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Results and Evaluation of Experimental Vertical Hydraulic Conductivity Testing at Boreholes DC-4 and DC-5

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RESULTS AND EVALUATION OF EXPERIMENTAL VERTICAL HYDRAULIC CONDUCTIVITY TESTING AT BOREHOLES DC-4 and DC-5

SUMMARY

TFST METHOD REVIEW

1. Available vertical hydraulic conductivity tests, reported in scientific journals of hydrology and the petroleum industry, were evaluated for possible use under Hanford Site test conditions.

2. Vertical hydraulic conductivity test methods reviewed can be grouped into two major categories: multiple well and single well tests.

3. Multiple well tests can be further categorized as:

   o Partial Penetration Tests.
   o Leaky Aquifer Tests.
   o Directional Hydraulic Conductivity Tests.

   A. Partial penetration tests include methods originally designed for determining vertical hydraulic conductivity within aquifers possessing relatively high permeability. Without modification, these test methods are not directly applicable for determining vertical hydraulic conductivity of low permeability horizons (i.e., confining zones).

   B. The leaky aquifer category refers to tests which determine vertical hydraulic conductivity of confining zones by direct or indirect methods.

      a. Indirect leaky aquifer tests attribute deviations in aquifer behavior during periods of stress (i.e., pumping) to confining zone properties.

      b. Direct leaky aquifer tests calculate vertical hydraulic conductivity by comparing the transient response within the confining zone and stressed aquifer over various increments of time.

   C. Directional hydraulic conductivity tests differ from the other methods in that stress and monitor zones are limited solely to the confining zone. Because of the recent development of these methods, they were not considered for the initial field vertical conductivity test.

4. Single well test methods were developed and utilized primarily within the petroleum industry. The test methods generally consist of an injection zone and associated monitoring zone, which are separated by a specified distance. Disadvantages of single well tests include the

apparently small area of investigation and unproven nature of these methods in low permeability horizons.

5. Based on the review of available vertical hydraulic conductivity test methods, the ratio method (a direct leaky aquifer technique) was selected for the initial experimental test evaluation.

TEST SITE INFORMATION

1. All available dual and multiple borehole locations were examined for possible utilization as the initial vertical conductivity test site.

2. Grande Ronde horizons evaluated for testing include the: Umtanum, McCoy Canyon, Cohassett and Rocky Coulee flows.

3. The site and horizon selected for the initial ratio test were boreholes DC-4 and DC-5, and a twenty-six foot section of the Rocky Coulee flow interior (confining zone) immediately overlying the composite Cohassett flow top (aquifer).

4. Significant factors considered in the test site and horizon selection included:

   o Favorable geographical siting within the reference repository location.

   o Presence of distinct stratigraphic contacts.

   o Relatively short distance between boreholes at test horizon depth.

   o Potential for obtaining positive test results within reasonable test times.

TEST RESULTS

1. The ratio test was performed by conducting a constant head injection at borehole DC-5 within the composite Cohassett flow top and monitoring the transient response at DC-4 within the flow top and overlying section of the Rocky Coulee flow interior.

2. Constant head injection conditions were maintained for eight weeks (February 3 to April 1, 1983). The constant head induced at borehole DC-5 was equivalent to 133 lb/in^2 (i.e., approximately 307 ft of water) above pre-test formation conditions. Injection flow rates varied from an initial 4.0 to 0.13 gpm during testing. Testing was terminated April 1, 1983, due to failure of the bottom bridge plug packer at borehole DC-5, which isolated the bottom section of the composite Cohassett flow top.

3. Results from testing indicate:

- No discernable formation response during eight weeks of testing the Rocky Coulee flow interior.
- Based on the lack of discernable formation response and known test system and formation characteristics, vertical hydraulic conductivity for the Rocky Coulee flow interior is estimated to be less than 10^{-5} ft/day.
- Test system components (i.e., injection system, downhole pressure probe, etc.) performed well over most of the period of testing.
- Compliance effects of approximately 9.8 lb/in^2 were experienced during initial phases of testing due to test system deformation.
- Because of BWIP test equipment constraints and existing formation conditions, use of the ratio test for determining vertical hydraulic conductivity of flow interiors, may be of limited application at the Hanford Site.

FUTURE STUDIES

1. Future field evaluation of vertical hydraulic conductivity tests should focus on newly developed directional hydraulic conductivity tests.
2. In addition to the primary emphasis placed on evaluating directional hydraulic conductivity methods, support should also be provided for examining single well tests. Due to the preponderance of single borehole sites, establishing the viability of single well tests could significantly increase the opportunity to acquire areal vertical hydraulic conductivity values on the Hanford Site.

INTRODUCTION

The Basalt Waste Isolation Project (BWIP), conducted by Rockwell Hanford Operations under contract to the U.S. Department of Energy, is involved in assessing the suitability of basalt as a repository medium for the long-term storage of high-level radioactive wastes. An important part of this assessment is determining the transport time of radioactive wastes from a candidate repository horizon to the accessible environment. To support performance assessment studies of potential radioactive waste transport, representative estimates of vertical hydraulic conductivity for basalts at the Hanford Site must be obtained.

This document reports the results of a recent experimental field test at boreholes DC-4 and DC-5 to assess the applicability of the "ratio method", described by Neuman and Witherspoon (1972), in determining vertical conductivity of basalt interiors under Hanford Site test conditions. The stratigraphic horizon tested at the dual borehole site during the initial test of the ratio method was a twenty-six foot section of Rocky Coulee flow interior (confining zone) immediately overlying the composite Cohassett flow top (aquifer). Also included in the report is a brief review of available vertical hydraulic conductivity test methods; a description of the test interval and ratio test design; and future BWIP plans for vertical hydraulic conductivity testing at the Hanford Site.

PREVIOUS INVESTIGATIONS

Previous performance assessment studies have indicated that potential radioactive waste transport from candidate horizons is strongly influenced by the effective vertical hydraulic conductivity of surrounding geologic formations. In layered hydrogeologic systems, such as the deep basalts beneath the Hanford Site, the effective vertical hydraulic conductivity is dominated by the smallest vertical hydraulic conductivity within the system (Freeze and Cherry, 1979). For basalts beneath the Hanford Site, the smallest vertical hydraulic conductivities are represented by dense basalt flow interiors (i.e., colonnade and entablature).

Values of vertical hydraulic conductivity which have been used in previous basalt groundwater studies have been obtained by arbitrarily assigned values, experimentally derived from computer simulations and sensitivity analysis or as an assumed ratio of known horizontal hydraulic conductivity values (e.g., Tanaka, et al., 1974, MacNish and Barker, 1976, Arnett, 1980). Due to the diverse manner that estimates of vertical hydraulic conductivity have been obtained, previously reported values for this hydraulic parameter have exhibited considerable range.

BWIP has performed sensitivity studies to assess the effects of varying vertical hydraulic conductivity for basalts on far-field modeling of areal hydraulic head distributions, groundwater flow patterns, and travel-time calculations within Pasco Basin (e.g., Arnett, 1980, Arnett, et al., 1981). These studies indicate that the groundwater flow fields and travel-time estimates are quite sensitive to the magnitude of vertical hydraulic conductivity and also to the ratio of vertical and horizontal conductivities. In addition, due to preferred joint and fracture orientations, it was assumed in these studies that vertical hydraulic conductivities of basalt flow interiors (i.e., colonnade and entablature zones) may be in the order of 100 times greater than measured lateral hydraulic conductivity values. Measured lateral hydraulic conductivity values for basalt flow interiors at the Hanford Site are reported by Spane (1982) to commonly range between 10^{-11} and 10^{-13} m/sec (10^{-6} and 10^{-8} ft/day).

Results of BWIP performance assessment studies also indicate that in the near-field, variability in vertical hydraulic conductivity can significantly affect the migration and transport of radionuclides in the vicinity of a candidate repository horizon. King, et al. (1981) reports that when the hydraulic conductivities (i.e., both horizontal and vertical) varied over a range of two orders of magnitude, the transport of radionuclides was significantly changed.

BWIP has recognized the need to determine the vertical hydraulic conductivity of dense basalt flow interiors through in-situ field measurements (Rockwell, 1982). The performance of field vertical hydraulic conductivity tests, however, is not routine. In addition, no known test examples have been reported for deep (i.e., depths in excess of 1,000 ft) test horizons.

BWIP's efforts in the past have focused on the review and evaluation of reported test methods which may be applicable for utilization under Hanford Site conditions. Consultants subcontracted to BWIP to provide recommendations concerning test design and review of vertical hydraulic conductivity tests conducted at the Hanford Site include:

Iraj Javandel	Lawrence Berkeley Laboratory
Charles Wilson	Lawrence Berkeley Laboratory
Shlomo Neuman	University of Arizona
Paul Fenske	University of Nevada - Desert Research Institute

Concurrent with the test method review, development and acquisition of equipment and instrumentation required for performing vertical hydraulic conductivity tests has also proceeded. Results of the test method evaluation and description of equipment employed during testing are discussed in following sections of the report.

REVIEW OF VERTICAL HYDRAULIC CONDUCTIVITY TEST METHODS

Descriptions of the performance and analysis of a number of vertical hydraulic conductivity test methods have been reported in scientific journals of hydrology and the petroleum industry. The test methods examined can be grouped into two major categories: multiple well and single well tests. Review and evaluation of the various methods for applicability under Hanford test conditions have been performed by consultant subcontractors to Rockwell Hanford Opertations, as well as BWIP hydrologists within the Site Analysis and Drilling and Testing Groups. Review comments and recommendations concerning the performance of vertical hydraulic testing in basalts at the Hanford Site are contained in correspondence by Javandel and Wilson to Baker (1982), Neuman to Hunt (1982), and Javandel to Leonhart (1983).

MULTIPLE WELL TESTS

Based on the technical review reported in the letter correspondence from Javandel to Leonhart (1983), multiple well tests can be grouped into three major categories:

- o Partial Penetration Tests.
- o Leaky Aquifer Tests.
- o Directional Hydraulic Conductivity Tests.

Partial penetration tests evaluated (i.e., Weeks, 1969; Way and McKee, 1982), were originally designed to determine vertical hydraulic conductivity within pumped aquifers (not adjoining confining layers) possessing relatively high permeability. Since the initial BWIP effort is focused on acquiring estimates of vertical hydraulic conductivity for low permeability basalt flow interiors, which act as confining layers, these tests are not directly applicable. A detailed description of the assumptions and limitations of these methods is contained in the previously cited references.

Leaky aquifer tests are designed for determining the vertical hydraulic conductivity of confining layers by analyzing the aquifer response during stress (i.e., pumping). Specifically, deviations in aquifer behavior during pumping are attributed to confining layer properties. Leaky aquifer tests of this type are derivations of the "leaky aquifer" theory first discussed by Jacob (1946). Analysis methods of this type include: Hantush and Jacob (1955), Hantush (1960), Walton (1960), and Narasimhan (1968). A detailed review of these methods and others is contained in Neuman and Witherspoon (1969), Walton (1979), and in the correspondence of Javandel to Leonhart (1983).

A major advantage of leaky aquifer tests is that large volumes of rock (i.e., within the aquifer and confining layers) are investigated during testing. Vertical hydraulic conductivity values determined from these tests would, therefore, be more representative of average, areal characteristics of the confining layers. One of the major drawbacks for leaky aquifer tests of this type, however, is that the properties of confining layers are determined indirectly by analyzing the transient response of the stressed aquifer for deviation from predicted ideal, non-leaky conditions. In many cases, this deviation may be slight and difficult to discern with available analytical methods. In addition, properties determined by this method cannot be attributed solely to one of the adjoining confining layers.

Due to these inherent weaknesses, leaky aquifer tests were developed that directly examine the response of the confining layer or compare aquifer/confining zone transient behavior. Analyses of this type are described by Wolff (1970) and Neuman and Witherspoon (1972). A review of these tests methods is contained in the aforementioned references.

Directional hydraulic conductivity tests are of recent development. They contrast with previously discussed methods in that the stress and associated transient response are limited solely to the confining layer. For this test type, a specific section within the confining layer is stressed and the associated transient response recorded at a number of monitoring sections within a neighboring borehole site, as shown in Figure 1. Based on the transient response recorded, a permeability ellipsoid is developed for the stressed rock mass. From the permeability ellipsoid, vertical hydraulic conductivity (as well as other directional conductivities) can be determined.

An analytical advantage of directional hydraulic conductivity tests is that the orientation of principal hydraulic conductivities is not assumed. In the case of leaky aquifer tests, one principal hydraulic conductivity direction is assumed to be perpendicular to the bedding plane. Any bias imposed by predetermined permeability orientations, therefore, is eliminated by using directional hydraulic conductivity.

Because of the recent development of directional hydraulic conductivity tests, these methods were not considered by BWIP for the initial field vertical conductivity test. They are mentioned in this report, however, because of their future importance in BWIP vertical hydraulic conductivity testing plans. Examples of directional hydraulic conductivity tests are discussed in Hsieh, et al. (1983) and Javandel (1983).

SINGLE WELL TESTS

A number of single well tests for the determination of vertical hydraulic conductivity have been utilized in the petroleum industry. A major assumption common to these techniques is that one of the principal conductivity directions is vertical (letter from Javandel to Leonhart, 1983). Single well tests generally consist of an injection zone and associated monitoring zone, which are separated by a specified distance prescribed by the various test methods. Figure 2 shows the general test system deployment for these test types.

Although the utility of developed single well tests for obtaining vertical hydraulic conductivities in low permeability horizons is largely unproven,

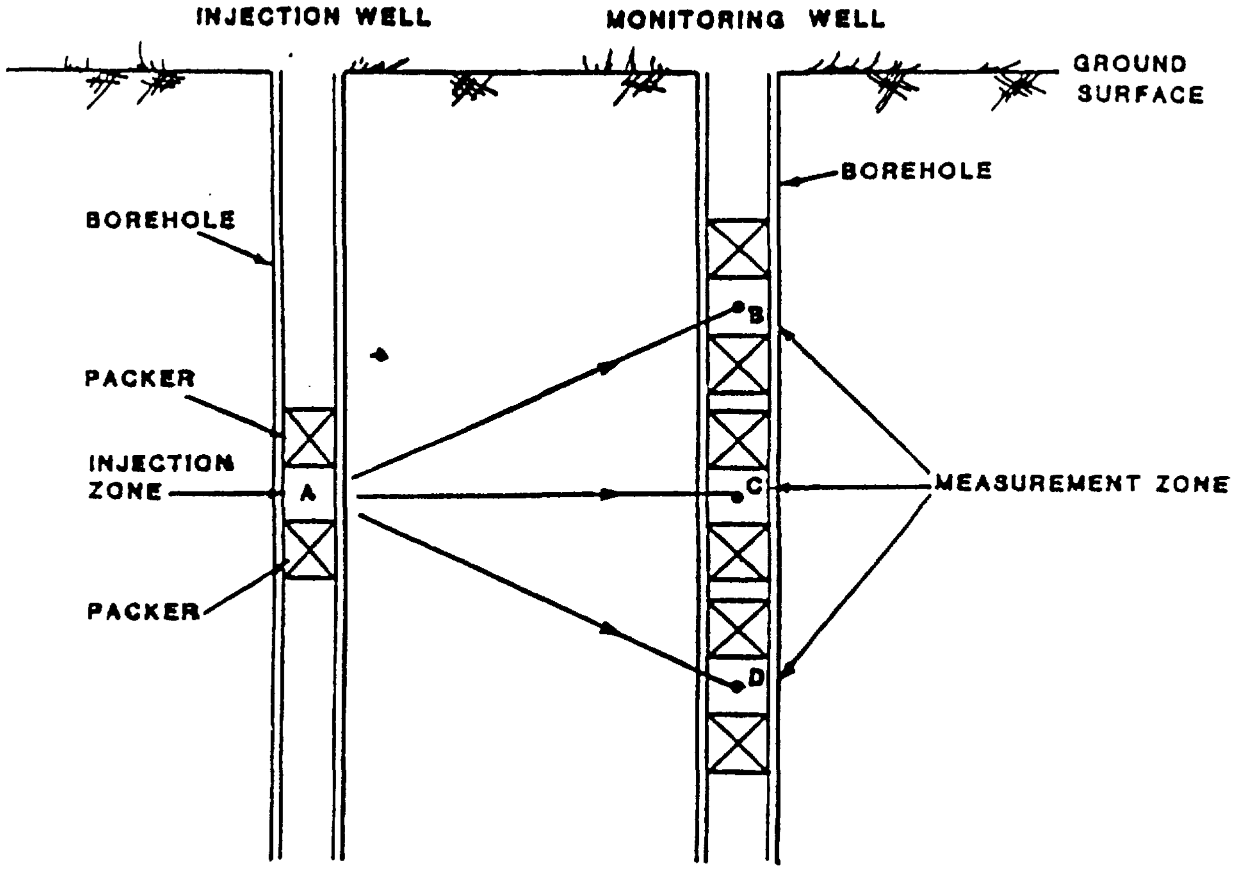

FIGURE 1. General Field Design for Multiple Well-Directional Hydraulic Conductivity Test (Modified from Javandel, 1983, Letter Correspondence to Leonhart).

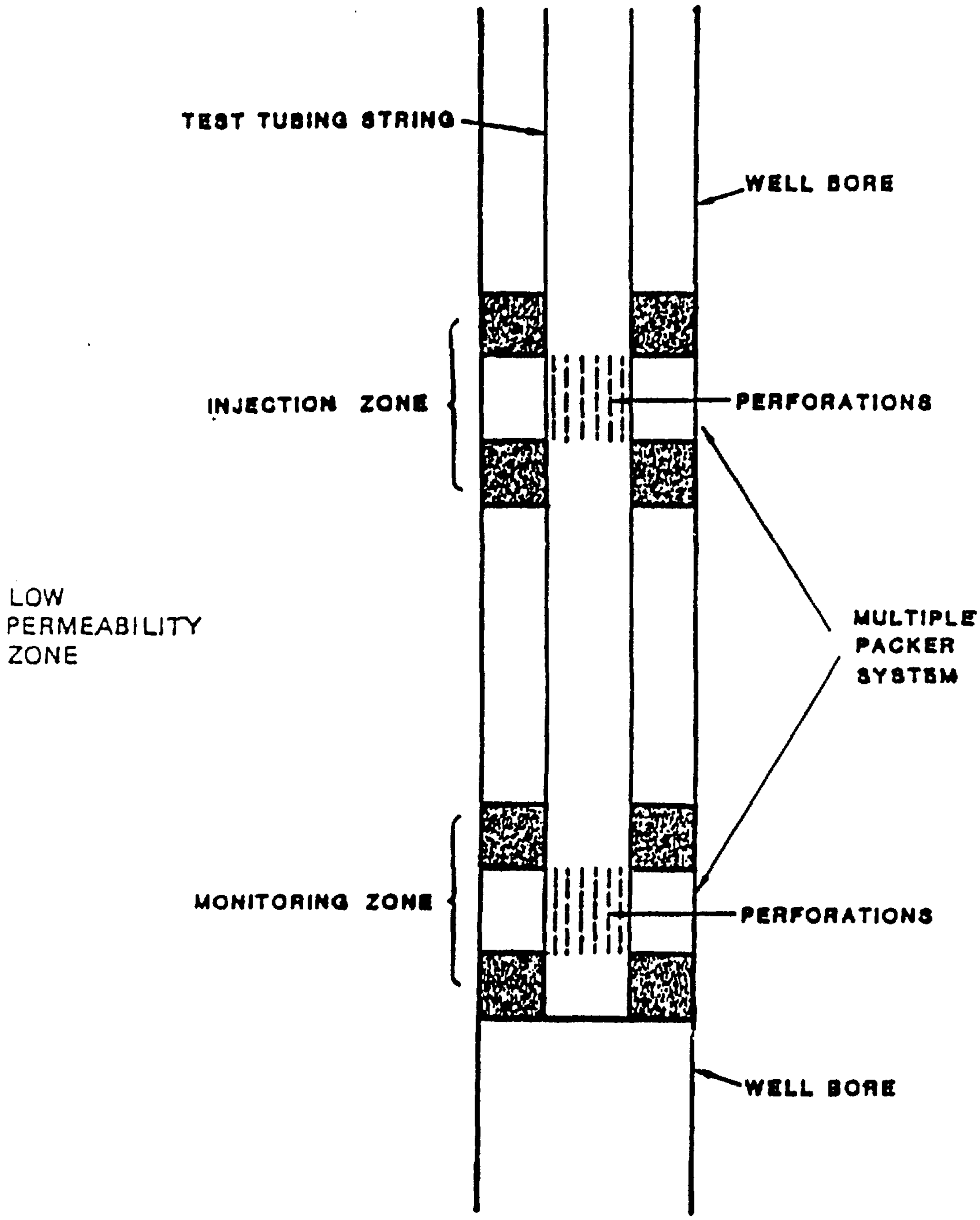

FIGURE 2. General Field Design for Single Well-Vertical Hydraulic Conductivity Test.

the fact that such tests investigate small distances outside the borehole may limit their usefulness. As with directional hydraulic conductivity tests, single well methods are mentioned in this report for possible consideration in future BWIP vertical hydraulic conductivity test plans. Examples of single well tests are provided in Burns (1969), Prats (1970), Hiraski (1974), and Raghaven and Clark (1975).

TEST METHOD SELECTION

Based on the review of available vertical hydraulic conductivity test methods, the multiple well ratio method, as described by Neuman and Witherspoon (1972) was selected as the initial technique for field evaluation. The traditional use of the ratio method requires the monitoring of pressure drawdown within an observation well in the stressed (i.e., pumped) aquifer and within the adjacent confining layer.

In the example test case cited by Neuman and Witherspoon (1972), field measurements were obtained by means of individual piezometers constructed within the stressed aquifer and adjoining confining layers. The same monitoring scheme, however, could be obtained through use of multiple packers for isolating discrete monitoring intervals within an individual borehole. Figure 3 shows the general test geometry for a dual-well ratio test using a multiple packer system.

As stated previously, the ratio method has an advantage over other leaky aquifer test methods in that the vertical hydraulic conductivity of the confining zone is calculated directly by comparing transient response of the aquifer and confining zone. In addition, this method is not subject to analysis errors associated with type-curve, curve-matching techniques, and can be relatively simple to apply, if certain aquifer and confining layer properties are known or can be estimated.

Other significant features cited by Neuman and Witherspoon (1972) concerning the method include:

- It can be applied to multiple, leaky-aquifer systems.
- Confining layers can be heterogeneous and anisotropic.
- It relies on early-time data, therefore, tests may be of short duration.
- It is more sensitive to time lag (i.e., when response is detected) within the confining zone, rather than actual magnitude of the response.
- It does not require a prior knowledge of confining layer thickness.

The general analysis procedure for the ratio method is presented in the following steps.

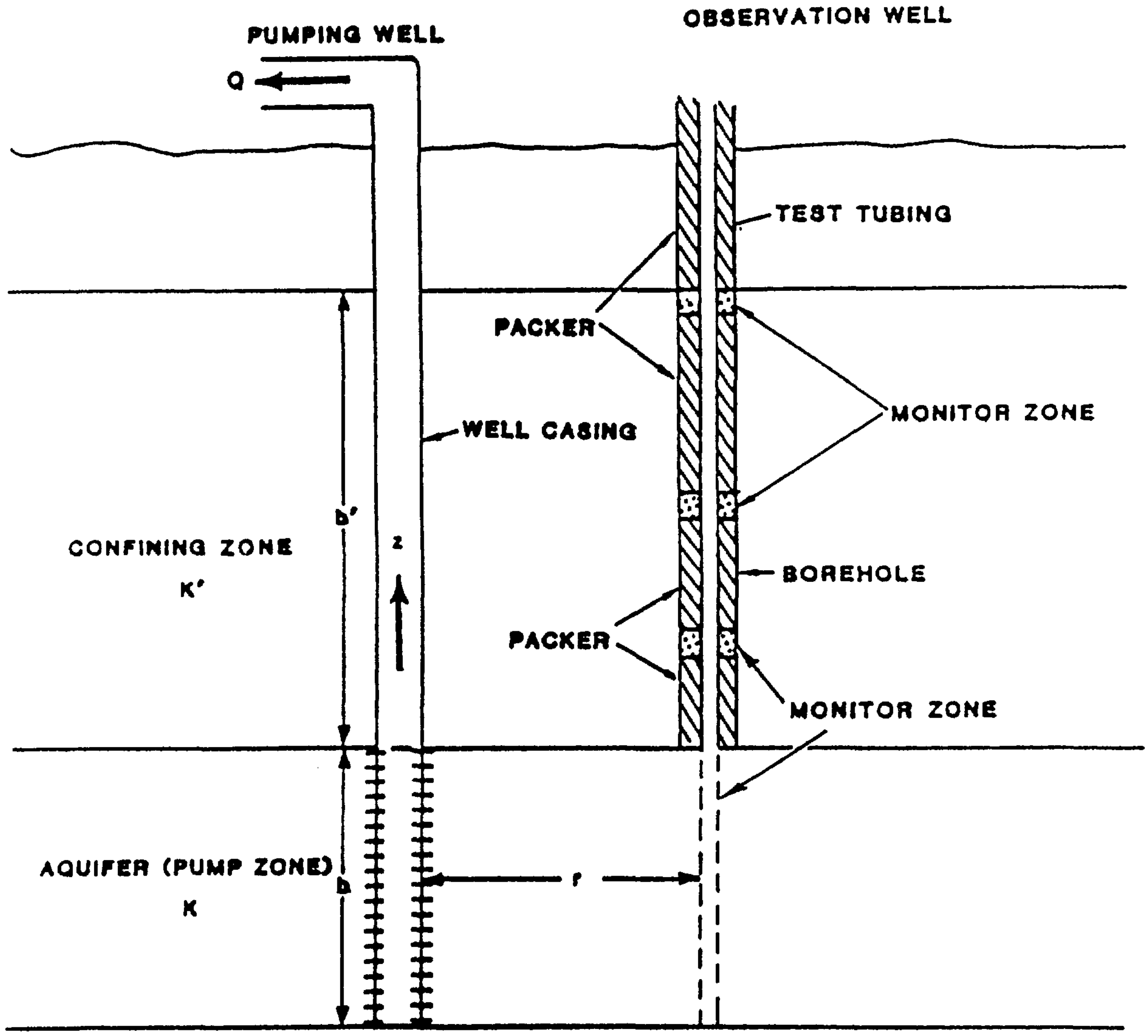

FIGURE 3. A Dual Well Arrangement of the Ratio Test Method, Utilizing a Multiple Packer-Monitoring System (Modified from Javandel, 1983, Letter Correspondence to Leonhart).

1. Construct log-log plots of drawdown versus time for a constant discharge pumping test (or buildup versus time for an injection test) for both the aquifer and monitored confining zone.

2. Determine the time that pressure responses first reach the top of the confining layer (i.e., by examining response in upper-most monitoring zone) and disregard all test data collected after this time.

3. From the constructed drawdown curve, obtain representative values of drawdown for the aquifer, s, and confining zone, s', for selected values of time, t.

4. Calculate the dimensionless time, t_D, for each selected time value using the following,

$$t_D = \frac{Kt}{S_s r^2} \qquad (1)$$

where,

K = hydraulic conductivity of the aquifer determined previously or from drawdown analysis during ratio test.

S_s = specific storage of the aquifer determined previously or from drawdown analysis during ratio test.

r = distance from observation well to pump well.

5. For the calculated values of t_D, use the corresponding t_D curves (shown in Figure 4) to calculate t'_D, for the appropriate ratios of s'/s, which were obtained in Step 2.

6. Calculate the vertical hydraulic conductivity of the confining zone, K', using the following,

$$K' = \frac{t'_D \, S'_s \, z^2}{t} \qquad (2)$$

where,

t'_D = dimensionless time for the confining zone, obtained from Step 4.

S'_s = specific storage of the confining zone determined previously from laboratory core analysis.

z = vertical distance from aquifer and confining zone contact to monitoring point in observation well.

7. Repeat Steps 3 through 6 for a number of observation times to obtain a representative range of test data. Compare results for consistency.

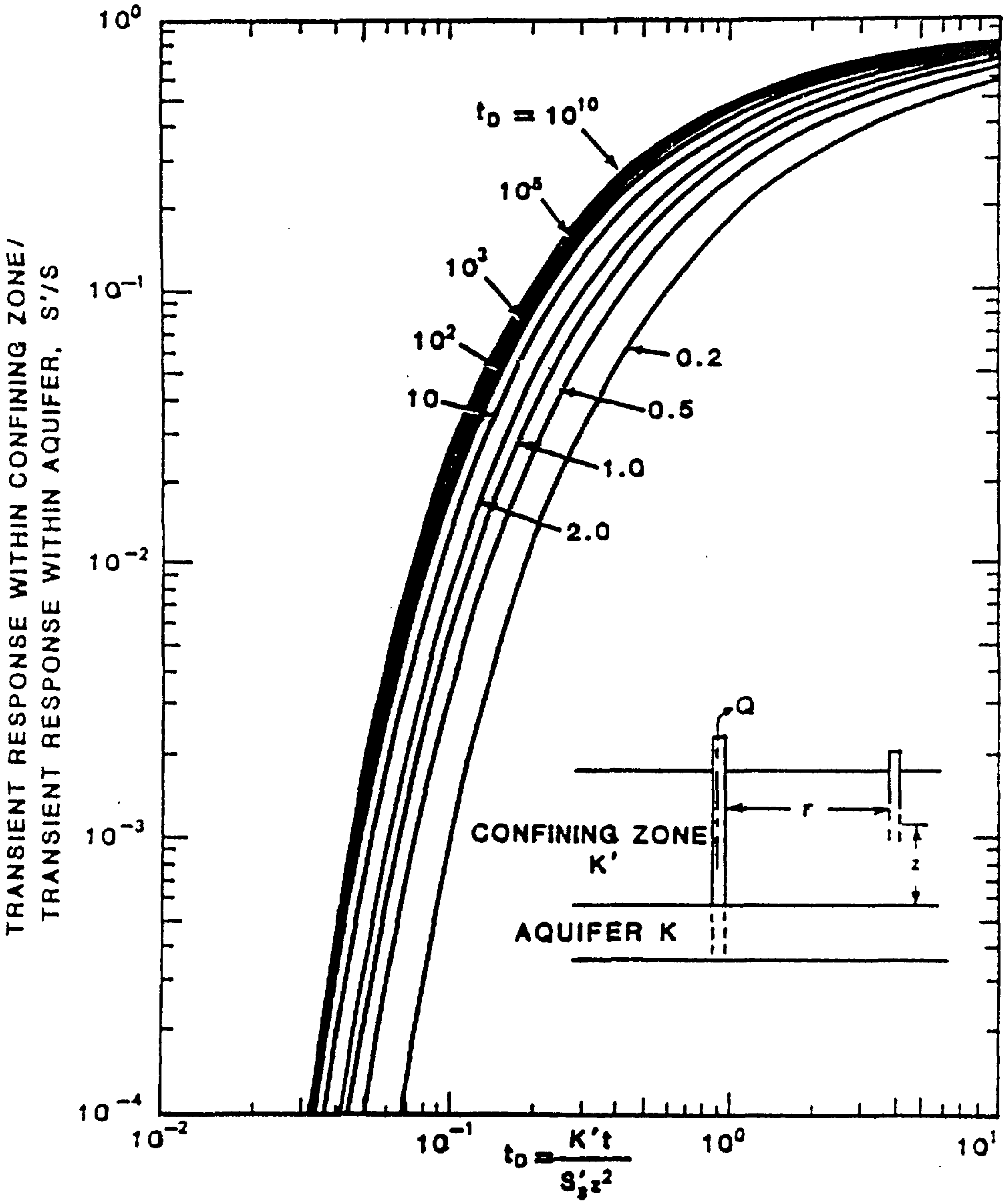

FIGURE 4. Variation of S'/S with t'_D for a Semi-Infinite Confining Zone (Modified from Witherspoon, et al., 1967).

While the ratio method analysis appears straight-forward, several uncertainties can, in some instances, reduce its applicability. First, as mentioned previously, the method is strictly valid only for test times not influenced by adjacent aquifers. For relatively thin confining layers, this requires monitoring the neighboring aquifer and confining zone boundary to discern interfering time effects. Second, unless the specific storage is known from laboratory core analyses, only hydraulic diffusivity, K'/S', for the confining zone can be determined.

BOREHOLE DC-4/5 TEST SITE

The site and horizon selected for the initial ratio test were boreholes DC-4 and DC-5, and a twenty-six foot section of Rocky Coulee flow interior (confining zone) located above the composite Cohassett flow top (aquifer). Boreholes DC-4 and DC-5 are located along the northern margin of the reference repository location, shown in Figure 5. The surface elevation of the test site is about 746 feet above mean sea level. Borehole DC-4 is located approximately 103 feet southwest of DC-5. Washington State coordinates for boreholes DC-4 and DC-5 are 454,469.15 feet north, 2,209,990.78 feet east and 454,537.3 feet north, 2,210,067.8 feet east, respectively. Details concerning borehole construction activities and test interval descriptions are presented in the following sections.

SELECTION CRITERIA

All available basalt dual and multiple borehole locations were examined for possible utilization as the initial vertical hydraulic conductivity test site. Grande Ronde horizons evaluated for testing include the Umtanum, McCoy Canyon, Cohassett and Rocky Coulee flows. Information obtained from previous hydrologic testing, ratio test modeling simulations, borehole geophysical logging, geologic description, core photographs, laboratory core analyses, and well construction activities were examined in the selection process.

Factors which were significant in selecting the borehole DC-4/5 test site and Rocky Coulee flow interior and composite Cohassett flow top test sections include:

- o Favorable geographical siting within the reference repository location.
- o Presence of distinct stratigraphic contacts.
- o Relatively short lateral distance between boreholes at test horizon depth.
- o Potential for obtaining positive test results within reasonable test times.

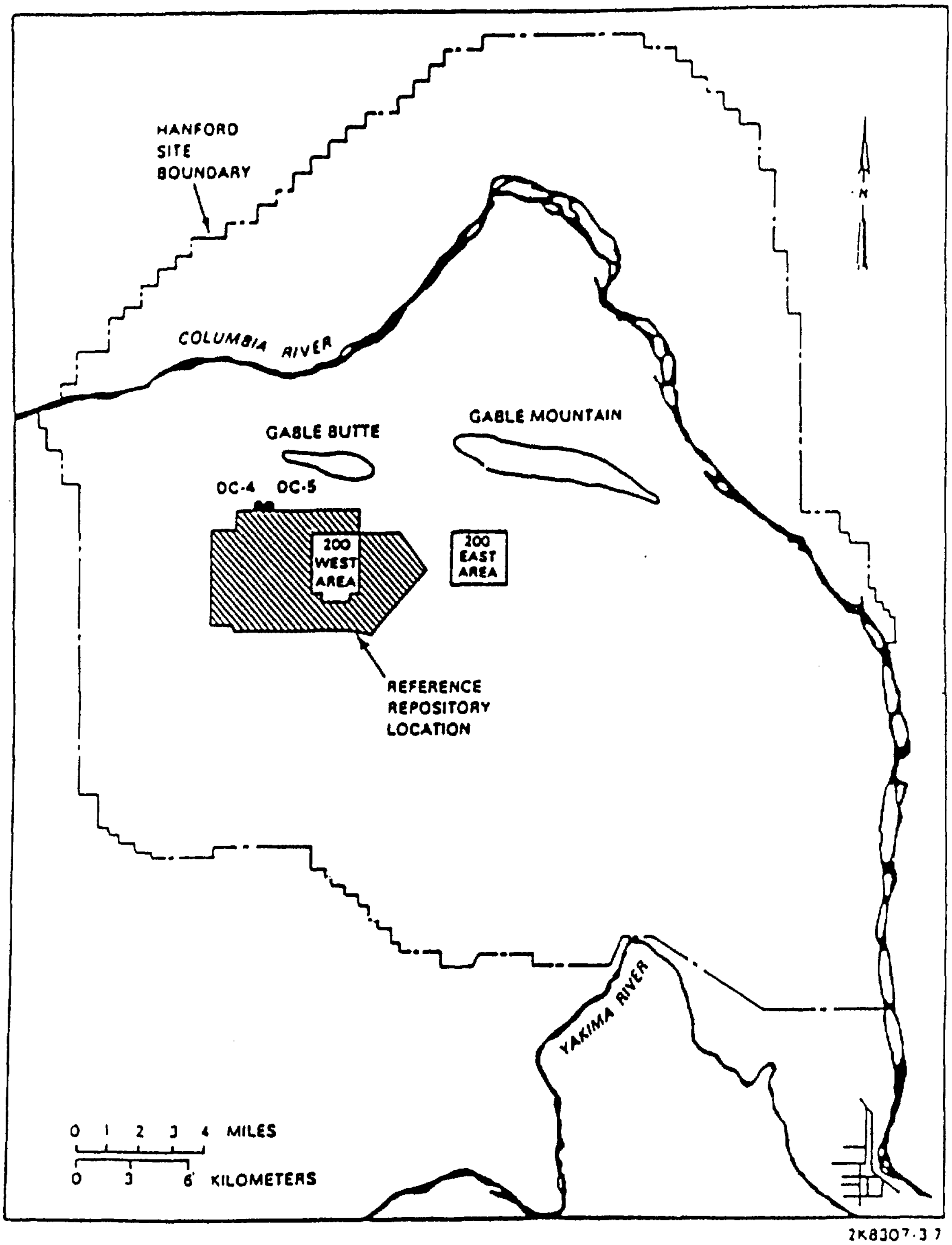

FIGURE 5. Location Map of Hanford Site, Reference Repository Location, and Boreholes DC-4 and DC-5.

BOREHOLE HISTORIES

A summary of construction and hydrologic testing activities is presented in Tables 1 and 2. As shown, borehole DC-4 was drilled from March through December 1978, and borehole DC-5 from December 1977 through February 1978.

Borehole DC-4 (Figure 6) was drilled initially to the top of the Saddle Mountains Basalt with a cable tool drilling rig. Following installation of casing to the top of basalt, a CP-50 core drilling rig was utilized for final completion of the borehole within the Grande Ronde Basalt, to a total depth of 3,998 ft. A detailed description of drilling activities at borehole DC-4 is available in Fenix and Scisson (1978a).

Borehole DC-5 (Figure 7) was drilled in its entirety with a rotary drilling rig, utilizing the mud-rotary method. Borehole DC-5 was completed within the Grande Ronde Basalt, to a total depth of 3,990 ft. A detailed description of drilling activities at borehole DC-5 is contained in Fenix and Scisson (1978b).

All hydrologic testing at boreholes DC-4 and DC-5 was conducted after final completion of the boreholes. Testing of the composite Umtanum flow top was attempted by Science Applications, Inc. between November and December 1979. The composite Grande Ronde Basalt was tested by BWIP during June 1981. Hydrologic testing of the Cohassett flow top was conducted during October and November 1982. Low permeability testing of the Rocky Coulee flow interior at borehole DC-4 was also performed following the completion of the vertical hydraulic conductivity testing described in this report. Results of other hydrologic tests performed at boreholes DC-4 and DC-5 will be included in subsequent BWIP reports.

INTERVAL DESCRIPTION

Vertical hydraulic conductivity testing was conducted within the lower twenty-six foot section of Rocky Coulee flow interior located above the vesicular and brecciated flow top of the composite Cohassett flow. Hydrologically, the Rocky Coulee flow interior acts as a confining zone between the underlying Cohassett flow top (aquifer) and overlying Rocky Coulee flow top (aquifer).

The Cohassett flow top (2,966 to 2,981 ft) at borehole DC-5 was isolated on January 13, 1983, by means of an inflatable bridge plug packer set at 3,017 ft and an inflatable packer with a Seling downhole pressure transducer system set at 2,950 ft. The effective injection zone at borehole DC-5 is ascribed to the 15 ft thick flow top isolated between the packers.

Dual monitoring zones at borehole DC-4 were isolated on November 16, 1982 by means of an inflatable bridge plug packer set at 3,012 ft and a Lynes straddle packer and downhole pressure transducer system with the lower packer element set at 2,942 ft and the upper packer element set at 2,894 ft. The Cohassett flow top (2,966 to 2,981 ft) was isolated between the bridge plug

TABLE 1. Drilling and Testing Activities at Borehole DC-4.

DATE	ACTIVITY
3/6/78-5/5/78	Drilled to 623 ft using cable tool rig. Set and cemented 6.625-in. casing to 617 ft.
6/1/78-6/13/78	Core drilled 4.95-in. hole to a depth of 1,538 ft.
6/25/78-7/6/78	Set 4.5-in. casing to 1,538 ft and cemented.
7/7/78-10/10/78	Core drilled 3.937-in. hole to a depth of 2,639 ft.
10/10/78	Directional survey of borehole from 0 to 2,550 ft conducted by Sperry-Sun, Inc.
10/13/78-10/23/78	Set 3.5-in. casing to 2,639 ft and cemented.
10/24/78-11/30/78	Core drilled 3.032-in. hole from 2,639 ft to total depth of 3,998 ft.
3/15/79-3/19/79	Geophysical logging by Birdwell, Inc.
5/21/79	Directional survey of borehole from 2,400 to 3,050 ft by Sperry-Sun, Inc.
5/24/79	Geophysical logging by Edcon.
8/21/79-8/23/79	Remedial cementing and drilling of zone 2,628 to 2,715 ft.
9/18/79-9/20/79	Geophysical logging by Edcon.
11/13/79-12/6/79	Hydrologic testing of the composite Umtanum flow top attempted by Science Applications, Inc.
5/11/81-5/13/81	Geophysical logging by Pacific Northwest Laboratory.
6/19/81-6/20/81	Hydrologic testing of the composite Grande Ronde Basalt.
10/11/82-11/16/82	Hydrologic testing of the composite Cohassett flow top using borehole DC-5 as a pumping and injection well and borehole DC-4 as an observation well.
11/16/82-4/27/83	Vertical hydraulic conductivity testing using borehole DC-5 to inject water into the composite Cohassett flow top and borehole DC-4 to monitor pressure response in the Rocky Coulee flow colonnade/entablature.
4/27/83-5/19/83	Conducted low permeability testing of the Rocky Coulee flow interior at borehole DC-4.

TABLE 2. Drilling and Testing Activities at Borehole DC-5.

DATE	ACTIVITY
12/10/77-12/11/77	Drilled 26-in. hole from surface to 42 ft.
12/11/77	Cemented 20-in. conductor casing in place.
12/12/77-12/15/77	Drilled 17.5-in. hole from 42 ft to 635 ft.
12/18/77	Placed 13.375-in. casing to 622 ft and cemented.
12/19/77-1/21/78	Drilled 12.25-in. hole from 635 ft to 2,635 ft.
1/21/78-1/22/78	Placed 9.625-in. casing to 2,635 ft and cemented.
1/23/78-1/26/78	Geophysical logging by Schumberger Well Services, Inc.
1/27/78-2/7/78	Drilled 8.625-in. hole from 2,635 ft to total depth of 3,990 ft.
8/9/78-8/19/78	Geophysical logging by Welex.
9/21/78	Directional survey by Sperry-Sun, Inc.
8/16/79-8/19/79	Remedial cementing and drilling of zone 2,525 to 2,711 ft.
11/13/79-12/6/79	Hydrologic testing of the composite Umtanum flow top attemped by Science Applications, Inc.
5/16/81-5/17/81	Geophysical logging by Pacific Northwest Laboratory.
10/18/82-11/16/82	Hydrologic testing of the composite Cohassett flow top using borehole DC-5 as a pumping and injection well and borehole DC-4 as an observation well.
11/16/82-4/27/83	Vertical hydraulic conductivity testing using borehole DC-5 to injection water into the composite Cohassett flow top and borehole DC-4 to monitor pressure response in the Rocky Coulee flow colonnade/entablature.

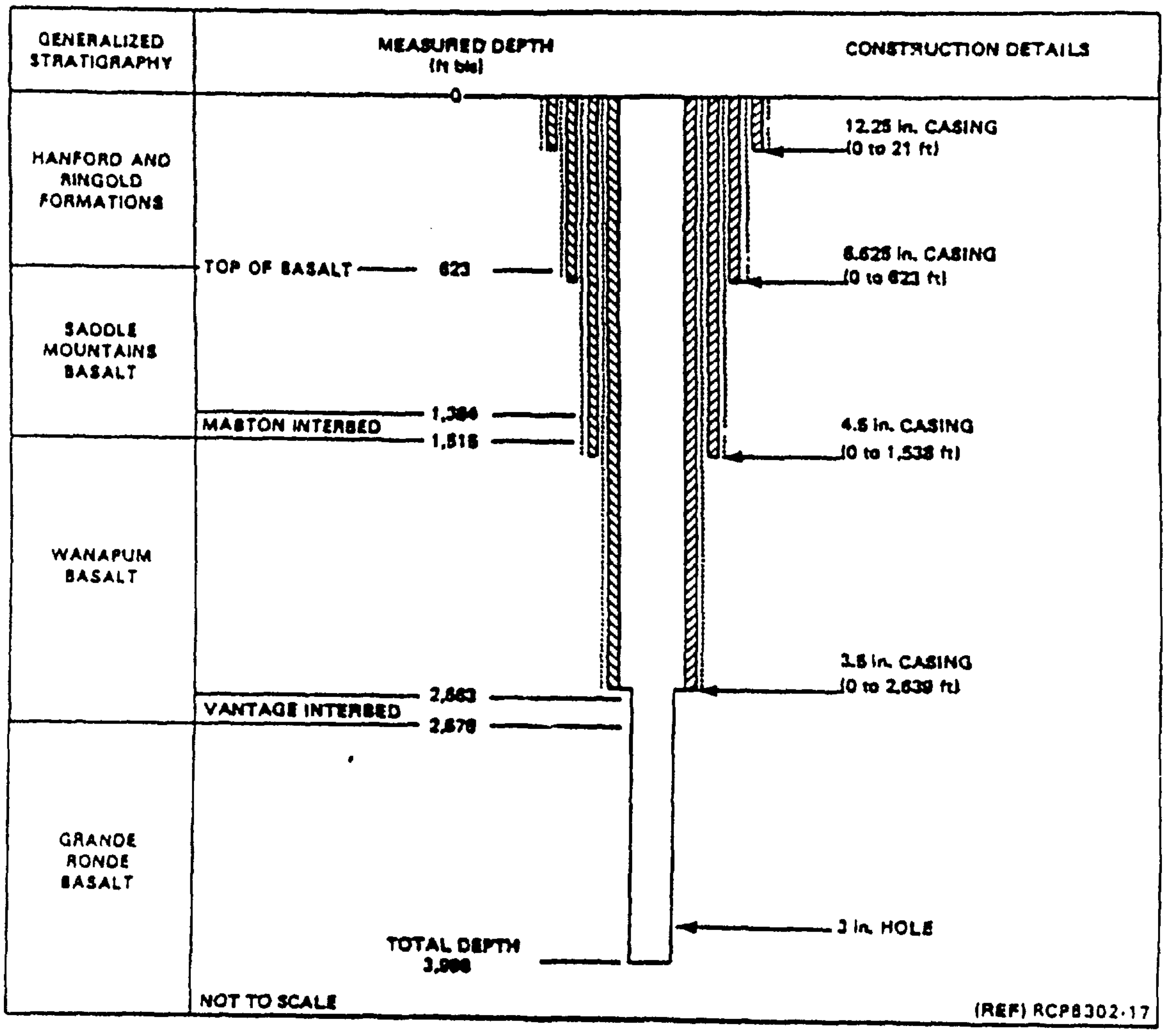

FIGURE 6. Borehole DC-4, As-Built Drawing.

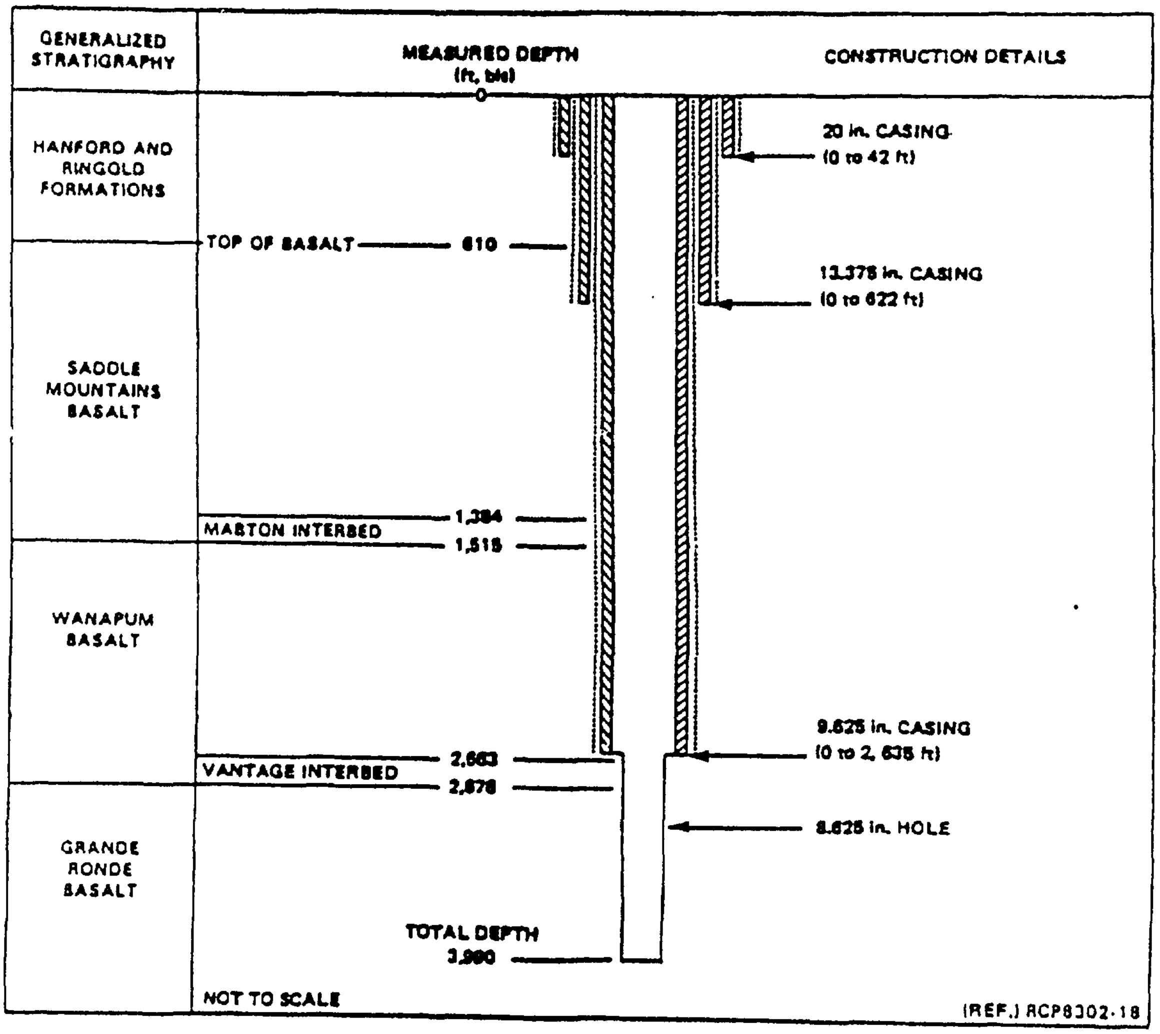

FIGURE 7. Borehole DC-5, As-Built Drawing.

and lower straddle packer element. A portion of the Rocky Coulee flow colonnade/entablature was included within the straddle zone to insure isolation. Packer settings were chosen by examining core from borehole DC-4 and geophysical logs for both boreholes to locate sections of dense, non-fractured basalt.

Borehole geophysical logging of the test interval was conducted by Pacific Northwest Laboratory (PNL) on April 3 and 6, 1981, and May 11 to 17, 1981. The borehole geophysical logs run include: gamma-gamma, natural gamma, neutron-epithermal-neutron, caliper, fluid temperature, sonic, spontaneous potential, and short and long normal resistivity. Log responses at boreholes DC-4 and DC-5 are displayed in Figures 8 and 9, respectively. Examination of log responses indicate the following:

- o Dense basalt throughout the colonnade/entablature of the Rocky Coulee flow (gamma-gamma, sonic and neutron-epithermal-neutron logs).
- o Relatively porous, less dense basalt within the Cohassett flow top (gamma-gamma, sonic and neutron-epithermal-neutron logs).
- o An abrupt change in fluid temperature gradient within the Cohassett flow top, indicating a zone of relatively high permeability (fluid temperature log).
- o Uniform borehole diameter in borehole DC-4 and irregular borehole diameter in borehole DC-5 (caliper log).

A general description of the test interval including a graphic log, neutron-epithermal-neutron log (for borehole DC-4), geologic description and location of packer settings is shown in Figure 10. A detailed description of the geologic characteristics and stratigraphic relationships of the Rocky Coulee and Cohassett flows within the vicinity of boreholes DC-4 and DC-5 is contained in Myers and Price (1981), Long, et al. (1982), Rockwell (1982), and Landon (1983).

TEST DESIGN

This section describes the test system configuration, equipment, and procedure used in performance of the experimental vertical hydraulic conductivity testing conducted at boreholes DC-4 and DC-5. The test design described below differs slightly from specifications previously proposed (Staff, 1982). The slight differences in test design are attributable to unanticipated borehole and formation conditions and incorporation of recommendations from various BWIP technical consultants.

TEST SYSTEM CONFIGURATION

As discussed previously, the selection of the initial packer settings within boreholes DC-4 and DC-5 was based on a review of geophysical log data,

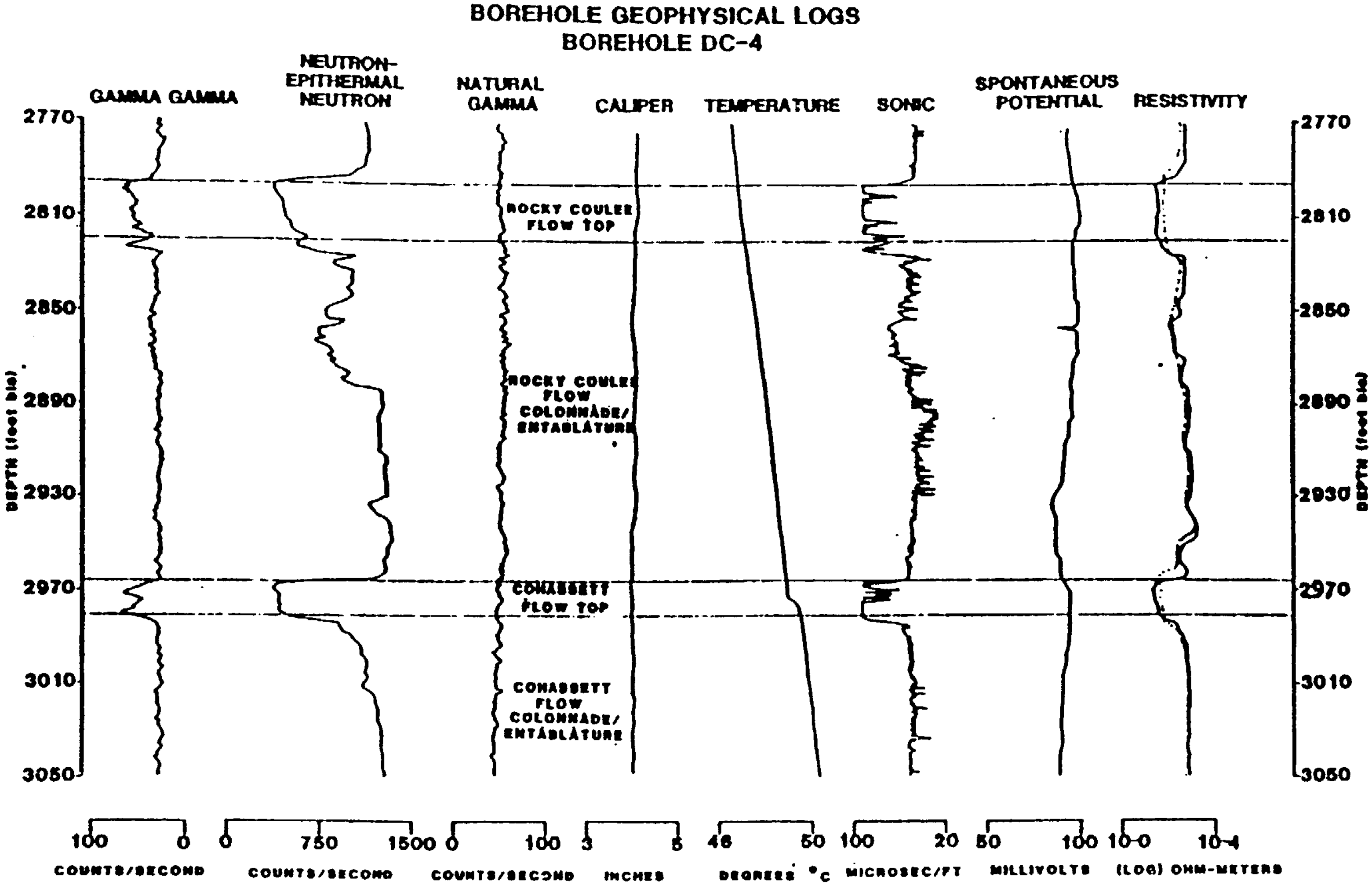

FIGURE 8. Borehole Geophysical Log Responses for the Composite Cohassett Flow Top and Rocky Coulee Interior Test Section at Borehole DC-4.

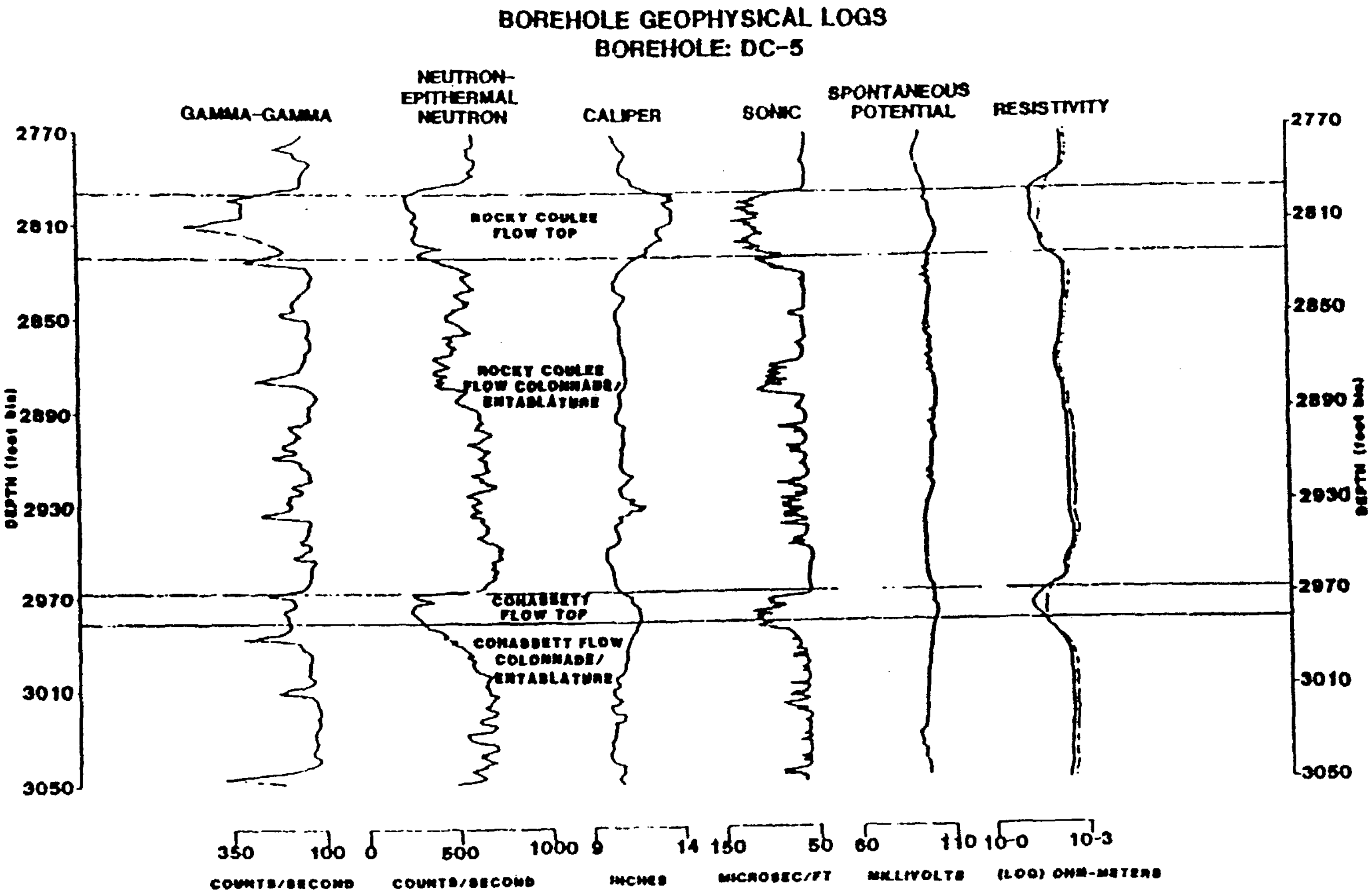

FIGURE 9. Borehole Geophysical Log Responses for the Composite Cohassett Flow Top and Rocky Coulee Interior Test Section at Borehole DC-5.

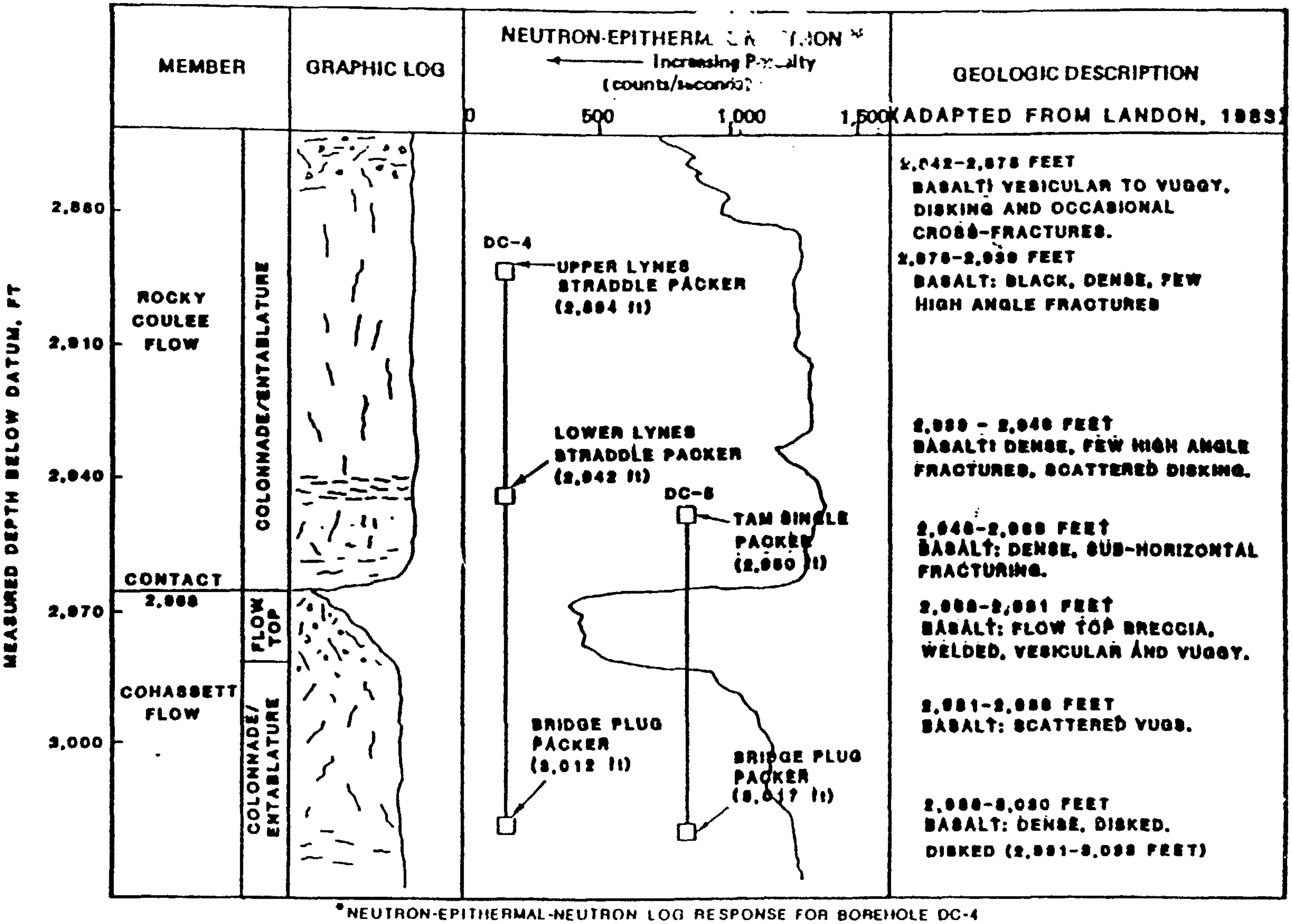

FIGURE 10. Graphic Log, Neutron-Epithermal Neutron Log, and Generalized Geologic Description of the Test Section at Boreholes DC-4 and DC-5.

core photographs, geologic descriptions and drilling histories. These data were available from previous site characterization activities.

Figure 11 shows a schematic of the vertical conductivity test configuration at boreholes DC-4 and DC-5. It should be noted, that the test system configuration shown in Figure 11 represents a modified version of the ratio method as originally recommended in consultant correspondance to BWIP (i.e., Javendal and Wilson to Baker, 1982; Neuman to Hunt, 1982; and Javandel to Leonhart, 1983). Significant modifications include:

- o A greater distance between aquifer and confining zone monitor zones.
- o Larger confining zone monitoring section.
- o Reduction from multiple to a single monitoring zone within the confining layer.

The cited modifications were predicated by existing formation conditions and limitations in existing BWIP test equipment systems.

Particulars of the test system configuration are outlined in Table 3. A description of the equipment utilized during testing is contained in the following sections.

TEST EQUIPMENT

Hydrologic test equipment used in performance of the initial vertical hydraulic conductivity test conducted at boreholes DC-4 and DC-5 are listed in Table 4. A detailed description of the hydrologic test equipment commonly utilized by BWIP is reported in Jackson (1980) and Strait, et al. (1982). The following, however, is a brief description of the major test system components.

Downhole Equipment

Single and straddle packers were used to isolate the intervals monitored within boreholes DC-4 and DC-5 during testing. A TAM International, Inc. (TAM), single packer system was used at borehole DC-5. This system is commonly used by BWIP to test boreholes which are progressively drilled and tested. A single bridge plug packer was used in conjuction with the TAM packer at borehole DC-5 to isolate the composite Cohassett flow top.

At borehole DC-4, a Lynes straddle packer system and an underlying inflatable bridge plug packer were utilized to isolate the two monitor zones. In conjunction with the downhole packer systems, a Lynes triple CWL (at borehole DC-4) and Seling triple subsurface probe (at borehole DC-5) were utilized to measure downhole pressure and temperature response. Both pressure probe sensors are capable of measuring pressures above, in between, and below a straddle interval. Temperature measurements

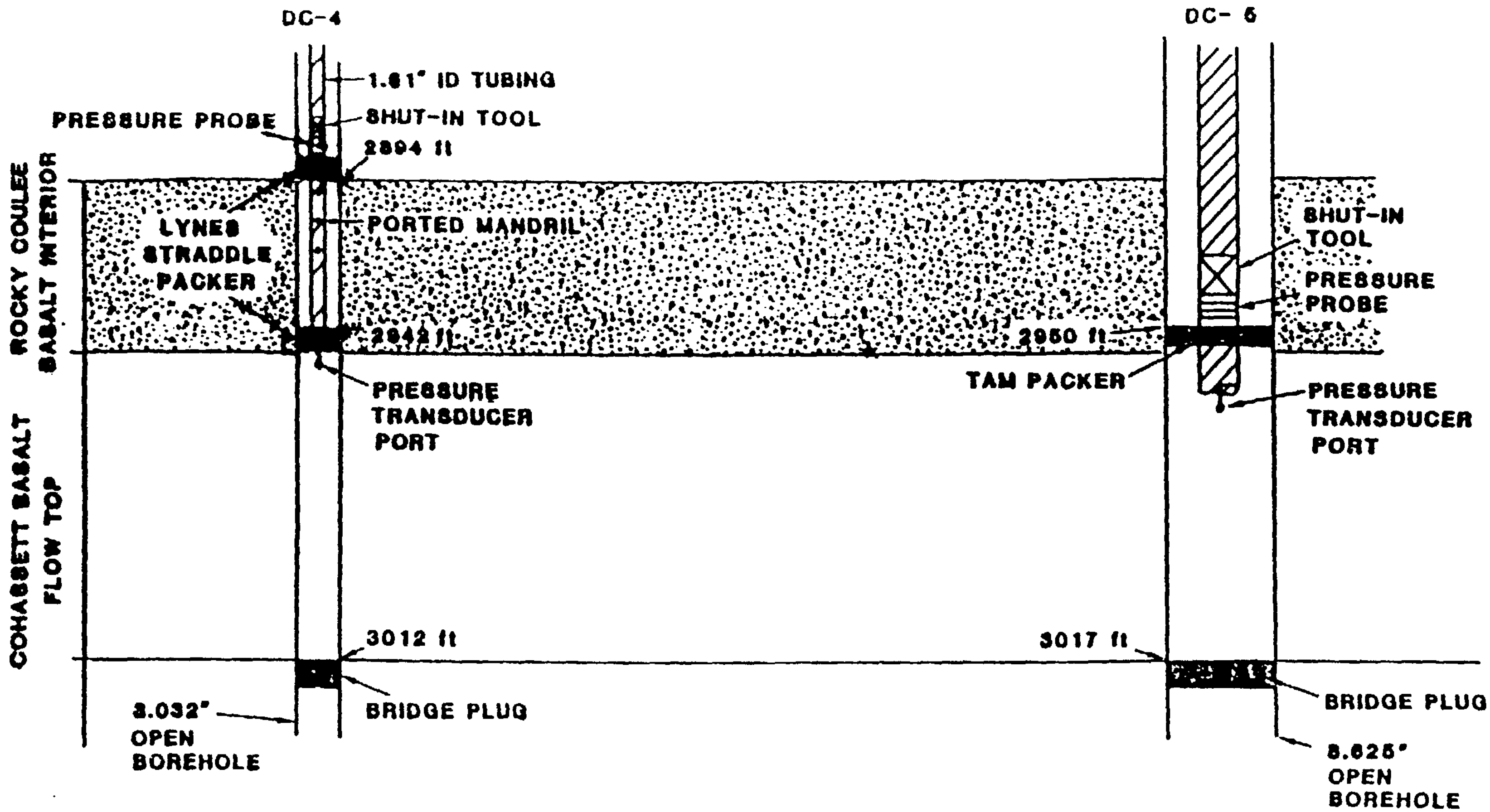

FIGURE 11. Schematic of Ratio Test System Configuration For Boreholes DC-4 and DC-5.

TABLE 3. Pertinent Data and Major Components of the Test System Configuration.

Monitored Test Zones

- Aquifer (stress zone) = composite Cohassett flow top (DC-4 and DC-5)
- Confining Layer = Rocky Coulee interior section (DC-4)

Test Equipment

DC-4 Downhole Pressure Measurement: Lynes triple pressure probe system, shut-in tool, Lynes straddle packers and inflatable bridge plug packer.

DC-5 Downhole Pressure Measurement: Seling pressure probe system, shut-in tool, TAM single packer and inflatable bridge plug packer.

Injection System: Centrifugal pump and syphon equipment

Flow Rate Measurement: Electronic and mechanical flow meters

Packer Depth Settings

DC-4:		
Lynes Straddle Packers	=	2,894 ft (top) 2,942 ft (bottom)
Bridge Plug Packer	=	3,012 ft
DC-5:		
TAM Packer	=	2,950 ft
Bridge Plug Packer	=	3,017 ft

TABLE 4. Equipment Used During the Initial Vertical Hydraulic Conductivity Testing at Boreholes DC-4 and DC-5.

Downhole Equipment

- Large diameter, 5-3/4-in. O.D., TAM straddle packer
- Small diameter, 2-9/16-in. O.D., Lynes straddle packer
- Lynes pressure/temperature probe (Triple CWL)
- Seling pressure/temperature probe (TSSP)
- Slope Indicator pressure transducer

Surface Recording Equipment

- Hewlett-Packard Model 9825B computer
- Hewlett-Packard Model 9876A thermal printer
- Hewlett-Packard Model 5328A universal counter
- Flowtech, Omniflow Model FTON-30-LJC electronic flow meter and strip chart recorder

Surface Support Equipment

- Catapillar 50 KW power supply generator
- Two, 800 gallon fiberglass water tanks
- Hays-Zurn 5/8-in. x 3/4-in. mechanical flow meter
- Dayton 1/2 HP electrical centrifugal pump
- Coates six-kilowatt water heater
- Electronic stopwatches
- Engineer's steel tape, 300 feet
- Filterite filter system, model 2 PS-75 micron
- Graduated cylinders, various sizes
- Miscellaneous valves, high-pressure hose, and pipe fittings
- Environmental wellhouse

reflect environmental conditions within the probe sensor and are utilized for pressure corrections.

Both probe systems transmit a multiplexed pressure and temperature data signal to surface electronic recording equipment via a single armored conductor cable. For the Lynes pressure sensor system, a converter detects the transmitted signal (i.e., current pulse frequency) at the surface. The signal is then routed to a universal counter and is transmitted to a computer which monitors the signal frequency and converts the transmitted signals into pressure (lb/in^2a) and temperature (°F). The computer is capable of monitoring readings as rapidly as two per second.

The Seling triple subsurface probe system is similar to the previously described Lynes system. The transmitted signal is received by a signal converter at the surface which routes the transmission to a universal counter. The universal counter measures the periods of various multiplexed signals, which are then transmitted to a computer which transforms the input signal into the monitored pressure and temperature.

Other common features of the dowhole test system include:

Packer Elements. Packers elements are water inflatable, with effective sealing lengths of 3 to 4 ft.

Sensor Carrier. The carrier is situated above the top packer element. It houses the pressure probe which contains three quartz pressure transducers and thermistors. The sensor carrier also provides internal access for the pressure probe for measuring pressures above, below and within the straddle interval.

J-Slot Tool. The J-slot tool is used to inflate or deflate the straddle packer, equalize pressures between the interval and the borehole annulus, and to open the tool to the test interval.

Shut-In Tool. The tool is used to isolate the tubing above the packer from the test interval, thereby causing a closed system (i.e., closed to the atmosphere) at the formation depth.

A test schematic of the downhole and surface-based support equipment previously discussed is shown in Figure 12.

Injection flow rates maintained at borehole DC-5 during testing were monitored using a Hayes-Zurn, Inc., mechanical flow meter and a Flowtech electronic flow meter. The two flow meter systems were utilized during testing to provide an overlapping range in injection flow rates, from 0.08 to 50 gpm.

In addition to the aforementioned equipment, an environmental wellhouse, which enclosed the wellhead at borehole DC-5, was utilized during constant head injection testing to minimize the effects of temperature fluctuations on test performance. The air temperature within the wellhouse was maintained at approximately 70°F during the test period.

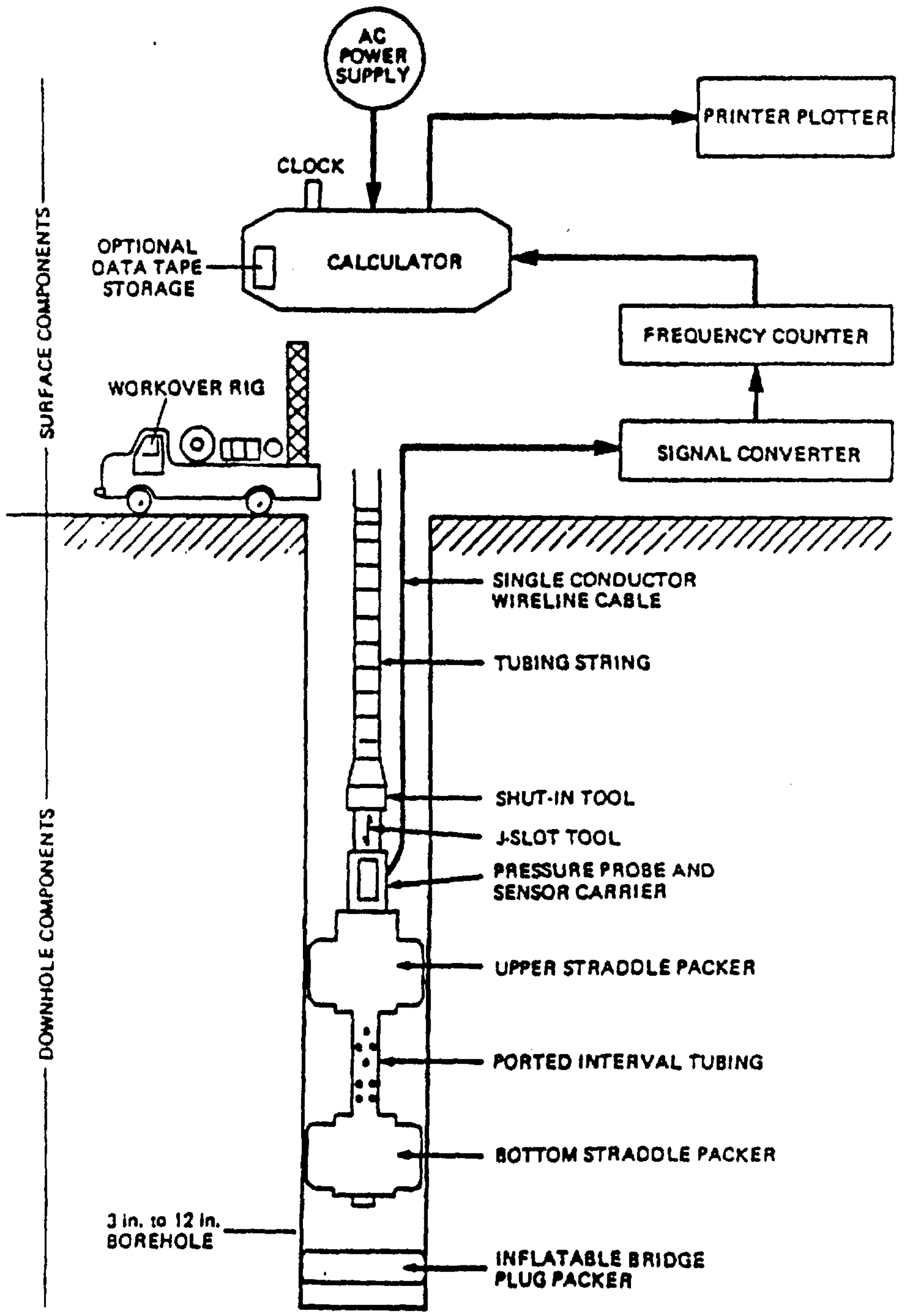

FIGURE 12. General Schematic of Downhole and Surface-Based Support Test Equipment (Modified from Strait, et al., 1982).

TEST PROCEDURE

Following the installation of the downhole test equipment and verification of the integrity (i.e., isolation) of the monitored test intervals, vertical hydraulic conductivity testing was initiated. The general procedure for performance of the test is outlined below:

- o With the downhole shut-in tool in the closed position, monitor pre-test trends of pressure and temperature at boreholes DC-4 and DC-5 for a period of time at least half that of the intended active injection phase of testing (i.e., approximately 2-4 weeks).

- o Following the pressure monitoring period and establishment of any pre-test trend relationships, the active phase of vertical hydraulic conductivity testing was to be initiated. The active phase of testing includes:

  (1) Constant head injection within the composite Cohassett flow top at borehole DC-5. The constant head injection was to be maintained by a surface syphon system shown diagrammatically in figures of Appendix A.

  (2) Monitoring downhole pressure and temperature responses in the composite Cohassett flow top at boreholes DC-4 and DC-5 and the overlying section of Rocky Coulee interior at borehole DC-4 during constant head injection. In addition, closely monitor injection flow rates at borehole DC-5.

  (3) After a minimum injection period of 4 weeks, review the performance of the test and decide the final test duration for the active phase of testing.

- o Following termination of the active injection phase, monitor recovery downhole pressures at boreholes DC-4 and DC-5 within the test zones. The recovery period would be of a length equal to that completed for the active injection period.

Details concerning the actual performance of the experimental vertical hydraulic conductivity test are contained in the following section.

HYDROLOGIC TEST RESULTS

This section describes the results of the initial experimental vertical hydraulic conductivity test performed by BWIP at boreholes DC-4 and DC-5 for the composite Cohassett flow top and Rocky Coulee interior. Testing activities occurred over the period November 16, 1982 to April 27, 1983. Hydrologic testing activities performed during this period are summarized in Table 5. Included in the table, for additional background, are summary hydrologic testing activities of the composite Cohassett flow top (October 11, 1982 to November 16, 1982) which were performed in support of vertical hydraulic conductivity

TABLE 5. Hydrologic Testing Activities for Boreholes DC-4 and DC-5.

DATE	ACTIVITY
10/11/82-11/16/82	HYDROLOGIC TESTING OF THE COMPOSITE COHASSETT FLOW TOP
10/11/82-10/12/82	Composite Cohassett flow top isolated at DC-4.
10/12/82-10/18/82	Pressure monitoring and test system equilibration at DC-4.
10/18/82	Composite Cohassett flow top isolated at DC-5.
10/18/82-10/25/82	Pressure monitoring and test system equilibration at DC-4 and DC-5.
10/25/82	Attempted unsuccessful air-lift test at DC-5.
10/25/82-10/28/82	Pressure monitoring and test system equilibration at DC-4 and DC-5.
10/28-82-11/1/82	Conducted air-lift pumping test at DC-5. Monitored test response at DC-4.
11/1/82-11/8/82	Monitoring pressure following air-lift test at DC-4 and DC-5.
11/8/82	Conducted slug test at DC-5. Monitored response at DC-4.
11/8/82-11/11/82	Performed field evaluation tests of new slug and pulse test methods at DC-4 and DC-5.
11/11/82-11/12/82	Attempted unsuccessful constant discharge pumping test using submersible pump at DC-5. Monitored response at DC-4.
11/12/82-11/16/82	Conducted constant discharge pumping test at DC-5. Monitored response at DC-4.
11/16/82	Terminated test. Hydrologic testing of composite Cohassett flow top completed.
11/16/82-4/27/83	EXPERIMENTAL VERTICAL HYDRAULIC CONDUCITIVITY TEST OF THE COMPOSITE COHASSETT FLOW TOP AND ROCKY COULEE INTERIOR
11/16/82-1/9/83	Unsuccessful attempts to isolate monitor zones in DC-4 and DC-5.
1/10/83	Composite Cohassett flow top isolated at DC-5.

TABLE 5. Hydrologic Testing Activities for Boreholes DC-4 and DC-5 (cont.).

DATE	ACTIVITY
1/10/83-1/13/83	Pressure monitoring and test system equilibration at DC-5.
1/13/83	Composite Cohassett flow top and Rocky Coulee flow interior isolated at DC-4.
1/13/83-2/1/83	Pressure monitoring and test system equilibration at DC-4 and DC-5.
2/1/83	Attempted unsuccessful constant head injection test at DC-5. Test aborted after 51 minute injection period.
2/1/83-2/4/83	Pressure monitoring and recovery from aborted constant head injection test.
2/4/83-4/1/83	Conducted constant head injection test at DC-5 while monitoring response in DC-4.
4/1/83	Lower packer failed at DC-5. Injection terminated.
4/1/83-4/27/83	Pressure monitoring and recovery from constant head injection test.

testing. A more detailed listing of daily testing activities is contained in Appendix B. Raw data and field data sheets for all hydrologic tests listed in Table 5 are available from the Data Management Unit of the Systems Integration and Performance Assessment Group, BWIP.

TEST INTERVAL ISOLATION

As indicated in Table 5, isolation of the monitored zone was completed on January 10, 1983 and January 13, 1983, for boreholes DC-5 and DC-4, respectively. The integrity of monitor zone isolation was evaluated by several methods before, during and after completion of hydrologic testing. Evaluation methods included:

- o Weight loading of packers at the beginning and termination of hydrologic testing.
- o Examining the pressure response in the monitor zone by stressing the borehole annular zone prior to hydrologic testing.
- o Examining the pressure response in the borehole annular zone and monitor zones during hydrologic testing.

It should be noted that the aforementioned methods of test interval isolation assessment were used primarily to evaluate the integrity of the top packer. Borehole and test equipment limitations restricted the complete evaluation of the lower bridge plug seat to only the weight loading method. All evaluation methods indicate that the monitor zones were isolated up to the termination of hydrologic testing.

TEST SYSTEM EQUILIBRATION

As indicated previously, after experiencing prolonged test equipment problems and unanticipated adverse borehole conditions, the monitor test zones were successfully isolated before mid-January 1983. Pressure monitoring and test system equilibration periods of nearly three weeks were completed prior to initiation of vertical hydraulic conductivity testing on February 3, 1983.

Figures 13 and 14 show the pre-test downhole pressure response for monitor zones in boreholes DC-4 and DC-5. For seven days prior to initiation of testing, pressure responses were declining slightly within all monitor zones. Table 6 lists the calculated pre-test pressure trends for the time period shown in Figures 13 and 14. The pre-test pressure trend observed for the various monitor zones is attributable to several factors, including:

- o Composite hydraulic head conditions caused by previous open borehole conditions (i.e., greater than three-year period).
- o Relatively low transmissivity for test zones monitored.

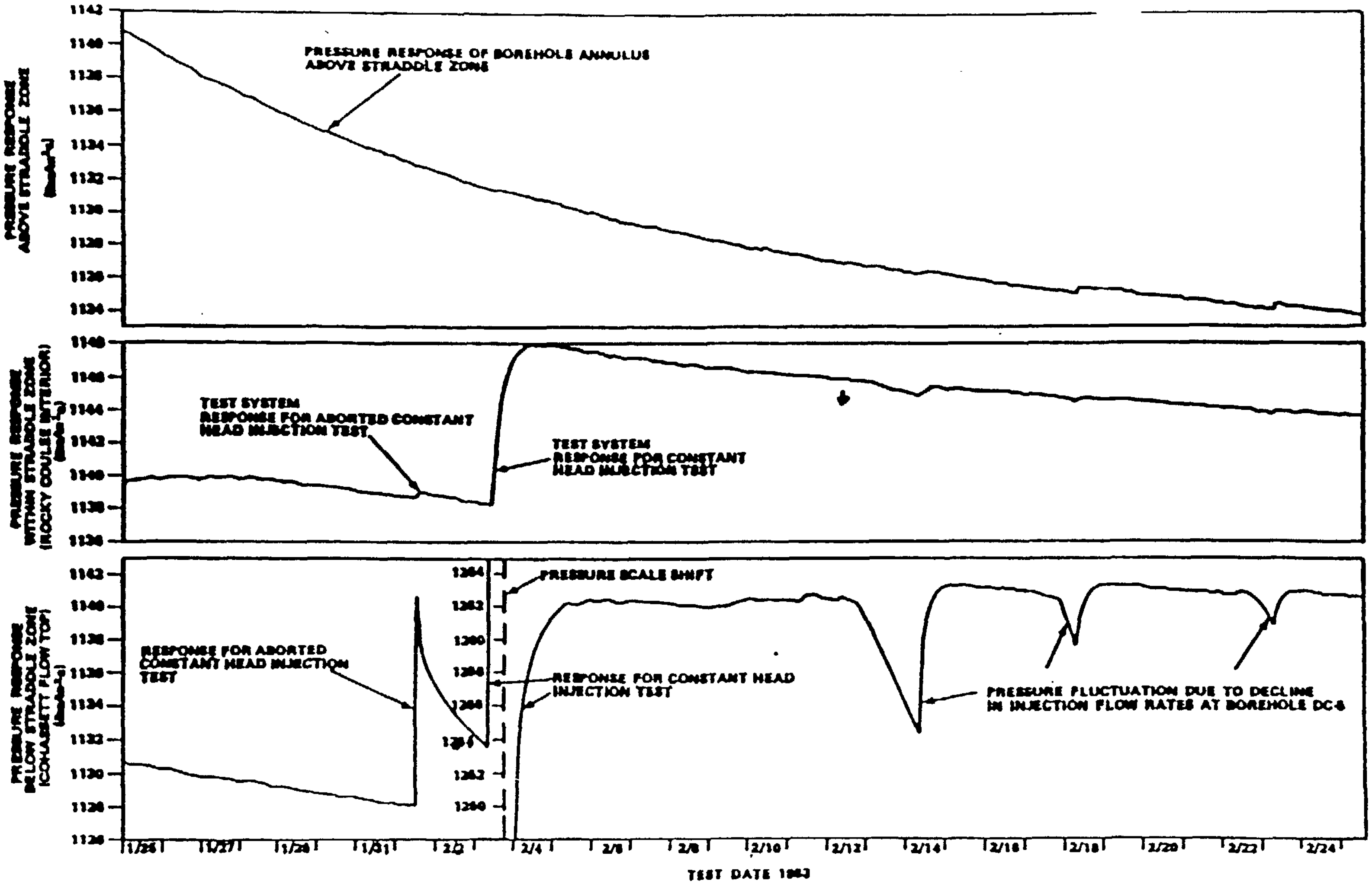

FIGURE 13. Hydrograph of Downhole Pressure Response for Monitor Zones at Borehole DC-4 During Constant Head Injection Test.

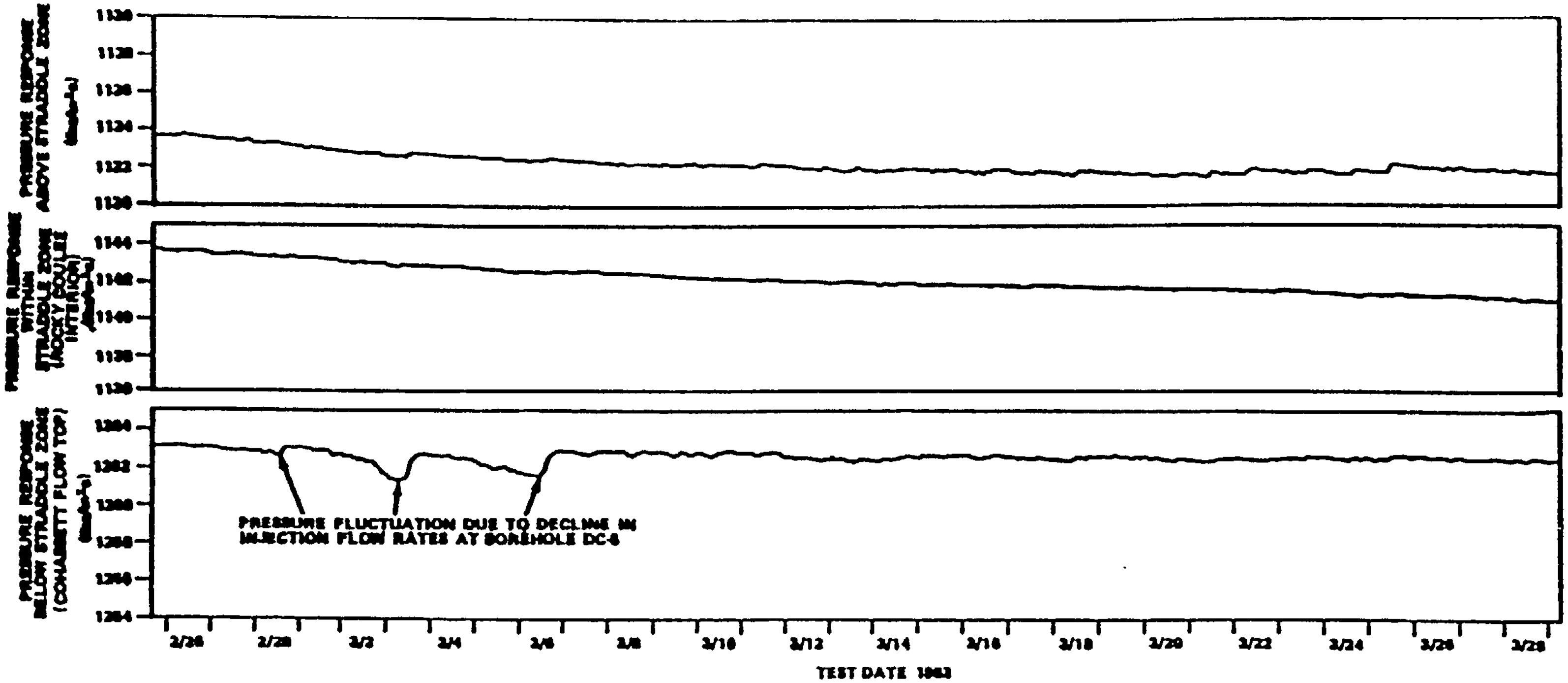

FIGURE 13. (cont.) Hydrograph of Downhole Pressure Response for Monitor Zones at Borehole DC-4 During Constant Head Injection Test.

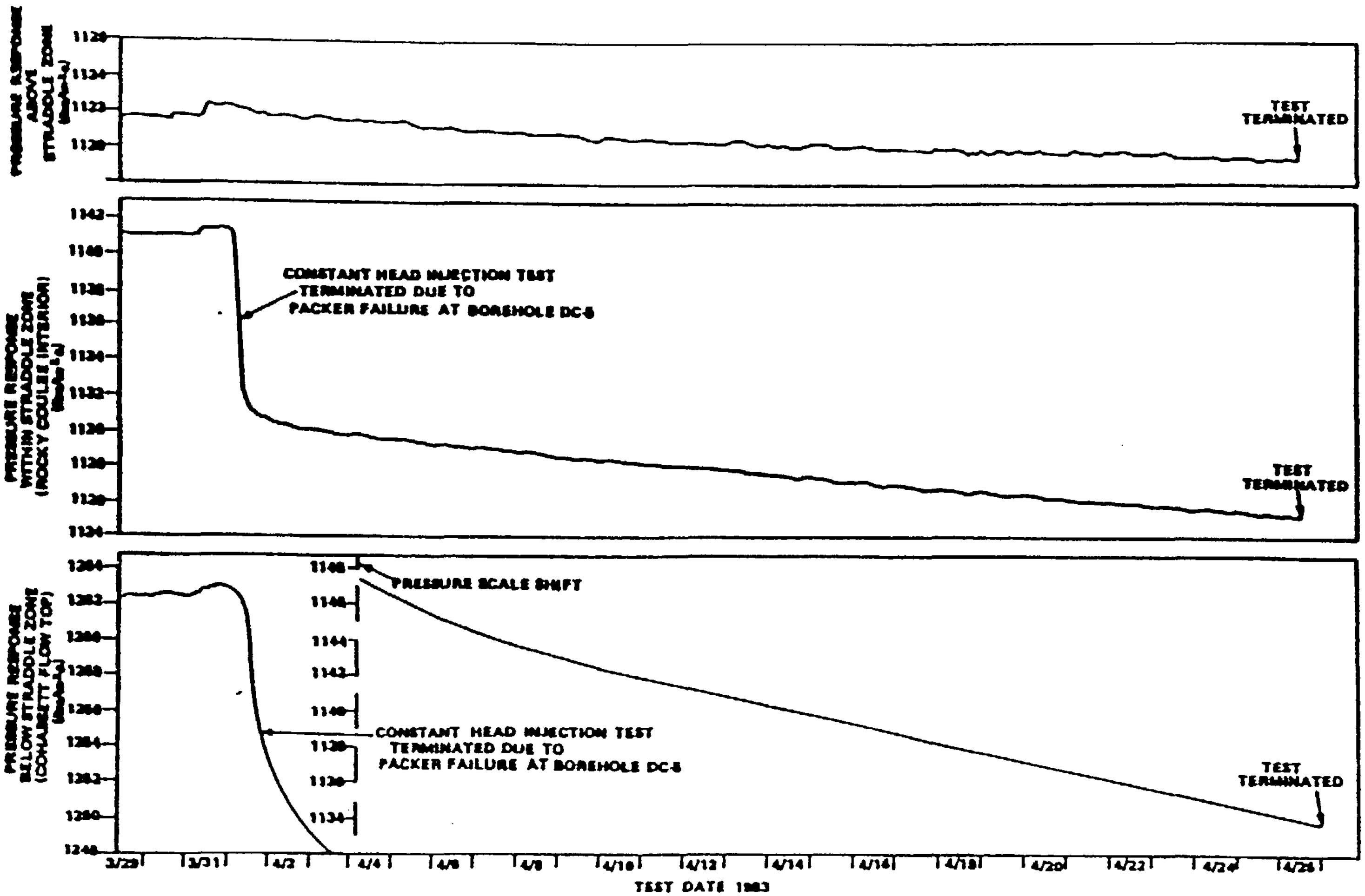

FIGURE 13. (cont.) Hydrograph of Downhole Pressure Response for Monitor Zones at Borehole DC-4 During Constant Head Injection Test.

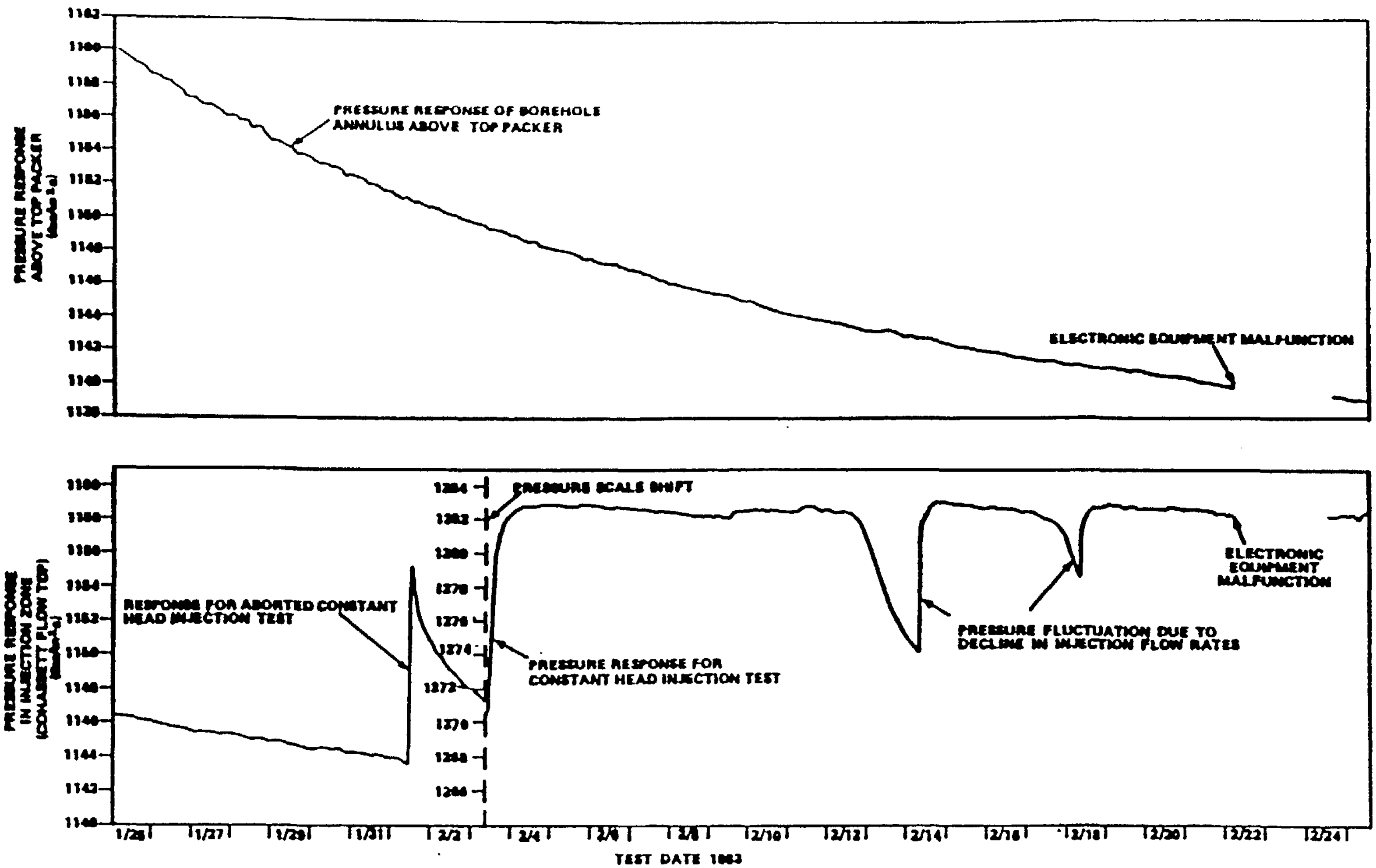

FIGURE 14. Hydrograph of Downhole Pressure Response for Monitor Zones at Borehole DC-5 During Constant Head Injection Test.

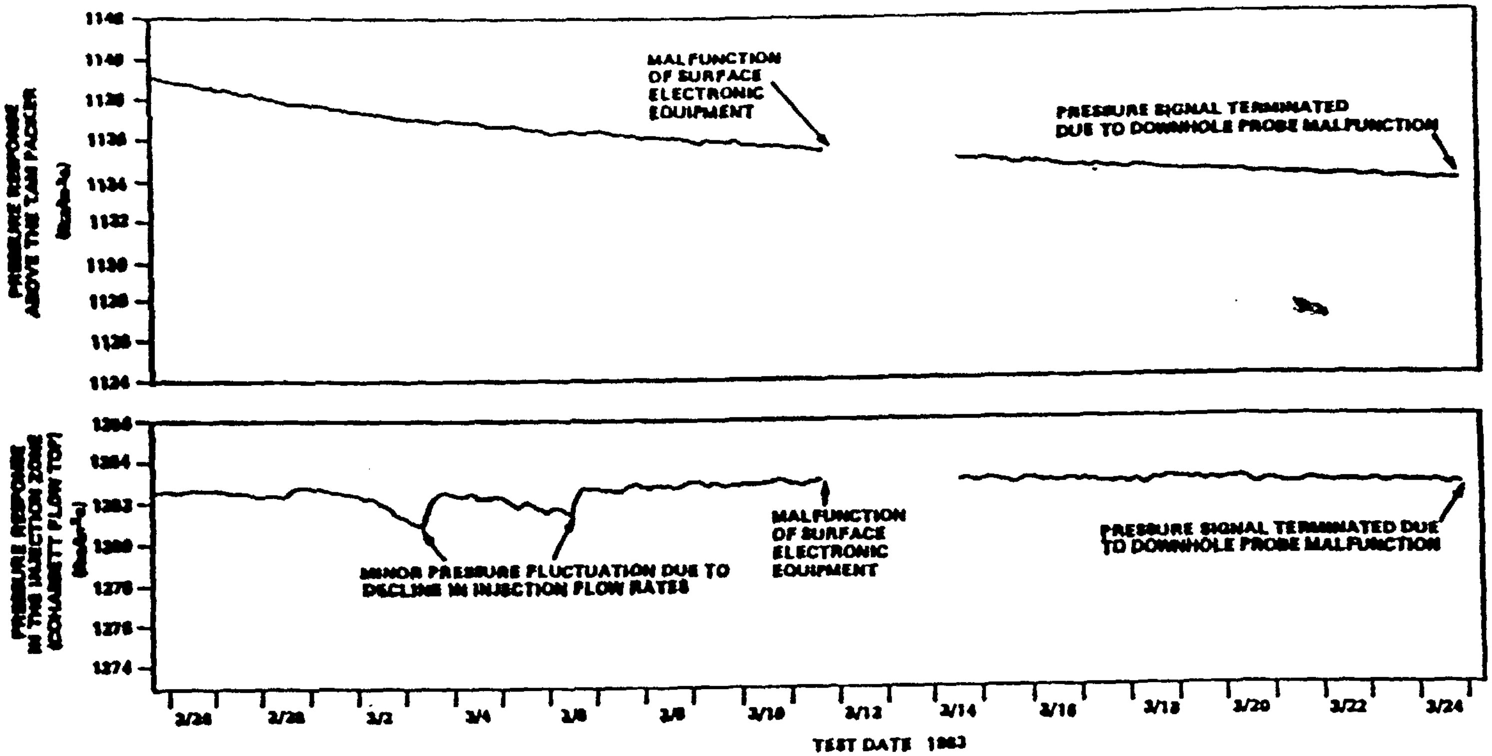

FIGURE 14. (cont.) Hydrograph of Downhole Pressure Response for Monitor Zones at Borehole DC-5 During Constant Head Injection Test.

TABLE 6. Downhole Pressure Trend Data Prior to Initiation of Vertical Hydraulic Conductivity Testing.

BOREHOLE DC-4	PRESSURE TREND (lb/in²/hr)
Annular Borehole Zone Above Top Lynes Straddle Packer	-3.13×10^{-2}
Rocky Coulee Flow Interior	-1.29×10^{-2}
Composite Cohassett Flow Top	-1.42×10^{-2}
BOREHOLE DC-5	
Annular Borehole Zone Above Top TAM Packer	-4.33×10^{-2}
Composite Cohassett Flow Top	-1.25×10^{-2}

- Perturbations caused by packer inflation, "squeeze" pressure (e.g., Rocky Coulee flow interior zone at borehole DC-4).
- Effects of test system compliancy.

CONSTANT HEAD INJECTION TESTING

Constant head injection for the composite Cohassett flow top at borehole DC-5 was originally started at 1045 hours on February 1, 1983. After 51 minutes of injection, however, testing was terminated due to multiphase conditions which developed within the test system, due to air entrainment caused by cascading surface injection water. After lowering the surface injection tubing and allowing for recovery of downhole pressures following the aborted test, constant head injection was resumed at 0900 hours on February 3, 1983. Early injection (i.e., the first 8 minutes) was provided by use of a 1/2 horsepower centrifugal pump. Natural syphon action was used to inject water during the remainder of the test.

The injection water was obtained from the Hanford Site supply system, trucked to the test site, and stored in two 800 gallon fiberglass water tanks located in close proximity to borehole DC-5. Water was circulated, heated, filtered and returned to the water tanks to maintain a relatively uniform temperature (i.e., about 20°C) for the surface injection water. Schematic drawings of the surface injection system at borehole DC-5 are presented in Appendix A.

Injection flow rates under constant head injection conditions ranged from about 4 gpm during the initial periods of syphon injection to 0.13 gpm at the end of testing. Figure 15 shows the hydrograph of injection flow rates during the period of testing. Examination of the figure indicates that following the initial day of testing, injection flow rates declined uniformly for the remainder of the eight weeks of testing, from 0.64 gpm to 0.13 gpm. Minor perturbations evident during the first two weeks of testing were attributable to periodic clogging of the mechanical flow meter, as well as gas bubble formation in the upper sections of the surface syphon system. These effects were remedied by removal of the mechanical flow meter and daily purging of the syphon injection system.

The total head imposed on the composite Cohassett flow top at borehole DC-5 was equivalent to 133 lb/in^2 (i.e., 307 ft of water) above pre-test conditions. A similar downhole pressure increase was also recorded for test formation depth conditions at borehole DC-4, which is located only 5.9 ft from borehole DC-5. While equal total head conditions were maintained at the boreholes during testing the composite Cohassett flow top, analysis of early-time test data indicates a lagged pressure response between boreholes DC-5 and DC-4 of approximately two minutes.

Downhole pressure response for the composite Cohassett flow top at the individual boreholes was shown previously in Figures 13 and 14. Examination of the figures indicates several periods of pressure fluctuations during the first weeks of testing. The downhole pressure fluctuations were attributable to minor fluctuations in injection flow rates at borehole DC-5, as previously

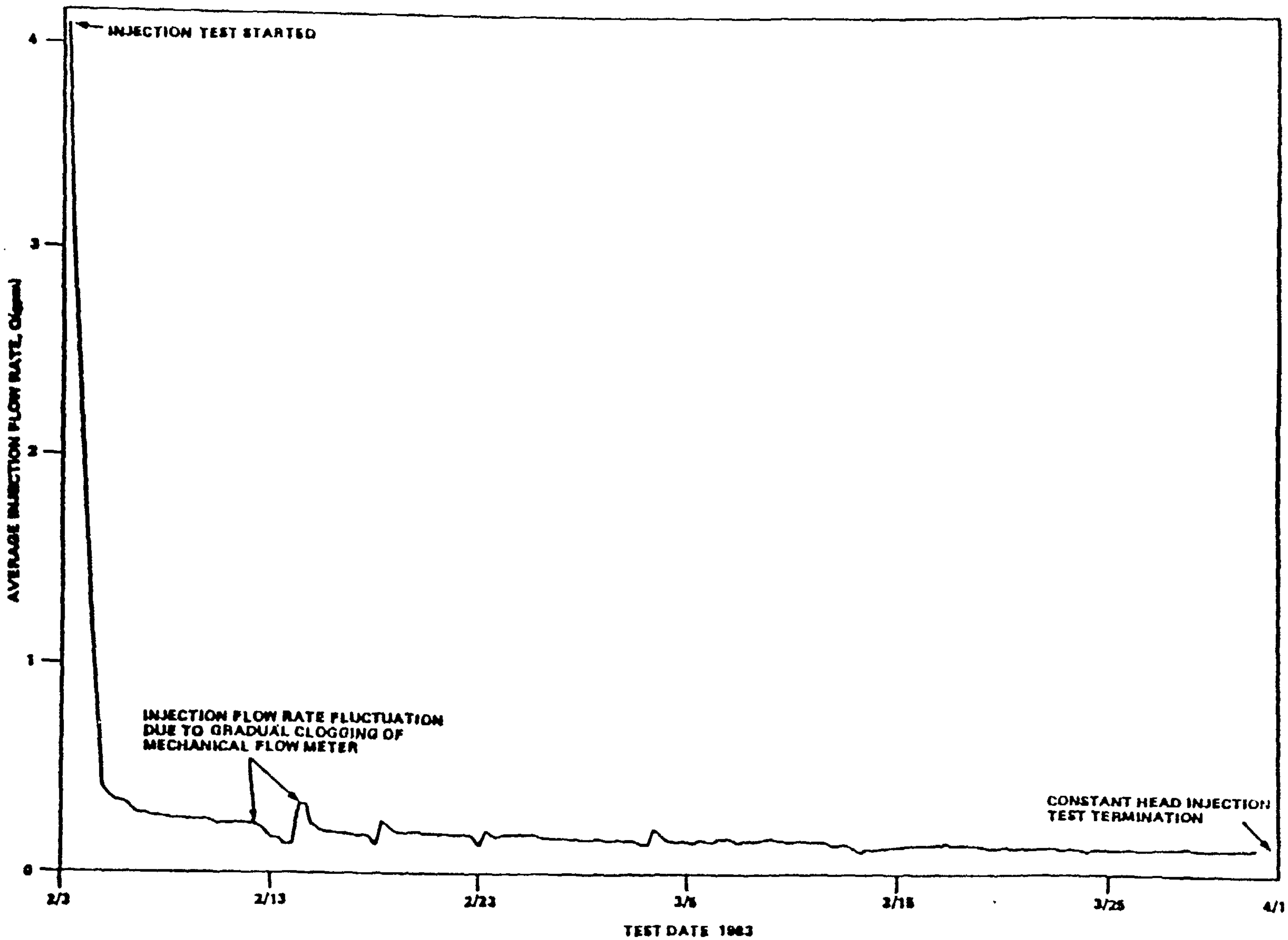

FIGURE 15. Hydrograph of Injection Flow Rates During Constant Head Injection Test at Borehole DC-5.

discussed. Examination of Figure 13 for downhole pressure response within the Rocky Coulee flow interior indicates an associated test response of about 9.8 lb/in^2. This was later shown, however, to be a function of test system compliancy and not a true formation response. This is discussed in detail in the next report section.

As indicated in Figure 14, the downhole pressure measurements at borehole DC-5 ended on March 24, 1983, one week prior to termination of constant head injection. This was attributable to a malfunction in the Seling pressure probe synchronization signal. Hydraulic head measurements during the recovery phase following termination of constant head injection, however, were maintained by steel tape measurements and/or pressure measurements obtained by surface-based pressure probe systems (i.e., SINCO).

Constant head injection testing was terminated at 1050 hours, April 1, 1983, when communication developed around the bottom bridge plug packer, which was used to isolate the bottom of the composite Cohassett flow top in borehole DC-5. Subsequently, it was learned that the bridge plug packer had deflated and slipped to the bottom of the hole in borehole DC-5.

In conclusion, the following can be summarized concerning the performance of the constant head injection test at boreholes DC-4 and DC-5:

- A constant head injection test was maintained for eight weeks, with a total head imposed on the composite Cohassett flow top of 133 lb/in^2 (i.e., 307 ft of water).
- Injection flow rates ranged from about 4.0 gpm during the initial periods of syphon injection to 0.13 gpm at the end of testing.
- Test system components (i.e., injection system, downhole probe, etc.) performed well over most of the testing period.
- A compliance-caused test system response of about 9.8 lbs/in^2 was recorded for the Rocky Coulee monitor zone at borehole DC-4.
- Testing was terminated due to deflation of the bridge plug packer which isolated the bottom of the composite Cohassett flow top at borehole DC-5.

EFFECTS OF TEST SYSTEM COMPLIANCE

As mentioned previously, a downhole pressure increase was recorded for the Rocky Coulee monitoring zone at borehole DC-4 during the early periods of constant head injection testing. As shown in Figure 13, the increase in downhole pressure for this zone was recorded as 9.8 lb/in^2 above pre-test levels. Available evidence, however, suggests that the increase in pressure recorded was associated strictly with compliancy of the downhole packer test system. This evidence includes:

- Reports of similar system response by other investigators.

- o Observed pressure response pattern.
- o Subsequent field compliancy testing.

Forster and Gale (1980 and 1981) have reported that for in-situ testing of low permeability rock types, downhole test systems may be susceptable to differential pressure application. For test cases, such as borehole DC-4, which have monitor zones within low permeability horizons (i.e., Rocky Coulee interior), differential pressure application can cause minor volume changes for horizons which are isolated by compliant packer systems. Changes in test system volumes, which are not immediately balanced by geomechanical formation properties, would have an associated pressure response (e.g., decrease in test system volume = increase in test system pressure). For the Rocky Coulee monitor zone at borehole DC-4, increases in downhole borehole pressure within the underlying composite Cohassett flow top (i.e., approximately 133 lb/in^2) are believed responsible for slightly deforming the Lynes straddle packer. Based on a test system volume of 2.11 ft^3 for the Rocky Coulee monitor zone, a pressure increase of 9.8 lb/in^2 would only require a decrease of 0.06 ft^3 in the volume of the test system.

The pressure response for the Rocky Coulee monitor zone also displays a pattern which is highly suspect of true formation response. As shown in Figure 13, downhole pressure increases in the Rocky Coulee test interval are directly associated with the large pressure buildup recorded early in the injection test for the underlying composite Cohassett flow top. Following stabilization of the downhole pressure within the composite Cohassett flow top, pressure measurements for the Rocky Coulee interior exhibit a declining trend. The declining pressure pattern is inconsistent with a true formation response attributed to constant head injection testing within the underlying composite Cohassett flow top. The declining pressure pattern is compatable, however, with a true formation response to a borehole pressure pulse induced by a test system volume reduction. For this case, the induced pressure pulse would decline depending on the transmissivity of the Rocky Coulee flow interior isolated at borehole DC-4 as described by Bredehoeft and Papadopulos (1980).

Following completion of the vertical hydraulic conductivity testing, field tests were performed on July 25 and July 27, 1983, to provide additional information on test system compliance. With the Lynes straddle packer set at the same depth utilized during the experimental vertical hydraulic conductivity test the borehole annulus (i.e., above the top straddle packer) was repeatedly stressed with varying volumes of water and the downhole pressure response for the Rocky Coulee test section monitored. Figure 16 shows the pressure response for the three monitored zones during compliance testing. Preliminary results indicate that pressure increases within the straddle interval were not linear over the full range of pressures applied to the borehole annulus. For applied annular pressure below 90 lb/in^2, associated straddle interval responses were in the range of 0.041 lb/in^2 per applied lb/in^2. For annular pressures above 90 lb/in^2, straddle packer increases up to 0.049 lb/in^2 per applied lb/in^2 were recorded.

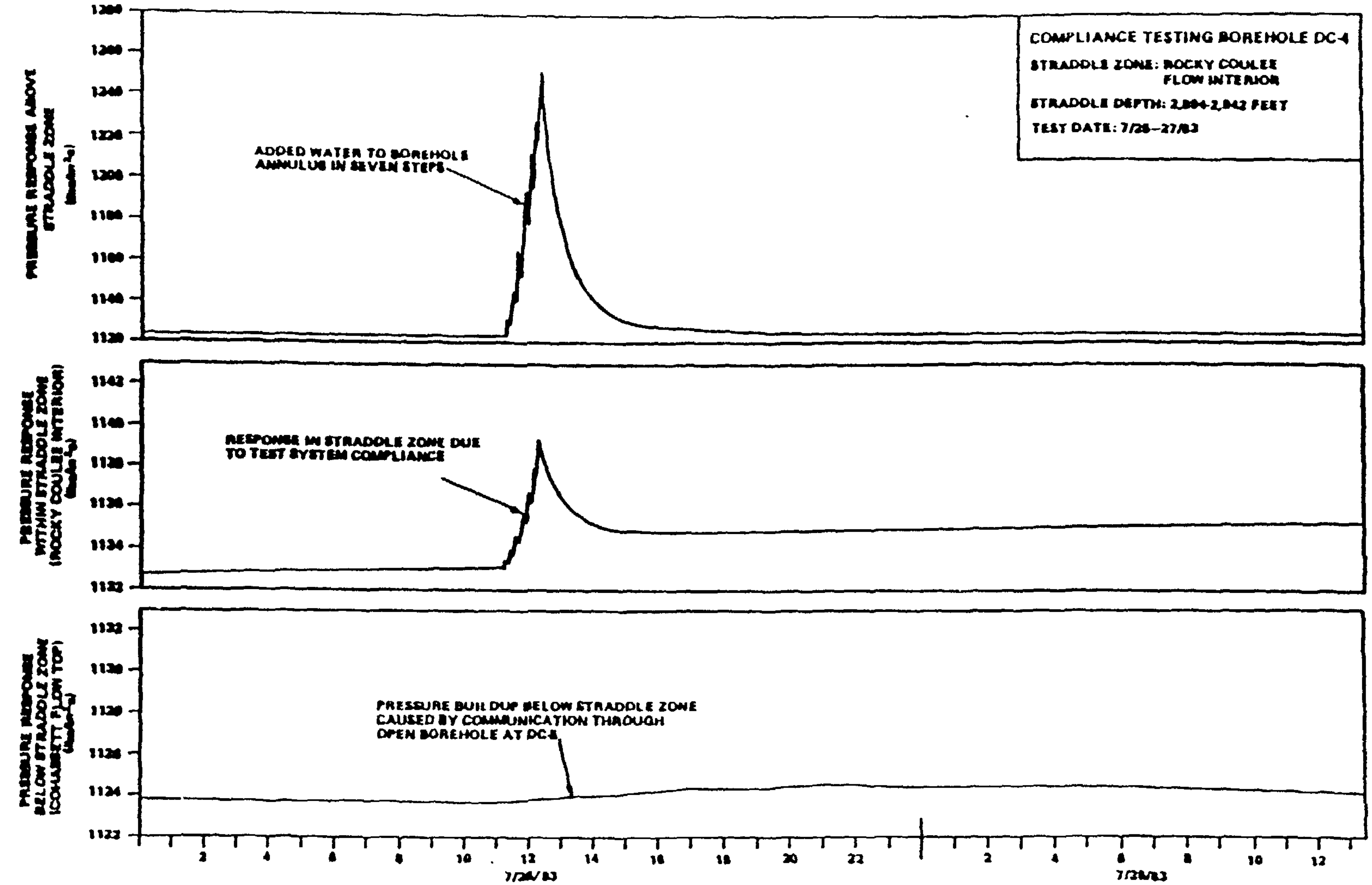

FIGURE 16. Downhole Pressure Response for Monitor Zones at Borehole DC-4 During Constant Head Injection Testing, For Vertical Hydraulic Conductivity Values 10^{-2} ft/day to 10^{-7} ft/day.

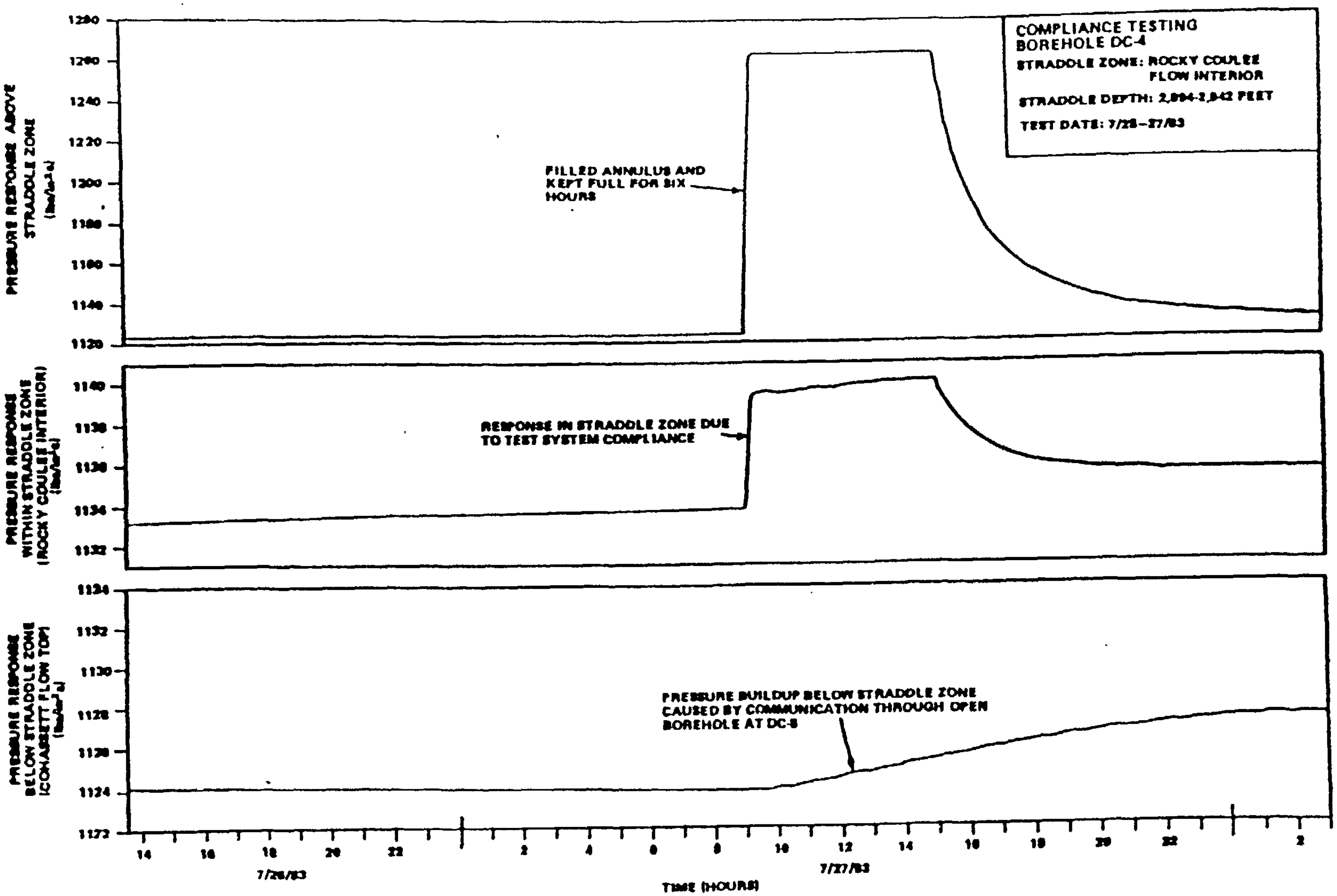

FIGURE 16. (cont.) Downhole Pressure Response for Monitor Zones at Borehole DC-4 During Constant Head Injection Testing, For Vertical Hydraulic Conductivity Values 10^{-2} ft/day to 10^{-7} ft/day.

HYDROLOGIC PROPERTY ANALYSIS

Figure 17 shows predicted buildup response for the monitor zone within the Rocky Coulee flow interior at borehole DC-4, during constant head injection at borehole DC-5, for varying values of vertical hydraulic conductivity within the confining zone. The buildup curves were developed using the relationships presented in Neuman and Witherspoon (1972) for analysis of vertical conductivity using the ratio method. Pertinent input data for generating the buildup curves include hydrologic properties for the aquifer and confining zone, imposed test conditions, and test system geometry parameters. These data are shown in Figure 17 and include:

Test Conditions

Average Discharge, Q	=	0.21 gpm (determined from flow records obtained during testing)
Radial Distance, r	=	6.0 ft (rounded vaue obtained from borehole gyroscopic survey)
Vertical Distance, z	=	26 ft (distance from Cohassett flow top to the top of the lower Lynes straddle packer)

Aquifer Characteristics

Transmissivity, T	=	0.12 ft^2/day (determined from previous hydraulic characterization testing)
Storativity, S	=	2.6 x 10^{-3} (determined from previous hydraulic characterization testing)

Confining Zone Characteristics

Specific Weight of Formation Fluid, γ_w	=	61.6 lb/ft^3 (for measured formation temperature of 115°F)
Coefficient of Compressibility, a_v	=	1 x 10^{-5} ft^2/lb (average value determined from core laboratory studies)
Void Ratio, e	=	.01% (average value obtained from core laboratory studies)

As indicated in Figure 17, for a test duration of eight weeks, vertical hydraulic conductivities of greater than 5 x 10^{-6} ft/day would be required to produce a discernable formation response of 0.25 lb/in^2 (i.e., 0.6 ft of water). In addition, vertical hydraulic conductivities of greater than 10^{-5} ft/day would be needed to produce a distinguishable formation response greater than the initial compliance response evident during testing. Based on the test results obtained, it is estimated that the vertical hydraulic conductivity for the section of Rocky Coulee flow interior from the top of the Cohassett flow top to the top of the lower Lynes straddle packer (i.e., 26 ft) is less than 10^{-5} ft/day.

Results also indicate that, given the test conditions existing at boreholes DC-4 and DC-5, constant head injection testing would have to be conducted

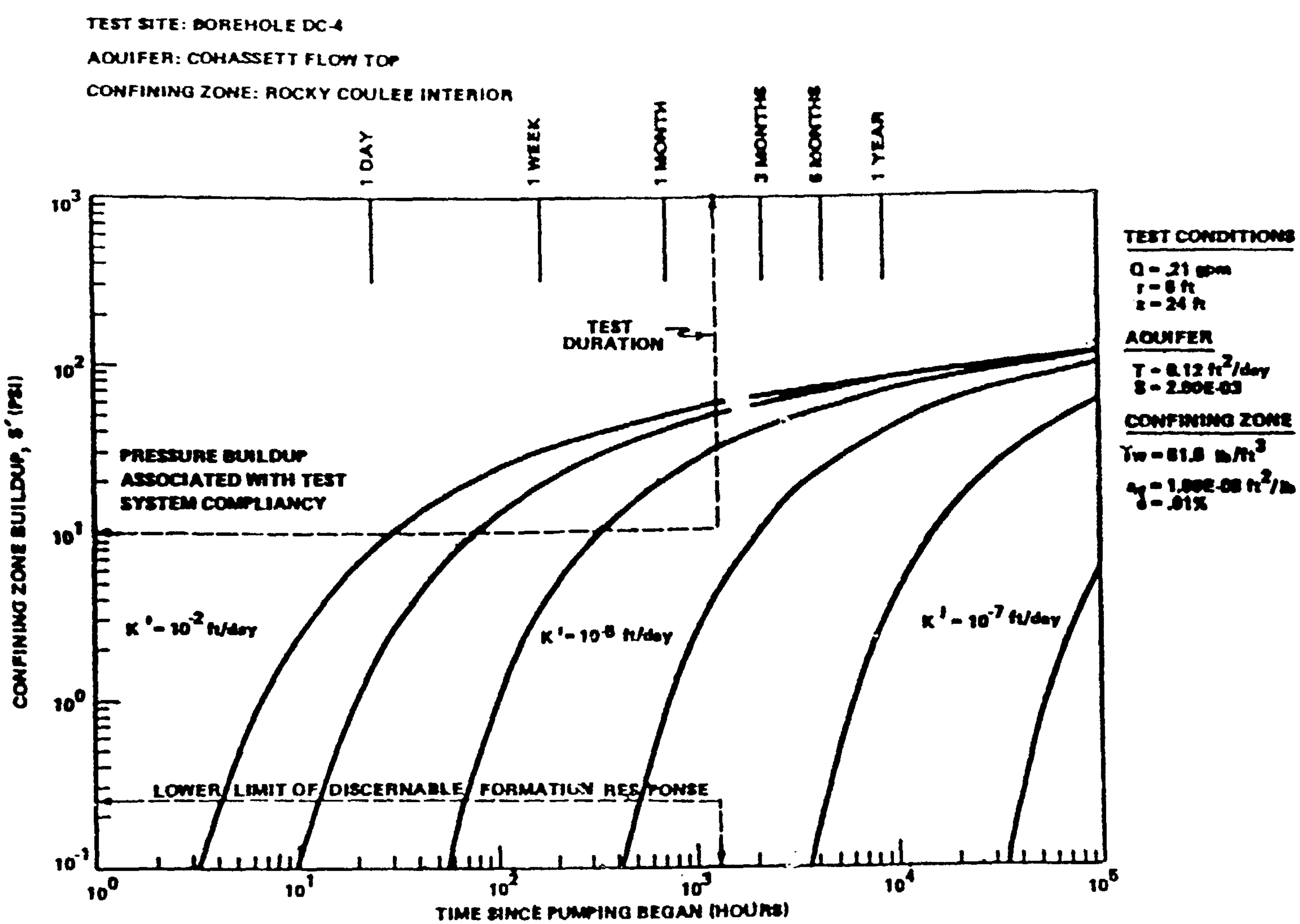

FIGURE 17. Predicted Pressure Buildup Within the Rocky Coulee Interior at Borehole DC-4 During Constant Head Injection Testing, for Vertical Hydraulic Conductivity Values 10^{-2} ft/day to 10^{-7} ft/day.

If the viability of single well tests can be established (i.e., through comparison studies with directional hydraulic conductivity tests), the ability to acquire areal vertical hydraulic conductivity values would be substantially increased, due to the preponderance of single borehole sites on the Hanford Site.

REFERENCES

Arnett, R. C., 1980, Far-Field Modeling: Simulation of the Natural Groundwater System in the Pasco Basin, in Basalt Waste Isolation Project, Annual Report Fiscal Year 1980, RHO-BWI-80-100, Rockwell Hanford Operations, Richland, Washington, pp. III-44 to III-53.

Arnett, R. C., Mudd, R. D., Baca, R. G., Martin, M. D., Norton, W. R., and McLaughlin, D. B., 1981, Pasco Basin Hydrologic Modeling and Far-Field Radionuclide Migration Potential, RHO-BWI-LD-44, Rockwell Hanford Operations, Richland, Washington.

Bredehoeft, J. D. and Papadopulos, S. S., 1980, A Method for Determining the Hydraulic Properties of Tight Formations, Water Resources Research, vol. 16, No. 1, pp. 233-238.

Burns, W. A., Jr., 1969, New Single-Well Test for Determining Vertical Permeability, Journal of Petroleum Technology, pp. 743-752.

Fenix and Scisson, Inc., 1978a, Hole History, Core Hole DC-4, Hanford Washington, 38p, also as RHO-BWI-C-40, Rockwell Hanford Operations, Richland, Washington.

Fenix and Scisson, Inc., 1978b, Hole History, Rotary Hole DC-5, Hanford, Washington, 25 p., also as RHO-BWI-C-7, Rockwell Hanford Operations, Richland, Washington.

Forster, C. B. and Gale, J. E., 1981, A Field Assessment of the Use of Bore-Hole Pressure Transients to Measure Permeability of Fractured Rock Masses, Lawrence Berkeley Laboratory, Tech. Rept. 11829, Univ. of California, Berkeley, California.

Forster, C. B. and Gale, J. E., 1980, Injection Versus Pulse Borehole Tests in Fractured Crystalline Rocks - Observations and Recent Experience, Third Invitational Well-Testing Symposium Proceedings, "Well Testing in Low Permeability Environments", pp. 74-83, Lawrence Berkeley Laboratory, Berkeley, California.

Freeze, R. A. and Cherry, J. A., 1979, Groundwater, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, pp. 604.

Hantush, M. S., 1960, Modification of the Theory of Leaky Aquifers, Journal of Geophysical Research, vol. 65, no. 11, pp. 3713-3726.

Hantush, M. S. and Jacob, C. E., 1955, Steady Three-Dimensional Flow to a Well in a Two-Layered Aquifer, Transaction, American Geophysical Union, vol. 36, no. 2, pp. 286-292.

Hiraski, G. J., 1974, Pulse Tests and Other Early Transient Pressure Analyses for In-Situ Estimation of Vertical Permeability, Transactions, AIME, vol. 257, pp. 75-90.

Hsieh, P. A., Neuman, S. P., and Simpson, E. S., 1983, Pressure Testing of Fractured Rocks--A Methdology Employing Three-Dimensional Cross-Hole Tests, NUREG/CR-3213, prepared for Div. of Health, Siting and Waste Management, Office of Nuclear Regulatory Research, U. S. Nuclear Regulatory Commission, Washington D.C., pp. 176.

Jackson, R. L., 1980, "Testing Techniques and Analysis Procedure Used in the Hydrology Program," in Basalt Waste Isolation Project Annual Report - Fiscal Year 1980, RHO-BWI-80-100, Rockwell Hanford Operations, Richland, Washington, November 1980.

Jacob, C. E., 1946, Radial Flow in a Leaky Artesian Aquifer, Trans. American Geophys. Union, vol. 27, pp. 198-205.

Javandel, I., 1983, Field Determination of the Hydrologic Properties and Parameters that Control the Vertical Component of Groundwater Movement, Earth Sciences Division, Lawerence Berkeley Laboratory (in preparation)

King, I. P., McLaughlin, D. B., Norton, W. R., Baca, R. G., and Arnett, R. C., 1981, Parametric and Sensitivity Analysis of Waste Isolation in a Basalt Medium, RHO-BWI-C-94, Rockwell Hanford Operations, Richland, Washington.

Landon, R. D., 1983, Geologic Thickness Data--Candidate Repository Horizons, SD-BWI-DP-011, Rockwell Hanford Operations, Richland, Washington.

Long, P. E., Apted, M. J., Spane, F. A., Jr., and Kim, K., 1982, "Geologic, Geomechanical, Rock Mechanics, and Hydrologic Characteristics of Candidate Repository Horizons," in Proceedings of the 1982 National Waste Terminal Storage Program Information Meeting, DOE/NWTS-30, Office of NWTS Integration, Columbus, Ohio, pp. 29-36; also RHO-BW-SA-252 P, Rockwell Hanford Opertations, Richland, Washington, September 1982.

MacNish, R. D., and Barker, R. A., 1976, Digital Simulation of a Basalt Aquifer System, Walla Walla River Basin, Washington and Oregon; Water Supply Bulletin 44, Washington State Department of Ecology, Olympia, Washington pp. 51.

Myers, C. W., and Price, S. M., eds., 1981, Subsurface Geology of the Cold Creek Syncline, RHO-BW-ST-14, Rockwell Hanford Operations, Richland, Washington, July 1981.

Narasimhan, T. N., 1968, Ratio Method for Determining Characteristics of Ideal, Leaky, and Bounded Aquifers, Bull. Int. Ass. Sci. Hydrol., vol. 13, no. 1, pp. 70-83.

Neuman, S. P., and Witherspoon, P. A., 1969, Applicability of Current Theories of Flow in Leaky Aquifers, Water Resources Research, vol. 5, no. 4, pp. 817-829.

Neuman, S. P., and Witherspoon, P. A., 1972, Field Determination of the Hydraulic Properties of Leaky Multiple Aquifer Systems, Water Resources Research, vol. 8, no. 5, pp. 1284-1298.

Prats, M., 1970, A Method for Determining the Net Vertical Permeability Near a Well From In-Situ Measurements, Journal of Petroleum Technology, pp. 637-643.

Raghaven, R., and Clark, K. K., 1975, Vertical Permeability From Limited Entry Flow Tests in Thick Formations, Society of Petroleum Engineers Journal, pp. 65-73.

Rockwell, 1982, Site Characterization Report for the Basalt Waste Isolation Project, DOE/RL82-3, Rockwell Hanford Operations for the U. S. Department of Energy, Washington D.C., November 1982.

Spane, F. A., Jr., 1982, "Hydrologic Studies Within the Pasco Basin", in Proceedings of the 1982 National Waste Terminal Storage Program Information Meeting, DOE/NWTS-30, Office of NWTS Integration, Columbus, Ohio, pp. 23-28, also RHO-BW-SA-251 P, Rockwell Hanford Operations, Richland, Washington.

Staff, 1982, Testing Specifications for Vertical Hydraulic Conductivity Testing in Boreholes DC-4 and DC-5, SD-BWI-TC-009, Rockwell Hanford Operations, Richland, Washington.

Strait, S. R., Spane, F. A., Jackson, R. L., and Pidcoe, W. W., 1982, Hydrologic Testing Methodology and Results from Deep Basalt Boreholes, RHO-BW-SA-189 P, Rockwell Hanford Operations, Richland, Washington.

Tanaka, H. H., Hansen, A. J., Jr., and Skrivan, J. A., 1974, Digital-Model Study of Groundwater Hydrology, Columbia Basin Irrigation Project Area, Washington, Water Supply Bulletin 40, Washington State Department of Ecology, Olympia, Washington, pp. 60.

Walton, W. C., 1960, Leaky Artesian Aquifer Condition in Illinois, Illinois State Water Survey Report Investigation no. 39.

Walton, W. C., 1979, Review of Leaky Artesian Aquifer Test Evaluation Methods, Groundwater, vol. 17, no. 13, pp. 270-283.

Way, Shao-Chih, and McKee, C. R., 1982, In-Situ Determination of Three-Dimensional Aquifer Permeabilities, Groundwater, vol. 20, no. 5, pp. 594-603.

Weeks, E. P., 1969, Determining the Ratio of Horizontal to Vertical Permeability by Aquifer-Test Analysis, Water Resources Research, vol. 5, no. 1, pp. 196-214.

Wolff, R. G., 1970, Field and Laboratory Determination of the Hydraulic Diffusivity of a Confining Bed, Water Resources Research, vol. 6, no. 1, pp. 194-203.

Witherspoon, P. A., Javandel, I., Neuman, S. P., and Freeze, R. A., 1967, Interpretation of Aquifer Gas Storage Conditions From Water Pumping Tests, American Gas Assoc., Inc., New York, New York, pp. 273.

LETTERS

Javandel, I., Lawrence Berkeley Laboratory, letter to L. S. Leonhart, BWIP, Rockwell Hanford Operations, August 16, 1983.

Javandel, I., and Wilson, C. R. Lawrence Berkeley Laboratory, letter to S. M. Baker, BWIP, Rockwell Hanford Operations, October 27, 1982.

Neuman, S. P., letter to G. S. Hunt, BWIP, Rockwell Hanford Operations, November 17, 1982.

APPENDIX A

Components of the Surface Constant Head Injection System

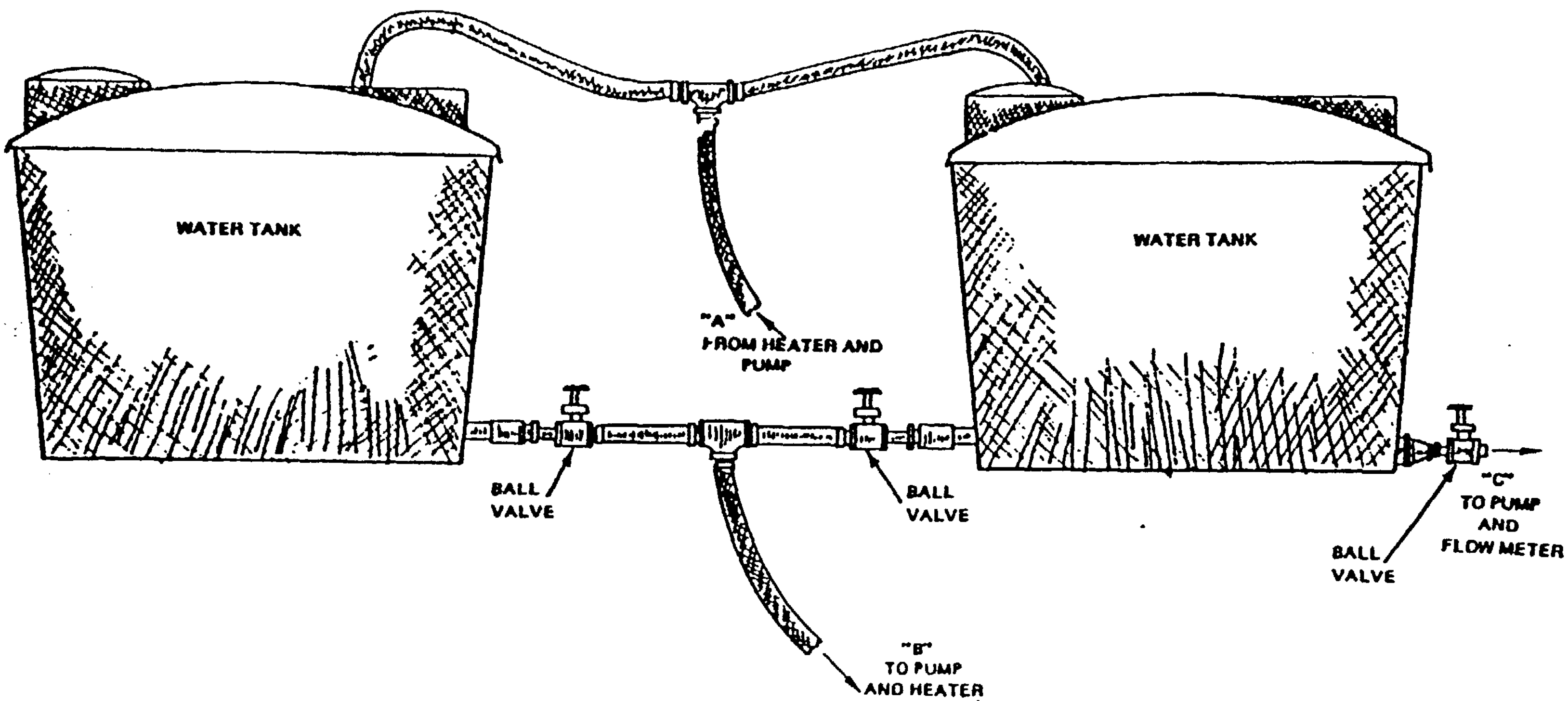

FIGURE A-1. Water Reservoir Storage Tanks at Borehole DC-5.

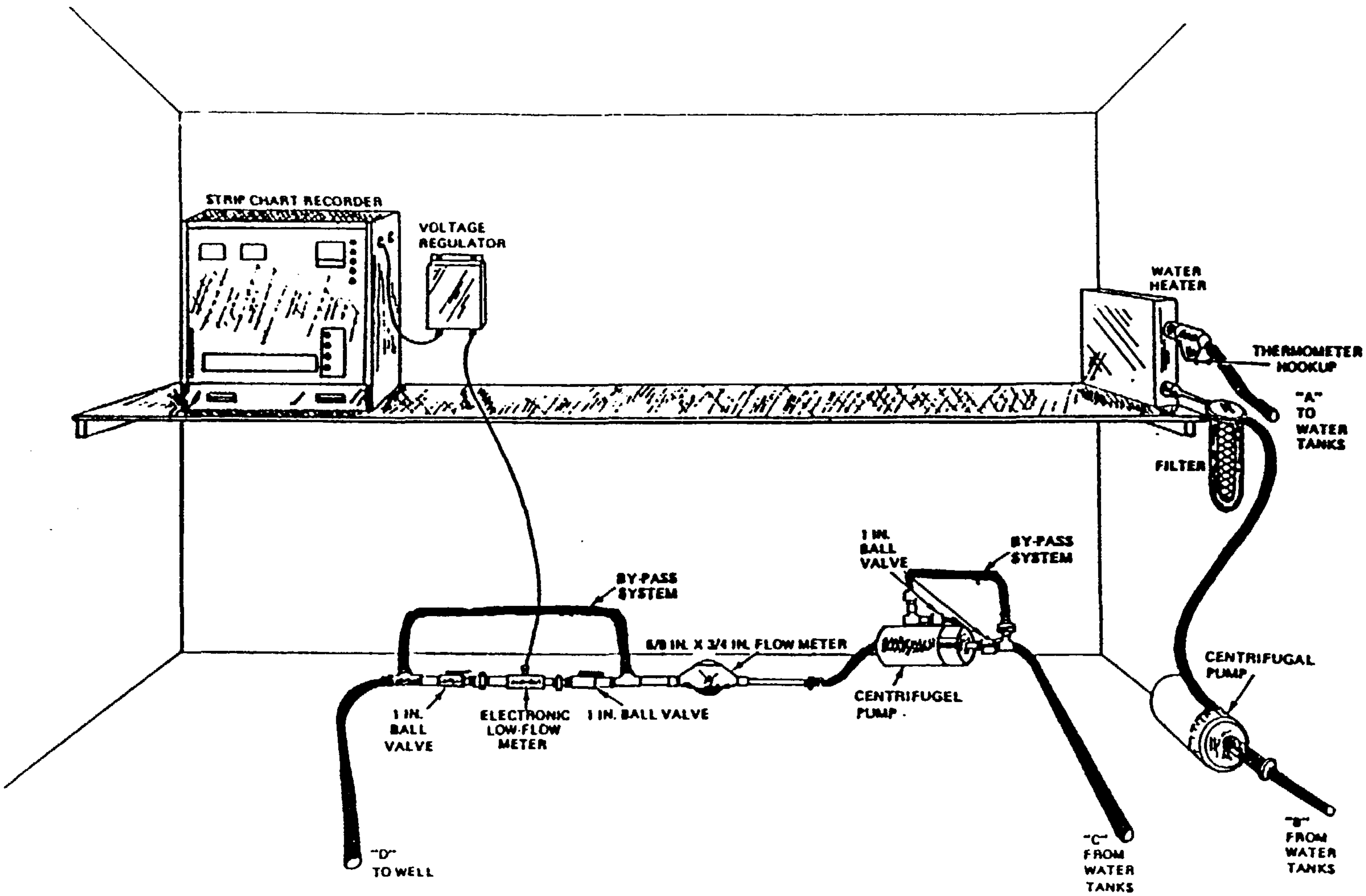

FIGURE A-2. Flow Monitoring, Filtering, and Heating Systems at Borehole DC-5.

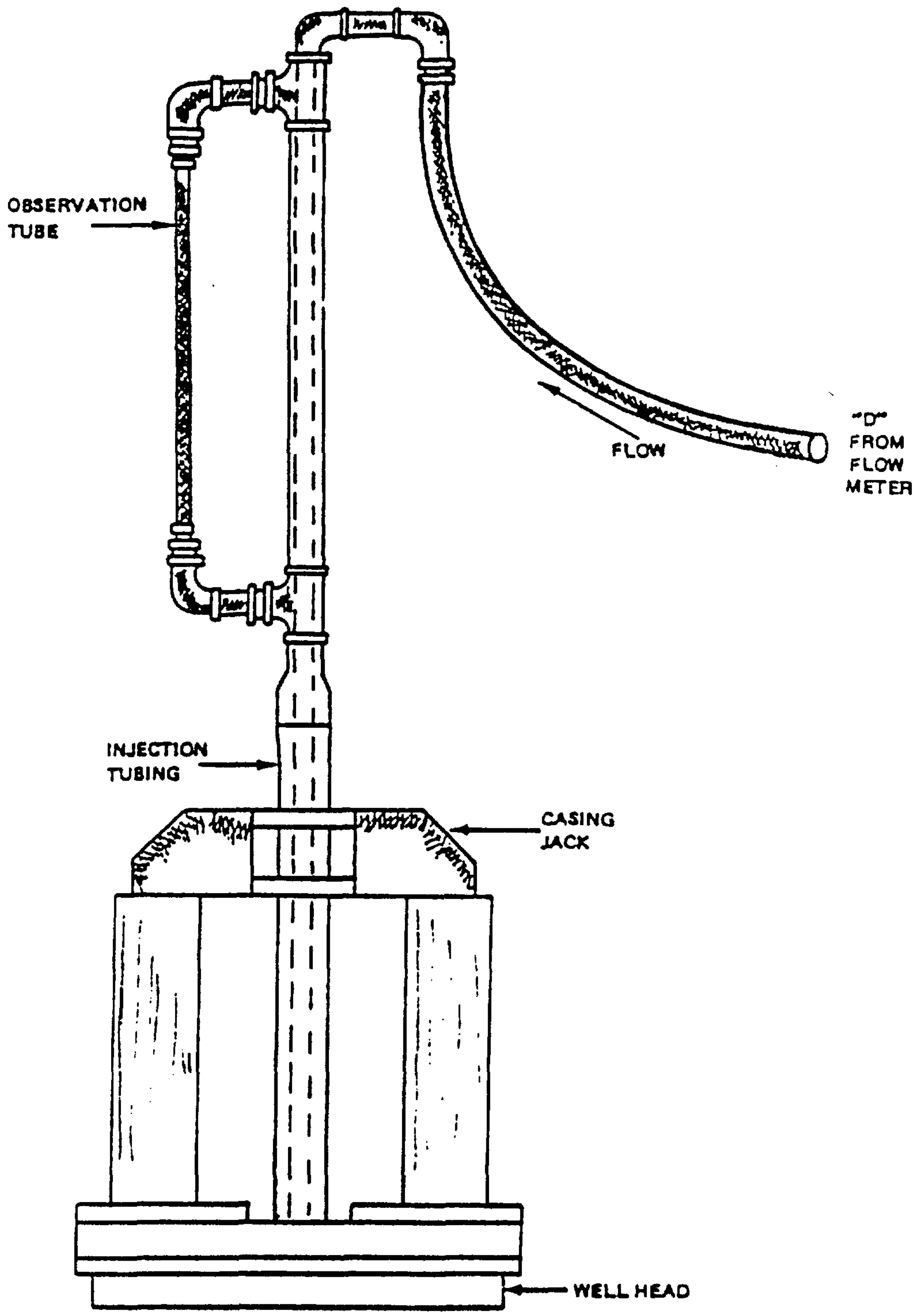

FIGURE A-3. Surface Well Head and Syphon System at Borehole DC-5.

APPENDIX B

Detailed Hydrologic Testing Activity Summary
October 11, 1982 to June 24, 1983.

Deailed Hydrologic Testing Activity Summary,
October 11, 1982 to June 24, 1983.

DATE	ACTIVITY
10/11/82	Set bridge plug at 2,998 ft and 2.563-in. TAM single packer with Seling recorder carrier at 2,945 ft in DC-4.
10/12/82	Monitor pressure readings in DC-4.
10/13/82	Started in with 7.375-in. bridge plug packer in DC-5. DC-4 equilibrating.
10/14/82	Set bridge plug at 3,006 ft and started in hole with TAM packer and Seling recorder carrier in DC-5. DC-4 equilibrating.
10/15/82	Discovered actual bridge plug at DC-5 was now at 3,036 ft, began tripping out to reset bridge plug. DC-4 equilibrating.
10/16/82	Reset bridge plug at 3,006 ft in DC-5. DC-4 equilibrating.
10/17/82	No activity at DC-5. DC-4 equilibrating.
10/18/82	TAM packer set at 2,950 ft in DC-5. DC-4 equilibrating.
10/19/82-10/21/82	Both borehole systems equilibrating.
10/22/82	Close both borehole shut-in tools. System checks revealed no communication around packers.
10/23/82-10/24/82	Boreholes equilibrating.
10/25/82	Opened DC-5 shut-in tool and attempted air-lift pumping test of the composite Cohassett flow top. Unsuccessful due to insufficient compressor volume.
10/26/82	Continued equilibration while waiting for workover rig to set small conductor air-line tubing in DC-5.
10/27/82	Set conductor tubing in DC-5. DC-4 equilibrating.
10/28/82	Initiated variable discharge air-lift pumping test of the composite Cohassett flow top at DC-5 at 1440 hours. Q ranged from 2 to 0.3 gpm. Monitored responses at DC-4 throughout test.

Detailed Hydrologic Testing Activity Summary,
October 11, 1982 to June 24, 1983 (cont.).

DATE	ACTIVITY
10/29/82-10/31/82	Continued air-lift testing.
11/1/82	Terminated variable discharge air-lift pumping test at 1430 hours. Closed shut-in tool at DC-5. Recovery monitored at both boreholes.
11/2/82-11/4/82	Continued monitoring recovery at both boreholes.
11/5/82	Pulled conductor air-line from DC-5. Continued monitoring.
11/6/82-11/7/82	Continued monitoring recovery at both boreholes.
11/8/82	Initiated slug injection test of the composite Cohassett flow top at DC-5 (1046 hours). Monitored response in both holes.
11/9/82	Terminated monitoring of slug injection test (0800 hours). Initiated multiple pulse injection test at DC-5.
11/10/82	Initiated argon slug injection test (1535 hours). Monitored recovery in both boreholes.
11/11/82	Initiated second argon slug injection test. Monitored recovery in both boreholes. Terminated recovery at 0800 hours. Submersible pump installed in DC-5. Initiated constant discharge pumping test of the composite Cohassett flow top at 1530 hours (Q = 0.5 gpm).
11/12/82	Terminated constant discharge pumping test due to filter plugging (0033 hours). Restarted test at 1630 hours and monitored drawdown in both boreholes.
11/13/82-11/15/82	Continued drawdown monitoring in both boreholes.
11/16/82	Terminated constant discharge pumping test (0900 hours). Workover rig moved to DC-4 to reset packers and bridge plug., DC-5 idle.
11/17/82-11/18/82	E:perienced packer seating problems at DC-4. DC-5 idle.
11/19/82	Packer depths adjusted. Packers set at 2,993 ft and 3,012 ft in DC-4. Tools dressed for DC-5. Workover rig moved to DC-5.

Detailed Hydrologic Testing Activity Summary, October 11, 1982 to June 24, 1983 (cont.).

DATE	ACTIVITY
11/20/82-11/21/82	Idle.
11/22/82	Set bridge plug in DC-5 at 3,024 ft. Began monitoring in situ pressures at DC-4.
11/23/82	Set packer in DC-5. Settings at 2,996 and 3,004 ft. DC-4 and DC-5 equilibrating.
11/24/82	Initiated pulse test in DC-4. Monitored both boreholes. DC-5 shut in.
11/25/82-11/28/82	Monitored pressure decay in DC-4. Monitored DC-5.
11/29/82	Terminated test at 0800 hours. Review of pressure data revealed a packer leak at DC-5.
11/30/82	Workover rig moved to DC-4. DC-5 idle. Lynes personnel arrived onsite to supervise installation of small-diameter straddle packers at DC-4.
12/1/82	Lynes straddle tools installed and calibrated in DC-4. Settings at 2,945 and 2,995 ft for packers and 3,012 ft for bridge plug. Tool leak detected. Tripped out of borehole and repaired tool. DC-5 idle.
12/2/82	Lynes straddle tool reinstalled in DC-4, pressurized, and calibrated. Lynes personnel departed site. DC-5 idle.
12/3/82	Workover rig moved to DC-5. DC-4 shut-in tool closed with a recorded "squeeze" pressure of about 500 psi. Decay monitored.
12/4/82-12/5/82	Monitored pressure decay in DC-4. DC-5 idle.
12/6/82	Monitored pressure decay in DC-4. TAM straddle packer being installed in DC-5.
12/7/82-12/9/82	Problems with setting TAM straddle packer in DC-5. Continued monitoring pressure decay at DC-4. Surface test equipment moved onsite, tested, and calibrated.
12/10/82	DC-4 probe failed in test interval. DC-5 signal failed, tripped out of DC-5.
12/11/82-12/12/82	Idle.

Detailed Hydrologic Testing Activity Summary, October 11, 1982 to June 24, 1983 (cont.).

DATE	ACTIVITY
12/13/82	Discovered damage to TAM unit in DC-5. Ordered replacement parts.
12/14/82	Idle.
12/15/82-12/16/82	Dressed TAM equipment and reheaded Seling pressure probe.
12/17/82	Lynes probe in DC-5 failed, notified Lynes.
12/18/82-12/19/82	Idle at both sites.
12/20/82	Lynes arrived at the site. Released tools and removed pressure probe. Replacement probe ordered. DC-5 idle.
12/21/82	DC-5 idle. Lynes replacement p. ,be delivered. Redressed tool and tripped into hole. Packer communication evident.
12/22/82	DC-5 idle. Packers reinflated and monitoring test system inflation pressures at DC-4.
12/23/82-12/26/82	Monitoring test system inflation at DC-4. DC-5 idle.
12/27/82	Packers set at DC-4, "squeeze" over-pressure at 2,285 psi recorded. Dressing tools for DC-5. The setting for DC-4 packers were 2,945 and 2,993 ft.
12/28/82	DC-4 monitoring pressure decay. DC-5 tools dressed and tripped into hole. Packers inflated.
12/29/82	Monitoring pressure decay at DC-4. Communication around bottom packer evident in DC-5. Pulled tools and reseated packers.
12/30/82	Communication around packers evident at DC-5, selected new seats. Monitoring pressure decay in DC-4.
12/31/82-1/2/83	Monitoring pressure decay in DC-4. DC-5 idle.
1/3/83	Monitoring pressure decay in DC-4. DC-5 tools removed and redressing packers.
1/4/83	Monitoring pressure decay in DC-4. Redressed tool and tripped back into DC-5. Packer element tailed during inflation. Tripped back out of hole.

Detailed Hydrologic Testing Activity Summary,
October 11, 1982 to June 24, 1983 (cont.).

DATE	ACTIVITY
1/5/83	Monitoring pressure decay in DC-4. Tripped back into DC-5. Packer communication evident tripped out.
1/6/83	Monitoring pressure decay in DC-4. Attempted new seat in DC-5 with slow inflation to minimize "squeeze" pressure. Evidence of bridge plug communication.
1/7/83	Monitoring in DC-4. Decided to modify packer configuration for DC-5. New system includes single TAM packer and underlying bridge plug packer.
1/8/83-1/9/83	Monitoring in DC-4. Idle in DC-5.
1/10/83	Monitoring in DC-4. Reseated tools in DC-5. Commencing monitoring with new packer seating. Bridge plug was set at 3,017 ft, packer set at 2,990 ft in DC-5.
1/11/83-1/13/83	Monitoring pressures in DC-4 and DC-5. 0830 hours moved tools in DC-4 up on stand, 50.89 ft with packer seats at 2,898 and 2,945 ft.
1/14/83	Monitoring pressures in DC-4 and DC-5.
1/15/83-1/31/83	Monitoring pressures in DC-4 and DC-5.
2/1/83	Attempted to start constant head injection test at DC-5. Started test at 1044 hours and stopped at 1136 hours. Monitoring pressures in DC-4.
2/2/83-2/3/83	Monitoring pressures in DC-4 and DC-5.
2/4/83	0900 hours, initiated constant head injection test for the composite Cohassett flow top.at DC-5 for experimental vertical hydraulic conductivity test evaluation. Monitoring pressures in DC-4.
2/5/83-2/12/83	Monitoring pressures in DC-4 and DC-5. Slight decrease in injection rate noted at DC-5 due to clogging of mechanical flow meter.
2/13/83-2/14/83	Monitoring pressures in DC-4 and DC-5.
2/15/83	Mechanical flow meter cleaned out and put in service at 0840 hours at DC-5. Monitoring pressures in DC-4 and DC-5.

Detailed Hydrologic Testing Activity Summary,
October 11, 1982 to June 24, 1983 (cont.).

DATE	ACTIVITY
2/16/83-2/17/83	Monitoring pressures in DC-4 and DC-5.
2/18/83	Monitoring pressures in DC-4 and DC-5. Mechanical flow meter removed from injection system at DC-5.
2/19/83-3/30/83	Monitoring pressures at DC-4 and DC-5.
4/1/83	Bridge plug failed at DC-5, injection terminated and recovery initiated. Monitoring pressures at DC-4 and DC-5.
4/2/83-6/23/83	Monitoring recovery pressures in DC-4 and DC-5.
6/24/83	Terminated recovery pressure monitoring.

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Prepared by (Name and Dept. No.)	F. A. Spane, Jr. P. D. Thorne W. H. Chapman-Riggsbee
Date	9/83

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Abstract

This document reports the results of a recent experimental field test to assess the applicability of the "ratio method" in determining vertical hydraulic conductivity of basalt interiors under Hanford Site test conditions. The test formation selected for the initial experimental test was a twenty-six foot section of Rocky Coulee flow interior located above the composite Cohassett flow top at boreholes DC-4 and DC-5.

Results from the experimental field test indicate no discernable formation response during the eight-week testing period. Based on the lack of a discernible formation response, and known test system and formation characteristics, vertical hydraulic conductivity for the Rocky Coulee interior test section is estimated to be less than 10^{-5} ft/day. Results from the test also suggest that the use of the ratio method for determining vertical hydraulic conductivity of flow interiors, may be of limited application at the Hanford Site, given existing formation conditions and Basalt Waste Isolation Project test equipment constraints.

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Issue Approval:

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