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Slug Test Characterization Results for Multi-Test/Depth Intervals Conducted During the Drilling of CERCLA Operable Unit OU UP-1 Wells 299-W19-48, 699-30-66, and 699-36-70B

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To M.E. Byrnes

From F.A. Spane and D.R. Newcomer

Subject Slug Test Characterization Results for Multi-Test/Depth Intervals Conducted During the Drilling of CERCLA Operable Unit OU UP-1 Wells 299-W19-48, 699-30-66, and 699-36-70B

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The following letter report presents test descriptions and analysis results for multiple, stress-level slug tests that were performed at selected test/depth intervals within three Operable Unit (OU) UP-1 wells: 299-W19-48 (C4300/Well K), 699-30-66 (C4298/Well R), and 699-36-70B (C4299/Well P). These wells are located within, adjacent to, and to the southeast of the Hanford Site 200-West Area, as indicated in Figure 1.1. The test intervals were characterized as the individual boreholes were advanced to their final drill depths. The primary objective of the hydrologic tests was to provide information pertaining to the areal variability and vertical distribution of hydraulic conductivity with depth at these locations within the OU UP-1 area. This type of characterization information is important for predicting/simulating contaminant migration (i.e., numerical flow/transport modeling) and designing proper monitor well strategies for OU and Waste Management Area locations.

For ease in referencing results for the OU UP-1 field testing program within the letter report, the following outline is provided:

LETTER REPORT OUTLINE

1. Executive Summary

Overall, the test results obtained from multiple, stress-level slug tests conducted during drilling and borehole advancement provide detailed information concerning the vertical distribution of hydraulic conductivity at two of the three Hanford Site Operable Unit (OU) UP-1 test well locations. The individual test/depth intervals were generally sited to provide hydraulic property information within the upper, middle, and lower sections of the unconfined aquifer (i.e., Ringold Formation, Unit 5). These characterization results complement previous and on-going drill-and-test characterization programs at surrounding 200-West and -East Area locations (e.g., Spane 2003, 2005).

Analysis of the slug test results indicate a relatively wide-range in the calculated average, test interval hydraulic conductivity (Table 5.2), with estimates ranging between 0.01 and 6.78 m/day. The hydraulic conductivity estimates were derived for test interval sections that ranged from 1.42 to 2.84 m in length (Table 5.1). Hydraulic conductivity estimates that are reflective of just the upper-section of the unconfined aquifer (i.e., Zone 1, Table 5.2) range more narrowly, between 2.73 and 6.78 m/day. These hydraulic conductivity estimates fall relatively close to and encompass the statistical geometric mean value (K = 3.08 m/day; $\sigma = \pm 7.70$ m/day) for recent slug tests conducted at thirty monitor well sites completed within the upper-10 m of the unconfined aquifer in the 200-West Area (Spane et al., 2001a, 2001b, 2002, 2003; Spane and Newcomer 2004).

The vertical hydraulic conductivity profiles for UP-1 wells 699-30-66 and 699-36-70B (based on only three test/depth intervals at each site) suggests a decrease in hydraulic conductivity within the Ringold Formation with depth at these two locations. Because of the limited number of depth intervals tested, it is not known whether this apparent vertical trend is uniform throughout the entire Ringold Formation section. More extensive, on-going (unpublished) drill-and-test characterization programs for boreholes located within the WMA S-SX and T areas (located generally west to northwest of the UP-1 test sites), however, do not exhibit similar decreasing permeability-with-depth profiles.

2. General Hydrologic Test Plan Description

The following general hydrologic test plan discussion is taken primarily from a similar slug test characterization program description presented previously in Spane (2003, 2005). Hydrologic testing was implemented when the approximate targeted depth interval within the upper, middle and lower sections of the unconfined aquifer were reached during drilling. To prepare the test zone for slug test characterization, the packer/well-screen test assembly was lowered to the bottom of the borehole and the drill casing retracted exposing an approximate ≤1.5-m open borehole section (note: ~2.9 m for well 299-W19-48). The packer was then inflated to isolate the well-screened/test interval, and testing string from the inside of the drill casing.

A series of multiple, stress-level slug tests were performed for each isolated test-interval section. The reason for utilizing a multi-stress level approach was to determine whether the associated slug test responses exhibited either a variable or stress-level dependence. As noted in Butler (1998) and Spane et al. (2003), tests exhibiting either variable or stress-level dependence can provide valuable information pertaining to the presence of dynamic well skin or non-linear (i.e., turbulence) test response conditions occurring within the test section. General slug test stress levels applied during testing were designed to be within the range of ~0.3 to 0.5 m for lower-stress tests and ≤1 m for higher-stress tests. The slug tests were initiated utilizing several slugging rods of different, known displacement volumes and/or conducted pneumatically using compressed air/gas.

For pneumatic tests, compressed air was used to depress the fluid-column levels within the test-casing system to the designed test stress levels. Actual stress levels applied for each test were determined by comparing pressure transducer readings below and above the borehole fluid-column surface. After the monitored fluid column stabilized for several minutes at the prescribed stress level, the slug test (slug withdrawal test) was initiated by rapidly releasing the compressed gas used to depress the borehole fluid-column level. The compressed gas was released from the borehole column by opening valves (e.g., ball valves) mounted on the surface wellhead used to seal the casing system. As noted in Spane et al. (1996), the gas release valves had a cross-sectional area that was greater (e.g. >1.5 times) than the cross-sectional area of the test system where fluid-level surface recovering took place during testing.

For most test zones, three or more multi-stress slug tests were conducted. Individual slug tests were fully recovered prior to depressing the fluid column for preparation of the next slug test within the characterization sequence. A wide-range in recovery times were expected based on anticipated range in permeability conditions. For example Spane et al., (2001a, 2001b, 2002, 2003) and Spane and Newcomer (2004) report recovery times as rapid as <15 sec for high permeability test intervals to >5 min for lower permeability test zones for 200-West Area wells. A description of the hydrologic test system utilized during slug test characterization is provided in the following report section.

3. Hydrologic Test System Description

Figure 3.1 shows the general test system configuration utilized for pneumatic slug tests conducted during the drilling and testing of the UP-1 wells. Salient features of the test system configuration are: the downhole packer/well-screen test assembly, and the sealed, surface well-head installation. The drill-casing strings used for borehole advancement during the drilling of the UP-1 wells varied for the respective well sites and had the following I.D./O.D. dimensions: well 299-W19-48 (0.244/0.273 m); well 699-30-66 (0.273/0.298 m); and well 699-36-70B (0.197/0.222 m).

As shown in Figure 3.1, an inflatable packer was used to seal and isolate the test interval and testing string from the encompassing drill casing area. A 20-slot, well-screen section was attached below the packer to maintain an open section for testing after retracting the drill casing. For testing at the UP-1 well sites, two different length packer/well-screen assemblies were utilized: well 299-W19-48 = 2.92 m well screen (Figure 3.2); wells 699-30-66 and 699-36-70B = 1.42 m well screen (Figure 3.3). In most cases, a strain-gauge, 0 to 345 kPa (0 to 50 psig) pressure transducer was installed within the test-casing string to monitor downhole test interval response prior to and during slug testing. Pictures of one of the packer/well-screen test assembly are shown in Appendix A.

The performance of pneumatic slug tests requires that a surface wellhead be utilized to seal the inner test-casing string. This wellhead isolation is required to contain the administered compressed air that is used to pneumatically depress the test-casing string fluid column to designed slug test stress levels, as discussed in Section 2. Salient features of the well-head assembly include:

- a sealed, pass-through connection allowing for passage of downhole pressure transducer and cable to be used to measure test interval pressure response within the test-casing string
- an outside pressure probe connection that allows direct measurement of the air/gas pressure within the test-casing below the surface seal
- a connection to allow compressed air to be introduced directly to the inside of the testing-string casing
- surface wellhead valves for the rapid release of the compressed air within the testing-string casing, which allows for the *immediate* initiation of slug test application.

The preceding discussion describes the test system as designed for use during pneumatic slug tests. Slug tests were also conducted using slugging rods to initiate the slug test response (i.e., at well 299-W19-48; well 699-30-66/Zones 2 & 3; and well 699-36-70B/Zone 3). The test system utilized is the same as shown in Figure 3.1, without the surface wellhead installation. The two slugging rods used for conducting the multiple, stress-level slug tests had O.D. dimensions of 0.038 and 0.051 m that theoretically produce a maximum initial displacement stress within the 0.102 m I.D. test casing of 0.255 and 0.458 m, respectively. Generally slug tests conducted with slugging rods were used for test/depth intervals with anticipated lower hydraulic property conditions (e.g., $K \leq 1$ m/day). This is because of the difficulty in establishing stability in downhole well pressures (i.e., prior to test initiated) when pneumatic methods are employed.

4. Slug Test Response/Analysis

The following discussion pertaining to slug test response and analysis is taken primarily from Spane (2003, 2005). As shown in Figure 4.1 and discussed in Butler (1998) and Spane et al. (2003b), 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 will be 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:

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

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.

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 various combinations anticipated for testing at UP-1 well sites 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

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.

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 (e.g., Hanford formation). Tests exhibiting under-damped behavior should be conducted with very small stress level applications. If too high of a stress is applied, the slug test response may exhibit oscillatory behavior superimposed on an over- or critically-damped recovery response. Methods are currently not available for the analysis of slug tests exhibiting this type of composite slug test response. For test sites exhibiting composite oscillatory behavior, the tests should be re-run at lower stress levels to allow analysis and quantitative hydraulic property determination using the appropriate, individual, analysis model method (under-, over-, or critically-damped).

As mentioned previously, critically-damped test responses are indicated by stress well water-level responses that are transitional to the over- and under-damped test conditions, as shown in Figure 4.1. They typically occur in wells that monitor test formations exhibiting high hydraulic conductivity. As noted in Butler (1998), distinguishing between over- and critically-damped slug test response may be difficult in some cases (i.e., due to test signal noise) when examined on arithmetic plots. Proper model identification may be enhanced when semi-log plots are utilized, i.e., log head versus time (e.g., Bouwer and Rice plot). Critically-damped slug tests exhibit a diagnostic concave-downward pattern when plotted in this semi-log plot format. This is in contrast to over-damped response behavior, which displays either a linear or concave upward (elastic) pattern.

All formational slug test responses conducted at the various well test/depth intervals exhibited over-damped/exponential decay characteristics. Figure 4.2 shows predicted slug test recovery as a function of hydraulic conductivity (K range: 1 to 100 m/day; 1.5 m test interval) for test intervals exhibiting over-damped response characteristics, as presented in Spane (2003). The test predictions shown in this figure are based on responses occurring within a test system casing I.D. = 0.152 m, which is exactly 1.5 times larger than the diameter testing-string casing used at UP-1 test well sites. Since over-damped slug test response is indirectly proportional to the square of the test casing radius, responses for the UP-1 test/depth intervals would be expected to dissipate faster by a factor of 2.25 from that shown in Figure 4.2. As indicated in the figure (even accounting for the faster test dissipation associated with the smaller testing-string diameter), test intervals having hydraulic conductivity values of approximately 100 m/day or less, should be readily resolved for tests exhibiting over-damped slug test behavior.

Methods that can be employed for analyzing unconfined aquifer tests exhibiting high permeability under-, over- or critically-damped characteristics include techniques described in Springer and Gelhar (1991), Butler (1998), McElwee and Zenner (1998), Butler and Garnett (2000), Zurbuchen et al. (2002), and Butler et al. (2003). For tests exhibiting intermediate to low permeability response characteristics, the unconfined aquifer analysis methods discussed in Butler (1998) can be employed.

A summary and examples of their use under Hanford Site conditions is provided in Spane et al. (2003) and Spane and Newcomer (2004).

5. Slug Test Results

The following discussion presents pertinent information describing slug testing activities and analysis results for the test/depth zones that were hydrologically characterized at the UP-1 boreholes, as they were advanced to their final drilling depths. Table 5.1 presents pertinent slug test information for the respective test/depth intervals, while Table 2 summarizes the slug test analysis results. Selected borehole logs are presented in Appendix B, which can be referred to for a geologic description of the respective well test zone/depth intervals.

5.1 Well 299-W19-48

Drilling of OU UP-1 well 299-W19-48 was initiated on October 5, 2004 and continued until reaching a final depth of 129.2 m bgs on December 14, 2004. The Lower Mud unit of the Ringold Formation was encountered at a depth of 128.1 m bgs, which represents the bottom boundary of the unconfined aquifer at this location. Initially three test/depth intervals were planned to be tested at the borehole location; however, end-of-year deadline requirements for completing the well restricted hydrologic testing to only the initial top test zone.

After reaching a depth of 89.37 m bgs on December 2, 2004, the packer/well-screen assembly was lowered to the bottom of the borehole and the 0.273 m O.D. drill casing retracted 2.84 m, producing a theoretical test/depth interval for Zone 1 of 86.53 to 89.37 m bgs. The borehole geology log (Appendix B; Figure B.1) indicates that the test interval section consists of a slightly silty, sandy gravel unit, comprised of 60 to 70% gravel, 30% sand, and 0 to 5% silt.

A series of four slug withdrawal tests (two low and two high stress tests) were conducted between 1235 hours and 1500 hours, (PST) December 2, 2004. The slug tests were initiated using slugging rods having two different displacement volumes. The calculated slugging rod volumes impart theoretical applied stress values of 0.255 m and 0.458 m for the low and high stress tests, respectively. Downhole test interval response pressures during testing were monitored using a 0 - 10 psig (0 - 69 kPa) pressure transducer set at a depth of ~81.4 m bgs. The static depth-to-water for the test interval during testing was 77.54 m bgs.

A comparison of the normalized, slug-test responses indicates very similar behavior indicative of linear, over-damped slug test behavior (e.g. Figure 5.1). Slug tests exhibiting this type of homogeneous formation response behavior can be analyzed quantitatively using standard, linear-response based analytical methods (i.e., using either the Bouwer and Rice or standard type-curve methods). A comparison of K estimates indicates that slightly lower results (~10% lower) were obtained for the Bouwer and Rice method. For the Bouwer and Rice method, estimates for K ranged between 3.78 and 4.18 m/day (average 3.99 m/day), while the type-curve method provided estimates between 4.19 and 4.58 m/day (average 4.44 m/day) for both stress-level tests. Specific storage estimates derived from the type-curve analysis method ranged between 5.0E-6 and 1.0E-5. These values are within the range commonly reported for slug tests conducted within alluvial formations (e.g., Butler 1998). Selected examples of analysis plots for this test interval are shown in Figure 5.1.

5.2 Well 699-30-66

Drilling of OU UP-1 well 699-30-66 was initiated on August 12, 2004 and continued until reaching a final depth of 123.89 m bgs on October 13, 2004. The Lower Mud unit of the Ringold Formation was encountered at a depth of 123.4 m bgs, which represents the bottom boundary of the unconfined aquifer at this location. Three test depth intervals were tested at the borehole location; Zone 1 = 82.77 - 84.19 m bgs; Zone 2 = 105.72 - 107.14 m bgs ; and Zone 3 = 121.58 - 123.00 m bgs.

5.2.1 Zone 1

After reaching a depth of 84.19 m bgs, the packer/well-screen assembly was lowered to the bottom of the borehole and the 0.298 m O.D. drill casing retracted 1.42 m, producing a test/depth interval for Zone 1 of 82.77 to 84.19 m bgs. The borehole geology log (Appendix B; Figure B.2) indicates that the test encompassing interval section of 75.7 to 89.0 m generally consists of a sandy gravel unit, comprised of 65% gravel, 30% sand, and 5% silt.

A series of four pneumatic slug withdrawal tests were conducted between 0805 hours and 1135 hours, (PDT) September 14, 2004. The pneumatic slug tests were conducted by pressurizing the 4-in testing-string casing (I.D. = 0.102 m) used to set the packer/well-screen assembly. The pneumatic tests used applied stress (compressed air) pressures that produced fluid-column depressions ranging between 0.3 and 0.7 m for individual tests, which was then rapidly released using the wellhead surface valves. Downhole test interval response pressures during testing were monitored using a 0 - 50 psig (0 - 345 kPa) pressure transducer set at a depth of ~78.3 m bgs, while pneumatic gas injection pressure was recorded utilizing a 10 psig (0 - 69 kPa) pressure transducer installed on the surface wellhead assembly. The static depth-to-water for the test interval during testing was 77.43 m bgs.

A comparison of the normalized, slug-test responses indicates a linear, inelastic (storage), over-damped slug test behavior (e.g. Figure 5.2). The slug tests exhibited heterogeneous formation response conditions during the initial 10 sec of the test response (early test data not shown on analysis figures). This heterogeneous formation response is attributed to an artificial higher permeability zone condition near the well screen, probably due to borehole collapse during drill casing pullback/retraction to expose the formation to the well-screen/test interval. A comparison between the low and high stress tests also exhibits a slight stress dependency, suggesting a near well dynamic skin condition.

Heterogeneous formation slug tests exhibiting this type of test response behavior can be analyzed quantitatively using standard, linear-response based analytical methods (i.e., using either the Bouwer and Rice or standard type-curve methods) following procedures described in Spane and Newcomer (2003). A comparison of K estimates indicates that slightly lower results (~10% lower) were obtained for the Bouwer and Rice method. For the Bouwer and Rice method, estimates for K ranged between 1.61 and 3.14 m/day (average 2.38 m/day), while the type-curve method provided estimates between 1.90 and 3.54 m/day (average 2.73 m/day) for both stress-level tests. Specific storage estimates derived from the type-curve analysis method ranged between 5.0E-6 and 3.0E-5. These values are within the range commonly reported for slug tests conducted within alluvial formations (e.g., Butler 1998). Selected examples of analysis plots for this test interval are shown in Figure 5.2.

5.2.2 Zone 2

After reaching a depth of 107.14 m bgs, the packer/well-screen assembly was lowered to the bottom of the borehole and the 0.298 m O.D. drill casing retracted 1.42 m, producing a theoretical test/depth interval for Zone 2 of 105.72 to 107.14 m bgs. The borehole geology log (Appendix B; Figure B.2) indicates that the test encompassing interval section of 89.0 to 123.4 m generally consists of a sandy gravel unit, comprised of 55 to 65% gravel, 40 to 45% sand, with only a trace of silt.

A series of three pneumatic slug withdrawal tests were conducted between 0946 hours and 1500 hours, (PDT) October 1, 2004. The pneumatic slug tests were conducted by pressurizing the 4-in testing-string casing (I.D. = 0.102 m) used to set the packer/well-screen assembly. The pneumatic tests used applied stress (compressed air) pressures that would theoretically produce fluid-column depressions ranging between 0.3 and 0.7 m for individual tests, which was then rapidly released using the wellhead surface valves. Downhole test interval response pressures during testing were monitored using a 0 - 50 psig (0 - 345 kPa) pressure transducer set at a depth of ~82.3 m bgs, while pneumatic gas injection pressure was recorded utilizing a 10 psig (0 - 69 kPa) pressure transducer installed on the surface wellhead assembly. The pre-test depth-to-water for the test interval during testing was 76.99 m bgs. This value is not considered to be representative of “static” conditions, since a declining water-level trend of -0.000329 m/min was observed during and for an extended monitoring period following testing.

In all cases, the slug tests exhibited slow over-damped recovery response behavior. Since the recovery times for these tests were extremely slow, with percent recovery less than 10% of the applied stress, a test history match approach was applied to the pneumatic (gas application) and slug withdrawal phases of the test. The test history match approach is particularly useful when analysis of individual tests may be uncertain (i.e., due to only small recovery %), and relies on superimposing the predicted test responses of the subsequent test activities, which can then be used to match the entire composite test sequence (test history match). Slug withdrawal tests SW #1 and #2, were compromised by leakage that occurred within components of the wellhead assembly. The leakage conditions were largely eliminated during the pneumatic phase (gas application) for test SW #3; and, therefore, this test represents the best test set for hydraulic property characterization.

Figure 5.3 shows the observed well response during the active pneumatic phase and slug withdrawal response during test SW #3. Also shown in the figure, is the predicted test history match for this testing sequence, which was produced by test response superposition. As noted previously, a declining water-level trend of -0.000329 m/min was observed over the test period and included in the test analysis. As indicated, a hydraulic conductivity, K, of 0.04 m/day provides a good match to the observed test response sequence. To demonstrate the sensitivity of the analytical solution, Figure 5.4 shows the predicted history match using K values of 0.08, 0.5 and 3 m/day. As indicated, significant departures in the test history matches of the observed test responses are produced with higher K values. This suggests that the interval tested exhibits a K value of ≤0.08 m/day. It is not completely certain whether the relatively low hydraulic conductivity indicated for Zone 2 is actually representative of in-situ formation conditions or an artifact of the drilling process or borehole instability (i.e., collapse of low permeability materials around the well screen during drill casing pullback/retraction to expose the depth interval for characterization. The low-permeability condition is corroborated, however, by: 1) the driller's pre-test observations during test zone development; 2) extremely small slug withdrawal stress displacements actually imposed (i.e., in comparison to theoretical stress levels; and 3) the observed slow static water-level recovery trend that was exhibited during and for the extended monitoring period following the pneumatic tests.

A short-duration slug injection (emersion) and withdrawal test was implemented and monitored briefly on October 4, 2004 to verify the test interval low permeability conditions. The observed test response (not shown) replicated displacement volume relationships imposed by the slugging rod with little discernable pressure recovery. This verifies qualitatively the presence of a low-permeability test interval condition.

5.2.3 Zone 3

After reaching a depth of 123.00 m bgs, the packer/well-screen assembly was lowered to the bottom of the borehole and the 0.298 m O.D. drill casing retracted 1.42 m, producing a theoretical test/depth interval for Zone 3 of 121.58 to 123.00 m bgs. This test interval is located immediately above the Lower Mud unit of the Ringold Formation. As for test Zone 2, the borehole geology log (Appendix B; Figure B.2) indicates that the test encompassing interval section of 89.0 to 123.4 m generally consists of a sandy gravel unit, comprised of 55 to 65% gravel, 40 to 45% sand, with only a trace of silt.

A slug injection test, followed by a slug withdrawal test (SI #1 and SW #1), were conducted between 1239 and 1504 hours, PDT October 14, 2004. The two slug test sequence was initiated by rapidly submerging a 0.051 O.D. slugging rod (slug injection test) below the fluid column within the 4-in testing-string casing (I.D. = 0.102 m) used to set the packer/well-screen assembly. After approximately 30 minutes of recovery, the previously submerged slugging rod was removed from the fluid column initiating a slug withdrawal test. Downhole test interval response pressures during testing were monitored using a 0 - 50 psig (0 - 345 kPa) pressure transducer set at a depth of ~82.0 m bgs. The pre-test depth-to-water for the test interval during testing was 76.13 m bgs. This value, however, is not considered to be representative of "static" conditions, since a declining water-level trend of -0.001927 m/min was observed during and for an extended monitoring period following testing.

Observed test responses for these slug tests indicate that the test interval exhibits relatively low permeability characteristics (i.e., low recovery response) and that the inflatable packer used to isolate the 0.102 I.D. test well screen within the 0.273 m I.D. drill casing was not effective. Evidence to support this observation includes observed slug test displacement levels and early-test time oscillatory response. The observed slug test displacement values of 0.070 m were considerably lower than these tests should have imposed (i.e., 0.458 m) within the 0.102 I.D. m testing-string casing. This observed value; however, is identical to a stress level that would occur within the larger composite annular drill casing and test-string areas. Additionally a rapid oscillatory, early-time test response (i.e., during the initial minute of testing) is consistent with a "u-tube" effect between the inner test string area (where the slugging rod was deployed) and the annular zone between the drill casing and testing string.

The presence of these test complications does not preclude use of these slugging test results for hydraulic property determination. Because the recovery times for these tests were extremely slow, the consecutive slug injection/withdrawal tests were combined and analyzed compositely using a test history match approach. As noted previously, this approach is particularly useful when analysis of individual tests may be uncertain (i.e., due to only small recovery percentage; e.g. ≤10%), and relies on superimposing the predicted test responses of subsequent testing activities, which can be used to match the entire composite test sequence (test history match).

Figure 5.5 shows the observed well response for the composite slug injection slug withdrawal tests using the 0.051 m O.D. slugging rod. Also shown in the figure, is the predicted test history match for the two tests, which was produced by superimposing the two individual slug tests at their appropriate time of test initiation. A declining water-level trend of -0.001927 m/min was observed over the test period and included in the test history match. As indicated, a hydraulic conductivity, K, of 0.2 m/day provides a good match to the observed test response sequence.

To demonstrate the sensitivity of the analytical solution, Figure 5.6 shows the predicted history match using K values of 0.2, 1.0 and 5 m/day. As indicated, significant departures in the test history matches of the observed test responses are produced with higher K values. This suggests that the interval tested exhibits a K value of ~0.2 m/day. It is not completely certain whether the relatively low hydraulic conductivity indicated for Zone 3 is actually representative of in-situ formation conditions or an artifact of the drilling process or borehole instability (i.e., collapse of low permeability materials around the well screen during drill casing pullback/retraction to expose the depth interval for characterization. The low-permeability condition is corroborated, however, by: the proximity of the test interval to the Lower Mud unit of the Ringold Formation, and the observed slow static water-level recovery trend that was exhibited during and for the extended monitoring period following the pneumatic tests.

Because of the uncertainty (at the time) of the reliability of the slug tests conducted with slugging rods, four pneumatic slug tests were attempted on October 15, 2004. Similar test response results were obtained during these tests and they also indicate the lack of isolation of the test interval using the inflatable packer system. Difficulties in regulating and maintaining uniform applied pneumatic pressures during these tests make analysis of these test responses less reliable than the uniform displacements imposed during the slugging rod tests. For this reason, analysis results obtained from the slugging rod tests are considered to be more reliable. The pre-test depth-to-water for the test interval prior to and following conducting the pneumatic slug tests was 77.75 m bgs. This value is considered to be more representative of "static" test zone conditions.

5.3 Well 699-36-70B

Drilling of OU UP-1 well 699-36-70B was initiated on June 9, 2004 and continued until reaching a final depth of 130.15 m bgs on September 28, 2004. The Lower Mud unit of the Ringold Formation was encountered at a depth of ~129.5 m bgs, which represents the bottom boundary of the unconfined aquifer at this location. Three test depth intervals were tested at the borehole location; Zone 1 = 81.91 - 83.33 m bgs; Zone 2 = 112.58 - 114.12 m bgs ; and Zone 3 = 124.11 - 125.43 m bgs.

5.3.1 Zone 1

After reaching a depth of 83.33 m bgs, the packer/well-screen assembly was lowered to the bottom of the borehole and the 0.222 m O.D. drill casing retracted 1.42 m, producing a test/depth interval for Zone 1 of 81.94 to 83.33 m bgs. The borehole geology log (Appendix B; Figure B.3) indicates that the test encompassing interval section of 75.7 to 89.0 m generally consists of a sandy gravel unit, comprised of 35% to 40% gravel, 55% to 60% sand, and 5% silt.

A series of three pneumatic slug withdrawal tests were conducted between 1422 hours and 1622 hours, (PDT) August 19, 2004. The pneumatic slug tests were conducted by pressurizing the 4-in testing-string casing (I.D. = 0.102 m) used to set the packer/well-screen assembly. The pneumatic tests used applied stress (compressed air) pressures that produced observed fluid-column depressions ranging between 0.2 and 0.6 m for individual tests, which was then rapidly released using the wellhead surface valves. Downhole test interval response pressures during testing were monitored using a 0 - 50 psig (0 - 345 kPa) pressure transducer set at a depth of ~81.7 m bgs, while pneumatic gas injection pressure was recorded utilizing a 10 psig (0 - 69 kPa) pressure transducer installed on the surface wellhead assembly. The static depth-to-water for the test interval during testing was 79.37 m bgs.

A comparison of the normalized, slug-test responses indicates the presence of a high-frequency, noise-related early-time test response (i.e., ≤10 sec). This type of high-frequency noise response is attributed to a water-hammer type effect that can occur with the release of the applied gas pressure used to depress the fluid column prior to slug test initiation. This portion of the test data (i.e., ≤10 sec) was smoothed using a moving-average scheme to facilitate the overall test analysis. A comparison between the low and high stress tests also exhibits a slight stress dependency, suggesting the presence of a near-well dynamic skin condition. Examination of the individual slug-test responses also indicates an elastic (concave upward) response displayed on the Bouwer and Rice analysis plot in Figure 5.7. The elastic response requires that a late-time analysis to be employed (i.e., the normalized head segment between 0.3 and 0.2) when using the Bouwer and Rice (1976) method, as recommended in Butler (1996, 1998). A comparison of analysis results indicates a similar average, but wider range for K estimates obtained for the Bouwer and Rice method. For the Bouwer and Rice method, estimates for K ranged between 4.69 and 8.68 m/day (average 6.69 m/day), while the type-curve method provided estimates between 6.35 and 7.21 m/day (average 6.78 m/day) for all stress-level tests. K estimates based on the Bouwer and Rice method are generally considered to provide less reliable results (due to inherent analysis restrictions) in comparison to those determined utilizing the type-curve method. Specific storage estimates derived from the type-curve analysis method ranged between 2.5E-3 and 3.5E-3. These values are within the range commonly reported for slug tests exhibiting elastic formation response characteristics (e.g., Butler 1998). Selected examples of analysis plots for this test interval are shown in Figure 5.7.

5.3.2 Zone 2

After reaching a depth of 114.12 m bgs, the packer/well-screen assembly was lowered to the bottom of the borehole and the 0.222 m O.D. drill casing retracted 1.42 m, producing a test/depth interval for Zone 2 of 112.70 to 114.12 m bgs. The borehole geology log (Appendix B; Figure B.3) indicates that the test encompassing interval section of 108.2 to 115.8 m generally consists of a slightly-silty, gravely sand unit, comprised of 10% gravel, 75% sand, and 15% silt.

A series of three pneumatic slug withdrawal tests were conducted between 0953 hours and 1455 hours, (PDT) September 16, 2004. The pneumatic slug tests were conducted by pressurizing the 4-in testing-string casing (I.D. = 0.102 m) used to set the packer/well-screen assembly. The pneumatic tests used applied stress (compressed air) pressures that produced observed fluid-column depressions ranging between 0.3 and 1.0 m for individual tests, which was rapidly released using the wellhead surface valves. Downhole test interval response pressures during testing were monitored using a 0 - 50 psig (0 - 345 kPa) pressure transducer set at a depth of ~82.5 m bgs, while pneumatic gas injection pressure was recorded utilizing a 10 psig (0 - 69 kPa) pressure transducer installed on the surface wellhead assembly. The static depth-to-water for the test interval during testing was 80.41 m bgs.

All slug-test responses indicated a heterogeneous formation behavior, with an "artificial", higher-permeability zone located in proximity to the well screen. This high-permeability inner zone is indicated by a rapid recovery rate at early test times (< 10 sec), which transitions to a slower recovery rate for the surrounding lower permeability aquifer material (exemplified on the Bouwer and Rice response plot in Figure 5.8). A comparison of the normalized, higher- and lower-stress, slug-test responses indicates nearly identical behavior, suggesting that the test interval was developed sufficiently to establish stable skin conditions. Slug withdrawal test SW #1 results were adversely affected by highly variable, pre-test, pneumatic gas pressures associated with gas leakage that occurred within regulator components of the wellhead assembly. The observed leakage conditions during the first test were corrected and more uniform gas injection pressures were maintained for slug withdrawal tests SW #2 and #3. For this reason, hydraulic property estimates for this test interval are based solely on these two tests and are reflective of only the lower permeability outer formation zone.

Slug tests exhibiting heterogeneous formation test response behavior can be analyzed quantitatively using homogeneous formation analysis approaches, as described in Spane and Newcomer 2003). For the homogeneous formation analysis, the type-curve method estimates for K ranged narrowly between 0.35 and 0.38 m/day (average 0.37 m/day) for both stress-level tests. Results obtained from the Bouwer and Rice method provided nearly identical estimates of K, which ranged between 0.36 and 0.38 m/day (average 0.37 m/day) for both stress-level tests. A uniform specific storage estimate of 1.0E-4 was derived from all the type-curve analyses. This value is consistent with slug tests exhibiting elastic formation response characteristics (e.g., Butler 1998). Selected examples of analysis plots for this test interval are shown in Figure 5.8.

5.3.3 Zone 3

Unstable borehole conditions ("heaving/flowing" sands) were encountered after reaching the final drill depth of 130.15 m bgs. With the drilling casing located at a depth of 126.45 m bgs, sand was added to the inside of the drill casing to a depth of 125.43 m bgs to help stabilize the borehole. The packer/well-screen assembly was then lowered to the bottom of the borehole and the 0.222 m O.D. drill casing retracted 2.44 m, producing a theoretical test/depth interval for Zone 3 of 124.01 to 125.43 m bgs. This test interval is located approximately 4 m above the Lower Mud unit of the Ringold Formation. The borehole geology log (Appendix B; Figure B.3) indicates that the test encompassing interval section generally consists of a slightly silty gravely sand unit, comprised of 10% gravel, 70% sand, and 15% silt/clay.

A number of indications suggested that this test interval would likely exhibit low permeability conditions. These indications included:

- proximity of the test interval to the Lower Mud unit
- previous low groundwater production indications during unsuccessful attempts to collect a hydrochemical water sample from this depth interval during borehole advancement (on September 23, 2004), and
- slow recovery of elevated the well fluid-column levels following stabilizing sand emplacement

Because of these low permeability indications, standard pneumatic and slugging rod slug tests were not considered to be viable for characterizing this test interval. Monitoring the recovery of the imposed elevated fluid column during sand emplacement, however, afforded the best opportunity for determining the characteristics of this test zone. To support this characterization effort, accurate time-keeping of physical activities affecting this test were collected. The drill casing was retracted at 0900 hrs, (PDT) September 29, 2004 and the packer inflated to isolate the packer/well-screen assembly within the drill casing at 0940 hrs. Downhole test interval response pressures during testing were monitored using a 0 - 50 psig (0 - 345 kPa) pressure transducer set at a depth of 86.62 m bgs.

Figure 5.9 shows the monitored decline of the imposed elevated fluid-column, following retraction of the drill casing and inflation of the packer/well-screen assembly. Monitoring of the recovery response continued until 0822 hrs, (PDT) September 30, 2004. The static well pressure reading of 7.25 m shown in the figure is based on the assumed static water level for Zone 1 (79.37 m bgs) and the test interval pressure transducer depth setting (86.62 m bgs). Figure 5.10 shows the type-curve analysis results of the slug test injection recovery response. The analysis results provide a hydraulic conductivity estimate of 0.01 m/day for this test/depth interval, which utilizes the "translation" method described in Butler (1998). As indicated in the analysis figure, the type-curve/derivative plot provides a good match over the initial 50% of the recovery response. The deviation of the plot match in later-test times is attributed to the presence of a borehole water-level trend, which may have been induced (given the low test interval permeability) by prior drilling and construction activities. Imposed borehole water-level trends are commonly produced in lower permeability environments by borehole drilling/construction activities. The fluid-column recovery data were not analyzed using the Bouwer and Rice method due to analytical restrictions of its use given the existing test conditions (e.g., high stress/test interval length ratio, proximity to a hydrologic boundary), as noted in Butler (1998).

It should be noted that a subsequent short-duration slug injection and withdrawal test were conducted using slugging rods on September 30, 2004. These tests were performed not for quantitative hydraulic property characterization, but primarily to verify that the inflatable packer system was effective in isolating the test interval/well-screen assembly from the annular zone between the packer test string and drill casing. The observed changes in downhole pressure associated with immersing and withdrawing the slugging rod closing matched the theoretical pressure change within the testing string (i.e., $H_o = 0.458$ m) based on slugging rod volumetric relationship. This indicates that the inflatable packer provided an effective seal and that the observed fluid-column recovery measurements are reflective of changes solely within the testing-string casing cross-sectional area.

6. Conclusions

Overall, test results were obtained for a total of seven test/depth intervals during the drilling and borehole advancement of three OU UP-1 wells: 299-W19-48, 699-30-66 and 699-36-70B. The results indicate that multiple, stress-level slug testing methods were successful in providing detailed information concerning the distribution of hydraulic conductivity at these Hanford Site locations. These characterization results are consistent with and complement previous and on-going drill-and-test characterization programs at surrounding 200-West and -East Area locations.

Results from the UP-1 well slug tests provide hydraulic characterization information only for the Ringold Formation (Unit 5), for individual test/depth intervals generally sited within the upper, middle, and lower sections of the unconfined aquifer. All test/depth intervals exhibit exponential-decay (over-damped) slug test response behavior. This type of slug test response pattern is indicative of test intervals having low to intermediate permeability conditions. Analysis of the slug test results indicate a wide-range in the calculated average, test interval hydraulic conductivity (Table 5.2), with estimates ranging between 0.01 and 6.78 m/day. The hydraulic conductivity estimates were derived for test interval sections that ranged from 1.42 to 2.84 m in length (Table 5.1).

For areal comparison purposes, Figure 6.1 shows a statistical summary for hydraulic conductivity based on recent slug test results (i.e., ≥FY1999) of the Ringold Formation, from thirty 200-West Area RCRA monitor wells (as reported in Spane et al. (2001a, 2001b, 2002, 2003) and Spane and Newcomer (2003)). As indicated in the figure, estimates of hydraulic conductivity for these 200-West Area Ringold Formation tests ranged between 0.07 to 28.1 m/day, with a geometric mean of 3.08 m/day and a standard deviation of ±7.70 m/day (note: based on type-curve slug test analysis results). It should be noted that these previously reported values are reflective of the upper 10 m of the unconfined aquifer (i.e., Ringold Formation). For a more representative comparison, test zones located within the upper 10 m of the unconfined aquifer (i.e., Zone 1; Table 5.2) at the three UP-1 test wells exhibited hydraulic conductivity estimates (2.73, 4.44, and 6.78 m/day; type-curve analysis results) that fall fairly close to the reported 200-West Area geometric mean value (3.08 m/day).

The vertical hydraulic conductivity profiles for UP-1 wells 699-30-66 and 699-36-70B are shown graphically in Figures 6.2 and 6.3, respectively. As indicated, the limited vertical profile information suggests a decrease in hydraulic conductivity with depth at these well site locations within the Ringold Formation. Because of the limited number of depth intervals tested at these locations, it is not known whether this apparent vertical trend is uniform, throughout the entire Ringold Formation section. More extensive, on-going (unpublished) drill-and-test characterization programs for boreholes located within the WMA S-SX and T areas (located generally west to northwest of the UP-1 test sites), however, do not exhibit similar decreasing permeability with depth patterns.

It should be noted that hydraulic property values reported in this letter report are determined from the slug test characterization that are believed to be representative of conditions in proximity to the individual well site locations. It is difficult to assess the representative scale or *radius of investigation* that the slug test characterization results represent. However based on theoretical relationships presented in Guyonnet et al. (1993), slug test results are likely more representative of formation conditions within ~3 m of test site. This scale-of-investigation estimate, however, is highly uncertain and provided only for qualitative discussion purposes. Previous Hanford Site hydraulic property comparisons of slug tests with larger scale-of-investigation pumping test results (reported in Spane et al. 2001a, 2001b, 2002, 2003) and Spane and Newcomer (2003) have indicated a fairly close agreement (i.e., within a factor of 2). This suggests that a larger scale may be representative for the slug test results.

7. References

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Table 5.1. Slug-Test Characteristics for Selected Test/Depth Intervals at Operable Unit UP-1 Test Wells: 299-W19-48, 699-30-66, and 699-36-70B.

Test Well	Test Zone	Test Parameters				Diagnostic Slug Test Response Model	Hydrogeologic Unit Tested [a]
		Test Date	Slug Tests #	Depth to Water, m bgs	Depth/Test Interval , m bgs		
299-W19-48	Zone 1	12/2/04	4	77.54	86.53 - 89.37 (2.84)	Exponential Decay (over-damped)	Ringold Formation (Unit 5)
699-30-66	Zone 1	9/14/04	4	77.43	82.77 - 84.19 (1.42)	Exponential Decay (over-damped)	Ringold Formation (Unit 5)
	Zone 2	10/1/04	3	~77.0	105.72 - 107.14 (1.42)	Exponential Decay (over-damped)	Ringold Formation (Unit 5)
	Zone 3	10/14 -15/04	6	77.75	121.58 - 123.00 (1.42)	Exponential Decay (over-damped)	Ringold Formation (Unit 5)
699-36-70B	Zone 1	8/19/04	3	79.37	81.91 - 83.33 (1.42)	Exponential Decay (over-damped)	Ringold Formation (Unit 5)
	Zone 2	9/16/04	3	~80.41	112.58 - 114.12 (1.42)	Exponential Decay (over-damped)	Ringold Formation (Unit 5)
	Zone 3	9/29-30/04	3	-	124.11 - 125.43 (1.42)	Exponential Decay (over-damped)	Ringold Formation (Unit 5)

Note: For all test wells, r_c = 0.051 meter; r_w ranged between 0.111 and 0.149 meters. The ~ symbol used in combination with depth-to-water measurements indicates that the value is not considered to reflect static conditions at the time of testing

(a) Unit number in parentheses indicates the relevant groundwater-flow model layer, as described in Thorne, et al., 1993.

Table 5.2 Slug-Test Analysis Results

Test Well	Test Zone	Bouwer and Rice Analysis Method	Type-Curve Analysis Method		Test History Matching/ Type-Curve Analysis Method[b]
		Horizontal Hydraulic Conductivity, K_h,[a] (m/day)	Horizontal Hydraulic Conductivity, K_h,[a] (m/day)	Specific Storage, S_s (m^{-1})	Horizontal Hydraulic Conductivity, K_h,[a] (m/day)
299-W19-48	Zone 1	3.78 - 4.18 (3.99)	4.19 - 4.58 (4.44)	5.0E-6 - 1.0E-5	NA
699-30-66	Zone 1	1.61 - 3.14 (2.38)	1.90 - 3.54 (2.73)	5.0E-6 - 3.0E-5	NA
	Zone 2	NA	NA	NA	0.08
	Zone 3	NA	NA	NA	0.20
699-36-70B	Zone 1	4.69 - 8.68 (6.69)	6.35 - 7.21 (6.78)	2.5E-3 - 3.5E-3	NA
	Zone 2	0.36 - 0.38 (0.37)	0.35 - 0.38 (0.37)	1.0E-4	NA
	Zone 3	NA	0.01	8.0E-4	NA

Number in parentheses is the average value.

NA = method is either not applicable or not applied

(a) Assumed to be uniform within the well-screen test section. For tests exhibiting a heterogeneous formation response, only outer zone analysis results are considered representative of in-situ formation conditions

(b) Because of test interval low-permeability conditions, insufficient test response recovery (i.e., ≤10%) was collected for these tests to permit use of standard analytical methods. For these tests, a test history matching/type-curve analysis approach was applied

Figure 1.1. Location Map Showing OU UP-1 Test Well Sites

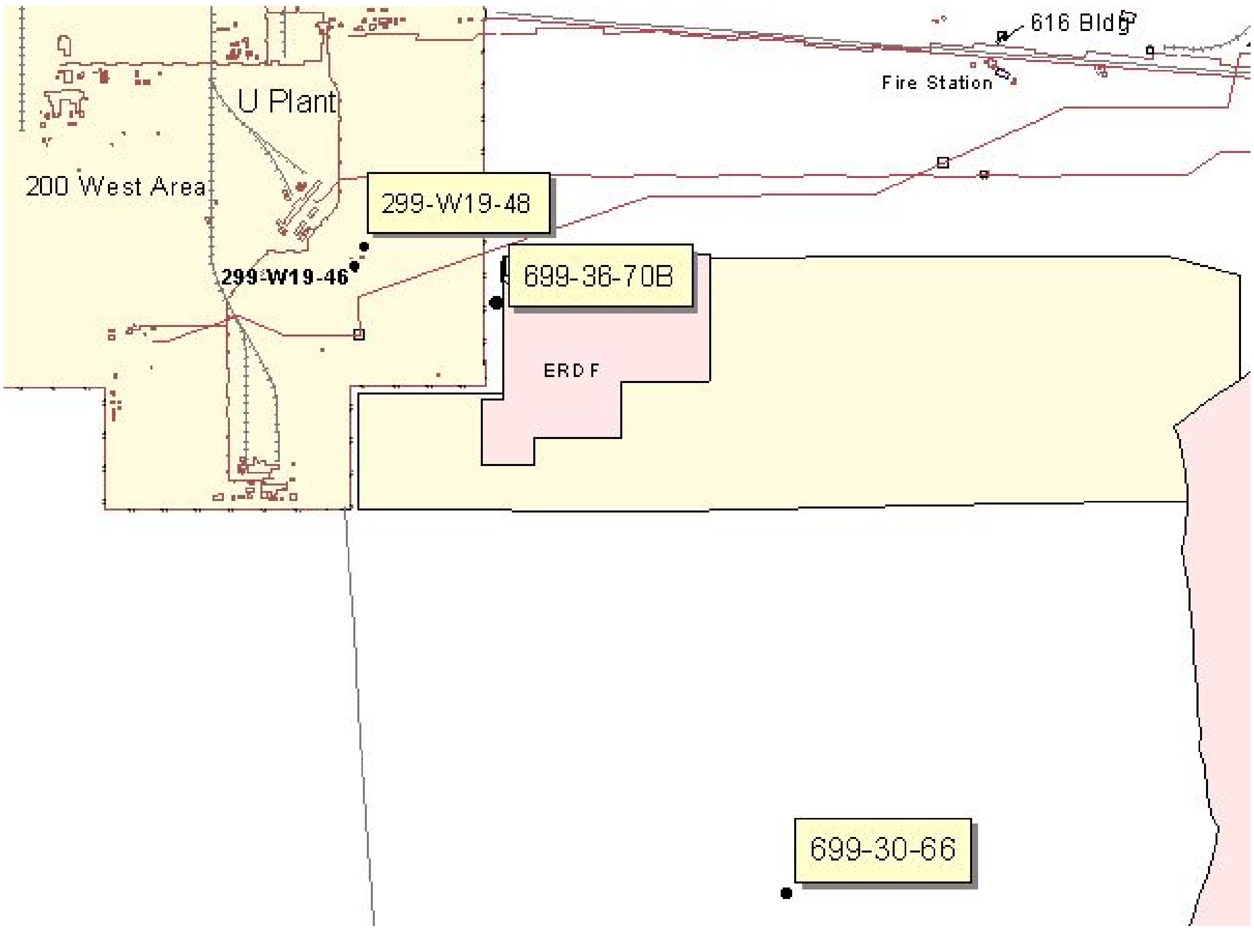


Figure 3.1. General Pneumatic Slug Test System Configuration

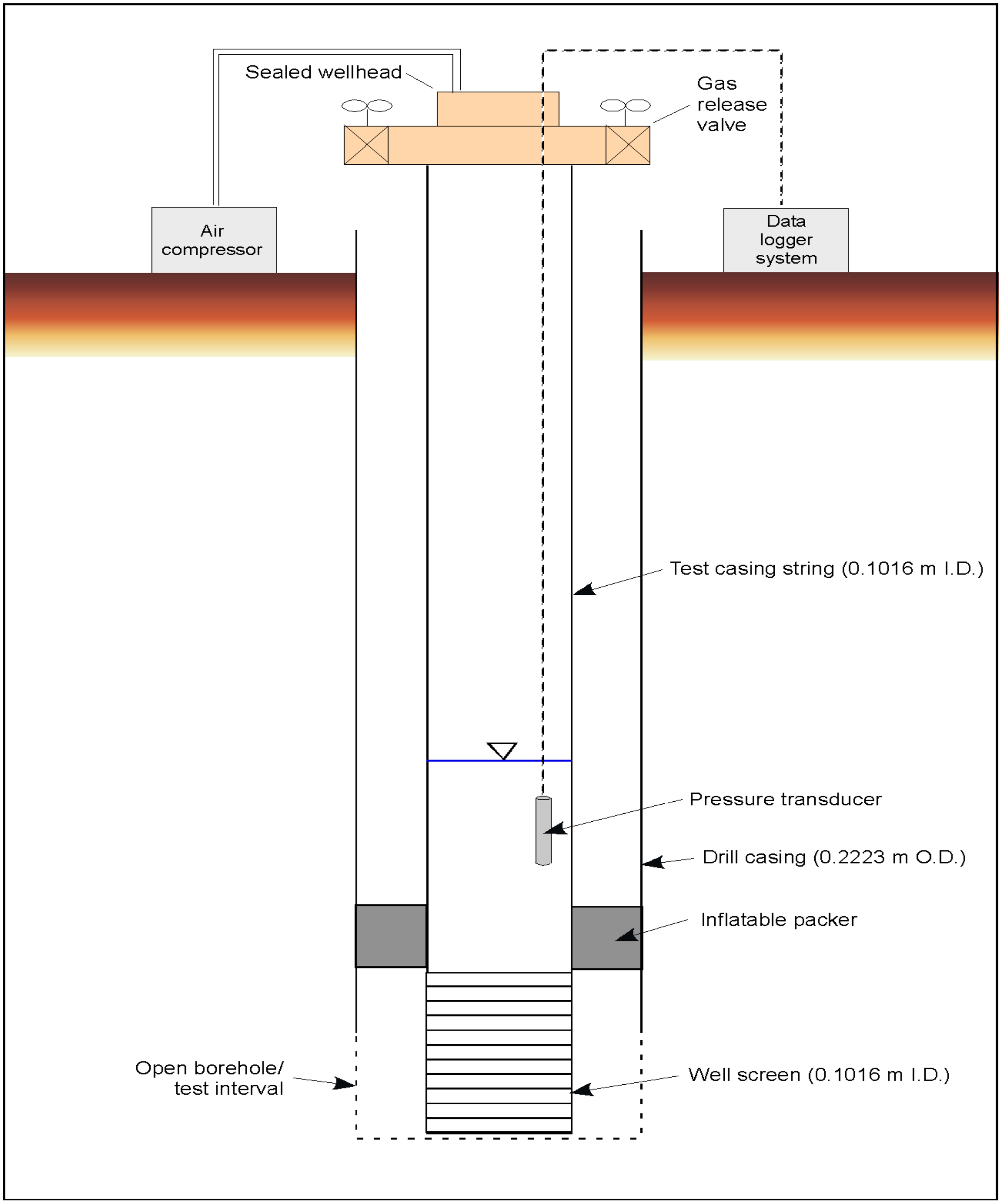


Figure 3.2. Packer/Well-Screen Assembly Dimensions: Smaller Test System

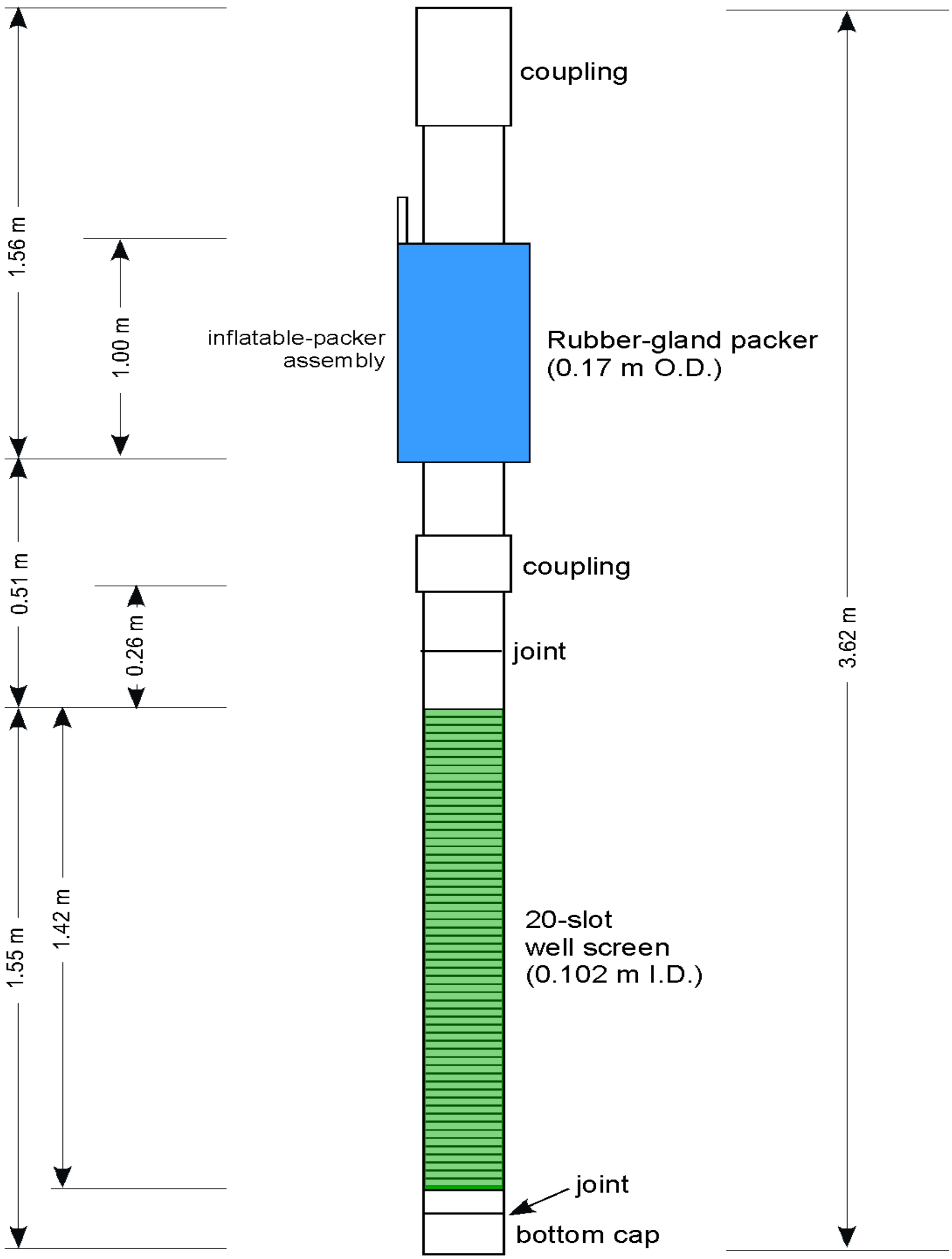


Figure 3.3. Packer/Well-Screen Assembly Dimensions: Larger Test System

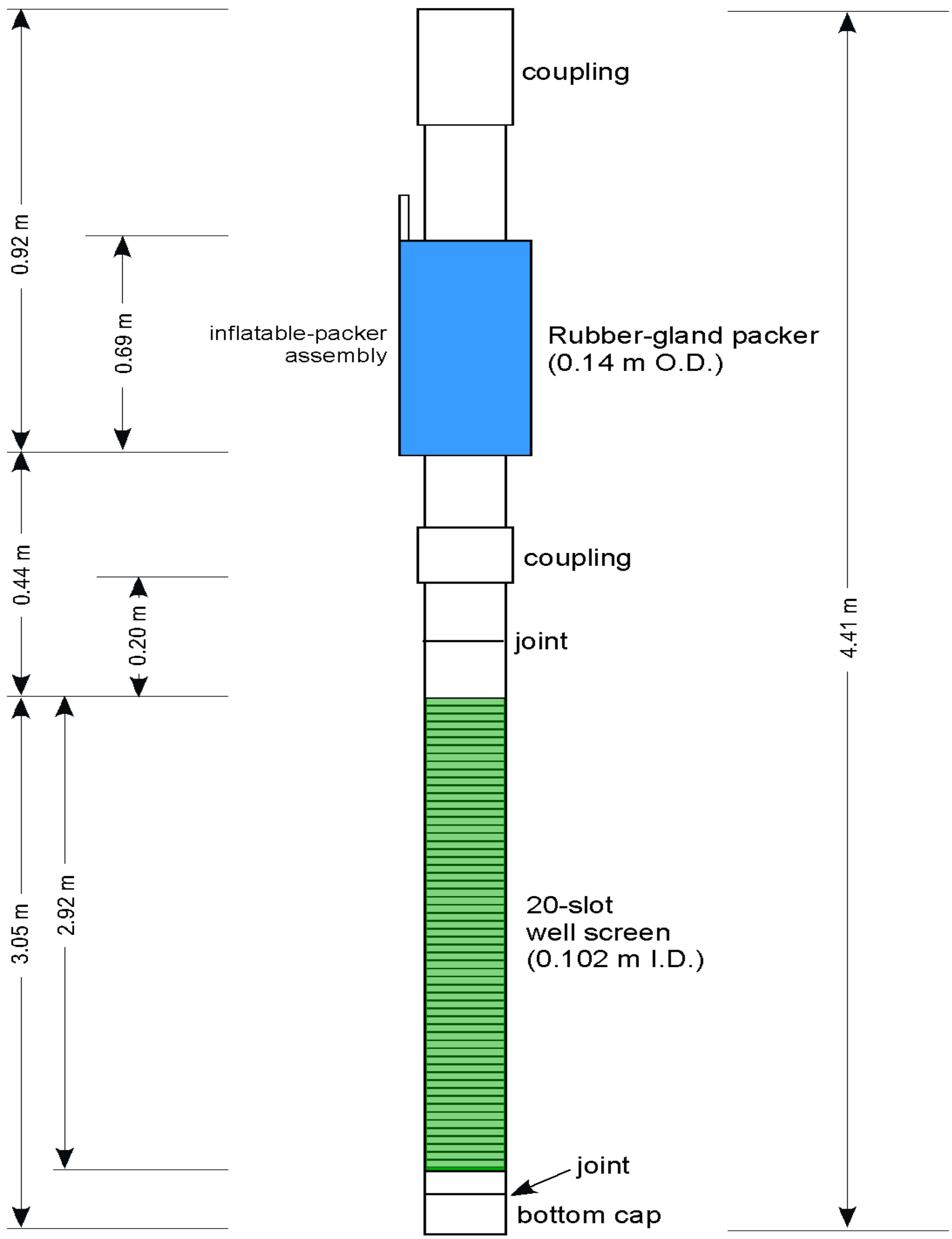


Figure 4.1. Diagnostic Slug Test Response (taken from Spane et al. (2003)

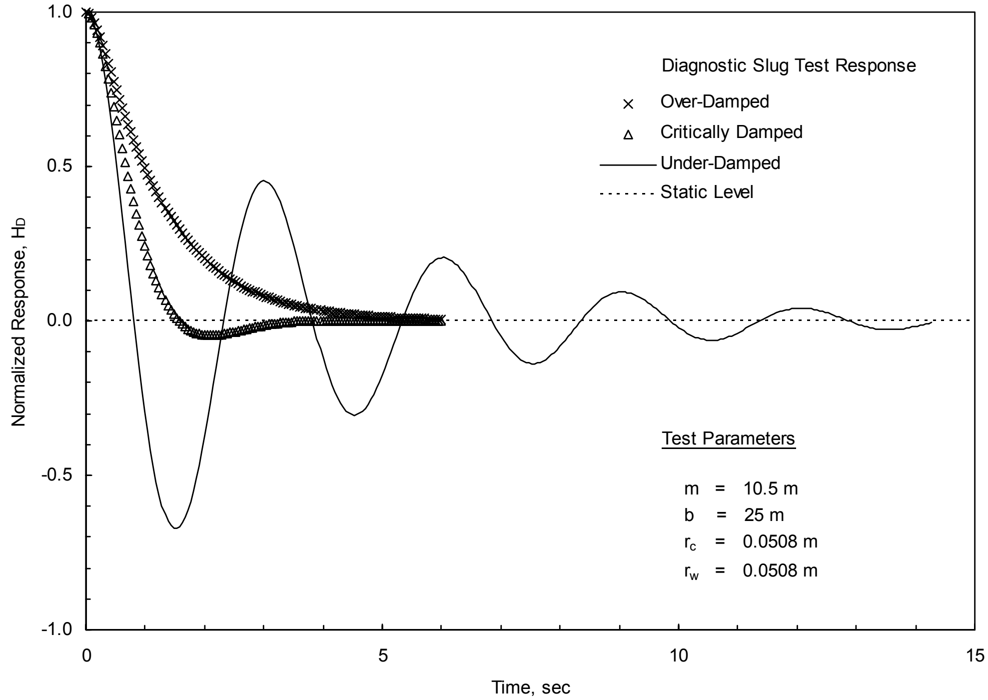


Figure 4.2 Predicted Over-Damped Slug Test Response as a Function of Test Interval Hydraulic Conductivity (taken from Spane 2003)

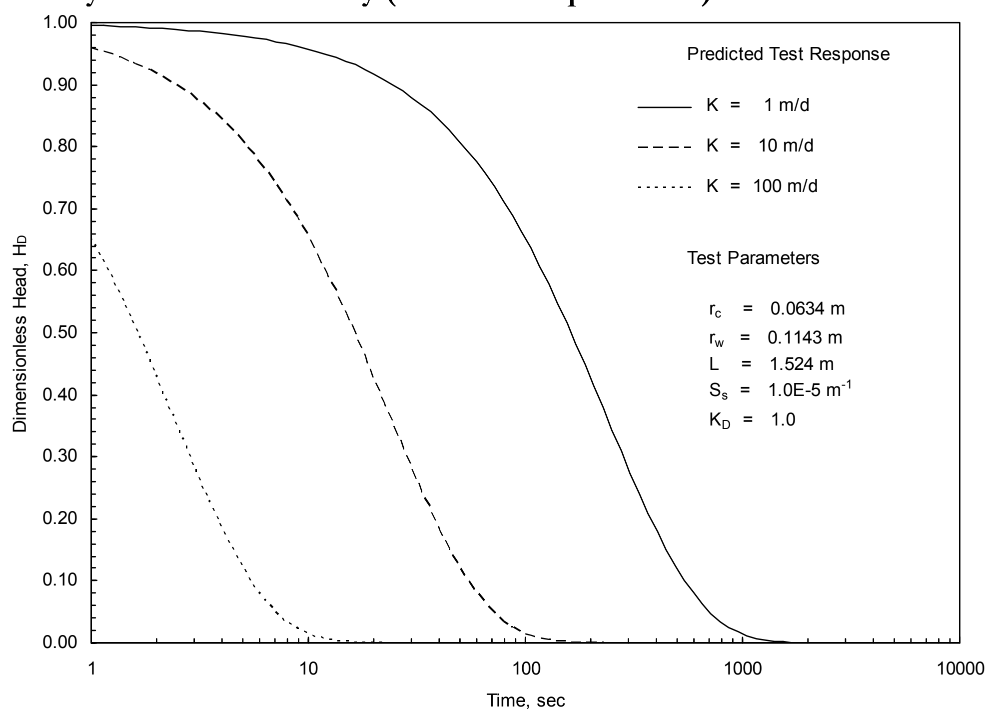


Figure 5.1 Selected Slug Test Analysis Plots for Well 299-W19-48 (Bouwer and Rice Method [top} and Type-Curve Method {bottom})

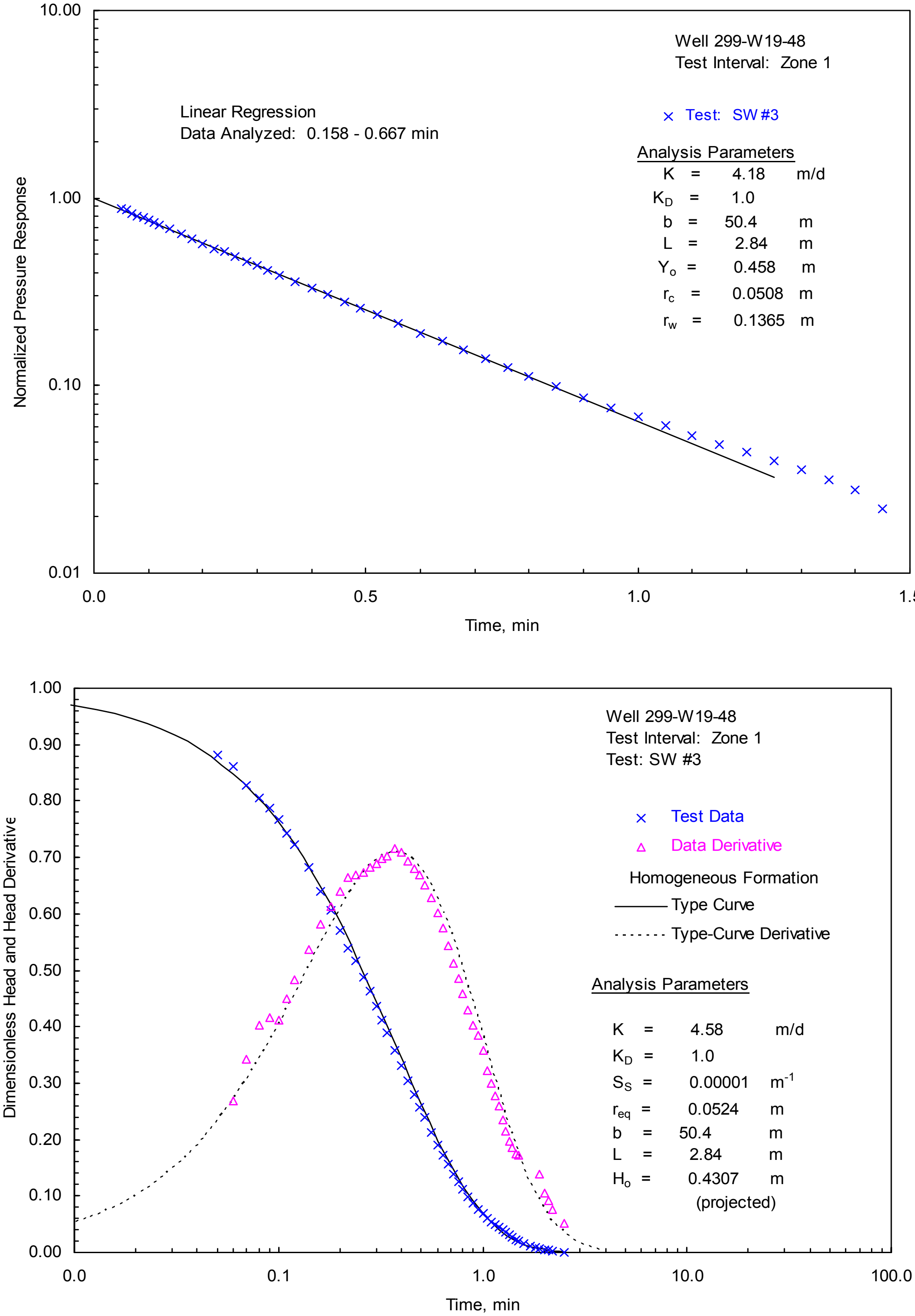
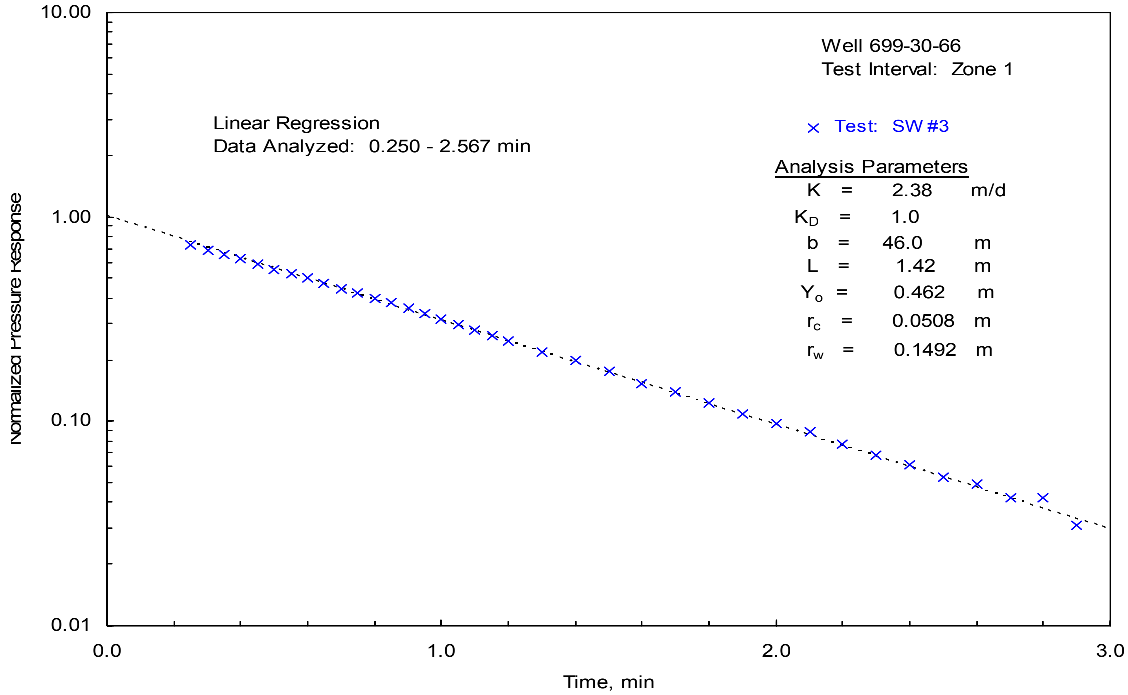


Figure 5.2 Selected Slug Test Analysis Plots for Well 699-30-68: Test Interval Zone 1 (Bouwer and Rice Method [top} and Type-Curve Method {bottom})



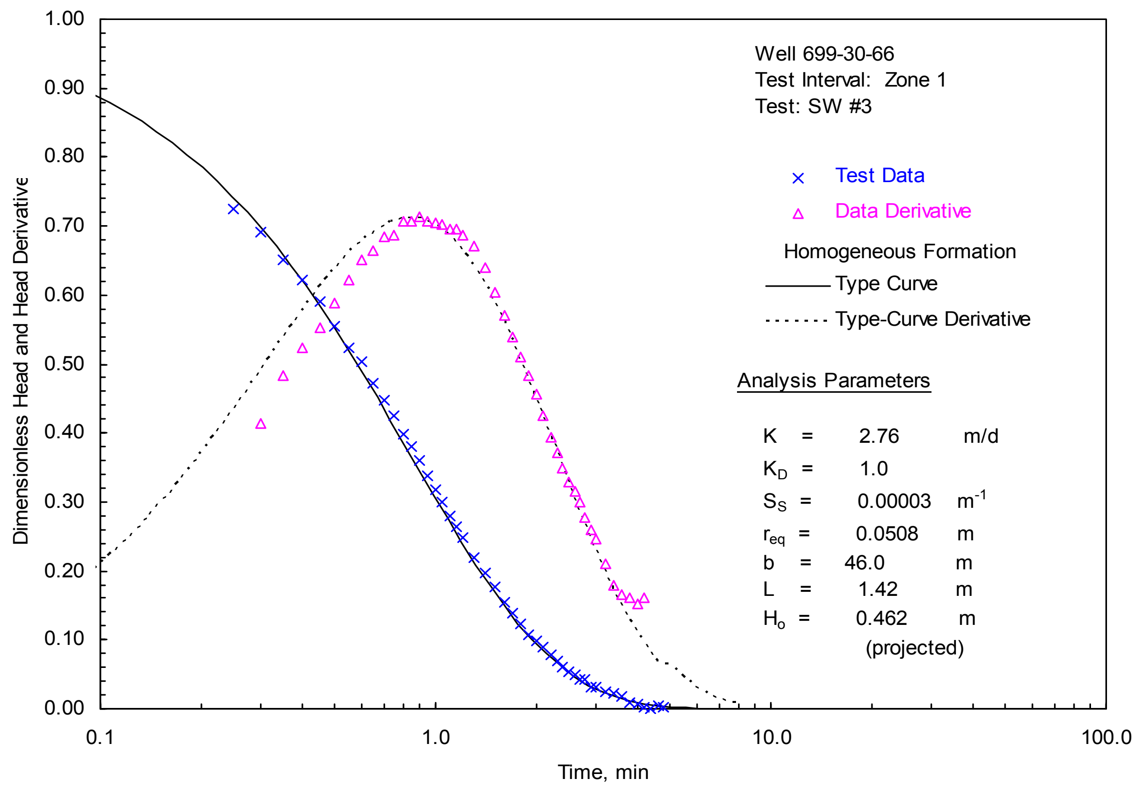


Figure 5.3 Slug Test SW #3 Response and Test History Match for Well 699-30-68: Test Interval Zone 2

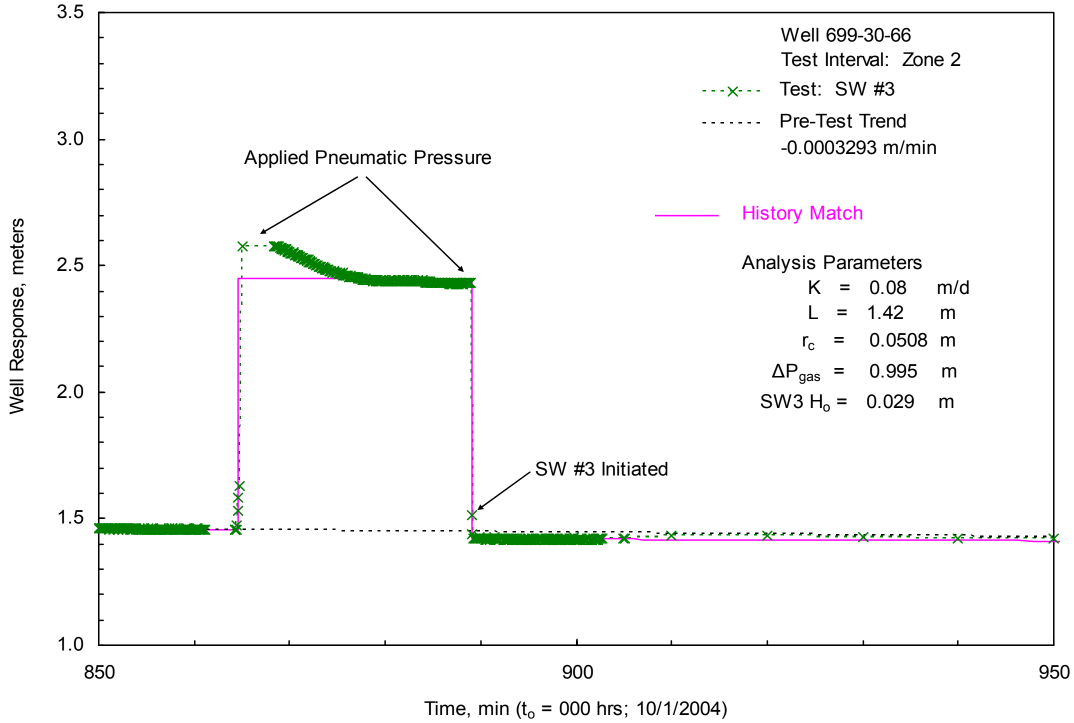


Figure 5.4 Slug Test SW #3 Response and Test History Match for Well 699-30-68 (Test Interval Zone 2): Sensitivity to Varying K Values (0.08, 0.5, 3.0 m/day)

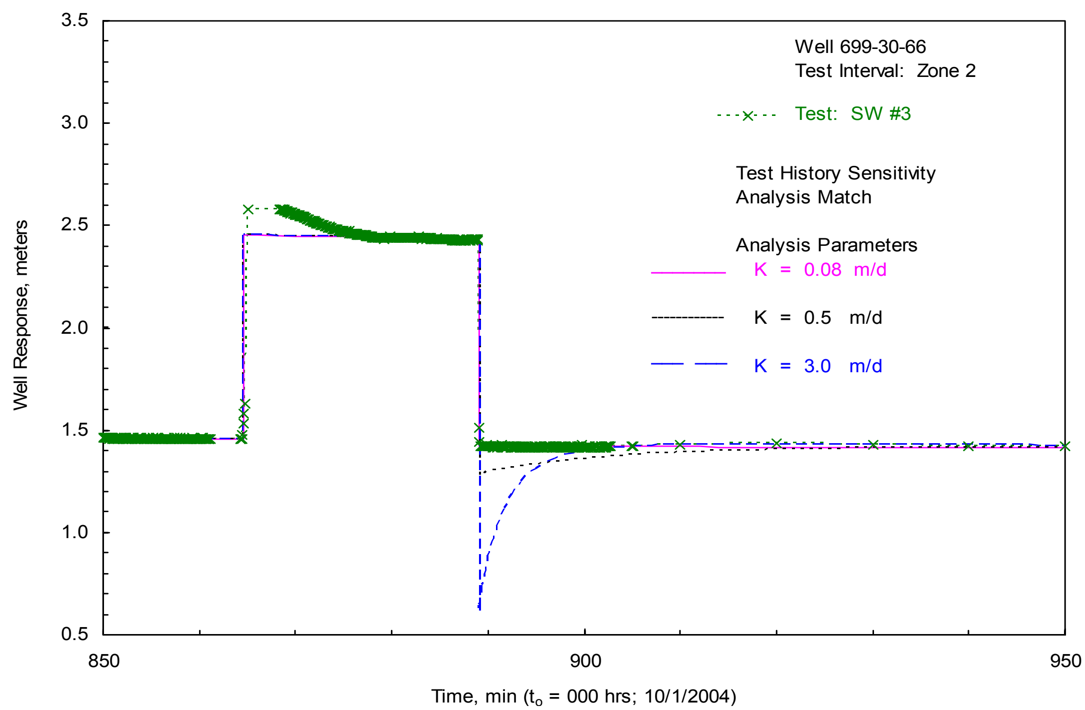


Figure 5.5 Slug Test SI #1 and SW #1 Response and Test History Match for Well 699-30-68: Test Interval Zone 3

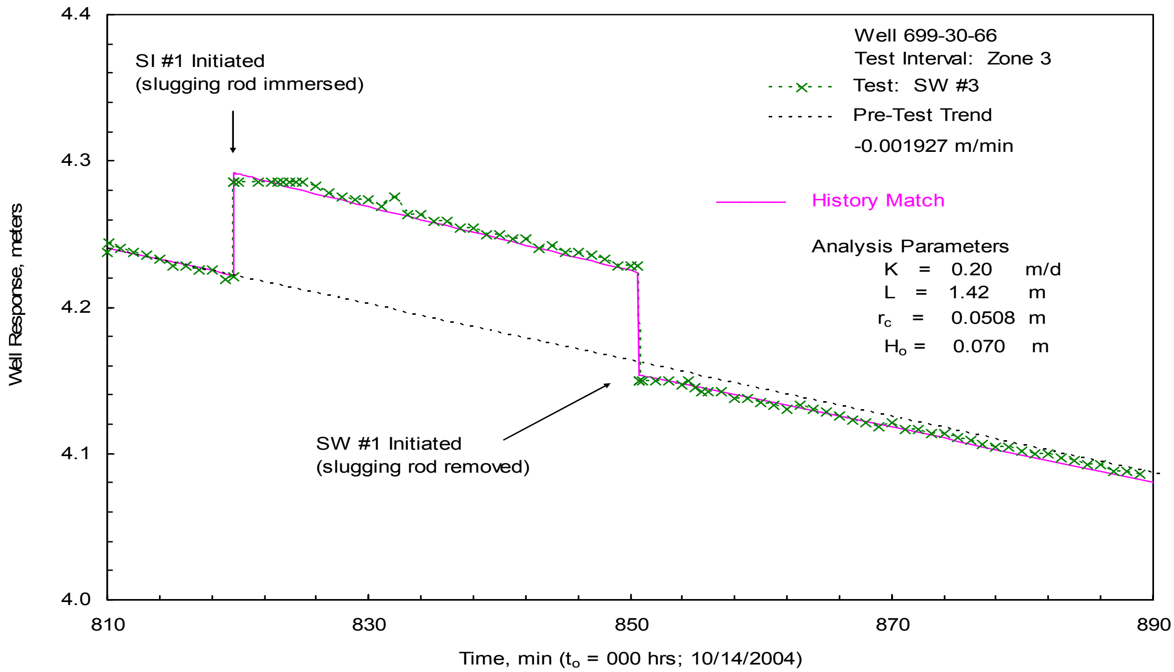


Figure 5.6 Slug Test SI #1 and SW #1 Response and Test History Match for Well 699-30-68 (Test Interval Zone 3): Sensitivity to Varying K Values (0.2, 1.0, 5.0 m/day)

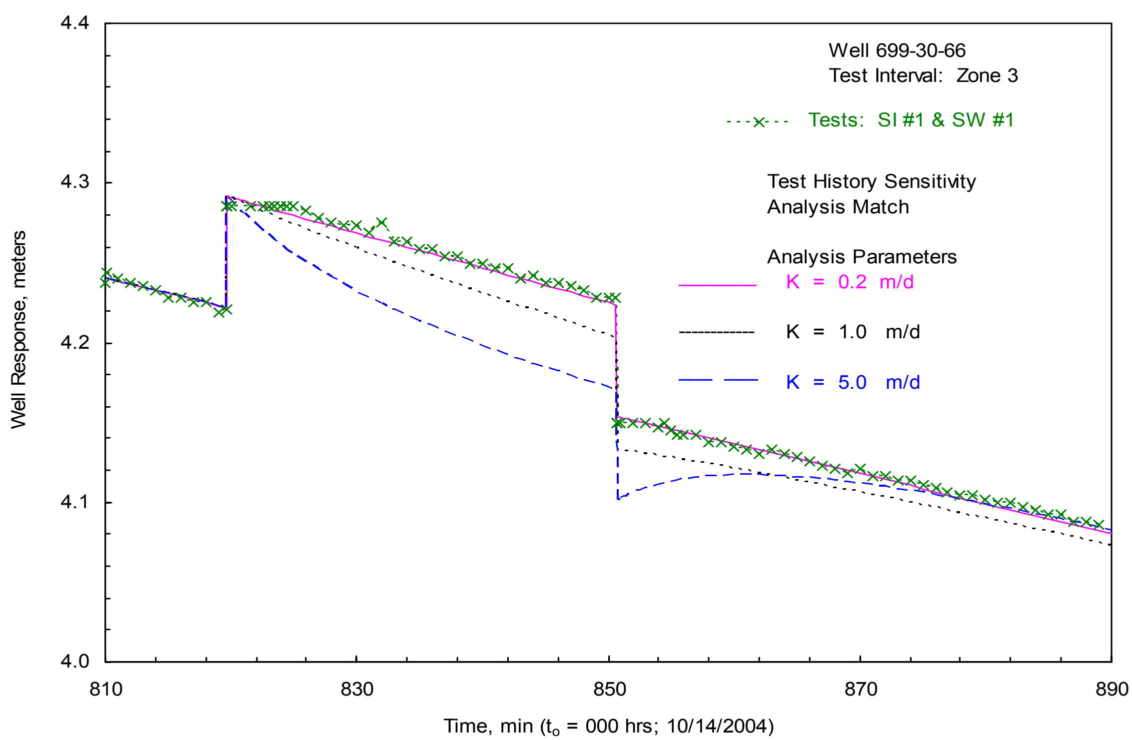
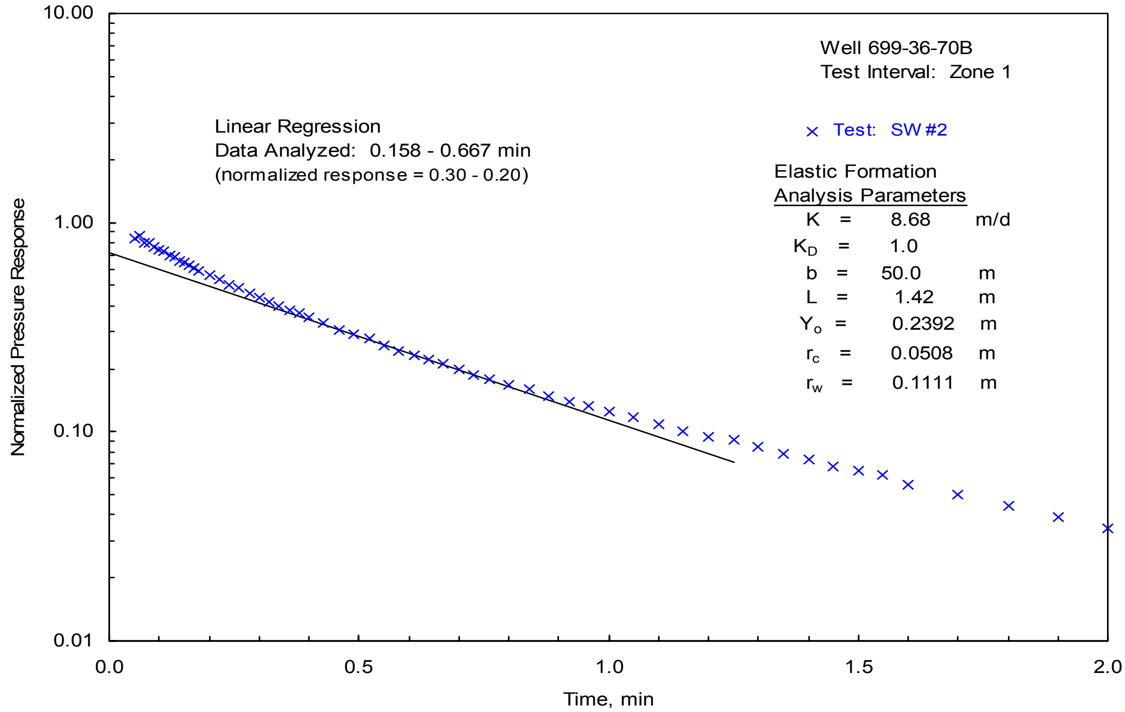


Figure 5.7 Selected Slug Test Analysis Plots for Well 699-36-70B: Test Interval Zone 1 (Bouwer and Rice Method [top} and Type-Curve Method {bottom})



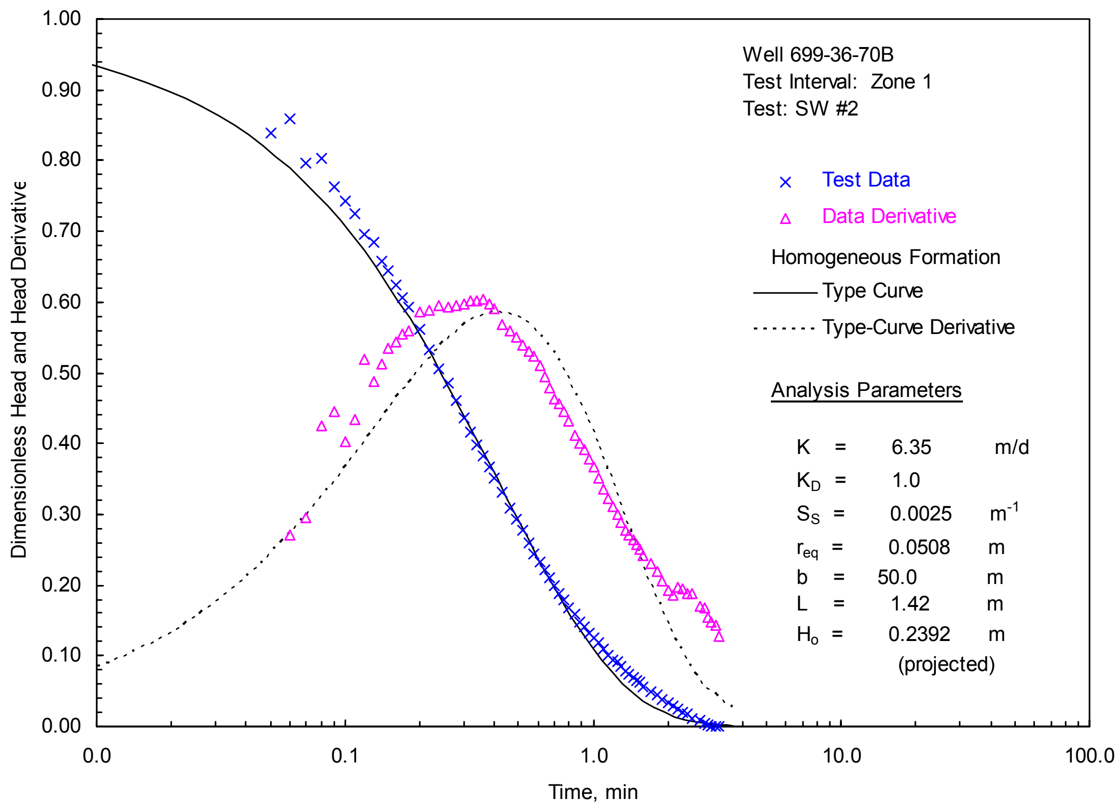
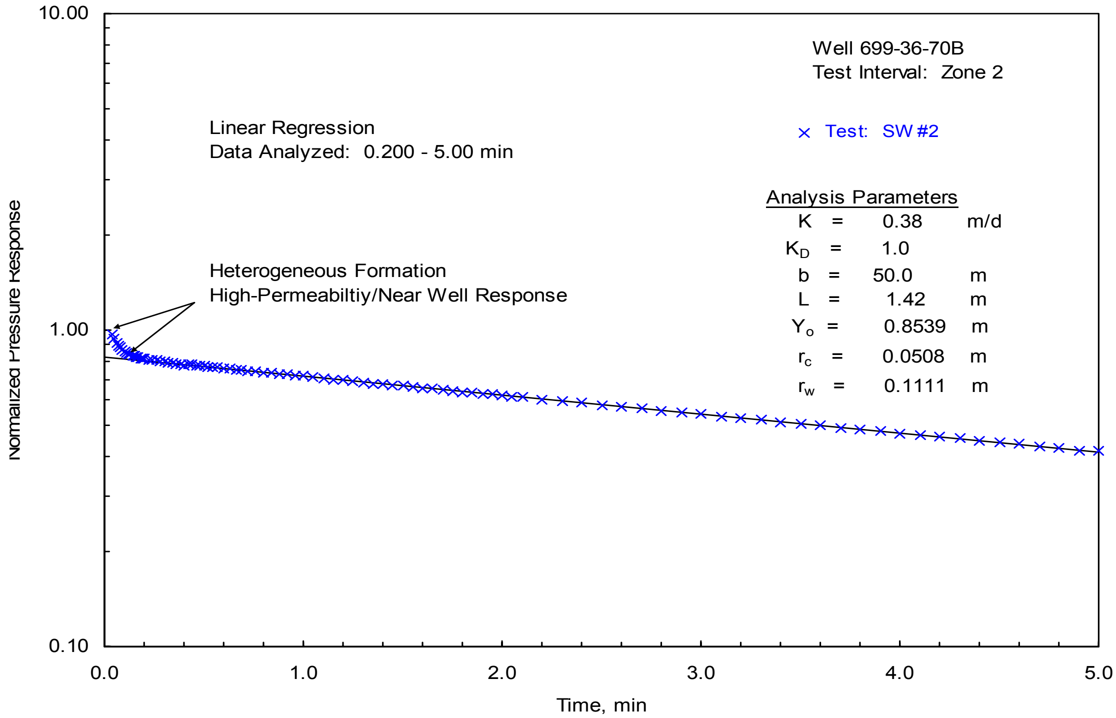


Figure 5.8 Selected Slug Test Analysis Plots for Well 699-36-70B: Test Interval Zone 2 (Bouwer and Rice Method [top} and Type-Curve Method {bottom})



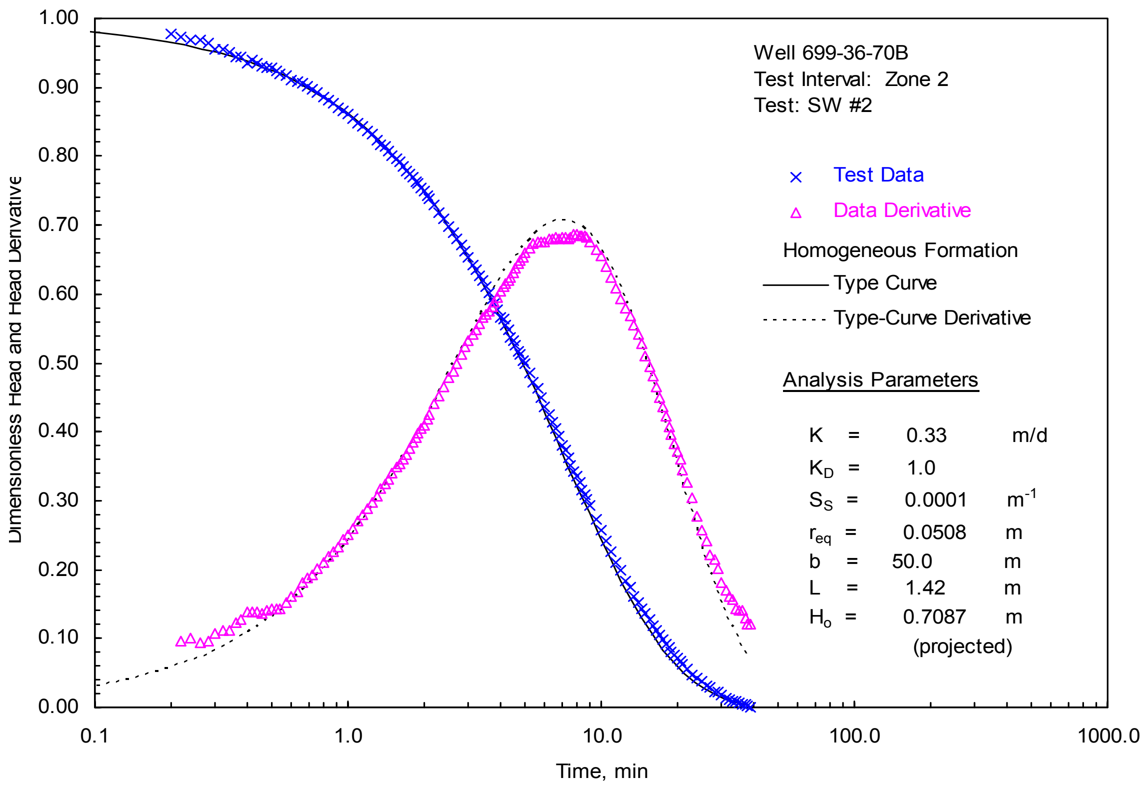


Figure 5.9 Fluid-Column Recovery for Well 699-36-70B: Test Interval Zone 3

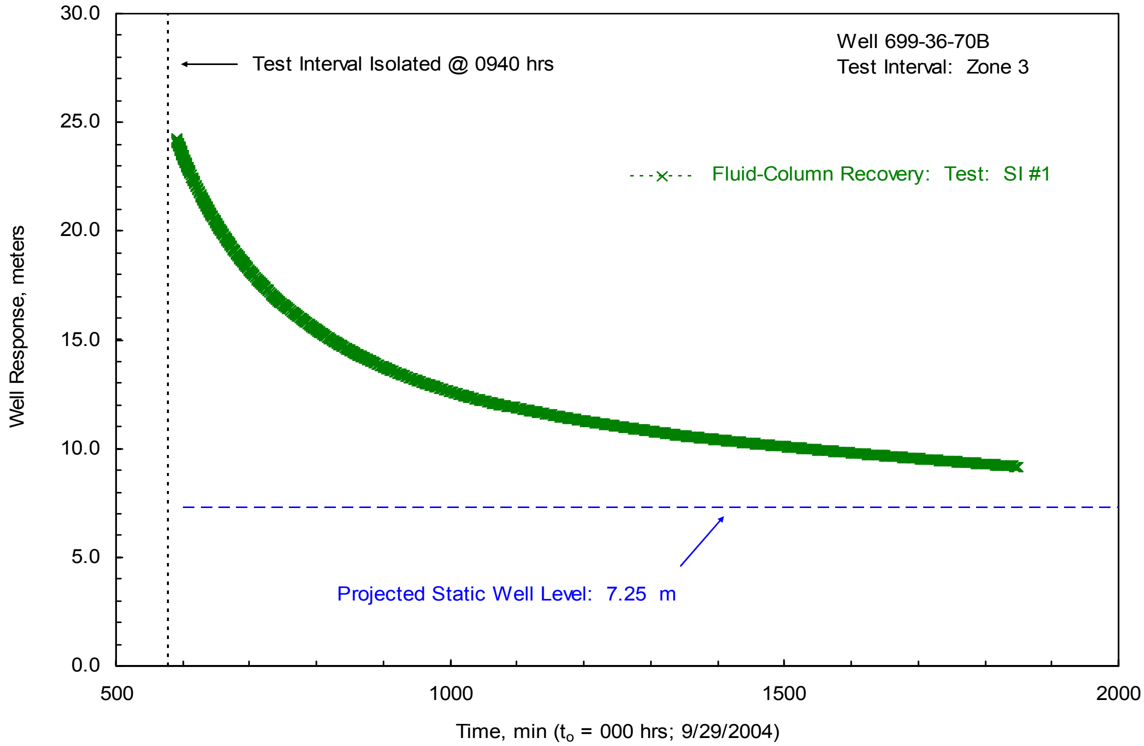


Figure 5.10 Slug Test Type-Curve Analysis Plot for Well 699-36-70B: Test Interval Zone 3

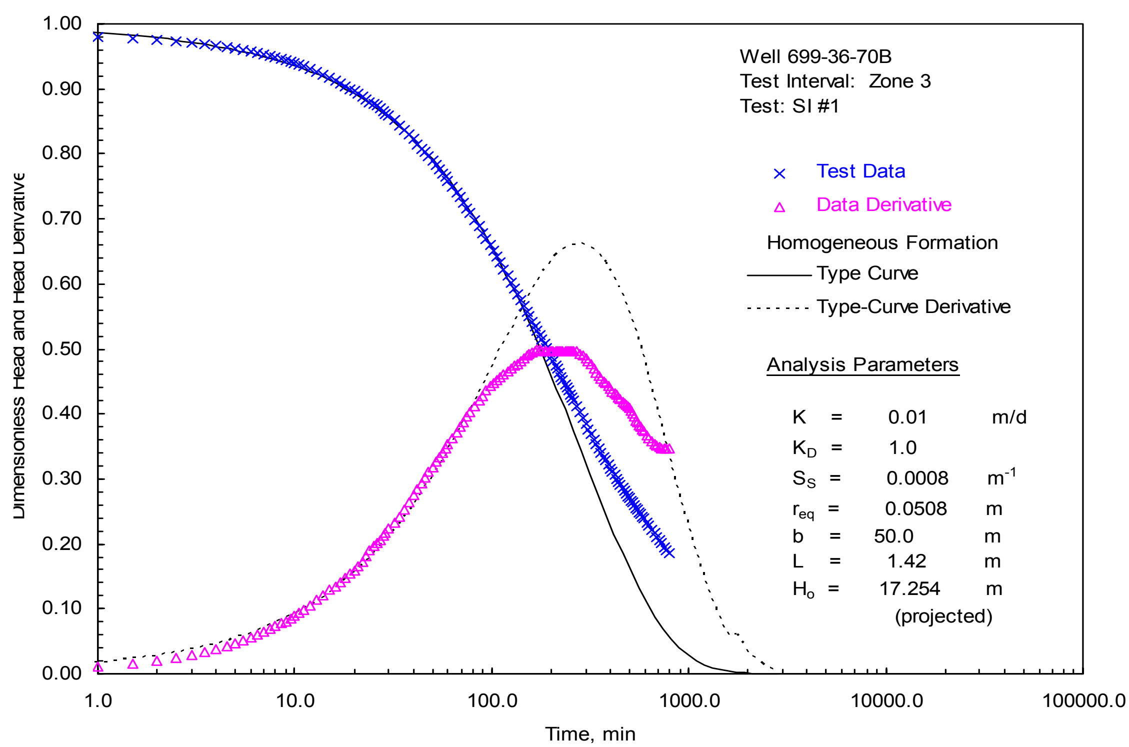


Figure 6.1 Hydraulic Conductivity Histogram for Recently Tested 200-West Area Wells

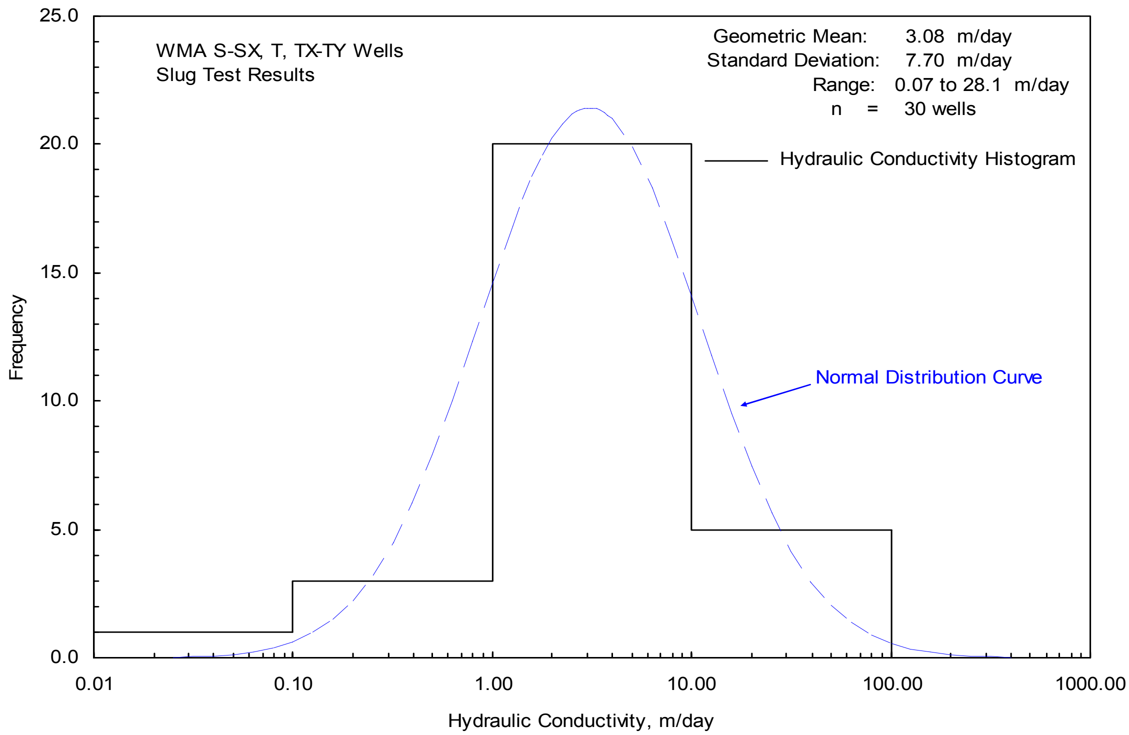


Figure 6.2 Hydraulic Conductivity Profile for UP-1 Well 699-30-66 Test/Depth Intervals

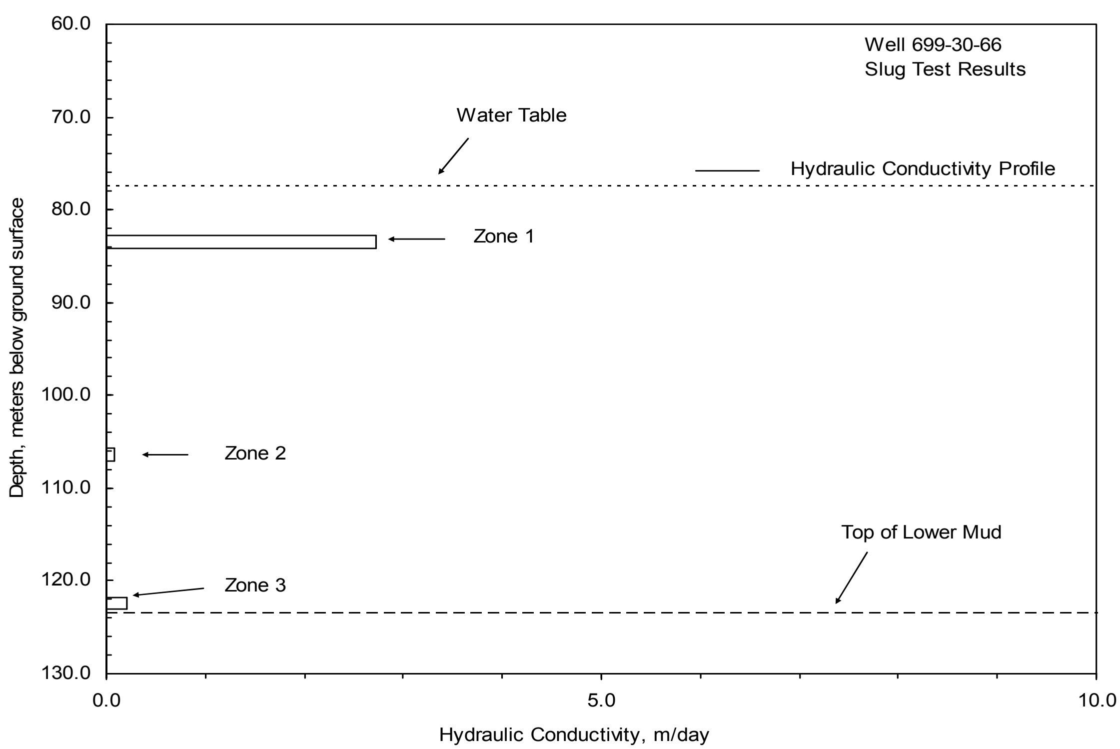
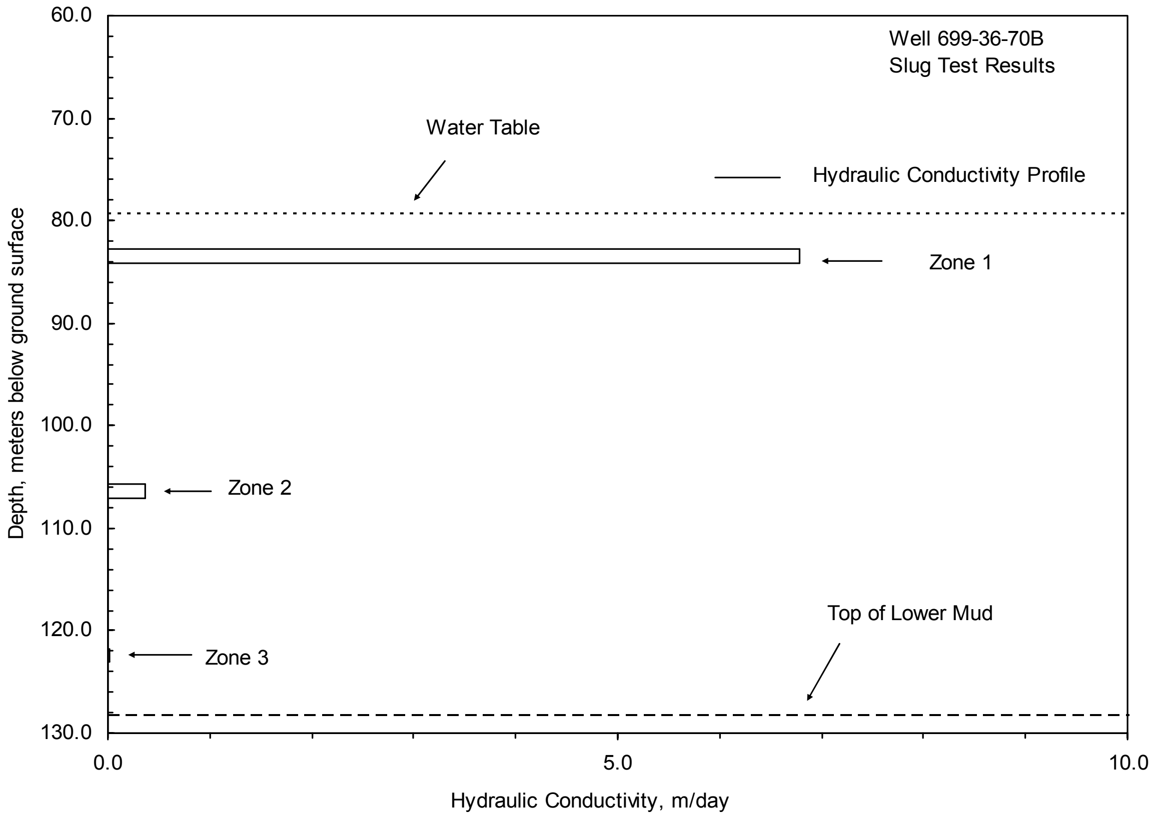


Figure 6.3. Hydraulic Conductivity Profile for UP-1 Well 699-36-70B Test/Depth Intervals



APPENDIX A. MISCELLANEOUS TEST EQUIPMENT PICTURES

Figure A.1 Inflatable Packer and Well-Screen (2.92 m) Assembly Shown on Pipe Rack

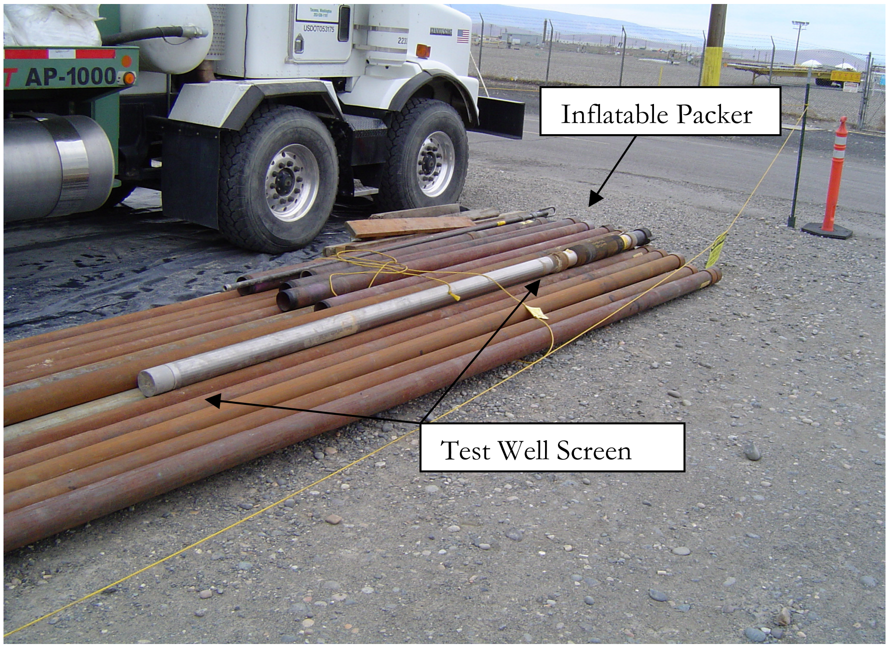
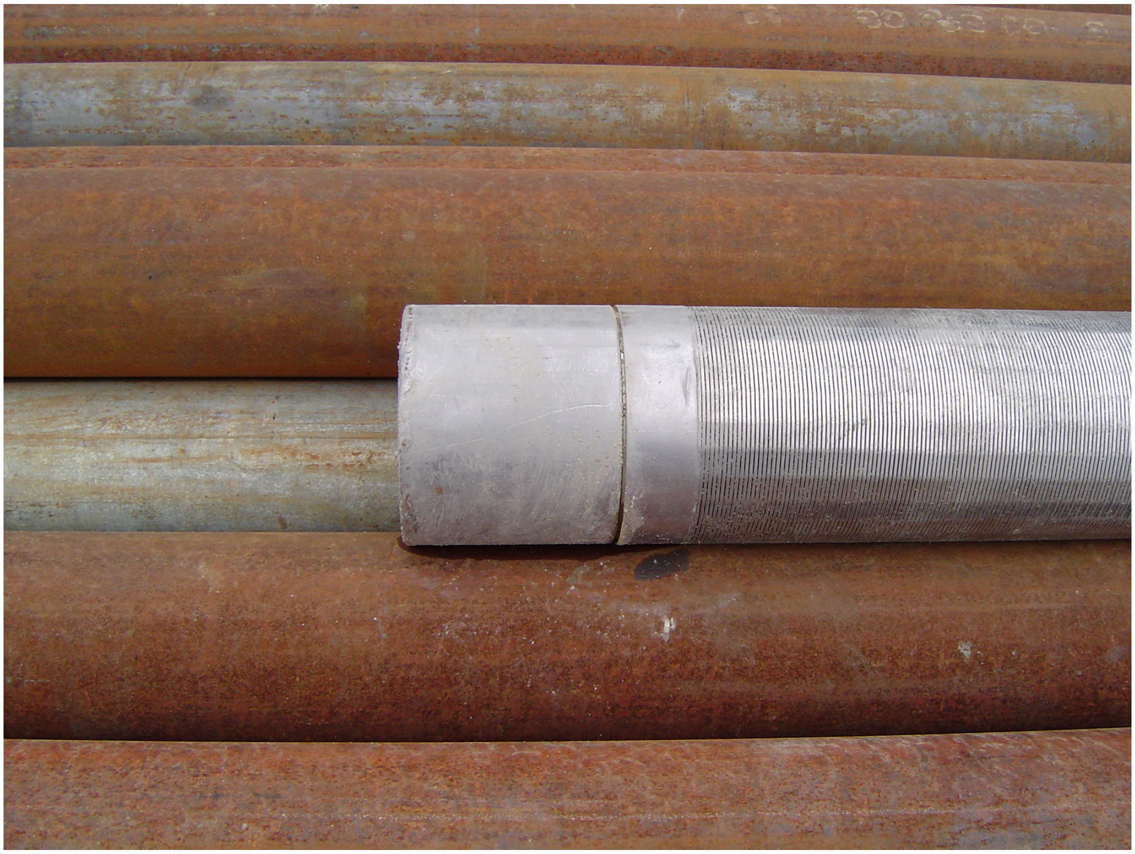


Figure A.2 Closer View of Packer/Well-Screen

Figure A.3 Close-up View of Test Well Screen and Bottom-End Cap



APPENDIX B. SELECTED BOREHOLE LOGS

Figure B.1 Well 299-W19-48

Figure B.2 Well 699-30-66

Figure B.3 Well 699-36-70B

Figure B.1 Selected Borehole Log for Well 299-W19-48

BOREHOLE LOG

Page 8 of 11
Date 11/22/04

Well ID C4300	Well Name 299-W19-48	Location 16th & BELOIT 1700 W	
Project 200-UP-1 GW CERCLA		Reference Measuring Point GS	

Depth (Ft)	Sample Type No	Sample Blows Recovery	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
280	Archive DB		280' - 420.1' slightly silty sandy gravel (msG) Gravel 60-70% Sand 35-25% silt ≈5% Sand ~~Gravel~~: 60% vcse, 30% cse, 10% fn-med Gravel: 50% fn-med pebbles, 50 cse-vcse Mod sorted, 15% basalt 85 qtz, 5/3 brn, wet, SA-A, no Rxn.	280' sx @ 0854 11/24/04
285	Archive	Split spoon H₂O		285' sx 1106 11/24/04 285'-287' - Split spoon sample. 290 H2O sx.
290	Archive	Aquifer	290' S 290'	290' for SST/Aquifer. @ 1541 11/24/04.
295	Archive		285' → 287' Split Spoon Sample Water sample at 290'	295' @ 12/1/04 @ 0722
300	Archive			300' Sx @ 12/7/04 @ 0720 RCT @ 0852 12/7/04 AM RCT @ 1308 12/7/04 PM
305	Archive			305' @ 1340 12/7/04 ND IH @ 1413 12/7/04 ND
310	Archive			310' @ 0645 12/8/04 0910 IH AM - ND 1006 RCT AM - ND
315	Archive			315' @ 0829 12/8/04
320	Archive			320' @ 1102 12/8/04 1250 IH - PM - ND 1422 RCT - PM - ND

Reported By C TRICE		Reviewed By L. D. Walker	
Title GEOLOGIST		Title Geologist	
Signature C Trice	Date 12/1/04	Signature [signature]	Date 1/7/05

A-6003-642 (03/03)

Figure B.2 Selected Borehole Log for Well 699-30-66

BOREHOLE LOG

Page 2 of 11
Date: 8/31/04

Well ID: C4298 | Well Name: 699-30-66 | Location: 2.5 miles of ECOLOGY

Project: 2004 CERCLA Drilling | Reference Measuring Point: Ground Surface

Depth (Ft.)	Sample: Type No.	Sample: Blows Recovery	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	Archive		Sand, slightly coarser, w/ ~25% m	AR @ 1345hrs
			grains and v. sporadic ½" or < gravel (<1%)	
			moderately to well cemented sand, CaCO3.	few 1"x½"x1" gravels or
			The formation is "getting tighter"	smaller @ 242'-244'
245	Archive			AR @ 1315hrs
	Drive Barrel			248' - end of day shift
			Hanford/Ringold contact	
		HANFORD GRAVEL DOMINANT	248.5-292': Sandy Gravel. 65% G, 30% S,	RCT - AM Survey < Bkgd
250	Archive		5% m. Gravel max size is 4"x4"x3", with	" PM " , < Bkgd
			majority about 1" in size; G is 35% f, 20% m	max size up to
			and 45% Cr - which contains the pebbles	> 8"x6"x5"
			and Cobbles. Sand is 20% f, 45% m	Cobbles and Boulders -
			and 35% Cr. The unit is ~45% basalt,	IH Tech - AM Survey - Nothing
			with both sands and Gravels being SA-SR. It	" PM " " "
255	Archive	254.45	is dry, poorly sorted, and reacts sl-mod. to HCl.	Difficult drilling, hole
	Split S.		Unit is silty-sand matrix @ 253.5	caves
	Hammer		Sediments are DAMP, nearing H2O Table	IH Tech 3.7 @ 254', 9/2/04
		Hard Tool drilling	Silt content (257-258.5) is up to 15%,	AM Survey, RCT < BKGD
260	Archive		then returns to ~5% by 259'. The rock	AR @ 0938 9/2/04
			continues uncemented, and basalt rich,	GW @ 254.45 ft bgs.
			with cobbles and boulders as in the	Split Spoon 254.45-256.45
			Hanford. The sediment is v. poorly sorted.	@ 1050 9/2/04
265	Archive			1330 PM Survey, RCT, < Bkgd
				1541 265 Sx
270	Archive		270'-272' SILT ≈10%. Unit is	270' Sx @ 1005 9/7/04
			65% basalt	Heaving sand requires
				water to keep it down.
275	Archive			275 Sx @ 1358 9/7/04

Reported By: JMFaurote / CTrice | Reviewed By: L.D. Walker

Title: Geologist | Title: Geologist

Signature: [signature] | Date: 9/7/04 | Signature: [signature] | Date: 10/19/04

A-6003-642 (03/03)

Figure B.2 Selected Borehole Log for Well 699-30-66, Cont'.

BOREHOLE LOG

Page 8 of 11
Date: 9/15/04

Well ID: C4298	Well Name: 699-30-66	Location: 2.5 Miles West of Ecology
Project: 2004 CERCLA Drilling		Reference Measuring Point: GS

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)
280	Archive				SX @ 280' @ 1109 on 9/15
	Hammer bolt bail				
					Cable Tool - Hard Tool
					11 3/4" OD Casing
285	Archive				285' 9/16/04 @ 0725
	SS				SS-287-289
290	Archive				290' 9/17/04 @ 1111
				292-405' Sandy GRAVEL (sG) 55-60% gravel, 40-45% sand, tr silt. Gravel: tr cobble, 20% vcse, 30% cse, 30% med, 20% fn-vfn; Sand: 20% vcse-cse, 50% med, 30% fn-vfne. 10YR 6/3-6/4, light yellowish brown, moist, poorly sorted, Sand: SA 80% qtz 20% basalt/other, tr mica; Gravel: SA-SR, max size ~90mm, no rxn HCl	
295	Archive				295' SX 9/20/04 RCT survey SPLcd 1H - no detect @ 0814
300	Archive				300' SX 9/20/04 @ 1030
305	Archive				305' SX 9/20/04 @ 1135 RCT/1H - No detect
310	Archive SS				310' SX 9/20/04 @ 1240
315	Archive				315' SX 9/22/04 @ 0735

Reported By: C. Trice	Reviewed By: L.D. Walker
Title: Geologist	Title: Geologist
Signature: [signature] Date: 9/21/04	Signature: [signature] Date: 10/19/04

A-6003-642 (03/03)

Figure B.2 Selected Borehole Log for Well 699-30-66, Cont'.

BOREHOLE LOG

Page 9 of 11
Date: 09/23/04

Well ID: C4298	Well Name: 699-30-66	Location: 2.5 MILES WEST OF ECOLOGY
Project: 2004 CERCLA DRILLING		Reference Measuring Point: GS

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
320	Archive CABLE HAMMER TOOL			cont. Sandy GRAVEL similar to above	320' SAMPLE 09/23/04 @1356
325	ARCHIVE				325' SAMPLE 09/23/04 @ 1509
330	Archive				330' SX 9/24/04 @ 0940
335	Archive				335 SX 9/27/04 @ 0845
340	Archive				340' SX 9/27/04 @ 1130
345	Archive SS				345' SX 9/27/04 @ 1300 Split Spoon 345' water sample and slug testing!
350	Archive				350' SX 10/05/04 @ 1251
355	Archive			355' increase to 60% basalt 40-60% basalt	355' SX 10/05/04 @ 1145 Drilling very hard increase in basalt Rb

Reported By: C TRICE		Reviewed By: L.D. Walker	
Title: GEOLOGIST		Title: Geologist	
Signature: C Trice	Date: 10/15/04	Signature: [signature]	Date: 10/19/04

A-6003-642 (03/03)

Figure B.2 Selected Borehole Log for Well 699-30-66, Cont'.

BOREHOLE LOG

Page 10 of 11
Date: 10/05/04

Well ID: C4298 | Well Name: 699-30-66 | Location: 2.5 MILES WEST OF ECOLOGY

Project: 2004 CERCLA DRILLING | Reference Measuring Point: GS

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)
360		Archive			360' SX on 10/6/04 @1245
					Cable Tool - Hard Tool
					11 3/4" OD Casing
				Sandy GRAVEL	
				similar to above	
365		Archive			365' SX on 10/6/04 @1430
370		Archive			370' SX on 10/8/04 @0935
					0919 IH AM Check - ND
					0926 RCT AM Check - ND
375		Archive			375' SX on 10/8/04 @ 1111
					1300 RCT PM Check ND
					1315 IH PM Check ND
380		Archive			380' on 10/8/04 @ 1245
385		Archive			385' on 10/8/04 @1515
		SS			SS 385-387.5 10/11/04
					0820 IH AM Check 10/11/04
					0856 RCT AM Check 10/11/04
390		Archive			390' on 10/11/04 @ 1220
395		Archive			SX 395' on 10/13/04 @850

Reported By: C TRICE | Reviewed By: L. D. Walker

Title: GEOLOGIST | Title: Geologist

Signature: [signature] Date: 10/13/04 | Signature: [signature] Date: 10/19/04

A-6003-642 (03/03)

Figure B.2 Selected Borehole Log for Well 699-30-66, Cont'.

BOREHOLE LOG

Page 11 of 11
Date: 10/13/04

Well ID: C4298 | Well Name: 699-30-66 | Location: 2.5 M WEST OF ECOLOGY

Project: 2004 CERCLA DRILLING | Reference Measuring Point: GS

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
400		Archive			400' Archive @ 1056 10/13/04 Cable tool - Hard tool 11¾" OD casing
405		Archive		405' - RINGOLD LOWER MUD SILT and CLAY (M) 100% SILT + CLAY 10YR 6/3 (pale brown), wet, low plasticity, wk rxn HCl.	405 - Sx @ 1404 RLM - 405' BGS TD = 406.3
410				TD - 406.3' tagged bottom.	

Reported By: CTRICE | Reviewed By: L.D. Walker

Title: GEOLOGIST | Title: Geologist

Signature: [signature] Date: 10/13/04 | Signature: [signature] Date: 10/19/04

A-6003-642 (03/03)

Figure B.3 Selected Borehole Log for Well 699-36-70B

BOREHOLE LOG — Page 7 of 11 — Date: 8-11-04

Well ID: C4299 | Well Name: 699-36-70B | Location: W of ERDF

Project: CERCLA Groundwater 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)
240'	Grab			240' SLIGHTLY SILTY SAND gravel decreased To 5% silt inc 15%.	Collect 240' archive Cable Tool 8" nom. dia. casing
245'	Grab			245' Same as above	Collect 245' archive
				248' SAND difficult to remove difficult to drill through	drilling is very slow
250'	Grab			250' - SANDY GRAVEL 35% gravel 55% Sand, 10% silt, gravel R-A 40% basalt 60% Qtz and others up to 1". Sand SA-A, 40% basalt 60% qtz/others. Poor Sorting mod rxn HCL 2.5YR 8/2 pale Yellow (dry)	Collect 250' archive
255'	Grab			255' SANDY GRAVEL 40% gravel 55% sand, 5% silt	Collect 255' archive
260'	Grab	SS 100% recov		260'-262' SANDY GRAVEL 40% gravel, 55% sand, 5% silt, gravel SA-WR poorly sorted 20% basalt 80% qtz/other sm pebbles-med cobbles, Sand A-SA poorly sorted fine-coarse, mod rxn HCL, 2.5YR 5/3 light olive brown (moist)	Collect 260' archive SS#1 260'-262.5' for sieve analysis Switch to drive barrel 264' driller notices change possibly due to water
265'	Grab			265' - gravel decreases to 35% sand increases to 60% Basalt decreases to 10% 267' gravel inc 40%, basalt inc 20% 268' - cuttings are wet	265' collect archive Checked depth 1' off 265 = 264' No water in well at 265'
270'	Grab	SS 100% recovery SS 100% recovery		270' - SANDY GRAVEL 35% gravel 60% sand 5% silt, gravel R-WR V. Poorly sorted >5% basalt, mostly qtz/other, Sand SR-WR, >5% basalt, <95% Qtz/others, pyrite 2.5YR 4/3 olive brown (moist)	Collect 270' archive (DTW 266 BGS) 271' - 45 gallons of water added because of heaving sands
275'		SS 50% recovery		275' - increase sand 65%, inc silt (JW)	DTW 260 BGS 269-274 3 slug tests completed by PNNL

Reported By: Jeffrey Weiss | Reviewed By: L.D. Walker

Title: Geologist | Title: Geologist

Signature: [signature] | Date: 8-23-04 | Signature: [signature] | Date: 11/3/04

A-6003-642 (03/03)

Figure B.3 Selected Borehole Log for Well 699-36-70B, Cont'.

BOREHOLE LOG			Page 8 of 11
			Date: 8-23-04
Well ID: C4299	Well Name: 699-36-70B	Location: W of ERDF	
Project: CERCLA Groundwater Well		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)
280'	Grab			280' SANDY GRAVEL same as previous	Collect 280' archive Cable Tool 8 5/8" OD drill casing
285'	Grab			285' SANDY GRAVEL basalt increases to 20%	Collect 285' archive
290'	GRAB			290' SANDY GRAVEL same as above	Collect 290' archive
295'	GRAB	SS 100% Recovery		295 SANDY GRAVEL gravel 30% Sand 65%, Silt 5%, gravel V. poorly sorted SR-R Cobble-Pebbles 5% basalt 95% qtz/other, Sand poorly sorted SA-A 5% basalt 95% Qtz/others, No Rxn HCL, 2.5YR 5/3 Light olive brown (wet color)	Collect 295' archive SS 295-297.5 for sieve analysis
300'	GRAB			300' SANDY GRAVEL basalt increases, 10%.	Collect 300' archive 301' water sample
				305'	
305'	GRAB			~~305'~~ SANDY GRAVEL same as above 306' SAND	Collect 305' archive
		SS 100% Recovery			307' Heaving Sand
310'	GRAB	SS 100% Recovery		310' SAND 95% Sand, 5% silt Sand poorly sorted, SA-SR 10% basalt 90% Qtz/others, weak rxn HCL, 2.5Y 4/2 dark grayish brown (wet) 311' SANDY GRAVEL	Collect 310' archive
315'	GRAB			315' SANDY GRAVEL gravel 30% sand 65% silt 5%, gravel V. poorly sorted SR-R 15% basalt 85% qtz/other, ~~2.5Y~~ sand poorly sorted m-F grained 10% basalt 90% qtz/other, No Rxn HCL, 2.5Y 5/3 L. Olive Brn.	Collect 315' archive

Reported By: Jeffrey Weiss		Reviewed By: L.D. Walker	
Title: Geologist		Title: Geologist	
Signature: [signature]	Date: 9-2-04	Signature: [signature]	Date: 11/3/04

A-6003-642 (03/03)

Figure B.3 Selected Borehole Log for Well 699-36-70B, Cont'.

BOREHOLE LOG — Page 9 of 11 — Date: 9-2-04

Well ID: C4299 | Well Name: 699-36-70B | Location: W of ERDF

Project: CERCLA Groundwater Well | 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)
320'	GRAB			320' SANDY GRAVEL same as above	Collect 320' archive Cable Tool 8 5/8" OD drill casing
325'	GRAB			325' GRAVELLY SAND 20% gravel, 70% Sand, 10% silt, gravel P. Sorted R-SR 10% basalt 90% Qtz/others, Sand m. sorting SA-A 5% basalt 95% Qtz/others Coarse-F grained, No Rxn HCL, 2.5Y 5/3 light olive brown (wet)	Collect 325' archive
330'	GRAB			330' GRAVELLY SAND same as above	Collect 330' archive
335'	GRAB			335' GRAVELLY SAND same as above	Collect 335' archive
340'	GRAB	SS 100% recovery SS 100% recovery		340' GRAVELLY SAND basalt inc. 15%	Collect 340' archive 340 Water sample
345'	GRAB			345' GRAVELLY SAND gravel dec 10% Sand inc 80%	Collect 345' archive
350'	GRAB			350' GRAVELLY SAND same as above	collect 350' archive
355'	GRAB			355' SLIGHTLY SILTY GRAVELLY SAND 10% gravel, 75% Sand, 15% silt, gravel P. Sorted SR-R 40% basalt 60% Qtz/other, Sand mod Sorted SR-R 40% basalt 60% Qtz/other, NO Rxn HCL, 2.5Y 5/2 grayish brown	collect 355' archive

Reported By: Jeffrey Weiss | Reviewed By: L.D. Walker

Title: Geologist | Title: Geologist

Signature: Jeffrey Weiss | Date: 9-9-04 | Signature: L.D. Walker | Date: 11/3/04

A-6003-642 (03/03

Figure B.3 Selected Borehole Log for Well 699-36-70B, Cont'.

BOREHOLE LOG — Page 10 of 11 — Date: 9-10-04

Well ID: C4299 | Well Name: 699-36-70B | Location: W of ERDF
Project: CERCLA Groundwater Well | 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)
360'	GRAB			360' SLIGHTLY SILTY GRAVELY SAND, silt inc 20%, Sand 70%, gravel 10%	Collect 360' archive; Cable Tool; 8 5/8" OD drill casing
365'	GRAB			365' SLIGHTLY SILTY GRAVELY SAND Same as above	Collect 365' archive
370'	GRAB	SS 100% recovery; SS 100% recovery		370' SLIGHTLY SILTY GRAVELY SAND same as above	Collect 370' archive; 370'-375', 3 slug test are completed by PNNL
375'	GRAB			375' SLIGHTLY SILTY GRAVELY SAND Same as above	Collect 375' archive; 375' water sample
380'	GRAB			380' GRAVELY SAND 20% gravel, 70% sand, 10% silt, gravel R-WR P.sorted 20% basalt 80% Qtz/other, Sand med-F grain P.sorted SA-SR 20% basalt 80 Qtz/others mica, 5Y 5/3 olive, no rxn HCL	Collect 380' archive; 380' Drilling is easier
385'	GRAB			385' GRAVELY SAND same as above	Collect 385' archive
390'	GRAB			390' GRAVELY SAND 20% gravel, 70% sand, 10% silt, gravel R-WR, P.sorted 20% basalt 80% Qtz/others, Sand Coarse-F grained P.sorted, SA-SR 15% basalt 85% Qtz/other, Silt med plasticity, no rxn HCL 10YR 5/3 Brown	Collect 390' archive
395'	GRAB			395' GRAVELY SAND gravel dec 15% Sand inc 75%	Collect 395 archive

Reported By: Jeffrey Weiss | Reviewed By: L.D. Walker
Title: Geologist | Title: Geologist
Signature: [signature] Date: 9-20-04 | Signature: [signature] Date: 11/3/04

A-6003-642 (03/03)

Figure B.3 Selected Borehole Log for Well 699-36-70B, Cont'.

BOREHOLE LOG

Page 11 of 11
Date: 9-20-04

Well ID: C4299 | Well Name: 699-36-70B | Location: W of ERDF

Project: CERCLA GW well | 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)
400'	GRAB			400' GRAVELY SAND 15% gravel, 75% sand, 10% silt, gravel SR-R ~~we~~ poorly sorted 10% basalt 90% Qtz/others, Sand coarse-F grained subangular-rounded, no rxn HCL 2.5Y 5/3 light olive brown	Collect 400' archive Cable Tool 8 5/8" OD drill casing
405'	GRAB			405' SLIGHTLY SILTY ~~SANDY~~ GRAVELY SAND 15% gravel 70% sand 15% silt gravel SR-R 10% basalt 90% Qtz/other Sand coarse-F grained SA-R, no rxn HCL 2.5Y 5/3 light olive brown	Collect 405' archive
410'	GRAB			410' SLIGHTLY SILTY GRAVELY SAND gravel dec 10% silt inc 20%	Collect 410' archive
415'	GRAB	SS 100% recovery SS 100% recovery		415' GRAVELY SAND 15% gravel, 75% sand 10% silt, gravel SR-R Poorly sorted 10% basalt 90% Qtz/others, Sand coarse-F grained SA-R, no rxn HCL 2.5Y 5/3 light olive brown	Collect 415' archive 417' collect water samples DTW 280'
420'	GRAB			420' SILTY SAND 75% sand, 25% silt Sand med-Fine grained SA-R 20% basalt 80% Qtz/other, Silt med plasticity no rxn HCL, 2.5Y 5/3 light olive brown	Collect 420' archive
425'	GRAB			425' SILTY SAND sand dec 60% silt Inc 40% sand same as above	Collect 425' archive
				427' = Total drilled depth.	
430'					
435'					

Reported By: Jeffrey Weiss | Reviewed By: L.D. Walker

Title: Geologist | Title: Geologist

Signature: [signature] Date: 9/20/04 | Signature: [signature] Date: 11/3/04