PNL-8173
UC-903

Hydraulic Test Results for Savage Island Wells: 699-32-22B, 699-42-E9A, and 699-42-E9B

F. A. Spane, Jr.

June 1992

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Received by USTI

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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PNL-8173

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operated by
BATTELLE MEMORIAL INSTITUTE
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DE93 002043

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Pacific Northwest Laboratory
Richland, Washington 99352

SUMMARY

This report presents the results of hydraulic characterization tests conducted at the three Savage Island wells that were constructed as part of the Ground-Water Surveillance Project, Hanford Site Flow System Characterization Task. A total of four test intervals were characterized at the wells tested. Characterization efforts for an additional upper-confined aquifer horizon (i.e., the Rattlesnake Ridge interbed at well 699-32-22B) were suspended when a possible problem with the well annular sealing materials was detected during test interval development activities. In addition, characterization efforts for the lower monitoring well within a nested, dual-well facility completed in the Ringold Formation (well 699-42-E9A) were aborted following problems experienced during test zone development, following well completion activities. Because of the severity of the problems that were experienced (i.e., damage to the well casing), the lower monitoring well was subsequently abandoned, and no additional characterization for this test interval was attempted.

Methods used for the test analysis included recently developed pressure derivative techniques, which were used in concert with standard hydrologic test methods for the analysis of slug and constant-rate pumping tests. Pressure derivative techniques are particularly useful for identifying operative model responses (i.e., homogeneous vs. heterogeneous formation response), presence of non-formational response patterns (e.g., wellbore storage, skin effects, etc.), and identifying regions within the test data where standard analysis techniques can be applied.

Results of the hydraulic test analysis indicate a best estimate transmissivity range of 51 ft^2/d (4.7 m^2/d) to 690 ft^2/d (64.1 m^2/d) for basalt flow contacts within the Elephant Mountain Basalt, and a value of 65 ft^2/d (6.0 m^2/d) for the one test completed in the Ringold Formation. The hydraulic property estimates obtained from the transient test analysis fall within the range previously cited (e.g., Gephart et al. 1979, Graham et al. 1984, DOE 1988) for similar units within the uppermost aquifer systems on the Hanford Site.

ACKNOWLEDGMENTS

A number of people collaborated in the conduct of the field slug interference test. In particular, important field test support contributions and preliminary test analyses were made by J. V. Borghese and D. R. Newcomer. Drilling history and subsurface geological information was provided by M. A. Chamness. P. D. Thorne and S. P. Luttrell provided technical peer review comments for the test analysis results. The editorial review and guidance provided by W. R. Gorst and J. B. Flynn are also acknowledged.

CONVERSION TABLE

English units are utilized as the primary convention in the text and in text figures and tables. For converting English units presented in text figures and tables to associated metric values, the following conversion table is provided:

Multiply	By	To Obtain
inches	2.540	centimeters
feet	0.3408	meters
miles	1.6093	kilometers
gallons	3.7854	liters
$feet^2$/day	0.0929	$meters^2$/day
pounds/$inches^2$	6.8948	kilo-Pascals

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1.0 INTRODUCTION

As part of the Ground-Water Surveillance Project, Hanford Site Flow System Characterization Task, Pacific Northwest Laboratory (PNL) examines the potential for offsite migration of contamination within the upper-confined aquifer system for U.S. Department of Energy (DOE). As part of this activity, a hydraulic characterization investigation was conducted on three newly constructed wells. The three wells are collectively referred to as the Savage Island wells, which is in reference to the location of two of the three wells tested during this investigation. Results of characterization tests conducted as part of this investigation will be used by PNL in its assessment of the extent of contamination within the upper-confined aquifer system, and its potential for offsite migration.

This report presents the results of hydraulic characterization tests conducted at the three Savage Island wells that were constructed during fiscal year 1991. Results from hydrochemical, geological, and geophysical characterization activities will be reported in subsequent PNL reports.

2.0 GENERAL SITE/TEST FORMATION DESCRIPTION

The location of the three Savage Island wells is shown in Figure 2.1. As shown, wells 699-42-E9A and 699-42-E9B are located east of the Columbia River - immediately east of Savage island, while well 699-32-22B is located west of the Columbia River - approximately 8 miles (13 km) southwest of Savage Island. The objective of drilling and characterization activities at the wells was to test for the presence of contamination within selected test intervals and to provide hydrogeologic information that can be used to assess the potential for offsite migration of contamination within the upper-confined aquifer system.

Table 2.1 shows the general geologic relationships encountered during drilling of the Savage Island wells. On the Hanford Site, the uppermost aquifer consists of glaciofluvial deposits of the Hanford formation (informal designation) and fluvial and lacustrine deposits of the underlying Ringold Formation. Site-wide, unconfined conditions are most prevalent within the uppermost aquifer; however locally semi-confined and confined conditions may exist in the lower section of the Ringold Formation (e.g., 200 West Area). From a larger site-wide perspective, the locally semi-confined and confined units within the Ringold Formation are considered part of the uppermost aquifer system. Below the uppermost aquifer, is a laterally extensive upper-confined aquifer system consisting of transmissive units within the Saddle Mountains Basalt, which directly underlies the Ringold Formation (see Table 2.1). Identified laterally extensive and transmissive zones within the upper-confined aquifer system include the Rattlesnake Ridge interbed and interflow contacts (i.e., brecciated contact zones between individual basalt flow members) within the Elephant Mountain Basalt. A detailed hydrogeologic description of these units is presented in Myers and Price (1981) and DOE (1988). Table 2.2 provides an outline of pertinent information for intervals tested at each Savage Island well.

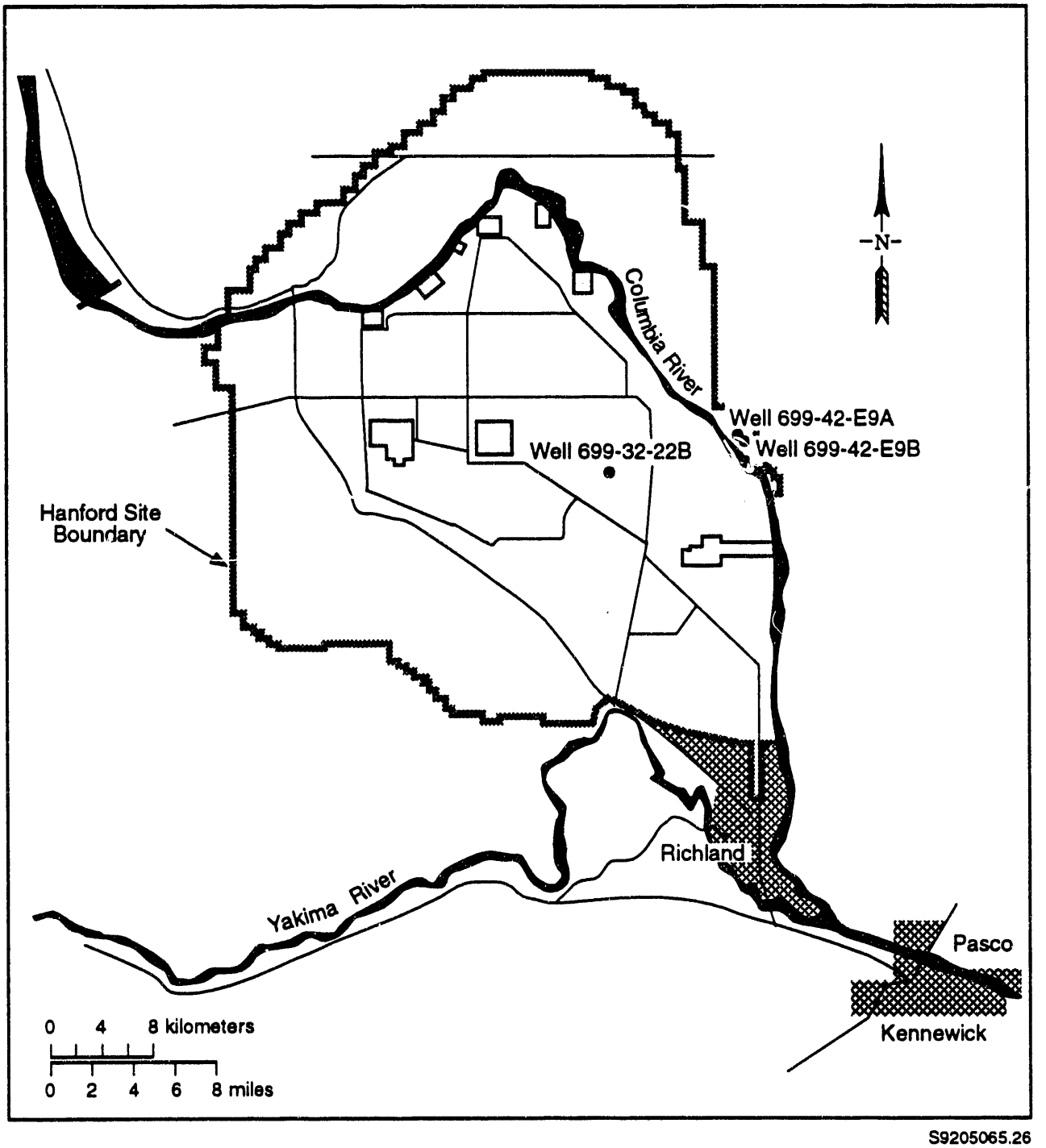

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FIGURE 2.1. Savage Island Well Location Map

TABLE 2.1. Generalized Geology Encountered During Drilling of the Savage Island Wells

Geologic Unit	Encountered Saturated Thickness Range	Hydrogeologic Conditions
Ringold Formation	200 - 525 ft	Uppermost aquifer; site-wide unconfined, locally semi-confined to confined conditions
Elephant Mountain	128 - 145 ft	Upper-confined aquifer; basalt pervious interflow contact laterally extensive in eastern part of Hanford Site
Rattlesnake Ridge	0 - 60 ft	Upper-confined aquifer. Interbed locally discontinuous
Pomona Basalt	not completely penetrated	Upper-confined aquifer; where Rattlesnake Ridge interbed is discontinuous, forms pervious flow contact zone with overlying Elephant Mt. Basalt

TABLE 2.2. Pertinent Savage Island Well Test Interval Information

Well	Test Formation	Test Interval	Test Type	Test Date
32-22B	Elephant Mt. Basalt interflow	655 - 686 ft	Slug Injection & Withdrawal; Constant Discharge	5/30/91 6/1/91
32-22B	Rattlesnake Ridge interbed	780 - 836 ft	Aborted Constant Discharge/Develop. Pumping	8/9 - 9/24/91
42-E9A	Ringold Formation	195 - 232 ft	Slug Injection & Withdrawal	12/18/90
42-E9A	Ringold Formation	213 - 232 ft	Aborted Constant Discharge/Develop. Pumping	1/11/91
42-E9B	Elephant Mt. Basalt interflow	232 - 285 ft	Slug Withdrawal; Constant Discharge	3/18/91 3/19/91
42-E9B	Elephant Mt./ Pomona Basalt flow contact	354 - 389 ft	Constant Discharge	4/18/91

3.0 ANALYTICAL TEST METHOD DESCRIPTION

Hydrologic test methods utilized to hydraulically characterize the test intervals at the three Savage Island wells included constant-rate pumping tests and slug tests. A brief description of the analytical test methods used are provided below.

3.1 CONSTANT-RATE PUMPING TESTS

For constant-rate pumping tests, groundwater is withdrawn from the well commonly utilizing a downhole pump (e.g., submersible, turbine, etc.). Discharge during the withdrawal period is regulated and maintained at a constant rate. Water-level response within the well is monitored during the active pumping phase (i.e., drawdown) and during the subsequent recovery phase following termination of pumping. The analysis of drawdown and recovery water-level response within the stress well (and any monitored, nearby observation wells) provides a means for estimating the hydraulic properties of the tested aquifer; as well as discerning formational and nonformational flow conditions (e.g., wellbore storage, wellbore damage, presence of boundaries, etc.). Standard analytical methods that are used for constant-rate pumping tests include both log-log, type-curve matching and semi-log, straight-line methods.

In groundwater hydrology, log-log methods are normally reserved for analyzing observation well response (both individually and collectively). Log-log methods are not normally used for quantitative analysis of the pumped well, since part of the drawdown or recovery water-level response at the well location is associated with well/formation inefficiencies or damage induced by the drilling process. In the petroleum industry, the effects of well/formation inefficiencies or damage are lumped-together and referred to as "skin-effects." In petroleum reservoir analysis procedures, storativity, S, is independently estimated for the test formation, and transmissivity, T, and skin-effect, s, are calculated simultaneously by matching the log-log drawdown or recovery response with appropriate type-curves for various skin-effect conditions.

For semi-log analysis methods, the rate-of-change of water levels within the well during drawdown and/or recovery is analyzed to provide hydraulic property estimates. Since skin effects are constant with time during constant-rate tests, semi-log methods can be utilized to quantitatively analyze the water-level response at both pumped and observation wells. In groundwater hydrology, the semi-log, straight-line analysis techniques commonly used are either based on the Cooper and Jacob (1946) method (for drawdown analysis) and the Theis (1935) recovery method (for recovery analysis). For these analysis methods, drawdown or recovery (i.e., residual drawdown) water-level data are plotted versus the log of time or time parameter, and T is calculated using one of the following two equations:

$$T = (2.3\ Q)/(4\pi\ \Delta h/\Delta \log t) \quad \text{(drawdown analysis)} \tag{1}$$

$$T = (2.3\ Q)/(4\pi\ \Delta s/\Delta \log t/t') \quad \text{(recovery analysis)} \tag{2}$$

where Q = pumping discharge rate $[L^3/T]$

Δh = water-level change $[L]$

Δs = residual drawdown $[L]$

t = time since pumping started $[T]$

t' = time since pumping terminated $[T]$

The straight-line solutions represent an approximation of the general equation describing radial flow to a well, and are valid only after a specified period of time and after radial flow conditions have been established within the test formation. As indicated in Lohman (1972), the time required for the straight-line approximation to be valid can be calculated from the following:

$$t \geq (r^2\ S)/(4T\ u) \tag{3}$$

where r = observation distance from the pumped well [L]

u = 0.01 [dimensionless]

While the time required for the straight-line approximation to be valid can be calculated, determining when radial flow conditions are exhibited has (in the past) been more difficult to discern. Since analysis of constant-rate tests depends primarily on semi-log, straight-line solutions, it is important that the analyses be correctly applied, only for that portion of the pumping test data for which it is valid (i.e., homogeneous formation - radial flow conditions). A recently developed method that has been used in the petroleum industry (e.g., Bourdet et al. 1983, 1989; Ehlig-Economides. 1988) to help identify various formation responses (i.e., homogeneous vs. heterogeneous formation) and flow conditions (wellbore storage, skin effects, radial flow, boundaries, etc.), is the use of pressure derivatives. When plotted in log-log format in combination with the traditional pressure change vs. time plot, the pressure derivative response curve can be used diagnostically to identify the presence of wellbore storage and boundaries, and to precisely indicate the establishment of radial flow conditions for which straight-line solutions are appropriate.

Figure 3.1 shows the pattern of dimensionless pressure, P_D, and the dimensionless pressure derivative, P_D', during a constant-rate test for a stress well with no storage (Theis type curve) and for various wellbore storage conditions. As indicated in the figure, wellbore storage produces a characteristic "hump" pattern in the pressure derivative plot, which increases in amplitude and duration as the associated dimensionless wellbore storage value, C_D, increases. Radial flow conditions are indicated when the pressure derivative curve becomes horizontal (i.e., when the pressure derivative becomes constant) at a P_D' value equal to 0.5. For the examples shown, radial flow conditions are established for test times with T_D/C_D values greater than about 1000. The dimensionless parameters shown in Figure 3.1 are defined as:

$$P_D = (2\pi\ T/Q)\Delta h \qquad (4)$$

$$C_D = r_c^2/(2r_w^2\ S) \tag{5}$$

$$T_D = (T\ t)/(r_w^2\ S) \tag{6}$$

where r_c = stress well casing radius $[L^2]$

r_w = stress well radius in test interval $[L^2]$

The presence of non-radial flow conditions caused by vertical flow, leaky aquifer behavior or the presence of recharge boundaries, is denoted on a

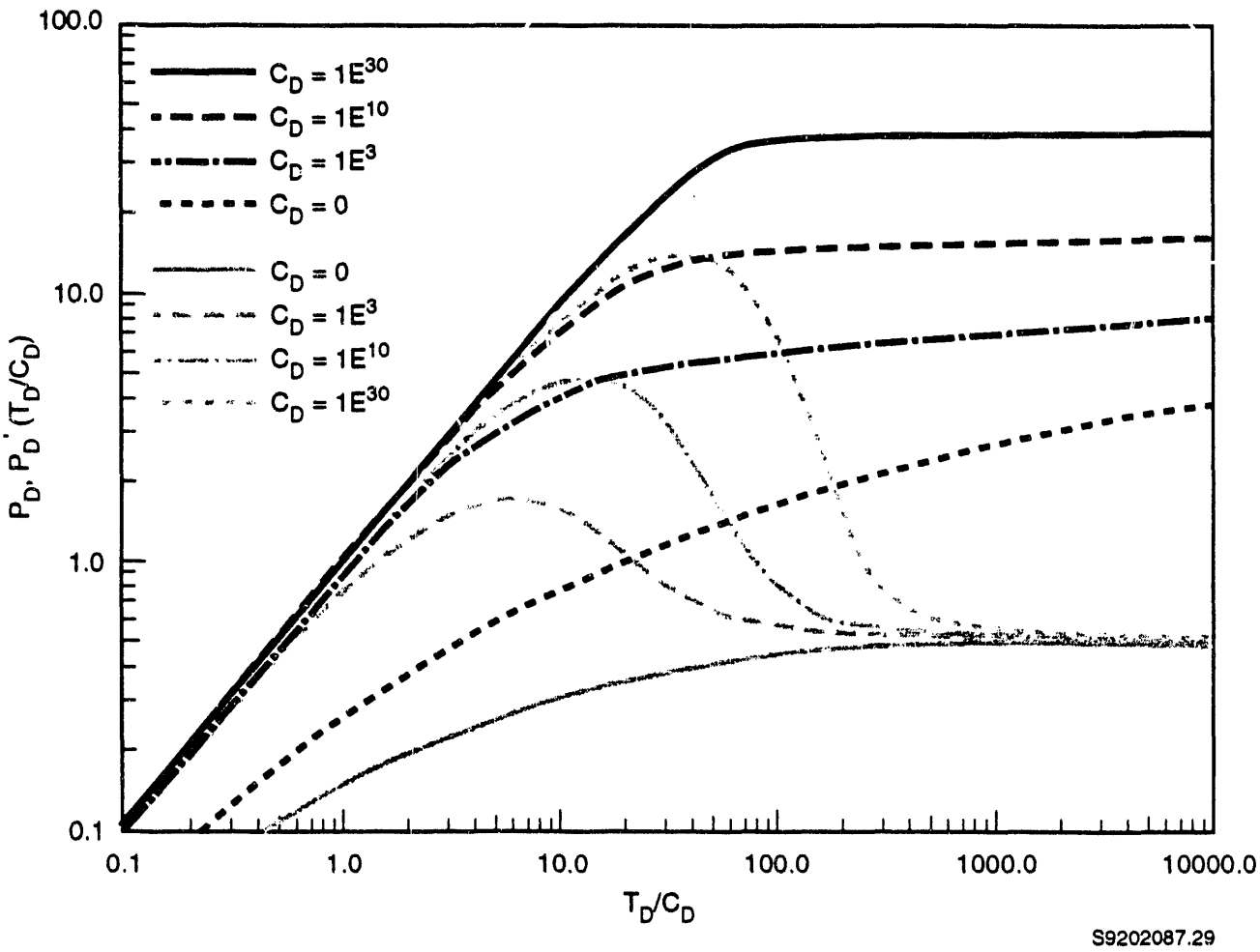

FIGURE 3.1. Dimensionsless Pressure and Dimensionless Pressure Derivative Type Curves for Constant-Rate Pumping Tests (After Bourdet et al. 1983)

pressure derivative plot by a diagnostic response pattern that significantly deviates from the horizontal radial flow-line region of the graph (i.e., $P_D' = 0.5$). In comparison, these non-radial flow conditions are less obvious on a dimensionless pressure change plot without the derivative. Its presence is only suggested by a subtle deviation from the pressure change plot.

In summary, pressure derivative analysis of pumping test results can be used to:

- diagnostically determine formation response (homogeneous vs. heterogeneous) and boundary conditions (recharge or discharge) that are evident during the test,
- determine when radial flow conditions are established and, therefore, when straight-line solution analysis of test data is valid, and
- assist in log-log type-curve matching to determine hydraulic properties for test data exhibiting wellbore storage effects and boundary conditions.

3.2 SLUG TESTS

The analytical solution for a slug test response for a stress well with a finite radius within a confined aquifer containing a compressible fluid, was first presented in Cooper et al. (1967). In their article, type curves were presented that related dimensionless head response, H_D, versus the dimensionless time parameter, beta (β), β, for various values of the dimensionless storage parameter, alpha (α), α; where:

$$H_D = H/H_o \tag{7}$$

$$\beta = Tt/r_c^2 \tag{8}$$

$$\alpha = r_w^2 S/r_c^2 \tag{9}$$

where H = observed head at time t, minus pre-test static head level in well [L]

H_o = instantaneous head change applied to well at the start of the test [L]

T = transmissivity of test interval [L^2/T]

t = test time [T]

r_c = radius of well casing in the interval over which head change takes place [L]

r_w = effective radius of well within test interval [L]

S = storativity of test interval [dimensionless]

Type curves presented in Cooper et al. (1967) can be used to match slug test response data at the stress well to solve for transmissivity (T) and storativity (S) using Equations (8) and (9), respectively. Slug test data can also be analyzed utilizing the technique described in Ostrowski and Kloska (1989), which employs the simultaneous type-curve matching of the dimensionsless pressure (i.e., H/H_o) versus time and the derivative of dimensionsless pressure versus time. The technique is superior to the procedure described in Cooper et al. (1967) for dimensionless pressure versus time in that the ambiguity in type-curve selection is significantly reduced.

Figure 3.2 shows selected type-curve responses for dimensionless pressure versus beta (as described by Cooper et al. 1967) and the derivative of dimensionless pressure versus beta (as reported in Ostrowski and Kloska 1989). As indicated, while little difference is exhibited for dimensionless pressure type curves for the range of alpha examined, significant differences in shape and amplitude are evident for the pressure derivative type curves. Because of these exhibited differences, slug test analysis utilizing the Ostrowski and Kloska (1989) procedure is preferable. Both the Cooper et al. (1967) and Ostrowski and Kloska (1989) analysis techniques are strictly valid only for fully penetrating wells. However, as indicated by Cooper et al. (1967) few wells completely penetrate an aquifer, and for wells partially penetrating stratified aquifers (where vertical hydraulic conductivities are commonly less than horizontal hydraulic conductivities) it can be assumed that two-dimensional flow conditions exist during the test. For these situations,

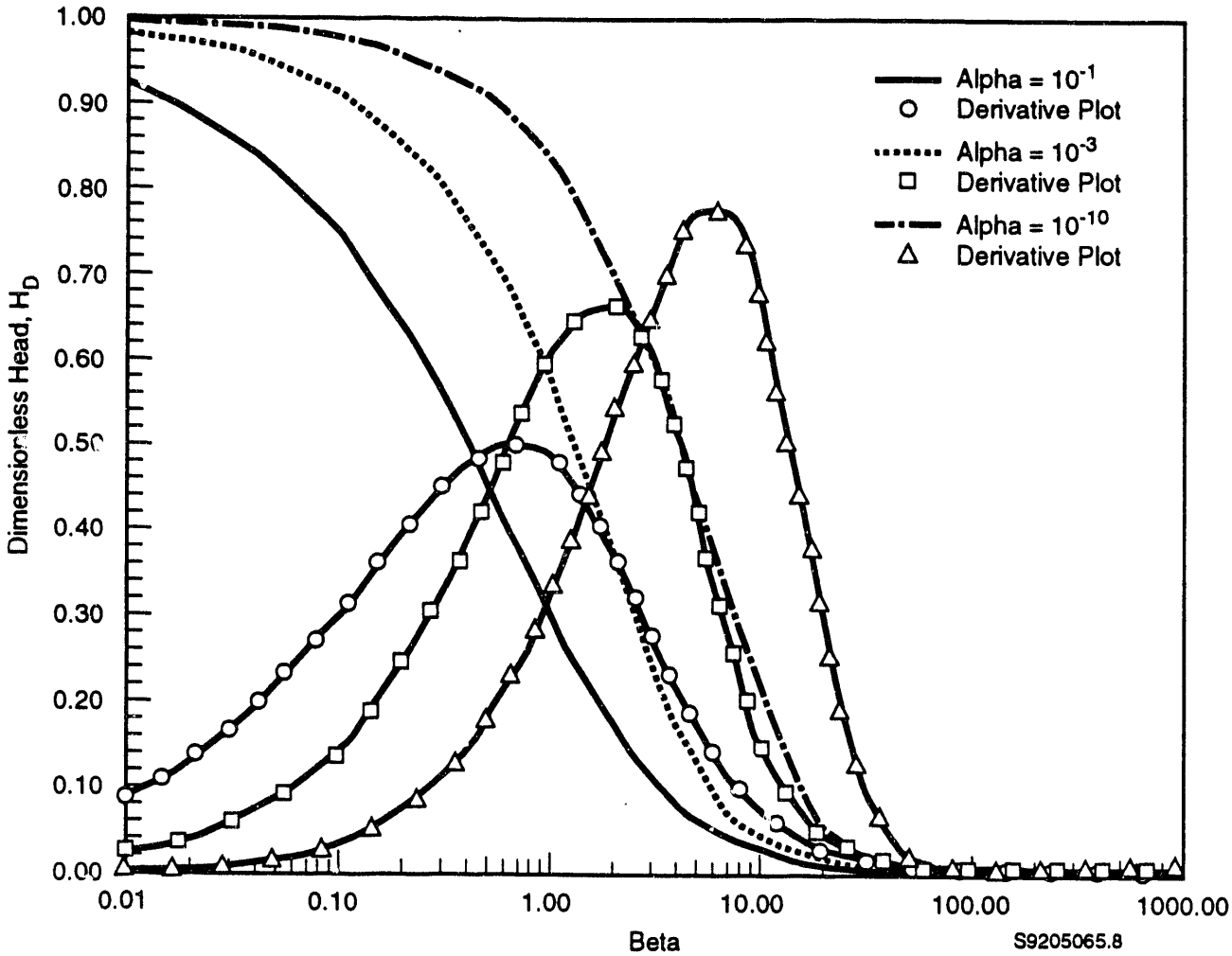

FIGURE 3.2. Dimensionsless Pressure and Dimensionless Pressure Derivative Type Curves for Slug Tests

"... the determined value of transmissivity (T) would represent approximately the transmissivity of that part of the aquifer in which the well is screened..." (Cooper et al. 1967).

3.3 ANALYTICAL SOFTWARE DESCRIPTION

To support analysis of hydraulic characterization tests conducted at the Savage Island wells, a software program presented in Novakowski (1990) was utilized. The Novakowski (1990) analysis software consists of a FORTRAN program that can generate constant-rate pumping and slug test type curves, based on the analytical solutions and boundary conditions presented in Papadopulos

and Cooper (1967) and Cooper et al. (1967), respectively. As stated in Novakowski (1990), the analytical solutions included in the program are given in the Laplace domain and are numerically inverted to generate data for the type curves. Pressure derivative type curves were generated from the pumping and slug test data obtained with the Novakowski (1990) program following the procedures presented in Bourdet et al. (1989) - for pumping tests, and Ostrowski and Kloska (1989) - for slug tests.

To facilitate analysis of the Savage Island hydraulic test data, the original Novakowski (1990) program was modified: to allow increased density of generated type-curve data points, to extend the dimensionless head lower limit, and to provide additional test description information in the computer file output. The validity of the modified program version was examined previously and reported in Spane (1992). As reported in Spane (1992), the modified Novakowski (1990) program produced test results that were in close agreement with the aforementioned published type-curve data (i.e., within 3 or 4 significant decimal places for dimensionless head, H_D). A detailed description of the original program and its use is contained in Novakowski (1990).

4.0 HYDRAULIC TEST RESULTS

A description and analysis of hydraulic tests conducted at the respective Savage Island wells are provided in the following report section. Included in the test description are

- an illustration of the well as-built at time of testing
- a chronology of well testing activities for each test interval
- a listing of equipment utilized during the well test
- detailed discussion of the test analysis results.

4.1 WELL 699-32-22B

As indicated in Figure 2.1, well 699-32-22B is in the central region of the Hanford Site approximately 5 miles (8 km) east-southeast of the 200 East Area. The Hanford Site coordinates for the well site are 31,935 ft north and 11,982 ft west (Lambert coordinates: 133,240.31 m north, 583,199.96 m east). Elevation of the surface control datum (brass cap) is 514.53 ft (156.83 m) above mean sea level (msl).

Drilling was initiated at the site on April 11, 1991, and continued until a depth of 841.5 ft below land surface (bls) was reached on June 17, 1991. As listed in Table 2.1, hydraulic testing was attempted for two zones encountered at the well site: (1) an Elephant Mountain Basalt interflow zone (test interval = 655 - 686 ft bls) and (2) the Rattlesnake Ridge interbed (test interval = 780 - 836 ft bls). Hydraulic testing was conducted for the first zone during a temporary cessation of drilling the well (i.e., borehole depth = 686 ft bls). Hydraulic testing for the Rattlesnake Ridge interbed was attempted after termination of drilling and after well completion activities were finalized. Attempts to develop and test the Rattlesnake Ridge interbed in the completed well, however, were aborted when field test information obtained during well development indicated potential problems with the well completion (i.e., significant decrease in groundwater production, presence of bentonite sealing material in discharge water, etc.). A detailed description of the drilling history and well completion details, as well as results from

geological, geophysical and hydrochemical characterization activities at the well site, will be reported in a subsequent PNL report.

4.1.1 Elephant Mountain Basalt Interflow Zone

The Elephant Mountain basalt interflow zone was hydraulically tested during a temporary cessation of well drilling. During the course of drilling through the depth section 655 to 686 ft bls (i.e., on May 29, 1991), evidence in the drilling fluid circulation and drilling penetration rates suggested that the basalt interflow contact encountered in this interval (i.e., approximately at 668 ft) was pervious. Drilling of this borehole section was accomplished utilizing the air-rotary method, with a drilling bit diameter of 9-7/8 in. The borehole diameter within the test interval (as indicated by the caliper log shown in Figure 4.1) ranged between 9.65 and 10.92 in. and averaged 10.19 in. Figure 4.1 shows the well configuration during hydraulic characterization of the Elephant Mountain basalt interflow zone. Hydraulic tests conducted during the characterization period of May 30 to June 1, 1991, included a slug injection and withdrawal test, and a constant-rate pumping test.

4.1.1.1 Slug Injection and Withdrawal Test Descriptions

To provide an initial estimate of hydraulic properties for the test interval, slug injection and withdrawal tests were conducted between 1016 hr and 1237 hr, May 30, 1991, and 1240 hr and 1337 hr, May 30, 1991, respectively. The slug tests were initiated by suddenly immersing (for the injection test) and removing (for the withdrawal test) a slugging rod of known volume (0.794 ft^3) from the water column in the well). The sudden emersion and removal of the slugging rod caused induced stress levels, H_o, of approximately 1.46 ft of water to be applied at the initiation of the slug tests. Pressure recovery measurements within the well were monitored with a downhole Druck, Inc., pressure transducer (0 to 10 psi, model # 950/TI, serial # 382975) and recorded on a Campbell Scientific, Inc., datalogger (model # CR10, serial # 9409). The transducer was installed at a depth of approximately 128 ft below the top of the 10 in. casing (btc). The static water level within the well prior to testing was 113.67 ft btc (401.72 ft msl), which was measured using a Lufkin steel tape (serial # L500-18).

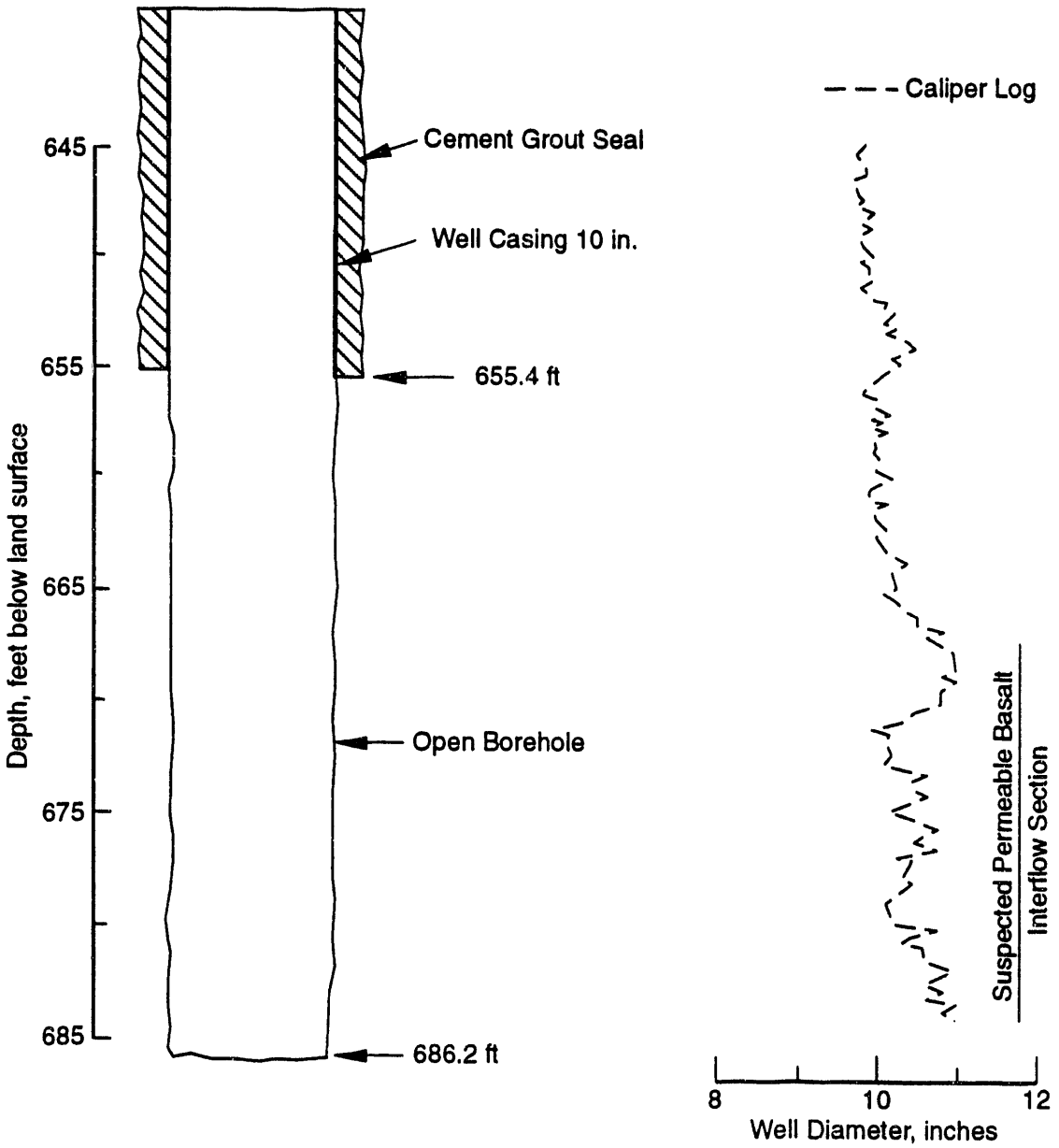

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FIGURE 4.1. Configuration of Well 699-32-22B at Time of Hydraulically Testing the Elephant Mountain Basalt Interflow Zone

4.1.1.2 Slug Test Analyses

The slug injection and withdrawal tests were analyzed utilizing the Cooper et al. (1967) and Ostrowski and Kloska (1989) methods described in Section 3.2. Figures 4.2 and 4.3 show the slug test data and data derivative analysis for the slug injection and withdrawal tests, respectively. The slug injection and withdrawal tests displayed nearly identical responses, although the slug withdrawal test exhibited more variability (i.e., data noise). The cause for the slightly greater data noise is believed to be attributable to the possibility that the slugging rod was not fully withdrawn during the initiation of the test. This caused a lower induced stress level ($H_o \approx 1.284$ ft) and a reduced effective well casing radius (i.e., inside well casing area = 0.546 ft^2 minus the area of the slugging rod = 0.113 ft^2) calculated to be 0.371 ft.

As indicated, a transmissivity of 15 ft^2/d (1.4 m^2/d) and storativity of 10^{-3} provide good matches of the observed slug test and slug test derivative responses. The slug test and slug test derivative type curves were obtained using the modified Novakowski (1990) program described in Section 3.2. Because of the low stress levels utilized during the slug tests, the hydraulic properties are considered to be only representative of formation conditions in the immediate vicinity of the well location. Pertinent analysis parameters utilized in the test analysis include: induced stress level, H_o = 1.46 ft (slug injection test) and 1.284 ft (slug withdrawal test); effective radius of the well casing, r_c = 0.4167 ft (slug injection test) and 0.371 ft (slug withdrawal test); and well radius in the test interval, r_w = 0.4246 ft (average value from caliper log results). Field test data acquired during the slug injection and withdrawal tests are contained in Appendix A.

4.1.1.3 Constant-Rate Pumping Test Description

To provide an estimate of hydraulic properties for the test interval over a larger area surrounding the well site, a constant-rate pumping test was conducted between 0745 hr and 1745 hr, June 1, 1991. The constant-rate pumping test was performed using a submersible pump. Flow rate was manually controlled with a valve in the surface discharge line to maintain a uniform discharge rate. Discharge (i.e., after the first minute) began initially at

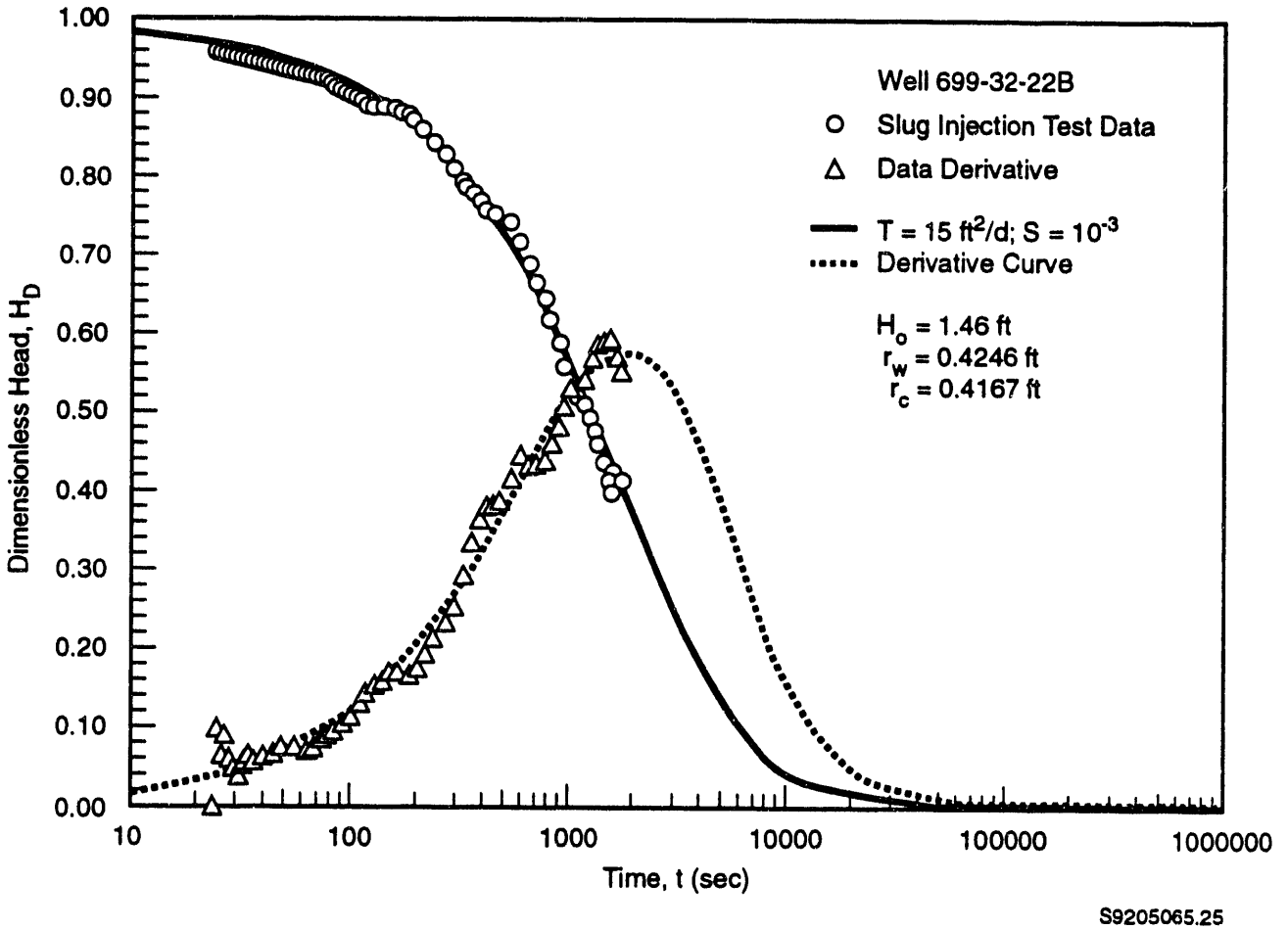

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FIGURE 4.2. Slug Injection Test Analysis for the Elephant Mountain Interflow Zone, at Well 699-32-22B

15.0 gpm and gradually lowered to 12.5 gpm during the course of the test. In total, 8,042 gal of water were produced from the test interval for an average discharge of approximately 13.4 gpm during the test. Groundwater pumped from the test interval was transported approximately 1000 ft east of the well site and discharged to the land surface. Approximately 24 hr prior to conducting the constant-rate pumping test, a short preliminary period of pumping was initiated within the test interval. The preliminary pumping period was implemented for test interval development and to examine the performance of selected components of the test system, prior to initiation of the constant-rate pumping test. Approximately 2,280 gal of water were produced during this pre-test activity. The effects of the preliminary pumping period had dissipated prior to initiation of the constant-rate pumping test.

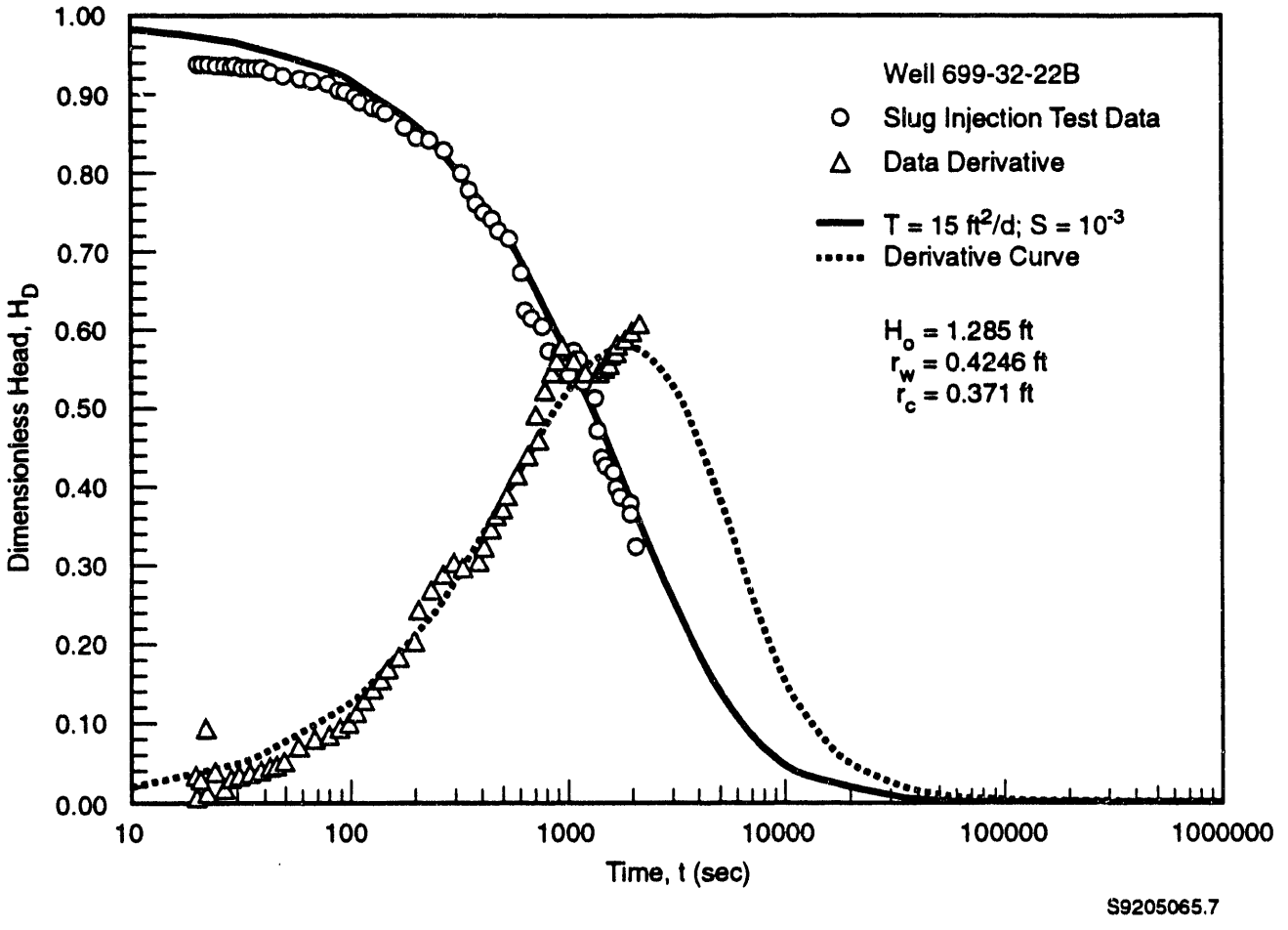

FIGURE 4.3. Slug Withdrawal Test Analysis for the Elephant Mountain Interflow Zone, at Well 699-32-22B

Water-level measurements during the pumping test were monitored with two downhole Druck, Inc. pressure transducers (0 to 10 psi, model # 950/TI, serial # 382975 and 382982) set at depth settings of 136 ft and 159 ft btc; as well as measured directly with a calibrated Solinst Inc., electric water-level sensor (serial # 11053), and steel tape. The pressure transducer readings were recorded on a Campbell Scientific, Inc., datalogger (model # CR10, serial # 9409). The static water level within the well prior to testing was 113.51 ft btc, which was measured using a Lufkin steel tape (serial # L300-15).

Groundwater was pumped from the well utilizing a Grundfos, Inc., 5-hp submersible pump (model # 252 50-26), which was set at a depth of

approximately 360 ft btc. Discharge flow rates were monitored utilizing a calibrated, in-line Micrometer, Inc., flow meter (model # 83-5-573). Instantaneous discharge rates were also periodically field-checked by recording the time required to fill a 5-gal bucket. During the course of the constant-rate pumping test, selected hydrochemical parameters were monitored from discrete samples collected from the surface discharge line. The hydrochemical parameters included: pH, electrical conductivity, Eh, temperature and turbidity. Results of the hydrochemical parameter field analysis, as well as other salient hydrologic data collected during the test are contained in Appendix A.

4.1.1.4 Constant-Rate Pumping Test Analysis

The constant-rate pumping test drawdown and recovery data were analyzed utilizing the methods described in Section 3.1. Briefly described, the analysis procedure included the following steps:

1) Diagnostic analysis of the drawdown and recovery water-level response using a log-log pressure change and pressure change derivative plot.

2) Quantitative semi-log analysis of the radial flow portion of the drawdown and recovery water-level data record, as indicated from the log-log pressure derivative plot.

Drawdown Analysis. Figure 4.4 shows the log-log drawdown data and drawdown data derivative plot for the constant-rate pumping test. Because of the inherent "noise" in drawdown data due to flow variability that is common in constant-rate tests, an L-spacing (i.e., the data log spacing) of 0.3 was used in calculation of the drawdown derivative. It should be noted that the log-log drawdown data does not exhibit the unit slope pattern characteristic of wellbore storage. However because of the lack of early-time data (i.e., prior to t = 10 min) and the "noise" exhibited in the drawdown data, more dependence was placed on the drawdown data derivative plot for identifying the presence of wellbore storage effects.

As indicated by the drawdown derivative plot in the figure, almost all the test data are significantly influenced by the presence of wellbore storage effects. Only data during the later stages of the test (i.e., t > than

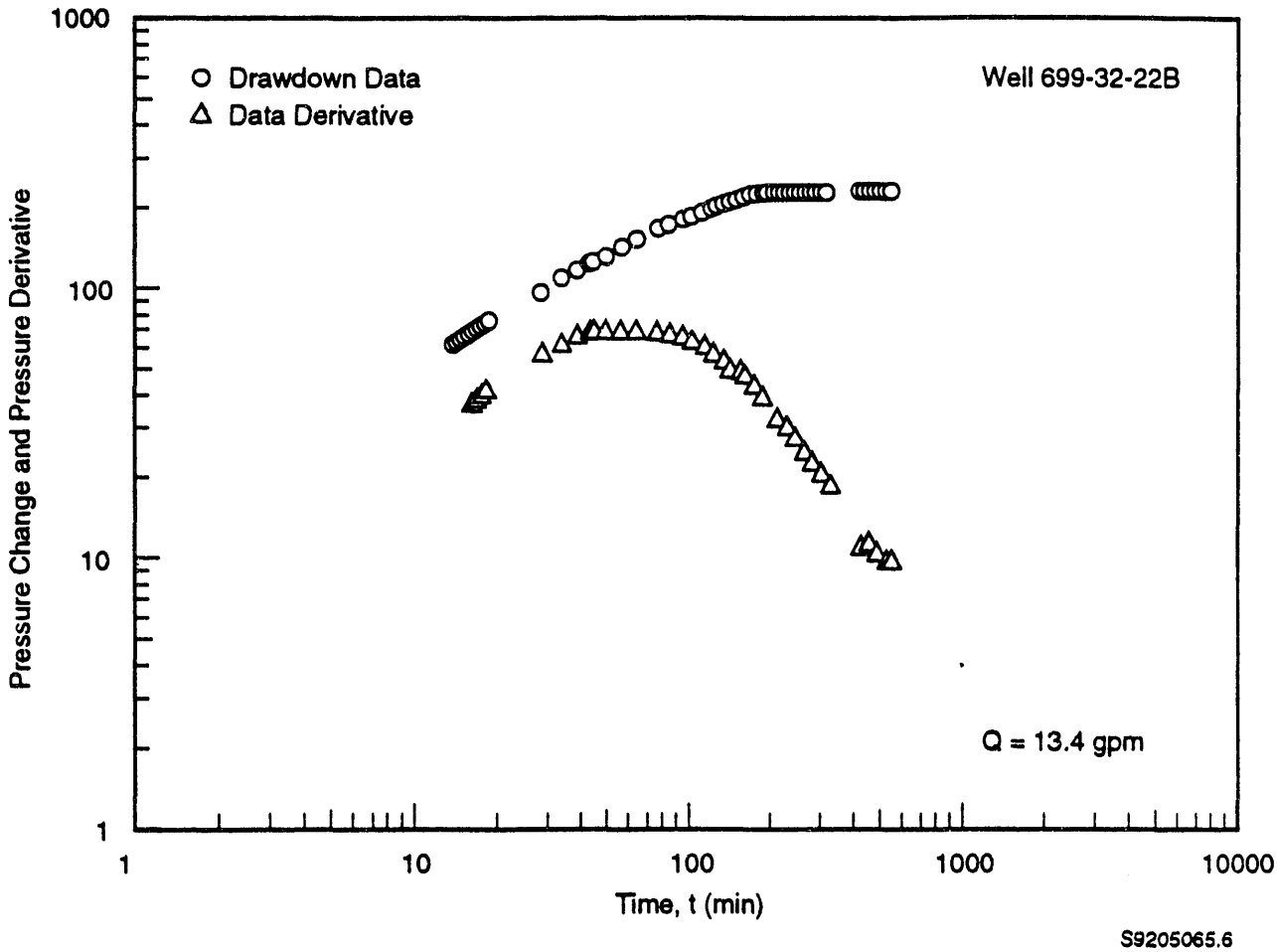

FIGURE 4.4. Diagnostic Constant-Rate Test Drawdown Analysis for the Elephant Mountain Basalt Interflow Zone, at Well 699-32-22B

500 min) appear to "approach" radial flow conditions. Although only radial flow test data can be analyzed utilizing straight-line solution techniques, data after 500 min during the test were analyzed with the Cooper and Jacob (1946) method to provide a qualitative estimate of transmissivity for the test. As indicated in Figure 4.5, a transmissivity estimate of 34 ft^2/d (3.2 m^2/d) was obtained from the straight-line analysis. This estimate is considered to be slightly lower than the actual transmissivity value, since the semi-log, straight-line slope would be greater for the time period immediately before radial flow conditions are established.

Recovery Analysis. Figure 4.6 shows the log-log recovery data and recovery data derivative plot following the constant-rate pumping test. In contrast to the drawdown derivative analysis, a smaller L-spacing of 0.2 was

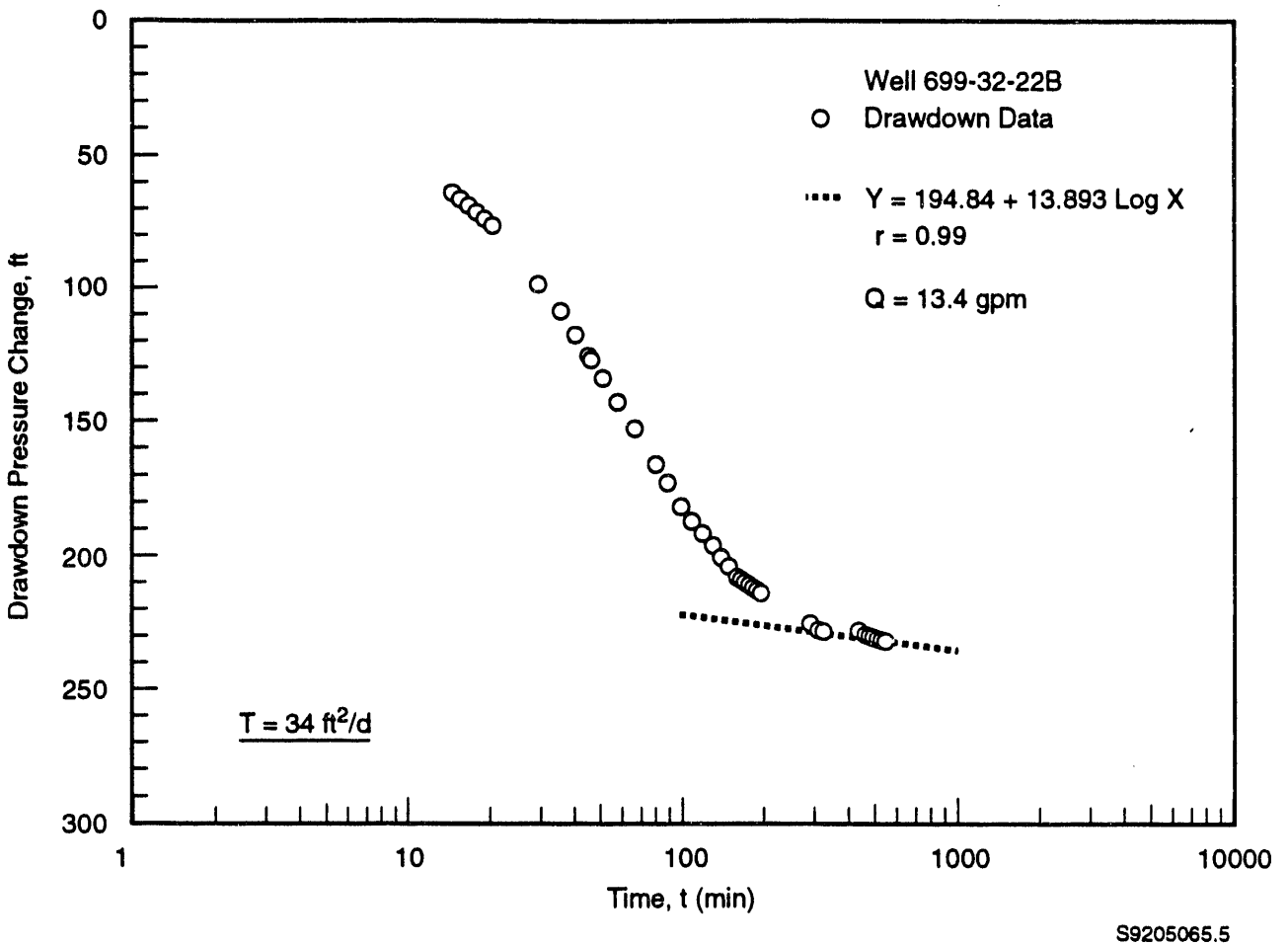

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FIGURE 4.5. Semi-Logarithmic, Straight-Line Analysis of Constant-Rate Test Drawdown Data for the Elephant Mountain Basalt Interflow Zone, at Well 699-32-22B

used in the calculation of the recovery derivative. The lower L-spacing value was selected based on the lower data variability exhibited during the recovery period. The recovery derivative was calculated using the modified Horner time function following the procedure outlined in Bourdet et al. (1989). Using modified Horner time accounts for the length of the drawdown time period, and allows recovery plots to be analyzed with drawdown type curves. Modified Horner time, Δt_e, is defined by Agarwal (1980) as:

$$\Delta t_e = (t_p \times \Delta t)/(t_p + \Delta t) \qquad (10)$$

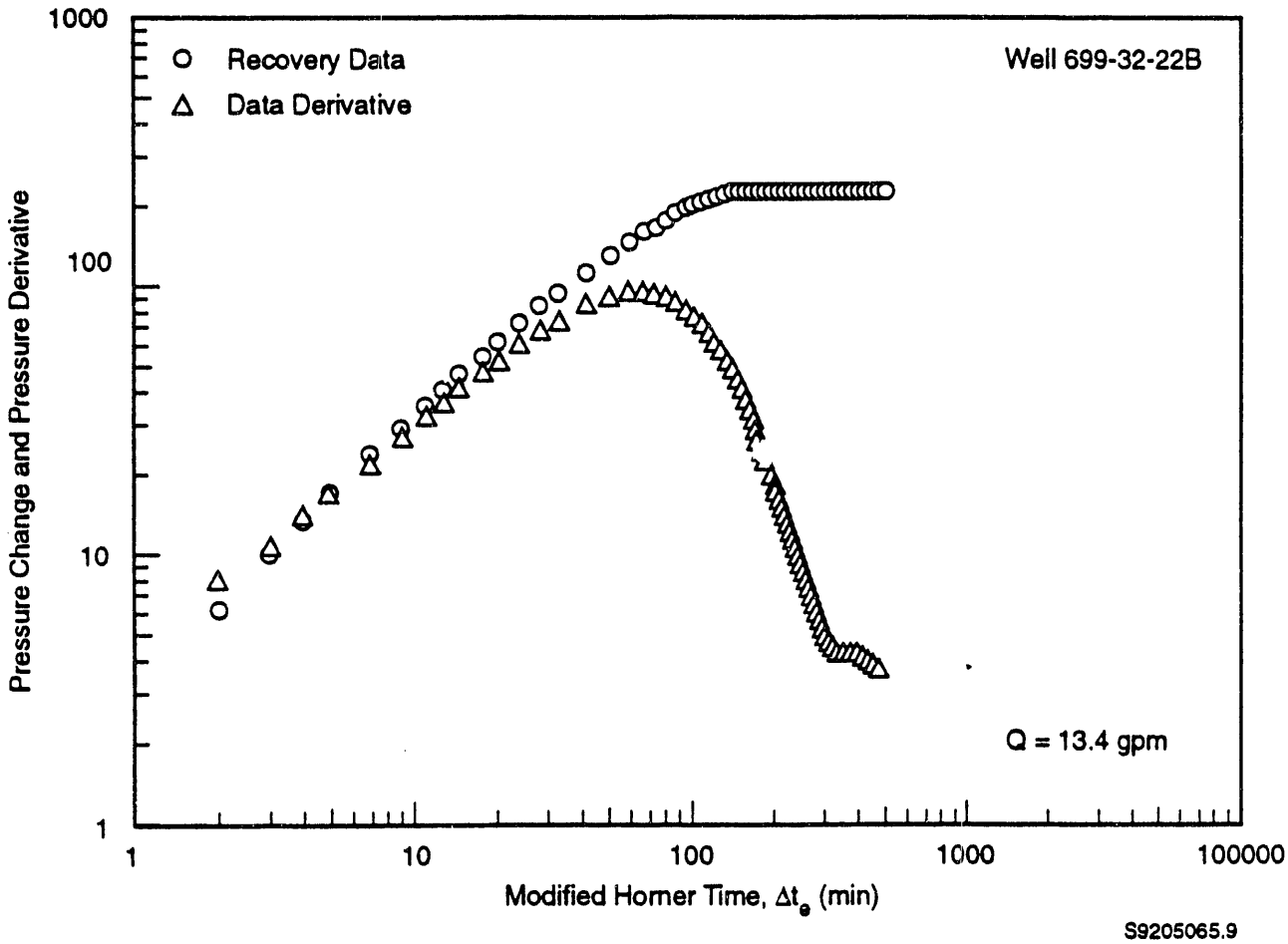

FIGURE 4.6. Diagnostic Constant-Rate Test Recovery Analysis for the Elephant Mountain Basalt Interflow Zone, at Well 699-32-22B

where t_p = duration of the pumping test (T)

Δt = time since pumping terminated (T)

[Note: "un-modified" Horner time equals $(t_p/(t_p + \Delta t)]$

As was the case for the constant-rate drawdown phase, the recovery derivative plot shown in the Figure 4.6 indicates that most of the recovery test data is significantly influenced by the presence of wellbore storage effects. Only data during the later stages of the test (i.e., Δt_e > than 400 min) appear to "approach" radial flow conditions.

Recovery data for modified Horner times greater than 400 minutes were analyzed with the Theis (1935) recovery method to provide a quantitative

estimate of transmissivity for the test interval. As indicated in Figure 4.7, an estimate of 51 ft^2/d (4.7 m^2/d) was obtained from the straight-line analysis.

4.1.1.5 Hydraulic Property Summary

Results from slug tests and the constant-rate pumping test conducted for the test interval provided an estimate range for transmissivity ranging between 15 ft^2/d (1.4 m^2/d) and 51 ft^2/d (4.7 m^2/d). Because of the low stress levels employed during slug testing, hydraulic property estimates obtained from the slug tests are considered to be reflective of test interval conditions in the near vicinity of the borehole. The storativity estimate obtained from slug testing (i.e., 10^{-3}) is considered to be qualitative in nature. This is attributed to the fact that the data derivative responses did not fully define the derivative peak region, which is required for quantitative storativity determination. It is interesting to note, however, that the storativity estimate of 10^{-3} obtained from slug test analysis falls within the higher range commonly attributed to confined aquifer systems (Heath 1983).

The best estimate for transmissivity for the Elephant Mountain basalt interflow zone at well 699-32-22B is 51 ft^2/d (4.7 m^2/d), which was obtained from analysis of recovery data following completion of the constant-rate pumping test. The constant-rate recovery analysis is considered to be superior to analysis of the drawdown phase, since the transient effects of pumping-rate variability do not significantly affect recovery buildup data. It should be noted, however, that the qualitative drawdown analysis provided a transmissivity estimate of 34 ft^2/d (3.2 m^2/d), which is comparable to the recovery analysis result. As indicated previously, transmissivity estimates based on the straight-line analysis of the constant-rate drawdown and recovery test data are expected to underestimate the actual test interval transmissivity. This is due to the fact that radial flow conditions were not fully established prior to the termination of the constant-rate test.

4.1.2 Rattlesnake Ridge Interbed

As discussed in Section 4.1, hydraulic characterization of the Rattlesnake Ridge interbed was planned after final well completion. Attempts to develop and test the Rattlesnake Ridge interbed at well 699-32-22B, however, were aborted when field test information obtained during well development indicated potential problems with the well completion (i.e., significant decrease in groundwater

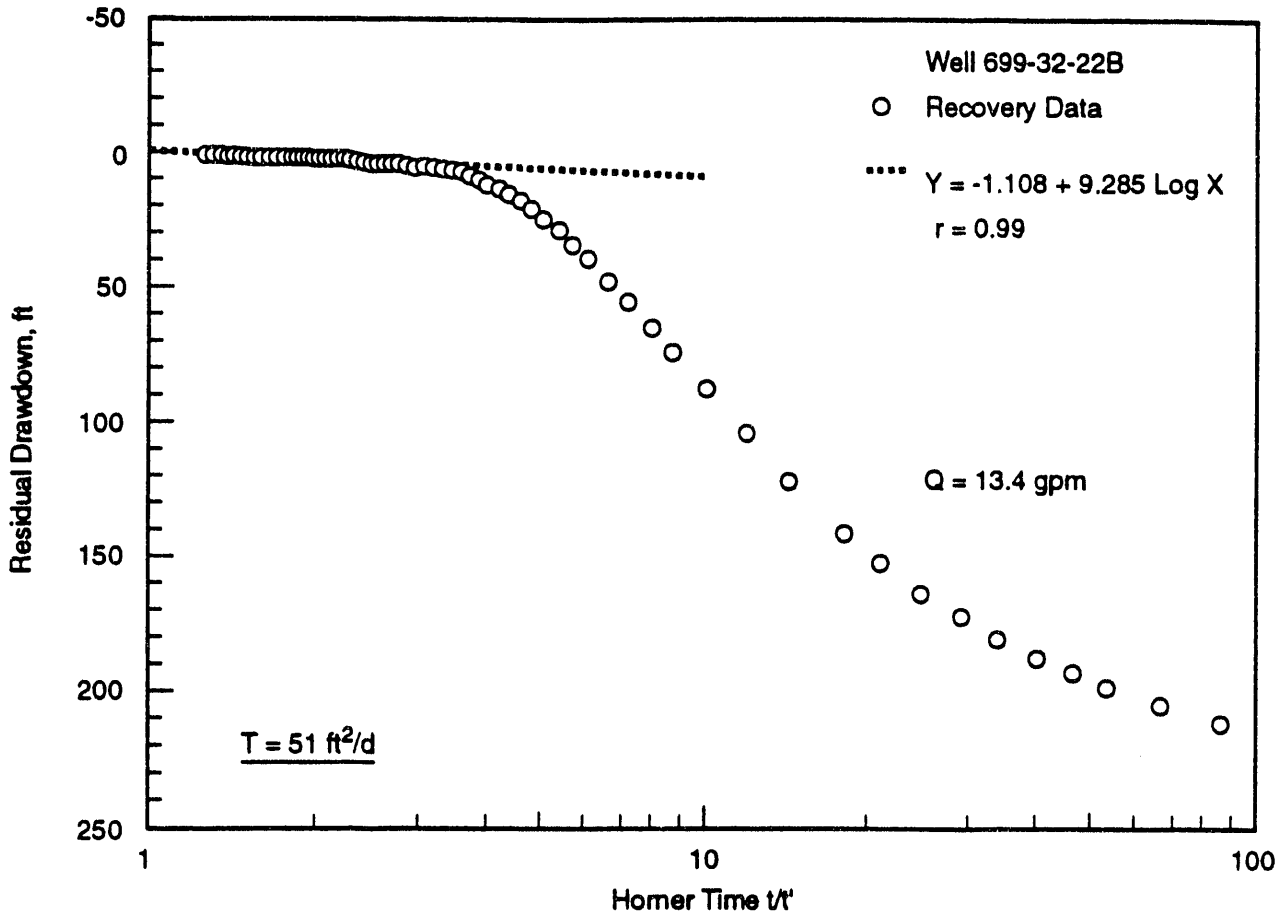

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FIGURE 4.7. Semi-Logarithmic, Straight-Line Analysis of Constant-Rate Test Recovery Data for the Elephant Mountain Basalt Interflow Zone, at Well 699-32-22B

production and presence of bentonite sealing material in discharge water). Hydraulic characterization activities were suspended until evaluation of the well condition could be resolved. At the time of the report writing, no well remediation or hydraulic characterization activities had been completed.

4.2 WELL 699-42-E9A

As indicated in Figure 2.1, well 699-42-E9A is located east of the Columbia River along the eastern margin of the Hanford Site, immediately east of Savage Island. The Hanford Site coordinates for the well site are 41,970 ft north and 8,350 ft west (Lambert coordinates: 136,324.81 m north,

592,435.40 m east). Elevation of the surface control datum (brass cap) is 384.54 ft (117.21 m) above mean sea level (msl).

Well 699-42-E9A was designed to be completed as a nested, dual-well monitoring facility within the uppermost aquifer, (i.e., within the Ringold Formation). Characterization results, including static, pre-test hydraulic head elevation, obtained from well 699-42-E9A were designed to serve as comparison with results obtained at nearby well 699-42-E9B, which was designed to provide information from the underlying upper-confined aquifer system.

Drilling at well 699-42-E9A was initiated on November 12, 1990, and continued until a depth of 231.9 ft below land surface (bls) was reached on December 13, 1990. As listed in Table 2.1, hydraulic testing was attempted for two depth zones within the Ringold Formation encountered at the well site: (1) depth interval = 195 - 232 ft bls, and (2) depth interval = 210 - 232 ft bls. Hydraulic testing was conducted for the first depth zone after the well had reached total depth (i.e., 232 ft bls), and prior to final well completion. Hydraulic testing of the second depth interval was attempted within the lower monitoring well after well completion activities had been finalized. Hydraulic testing of the lower monitoring well, however, proved to be unsuccessful due to lodging of the submersible pump within the well casing. Subsequent efforts to remove the pump caused severe damage to the well casing. As a consequence, the lower monitoring well was plugged and abandoned, and no additional hydraulic testing was attempted at the well site. A detailed description of the drilling history and well completion details, as well as results from geological, geophysical and hydrochemical characterization activities at the well site, will be reported in a subsequent PNL report.

4.2.1 Ringold Formation: Test Depth Interval - 195 to 232 ft

The depth interval of 195 to 232 ft bls within the Ringold Formation was tested in an open borehole condition, prior to final well completion activities. Drilling of this borehole section was accomplished utilizing the cable-tool drilling method, with an 8-in. drilling bit diameter. Eight-inch well casing was driven during drilling to a depth of 195 ft bls. The borehole diameter within the test interval (as indicated by the caliper log shown in

Figure 4.8) ranged between 8.93 and 13.78 in., and averaged 10.43 in. Figure 4.8 shows the well configuration during hydraulic characterization of the Ringold Formation depth interval 195 to 232 ft. Hydraulic tests utilized during the characterization included a slug injection and withdrawal test, which were conducted on December 18, 1990. The results from slug testing were to serve as input information for the design of a more quantitative constant-rate pumping test that was to be completed on the lower section of the Ringold Formation, following completion of the well. Pertinent field test data information utilized in the analysis of the slug injection and withdrawal tests are contained in Appendix B.

4.2.1.1 Slug Injection and Withdrawal Test Descriptions

To provide an initial estimate of hydraulic properties for the lower section of Ringold Formation encountered at well 699-42-E9A, slug injection and withdrawal tests were conducted between 1020 hr and 1146 hr, and 1152 hr and 1250 hr, December 18, 1990, respectively. The slug tests were initiated by suddenly immersing (for the injection test) and removing (for the withdrawal test) a slugging rod of known volume (0.692 ft^3) from the water column in the well. The sudden emersion and removal of the slugging rod caused an induced stress level, H_o, of approximately 1.98 ft of water to be applied at the initiation of the slug tests. Pressure recovery measurements within the well were monitored with a downhole Insitu, Inc. pressure transducer (0 to 10 psi) and recorded on an Insitu, Inc., Hermit datalogger (model # SE1000B, serial # 1KB 701). The transducer was installed at a depth of approximately 13.2 ft below the static water level within the well, which was measured prior to testing at a depth of 29.28 ft below the top of the 8-in. casing (btc) (356.34 ft msl).

4.2.1.2 Slug Test Analyses

The slug injection and withdrawal tests were analyzed utilizing the Cooper et al. (1967) and Ostrowski and Kloska (1989) methods described in Section 3.2. Figures 4.9 and 4.10 show the slug test data and data derivative analysis for the slug injection and withdrawal tests, respectively.

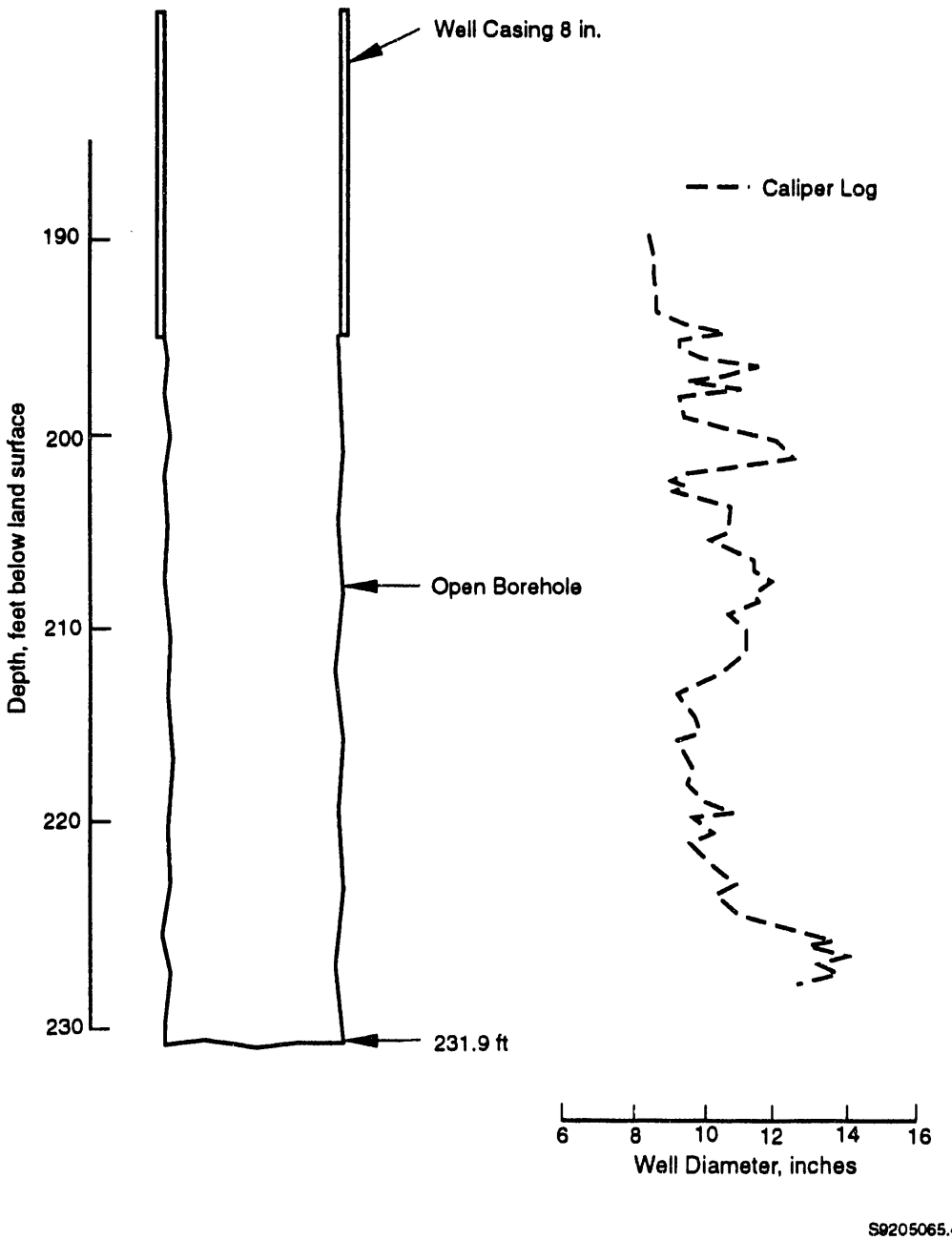

FIGURE 4.8. Configuration of Well 699-42-E9A at Time of Hydraulically Testing the Ringold Formation Depth Interval 195 to 232 ft

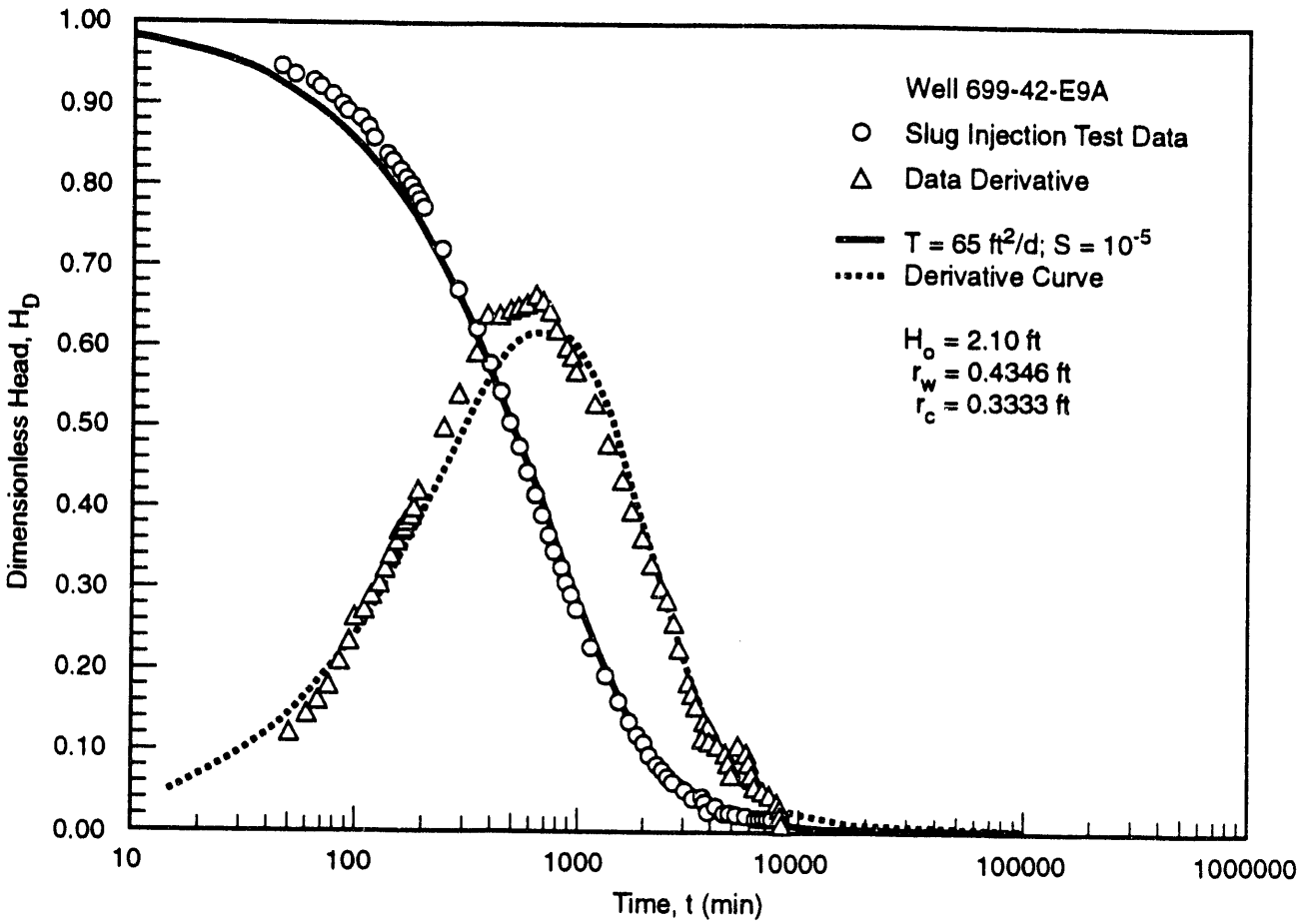

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FIGURE 4.9. Slug Injection Test Analysis for the Ringold Formation Depth Interval 195 to 232 ft, at Well 699-42-E9A

The slug injection and withdrawal tests displayed slightly different responses, with the slug withdrawal test exhibiting more variability (i.e., early-time oscillations, changes in recovery rate, etc.). The cause for the dissimilarity in test response is believed to be attributable to the possibility that the part of the open borehole test section may have "sloughed" into the borehole a short time after removal of the slugging rod during the slug withdrawal test. Evidence for this includes a noticeable change in recovery rate (i.e., a slower rate) detected at approximately 1 min into the slug withdrawal test (see dimensionless head and derivative response in Figure 4.10), and the presence of approximately 4 ft of fill material that may have impeded groundwater flow from a lower permeable sand unit, which was encountered near the bottom of the borehole.

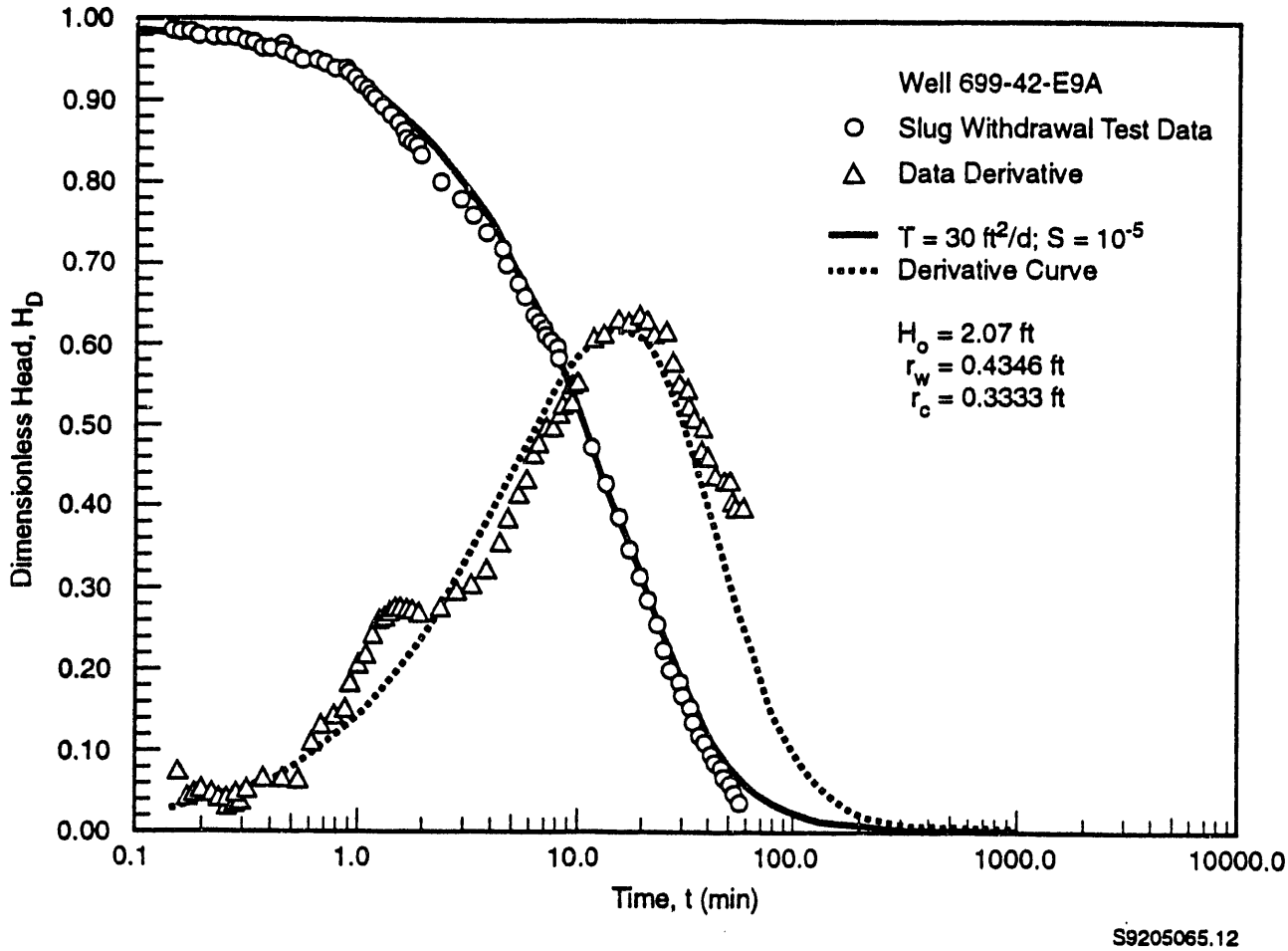

FIGURE 4.10. Slug Withdrawal Test Analysis for the Ringold Formation Depth Interval 195 to 232 ft, at Well 699-42-E9A

Type-curve analysis of the slug test responses indicate transmissivity estimates of 65 ft^2/d (19.8 m^2/d) and 30 ft^2/d (9.1 m^2/d) for the slug injection and withdrawal tests, respectively for a common storativity value of 10^{-5}. The slug test data were matched with slug test and slug test derivative type curves, which were obtained using the modified Novakowski (1990) program described in Section 3.2. Because of the low stress levels utilized during the slug tests, the calculated hydraulic properties are considered to be only representative of formation conditions in the immediate vicinity of the well location. Pertinent analysis parameters utilized in the test analysis include: induced stress level, H_o = 2.10 ft (slug injection test) and 2.07 ft

(slug withdrawal test); radius of the well casing, r_c = 0.3333 ft; and radius of the well test interval, r_w = 0.4346 ft (based on averaging the caliper log response within the test interval).

Stress levels, H_o, for each slug test were calculated by extrapolation of the linear early-time test response, back to the time of test initiation. This provided a calculated stress level of 2.10 ft and 2.07 ft for the slug injection and slug withdrawal tests, respectively. These slug stress calculations compare well with the estimated displacement height for the slugging rod of 1.98 ft.

The analytical solution (Cooper et al. 1967) on which the modified Novakowski (1990) program is based is strictly valid only for tests conducted in confined aquifers. Their solution, however, yields acceptable results for unconfined aquifer tests provided that the saturated thickness of the unconfined aquifer does not change significantly (Walter and Thompson 1982) and radial flow conditions exist. These conditions were met for these tests.

In addition, the slug test type-curve analysis method used in Figures 4.9 and 4.10 is strictly valid only for fully penetrating wells. However, as indicated by Cooper et al. (1967) few wells completely penetrate an aquifer, and for wells partially penetrating stratified aquifers (where vertical hydraulic conductivities are commonly less than horizontal hydraulic conductivities) it can be assumed that two-dimensional flow conditions exist during the test. For these situations, "... the determined value of transmissivity (T) would represent approximately the transmissivity of the part of that part of the aquifer in which the well is screened..." (Cooper et al. 1967). Based on the analysis results and an open borehole test length of 37 ft, an equivalent hydraulic conductivity, K_e, for the lower Ringold Formation test section ranging between 0.8 ft/d (0.24 m^2/d) to 1.8 ft/d (0.55 m^2/d)is indicated.

For test analysis comparison, slug injection test data were also analyzed utilizing the procedure described in Bouwer and Rice (1976) and Bouwer (1989). This analysis procedure (which is based on the Thiem equation) was developed for unconfined aquifer conditions and accounts for the effects of

partial penetration at the stress well. For this analysis procedure, equivalent hydraulic conductivity for the interval tested is equal to:

$$K_e = \frac{r_c^2 \ln(R_e/r_w) \ln(y_o/y_t)}{2 L_e t} \quad , \qquad (11)$$

where r_c = radius of the well casing (ft)

r_w = radius of the well (ft)

R_e = effective test radius (ft)

y_o = pressure difference from static pressure at time t_o (lb/in²)

y_t = pressure difference from static pressure at time t (lb/in²)

L_e = screened test interval length (ft)

t = test time at y_t (sec).

For the case in which the distance (L_w) from the water table to the bottom of the test interval is equal to the aquifer thickness (H):

$$\ln R_e/r_w = [(1.1/\ln(L_w/r_w)) + C/(\ln\{L_e/r_w\})]^{-1} \qquad (12)$$

For the case in which $L_w < H$:

$$\ln R_e/r_w = [(1.1/\ln(L_w/r_w)) + (A + B \ln\{(H-L_w)/r_w\}/(\ln(L_e/r_w)]^{-1} \qquad (13)$$

where A, B, and C = dimensionless parameters that are functions of L_w/r_w.

This analysis method has been commonly used for slug tests conducted in the unconfined aquifer on the Hanford Site. Bouwer and Rice (1976) indicate that their analysis method should provide estimates of transmissivity that are of the "same order" as those calculated with the procedure of Cooper et al. (1967). It should also be noted that this method is dependent on accurate "early-time" data. The slug withdrawal test was not analyzed with this

method, because of this dependence and the previously noted non-formational responses that occurred during the early stages of the test.

Figure 4.11 shows the analysis results for the slug injection test based on the Bouwer and Rice (1976) method. As indicated, a hydraulic conductivity value of 1.4 ft/d (0.43 m/d) ($T = 52\ ft^2/d$ for a test interval thickness of 37 ft) was obtained based on the following input parameters: $H = 203$ ft (static water level to the bottom of the borehole); $r_c = 0.3333$ ft; $\ln (R_e/r_w) = 4.519$ (calculated from Equation 4 and Figure 2 in Bouwer (1989) for $L_e/r_w = 85.14$); $y_o = 2.1$ ft; $y_t = 0.125$ ft (Figure 4.11); $L_e = 37$ ft; and, $t = 20$ min (Figure 4.11).

The Bouwer and Rice (1976) method is based on the Thiem steady-state solution, which does not account for aquifer elastic storage during testing. In addition, the dimensionless parameters A, B, and C that are used in the analysis procedure (Equations 12 and 13) are based on empirical relationships developed from electric analog studies that relate effective test radius, R_e, with various test geometries. Because of the empirical nature of the developed relationships, Bouwer and Rice (1976) cite a relative accuracy for their technique to within 10% to 25%.

4.2.1.3 Hydraulic Property Summary

Results from slug tests conducted for the test interval provided an estimated range for transmissivity between 30 ft^2/d (2.8 m^2/d) and 65 ft^2/d (6.0 m^2/d). Because of the low stress levels employed during slug testing, hydraulic property estimates obtained from the slug tests are considered to be reflective of test interval conditions in the near vicinity of the borehole. The storativity estimate obtained from slug testing (i.e., 10^{-5}) falls within the range commonly attributed to confined aquifer systems (Heath 1983). Low storativity values indicative of locally confining conditions have been noted previously for the Ringold Formation and parts of the uppermost aquifer on the Hanford Site (e.g., DOE 1988). Because of the presence of overlying clay and silt horizons encountered at the test site and the basal location of the test section within the Ringold Formation, the storativity value of 10^{-5} obtained from the slug test analysis appears to be a reasonable estimate.

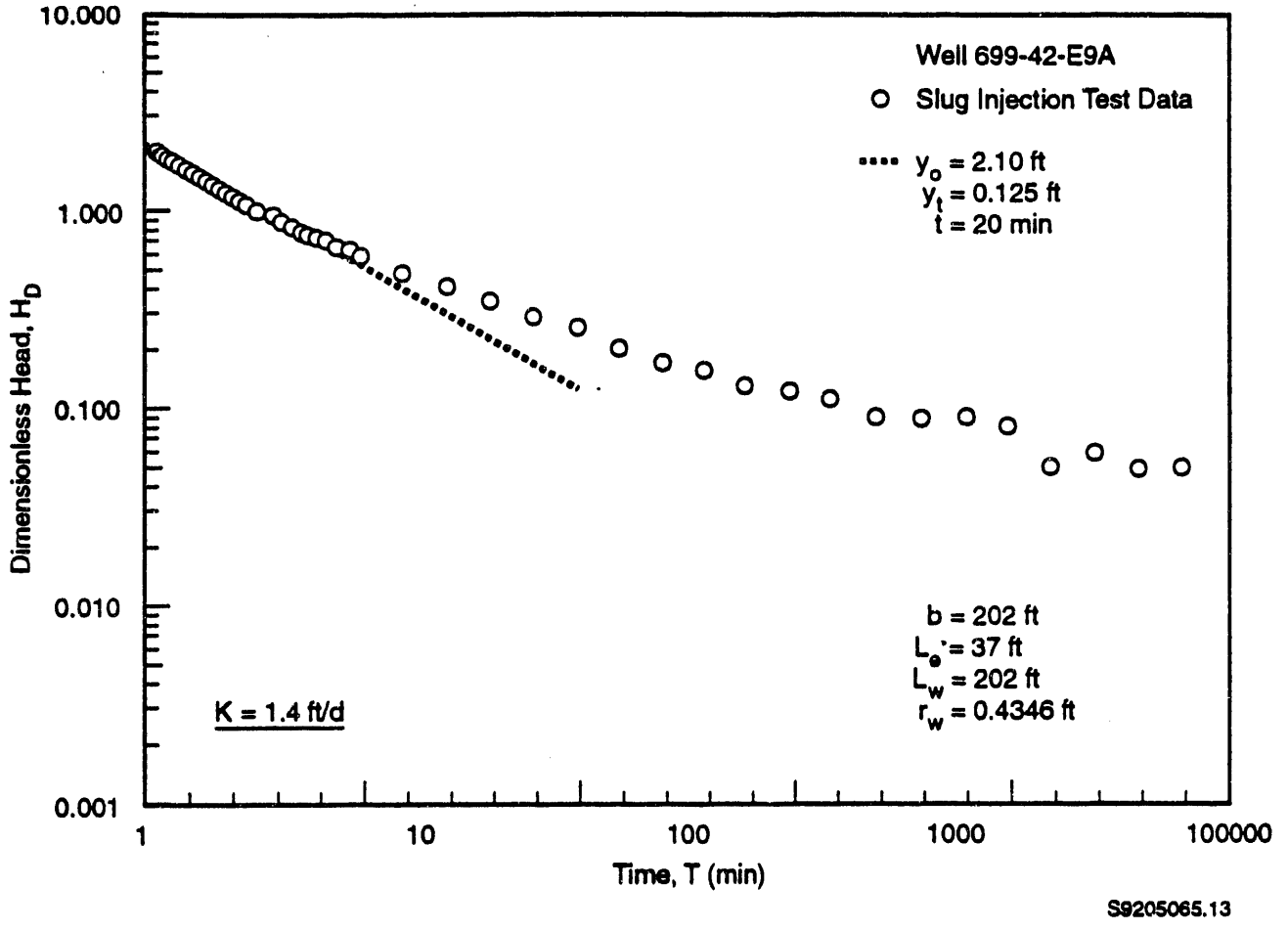

FIGURE 4.11. Slug Injection Test Analysis for Stress Well 699-42-E9A Using the Bouwer and Rice (1976) Analysis Method

The best estimate for transmissivity for the Ringold Formation test section at well 699-42-E9A is 65 ft^2/d (6.0 m^2/d), which was obtained from analyzing the slug injection test results using the Cooper et al. (1967) and Ostrowski and Kloska (1989) analysis methods. As previously discussed, the slug injection test results are considered to be more representative of actual test formation conditions, due to possible test condition complications that may have occurred during the slug withdrawal testing. In addition, the slug injection test analysis based on the Cooper et al. (1967) and Ostrowski and Kloska (1989) methods is considered to be superior to Bouwer and Rice (1976) technique, due to the latter method's lack of accounting for test formation elastic storage and the uncertainty associated with empirical relationships used in the analysis.

4.2.2 Ringold Formation: Test Depth Interval - 213 to 232 ft

As discussed previously, slug testing results obtained for the open borehole section within the Ringold Formation, were to provide information for designing a constant-rate pumping test, which would be initiated following completion of the monitoring well. Following completion of the monitoring well facility, however, a submersible pump used for developing the well became lodged at a depth of approximately 176 ft bls. Subsequent efforts to retrieve the submersible pump caused the monitoring well casing to be severely damaged at a depth of approximately 155 ft bls. Annular sealing material (bentonite) then entered the monitoring well casing. Because of the severity of the well damage, the lower monitoring well was plugged and abandoned, and no additional hydraulic characterization for the lower Ringold Formation was attempted at this well site. Details concerning well completion, and well damage and abandonment will be reported in a subsequent PNL document.

4.3 WELL 699-42-E9B

As indicated in Figure 2.1, well 699-42-E9B is located east of the Columbia River along the eastern margin of the Hanford Site, immediately east of Savage Island. The Hanford Site coordinates for the well site are 41,775 ft north and 8,452 ft west (Lambert coordinates: 136,265.43 m north, 592,466.69 m east). Elevation of the surface control datum (brass cap) is 383.52 ft (116.90 m) above mean sea level (msl).

Well 699-42-E9B was designed to be completed within the upper-confined aquifer, (i.e., within the Rattlesnake Ridge interbed). Characterization results obtained from well 699-42-E9B were to be used for comparison with results obtained at nearby companion well 699-42-E9A, which was designed to provide information for the overlying unconfined aquifer system.

Drilling was initiated at the site on February 14, 1991, and continued until a depth of 388.7 ft below land surface (bls) was reached on March 26, 1991. As listed in Table 2.1, hydraulic testing was attempted for two zones encountered at the well site: 1) an Elephant Mountain Basalt interflow zone (test interval = 232 - 285 ft bls) and 2) the Elephant Mountain/Pomona Basalt flow contact zone (test interval = 348 - 389 ft bls). Hydraulic testing was

conducted for the first zone during a temporary cessation of drilling the well (i.e., borehole depth = 285 ft bls). Hydraulic testing for the second zone was conducted after termination of drilling and after well completion activities were finalized. The second test zone was originally designed to be the Rattlesnake Ridge interbed, which was to be tested following well completion; however, the sedimentary interbed was not encountered during the course of drilling. Final hydraulic characterization and monitoring well completion activities were then modified to test the equivalent stratigraphic-time horizon, which is the Elephant Mountain/Pomona Basalt flow contact zone. A detailed description of the drilling history and well completion details, as well as results from geological, geophysical and hydrochemical characterization activities at the well site, will be reported in a subsequent PNL report.

4.3.1 Elephant Mountain Basalt Interflow Zone

The Elephant Mountain basalt interflow zone was hydraulically tested during a temporary cessation of well drilling. During the course of drilling through the depth section 243 to 250 ft bls (i.e., on March 15, 1991), evidence in the drilling fluid circulation and drilling penetration rates suggested that the basalt interflow contact encountered in this interval was pervious. Drilling of this borehole section was accomplished utilizing the air-hammer rotary method, with a drilling bit diameter of 9-7/8 in. The borehole diameter within the test interval (as indicated by the caliper log shown in Figure 4.12) ranged between 10.01 and 25.11 in., and averaged 11.65 in. Of particular note is the significant increase in borehole diameter which occurred within the basalt interflow zone, at a depth of approximately 246 ft bls.

Figure 4.12 shows the well configuration during hydraulic characterization of the Elephant Mountain basalt interflow zone. Hydraulic tests utilized during the characterization included two slug withdrawal tests, and a constant-rate pumping test, which were conducted during the time period of March 18 and 19, 1991.

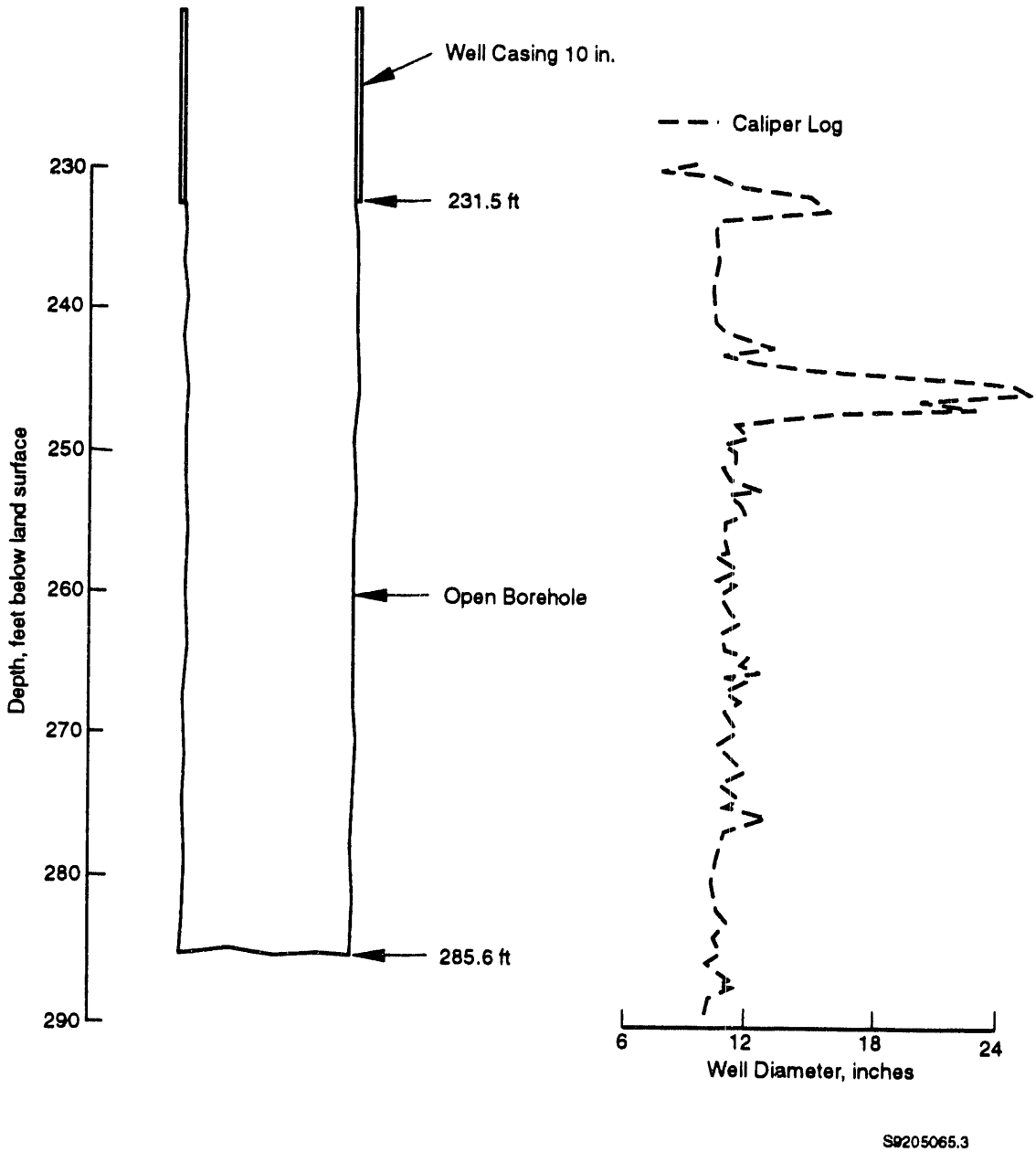

FIGURE 4.12. Configuration of Well 699-42-E9B at Time of Hydraulically Testing the Elephant Mountain Basalt Interflow Zone

4.3.1.1 Slug Withdrawal Test Descriptions

To provide an initial estimate of hydraulic properties for the test interval, two slug withdrawal tests were conducted between 1542 hr and 1648 hr, March 18, 1991. The slug tests were initiated by suddenly removing a slugging rod of known volume (0.794 ft^3) from the water column in the well. The sudden removal of the slugging rod caused an induced stress level, H_o, of approximately 1.46 ft of water to be applied at the initiation of each slug test. Pressure recovery measurements within the well were monitored with a downhole Druck, Inc., pressure transducer (0 to 10 psi, model # 950/TI, serial # 382982) and recorded on a Campbell Scientific, Inc., datalogger (model # CR10, serial # 1207). The transducer was installed at a depth of approximately 41 ft below the top of the 10 in. casing (btc). The static water level within the well prior to testing was 26.65 ft btc (358.31 ft msl), which was measured using a Lufkin steel tape (serial # L300-16).

4.3.1.2 Slug Test Analyses

The slug withdrawal tests were analyzed utilizing the Cooper et al. (1967) and Ostrowski and Kloska (1989) methods described in Section 3.2. Figure 4.13 shows the slug withdrawal data and data derivative responses for both withdrawal tests (i.e., slug withdrawal test #1 and slug withdrawal test #2). As indicated, nearly identical data and data derivative responses were exhibited for both tests. Calculated stress levels, based on projection of the linear early-time test response back to the time of test initiation, equalled 1.393 ft and 1.385 ft for slug withdrawal tests #1 and #2, respectively. The calculated slug stress levels compare favorably with the estimated displacement height for the slugging rod of 1.46 ft.

Figure 4.14 shows test data and data derivative analysis for slug withdrawal test #1. Because of their demonstrated close similarity, analysis of slug withdrawal test #1 and #2 was expected to produce very similar results. As indicated, a transmissivity of 1100 ft^2/d (102.2 m^2/d) and storativity of 10^{-4} provide good matches of the observed slug test and slug test derivative responses for both tests. The slug test and slug test derivative type curves were obtained using the modified Novakowski (1990) program described in

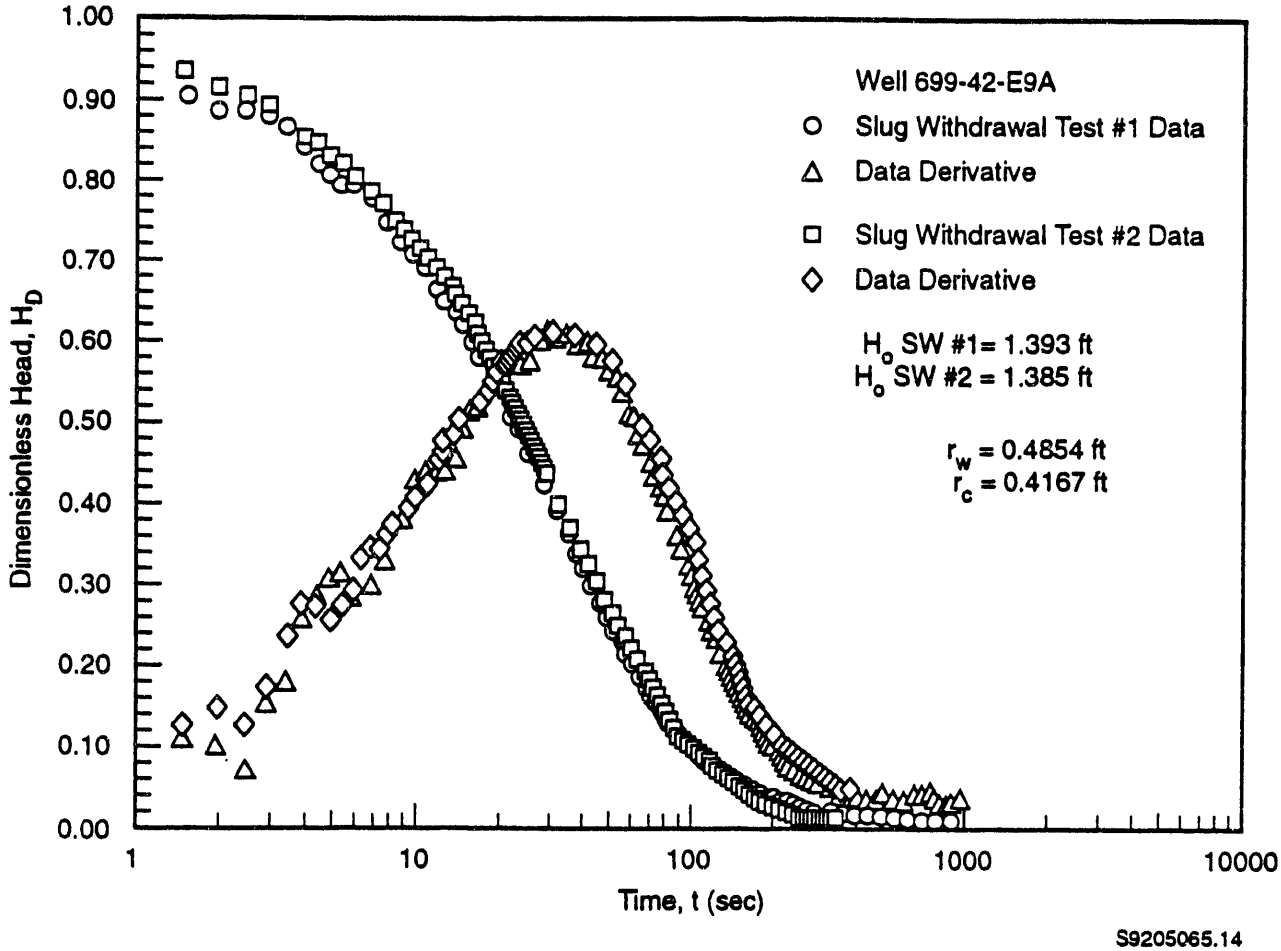

FIGURE 4.13. Test Data and Data Derivative Responses for Slug Withdrawal Tests Conducted for the Elephant Mountain Basalt Interflow Zone, at Well 699-42-E9B

Section 3.2. Because of the low stress levels utilized during the slug tests, the hydraulic properties are considered to be only representative of formation conditions in the immediate vicinity of the well location. Pertinent analysis parameters utilized in the analysis of slug withdrawal test #1 include: induced stress level, H_o = 1.395 ft; radius of the well casing, r_c = 0.4167 ft; and well radius in the test interval, r_w = 0.4854 ft (average value from caliper log results). Pertinent field test data acquired during the slug withdrawal tests are contained in Appendix C.

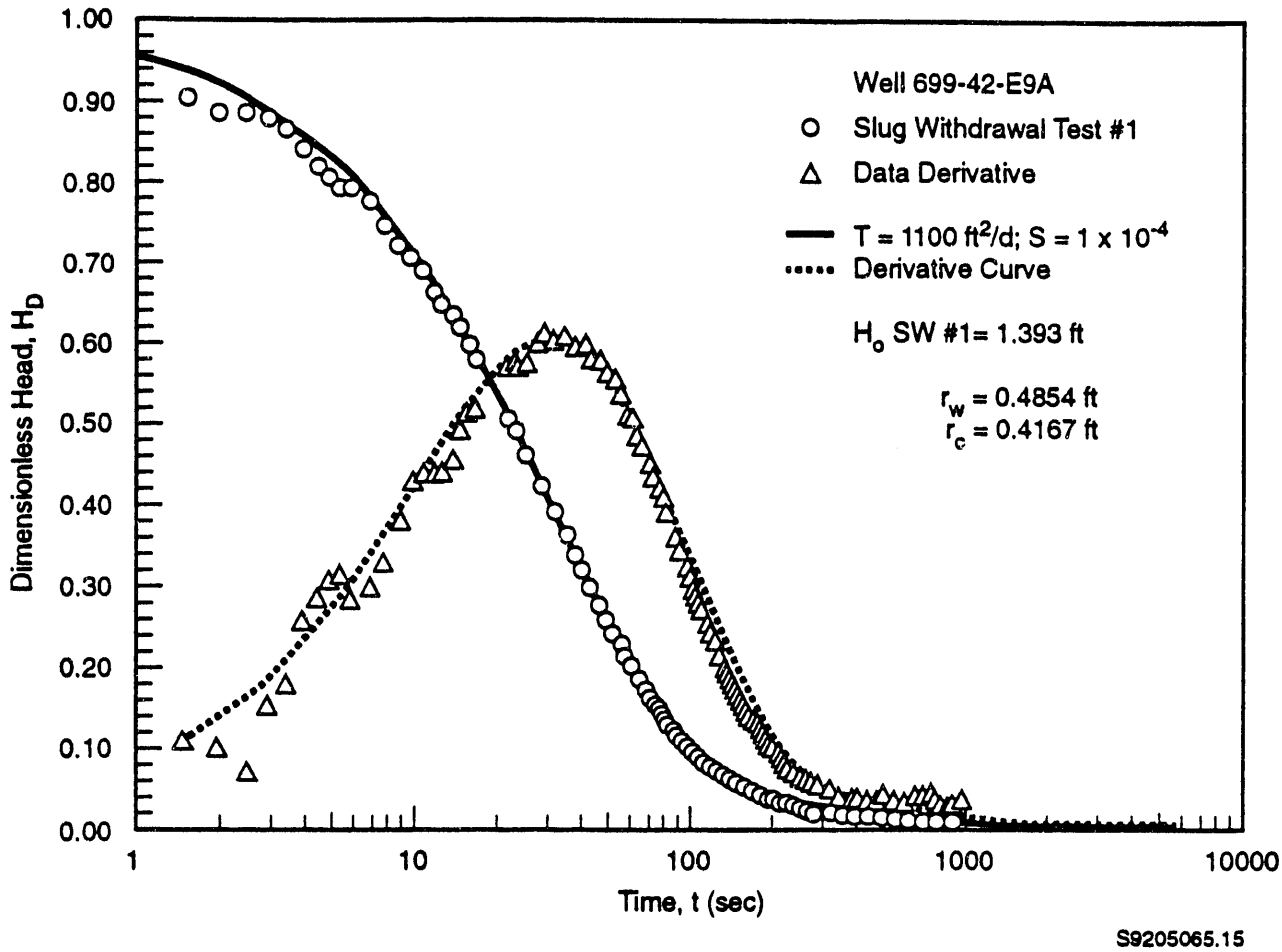

FIGURE 4.14. Slug Withdrawal Test Analysis for the Elephant Mountain Basalt Interflow Zone, at Well 699-42-E9B

4.3.1.3 Constant-Rate Pumping Test Description

To provide an estimate of hydraulic properties for the test interval for a larger area surrounding the well site, a constant-rate pumping test was conducted between 1816 hr, March 18 and 1145 hr, March 19, 1991. The constant-rate pumping test was performed using a submersible pump. Flow rate was manually controlled with a valve in the surface discharge line to maintain a uniform discharge rate. Discharge rate varied during the first hours of the test between 48 gpm (i.e., recorded in the first 10 min of the test) and 37 gpm. Recorded average discharge rates during the last 6 hr of the test were more uniform, varying only between 41 and 42 gpm. In total, 43,839 gal

of water were produced from the test interval for an average discharge of approximately 41.8 gpm during the test. Groundwater pumped from the test interval was transported approximately 1000 ft from the well site and discharged to the land surface.

Water-level measurements during the pumping test were monitored with a downhole Druck, Inc. pressure transducer (0 to 10 psi, model # 950/TI, serial # 382982) set at depth setting initially of about 41 ft btc; as well as measured directly with a calibrated Solinst Inc., electric water-level sensor (serial # 11053), and steel tape. The pressure transducer readings were recorded on a Campbell Scientific, Inc. datalogger (model # CR10, serial # 1287). The static water level within the well prior to testing was 26.61 ft btc (358.35 ft msl), which was measured using a Lufkin steel tape (serial # L300-16).

Groundwater was pumped from the well utilizing a Grundfos, Inc., 5-hp 25S submersible pump (model # 224 43-03-70004), which was set at a depth of approximately 82 ft bls. Discharge flow rates were monitored utilizing a calibrated, in-line Micrometer, Inc., flow meter (model # 83-5-573). Instantaneous discharge rates were also periodically field-checked at the end of the discharge line, by recording the time required to fill a 5-gal bucket. During the course of the constant-rate pumping test, turbidity measurements were performed on discrete water samples collected from the surface discharge line. Pertinent hydrologic data collected during the test, including results of the turbidity measurements, are contained in Appendix C.

4.3.1.4 Constant-Rate Pumping Test Analysis

The constant-rate pumping test drawdown and recovery data were analyzed utilizing the methods described in Section 3.1. Briefly described, the analysis procedure included the following steps:

1) Diagnostic analysis of the combined drawdown and recovery water-level response using a log-log pressure change and pressure change derivative plot.

2) Quantitative semi-log analysis of the radial flow portion of the drawdown water-level data record, as indicated from the log-log pressure derivative plot.

Figure 4.15 shows the log-log drawdown data plot for the constant-rate pumping test. It should be noted that early-time drawdown data (i.e., the first 10 minutes of the test) were not recorded due to a data acquisition system malfunction. To help facilitate identification of non-formational test responses (e.g., wellbore storage) during this early-time test period, recovery pressure data collected following termination of the pumping test were utilized. As discussed previously in Section 4.1.1.4, recovery data can be analyzed in similar fashion as constant-rate drawdown data, if the recovery time data are modified using the modified Horner time, Δt_e, relationship presented in Equation 10. Early-time recovery data were utilized in combination with drawdown data to produce a "combined" log-log drawdown data and data derivative plot, as shown in Figure 4.15. The data derivative was calculated using a L-spacing (i.e., the data log spacing) of 0.2.

As shown in Figure 4.15, the (combined) drawdown derivative plot in the figure, shows that the effects of wellbore storage are primarily over after 15 min of the test. Radial flow conditions occur after 15 min into the test and persist until approximately a time of 55 min. The effects of a possible "no-flow" type boundary then are exhibited (i.e., as indicated by the upward deflection of the drawdown derivative), and begin to influence the drawdown test response. The diagnostic drawdown analysis indicates that only data collected during the time period of 15 to 55 min are indicative of radial flow conditions; and consequently, can be analyzed utilizing straight-line solution techniques.

Figure 4.16 shows the semi-log, straight-line analysis of the data set/time period 15 to 55 min using the Cooper and Jacob (1946) method. As indicated, a transmissivity of 690 ft^2/d (64.1 m^2/d) was calculated for the semi-log drawdown analysis. Also clearly indicated in the later stages of the test is the presence of a "no-flow" boundary type response. A no-flow boundary response is represented on semi-log plots by a doubling of the slope indicated during the radial flow period. For the test analysis shown, the radial flow period slope is 2.13 ft per log cycle, while the slope during the semi-log time period that is suspected to be dominated by the presence of a no-flow boundary (i.e., after 500 min) is approximately 4.3 ft per log cycle.

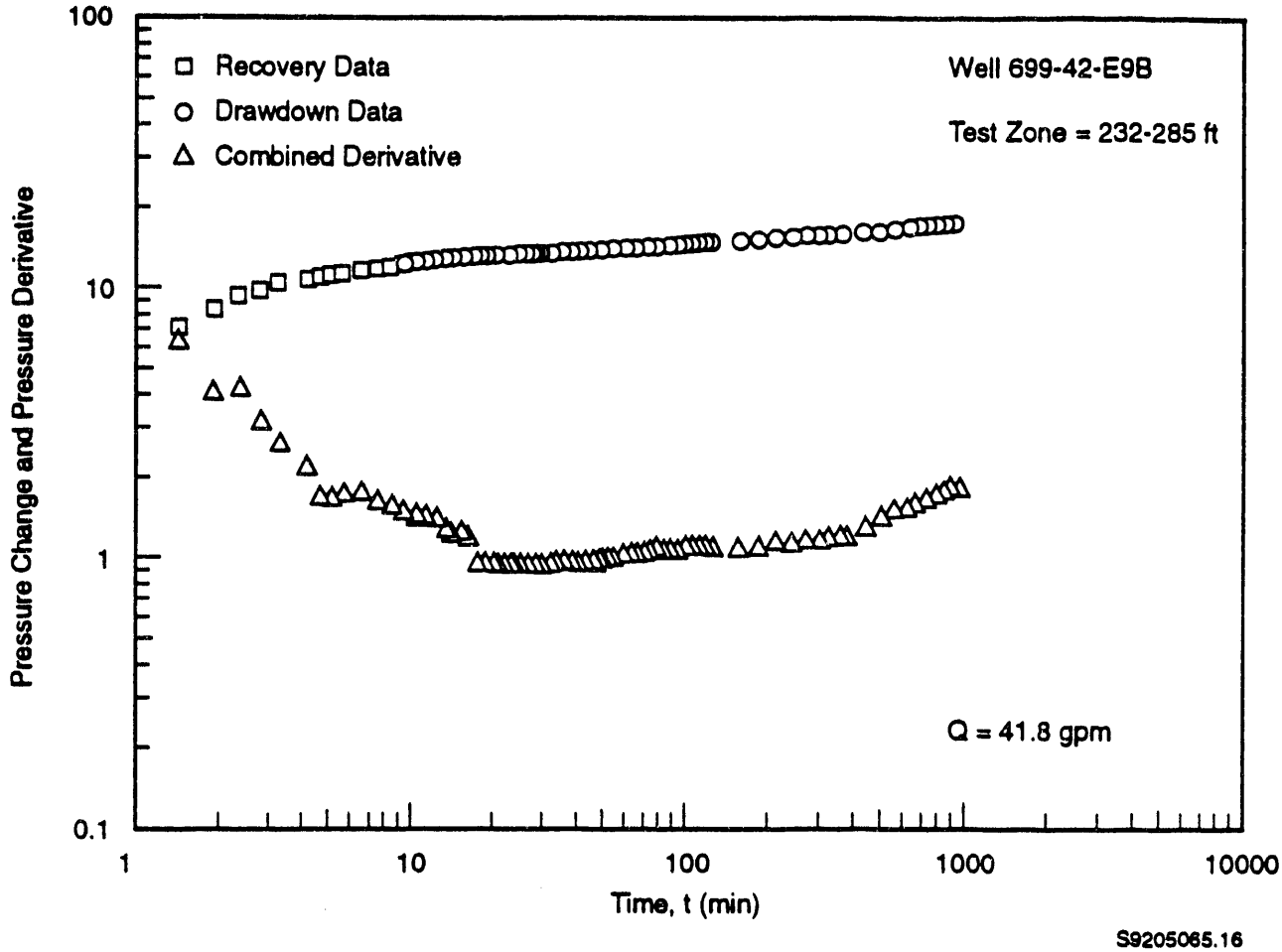

FIGURE 4.15. Diagnostic Constant-Rate Test Drawdown Analysis for the Elephant Mountain Basalt Interflow Zone, at Well 699-42-E9B

As a qualitative comparison of predicted versus observed test response, log-log type curve and derivative type curves were calculated using the modified Novakowski (1990) program, for a transmissivity of 690 ft^2/d (64.1 m^2/d)(from the straight-line analysis; Figure 4.16) and a storativity of 10^{-4} (from the slug test analysis; Figure 4.14). As shown in Figure 4.17, a good match for predicted and observed response data and the data derivative are indicated. It should be noted that a detailed recovery analysis for data collected following termination of the constant-rate test was not possible, due to the limited amount of recovery data that was collected.

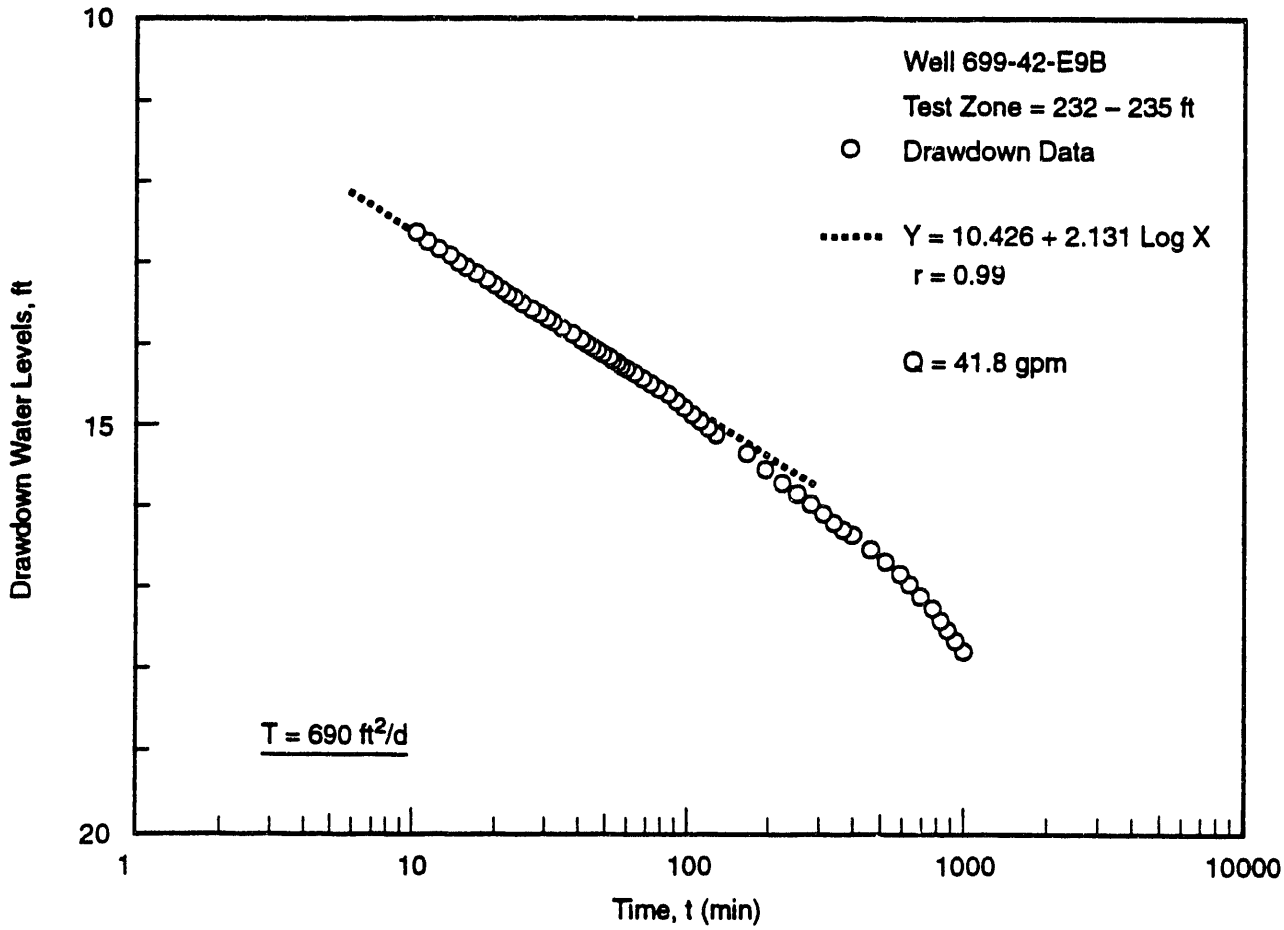

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FIGURE 4.16. Semi-Logarithmic, Straight-Line Analysis of Constant-Rate Test Drawdown Data for the Elephant Mountain Basalt Interflow Zone, at Well 699-42-E9B

4.3.1.5 Hydraulic Property Summary

Results from slug tests and the constant-rate pumping test conducted for the test interval provided an estimate for transmissivity ranging between 690 ft^2/d (64.1 m^2/d) and 1100 ft^2/d (102.2 m^2/d). Because of the low stress levels employed during slug testing, hydraulic property estimates obtained from the slug tests are considered to be reflective of test interval conditions near the borehole. In addition, storativity estimates obtained from slug testing are considered to be qualitative in nature (Cooper et al. 1967). However because of the close correspondence in the slug test derivative match (Figure 4.14) as well as the corroborative log-log type curve and derivative curve matching results obtained from the constant-rate drawdown

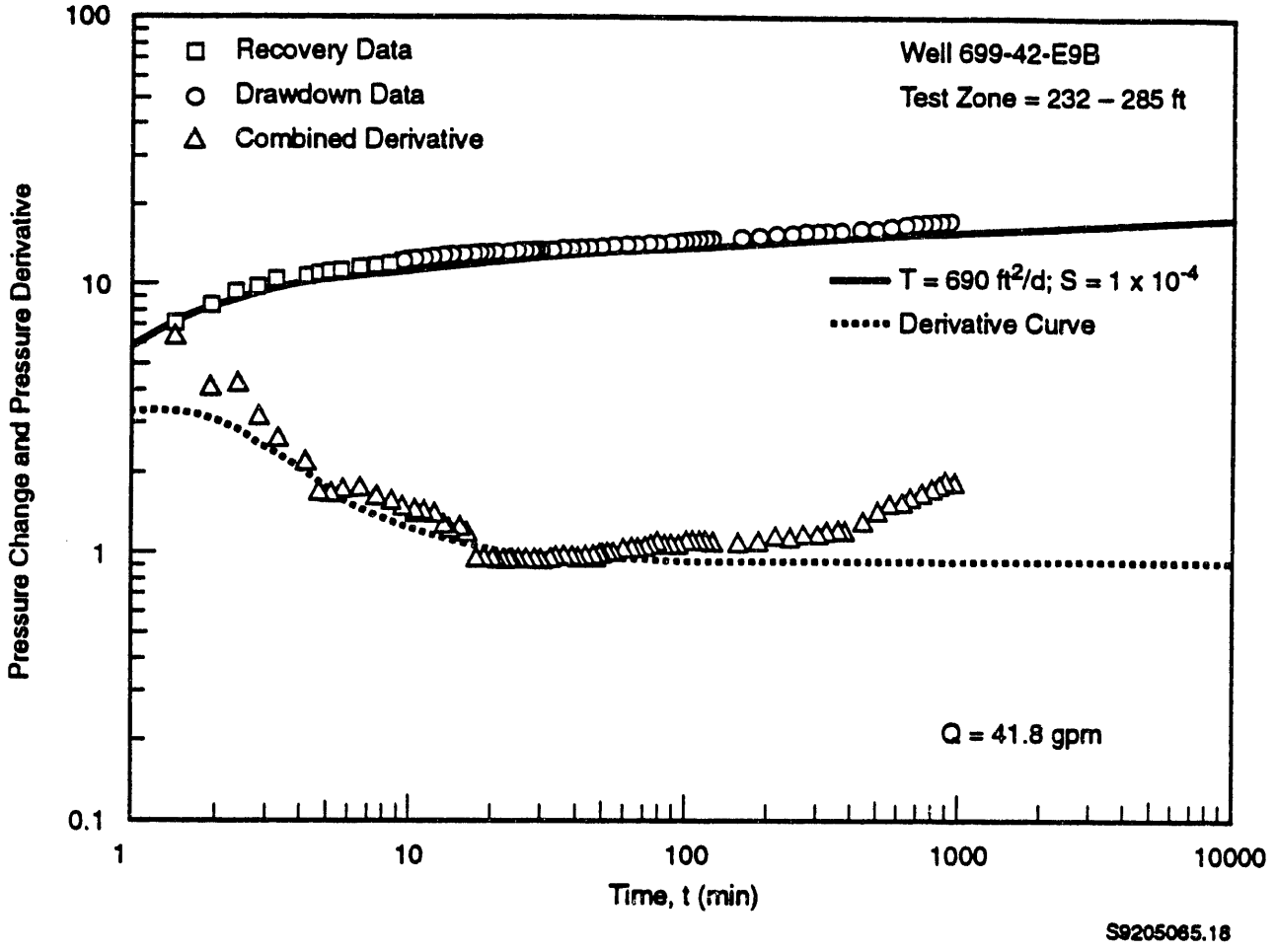

FIGURE 4.17. Log-Log Type Curve and Derivative Analysis for Constant-Rate Test Drawdown Data for the Elephant Mountain Basalt Interflow Zone, at Well 699-42-E9B

analysis (Figure 4.17), the storativity value of 10^{-4} is considered to be a representative estimate of storativity within the test interval.

The best estimate for transmissivity for the Elephant Mountain Basalt interflow zone at well 699-42-E9B is 690 ft^2/d (64.1 M^2/d). This was obtained from analysis of drawdown data collected during the constant-rate pumping test. The constant-rate drawdown analysis is considered to be superior to the slug test analysis results due to its larger area of investigation. It is interesting to note, however, that the slug test analysis results are within the factor range of 3 (i.e., 1100/690 = 1.6), which is commonly reported for

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slug test versus constant-rate pumping test result comparisons (Van der Kamp 1975, Barker and Black 1983).

4.3.2 Elephant Mountain Basalt/Pomona Basalt Flow Contact

Hydraulic testing of the second zone was conducted after termination of drilling and after well completion activities. As previously discussed, the second test zone was originally designed to be the Rattlesnake Ridge interbed; however, the sedimentary interbed was not encountered during the course of drilling. Final hydraulic characterization and monitoring well completion activities were then modified to test the equivalent stratigraphic-time horizon, which is the Elephant Mountain/Pomona basalt flow contact zone.

During the course of drilling through the depth section 354 to 390 ft bls (i.e., on March 15, 1991), evidence from the drilling fluid circulation and drilling penetration rates suggested that the basalt interflow contact encountered in this interval (i.e., 359 to 365 ft) was pervious. Drilling of this borehole section was accomplished utilizing the air-hammer rotary method, with a drilling bit diameter of 9-7/8 in. The borehole diameter within the test interval (as indicated by the caliper log shown in Figure 4.18) ranged between 9.64 and 11.42 in., and averaged 10.04 in.

Figure 4.18 shows the well configuration during hydraulic characterization of the Elephant Mountain/Pomona basalt flow contact zone. The test zone was characterized using a constant-rate pumping test. The test was conducted on April 18, 1991.

4.3.2.1 Constant-Rate Pumping Test Description

To provide an estimate of hydraulic properties for the test interval surrounding the well site, a constant-rate pumping test was conducted between 1300 hr and 2357 hr, April 18, 1991. The constant-rate pumping test was performed using a submersible pump. Flow rate was manually controlled with a valve in the surface discharge line to maintain a uniform discharge rate.

Discharge rate varied during the first hours of the test between approximately 50 gpm (i.e., recorded during the first 10 min of the test) and

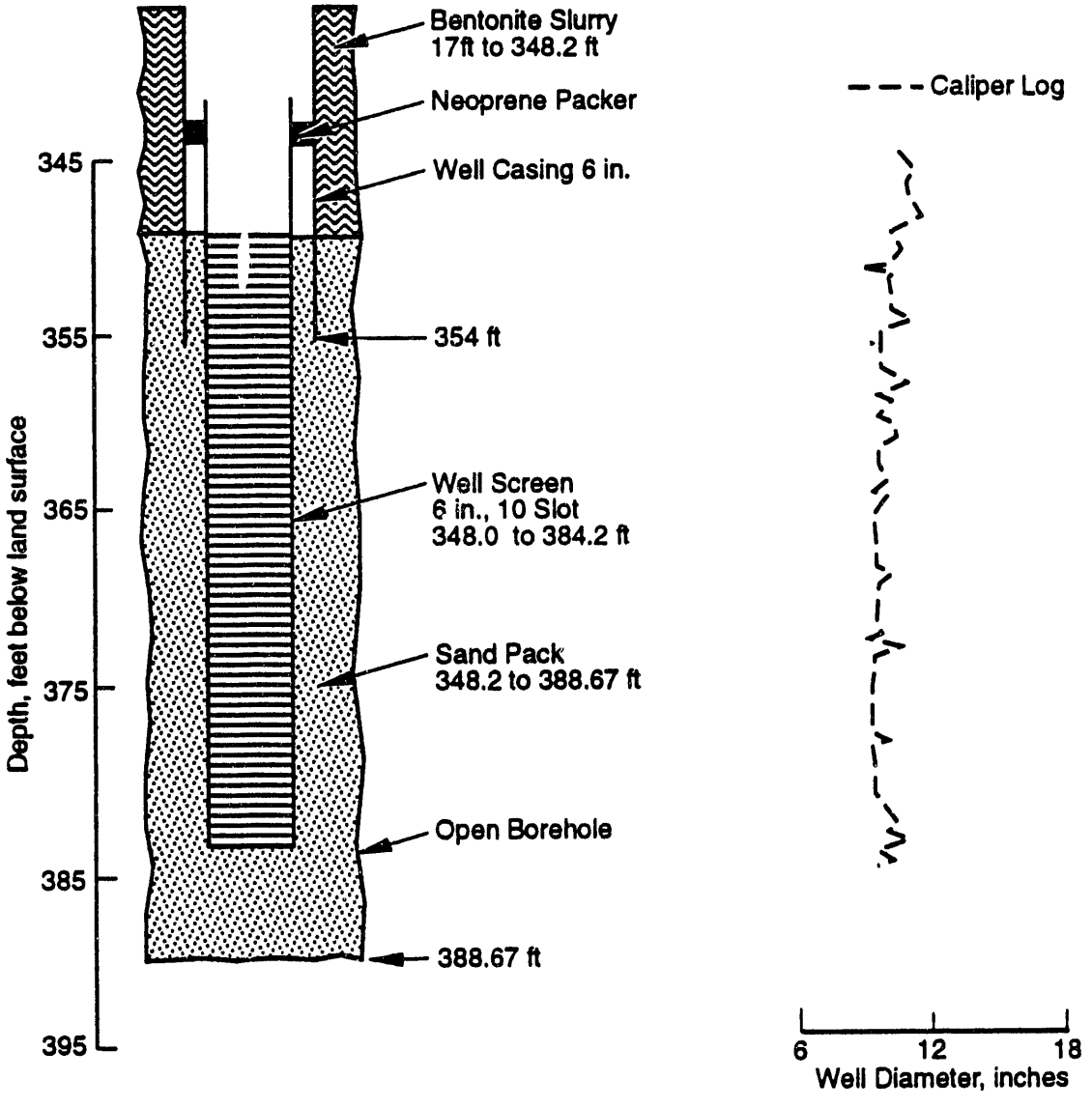

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FIGURE 4.18. Configuration of Well 699-42-E9B at Time of Hydraulically Testing the Elephant Mountain/Pomona Basalt Flow Contact Zone

38 gpm. Recorded average discharge rates during the last 7 hr of the testwere more uniform, varying only between 38 and 39 gpm. In total, 25,650 gal of water were produced from the test interval for an average discharge of

approximately 39.04 gpm during the test. Groundwater pumped from the test interval was transported approximately 1000 ft from the well site and discharged to the land surface.

Water-level measurements during the pumping test were monitored with two downhole Druck, Inc., pressure transducers (0 to 10 psi, model # 950/TI, serial # 382975 and 382982) set at depth settings of 45 ft and 61 ft btc, as well as measured directly with a calibrated Solinst, Inc., electric water-level sensor (serial # 11053), and steel tape. The pressure transducer readings were recorded on a Campbell Scientific, Inc., datalogger (model # CR10, serial # 1287). The static water level within the well prior to testing was 25.43 ft btc (359.53 ft msl), which was measured using a Lufkin steel tape (serial # L300-11).

Groundwater was pumped from the well utilizing a Grundfos, Inc., submersible pump. Discharge flow rates were monitored with a calibrated, in-line Micrometer, Inc., flow meter (model # 83-3-373). Instantaneous discharge rates were also periodically field-checked at the end of the discharge line, by recording the time required to fill a 5-gal bucket. Pertinent hydrologic data collected during the test are contained in Appendix D.

4.3.2.2 Constant-Rate Pumping Test Analysis

The constant-rate pumping test drawdown and recovery data were analyzed utilizing the methods described in Section 3.1. Briefly described, the analysis procedure included the following steps:

1) Diagnostic analysis of the drawdown and recovery water-level response using a log-log pressure change and pressure change derivative plot.

2) Quantitative semi-log analysis of the radial flow portion of the drawdown and recovery water-level data record, as indicated from the log-log pressure derivative plot.

Drawdown Analysis. Figure 4.19 shows the log-log drawdown data and drawdown data derivative plot for the constant-rate pumping test. Because of the inherent "noise" in drawdown data due to flow variability that is common in constant-rate tests, a L-spacing (i.e., the data log spacing) of 0.3 was used in calculation of the drawdown derivative. As indicated by the drawdown

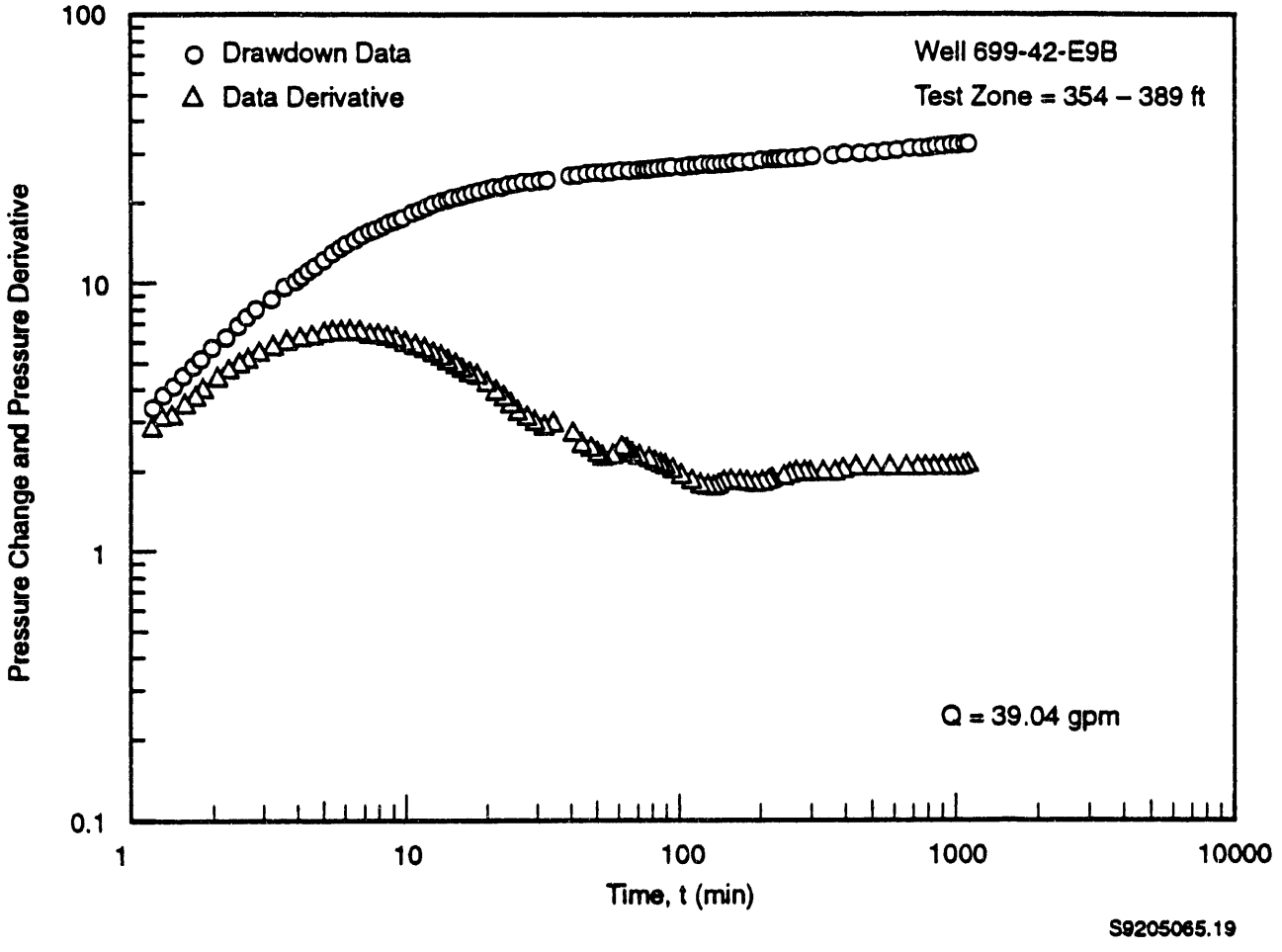

FIGURE 4.19. Diagnostic Constant-Rate Test Drawdown Analysis for the Elephant Mountain/Pomona Basalt Flow Contact Zone, at Well 699-42-E9B

derivative plot in the figure, test data during the early phases of the test exhibit the effects of wellbore storage during the early phases of the test. Test data collected after approximately 30 min into the test appear to fall within the region indicative of radial flow conditions (i.e., horizontal line on the pressure derivative plot.

Figure 4.20 shows the semi-log, straight-line analysis of the data set/ time period 30 to 657 min using the Cooper and Jacob (1946) method. As indicated, a transmissivity of 300 ft^2/d (27.9 m^2/d) was calculated for the semi-log drawdown analysis. As a qualitative comparison of predicted versus

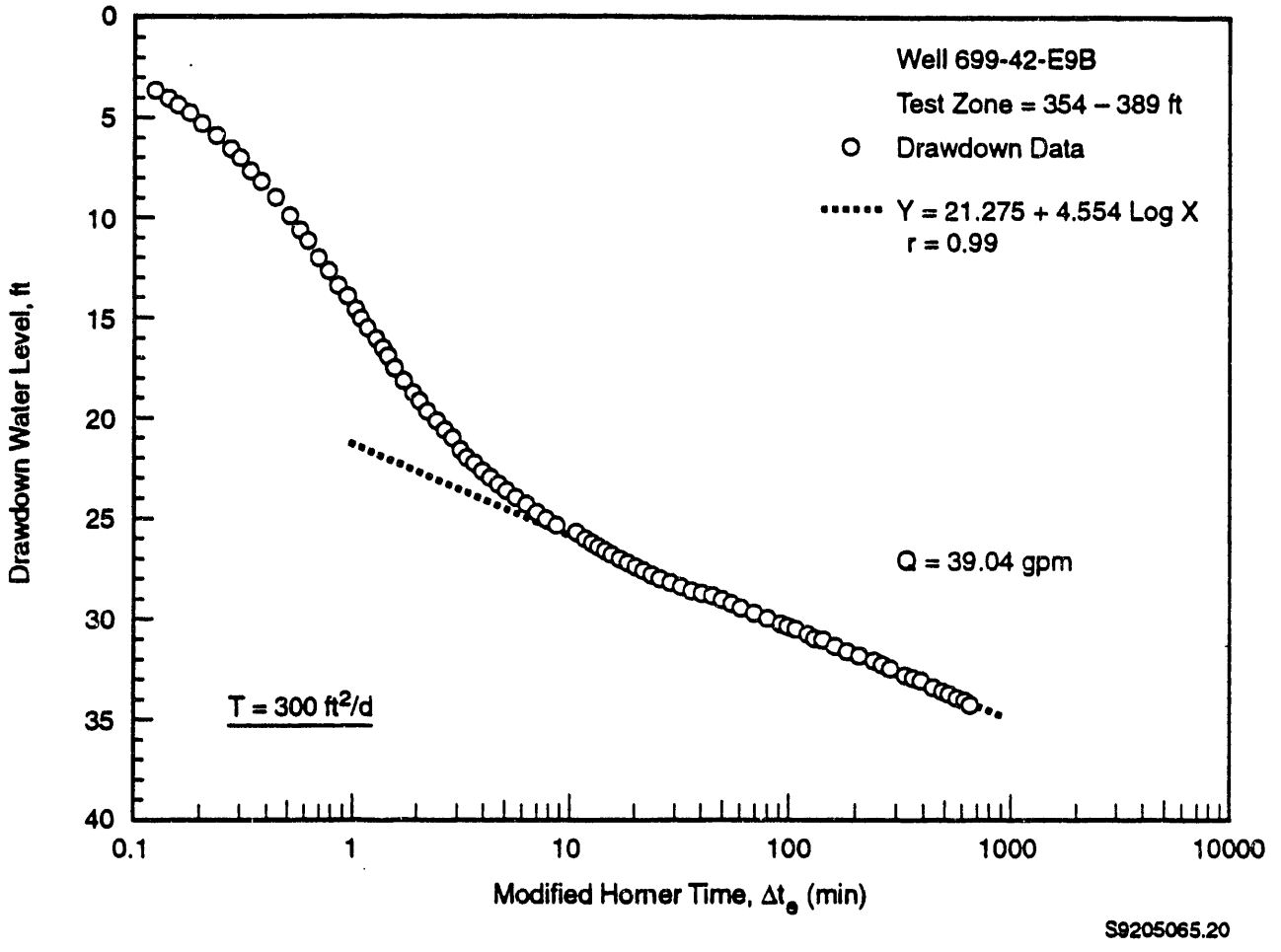

FIGURE 4.20. Semi-Logarithmic, Straight-Line Analysis of Constant-Rate Test Drawdown Data for the Elephant Mountain/Pomona Basalt Flow Contact Zone, at Well 699-42-E9B

observed test response, log-log type curve and derivative type curves were calculated using the modified Novakowski (1990) program, for a transmissivity of 300 ft^2/d (27.9 m^2/d) (from the straight-line analysis; Figure 4.21) and a storativity of 10^{-4} (assumed value). As shown in Figure 4.21, a good match for predicted and observed response data and the data derivative are indicated.

Recovery Analysis. Figure 4.22 shows the log-log recovery data and recovery data derivative plot following the constant-rate pumping test. In comparison to the drawdown plot shown in Figure 4.19, nearly identical log-log pressure drawdown patterns were evident after the first 5 min of recovery. A slightly different response, however, was exhibited for the recovery pressure

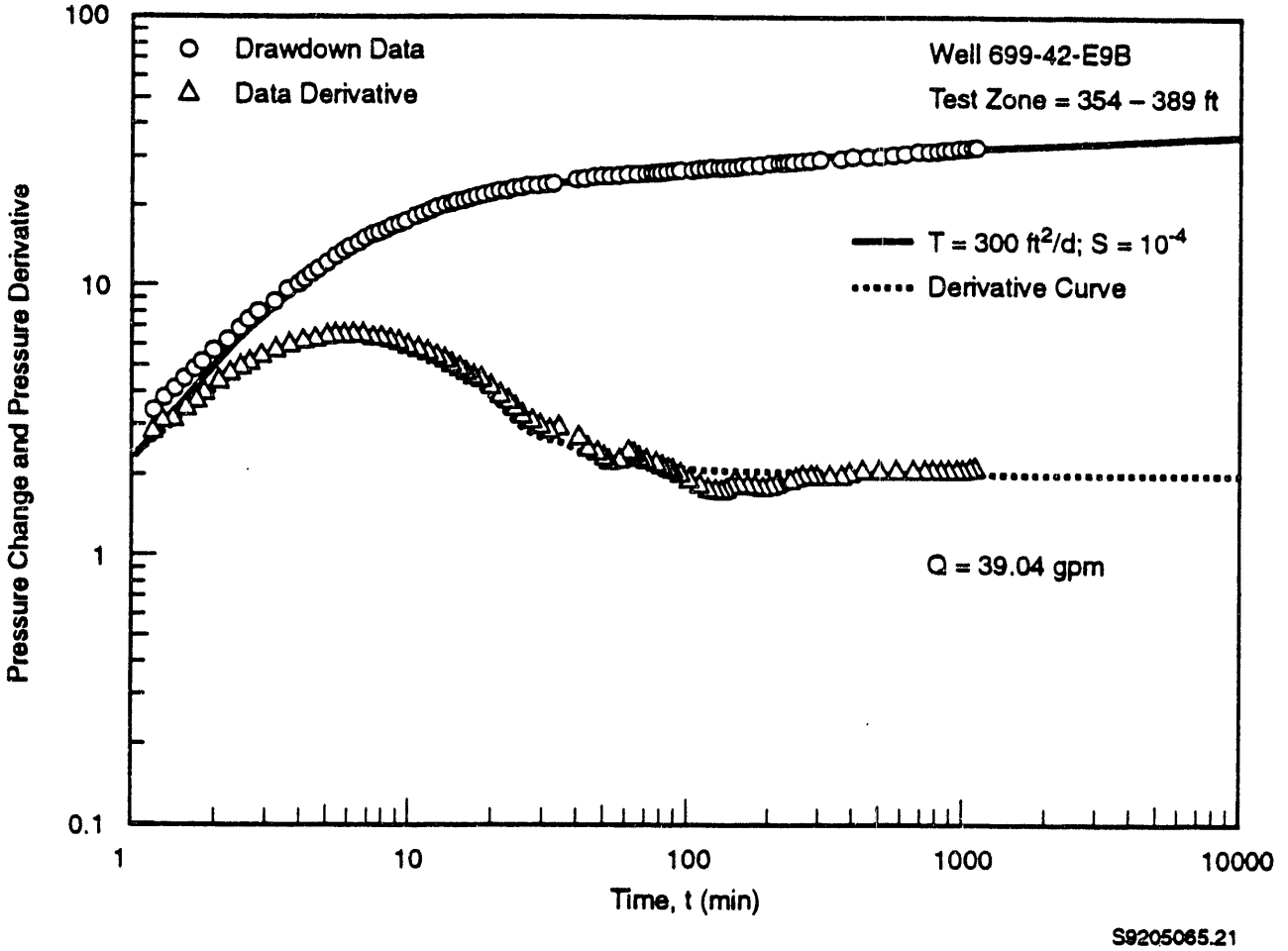

FIGURE 4.21. Log-Log Type Curve and Derivative Analysis for Constant-Rate Test Drawdown Data for the Elephant Mountain/Pomona Basalt Flow Contact Zone, at Well 699-42-E9B

derivative pattern (i.e., more wellbore storage and lower derivative stabilization). The cause for this slight difference is not completely understood. It may be attributable to water leakage from the pump column that slowly leaked past a check valve and back into the well. A review of field notes during submersible pump removal indicated that water was not present within the top joint of pump column (i.e., the first 10 ft bls), suggesting that water may have slowly drained back into the well following termination of the constant-rate test.

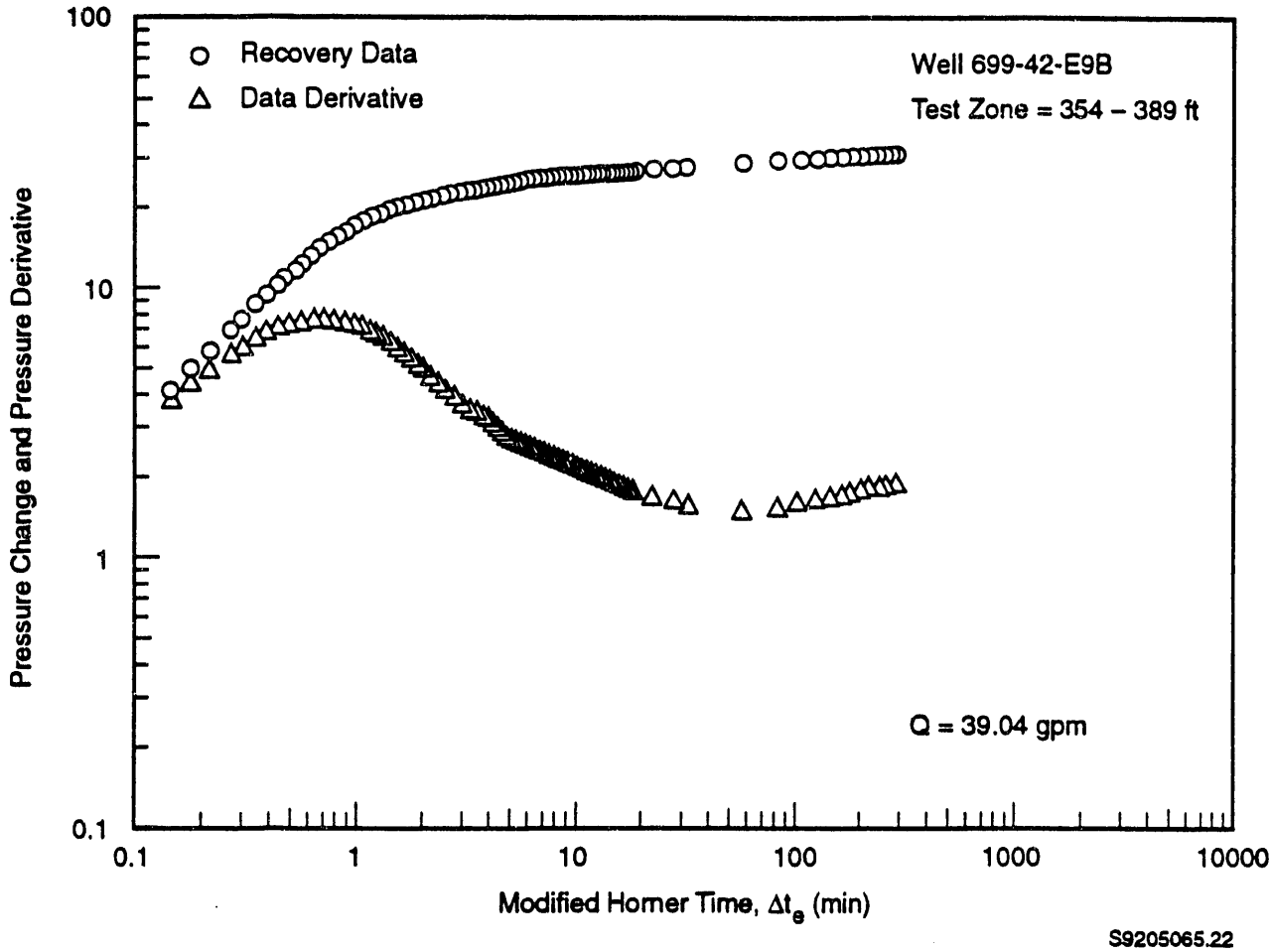

FIGURE 4.22. Diagnostic Constant-Rate Test Recovery Analysis for the Elephant Mountain/Pomona Basalt Flow Contact Zone, at Well 699-42-E9B

The recovery derivative was calculated using the modified Horner time, Δt_e, (Equation 10) following the procedure outlined in Bourdet et al. (1989). Using modified Horner time accounts for the length of the drawdown time period, and allows recovery plots to be analyzed with drawdown type curves. As was the case for the constant-rate drawdown phase, the recovery derivative plot shown in the Figure 4.22 indicates that recovery test data after approximately 20 min into recovery display radial flow conditions. Recovery data for modified Horner times greater than 20 minutes were analyzed with the Theis (1935) recovery method to provide a quantitative estimate of transmissivity for the test interval. As indicated in Figure 4.23, an estimate of 365 ft^2/d

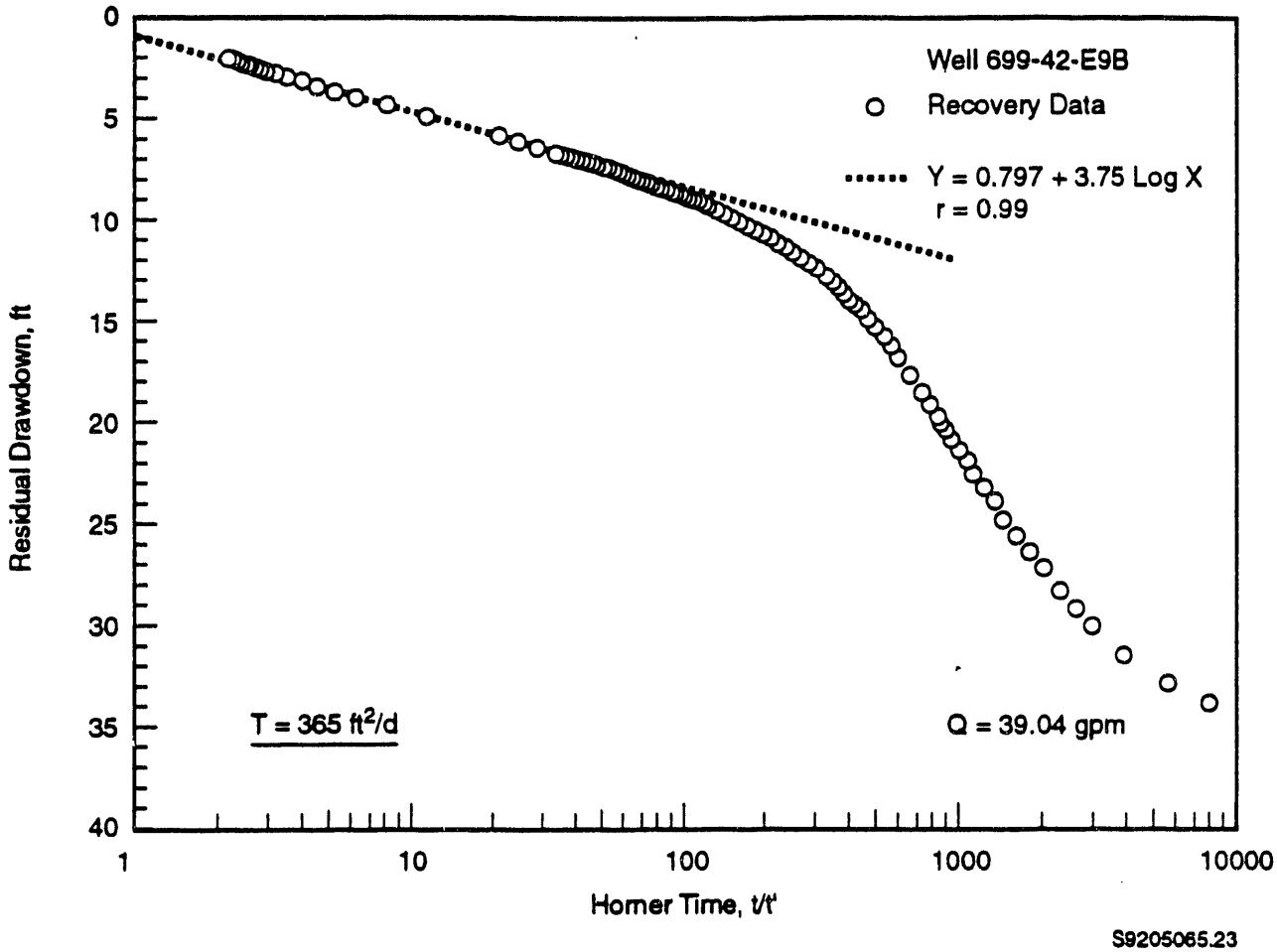

FIGURE 4.23. Semi-Logarithmic, Straight-Line Analysis of Constant-Rate Test Recovery Data for the Elephant Mountain/Pomona Basalt Flow Contact Zone, at Well 699-42-E9B

(33.9 m^2/d) was obtained from the straight-line analysis, which is in good agreement with the drawdown analysis results.

As a qualitative comparison of predicted versus observed test response, log-log type curve and derivative type curves were calculated using the modified Novakowski (1990) program, for a transmissivity of 365 ft^2/d (33.9 m^2/d) (from the straight-line analysis; Figure 4.23) and a storativity of 10^{-4} (assumed value). The type-curve match (not shown), however, did not provide as good a match as attained from analysis of the constant-rate drawdown data (Figure 4.21). A better type-curve match of the recovery data (Figure 4.24)

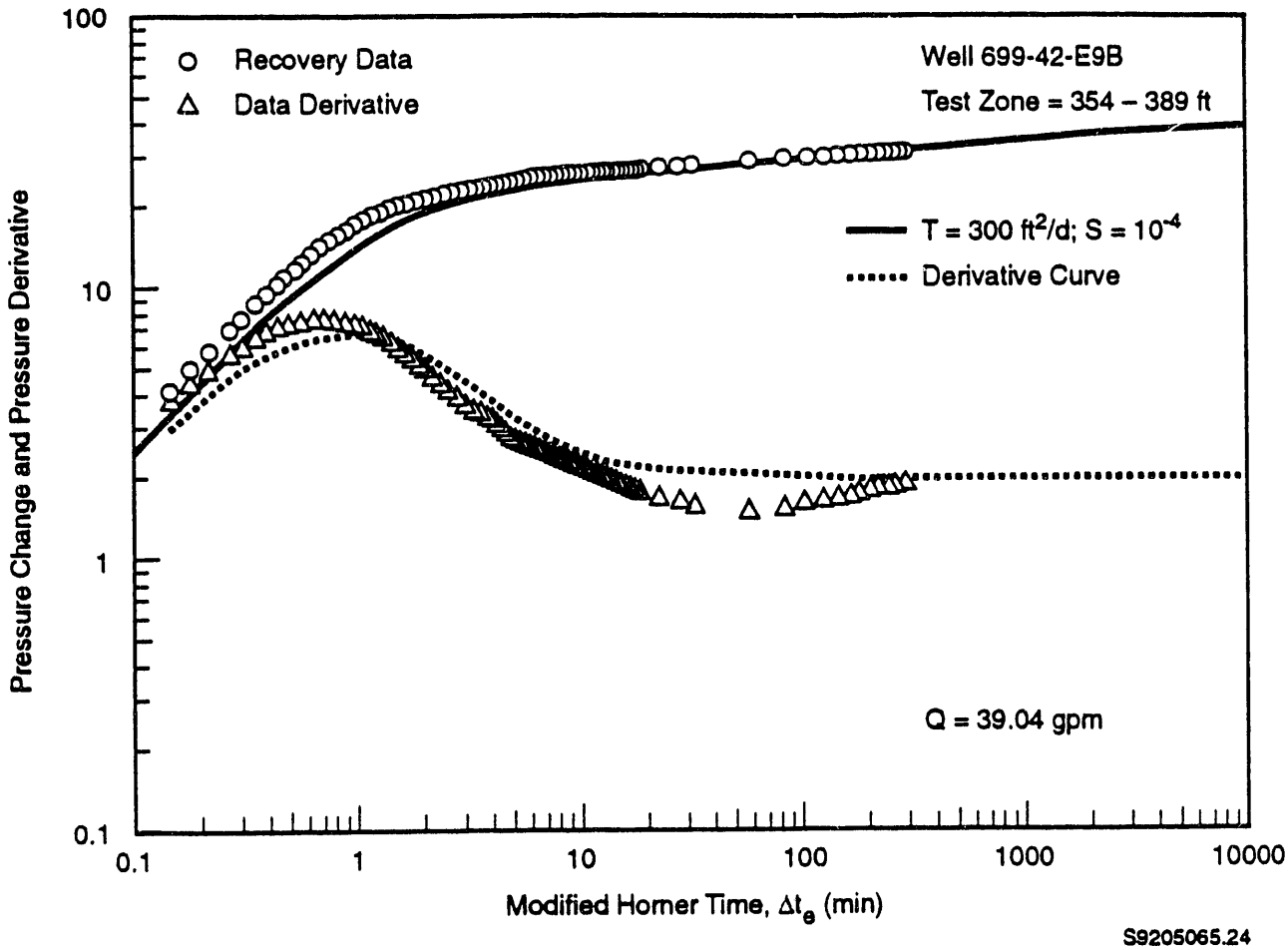

FIGURE 4.24. Log-Log Type Curve and Derivative Analysis for Constant-Rate Test Recovery Data for the Elephant Mountain/Pomona Basalt Flow Contact Zone, at Well 699-42-E9B

was obtained using hydraulic property estimates calculated from the drawdown analysis (i.e., T = 300 ft^2/d (27.9 m^2/d), S = 10^{-4}).

4.3.2.3 Hydraulic Property Summary

Results from the constant-rate pumping test analysis provided an estimate for transmissivity ranging between 300 ft^2/d (27.9 m^2/d) and 365 ft^2/d (33.9 m^2/d) for the Elephant Mountain/Pomona Basalt flow contact zone. The best estimate for transmissivity for the test interval at well 699-42-E9B is 300 ft^2/d (27.9 m^2/d), which was obtained from analysis of drawdown data obtained during the constant-rate pumping test. The constant-rate drawdown analysis is considered to provide the best estimate for transmissivity because

of the consistency obtained from semi-log, straight-line analysis and log-log type-curve matching results (i.e., Figures 4.20 and 4.21), and the possible adverse effect that pump-column water leakage may have had on the recovery data response.

No quantitative estimate for storativity is obtainable from the test analysis. The value of 10^{-4} that was assumed in the drawdown analysis, however, provides good log-log type-curve matching results as evident in Figure 4.21. This storativity estimate falls within the range commonly attributed to confined aquifer systems (Heath 1983) and is consistent with the value obtained from test analysis of the overlying Elephant Mountain basalt interflow zone.

5.0 HYDRAULIC TESTING SUMMARY

Table 5.1 summarizes results obtained from tests conducted as part of the hydraulic characterization investigation of wells constructed as part of the Savage Island well program. A total of four test intervals were successfully characterized at the wells tested. Characterization efforts for an additional upper-confined aquifer horizon (i.e., the Rattlesnake Ridge interbed at well 699-32-22B) were suspended when a possible problem with the well annular sealing materials was detected during test interval development activities. Characterization of this test interval will be initiated following remediation of the well completion problem. In addition, characterization efforts for a monitoring well completed in the uppermost aquifer (well 699-42-E9A) were aborted following problems experienced during test zone development. Because of the severity of the problems that were experienced (i.e., damage to the well casing), the well was subsequently abandoned, and no additional characterization for this test interval was attempted.

Results of the hydraulic test analysis indicate a best estimate transmissivity range of 51 ft^2/d (4.7 m^2/d) to 690 ft^2/d (64.1 m^2/d) for basalt flow contacts within the Elephant Mountain Basalt, and a value of 65 ft^2/d (6.0 m^2/d) for the one test completed in the Ringold Formation. The hydraulic property estimate results obtained from hydraulic test analysis fall within the range previously cited (e.g., Gephart et al. 1979, Graham et al. 1984, DOE 1988) for similar units within the upper-confined and uppermost aquifer systems on the Hanford Site.

TABLE 5.1. Hydraulic Test Summary

Well	Test Formation	Test Interval (ft, bls)	Pre-Test Static Water-Level (ft, msl)	Hydraulic Properties/ Best Estimate	
				Transmissivity (ft^2/d[a])	Storativity[b]
699-32-22B	Elephant Mt. basalt interflow	655 - 686	401.7	51 (15 - 51)	10^{-3}
699-42-E9A	Ringold Formation	195 - 232	356.3	65 (30 - 65)	10^{-5}
699-42-E9B	Elephant Mt. basalt interflow	232 - 285	358.3	690 (690 - 1100)	10^{-4}
699-42-E9B	Elephant Mt./ Pomona Basalt flow contact	354 - 389	359.5	300 (300 - 365)	10^{-4}

(a) Transmissivity range listed in parentheses; range determined from all test methods used during characterization.

(b) Storativity values determined from single-well tests; therefore, values should be considered to be only qualitative estimates.

6.0 REFERENCES

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APPENDIX A

HYDRAULIC TEST DATA FOR WELL 699-32-22B, ELEPHANT MOUNTAIN BASALT INTERFLOW ZONE

A.1. Slug Injection Test Data

A.2. Slug Withdrawal Test Data

A.3. Constant-Rate Pumping Test: Pertinent Hydraulic Field Test Data

A.4. Constant-Rate Pumping Test: Hydrochemical Parameter Field Analyses

A.5. Constant-Rate Pumping Test: Recovery Test Data

TABLE A.1. Slug Injection Test Data for Well 699-32-22B, Elephant Mountain Basalt Inferflow Zone

Test Time seconds	Pressure Transducer Reading, H feet	$H-H_i$ feet	$(H-H_i)/H_o$	Data Derivative
24.0000	14.7110	1.3990	.9582	.0000
25.0000	14.7080	1.3960	.9562	.0991
26.0000	14.7070	1.3950	.9555	.0683
27.0000	14.7030	1.3910	.9527	.0898
28.0000	14.7040	1.3920	.9534	.0630
29.0000	14.7020	1.3900	.9521	.0656
30.0000	14.7040	1.3920	.9534	.0495
31.0000	14.7050	1.3930	.9541	.0428
32.0000	14.7020	1.3900	.9521	.0510
33.0000	14.6990	1.3870	.9500	.0579
34.0000	14.6940	1.3820	.9466	.0685
35.0000	14.6960	1.3840	.9479	.0613
36.0000	14.6960	1.3840	.9479	.0603
40.0000	14.6900	1.3780	.9438	.0678
45.0000	14.6840	1.3720	.9397	.0735
50.0000	14.6790	1.3670	.9363	.0768
55.0000	14.6750	1.3630	.9336	.0770
60.0000	14.6710	1.3590	.9308	.0741
65.0000	14.6650	1.3530	.9267	.0766
70.0000	14.6590	1.3470	.9226	.0791
75.0000	14.6550	1.3430	.9199	.0874
80.0000	14.6480	1.3360	.9151	.0946
85.0000	14.6460	1.3340	.9137	.0966
90.0000	14.6420	1.3300	.9110	.1085
95.0000	14.6370	1.3250	.9075	.1105
100.0000	14.6340	1.3220	.9055	.1190
105.0000	14.6270	1.3150	.9007	.1220
110.0000	14.6240	1.3120	.8986	.1323
120.0000	14.6150	1.3030	.8925	.1473
130.0000	14.6100	1.2980	.8890	.1555
140.0000	14.6090	1.2970	.8884	.1633
150.0000	14.6060	1.2940	.8863	.1724
160.0000	14.6070	1.2950	.8870	.1744
170.0000	14.6010	1.2890	.8829	.1723
180.0000	14.5960	1.2840	.8795	.1706
190.0000	14.5860	1.2740	.8726	.1757
200.0000	14.5790	1.2670	.8678	.1754
210.0000	14.5710	1.2590	.8623	.1829
220.0000	14.5610	1.2490	.8555	.1956
240.0000	14.5430	1.2310	.8432	.2202
270.0000	14.5200	1.2080	.8274	.2377

TABLE A.1. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	$H-H_i$ feet	$(H-H_i)/H_o$	Data Derivative
300.0000	14.4940	1.1820	.8096	.2587
330.0000	14.4660	1.1540	.7904	.2966
360.0000	14.4480	1.1360	.7781	.3407
390.0000	14.4310	1.1190	.7664	.3707
420.0000	14.4190	1.1070	.7582	.3856
450.0000	14.4140	1.1020	.7548	.3865
480.0000	14.4110	1.0990	.7527	.3924
540.0000	14.3950	1.0830	.7418	.4207
600.0000	14.3590	1.0470	.7171	.4478
660.0000	14.3140	1.0020	.6863	.4359
720.0000	14.2880	.9760	.6685	.4381
780.0000	14.2570	.9450	.6473	.4425
840.0000	14.2130	.9010	.6171	.4663
900.0000	14.1730	.8610	.5897	.4856
960.0000	14.1290	.8170	.5596	.5095
1020.0000	14.0950	.7830	.5363	.5301
1080.0000	14.0740	.7620	.5219	.5463
1140.0000	14.0730	.7610	.5212	.5479
1200.0000	14.0610	.7490	.5130	.5422
1260.0000	14.0340	.7220	.4945	.5731
1320.0000	14.0140	.7020	.4808	.5730
1380.0000	13.9870	.6750	.4623	.5881
1440.0000	13.9620	.6500	.4452	.5923
1500.0000	13.9500	.6380	.4370	.5867
1560.0000	13.9210	.6090	.4171	.5950
1620.0000	13.9030	.5910	.4048	.5949
1680.0000	13.9310	.6190	.4240	.5697
1740.0000	13.9330	.6210	.4253	.5562
1800.0000	13.9170	.6050	.4144	.5581

Test initiated at 1016 hr, May 30, 1991

Initial pressure transducer reading, H_i = 13.312 ft

Induced Slug Stress Level, H_o = 1.46 ft.

TABLE A.2. Slug Withdrawal Test Data for Well 699-32-22B, Elephant Mountain Basalt Interflow Zone

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
20.0000	12.2690	1.2070	.9400	.0000
21.0000	12.2680	1.2080	.9408	.0322
22.0000	12.2630	1.2130	.9447	.0933
23.0000	12.2700	1.2060	.9393	.0108
24.0000	12.2740	1.2020	.9361	.0394
25.0000	12.2700	1.2060	.9393	.0311
26.0000	12.2670	1.2090	.9416	.0171
27.0000	12.2710	1.2050	.9385	.0203
28.0000	12.2750	1.2010	.9354	.0289
29.0000	12.2780	1.1980	.9330	.0382
30.0000	12.2730	1.2030	.9369	.0361
31.0000	12.2740	1.2020	.9361	.0352
32.0000	12.2770	1.1990	.9338	.0381
33.0000	12.2780	1.1980	.9330	.0400
34.0000	12.2770	1.1990	.9338	.0404
35.0000	12.2760	1.2000	.9346	.0406
36.0000	12.2780	1.1980	.9330	.0411
37.0000	12.2810	1.1950	.9307	.0429
38.0000	12.2810	1.1950	.9307	.0451
39.0000	12.2810	1.1950	.9307	.0462
40.0000	12.2800	1.1960	.9315	.0468
41.0000	12.2810	1.1950	.9307	.0475
42.0000	12.2810	1.1950	.9307	.0489
43.0000	12.2810	1.1950	.9307	.0496
44.0000	12.2820	1.1940	.9299	.0505
45.0000	12.2830	1.1930	.9291	.0515
50.0000	12.2890	1.1870	.9245	.0593
60.0000	12.2930	1.1830	.9213	.0727
70.0000	12.2980	1.1780	.9174	.0810
80.0000	12.3020	1.1740	.9143	.0876
90.0000	12.3090	1.1670	.9089	.0929
100.0000	12.3170	1.1590	.9026	.1019
110.0000	12.3270	1.1490	.8949	.1158
120.0000	12.3310	1.1450	.8917	.1316
130.0000	12.3380	1.1380	.8863	.1447
140.0000	12.3440	1.1320	.8816	.1574
150.0000	12.3490	1.1270	.8777	.1705
180.0000	12.3730	1.1030	.8590	.2002
210.0000	12.3890	1.0870	.8466	.2463
240.0000	12.3980	1.0780	.8396	.2720
270.0000	12.4070	1.0690	.8326	.2922

TABLE A.2. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
300.0000	12.4230	1.0530	.8201	.3052
330.0000	12.4460	1.0300	.8022	.2997
360.0000	12.4770	.9990	.7780	.3044
390.0000	12.5060	.9700	.7555	.3088
420.0000	12.5130	.9630	.7500	.3248
450.0000	12.5200	.9560	.7445	.3446
480.0000	12.5380	.9380	.7305	.3648
510.0000	12.5530	.9230	.7188	.3758
540.0000	12.5590	.9170	.7142	.3886
600.0000	12.6080	.8680	.6760	.4166
660.0000	12.6720	.8040	.6262	.4431
720.0000	12.6890	.7870	.6129	.4918
780.0000	12.6980	.7780	.6059	.5241
840.0000	12.7380	.7380	.5748	.5460
900.0000	12.7550	.7210	.5615	.5699
960.0000	12.7710	.7050	.5491	.5768
1020.0000	12.7730	.7030	.5475	.5761
1080.0000	12.7400	.7360	.5732	.5634
1140.0000	12.7510	.7250	.5646	.5524
1200.0000	12.7710	.7050	.5491	.5476
1260.0000	12.7970	.6790	.5288	.5448
1320.0000	12.8170	.6590	.5132	.5458
1380.0000	12.8680	.6080	.4735	.5492
1440.0000	12.9110	.5650	.4400	.5550
1500.0000	12.9290	.5470	.4260	.5664
1560.0000	12.9270	.5490	.4276	.5692
1620.0000	12.9410	.5350	.4167	.5714
1680.0000	12.9580	.5180	.4034	.5786
1740.0000	12.9820	.4940	.3847	.5781
1800.0000	12.9970	.4790	.3731	.5865
1860.0000	13.0060	.4700	.3660	.5930
1920.0000	12.9960	.4800	.3738	.5933
1980.0000	12.9920	.4840	.3769	.5935
2040.0000	13.0060	.4700	.3660	.5943
2100.0000	13.0560	.4200	.3271	.6074
2160.0000	13.0770	.3990	.3107	.6142
2220.0000	13.0910	.3850	.2998	.6203
2280.0000	13.1020	.3740	.2913	.6341
2340.0000	13.1140	.3620	.2819	.6387
2400.0000	13.1230	.3530	.2749	.6425
2460.0000	13.1210	.3550	.2765	.6443
2520.0000	13.1300	.3460	.2695	.6528

TABLE A.2. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
2580.0000	13.1470	.3290	.2562	.6547
2640.0000	13.1560	.3200	.2492	.6563
2700.0000	13.1730	.3030	.2360	.6692
2760.0000	13.1940	.2820	.2196	.6720
2820.0000	13.1990	.2770	.2157	.6739
2880.0000	13.1910	.2850	.2220	.6848
2940.0000	13.1890	.2870	.2235	.6831
3000.0000	13.1840	.2920	.2274	.6802
3060.0000	13.1810	.2950	.2298	.6862
3120.0000	13.1760	.3000	.2336	.6810
3180.0000	13.1790	.2970	.2313	.6761

Test initiated at 1240 hr, May 30, 1991

Initial pressure transducer reading, H_i = 13.476 ft

Induced Slug Stress Level, H_o = 1.284 ft

TABLE A.3. Pertinent Field Test Data for Well 699-32-22B, Elephant Mountain Basalt Interflow Zone - Constant-Rate Pumping Test

Test Time min	Water-Level ft, btc	Flowmeter Reading gal	Instantaneous Discharge Measurement gpm	Comments
0	113.51	77450		Test started at 0745 hr, 6/1/91
12			15.0	5 gal in 20 s
14.17	176.3			
15	177.3			
16	179.85			
17	182.35			
18	184.5			
19.25	187.5			
20	189.1			
30.25	211.0			
36	222.0			
41.17	230.6			
42		77920		
46.17	238.5			
47.17	240.0			
52	246.45			
59	255.45			
68	266.0			
71		78190		
81	279.7			
90	286.6			
100	294.6			
102			13.6	5 gal in 22 s
110	300.85			
120	305.93			
130.33	310.65			
141	314.8			
150	318.1			
151		78870		
161	322.6			
169	324.6			
178			13.0	5 gal in 23 s
180	326.95			
194	329.55			
220	333.61	79440		
240	336.9			
244			13.0	5 gal in 23 s
255	338.15			
275	339.43			

TABLE A.3. (contd)

Test Time min	Water-Level ft, btc	Flowmeter Reading gal	Instantaneous Discharge Measurement gpm	Comments
296	340.5			
318	342.55			
343	342.67			
345		80420		
420			12.8	5 gal in 23.5 s
421		80990		
445	343.63			
475	346.1			
509	346.23			
539		81910		
546			13.0	5 gal in 23 s
555	346.83			
570	346.88			
600		82380		Test terminated 1745 hr, 6/1/91

TABLE A.4. Hydrochemical Parameter Field Analyses for Well 699-32-22B, Elephant Mountain Basalt Interflow Zone - Constant-Rate Pumping Test

Clock Time hr	pH	Conductivity µmhos/cm @ 25 C	Temperature ° C	Eh mV	Turbidity NTU
0805		290	22.8	-124	
0808	7.71				
0809					6.7
0850					7.7
0917		357	24.4	-290	
0920	7.95				
0920	8.02				6.1
1024		356	24.8	-244	
1027	7.95				
1032					3.6
1138	7.98	288	24.8	-121	
1142					1.0
1252					
1252	8.04				
1252	8.05				0.8
1259		268	24.9	-186	
1410		355	25.1	-198	
1411	8.15				0.6
1411					0.65
1520	8.13	317	25.2	-191	0.66
1638	8.12	355	25.1	-205	0.52
1723	8.24	355	25.1	-210	0.71

Turbidity measured with a Hach, Inc., Turbidimeter, serial # 880903404.

PH measured with an Orion Research, Inc., pH meter, model # SA250, serial # 2028.

Conductivity, temperature, and Eh measured with a Water Quality Monitor, Inc., model # YSI 3500, serial # K8000138.

TABLE A.5. Recovery Test Data for Well 699-32-22B, Elephant Mountain Basalt Interflow Zone - Constant-Rate Pumping Test

Recovery Time, Δt min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
1.00	231.0200	2.0600	601.0000	.9983	
2.00	226.8600	6.2200	301.0000	1.9934	8.0046
3.00	223.0700	10.0100	201.0000	2.9851	10.8399
4.00	219.4700	13.6100	151.0000	3.9735	13.9493
5.00	216.0000	17.0800	121.0000	4.9587	16.8809
7.00	209.6700	23.4100	86.7143	6.9193	21.9190
9.00	203.5600	29.5200	67.6667	8.8670	27.2485
11.25	196.9000	36.1800	54.3333	11.0429	33.1230
13.00	191.8500	41.2300	47.1538	12.7243	36.9130
15.00	186.2400	46.8400	41.0000	14.6341	41.7361
18.00	178.3800	54.7000	34.3333	17.4757	48.0839
21.00	170.7600	62.3200	29.5714	20.2899	52.9852
25.00	161.0100	72.0700	25.0000	24.0000	60.8406
30.00	149.4800	83.6000	21.0000	28.5714	68.7426
35.25	138.2500	94.8300	18.0213	33.2940	75.6923
45.00	119.4400	113.6400	14.3333	41.8605	85.6469
55.00	102.5300	130.5500	11.9091	50.3817	91.5196
66.25	86.0800	147.0000	10.0566	59.6623	95.5054
77.00	72.6500	160.4300	8.7922	68.2422	96.3318
85.00	63.8700	169.2100	8.0588	74.4526	93.4840
95.00	54.3500	178.7300	7.3158	82.0144	91.5431
105.00	46.1700	186.9100	6.7143	89.3617	86.2779
115.00	39.4730	193.6070	6.2174	96.5035	82.7501
115.50	38.8700	194.2100	6.1948	96.8553	81.7256
125.00	33.5370	199.5430	5.8000	103.4483	75.9394
135.00	28.5250	204.5550	5.4444	110.2041	70.9001
145.00	24.3160	208.7640	5.1379	116.7785	64.8231
155.00	20.7850	212.2950	4.8710	123.1788	60.1203
165.00	17.8400	215.2400	4.6364	129.4118	54.8398
175.00	15.3840	217.6960	4.4286	135.4839	50.8366
185.00	13.3410	219.7390	4.2432	141.4013	46.6238
195.00	11.6450	221.4350	4.0769	147.1698	43.6422
205.00	10.2320	222.8480	3.9268	152.7950	40.2671
215.00	9.0580	224.0220	3.7907	158.2822	36.2191
225.00	8.0850	224.9950	3.6667	163.6364	33.5130
235.00	7.2760	225.8040	3.5532	168.8623	30.5442
245.00	6.5980	226.4820	3.4490	173.9645	28.4085
255.00	6.0270	227.0530	3.3529	178.9474	25.9368
265.00	5.5460	227.5340	3.2642	183.8150	24.2485
275.00	5.1440	227.9360	3.1818	188.5714	22.0881
285.00	4.7900	228.2900	3.1053	193.2203	20.7479
295.00	4.5010	228.5790	3.0339	197.7654	18.8721

TABLE A.5. (contd)

Recovery Time, ▲t min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+▲t)/▲t$	Modified Horner Time $(t_p \times ▲t)/(t_p + ▲t)$ min	Derivative
305.00	4.2620	228.8180	2.9672	202.2099	17.7992
315.00	4.0150	229.0650	2.9048	206.5574	16.2010
325.00	3.8230	229.2570	2.8462	210.8108	15.3579
335.00	3.6440	229.4360	2.7910	214.9733	14.0397
345.00	3.4860	229.5940	2.7391	219.0476	13.3698
355.00	3.3430	229.7370	2.6901	223.0367	12.7976
365.00	3.2150	229.8650	2.6438	226.9430	11.7455
375.00	3.0950	229.9850	2.6000	230.7692	11.2880
385.00	2.9860	230.0940	2.5584	234.5178	10.4108
395.00	2.8910	230.1890	2.5190	238.1909	10.0459
405.00	2.7990	230.2810	2.4815	241.7910	9.7077
415.00	2.7050	230.3750	2.4458	245.3202	9.0133
425.00	2.6230	230.4570	2.4118	248.7805	8.7553
435.00	2.5440	230.5360	2.3793	252.1739	8.1910
445.00	2.4680	230.6120	2.3483	255.5024	7.9863
455.00	2.3920	230.6880	2.3187	258.7678	7.7962
465.00	2.3320	230.7480	2.2903	261.9718	7.3488
475.00	2.2670	230.8130	2.2632	265.1163	7.1921
485.00	2.2070	230.8730	2.2371	268.2028	6.8275
495.00	2.1560	230.9240	2.2121	271.2329	6.6958
505.00	2.0980	230.9820	2.1881	274.2081	6.5731
515.00	2.0380	231.0420	2.1650	277.1300	6.2768
525.00	1.9840	231.0960	2.1429	280.0000	6.1692
535.00	1.9360	231.1440	2.1215	282.8194	6.0649
545.00	1.8930	231.1870	2.1009	285.5895	5.8227
555.00	1.8550	231.2250	2.0811	288.3117	5.7263
565.00	1.8100	231.2700	2.0619	290.9871	5.6321
575.00	1.7710	231.3090	2.0435	293.6170	5.4306
585.00	1.7290	231.3510	2.0256	296.2025	5.3420
595.00	1.6900	231.3900	2.0084	298.7448	5.2552
605.00	1.6460	231.4340	1.9917	301.2448	5.1215
615.00	1.6070	231.4730	1.9756	303.7037	5.0800
625.00	1.5730	231.5070	1.9600	306.1224	5.0406
635.00	1.5460	231.5340	1.9449	308.5020	4.9355
645.00	1.5040	231.5760	1.9302	310.8434	4.9020
655.00	1.4790	231.6010	1.9160	313.1474	4.8691
665.00	1.4410	231.6390	1.9023	315.4150	4.7838
675.00	1.4090	231.6710	1.8889	317.6471	4.7564
685.00	1.3770	231.7030	1.8759	319.8444	4.7308
695.00	1.3490	231.7310	1.8633	322.0077	4.6575
705.00	1.3210	231.7590	1.8511	324.1379	4.6354
715.00	1.2960	231.7840	1.8392	326.2357	4.6131
725.00	1.2680	231.8120	1.8276	328.3019	4.5567

TABLE A.5. (contd)

Recovery Time, ▲t min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
735.00	1.2350	231.8450	1.8163	330.3371	4.5381
745.00	1.2170	231.8630	1.8054	332.3420	4.5198
755.00	1.1910	231.8890	1.7947	334.3174	4.4715
765.00	1.1690	231.9110	1.7843	336.2637	4.4552
775.00	1.1410	231.9390	1.7742	338.1818	4.4394
785.00	1.1270	231.9530	1.7643	340.0722	4.4230
795.00	1.0940	231.9860	1.7547	341.9355	4.3844
805.00	1.0740	232.0060	1.7453	343.7722	4.3706
815.00	1.0500	232.0300	1.7362	345.5830	4.3585
825.00	1.0400	232.0400	1.7273	347.3684	4.3242
835.00	1.0110	232.0690	1.7186	349.1289	4.3127
845.00	.9880	232.0920	1.7101	350.8651	4.3020
855.00	.9720	232.1080	1.7018	352.5773	4.2909
865.00	.9540	232.1260	1.6936	354.2662	4.2642
875.00	.9310	232.1490	1.6857	355.9322	4.2539
885.00	.9160	232.1640	1.6780	357.5757	4.2435
895.00	.8970	232.1830	1.6704	359.1973	4.2343
905.00	.8760	232.2040	1.6630	360.7973	4.2099
915.00	.8610	232.2190	1.6557	362.3763	4.2008
925.00	.8360	232.2440	1.6486	363.9344	4.1933
935.00	.8220	232.2580	1.6417	365.4723	4.1854
945.00	.7940	232.2860	1.6349	366.9903	4.1669
955.00	.7790	232.3010	1.6283	368.4887	4.1611
965.00	.7510	232.3290	1.6218	369.9680	4.1563
975.00	.7520	232.3280	1.6154	371.4286	4.1499
985.00	.7320	232.3480	1.6091	372.8707	4.1350
995.00	.7080	232.3720	1.6030	374.2947	4.1302
1005.00	.7020	232.3780	1.5970	375.7009	4.1249
1015.00	.7030	232.3770	1.5911	377.0898	4.1185
1025.00	.6820	232.3980	1.5854	378.4615	4.1021
1035.00	.6700	232.4100	1.5797	379.8165	4.0967
1045.00	.6510	232.4290	1.5742	381.1550	4.0912
1055.00	.6220	232.4580	1.5687	382.4774	4.0871
1065.00	.6270	232.4530	1.5634	383.7838	4.0732
1075.00	.6080	232.4720	1.5581	385.0746	4.0684
1085.00	.6090	232.4710	1.5530	386.3502	4.0628
1095.00	.5840	232.4960	1.5479	387.6106	4.0578
1105.00	.5650	232.5150	1.5430	388.8563	4.0455
1115.00	.5440	232.5360	1.5381	390.0875	4.0422
1125.00	.5350	232.5450	1.5333	391.3044	4.0388
1135.00	.5270	232.5530	1.5286	392.5072	4.0355
1145.00	.5150	232.5650	1.5240	393.6963	4.0322
1155.00	.5290	232.5510	1.5195	394.8718	4.0204

TABLE A.5. (contd)

Recovery Time, ▲t min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+▲t)/▲t$	Modified Horner Time $(t_p \times ▲t)/(t_p + ▲t)$ min	Derivative
1165.00	.4910	232.5890	1.5150	396.0340	4.0174
1175.00	.5020	232.5780	1.5106	397.1831	4.0129
1185.00	.4740	232.6060	1.5063	398.3193	4.0093
1195.00	.4510	232.6290	1.5021	399.4429	4.0071
1205.00	.4480	232.6320	1.4979	400.5540	3.9993
1215.00	.4300	232.6500	1.4938	401.6529	3.9967
1225.00	.4420	232.6380	1.4898	402.7397	3.9928
1235.00	.4180	232.6620	1.4858	403.8147	3.9896
1245.00	.3910	232.6890	1.4819	404.8781	3.9882
1255.00	.3770	232.7030	1.4781	405.9299	3.9831
1265.00	.3900	232.6900	1.4743	406.9705	3.9798
1275.00	.3670	232.7130	1.4706	408.0000	3.9777
1285.00	.3660	232.7140	1.4669	409.0186	3.9751
1295.00	.3720	232.7080	1.4633	410.0264	3.9720
1305.00	.3610	232.7190	1.4598	411.0236	3.9647
1315.00	.3270	232.7530	1.4563	412.0104	3.9632
1325.00	.2710	232.8090	1.4528	412.9870	3.9642
1335.00	.3380	232.7420	1.4494	413.9535	3.9599
1345.00	.3150	232.7650	1.4461	414.9100	3.9574
1355.00	.3070	232.7730	1.4428	415.8568	3.9514
1365.00	.3000	232.7800	1.4396	416.7939	3.9488
1375.00	.2770	232.8030	1.4364	417.7215	3.9467
1385.00	.2660	232.8140	1.4332	418.6398	3.9445
1395.00	.2690	232.8110	1.4301	419.5489	3.9423
1405.00	.2620	232.8180	1.4270	420.4489	3.9390
1415.00	.2630	232.8170	1.4240	421.3399	3.9365
1425.00	.2440	232.8360	1.4211	422.2222	3.9346
1435.00	.2470	232.8330	1.4181	423.0958	3.9320
1445.00	.2380	232.8420	1.4152	423.9609	3.9291
1455.00	.2270	232.8530	1.4124	424.8175	3.9264
1465.00	.2220	232.8580	1.4096	425.6659	3.9205
1475.00	.2110	232.8690	1.4068	426.5060	3.9178
1485.00	.2180	232.8620	1.4040	427.3381	3.9145
1495.00	.2120	232.8680	1.4013	428.1623	3.9118
1505.00	.2020	232.8780	1.3987	428.9786	3.9090
1515.00	.1850	232.8950	1.3960	429.7872	3.9070
1525.00	.1830	232.8970	1.3934	430.5882	3.9020
1535.00	.1890	232.8910	1.3909	431.3817	3.8995
1545.00	.1800	232.9000	1.3883	432.1678	3.8962
1555.00	.1700	232.9100	1.3859	432.9466	3.8938
1565.00	.1780	232.9020	1.3834	433.7182	3.8905
1575.00	.1590	232.9210	1.3810	434.4828	3.8881
1585.00	.1530	232.9270	1.3785	435.2403	3.8833

TABLE A.5. (contd)

Recovery Time, Δt min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
1595.00	.1600	232.9200	1.3762	435.9909	3.8804
1605.00	.1520	232.9280	1.3738	436.7347	3.8777
1615.00	.1480	232.9320	1.3715	437.4718	3.8744
1625.00	.1390	232.9410	1.3692	438.2022	3.8719
1635.00	.1460	232.9340	1.3670	438.9262	3.8689
1645.00	.1380	232.9420	1.3647	439.6436	3.8629
1655.00	.1360	232.9440	1.3625	440.3548	3.8597
1665.00	.1340	232.9460	1.3604	441.0596	3.8563
1675.00	.1290	232.9510	1.3582	441.7582	3.8529
1685.00	.1270	232.9530	1.3561	442.4508	3.8495
1695.00	.1260	232.9540	1.3540	443.1373	3.8460
1705.00	.1230	232.9570	1.3519	443.8178	3.8399
1715.00	.1170	232.9630	1.3499	444.4924	3.8365
1725.00	.1140	232.9660	1.3478	445.1613	3.8332
1735.00	.1100	232.9700	1.3458	445.8244	3.8297
1745.00	.1070	232.9730	1.3438	446.4819	3.8260
1755.00	.1060	232.9740	1.3419	447.1338	3.8226
1765.00	.1060	232.9740	1.3399	447.7801	3.8188
1775.00	.1040	232.9760	1.3380	448.4211	3.8122
1785.00	.1010	232.9790	1.3361	449.0566	3.8087
1795.00	.0930	232.9870	1.3343	449.6869	3.8055
1805.00	.0970	232.9830	1.3324	450.3119	3.8013
1815.00	.0930	232.9870	1.3306	450.9317	3.7977
1825.00	.0860	232.9940	1.3288	451.5464	3.7941
1835.00	.0870	232.9930	1.3270	452.1561	3.7903
1845.00	.0820	232.9980	1.3252	452.7607	3.7823
1855.00	.0790	233.0010	1.3235	453.3605	3.7787
1865.00	.0780	233.0020	1.3217	453.9554	3.7750
1875.00	.0730	233.0070	1.3200	454.5454	3.7717
1885.00	.0730	233.0070	1.3183	455.1308	3.7684
1895.00	.0710	233.0090	1.3166	455.7114	3.7652
1905.00	.0670	233.0130	1.3150	456.2874	3.7614
1915.00	.0660	233.0140	1.3133	456.8589	3.7581
1925.00	.0630	233.0170	1.3117	457.4258	3.7494
1935.00	.0600	233.0200	1.3101	457.9882	3.7458
1945.00	.0570	233.0230	1.3085	458.5462	3.7421
1955.00	.0550	233.0250	1.3069	459.0998	3.7386
1965.00	.0560	233.0240	1.3053	459.6491	3.7354
1975.00	.0500	233.0300	1.3038	460.1942	3.7319
1985.00	.0510	233.0290	1.3023	460.7350	3.7284
1995.00	.0440	233.0360	1.3008	461.2717	3.7185
2005.00	.0430	233.0370	1.2993	461.8042	3.7148
2015.00	.0440	233.0360	1.2978	462.3327	3.7115

TABLE A.5. (contd)

Recovery Time, Δt min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
2025.00	.0430	233.0370	1.2963	462.8571	3.7076
2035.00	.0440	233.0360	1.2948	463.3776	3.7041
2045.00	.0360	233.0440	1.2934	463.8941	3.7007
2055.00	.0340	233.0460	1.2920	464.4068	3.6971
2065.00	.0250	233.0550	1.2906	464.9156	3.6941
2075.00	.0320	233.0480	1.2892	465.4206	3.6840
2085.00	.0300	233.0500	1.2878	465.9218	3.6807
2095.00	.0280	233.0520	1.2864	466.4193	3.6772
2105.00	.0270	233.0530	1.2850	466.9131	3.6737
2115.00	.0210	233.0590	1.2837	467.4033	3.6706
2125.00	.0210	233.0590	1.2824	467.8899	3.6675
2135.00	.0200	233.0600	1.2810	468.3730	3.6645
2145.00	.0170	233.0630	1.2797	468.8524	3.6610
2155.00	.0210	233.0590	1.2784	469.3285	3.6577
2165.00	.0220	233.0580	1.2771	469.8011	3.6471
2175.00	.0240	233.0560	1.2759	470.2703	3.6436
2185.00	.0180	233.0620	1.2746	470.7361	3.6401
2195.00	.0150	233.0650	1.2733	471.1986	3.6365
2205.00	.0170	233.0630	1.2721	471.6577	3.6331
2215.00	.0120	233.0680	1.2709	472.1137	3.6300
2225.00	.0100	233.0700	1.2697	472.5664	3.6269
2235.00	.0070	233.0730	1.2685	473.0159	3.6235
2245.00	.0070	233.0730	1.2673	473.4622	3.6206
2255.00	.0090	233.0710	1.2661	473.9054	3.6090
2265.00	.0080	233.0720	1.2649	474.3456	3.6058
2275.00	.0020	233.0780	1.2637	474.7826	3.6024

P_o = Observed water level at time Δt

P_i = Initial water level prior to constant-rate test; 113.51 ft btc

P_{wf} = Water level at termination of constant-rate test; 233.08 ft btc

t_p = Duration of constant-rate test; 600 min

Δt = Recovery time; time since termination of constant-rate test

APPENDIX B

HYDRAULIC TEST DATA FOR WELL 699-42-E9A, RINGOLD FORMATION: DEPTH INTERVAL = 195 TO 232 FT

B.1. Slug Injection Test Data

B.2. Slug Withdrawal Test Data

TABLE B.1. Slug Injection Test Data for Well 699-42-E9A, Ringold Formation: Depth Interval = 195 to 232 ft

Test Time min	Pressure Transducer Reading, H feet	$H-H_i$ feet	$(H-H_i)/H_o$	Data Derivative
.450	1.9800	1.9800	.9429	
.533	1.9600	1.9600	.9333	.1202
.616	1.9400	1.9400	.9238	.1460
.700	1.9300	1.9300	.9190	.1633
.783	1.9100	1.9100	.9095	.1783
.866	1.8800	1.8800	.8952	.2098
.950	1.8600	1.8600	.8857	.2374
1.033	1.8400	1.8400	.8762	.2667
1.116	1.8200	1.8200	.8667	.2780
1.200	1.7900	1.7900	.8524	.2918
1.283	1.7700	1.7700	.8429	.3097
1.366	1.7500	1.7500	.8333	.3256
1.450	1.7300	1.7300	.8238	.3439
1.533	1.7100	1.7100	.8143	.3587
1.616	1.6900	1.6900	.8048	.3722
1.700	1.6700	1.6700	.7952	.3818
1.783	1.6500	1.6500	.7857	.3875
1.866	1.6300	1.6300	.7762	.4043
1.950	1.6100	1.6100	.7667	.4201
2.450	1.5000	1.5000	.7143	.4962
2.950	1.4000	1.4000	.6667	.5379
3.450	1.3000	1.3000	.6190	.5880
3.950	1.2100	1.2100	.5762	.6358
4.450	1.1400	1.1400	.5429	.6371
4.950	1.0600	1.0600	.5048	.6418
5.450	.9900	.9900	.4714	.6464
5.950	.9300	.9300	.4429	.6508
6.450	.8700	.8700	.4143	.6630
6.950	.8200	.8200	.3905	.6512
7.450	.7700	.7700	.3667	.6414
7.950	.7300	.7300	.3476	.6205
8.450	.6900	.6900	.3286	.6047
8.950	.6500	.6500	.3095	.5958
9.450	.6200	.6200	.2952	.5795
9.950	.5800	.5800	.2762	.5667
11.950	.4800	.4800	.2286	.5248
13.950	.4100	.4100	.1952	.4779
15.950	.3400	.3400	.1619	.4345
17.950	.2900	.2900	.1381	.3980
19.950	.2500	.2500	.1190	.3643
21.950	.2000	.2000	.0952	.3315
23.950	.1700	.1700	.0810	.3031
25.950	.1500	.1500	.0714	.2891

TABLE B.1. (contd)

Test Time min	Pressure Transducer Reading, H feet	$H-H_i$ feet	$(H-H_i)/H_o$	Data Derivative
27.950	.1300	.1300	.0619	.2622
29.950	.1200	.1200	.0571	.2320
31.950	.1100	.1100	.0524	.1872
33.950	.0900	.0900	.0429	.1725
35.950	.0900	.0900	.0429	.1558
37.950	.0900	.0900	.0429	.1359
39.950	.0800	.0800	.0381	.1154
41.950	.0500	.0500	.0238	.1142
43.950	.0600	.0600	.0286	.1097
45.950	.0500	.0500	.0238	.1061
47.950	.0500	.0500	.0238	.0994
49.950	.0500	.0500	.0238	.0878
51.950	.0400	.0400	.0190	.0743
53.950	.0500	.0500	.0238	.1048
55.950	.0400	.0400	.0190	.0989
57.950	.0300	.0300	.0143	.0956
59.950	.0400	.0400	.0190	.0863
61.950	.0300	.0300	.0143	.0708
63.950	.0300	.0300	.0143	.0544
65.950	.0300	.0300	.0143	.0536
67.950	.0300	.0300	.0143	.0591
69.950	.0300	.0300	.0143	.0518
71.950	.0300	.0300	.0143	.0484
73.950	.0300	.0300	.0143	.0460
75.950	.0300	.0300	.0143	.0424
77.950	.0300	.0300	.0143	.0372
79.950	.0300	.0300	.0143	.0292
81.950	.0400	.0400	.0190	.0210
83.950	.0400	.0400	.0190	.0135
85.950	.0300	.0300	.0143	.0032

Test initiated at 1020 hr, December 18, 1990

Initial pressure transducer reading, H_i = 0.00; (Note: pressure transducer reading set equal to zero)

Induced slug stress level, H_o = 2.10 ft

TABLE B.2. Slug Withdrawal Test Data for Well 699-42-E9A, Ringold Formation: Depth Interval = 195 to 232 ft

Test Time min	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
.143	-2.0500	2.0500	.9903	
.160	-2.0400	2.0400	.9855	.0751
.176	-2.0400	2.0400	.9855	.0438
.193	-2.0300	2.0300	.9807	.0475
.210	-2.0300	2.0300	.9807	.0489
.226	-2.0300	2.0300	.9807	.0469
.243	-2.0300	2.0300	.9807	.0404
.260	-2.0300	2.0300	.9807	.0339
.276	-2.0200	2.0200	.9758	.0397
.293	-2.0200	2.0200	.9758	.0308
.310	-2.0200	2.0200	.9758	.0409
.393	-2.0000	2.0000	.9662	.0649
.476	-2.0000	2.0000	.9662	.0656
.560	-1.9800	1.9800	.9565	.0668
.643	-1.9700	1.9700	.9517	.1112
.726	-1.9600	1.9600	.9469	.1331
.810	-1.9500	1.9500	.9420	.1404
.893	-1.9400	1.9400	.9372	.1522
.976	-1.9200	1.9200	.9275	.1876
1.060	-1.9000	1.9000	.9179	.2075
1.143	-1.8800	1.8800	.9082	.2168
1.226	-1.8600	1.8600	.8986	.2439
1.310	-1.8400	1.8400	.8889	.2602
1.393	-1.8200	1.8200	.8792	.2643
1.476	-1.8100	1.8100	.8744	.2674
1.560	-1.7900	1.7900	.8647	.2735
1.643	-1.7800	1.7800	.8599	.2695
1.726	-1.7600	1.7600	.8502	.2747
1.810	-1.7500	1.7500	.8454	.2727
1.893	-1.7400	1.7400	.8406	.2684
1.976	-1.7200	1.7200	.8309	.2712
2.476	-1.6600	1.6600	.8019	.2746
2.976	-1.6100	1.6100	.7778	.2973
3.476	-1.5700	1.5700	.7585	.3019
3.976	-1.5300	1.5300	.7391	.3224
4.476	-1.4800	1.4800	.7150	.3550
4.976	-1.4400	1.4400	.6957	.3847
5.476	-1.4000	1.4000	.6763	.4131
5.976	-1.3600	1.3600	.6570	.4303
6.476	-1.3200	1.3200	.6377	.4620
6.976	-1.2900	1.2900	.6232	.4771
7.476	-1.2600	1.2600	.6087	.4954
7.976	-1.2300	1.2300	.5942	.4966

TABLE B.2. (contd)

Test Time min	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
8.476	-1.2000	1.2000	.5797	.5154
8.976	-1.1600	1.1600	.5604	.5281
9.476	-1.1400	1.1400	.5507	.5294
9.976	-1.1000	1.1000	.5314	.5511
11.976	-.9800	.9800	.4734	.6071
13.976	-.8900	.8900	.4300	.6141
15.976	-.8000	.8000	.3865	.6304
17.976	-.7200	.7200	.3478	.6291
19.976	-.6500	.6500	.3140	.6349
21.976	-.5900	.5900	.2850	.6248
23.976	-.5300	.5300	.2560	.6091
25.976	-.4600	.4600	.2222	.6134
27.976	-.4100	.4100	.1981	.5781
29.976	-.3800	.3800	.1836	.5544
31.976	-.3500	.3500	.1691	.5482
33.976	-.3200	.3200	.1546	.5210
35.976	-.2800	.2800	.1353	.5078
37.976	-.2500	.2500	.1208	.4983
39.976	-.2300	.2300	.1111	.4630
41.976	-.2000	.2000	.0966	.4564
43.976	-.1900	.1900	.0918	.4383
45.976	-.1700	.1700	.0821	.4416
47.976	-.1600	.1600	.0773	.4306
49.976	-.1400	.1400	.0676	.4305
51.976	-.1200	.1200	.0580	.4312
53.976	-.1100	.1100	.0531	.4049
55.976	-.1000	.1000	.0483	.3990
57.976	-.0800	.0800	.0386	.3961

Test initiated at 1152 hr, December 18, 1990

Initial pressure transducer reading, H_i = 0.00; (Note: pressure transducer reading set equal to zero)

Induced slug stress level, H_o = 2.07 ft

APPENDIX C

HYDRAULIC TEST DATA FOR WELL 699-42-E9B, ELEPHANT MOUNTAIN BASALT INTERFLOW ZONE

C.1. Slug Withdrawal Test #1 Data

C.2. Slug Withdrawal Test #2 Data

C.3. Constant-Rate Pumping Test: Pertinent Hydraulic Field Test Data

C.4. Constant-Rate Pumping Test: Composite Drawdown Analysis Data Set

TABLE C.1. Slug Withdrawal Test #1 Data for Well 699-42-E9B, Elephant Mountain Basalt Interflow Zone

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
.49	13.0190	1.3390	.9612	
.99	13.0620	1.2960	.9304	.1087
1.50	13.1020	1.2560	.9017	.1087
1.99	13.1240	1.2340	.8859	.0987
2.49	13.1260	1.2320	.8844	.0697
3.00	13.1340	1.2240	.8787	.1516
3.49	13.1540	1.2040	.8643	.1780
3.99	13.1880	1.1700	.8399	.2573
4.50	13.2190	1.1390	.8177	.2859
4.99	13.2400	1.1180	.8026	.3088
5.49	13.2540	1.1040	.7925	.3135
6.00	13.2560	1.1020	.7911	.2847
6.99	13.2790	1.0790	.7746	.2991
7.99	13.3250	1.0330	.7416	.3274
9.00	13.3600	.9980	.7164	.3807
9.99	13.3770	.9810	.7042	.4272
10.99	13.4040	.9540	.6849	.4375
12.00	13.4390	.9190	.6597	.4379
12.99	13.4600	.8980	.6447	.4375
13.99	13.4780	.8800	.6317	.4554
15.00	13.5010	.8570	.6152	.4904
15.99	13.5310	.8270	.5937	.5143
16.99	13.5550	.8030	.5765	.5180
22.50	13.6540	.7040	.5054	.5696
23.49	13.6690	.6890	.4946	.5778
24.00	13.6810	.6770	.4860	.5693
25.99	13.7170	.6410	.4602	.5743
27.99	13.7430	.6150	.4415	.5947
30.00	13.7760	.5820	.4178	.6097
33.00	13.8140	.5440	.3905	.6040
36.00	13.8510	.5070	.3640	.6063
39.00	13.8890	.4690	.3367	.5934
42.00	13.9190	.4390	.3151	.5953
45.00	13.9470	.4110	.2950	.5797
48.00	13.9760	.3820	.2742	.5784
51.00	14.0010	.3570	.2563	.5615
54.00	14.0230	.3350	.2405	.5519
57.00	14.0430	.3150	.2261	.5338
60.00	14.0640	.2940	.2111	.5118
63.00	14.0810	.2770	.1989	.5049
66.00	14.0970	.2610	.1874	.4833
69.00	14.1130	.2450	.1759	.4723
72.00	14.1270	.2310	.1658	.4502

TABLE C.1. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
75.00	14.1420	.2160	.1551	.4346
78.00	14.1530	.2050	.1472	.4200
81.00	14.1630	.1950	.1400	.4071
84.00	14.1740	.1840	.1321	.3898
87.00	14.1840	.1740	.1249	.3793
90.00	14.1920	.1660	.1192	.3610
93.00	14.2010	.1570	.1127	.3476
96.00	14.2060	.1520	.1091	.3379
99.00	14.2150	.1430	.1027	.3244
102.00	14.2230	.1350	.0969	.3104
105.00	14.2260	.1320	.0948	.2963
108.00	14.2330	.1250	.0897	.2872
111.00	14.2380	.1200	.0861	.2784
114.00	14.2420	.1160	.0833	.2675
117.00	14.2450	.1130	.0811	.2547
120.00	14.2500	.1080	.0775	.2461
123.00	14.2540	.1040	.0747	.2360
126.00	14.2580	.1000	.0718	.2334
129.00	14.2620	.0960	.0689	.2209
132.00	14.2660	.0920	.0660	.2152
135.00	14.2670	.0910	.0653	.2036
138.00	14.2710	.0870	.0625	.1976
141.00	14.2740	.0840	.0603	.1925
144.00	14.2740	.0840	.0603	.1829
147.00	14.2770	.0810	.0581	.1783
150.00	14.2800	.0780	.0560	.1757
153.00	14.2840	.0740	.0531	.1669
156.00	14.2830	.0750	.0538	.1603
159.00	14.2870	.0710	.0510	.1528
162.00	14.2870	.0710	.0510	.1522
165.00	14.2890	.0690	.0495	.1499
168.00	14.2900	.0680	.0488	.1402
171.00	14.2940	.0640	.0459	.1372
174.00	14.2940	.0640	.0459	.1290
177.00	14.2970	.0610	.0438	.1282
180.00	14.2970	.0610	.0438	.1238
183.00	14.2990	.0590	.0424	.1232
186.00	14.3010	.0570	.0409	.1189
189.00	14.3000	.0580	.0416	.1183
192.00	14.3030	.0550	.0395	.1154
195.00	14.3030	.0550	.0395	.1105
198.00	14.3050	.0530	.0380	.1082
201.00	14.3080	.0500	.0359	.1046
204.00	14.3080	.0500	.0359	.1014

TABLE C.1. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
207.00	14.3080	.0500	.0359	.0969
210.00	14.3100	.0480	.0345	.0984
213.00	14.3110	.0470	.0337	.0958
216.00	14.3100	.0480	.0345	.0902
219.00	14.3110	.0470	.0337	.0870
222.00	14.3120	.0460	.0330	.0850
225.00	14.3130	.0450	.0323	.0867
228.00	14.3140	.0440	.0316	.0895
231.00	14.3140	.0440	.0316	.0859
234.00	14.3150	.0430	.0309	.0826
237.00	14.3150	.0430	.0309	.0807
240.00	14.3160	.0420	.0302	.0757
243.00	14.3170	.0410	.0294	.0789
246.00	14.3190	.0390	.0280	.0772
249.00	14.3170	.0410	.0294	.0694
252.00	14.3180	.0400	.0287	.0710
255.00	14.3190	.0390	.0280	.0695
258.00	14.3190	.0390	.0280	.0672
261.00	14.3200	.0380	.0273	.0657
264.00	14.3210	.0370	.0266	.0652
267.00	14.3200	.0380	.0273	.0579
270.00	14.3210	.0370	.0266	.0568
273.00	14.3210	.0370	.0266	.0575
276.00	14.3190	.0390	.0280	.0526
279.00	14.3200	.0380	.0273	.0518
282.00	14.3210	.0370	.0266	.0527
285.00	14.3230	.0350	.0251	.0561
288.00	14.3210	.0370	.0266	.0527
291.00	14.3220	.0360	.0258	.0504
294.00	14.3230	.0350	.0251	.0498
297.00	14.3230	.0350	.0251	.0521
299.00	14.3220	.0360	.0258	.0514
330.50	14.3270	.0310	.0223	.0476
360.50	14.3280	.0300	.0215	.0404
390.50	14.3320	.0260	.0187	.0377
420.50	14.3310	.0270	.0194	.0375
450.50	14.3300	.0280	.0201	.0338
480.50	14.3330	.0250	.0179	.0336
510.50	14.3400	.0180	.0129	.0372
540.50	14.3410	.0170	.0122	.0318
570.50	14.3420	.0160	.0115	.0325
600.49	14.3410	.0170	.0122	.0303
630.49	14.3410	.0170	.0122	.0332
660.49	14.3430	.0150	.0108	.0344

TABLE C.1. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
690.49	14.3450	.0130	.0093	.0410
720.49	14.3450	.0130	.0093	.0370
750.49	14.3480	.0100	.0072	.0397
780.49	14.3490	.0090	.0065	.0305
810.49	14.3500	.0080	.0057	.0313
840.49	14.3460	.0120	.0086	.0232
870.49	14.3460	.0120	.0086	.0216
900.49	14.3480	.0100	.0072	.0246
930.49	14.3490	.0090	.0065	.0283
960.49	14.3510	.0070	.0050	.0324
990.49	14.3520	.0060	.0043	.0328

Test initiated at 1542 hr, March 18, 1990

Initial pressure transducer reading, H_i = 14.358 ft

Induced slug stress level, H_o = 1.393 ft

TABLE C.2. Slug Withdrawal Test #2 Data for Well 699-42-E9B, Elephant Mountain Basalt Interflow Zone

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
.499	13.0050	1.3660	.9863	
.999	13.0370	1.3340	.9632	.1021
1.499	13.0760	1.2950	.9350	.1275
1.999	13.1030	1.2680	.9155	.1482
2.499	13.1160	1.2550	.9061	.1292
2.999	13.1320	1.2390	.8946	.1739
3.499	13.1700	1.2010	.8671	.2354
3.999	13.1890	1.1820	.8534	.2770
4.499	13.2000	1.1710	.8455	.2714
4.999	13.2250	1.1460	.8274	.2578
5.499	13.2390	1.1320	.8173	.2735
5.999	13.2600	1.1110	.8022	.2948
6.499	13.2770	1.0940	.7899	.3293
6.999	13.2940	1.0770	.7776	.3434
7.500	13.3090	1.0620	.7668	.3456
7.999	13.3240	1.0470	.7560	.3611
8.499	13.3360	1.0350	.7473	.3746
8.999	13.3520	1.0190	.7357	.3830
9.499	13.3710	1.0000	.7220	.3942
9.999	13.3830	.9880	.7134	.4073
10.500	13.3980	.9730	.7025	.4161
10.999	13.4110	.9600	.6931	.4241
11.499	13.4260	.9450	.6823	.4368
12.000	13.4390	.9320	.6729	.4492
12.499	13.4530	.9180	.6628	.4610
12.999	13.4600	.9110	.6578	.4752
13.500	13.4740	.8970	.6477	.4807
13.999	13.4890	.8820	.6368	.4857
14.499	13.5000	.8710	.6289	.4828
15.000	13.5100	.8610	.6217	.4954
15.499	13.5210	.8500	.6137	.5045
15.999	13.5340	.8370	.6043	.5097
16.499	13.5440	.8270	.5971	.5170
16.999	13.5550	.8160	.5892	.5185
17.499	13.5640	.8070	.5827	.5276
18.000	13.5760	.7950	.5740	.5353
18.499	13.5850	.7860	.5675	.5401
18.999	13.5960	.7750	.5596	.5437
19.500	13.6060	.7650	.5523	.5471
19.999	13.6180	.7530	.5437	.5634
20.499	13.6260	.7450	.5379	.5671
21.000	13.6380	.7330	.5292	.5649
21.499	13.6460	.7250	.5235	.5633

TABLE C.2. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
21.999	13.6550	.7160	.5170	.5670
22.500	13.6620	.7090	.5119	.5721
22.999	13.6690	.7020	.5069	.5758
23.499	13.6820	.6890	.4975	.5813
24.000	13.6900	.6810	.4917	.5854
24.499	13.6990	.6720	.4852	.5880
24.999	13.7060	.6650	.4801	.5888
25.500	13.7140	.6570	.4744	.5938
25.999	13.7220	.6490	.4686	.5964
26.499	13.7310	.6400	.4621	.5993
27.000	13.7350	.6360	.4592	.5987
27.499	13.7460	.6250	.4513	.6021
27.999	13.7550	.6160	.4448	.6023
28.500	13.7620	.6090	.4397	.6014
28.999	13.7710	.6000	.4332	.6063
29.499	13.7780	.5930	.4282	.6067
30.000	13.7850	.5860	.4231	.6074
33.000	13.8270	.5440	.3928	.6053
36.000	13.8620	.5090	.3675	.6101
39.000	13.8970	.4740	.3422	.6058
42.000	13.9310	.4400	.3177	.6047
45.000	13.9590	.4120	.2975	.5899
48.000	13.9860	.3850	.2780	.5765
51.000	14.0110	.3600	.2599	.5657
54.000	14.0340	.3370	.2433	.5579
57.000	14.0540	.3170	.2289	.5412
60.000	14.0730	.2980	.2152	.5282
63.000	14.0930	.2780	.2007	.5091
66.000	14.1100	.2610	.1884	.4923
69.000	14.1250	.2460	.1776	.4808
72.000	14.1400	.2310	.1668	.4667
75.000	14.1530	.2180	.1574	.4508
78.000	14.1640	.2070	.1495	.4356
81.000	14.1770	.1940	.1401	.4245
84.000	14.1870	.1840	.1329	.4101
87.000	14.1970	.1740	.1256	.3985
90.000	14.2060	.1650	.1191	.3800
93.000	14.2150	.1560	.1126	.3712
96.000	14.2230	.1480	.1069	.3547
99.000	14.2310	.1400	.1011	.3402
102.000	14.2360	.1350	.0975	.3288
105.000	14.2420	.1290	.0931	.3198
108.000	14.2480	.1230	.0888	.3080
111.000	14.2540	.1170	.0845	.2956

TABLE C.2. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
114.000	14.2600	.1110	.0801	.2875
117.000	14.2640	.1070	.0773	.2785
120.000	14.2690	.1020	.0736	.2718
123.000	14.2740	.0970	.0700	.2595
126.000	14.2770	.0940	.0679	.2506
132.000	14.2860	.0850	.0614	.2339
135.000	14.2900	.0810	.0585	.2292
138.000	14.2930	.0780	.0563	.2233
141.000	14.2940	.0770	.0556	.2140
144.000	14.2960	.0750	.0542	.2050
147.000	14.3000	.0710	.0513	.1983
150.000	14.3030	.0680	.0491	.1911
153.000	14.3050	.0660	.0477	.1840
156.000	14.3070	.0640	.0462	.1787
159.000	14.3080	.0630	.0455	.1762
162.000	14.3110	.0600	.0433	.1683
165.000	14.3130	.0580	.0419	.1668
168.000	14.3160	.0550	.0397	.1609
171.000	14.3190	.0520	.0375	.1554
177.000	14.3200	.0510	.0368	.1465
180.000	14.3220	.0490	.0354	.1418
183.000	14.3240	.0470	.0339	.1383
186.000	14.3260	.0450	.0325	.1328
189.000	14.3280	.0430	.0310	.1302
192.000	14.3290	.0420	.0303	.1260
195.000	14.3280	.0430	.0310	.1244
198.000	14.3300	.0410	.0296	.1211
201.000	14.3320	.0390	.0282	.1139
204.000	14.3330	.0380	.0274	.1106
207.000	14.3330	.0380	.0274	.1072
210.000	14.3340	.0370	.0267	.1056
213.000	14.3350	.0360	.0260	.1027
216.000	14.3380	.0330	.0238	.1013
219.000	14.3400	.0310	.0224	.1001
222.000	14.3400	.0310	.0224	.0986
225.000	14.3400	.0310	.0224	.0985
228.000	14.3400	.0310	.0224	.0973
231.000	14.3410	.0300	.0217	.0924
234.000	14.3410	.0300	.0217	.0889
237.000	14.3430	.0280	.0202	.0883
240.000	14.3420	.0290	.0209	.0848
243.000	14.3430	.0280	.0202	.0843
246.000	14.3430	.0280	.0202	.0823
249.000	14.3440	.0270	.0195	.0834

TABLE C.2. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
252.000	14.3450	.0260	.0188	.0812
255.000	14.3440	.0270	.0195	.0778
258.000	14.3440	.0270	.0195	.0755
261.000	14.3460	.0250	.0181	.0771
264.000	14.3470	.0240	.0173	.0748
267.000	14.3470	.0240	.0173	.0707
270.000	14.3480	.0230	.0166	.0710
273.000	14.3470	.0240	.0173	.0706
276.000	14.3480	.0230	.0166	.0709
279.000	14.3480	.0230	.0166	.0696
285.000	14.3490	.0220	.0159	.0675
288.000	14.3500	.0210	.0152	.0665
291.000	14.3500	.0210	.0152	.0639
294.000	14.3500	.0210	.0152	.0629
297.000	14.3500	.0210	.0152	.0603
300.000	14.3510	.0200	.0144	.0608
303.000	14.3520	.0190	.0137	.0615
306.000	14.3520	.0190	.0137	.0636
309.000	14.3530	.0180	.0130	.0642
312.000	14.3530	.0180	.0130	.0616
315.000	14.3530	.0180	.0130	.0589
318.000	14.3530	.0180	.0130	.0581
324.000	14.3530	.0180	.0130	.0573
327.000	14.3550	.0160	.0116	.0598
330.000	14.3530	.0180	.0130	.0554
333.000	14.3550	.0160	.0116	.0574
336.000	14.3540	.0170	.0123	.0551
339.000	14.3550	.0160	.0116	.0523
342.000	14.3550	.0160	.0116	.0517
345.000	14.3560	.0150	.0108	.0504
348.000	14.3550	.0160	.0116	.0491
351.000	14.3550	.0160	.0116	.0486
354.000	14.3560	.0150	.0108	.0505
357.000	14.3570	.0140	.0101	.0524
360.000	14.3560	.0150	.0108	.0503
363.000	14.3580	.0130	.0094	.0522
366.000	14.3570	.0140	.0101	.0501
369.000	14.3580	.0130	.0094	.0520
372.000	14.3580	.0130	.0094	.0490

TABLE C.2. (contd)

Test Time seconds	Pressure Transducer Reading, H feet	H_i-H feet	$(H_i-H)/H_o$	Data Derivative
375.000	14.3580	.0130	.0094	.0486
378.000	14.3590	.0120	.0087	.0520
381.000	14.3580	.0130	.0094	.0491

Test initiated at 1627 hr, March 18, 1990

Initial pressure transducer reading, H_i = 14.371 ft

Induced slug stress level, H_o = 1.385 ft

TABLE C.3. Pertinent Field Test Data for Well 699-42-E9B, Elephant Mountain Basalt Interflow Zone - Constant-Rate Pumping Test

Test Time min	Water-Level ft, btc	Flowmeter Reading gal	Turbidity Measurement NTU	Comments
0	26.605	1480		Test started at 1816 hr, 3/18/91
10		1960		
29			2.2	
90	41.2	5160		
93			2.5	
127	41.6	6580		
144			0.58	
156		7750		
164			0.42	
188				Discharge = 5 gal in 8 s
227	42.23	10540	0.60	
278	42.50	12730		
299			0.44	
307		13810		
353			0.34	
407	42.85	18250		
498	43.14	22000	0.50	
560	43.34	24610	0.41	
618	43.50	27040	0.39	
650	43.58	28400		
704				Discharge = 5 gal in 9 s
739			0.28	
787		34230		
889	44.12	38590		
894			0.33	
969				Discharge = 5 gal in 8 s
974	44.30			
1009			0.26	
1040	44.50		0.36	
1049		45310		Test terminated

Turbidity measured with a Hach, Inc., Turbidimeter, model # 161800, serial number 880903404.

TABLE C.4. Composite Drawdown Analysis Data Set for Well 699-42-E9B, Elephant Mountain Basalt Interflow Zone - Constant-Rate Pumping Test

Test Time, t min	Calculated Drawdown $P_o - P_i$ ft	Data Derivative
1.00	4.0000	
1.50	7.2000	6.3996
2.00	8.4000	4.0979
2.49	9.5000	4.2844
2.99	10.0000	3.2479
3.49	10.6000	2.6697
4.48	11.0000	2.1597
4.98	11.2000	1.6806
5.47	11.4000	1.6506
5.97	11.5100	1.7152
6.95	11.7800	1.7435
7.94	11.9800	1.6091
8.92	12.1400	1.5516
9.91	12.3200	1.4670
10.89	12.4200	1.3913
11.00	12.6410	1.4205
12.00	12.7100	1.4192
13.00	12.8070	1.4013
14.00	12.8650	1.2647
15.00	12.9370	1.2227
16.00	12.9850	1.2290
17.00	13.0610	1.1811
18.00	13.0990	.9531
19.00	13.1350	.9567
20.00	13.2150	.9632
21.00	13.2520	.9384
22.00	13.2690	.9325
23.00	13.3040	.9171
24.00	13.3710	.9431
25.00	13.3930	.9394
26.00	13.4360	.9147
27.00	13.4840	.9387
28.00	13.4940	.9295
29.00	13.5500	.9554
30.00	13.5780	.9407
31.00	13.6200	.9033
32.00	13.6760	.9127
34.00	13.6950	.9349
36.00	13.7490	.9608
38.00	13.7990	.9507
40.00	13.8470	.9648
42.00	13.8920	.9373
44.00	13.9360	.9713

TABLE C.4. (contd)

Test Time, t min	Calculated Drawdown $P_o - P_i$ ft	Data Derivative
47.00	13.9970	.9666
48.00	14.0060	.9514
49.00	14.0230	.9577
50.00	14.0410	.9326
51.00	14.0530	.9732
52.00	14.0730	.9821
53.00	14.0970	.9908
54.00	14.1060	.9684
55.00	14.1330	.9789
56.00	14.1480	.9849
59.00	14.2060	1.0108
64.00	14.3060	1.0219
69.00	14.3650	1.0281
74.00	14.4370	1.0244
79.00	14.5190	1.0642
84.00	14.5940	1.0911
89.00	14.6440	1.0659
94.00	14.7190	1.0590
99.00	14.7540	1.0487
104.00	14.8240	1.1012
109.00	14.8710	1.0951
114.00	14.9230	1.1019
119.00	14.9510	1.0803
124.00	15.0220	1.0946
129.00	15.0510	1.0765
134.00	15.0970	1.0960
164.00	15.2960	1.0874
194.00	15.4940	1.0888
224.00	15.6530	1.1355
254.00	15.7940	1.1287
284.00	15.9270	1.1426
314.00	16.0360	1.1521
344.00	16.1390	1.1798
374.00	16.2270	1.1871
404.00	16.3130	1.1878
464.00	16.4920	1.2881
524.00	16.6400	1.3955
584.00	16.7940	1.5139
644.00	16.9240	1.5030
704.00	17.0730	1.5705
764.00	17.2110	1.6286
824.00	17.3810	1.7035

TABLE C.4. (contd)

Test Time, t min	Calculated Calculated Drawdown $P_o - P_i$ ft	Data Derivative
884.00	17.5030	1.7399
944.00	17.6460	1.8375
1004.00	17.7520	1.8212

P_i = 26.605 ft btc

Note: Because of a data acquisition system failure during the beginning of the constant-rate pumping test, no actual drawdown measurements were obtained during the first 10 minutes of the test. To facilitate diagnostic analysis of the drawdown phase, calculated drawdown data prior to t = 10 min were derived from recovery water-level measurements. Time values used for recovery water-levels were calculated using the modified Horner time parameter, Δt_e, which is defined by Agarwal (1980) as:

$$\Delta t_e = (t_p \times \Delta t)/(t_p + \Delta t)$$

where t_p = duration of the pumping test; (T)

Δt = time since pumping terminated; (T)

REFERENCE

Agarwal, R. G. 1980. "A New Method to Account For Producing Time Effects When Drawdown Type Curves Are Used to Analyze Pressure Buildup and Other Test Data." Society of Petroleum Engineers, SPE Paper 9289, presented at the 1980 SPE Annual Technical Conference and Exhibition, Dallas, Sept. 21-24.

APPENDIX D

HYDRAULIC TEST DATA FOR WELL 699-42-E9B, ELEPHANT MOUNTAIN/ POMONA BASALT FLOW CONTACT ZONE

D.1. Constant-Rate Pumping Test: Pertinent Hydraulic Field Test Data
D.2. Constant-Rate Pumping Test: Drawdown Analysis Data Set
D.3. Constant-Rate Pumping Test: Recovery Analysis Data Set

TABLE D.1. Pertinent Field Test Data for Well 699-42-E9B, Elephant Mountain/ Pomona Basalt Flow Contact Zone - Constant-Rate Pumping Test

Test Time min	Water-Level ft, btc	Flowmeter Reading gpm	Discharge Check	Comments
0	25.36	50400		Test started at 1300 hr, 4/18/91
7			50	5 gal/6 s
9		50770	47.3	5 gal/6.34 s; decreased flow rate
46		52230	37.5	5 gal/8 s
156		56540	37.5	5 gal/8 s
194		58000		
262		60680		
314		62700		
387		65570		
473		68900		
616		74480		
657		76050		Test terminated

TABLE D.2. Drawdown Analysis Data Set for Well 699-42-E9B, Elephant Mountain/Pomona Basalt Flow Contact - Constant-Rate Pumping Test

Test Time, t min	Pressure Transducer Readings ft	Calculated Drawdown Po - Pi ft	Data Derivative
.050	38.2174	1.5026	
.125	36.2907	3.4293	2.9449
.142	35.8782	3.8418	3.3381
.159	35.5682	4.1518	3.2991
.175	35.1820	4.5380	3.5810
.192	34.8450	4.8750	3.8013
.208	34.5350	5.1850	3.9912
.242	33.8924	5.8276	4.3553
.275	33.3098	6.4102	4.6867
.309	32.7657	6.9543	4.9318
.342	32.2145	7.5055	5.1448
.375	31.7041	8.0159	5.3740
.442	30.8067	8.9133	5.7372
.509	29.9379	9.7822	6.0222
.575	29.1637	10.5563	6.2398
.625	28.6544	11.0656	6.3380
.708	27.7785	11.9415	6.4806
.791	27.0532	12.6668	6.6225
.875	26.3644	13.3556	6.6348
.958	25.7278	13.9922	6.6709
1.041	25.1563	14.5637	6.6690
1.125	24.6071	15.1129	6.6321
1.208	24.0848	15.6352	6.6363
1.291	23.6758	16.0443	6.6140
1.375	23.2803	16.4397	6.5160
1.458	22.8402	16.8798	6.4839
1.541	22.5124	17.2076	6.3905
1.625	22.1083	17.6117	6.3222
1.791	21.5408	18.1792	6.1683
1.967	20.9330	18.7870	6.0056
2.125	20.5190	19.2010	5.8191
2.291	20.0086	19.7114	5.6550
2.458	19.6206	20.0994	5.5294
2.625	19.2428	20.4772	5.3964
2.791	18.9554	20.7646	5.2395
2.958	18.6268	21.0932	5.1142
3.125	18.3501	21.3699	4.9805
3.291	18.1203	21.5997	4.8936
3.458	17.8768	21.8432	4.7744
3.625	17.6270	22.0930	4.6620
3.791	17.4461	22.2739	4.5681
4.125	17.1154	22.6046	4.3943

TABLE D.2. (contd)

Test Time, t min	Pressure Transducer Readings ft	Calculated Drawdown Po - Pi ft	Data Derivative
4.458	16.7963	22.9237	4.1579
4.791	16.5166	23.2034	3.9676
5.125	16.2374	23.4826	3.7947
5.458	16.0083	23.7117	3.6188
5.791	15.8169	23.9031	3.4609
6.125	15.5982	24.1218	3.3143
6.458	15.4016	24.3184	3.2338
6.791	15.2564	24.4636	3.1638
7.291	15.0375	24.6825	3.0831
7.791	14.8074	24.9126	3.0368
8.291	14.6080	25.1120	3.0105
8.791	14.4797	25.2403	3.0140
10.791	14.1610	25.5590	2.7933
11.791	13.9143	25.8057	2.5953
12.791	13.6884	26.0316	2.5013
12.958	13.6471	26.0729	2.4394
13.791	13.4829	26.2371	2.3755
14.791	13.2589	26.4611	2.3231
15.791	13.0864	26.6336	2.2930
16.791	12.9215	26.7985	2.3278
17.791	12.7682	26.9518	2.5016
18.791	12.6520	27.0680	2.4187
19.791	12.4586	27.2614	2.3776
20.791	12.3765	27.3435	2.3258
21.791	12.2593	27.4607	2.2969
22.791	12.1355	27.5845	2.2724
23.791	12.0142	27.7058	2.2661
24.791	11.9305	27.7895	2.2484
25.791	11.9064	27.8136	2.2001
26.791	11.7978	27.9222	2.1711
27.791	11.7512	27.9688	2.1374
28.791	11.6721	28.0479	2.1027
29.791	11.6026	28.1174	2.0728
30.791	11.6093	28.1107	2.0390
32.791	11.4664	28.2536	1.9865
34.791	11.4126	28.3074	1.9257
36.791	11.2491	28.4709	1.8695
38.791	11.1893	28.5307	1.8333
40.791	11.0550	28.6650	1.8201
42.791	11.0021	28.7179	1.7986
44.791	10.9340	28.7861	1.7500
46.791	10.7679	28.9521	1.7833
48.791	10.7647	28.9554	1.8181
50.791	10.6654	29.0546	1.8415

TABLE D.2. (contd)

Test Time, t min	Pressure Transducer Readings ft	Calculated Drawdown Po - Pi ft	Data Derivative
52.791	10.6647	29.0553	1.8398
54.791	10.5752	29.1448	1.8431
57.791	10.4620	29.2580	1.8552
60.791	10.4193	29.3007	1.8530
63.792	10.3212	29.3988	1.8319
66.792	10.1837	29.5363	1.8240
70.792	10.0865	29.6335	1.8182
75.792	9.9894	29.7306	1.8284
80.792	9.8036	29.9164	1.8591
85.792	9.7289	29.9911	1.8901
90.792	9.7421	29.9779	1.8556
95.792	9.4594	30.2606	1.8882
100.792	9.3701	30.3499	1.9314
110.792	9.2120	30.5080	1.9934
120.792	9.0559	30.6641	2.0055
130.792	8.9376	30.7824	1.9875
140.792	8.7980	30.9220	1.9807
160.792	8.5185	31.2015	1.9879
180.792	8.2147	31.5053	2.0357
210.792	7.9353	31.7847	2.0678
240.792	7.6463	32.0737	2.0685
270.792	7.4610	32.2590	2.0629
300.792	7.2133	32.5067	2.0631
330.792	6.9547	32.7653	2.0740
360.792	6.8010	32.9190	2.1194
390.792	6.6215	33.0985	2.1251
420.792	6.5048	33.2152	2.1202
450.792	6.3928	33.3272	2.0921
480.792	6.2676	33.4524	2.0785
510.792	6.1143	33.6057	2.0780
540.792	5.9860	33.7340	2.0470
570.792	5.8337	33.8863	2.0723
600.792	5.6646	34.0554	2.0976
630.792	5.5435	34.1765	2.1322
655.792	5.4287	34.2913	2.1610

Test initiated at 1300 hr, April 18, 1991

Initial pressure transducer reading, P_i = 39.720 ft

Test terminated at 2357 hr, April 18, 1991

TABLE D.3. Recovery Analysis Data Set for Well 699-42-E9B, Elephant Mountain/Pomona Basalt Flow Contact Zone - Constant-Rate Pumping Test

Recovery Time, Δt min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
.041	34.3216	.0516	16025.3900	.0410	
.083	34.0336	.2364	7916.6630	.0830	1.6990
.116	33.0317	1.2383	5664.7930	.1160	3.5209
.166	31.5108	2.7592	3958.8320	.1660	4.8346
.216	30.1084	4.1616	3042.6670	.2159	5.7801
.250	29.2309	5.0391	2629.0000	.2499	6.2975
.283	28.3897	5.8803	2322.5550	.2829	6.7536
.333	27.2250	7.0450	1973.9730	.3328	7.3667
.366	26.4910	7.7790	1796.0820	.3658	7.6609
.416	25.4509	8.8191	1580.3270	.4157	8.0180
.450	24.8078	9.4622	1461.0000	.4497	8.2017
.500	23.8938	10.3762	1315.0000	.4996	8.4327
.535	23.3179	10.9521	1229.0370	.5346	8.5058
.585	22.5072	11.7628	1124.0770	.5845	8.6425
.618	21.9997	12.2703	1064.1070	.6174	8.6463
.668	21.2817	12.9883	984.5330	.6673	8.6944
.702	20.8334	13.4366	936.8974	.7013	8.6480
.752	20.1987	14.0713	874.6702	.7511	8.6231
.785	19.8005	14.4695	837.9426	.7841	8.5842
.835	19.2230	15.0470	787.8264	.8339	8.5129
.843	19.1337	15.1363	780.3594	.8419	8.4708
.918	18.3679	15.9021	716.6863	.9167	8.3590
1.002	17.6047	16.6653	656.6887	1.0005	8.1383
1.085	16.9227	17.3474	606.5299	1.0832	7.9434
1.177	16.2568	18.0132	559.1988	1.1749	7.6683
1.252	15.7758	18.4942	525.7604	1.2496	7.4525
1.335	15.2977	18.9723	493.1348	1.3323	7.1921
1.418	14.8647	19.4053	464.3286	1.4149	6.9605
1.502	14.4725	19.7975	438.4168	1.4986	6.6989
1.585	14.1203	20.1497	415.5110	1.5812	6.5000
1.668	13.8013	20.4687	394.8849	1.6638	6.2748
1.752	13.5111	20.7589	376.0000	1.7473	6.0346
1.835	13.2478	21.0222	359.0381	1.8299	5.8362
1.918	13.0059	21.2641	343.5443	1.9124	5.6515
1.927	12.9814	21.2886	341.9445	1.9214	5.5716
2.002	12.7834	21.4866	329.1718	1.9959	5.4119
2.168	12.3870	21.8830	304.0443	2.1609	5.1296
2.335	12.0489	22.2211	282.3705	2.3267	4.8604
2.502	11.7511	22.5189	263.5899	2.4925	4.5993
2.668	11.4921	22.7779	247.2519	2.6572	4.3643
2.835	11.2580	23.0120	232.7460	2.8228	4.1566

TABLE D.3. (contd)

Recovery Time, Δt min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
3.002	11.0505	23.2195	219.8541	2.9883	3.9768
3.168	10.8596	23.4104	208.3864	3.1528	3.8226
3.335	10.6849	23.5851	198.0015	3.3182	3.6897
3.502	10.5268	23.7432	188.6071	3.4834	3.5737
3.668	10.3774	23.8926	180.1167	3.6476	3.4712
3.835	10.2380	24.0320	172.3168	3.8127	3.3792
4.002	10.1083	24.1617	165.1679	3.9778	3.2469
4.168	9.9857	24.2843	158.6295	4.1417	3.1505
4.335	9.8699	24.4002	152.5571	4.3066	3.0908
4.502	9.7604	24.5096	146.9352	4.4714	3.0135
4.668	9.6568	24.6132	141.7455	4.6351	2.9634
4.835	9.5571	24.7129	136.8842	4.7997	2.8992
5.002	9.4615	24.8085	132.3475	4.9642	2.8564
5.168	9.3727	24.8974	128.1285	5.1277	2.8035
5.335	9.2849	24.9851	124.1490	5.2920	2.7658
5.502	9.1998	25.0702	120.4111	5.4563	2.7216
5.668	9.1199	25.1501	116.9139	5.6195	2.6891
5.835	9.0430	25.2270	113.5964	5.7836	2.6531
6.002	8.9726	25.2974	110.4635	5.9477	2.6234
6.168	8.9006	25.3694	107.5175	6.1106	2.5915
6.335	8.8344	25.4356	104.7095	6.2745	2.5647
6.502	8.7681	25.5019	102.0458	6.4383	2.5370
6.668	8.7072	25.5628	99.5303	6.6010	2.5124
6.835	8.6456	25.6245	97.1229	6.7646	2.4873
7.002	8.5885	25.6815	94.8303	6.9282	2.4643
7.168	8.5315	25.7385	92.6574	7.0906	2.4406
7.335	8.4752	25.7948	90.5705	7.2540	2.4188
7.502	8.4233	25.8467	88.5766	7.4173	2.4058
7.668	8.3723	25.8978	86.6807	7.5795	2.3852
7.835	8.3228	25.9472	84.8545	7.7427	2.3679
8.002	8.2735	25.9965	83.1045	7.9057	2.3518
8.168	8.2277	26.0423	81.4358	8.0677	2.3320
8.335	8.1814	26.0886	79.8242	8.2306	2.3165
8.502	8.1363	26.1337	78.2759	8.3934	2.2996
8.668	8.0953	26.1747	76.7960	8.5551	2.2836
8.835	8.0519	26.2181	75.3633	8.7178	2.2656
9.002	8.0085	26.2615	73.9838	8.8803	2.2503
9.168	7.9704	26.2996	72.6623	9.0418	2.2336
9.335	7.9332	26.3368	71.3803	9.2042	2.2182
9.502	7.8935	26.3765	70.1433	9.3665	2.2255
9.668	7.8577	26.4123	68.9561	9.5278	2.2318
9.835	7.8213	26.4487	67.8022	9.6899	2.2153
10.002	7.7862	26.4838	66.6869	9.8520	2.2023

TABLE D.3. (contd)

Recovery Time, Δt min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
10.168	7.7520	26.5180	65.6145	10.0130	2.1867
10.335	7.7199	26.5501	64.5704	10.1749	2.1744
10.502	7.6869	26.5831	63.5595	10.3368	2.1589
10.668	7.6567	26.6133	62.5861	10.4975	2.1469
10.835	7.6225	26.6475	61.6368	10.6592	2.1323
11.002	7.5948	26.6752	60.7164	10.8208	2.1211
11.168	7.5653	26.7047	59.8288	10.9813	2.1070
11.335	7.5348	26.7352	58.9621	11.1428	2.1027
11.502	7.5050	26.7650	58.1205	11.3041	2.0893
11.668	7.4753	26.7947	57.3078	11.4644	2.0794
11.835	7.4487	26.8213	56.5133	11.6256	2.0672
12.002	7.4222	26.8478	55.7409	11.7867	2.0574
12.168	7.3947	26.8753	54.9941	11.9467	2.0452
12.335	7.3679	26.9021	54.2631	12.1077	2.0362
12.502	7.3414	26.9286	53.5516	12.2685	2.0251
12.668	7.3162	26.9538	52.8630	12.4284	2.0163
12.835	7.2911	26.9789	52.1882	12.5891	2.0058
13.002	7.2668	27.0032	51.5307	12.7497	1.9977
13.168	7.2424	27.0276	50.8937	12.9093	1.9878
13.335	7.2181	27.0519	50.2688	13.0697	1.9802
13.502	7.1960	27.0740	49.6595	13.2301	1.9704
13.668	7.1731	27.0969	49.0685	13.3895	1.9631
13.835	7.1519	27.1181	48.4883	13.5497	1.9937
14.002	7.1281	27.1419	47.9219	13.7098	1.9872
14.168	7.1059	27.1641	47.3721	13.8689	1.9775
14.335	7.0854	27.1846	46.8319	14.0289	1.9712
14.502	7.0665	27.2035	46.3041	14.1888	1.9617
14.668	7.0475	27.2225	45.7914	14.3477	1.9546
14.835	7.0277	27.2423	45.2872	14.5074	1.9446
15.002	7.0078	27.2622	44.7942	14.6671	1.9371
15.502	6.9485	27.3215	43.3816	15.1447	1.9188
16.002	6.8869	27.3831	42.0574	15.6215	1.9040
16.502	6.8296	27.4404	40.8134	16.0977	1.8875
17.002	6.7775	27.4925	39.6425	16.5731	1.8743
17.502	6.7322	27.5378	38.5386	17.0479	1.8603
18.002	6.6847	27.5853	37.4959	17.5219	1.8436
18.502	6.6431	27.6269	36.5097	17.9952	1.8294
19.002	6.6014	27.6686	35.5753	18.4679	1.8118
19.502	6.5586	27.7114	34.6889	18.9398	1.7950
23.002	6.2791	27.9909	29.5627	22.2239	1.7297
28.002	5.9705	28.2995	24.4626	26.8573	1.6558
33.002	5.7244	28.5456	20.9079	31.4236	1.6116
63.002	4.8106	29.4594	11.4282	57.4892	1.5274

TABLE D.3. (contd)

Recovery Time, Δt min	Residual Drawdown $P_o - P_i$ ft	Recovery Buildup $P_o - P_{wf}$ ft	Horner Time $(t_p+\Delta t)/\Delta t$	Modified Horner Time $(t_p \times \Delta t)/(t_p + \Delta t)$ min	Derivative
93.002	4.2718	29.9981	8.0644	81.4695	1.5733
123.002	3.9083	30.3617	6.3414	103.6053	1.6425
153.002	3.6138	30.6562	5.2941	124.1013	1.6646
183.002	3.3731	30.8968	4.5901	143.1334	1.7146
213.002	3.1770	31.0930	4.0845	160.8529	1.7376
243.002	2.9905	31.2795	3.7037	177.3911	1.7712
273.002	2.8091	31.4609	3.4066	192.8623	1.8054
303.002	2.6678	31.6022	3.1683	207.3666	1.8562
333.002	2.5550	31.7150	2.9730	220.9918	1.8638
363.002	2.4437	31.8263	2.8099	233.8155	1.8701
393.002	2.3618	31.9082	2.6717	245.9065	1.8691
423.002	2.2964	31.9736	2.5532	257.3257	1.8789
453.002	2.2145	32.0555	2.4503	268.1277	1.8727
483.002	2.1371	32.1328	2.3602	278.3612	1.8711
513.002	2.0679	32.2021	2.2807	288.0699	1.8753
543.002	1.9941	32.2759	2.2099	297.2931	1.8798

P_o = Observed water level at time Δt

P_i = Initial pressure transducer reading prior to constant-rate test; 39.720 ft

P_{wf} = Pressure transducer reading at termination of constant-rate test; 5.450 ft

t_p = Duration of constant-rate test; 657 min

Δt = Recovery time; time since termination of constant-rate test

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