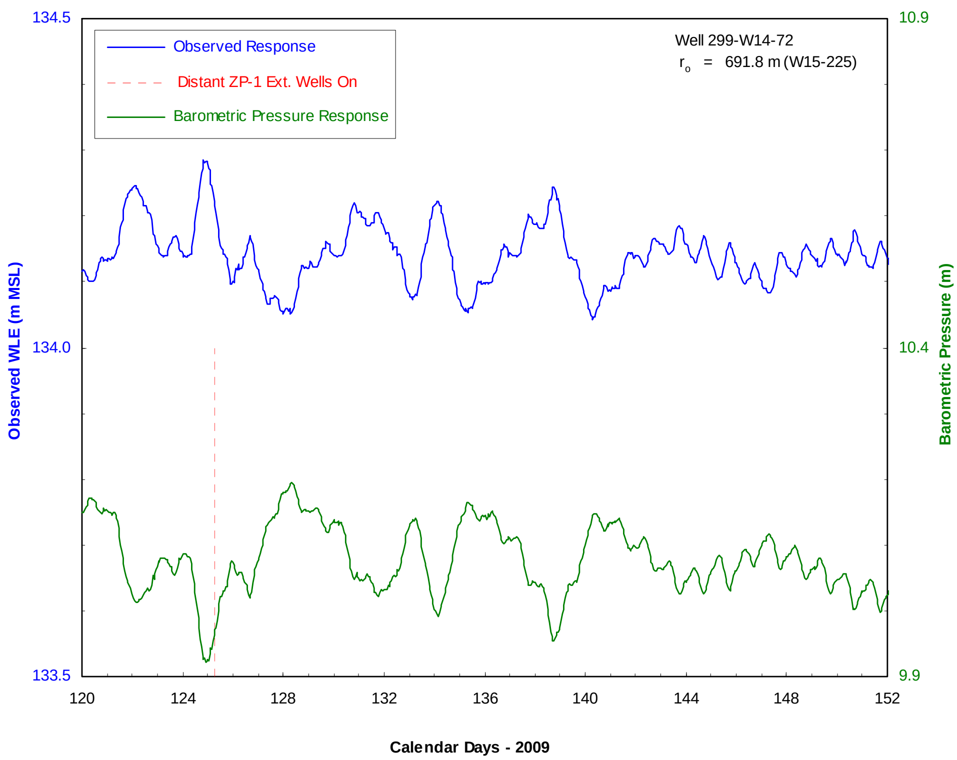
B.2 Observed Well 299-W15-41 Water Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

B.3 Observed Well 299-W15-43 Water Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

(a)

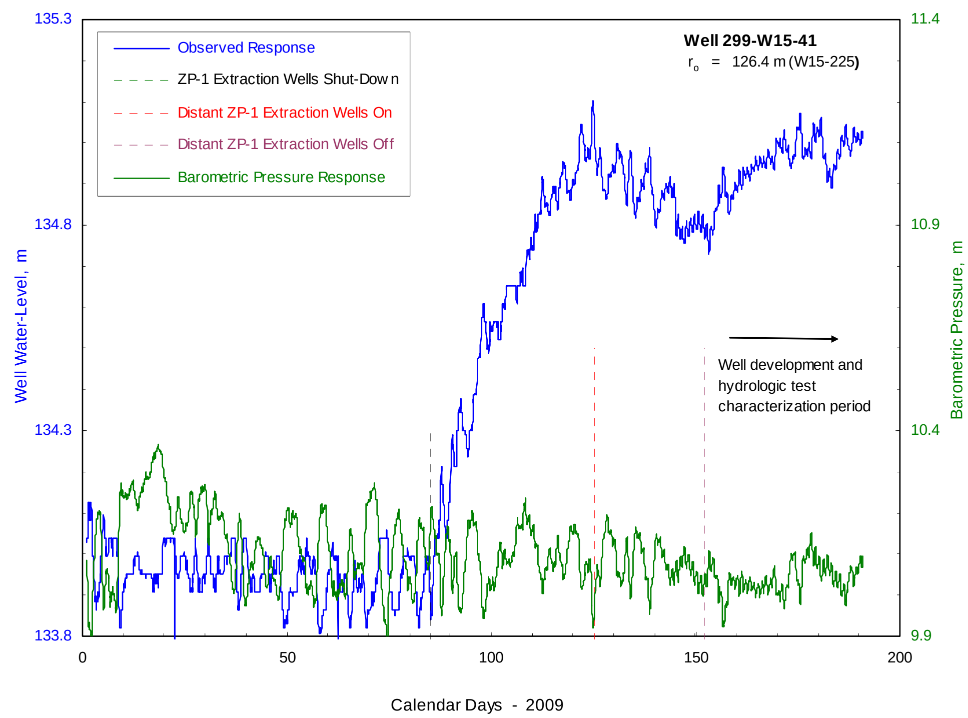


(b)

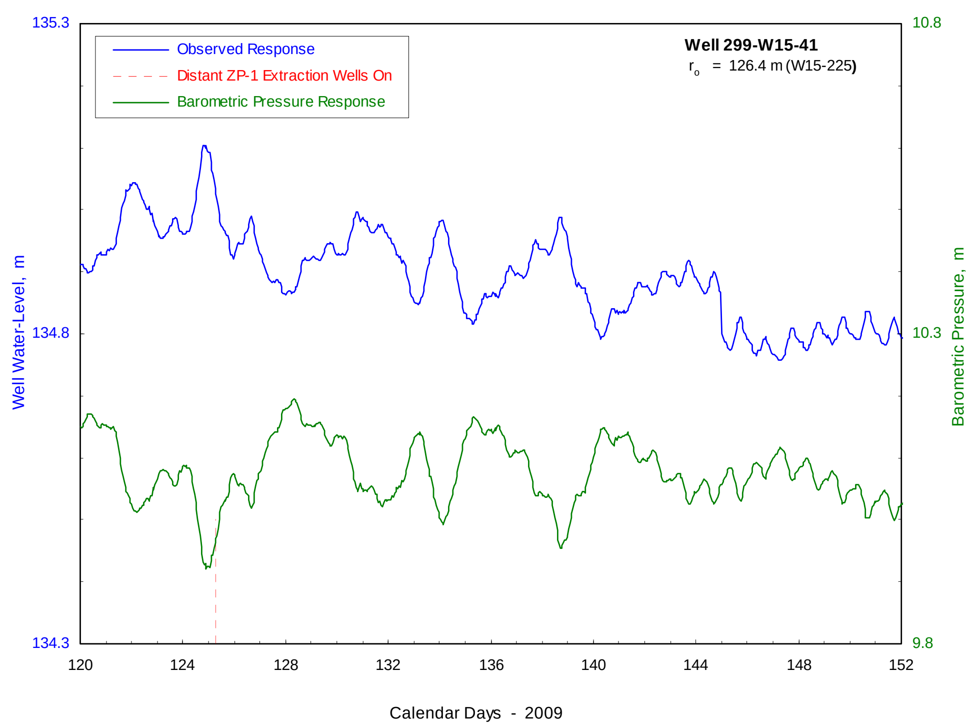


B.1. Observed Well 299-W14-72 Water Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

(a)

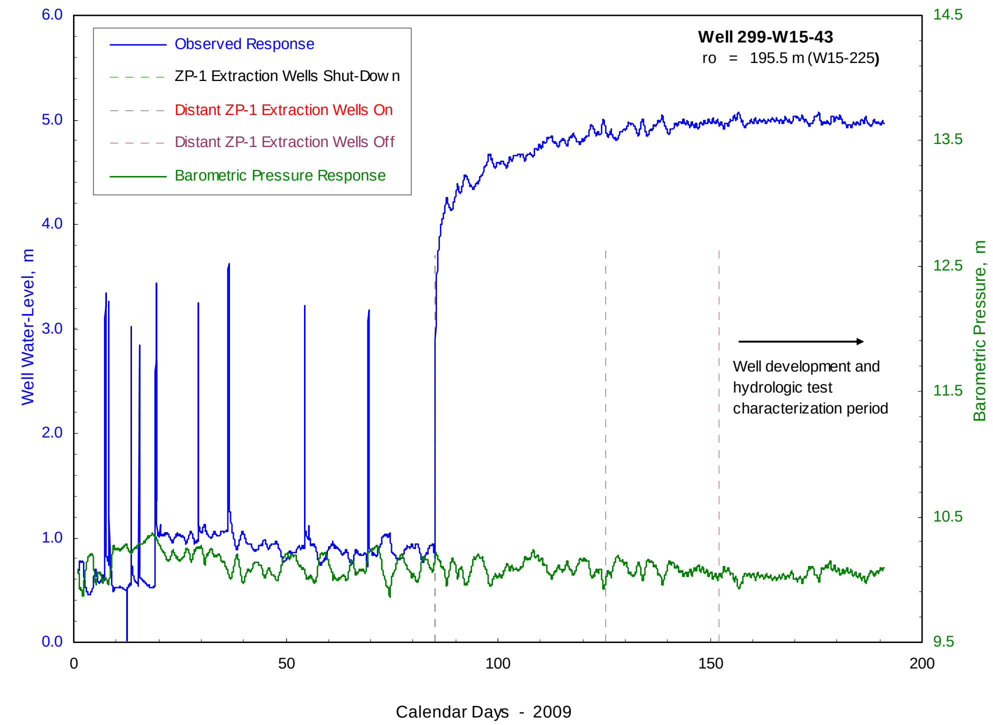


(b)

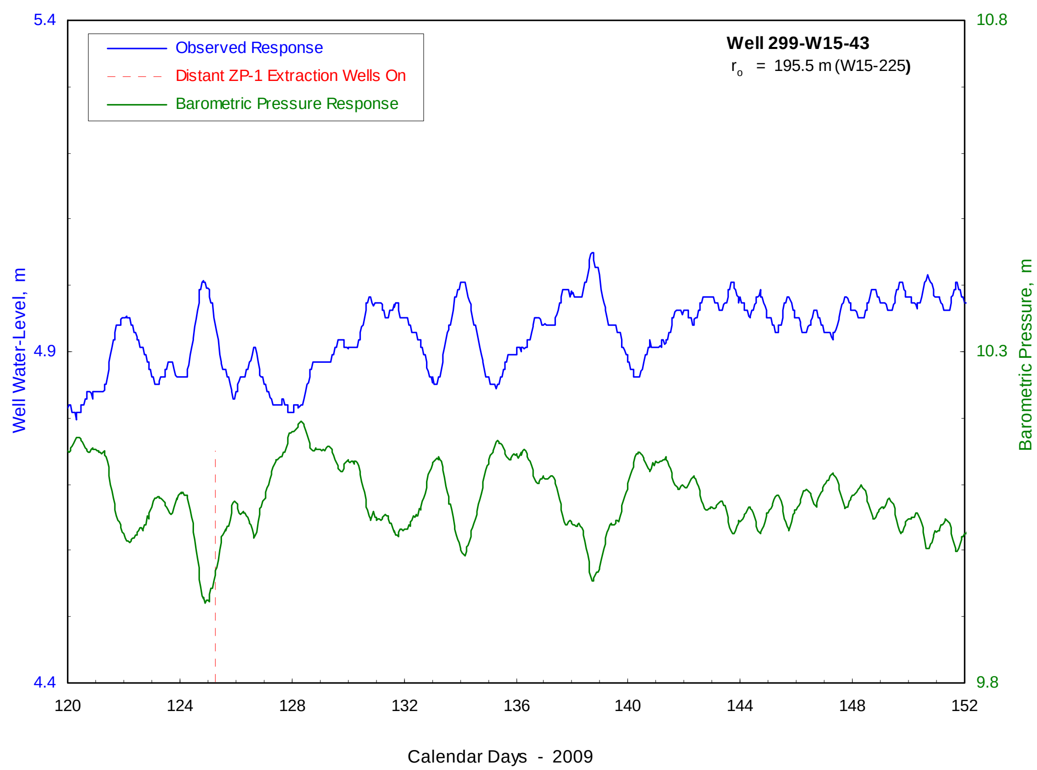


B.2. Observed Well 299-W15-41 Water Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

(a)



(b)



B.3. Observed Well 299-W15-43 Water Level versus Barometric Pressure Response: (a) Calendar Year 2009; (b) Calendar Year 2009, Days 120 to 152

Appendix C

Multiple-Regression Coefficient Analysis for Monitor Well 299-W14-14

Appendix C: Multiple-Regression Coefficient Analysis for Monitor Well 299-W14-14

Well 299-W14-14 Water-Level/Barometric Regression Analysis							
Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]	Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]
0	-0.84884	0.84884	0.88253	28	-0.00111	0.40884	0.39975
1	-0.06303	0.91187	0.87966	29	0.00345	0.40539	0.38146
2	0.02500	0.88687	0.87470	30	0.04905	0.35634	0.36018
3	0.01582	0.87105	0.87082	31	0.02733	0.32901	0.33950
4	0.01618	0.85487	0.84112	32	0.02769	0.30132	0.31728
5	0.02541	0.82946	0.82292	33	-0.00413	0.30545	0.30375
6	0.06610	0.76336	0.79865	34	0.01117	0.29428	0.30142
7	-0.03248	0.79584	0.78050	35	0.00560	0.28868	0.31480
8	0.04612	0.74972	0.76732	36	-0.02870	0.31738	0.31819
9	-0.01442	0.76414	0.75647	37	-0.05085	0.36823	0.31717
10	0.00058	0.76356	0.73240	38	0.04586	0.32237	0.31698
11	0.05447	0.70909	0.70793	39	0.03317	0.28920	0.30188
12	0.03359	0.67550	0.67270	40	0.00148	0.28772	0.26975
13	0.04813	0.62737	0.63643	41	0.04585	0.24187	0.24854
14	0.03938	0.58799	0.60829	42	0.03427	0.20760	0.23841
15	0.00580	0.58219	0.58690	43	-0.00873	0.21633	0.22377
16	0.01378	0.56841	0.58392	44	-0.02218	0.23851	0.21600
17	-0.00014	0.56855	0.57608	45	0.02395	0.21456	0.21585
18	-0.04392	0.61247	0.56824	46	0.01154	0.20302	0.21909
19	0.06370	0.54877	0.55898	47	-0.00381	0.20683	0.21355
20	0.00576	0.54301	0.54229	48	-0.02568	0.23251	0.21265
21	0.02093	0.52208	0.51015	49	0.02168	0.21083	0.21156
22	0.03696	0.48512	0.49065	50	0.00076	0.21007	0.20478
23	0.03337	0.45175	0.46920	51	0.01252	0.19755	0.19344
24	0.00046	0.45129	0.44887	52	0.02461	0.17294	0.18695
25	0.01551	0.43578	0.43340	53	-0.00287	0.17581	0.19074
26	0.01535	0.42043	0.42481	54	-0.00259	0.17840	0.20185
27	0.01270	0.40773	0.41563	55	-0.05061	0.22901	0.20666

(a) Absolute values for regression coefficient summation.

(b) Smoothed using a 5-point central moving average function

Well 299-W14-14 Water-Level/Barometric Regression Analysis							
Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]	Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]
56	-0.02410	0.25311	0.20113	84	0.02404	0.08460	0.09102
57	0.05613	0.19698	0.19443	85	-0.01348	0.09808	0.07972
58	0.04882	0.14816	0.17098	86	0.03351	0.06457	0.06918
59	0.00327	0.14489	0.14453	87	0.02188	0.04269	0.06296
60	0.03312	0.11177	0.12415	88	-0.01329	0.05598	0.06019
61	-0.00908	0.12085	0.12521	89	0.00248	0.05350	0.06492
62	0.02577	0.09508	0.12015	90	-0.03073	0.08423	0.07943
63	-0.05839	0.15347	0.13337	91	-0.00395	0.08818	0.08669
64	0.03390	0.11957	0.14376	92	-0.02708	0.11526	0.09379
65	-0.05832	0.17789	0.14786	93	0.02298	0.09228	0.09062
66	0.00510	0.17279	0.14105	94	0.00328	0.08900	0.08670
67	0.05719	0.11560	0.13622	95	0.02062	0.06838	0.06925
68	-0.00378	0.11938	0.12626	96	-0.00021	0.06859	0.05820
69	0.02395	0.09543	0.11264	97	0.04057	0.02802	0.04461
70	-0.03266	0.12809	0.11996	98	-0.00897	0.03699	0.03875
71	0.02339	0.10470	0.12268	99	0.01591	0.02108	0.04104
72	-0.04749	0.15219	0.12633	100	-0.01798	0.03906	0.04229
73	0.01922	0.13297	0.12070	101	-0.04100	0.08006	0.04832
74	0.01928	0.11369	0.12474	102	0.04582	0.03424	0.05365
75	0.01375	0.09994	0.11483	103	-0.03291	0.06715	0.05683
76	-0.02495	0.12489	0.10262	104	0.01940	0.04775	0.04368
77	0.02221	0.10268	0.09451	105	-0.00719	0.05494	0.05131
78	0.03076	0.07192	0.08344	106	0.04063	0.01431	0.04631
79	-0.00122	0.07314	0.07412	107	-0.05811	0.07242	0.04665
80	0.02856	0.04458	0.07342	108	0.03029	0.04213	0.04191
81	-0.03370	0.07828	0.08077	109	-0.00733	0.04946	0.05893
82	-0.02091	0.09919	0.08306	110	0.01821	0.03125	0.06076
83	-0.00945	0.10864	0.09376	111	-0.06812	0.09937	0.06001

(c) Absolute values for regression coefficient summation.

(d) Smoothed using a 5-point central moving average function

Well 299-W14-14 Water-Level/Barometric Regression Analysis							
Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]	Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]
112	0.01777	0.08160	0.05351	140	-0.00146	0.03348	0.00963
113	0.04323	0.03837	0.04885	141	0.03095	0.00253	0.00289
114	0.02143	0.01694	0.02914	142	0.03303	-0.03050	0.00808
115	0.00897	0.00797	0.01479	143	-0.00743	-0.02307	0.00348
116	0.00713	0.00084	0.01189	144	-0.08103	0.05796	0.00942
117	-0.00899	0.00983	0.02104	145	0.04750	0.01046	0.01995
118	-0.01402	0.02385	0.02971	146	-0.02181	0.03227	0.03355
119	-0.03885	0.06270	0.03718	147	0.01015	0.02212	0.02376
120	0.01137	0.05133	0.04432	148	-0.02280	0.04492	0.02300
121	0.01316	0.03817	0.04747	149	0.03589	0.00903	0.01624
122	-0.00740	0.04557	0.04470	150	0.00238	0.00665	0.01457
123	0.00600	0.03957	0.03568	151	0.00818	-0.00153	0.00177
124	-0.00930	0.04887	0.03081	152	-0.01533	0.01380	0.00035
125	0.04265	0.00622	0.02379	153	0.03291	-0.01911	-0.00662
126	-0.00762	0.01384	0.02171	154	-0.02104	0.00193	-0.01633
127	0.00340	0.01044	0.02133	155	0.03012	-0.02819	-0.01547
128	-0.01876	0.02920	0.02405	156	0.02188	-0.05007	-0.00014
129	-0.01777	0.04697	0.02498	157	-0.06816	0.01809	0.00568
130	0.02716	0.01981	0.02997	158	-0.03944	0.05753	0.01007
131	0.00132	0.01849	0.03364	159	0.02648	0.03105	0.02344
132	-0.01691	0.03540	0.02412	160	0.03732	-0.00627	0.01600
133	-0.01215	0.04755	0.01637	161	-0.02309	0.01682	0.00667
134	0.04818	-0.00063	0.01276	162	0.03594	-0.01912	-0.00794
135	0.01834	-0.01897	0.00652	163	-0.02999	0.01087	-0.00338
136	-0.01943	0.00046	-0.00087	164	0.05287	-0.04200	-0.00453
137	-0.00373	0.00419	0.00566	165	-0.05854	0.01654	0.00283
138	-0.00642	0.01061	0.01615	166	0.00550	0.01104	-0.00010
139	-0.02141	0.03202	0.01657	167	-0.00665	0.01769	0.00824

(e) Absolute values for regression coefficient summation.

(f) Smoothed using a 5-point central moving average function

Well 299-W14-14 Water-Level/Barometric Regression Analysis							
Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]	Time Lag, hr	Regression Coefficient	Regression Coefficient Sum[(a)]	Smoothed Regression Response[(b)]
168	0.02147	-0.00378	0.00382				
169	-0.00349	-0.00029	-0.00730				
170	0.00527	-0.00556	-0.01574				
171	0.03899	-0.04455	-0.02471				
172	-0.02002	-0.02453	-0.02337				
173	0.02409	-0.04862	-0.01995				
174	-0.05502	0.00640	-0.00310				
175	-0.00517	0.01157	0.00886				
176	-0.02811	0.03968	0.02135				
177	0.00442	0.03526	0.01754				
178	0.02143	0.01383	0.01339				
179	0.02648	-0.01265	0.00621				
180	-0.00349	-0.00916	-0.00697				
181	-0.01292	0.00376	-0.01074				
182	0.03439	-0.03063	-0.00903				
183	-0.02559	-0.00504	-0.00686				
184	-0.00097	-0.00407	-0.01452				
185	-0.00577	0.00170	-0.00613				
186	0.03624	-0.03454	-0.00742				
187	-0.04585	0.01131	-0.00690				
188	0.02281	-0.01150	-0.00873				
189	-0.01001	-0.00149	-0.00503				
190	0.00596	-0.00745	-0.01093				
191	0.00858	-0.01603	-0.00587				
192	0.00213	-0.01816	-0.00592				
193	-0.03195	0.01379	-0.00554				
194	0.01556	-0.00177	-0.00205				

(g) Absolute values for regression coefficient summation.

(h) Smoothed using a 5-point central moving average function

Appendix D

Selected Well Plots of Observed and Barometric-Corrected Well Water-Level Response in the Vicinity of WMA TX-TY

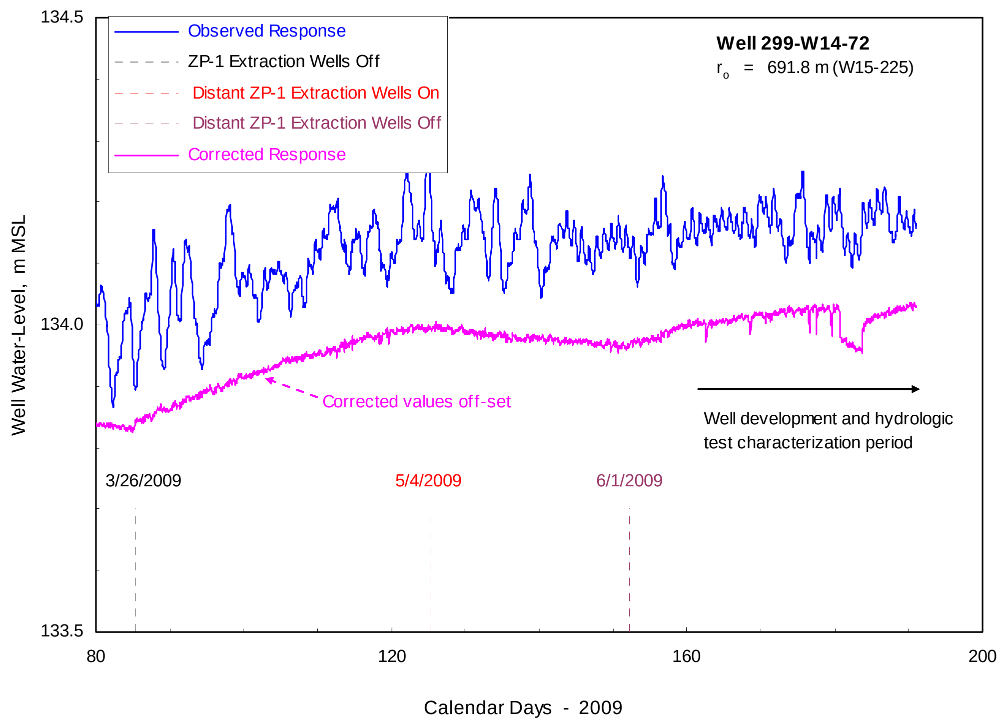
Appendix D: Selected Well Plots of Observed and Barometric-Corrected Well Water-Level Response in the Vicinity of WMA TX-TY

D.1 Observed and Corrected Baseline Well 299-W14-72 Water Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time-Period

D.2 Observed and Corrected Baseline Well 299-W15-41 Water Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time-Period

D.3 Observed and Corrected Baseline Well 299-W15-43 Water Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time-Period

(a)



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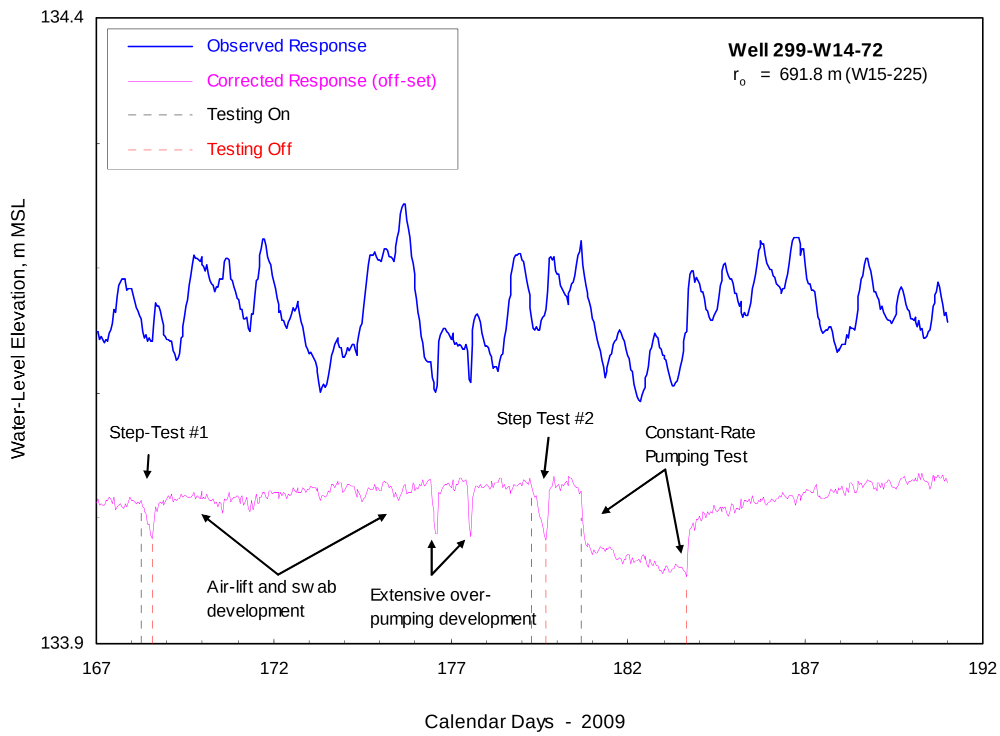
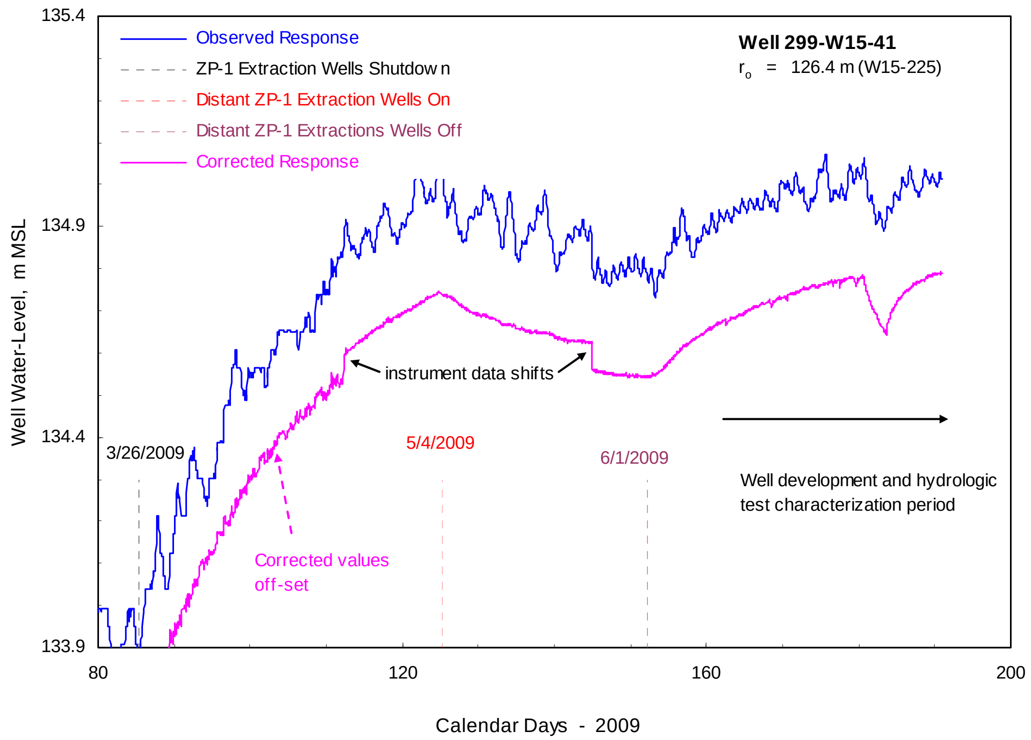
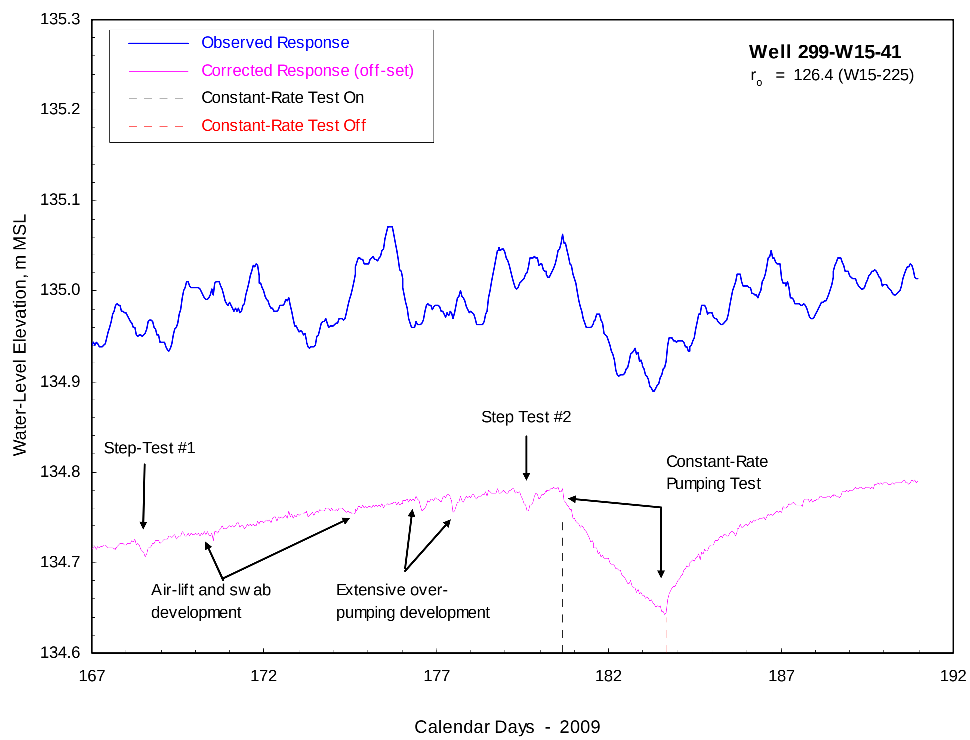


D.1. Observed and Corrected Baseline Well 299-W14-72 Water Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time-Period

(a)

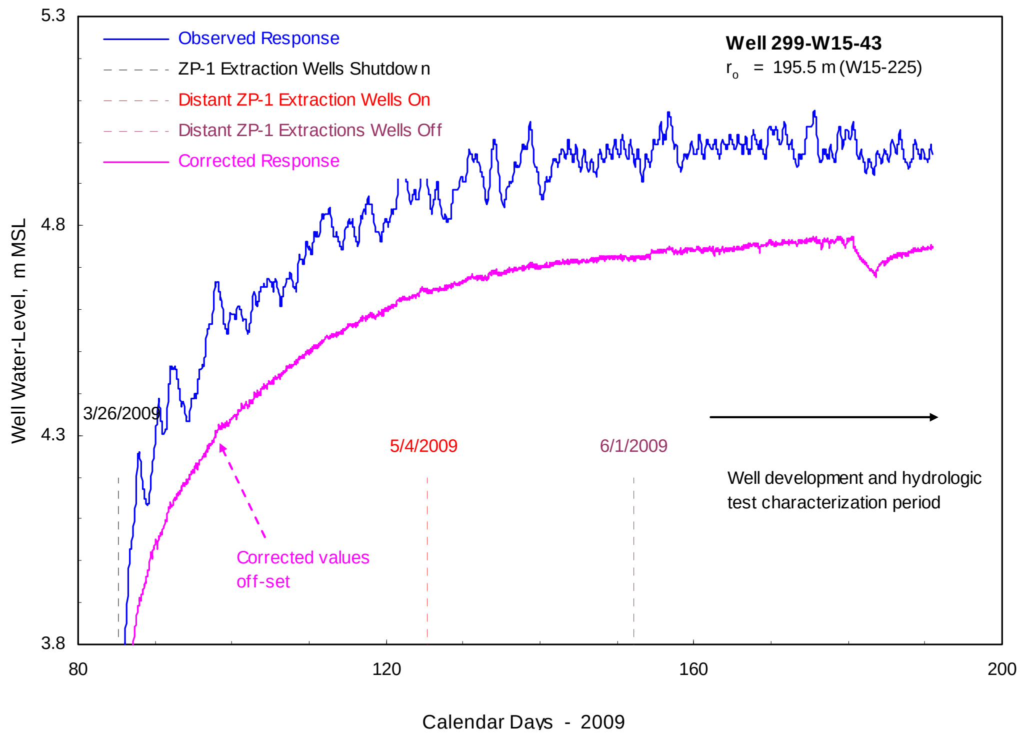


(b)

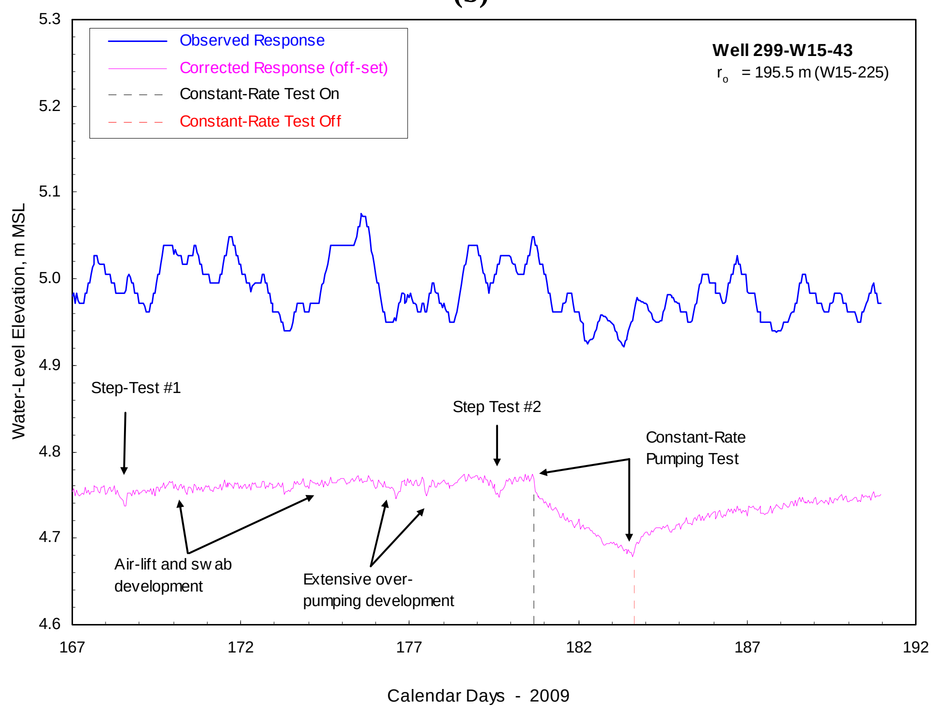


D.2. Observed and Corrected Baseline Well 299-W15-41 Water Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time-Period

(a)



(b)



D.3. Observed and Corrected Baseline Well 299-W15-43 Water Level Response: (a) Calendar Year 2009, Days 80 to 192; (b) During Well 299-W15-225 Hydrologic Testing Time Period

Appendix E

Summary of EBF Survey Test Data: Well 299-W15-225

Appendix E: Summary of EBF Survey Test Data: Well 299-W15-225

Depth m bgs	Net Flow LPM	Δ Q LPM	Δ z m	K_i/K_{ave}	Normalized K	Comments
123.5	0.0000					
118.0	1.1281	1.128	5.55	0.275	0.009	
116.4	7.4888	6.361	1.52	5.644	0.189	
114.9	9.6961	2.207	1.52	1.959	0.065	
113.4	11.1001	1.404	1.52	1.246	0.042	
111.7	12.1086	1.009	1.69	0.809	0.027	Corrugated Sleeve
110.2	12.1086	0.000	1.50	0.000	0.000	Corrugated Sleeve
108.8	12.3570	0.248	1.39	0.242	0.008	
107.3	12.7084	0.351	1.52	0.312	0.010	
105.8	14.9957	2.287	1.52	2.030	0.068	
104.2	15.1552	0.159	1.52	0.142	0.005	
102.7	15.7587	0.604	1.52	0.536	0.018	
101.2	17.6663	1.908	1.52	1.693	0.057	
99.7	22.0988	4.432	1.52	3.933	0.131	
98.1	22.1820	0.083	1.52	0.074	0.002	
96.6	22.5430	0.361	1.52	0.320	0.011	
95.1	23.1255	0.583	1.52	0.517	0.017	
93.6	23.7560	0.631	1.52	0.560	0.019	
93.0	23.9828	0.227	0.61	0.503	0.017	
92.0	24.3045	0.322	0.91	0.476	0.016	
90.5	24.7780	0.474	1.52	0.420	0.014	
89.0	25.5085	0.730	1.52	0.648	0.022	
87.5	26.8995	1.391	1.52	1.234	0.041	
86.0	28.2822	1.383	1.52	1.227	0.041	

Static D/W (m bgs) = 69.66
Pumped D/W (m bgs) = 69.80
Q_{pump} (LPM) = 36.2
Depth of Open Well Screen (m bgs): 74.7 - 80.8; 83.9 - 110.2; and 111.7 - 123.5
Well Screen Bottom, m bgs = 123.5
Dynamic b (m) = 44.2
$K_{ave} = \sum \Delta Q/\Delta z = 0.7394$
Detection Limit (LPM) = +/- 0.04

Depth m bgs	Net Flow LPM	Δ Q LPM	Δ z m	K_i/K_{ave}	Normalized K	Comments
85.2	28.3995	0.117	0.76	0.208	0.007	
84.4	28.5168	0.117	0.76	0.208	0.007	
83.9	28.7514	0.235	0.53	0.599	0.020	Blank Casing
80.8	28.7514	0.000	3.10	0.000	0.000	Blank Casing
79.9	29.2233	0.472	0.94	0.677	0.023	
78.3	30.8417	1.618	1.52	1.436	0.048	
76.8	31.8263	0.985	1.52	0.874	0.029	
75.3	32.4225	0.596	1.52	0.529	0.018	
74.7	32.6594	0.237	0.55	0.584	0.020	
Sum		**32.66**	**44.2**	**29.92**	**1.00**	

Static D/W (m bgs) = 69.66
Pumped D/W (m bgs) = 69.80
Q_{pump} (LPM) = 36.2
Depth of Open Well Screen (m bgs): 74.7 - 80.8; 83.9 - 110.2; and 111.7 - 123.5
Well Screen Bottom, m bgs = 123.5
Dynamic b (m) = 44.2
$K_{ave} = \sum \Delta Q/\Delta z = 0.7394$
Detection Limit (LPM) = +/- 0.04

* Note: corrugated sleeve and blank casing sections were not included in Δz summation

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