Mini-Report #8

ANALYSIS OF DRILLING RESPONSE AT THE HANFORD SITE: ANALYSIS

Basalt Waste Isolation Project
Subtask 2.5
Numerical Evaluation of Conceptual Models

Prepared by

Terra Therma Inc.

for

Nuclear Waste Consultants

December, 1986

TERRA THERMA, INC.
WATER CONSULTANTS AND ENGINEERS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

1.0 INTRODUCTION

1.1 STATEMENT OF THE PROBLEM

The majority of in situ hydrologic tests conducted at the BWIP site have been single borehole tests. A high degree of uncertainty exists in using these point-specific data to predict large-scale hydraulic properties of the layered basalt system. Very few multiple borehole tests measuring large-scale hydraulic properties have been conducted to date within the RRL and vicinity. However, large-scale tests have the potential to provide hydraulic parameter values which are more suitable to an evaluation of site performance.

Drilling and completion activities associated with construction of monitor wells have commonly involved withdrawal and/or injection of substantial quantities of water or other drilling fluids. On several occasions, hydraulic responses at distant observation piezometers have been measured and can be correlated with drilling and completion activities. The injection/withdrawal sequences and resulting hydraulic responses represent uncontrolled multiple borehole tests which, under appropriate conditions, are suitable for analysis for large-scale hydraulic parameters.

TTI Mini-Report #5 (TTI, 1986a) presents a methodology for analyzing drilling responses to obtain large-scale (bulk) values of key hydraulic parameters. This mini-report utilizes the same analytical technique to analyze existing data obtained during drilling/completion activities at the Hanford site. The study described herein analyzes hydraulic reponses measured in various piezometers resulting from drilling and testing activities in order to estimate bulk hydraulic parameters. The calculated parameters are compared to values obtained during the small-scale testing program. Estimates of bulk hydraulic parameters may be useful for performance modeling activities and for pre-analysis of the proposed LHS testing.

1.2 RELEVANCE TO THE NRC

The NRC is responsible for providing guidance to DOE on acceptable elements of a site characterization and licensing program. For the purposes of hydrogeologic reviews conducted by the NRC staff, relevance can be established only with reference to the regulations that the staff are directed to apply, that is, 10 CFR Part 60 and 40 CFR Part 191.

The relevance to this report is established as follows:

- 10 CFR 60.112, limiting releases of radioactive materials to the accessible environment (also limiting radiation exposures and concentrations of radionuclides in special sources of groundwaters) after permanent closure to those permitted by the EPA Standard (40 CFR Part 191).

- 10 CFR 60.113(a)(2), addressing minimum pre-emplacement groundwater travel time from the disturbed zone to the accessible environment.

- 10 CFR 60.113(b), factors Commission may take into account including sources of uncertainty.

- 10 CFR 60.122, addressing favorable and potentially adverse siting conditions regarding the ability to isolate the waste including pre-emplacement groundwater travel time, overall EPA Standard, and individual and groundwater protection.

For detailed discussions of the regulations, consult Federal Register, v. 50 no. 181, Thursday Sept. 19, 1985, p. 38066-38089. For discussion of the NRC staff position on the applicability of the EPA Standard to NRC licensing reviews, consult Draft Generic Technical Position on Licensing Assessment Methodology, April 30, 1984.

The evaluation of hydraulic parameters is considered necessary in order to determine groundwater travel times as it applies to the radionuclide release rates (during operation and after permanent closure), the favorable and potentially adverse siting conditions for pre-emplacement groundwater travel time, and the overall isolation standards.

1.3 RELATIONSHIP TO OTHER TASKS

Several analyses have been conducted by DOE to predict large- scale hydraulic properties based on single borehole test data. This report compares DOE's present findings with the large-scale parametric data developed herein.

DOE is currently formulating future testing activities for the BWIP site. These activities will be described in detail in the BWIP Site Characterization Plan (SCP). As part of the site testing strategy, DOE is proposing a multiple borehole hydraulic stress test to be conducted at the RRL-2 site and vicinity. Analysis of drilling response data can provide insight into the applicability of DOE's test design and the potential for success.

2.0 OBJECTIVE

The objective of this report is to determine, using the methodology presented in TTI Mini-Report #5 (TTI, 1986a), large-scale (bulk) parameters for transmissivity and storativity from data collected during drilling and completion activities at the BWIP site. These results are compared with data previously collected by DOE and their interpretation of large-scale hydraulic parameters.

3.0 ANALYSIS

Methodology from TTI Mini-Report #5 has been utilized in this report to analyze hydraulic responses observed during the drilling and completion of boreholes RRL-17, RRL-2B, DC-23W, DC-19C, and DC-20C. The following section contains results and discussions of these analyses.

The method of analysis uses a variable flow rate well-simulator to predict hydraulic head changes. The simulator accepts variable flow rates (injection and withdrawal) associated with drilling/completion activities. Assuming an ideal confined aquifer, the simulator uses superposition of the Theis (1935) equation to predict hydraulic drawdown/buildup at a monitoring well. Hydraulic parameter values entered into the simulator (transmissivity, storativity) are varied in a trial-and-error manner until the theoretical response best matches the measured field response. At this point, it is considered that the "calibrated" hydraulic parameter values used as input into the analytical model are similar to the actual in situ formation properties. For further explanation of the methods used, consult TTI Mini-Report #5 (TTI, 1986a).

4.0 RESULTS

Table 1 gives hydraulic parameter values obtained from each analysis. Table 2 presents comparison values obtained from various DOE documents. It is noted in Table 2 that, in general, the parametric values from the TTI analyses (Table 1) are not drastically different from those in the DOE range of "best guess" values. However, the DOE values are taken from only a few references and may not reflect their current interpretations of the BWIP site. Hydraulic conductivity values have not been calculated due to uncertainty in the thickness and uniformity of strata responding to the tests.

Detailed discussion and evaluation of the individual analyses are presented below. Data used for the analyses are given in Appendix A. A planer view of the study area, showing borehole locations, is presented in Appendix B.

4.1 RRL-17

While drilling borehole RRL-17, hydraulic responses were observed in borehole DC-20C in both the Rocky Coulee and Cohassett flow tops. Fluid loss during the drilling of RRL-17 is shown in Figure 1a and associated hydrographs at DC-20C are presented in Figure 1b. Note that hydraulic responses apparently did not occur in the Rosalia, Sentina' Gap, or Ginkgo flow tops. A very subdued hydraulic response may have occurred in the Umtanum flow top.

Analysis of hydrograph and fluid loss data yield the following results:

$$T = 80 \ ft^2/day^{(1)}$$

$$S = 1.1 \times 10^{-5}$$

These hydraulic parameters may represent the upper bounding case for the Cohassett flowtop if leakage at DC-20C is very local. Another possible explanation for these parameters would be an anomoly near the RRL-17 Rocky Coulee flowtop causing very low permeability locally which, in turn, produced no response in the DC-20C when fluid loss was encountered in drilling through the Rocky Coulee. In this case, one would consider the transmissivity and storativity values as composite hydraulic properties of the Rocky Coulee/Cohassett flows. Figure 2 displays the "best fit" curve for these values.

Data in the TTI single borehole database, collected from various DOE sources, give geometric mean transmissivity values for the Rocky Coulee and the Cohassett flow tops of 90 and .1 (includes the McGee Well), respectively or 30 and .03 (excludes the McGee Well), respectively (TTI, 1986b). Values from this database are found in Table 3. DOE values in this database obtained from small scale tests range from 30 to 300 in the Rocky Coulee flow top and 3×10^{-5} to 100 in the Cohassett flow top. The higher transmissivities were measured in the McGee Well (located west of the alleged Yakima Barrier).

---

[1] All transmissivities given in this document are in ft^2/day.

The variability in transmissivity values obtained from single hole tests exemplifies the need for large-scale testing. This variation is too large to provide any convincing evidence in support of large-scale transmissivity values derived from single borehole test information.

The TTI determined storativity value is in the range of values given by DOE (Strait, 1982) as between 10^{-3} and 10^{-6}.

The identical curves for the Rocky Coulee/Cohassett flow tops (Figure 1B) may imply significant vertical leakage between these flows. If vertical leakage between the Rocky Coulee and Cohassett is not significant, the identical nature of the associated hydrographs might indicate hydraulic communication within the DC-20C installation or the possibility that the Rocky Coulee and Cohassett units behave as one geohydrologic unit in the vicinity of DC-20C.

4.2 RRL-2B

Two analyses were performed to analyze hydraulic responses associated with the drilling of borehole RRL-2B. These include responses measured in the Rocky Coulee flow top at wells RRL-2A and RRL-2C, both located within 200 meters of RRL-2B. Results are as follows:

RRL-2A: $T = 1.3$

$S = 8 \times 10^{-6}$

RRL-2C: $T = 7$

$S = 6 \times 10^{-5}$

The "best fit" curves are presented in Figures 3 and 4.

The values obtained for transmissivity in the Rocky Coulee flow top have a fairly large variation. Note that the distance between RRL-2B and the two observation wells is less than 600 feet. Borehole RRL-2B is approximately 250 feet west of RRL-2C and 500 feet north of RRL-2A. One would expect both the transmissivity and storativity values to be similar, based solely on the location of the wells.

DOE transmissivity estimates from single hole tests at RRL-2A range from 10 to 100 in the Rocky Coulee flow top with 10 being DOE's best guess (Stone, 1984). Notice too that the nearness of these wells should lead to transmissivity and storativity values closer to that obtained from small scale tests. As mentioned previously, the storativity values obtained in these analyses are within the range of expected values presented by DOE.

The variation in TTI results may be the result of heterogeneity in the immediate vicinity, completion characteristics of the observation wells, and other deviations from assumptions associated with the analysis of this system (TTI, 1986a).

4.3 DC-23W

Analysis of the hydraulic response in the Priest Rapids at DC-20C resulting from drilling of DC-23W is discussed in TTI Mini-Report #5 (TTI, 1986a). Figure 5 is the "best fit" curve determined in the previous analysis and the results given in that report are as follows:

$$T = 3000$$

$$S = 2.5 \times 10^{-5}$$

As discussed in Mini-Report #5, boundaries located within 14 miles of the injection/withdrawal well could theoretically alter the hydraulic response at DC-20C.

Three large-scale multiple borehole tests were conducted by DOE in the Priest Rapids interval. These tests yielded transmissivity values of 3000 and 30,000 and values in the range of 10^{-4} for storativity (TTI, 1986b). Composite Wanapum storativity range values are given as 10^{-4} to 10^{-5} (Strait, 1982). DOE data contained in TTI's single borehole database (Table 3) for the Priest Rapids interval yields a range of transmissivity values of .3 to 30,000 ft^2/d.

Due to the identical nature of the two hydrograph curves considered for this analysis (Figure 6), an analysis of the drilling response observed in the DC-20C Sentinel Gap interval would yield similar results. Assuming that hydraulic communication does not occur within the DC-20C installation, it is possible that the Sentinel Gap and Priest Rapids intervals should, at least in the vicinity of DC-23W, be considered a single hydrogeologic unit. This would imply significant vertical leakage between these units and that the stated transmissivity and storativity values are composite values for a substantial thickness of the Wanapum. The single hydrogeologic unit concept has been discussed at length in Spane, 1985.

4.4 DC-19C

During the drilling and completion of DC-19C, hydrologic responses were detected in the Priest Rapids at borehole DB-14. One difficulty in conducting this analysis is the lack of fluid loss data. Lu (1984) estimated a constant discharge rate in DC-19C of approximately 40 gpm. With this assumption, results obtained with the TTI analysis are:

$$T = 210$$

$$S = 1.1 \times 10^{-5}$$

Transmissivity values of 290 and 120 were determined using different flow rate values of 50 and 30 gpm, respectively (Figures 7 - 9). All storativity values were in the range of 10^{-5}.

The range of transmissivity values obtained by DOE (Table 3) is very large (.3 - 30,000). The geometric mean transmissivity value for the Priest Rapids interval is 100, the same order of magnitude of the TTI result. Lu's analysis resulted in values of 210 and 8×10^{-6} for transmissivity and storativity, respectively. These values are in excellent agreement with the TTI results.

4.5 DC-20C

A drilling response was also detected in the Priest Rapids interval of DB-14 during the drilling of DC-20C. Similar values for transmissivity and storativity were obtained from this unit as is given for the Priest Rapids in Section 4.4. The "best fit" curve (Figure 10) using Lu's average discharge rate of 60 gpm for 31 days drilling, results in the following values:

$$T = 210$$

$$S = 8 \times 10^{-6}$$

Transmissivity values of 270 and 350 were obtained using flow rates of 75 and 115 gpm, respectively (Figures 11 - 12). Storativity values are in the 10^{-5} range for all cases considered.

5.0 CONCLUSIONS

A range of transmissivity and storativity values obtained from these analyses yield the following results:

Grande Ronde Basalt: $T = 1.3 - 80\ ft^2/day$

$S = 8x10^{-6} - 6x10^{-5}$

Wanapum Basalt: $T = 210 - 3,000\ ft^2/day$

$S = 8x10^{-6} - 2.5x10^{-5}$

The geometric mean values obtained by DOE from single borehole data are as follows:

Grande Ronde Basalt: $T = 2\ ft^2/day$

Wanapum Basalt: $T = 1000\ ft^2/day$

In general, values of transmissivity and storativity determined in this analysis were found to be within the range of values previously obtained by DOE from single borehole tests. Based on these findings, it may be realistic to conduct only one or two large-scale tests to verify our present interpretation of values and to narrow the range of values.

Note that all results were determined assuming no boundary conditions. Boundary conditions may have an effect on the evaluation of large-scale parameters. For example, by imposing a single boundary condition (constant head or impermeable) on the DC-20C analysis, effects were detected up to 21 miles from the observation well (DB-14). In other tests, the average distance for detection of boundary effects was on the order of 11 miles. The implication here is that potential boundary conditions may have an effect on the system at fairly large distances. Further knowledge of the actual boundary conditions is necessary.

The analyses did not identify any previously undetected boundaries within or adjacent to the RRL. However, a more detailed review of all water level data, including data for the remainder of 1986, will be performed when it becomes available.

6.0 DISCUSSION

These analyses continue to stress the need for large-scale hydrologic testing (LHS) at the Hanford site. However, assuming validity of data utilized herein, it appears that DOE's range of values are reasonable, though the variation is far too large in many cases to be of much use in defining large-scale parametric data. Based on these facts, TTI concludes that more attention needs be given to the range of acceptable values necessary to meet the licensing requirements presented in Section 1.1. This will entail an analysis of levels of uncertainty and evaluation of the sensitivity of large-scale hydraulic parameters allowable. Actual large-scale testing should be centered around these data needs.

This report not only indicates the usefulness for large-scale hydraulic testing (LHS) of the BWIP site, it also indicates, due to the observed responses during the drilling and completion activities, a high probability of success if proper testing procedures are used.

These analyses considered the ideal response based on the Theis equation. Further analyses on this and other drilling and completion response data considering leakage properties would be helpful in the design of further test plans. If leakage were significant, actual transmissivities would be greater than the reported TTI values. Thus, the transmissivity values reported herein can be considered minimum values. Sensitivity analyses to determine acceptable range of values should also be conducted.

It is noted previously that in both the drilling responses observed at DC-20C for drilling DC-23W and RRL-17, there are identical curves for two supposedly separate hydrogeologic units. During the drilling of DC-23W, Sentinel Gap and Priest Rapids display almost identical hydrographs. During drilling of the RRL-17, this same phenomenon is displayed in the Rocky Coulee and Cohassett hydrographs. This raises the question of integrity of the DC-20C installation. The integrity of borehole DC-20C needs to be established to grant a greater level of certainty to the evaluation of drilling response data from this well. Presently, TTI gives a high degree of uncertainty to the data from DC-20C based on lack of information confirming the integrity of the hole. If this integrity can be demonstrated, further evaluation of the possibilities of high vertical permeability existing in this general vicinity in both the Wanapum and upper Grande Ronde Basalts need be addressed.

All storativity values in these analyses are in the range of 10^{-6} to 10^{-5}. TTI places a high level of certainty on this range of values; therefore, TTI would conclude that measurement of storativity is not a high priority for the site characterization at BWIP.

7.0 REFERENCES

Lu, A.H., 1984. Opportunistic Use of Drilling-Stress Data to Estimate Aquifer Properties. Rockwell Hanford Operations.

Spane, F.A., 1986. Preliminary Evaluation of Piezometer Responses at DC-19, DC-20, and DC-22, During Construction of DC-23W. Prepared by Rockwell International for the United States Department of Energy.

Stone, R., P.M. Rogers, R.L. Jackson, A.H. Lu, and D.J. Moak, 1984. Draft Strategy and Preliminary Plans for Large-Scale Hydraulic Stress Testing of Selected Hydrogeologic Units at the RRL-2 Location. Prepared by Rockwell International for the United States Department of Energy.

Strait, S.R., F.A. Spane, R.L. Jackson, and W.W. Pidcoe, 1982. Hydrologic Testing Methodology and Results from Deep Basalt Boreholes. Prepared by Rockwell International for the United States Department of Energy. RHO-BW-SA-189.

Terra Therma, Inc., 1986a. Analysis of Drilling Response at the Hanford Site. Prepared by Terra Therma for Nuclear Waste Consultants.

Terra Therma, Inc., 1986b. Data Management Report Update. Prepared by Terra Therma for Nuclear Waste Consultants.

Theis, C.V., 1935. The Relation Between Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well Using Groundwater Storage. Trans. Amer. Geophys. Union, vol 16, pp. 519-524.

United States Department of Energy, 1984. Basalt Waste Isolation Project Presentation to Nuclear Regulatory Commission on Basalt Waste Isolation Project Hydrologic Characterization Plans/Status.

United States Department of Energy, 1985. Basalt Waste Isolation Project Large Scale Hydraulic Stress Testing Pre-Test Consultation Meeting.

TABLE 1. TTI RESULTS

DRILLED BOREHOLE	MONITORED BOREHOLE	RADIAL DISTANCE	MONITORED FORMATION	T (ft^2/d)	S	COMMENTS
RRL-17	DC-20C	4000	Rocky Coulee Cohassett	80	1.1×10^{-5}	RC/CH identical curves
RRL-2B	RRL-2A	500	Rocky Coulee	7	6×10^{-5}	
RRL-2B	RRL-2C	250	Rocky Coulee	1.3	8×10^{-6}	not a good fit
DC-23W	DC-20C	11400	Priest Rapids Sentinel Gap	3000	2.5×10^{-5}	PR/SG identical curves
DC-19C	DB-14	10000	Priest Rapids	210	1.1×10^{-5}	Q=40 gpm
DC-20C	DB-14	21700	Priest Rapids	210	8×10^{-6}	Q=60 gpm

TABLE 2. DOE DATA

REFERENCE	MONITORED FORMATION	T(DOE) (ft^2/day)	S(DOE)
DOE/NRC Mtg. Notes (1985)	Grande Ronde FT(s)[2]	2.35	
Strait (1982)	Grande Ronde FT(s)		10^{-3}-10^{-6}
DOE/NRC Mtg. Notes (1985)	Cohassett FT	.21	
DOE/NRC Mtg. Notes (1984)	Cohassett FT (w/McGee)[3]	34.7	
DOE/NRC Mtg. Notes (1984)	Cohassett FT (w/o McGee)[3]	1.6	
DOE/NRC Mtg. Notes (1985)	Rocky Coulee FT	2.6	
DOE/NRC Mtg. Notes (1984)	Rocky Coulee FT (w/McGee)[3]	60.15	
DOE/NRC Mtg. Notes (1984)	Rocky Coulee FT (w/o McGee)[3]	3.5	
Lu (1984)	Priest Rapids	210	8×10^{-6}
Strait (1982)	Wanapum FT(s)		10^{-4}-10^{-5}

[2] FT = Flow Top

[3] McGee Well is west of alleged Yakima Barrier.

FIGURE 1. FLUID LOSS DATA AND HYDROGRAPH AT DC-20C
DURING RRL-17 DRILLING

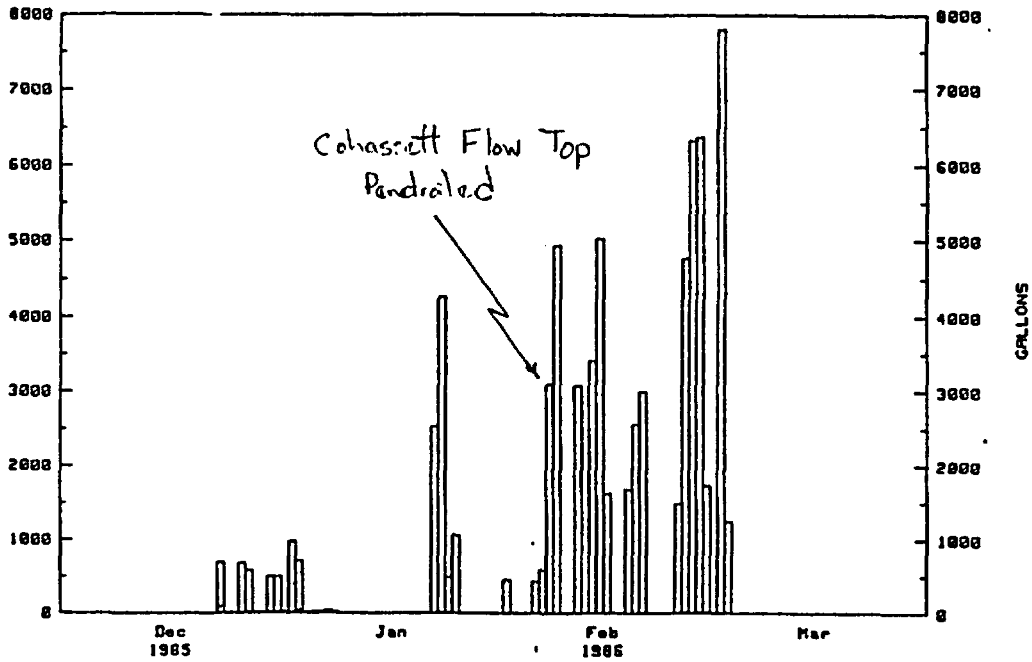


FIGURE 1A

BOREHOLE: DC-20C HYDROGEOLOGIC UNIT: GRANDE RONDE & WANAPUM

LOCATION: N 451,884 E 2,215,288 DATUM ELEVATION: MEAN SEA LEVEL

ADJUSTED TO A CONSTANT ATMOSPHERIC PRESSURE OF 14.347 PSI

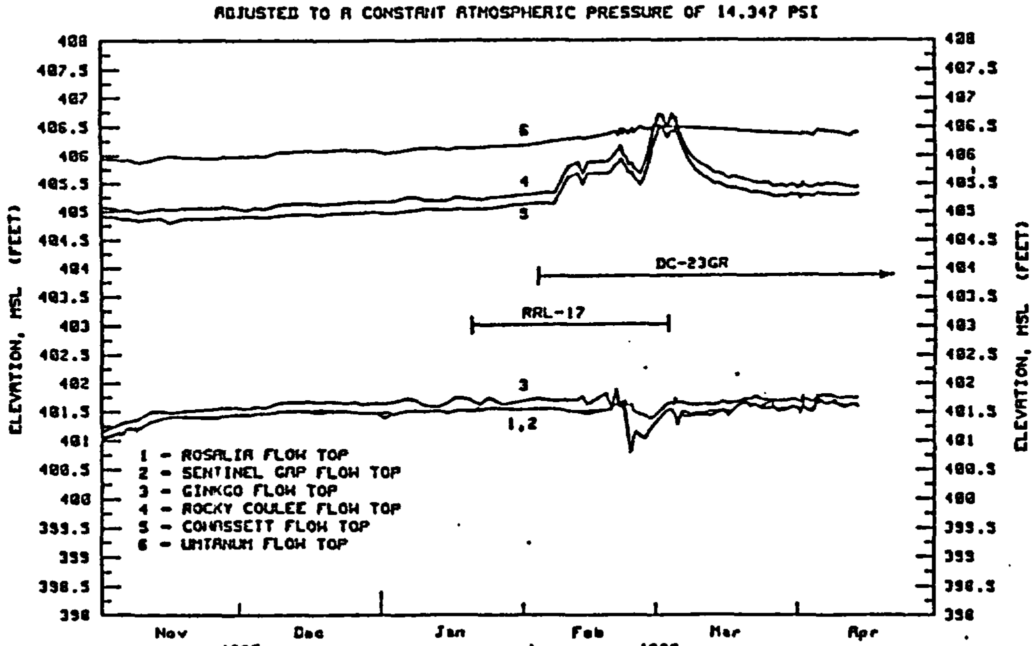


FIGURE 1B

Terra Therma, Inc

FIGURE 2. "BEST FIT" CURVE FOR RRL-17 DRILLING RESPONSE SEEN AT DC-20C

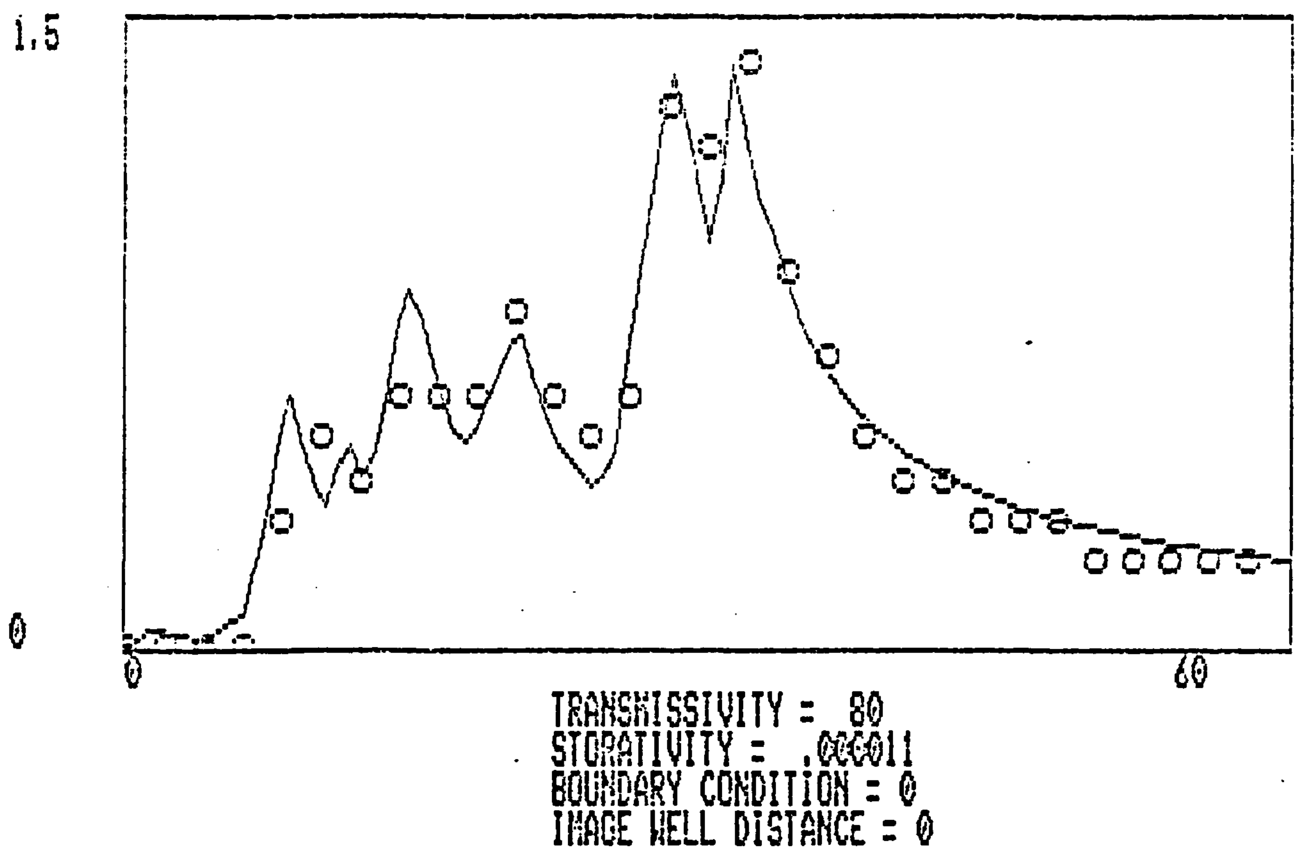


TABLE 3

DOE VALUES IN TTI DATABASE

TEST HOLE	TEST INTERVAL TOP	TEST INTERVAL BOTTOM	GROUP	UNIT	BASALT STRUCTURE	TRANSMISSIVITY (sq.m/s)	TRANSMISSIVITY (sq.ft/d)
DB-02	313.3	362.7	WN	PRIEST	COMP	3E-04	3E+02
RRL-02	479.8	522.4	WN	PRIEST	FT	3E-04	3E+02
DB-01	329.2	347.2	WN	PRIEST	IF	3E-04	3E+02
DC-15	350.2	362.4	WN	PRIEST	IF	3E-07	3E-01
DC-14	364.5	370.9	WN	PRIEST	IF	3E-03	3E+03
DC-16A	515.1	526.7	WN	PRIEST	IF	1E-06	1E+00
MCGEE	247.5	250.5	WN	PRIEST	IF	3E-02	3E+04
DC-12	370.9	382.2	WN	PRIEST	IF	1E-04	1E+02
MCGEE	281.9	285.0	WN	ROZA	FT	3E-02	3E+04
RRL-02	528.8	540.4	WN	ROZA	FT	3E-03	3E+03
DB-02	355.4	362.7	WN	ROZA	FT	3E-05	3E+01
DC-16A	536.4	557.2	WN	ROZA	IF	3E-02	3E+04
DC-14	391.7	410.3	WN	ROZA	IF	3E-03	3E+03
DC-15	413.6	423.7	WN	ROZA	IF	3E-04	3E+02
DC-12	404.8	415.7	WN	ROZA	IF	1E-04	1E+02
DC-15	371.6	394.1	WN	ROZA	IF	3E-03	3E+03
DB-15	396.2	409.3	WN	FRENCH	IF	3E-04	3E+02
DB-15	442.0	466.3	WN	FRENCH	IF	3E-05	3E+01
DC-14	554.7	571.5	WN	FRENCH	IF	3E-04	3E+02
DC-12	514.4	521.2	WN	FRENCH	IF	4E-05	4E+01
DB-15	524.3	548.6	WN	FRENCH	IF	3E-09	3E-03
DC-15	451.4	459.0	WN	FRENCH	IF	3E-03	3E+03
DB-15	424.6	439.8	WN	FRENCH	IF	3E-04	3E+02
DC-14	575.5	604.4	WN	FRENCH	IF	3E-03	3E+03
DC-12	582.0	604.7	WN	FRENCH	IF	9E-07	8E-01
DC-15	458.7	473.4	WN	FRENCH	IF	3E-04	3E+02
DC-12	625.0	633.7	WN	FRENCH	IF	6E-05	5E+01
MCGEE	538.0	562.1	WN	FRENCH	IF	3E-06	3E+00
RRL-06	640.7	652.6	WN	FRENCH	TB	3E-11	3E-05
DC-16A	641.6	657.1	WN	FRENCH	IF	1E-05	1E+01
DC-15	425.2	449.0	WN	FRENCH	IF	3E-06	3E+00
RRL-02	684.0	805.9	WN	FRENCH	COMP	3E-03	3E+03
DC-14	480.1	497.4	WN	FRENCH	IF	3E-04	3E+02
RRL-02	581.3	677.3	WN	FRENCH	COMP	3E-03	3E+03
DC-12	459.6	467.6	WN	FRENCH	IF	1E-05	1E+01
DB-15	412.4	418.5	WN	FRENCH	IF	3E-04	3E+02
DC-16A	690.7	722.7	WN	FRENCH	IF	3E-05	3E+01
DC-15	469.4	485.5	WN	FRENCH	IF	1E-03	1E+03
DC-15	559.0	575.2	WN	FRENCH	IF	3E-03	3E+03

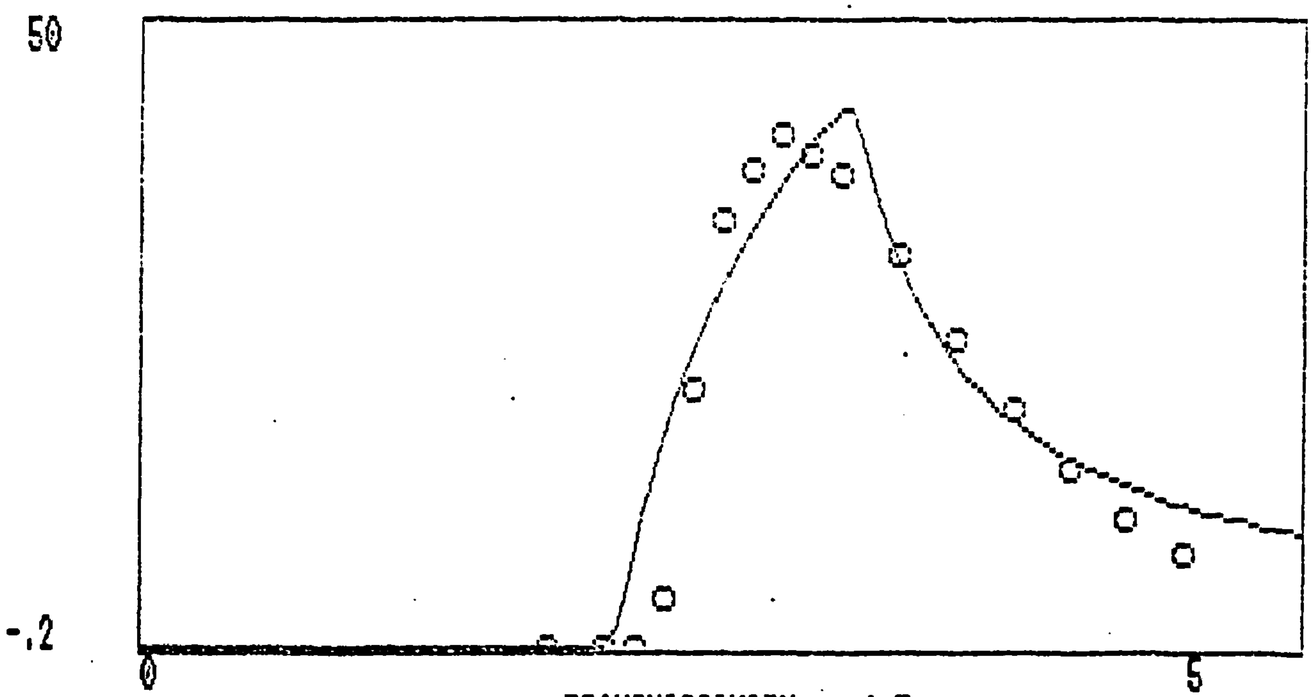
TABLE 3 (cont)

TEST HOLE	TEST INTERVAL TOP	BOTTOM	GROUP	UNIT	BASALT STRUCTURE	TRANSMISSIVITY (sq.m/s)	(sq.ft/d)
DC-15	528.8	558.7	WN	FRENCH	IF	3E-05	3E+01
RRL-02	829.8	887.9	GR	?	COMP	3E-05	3E+01
DC-12	907.7	961.0	GR	?	COMP	2E-07	1E-01
DC-12	1018.3	1240.5	GR	?	COMP	6E-04	6E+02
RRL-02	1026.6	1055.2	GR	?	COMP	3E-10	3E-04
DC-12	1225.6	1240.5	GR	?	COMP	6E-04	6E+02
DC-12	1244.8	1357.9	GR	?	COMP	1E-04	1E+02
DC-07	1255.8	1297.5	GR	?	COMP	3E-09	3E-03
DC-12	1324.1	1357.9	GR	?	COMP	1E-04	1E+02
DC-07	1354.5	1406.7	GR	?	COMP	3E-08	3E-02
MCGEE	592.5	607.2	GR	?	FT	3E-04	3E+02
DC-15	639.5	670.3	GR	?	FT	3E-06	3E+00
DC-15	678.8	714.1	GR	?	FT	3E-03	3E+03
DC-12	691.0	701.3	GR	?	FT	3E-06	3E+00
DC-14	717.8	733.0	GR	?	FT	3E-07	3E-01
DC-15	723.0	758.0	GR	?	FT	3E-06	3E+00
DC-14	734.6	766.0	GR	?	FT	3E-06	3E+00
DC-15	759.6	776.6	GR	?	FT	3E-04	3E+02
DC-14	841.2	876.0	GR	?	FT	3E-09	3E-03
DC-15	857.4	874.2	GR	?	FT	3E-06	3E+00
DC-12	858.9	866.5	GR	?	FT	3E-03	3E+03
DC-12	858.9	866.5	GR	?	FT	2E-03	2E+03
DC-16A	864.1	897.9	GR	?	FT	3E-06	3E+00
DC-12	865.0	872.6	GR	?	FT	3E-04	3E+02
DC-14	877.8	906.8	GR	?	FT	3E-07	3E-01
DC-14	969.3	983.0	GR	?	FT	3E-06	3E+00
DC-15	989.1	1004.6	GR	?	FT	1E-05	1E+01
DC-15	1140.3	1172.0	GR	?	FT	3E-07	3E-01
DC-16A	1193.0	1231.1	GR	?	FT	3E-07	3E-01
DC-14	646.2	681.2	GR	?	IF	3E-04	3E+02
DC-12	676.0	688.8	GR	?	IF	5E-07	5E-01
DC-14	809.9	876.0	GR	?	IF	1E-08	1E-02
DC-12	865.0	872.6	GR	?	IF	2E-04	2E+02
DC-14	993.6	1016.5	GR	?	IF	3E-05	3E+01
DC-15	1261.3	1293.3	GR	?	IF	1E-05	1E+01
DC-07	1298.8	1351.5	GR	?	IF	3E-09	3E-03
DC-07	1427.7	1471.3	GR	?	IF	3E-09	3E-03
DC-16A	1031.0	1065.3	GR	?	?	3E-11	3E-05
MCGEE	562.7	591.9	GR	VANTAGE	IB	3E-06	3E+00

TABLE 3 (cont)

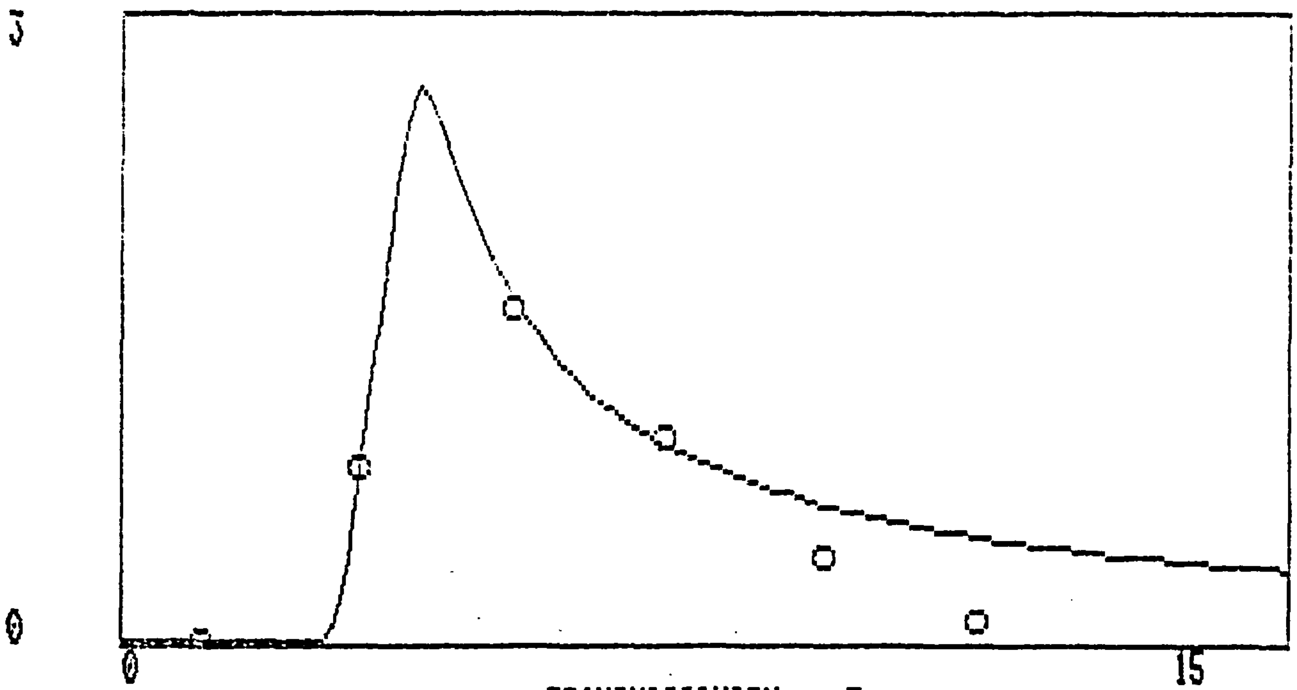
TEST HOLE	TEST INTERVAL TOP	BOTTOM	GROUP	UNIT	BASALT STRUCTURE	TRANSMISSIVITY (sq.m/s)	(sq.ft/d)
DB-15	588.9	600.8	GR	VANTAGE	IB	1E-11	1E-05
RRL-02	812.3	826.9	GR	VANTAGE	IB	3E-06	3E+00
DC-06	688.8	1320.7	GR	COMP	COMP	1E-04	1E+02
DC-06	730.3	822.0	GR	COMP	COMP	3E-05	3E+01
DC-06	822.0	881.8	GR	COMP	IF	1E-05	1E+01
DC-06	1075.9	1165.6	GR	COMP	IF	3E-05	3E+01
DC-06	1270.7	1320.7	GR	COMP	FT	3E-06	3E+00
DC-12	734.0	745.5	GR	ROCKY	FT	3E-05	3E+01
MCGEE	606.9	637.6	GR	ROCKY	FT	3E-04	3E+02
MCGEE	648.6	670.3	GR	COHASSETT	FT	3E-06	3E+00
MCGEE	666.9	712.3	GR	COHASSETT	FT	2E-04	1E+02
DC-04	899.2	915.6	GR	COHASSETT	FT	3E-07	3E-01
DC-05	899.2	915.3	GR	COHASSETT	FT	3E-07	3E-01
DC-16A	905.3	940.6	GR	COHASSETT	FT	1E-06	1E+00
RRL-02	908.6	920.5	GR	COHASSETT	FT	5E-08	4E-02
RRL-06	929.0	951.3	GR	COHASSETT	FT	3E-11	3E-05
RRL-14	937.9	959.2	GR	COHASSETT	FT	3E-06	3E+00
RRL-06	940.0	951.3	GR	COHASSETT	FT	3E-11	3E-05
DC-12	781.8	811.2	GR	COHASSETT	COMP	3E-07	3E-01
MCGEE	729.4	769.3	GR	COHASSETT	FB	1E-06	1E+00
RRL-02	989.7	1019.3	GR	COHASSETT	FB	8E-04	8E+02
DC-16A	991.8	1024.1	GR	COHASSETT	FB	3E-09	3E-03
RRL-14	1004.0	1037.2	GR	COHASSETT	FB	3E-06	3E+00
RRL-06	1015.0	1041.2	GR	COHASSETT	FB	3E-08	3E-02

FIGURE 3. "BEST FIT" CURVE FOR RRL-2B DRILLING RESPONSE SEEN AT RRL-2C



TRANSMISSIVITY = 1.3
STORATIVITY = .000008
BOUNDARY CONDITION = 0
IMAGE WELL DISTANCE = 0

FIGURE 4. "BEST FIT" CURVE FOR RRL-2B DRILLING RESPONSE SEEN AT RRL-2A



TRANSMISSIVITY = 7
STORATIVITY = .00006
BOUNDARY CONDITION = 0
IMAGE WELL DISTANCE = 0

FIGURE 5. "BEST FIT" CURVE FOR DC-23W DRILLING RESPONSE
SEEN AT DC-20C

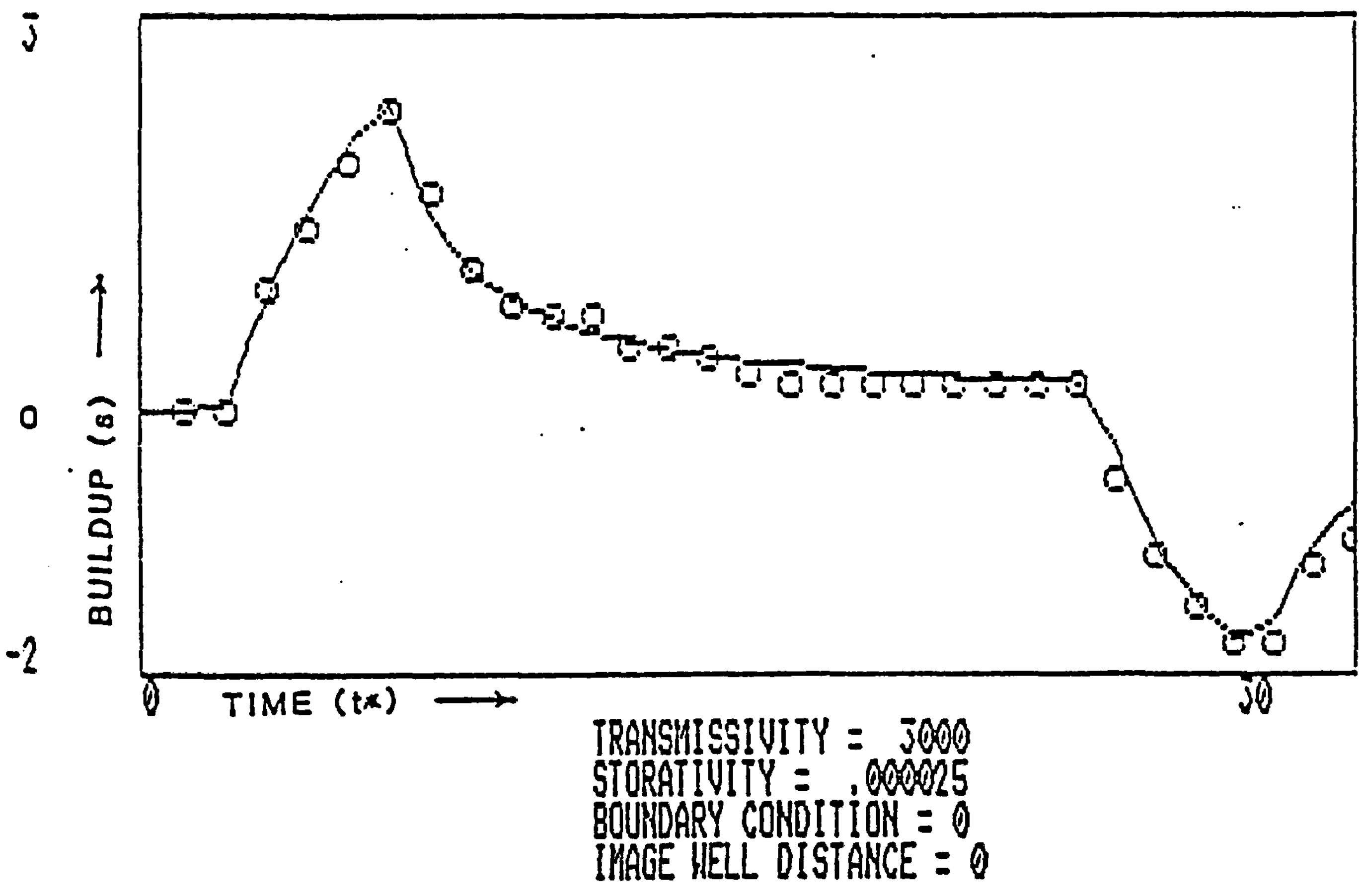
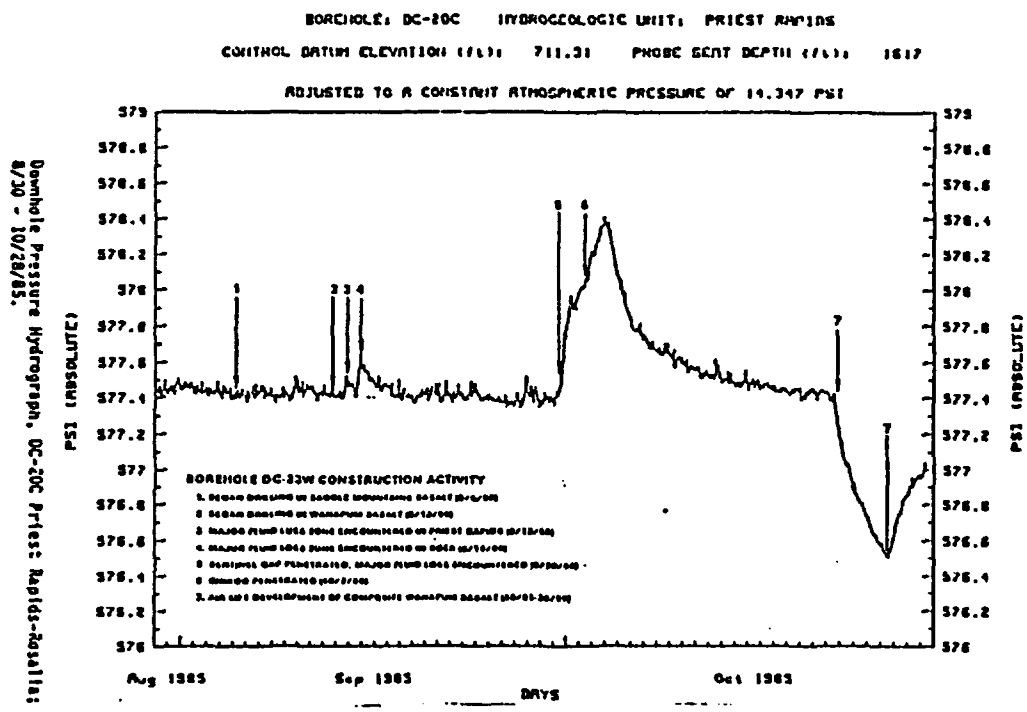


FIGURE 6. HYDROGRAPH AT DC-20C DURING DC-23W DRILLING



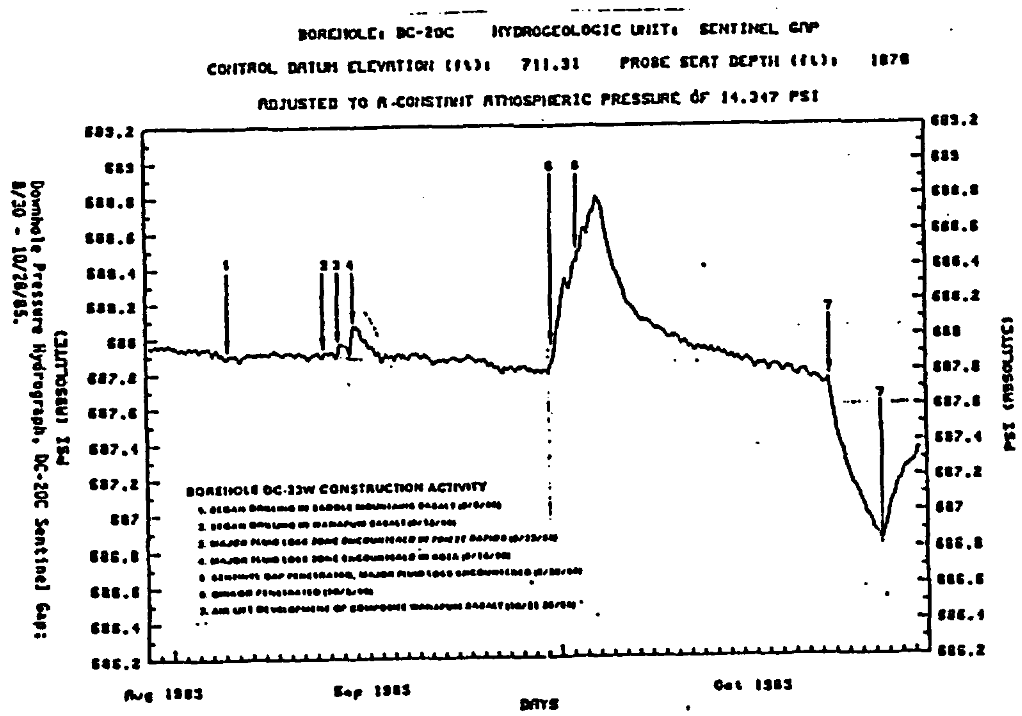


FIGURE 7. "BEST FIT" CURVE FOR DC-19C DRILLING RESPONSE SEEN AT DB-14 (Q = 40 gpm)

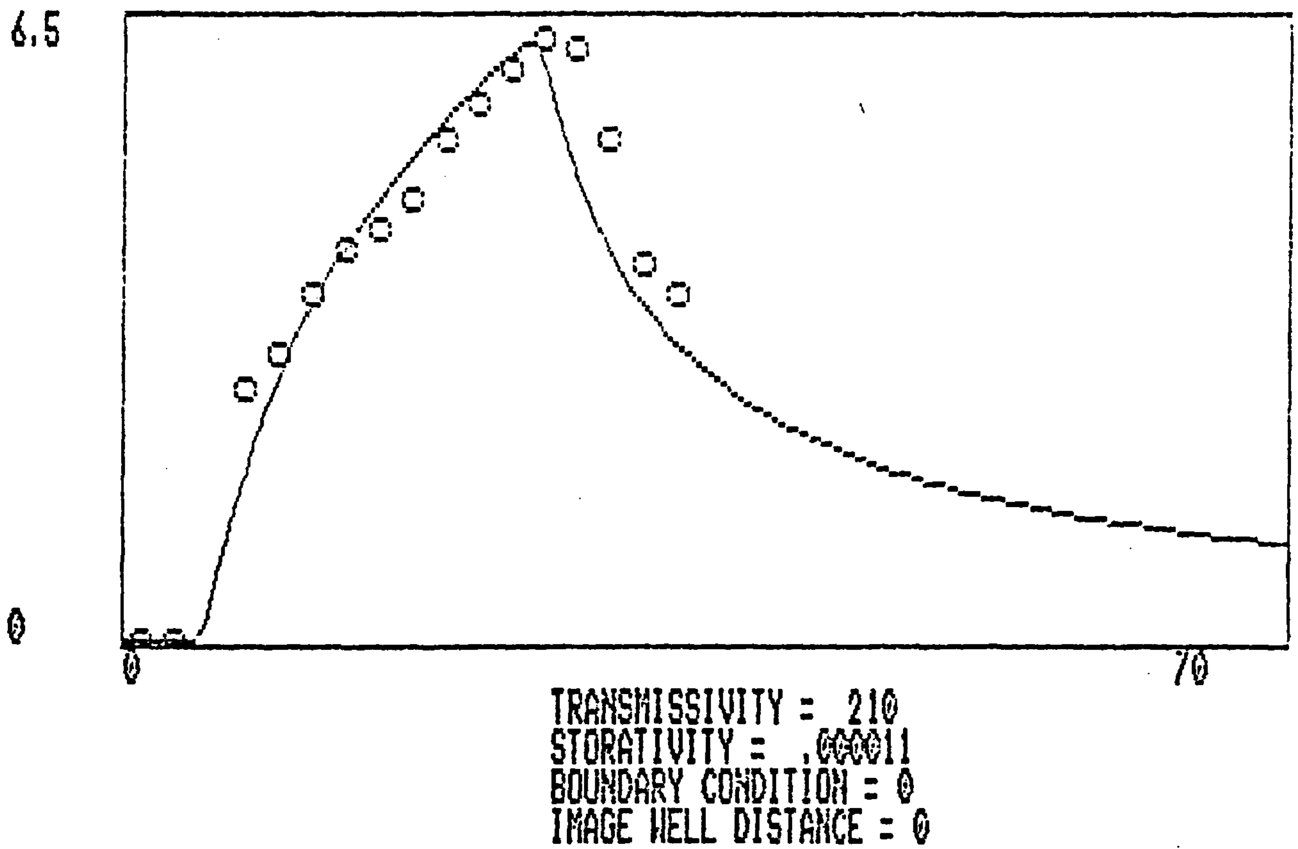
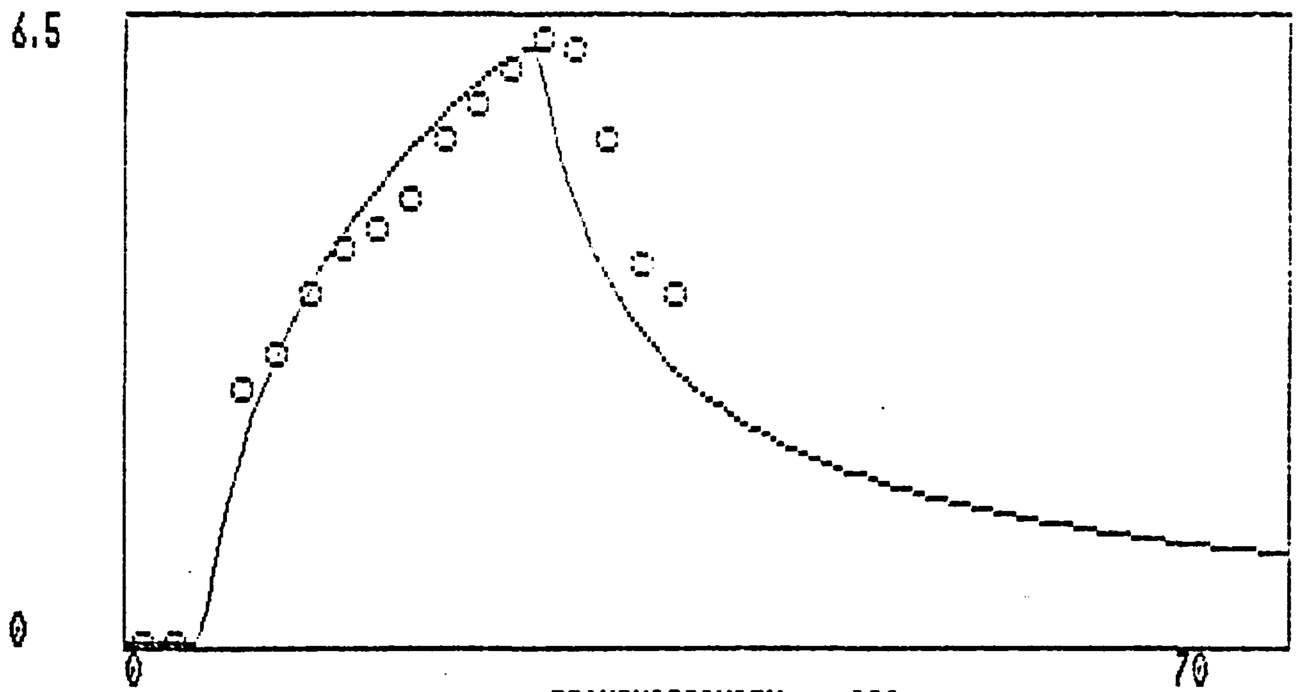


FIGURE 8. "BEST FIT" CURVE FOR DC-19C DRILLING RESPONSE
SEEN AT DB-14 (Q = 50 gpm)



TRANSMISSIVITY = 290
STORATIVITY = .000012
BOUNDARY CONDITION = 0
IMAGE WELL DISTANCE = 0

FIGURE 9. "BEST FIT" CURVE FOR DC-19C DRILLING RESPONSE SEEN AT DB-14 (Q = 30 gpm)

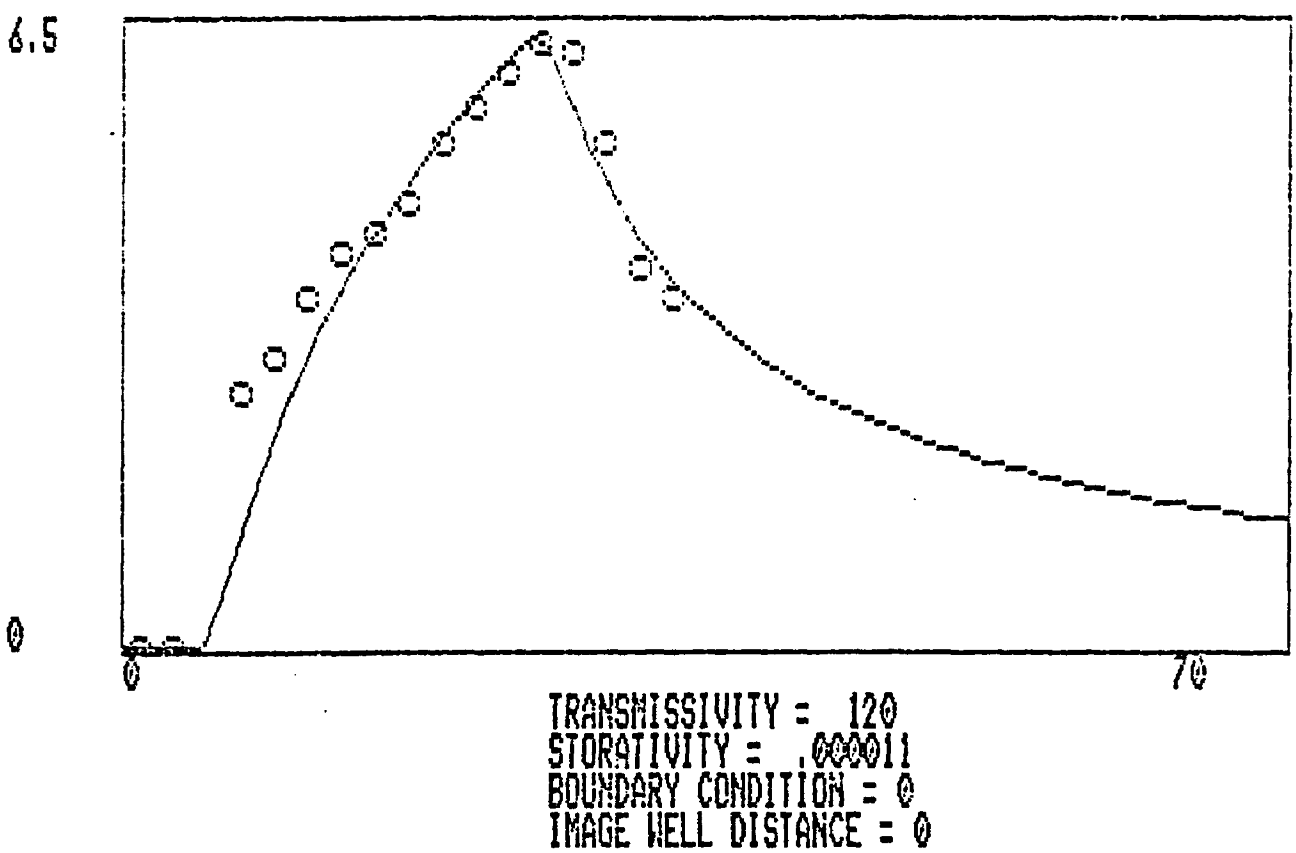


FIGURE 10. "BEST FIT" CURVE FOR DC-20C DRILLING RESPONSE
SEEN AT DB-14 (Q = 60 gpm)

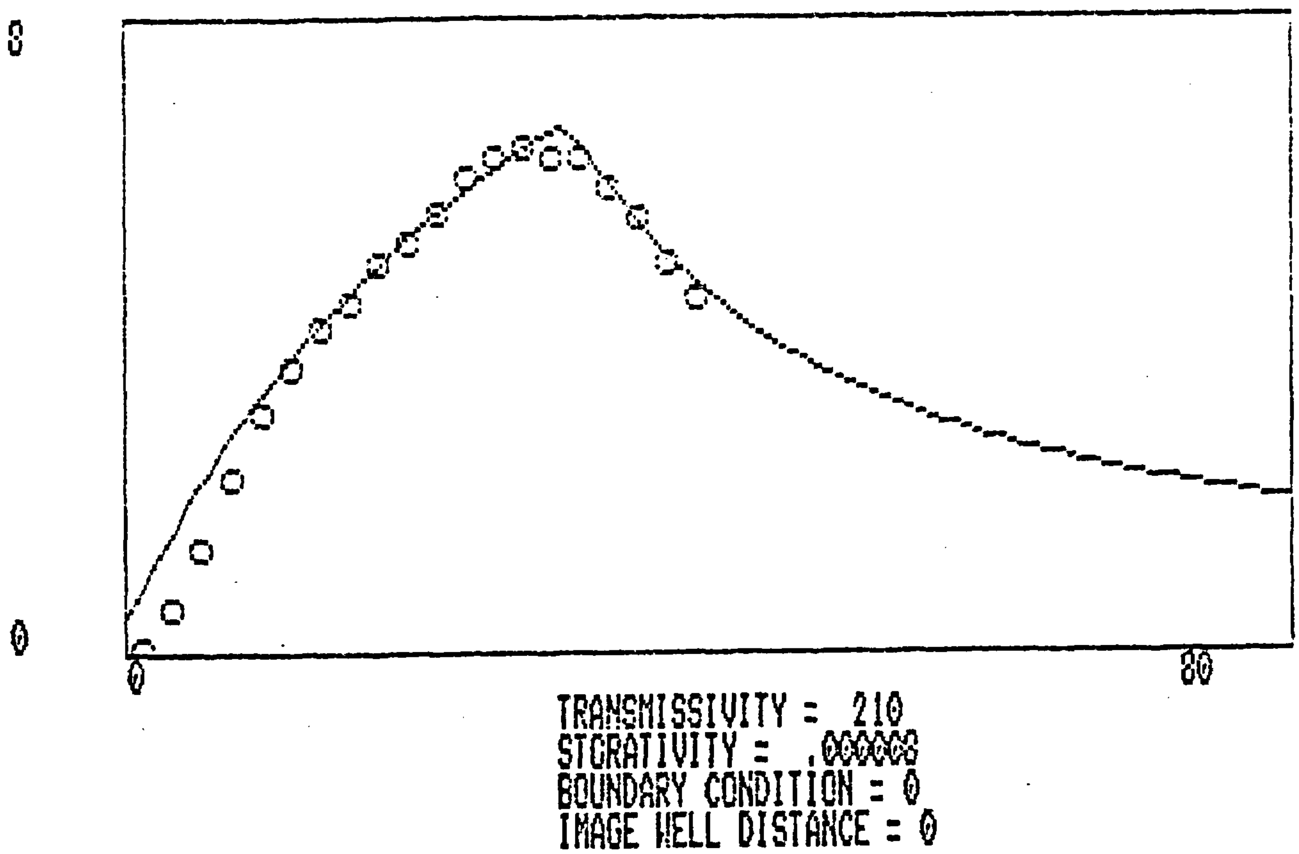


FIGURE 11. "BEST FIT" CURVE FOR DC-20C DRILLING RESPONSE SEEN AT DB-14 (Q = 75 gpm)

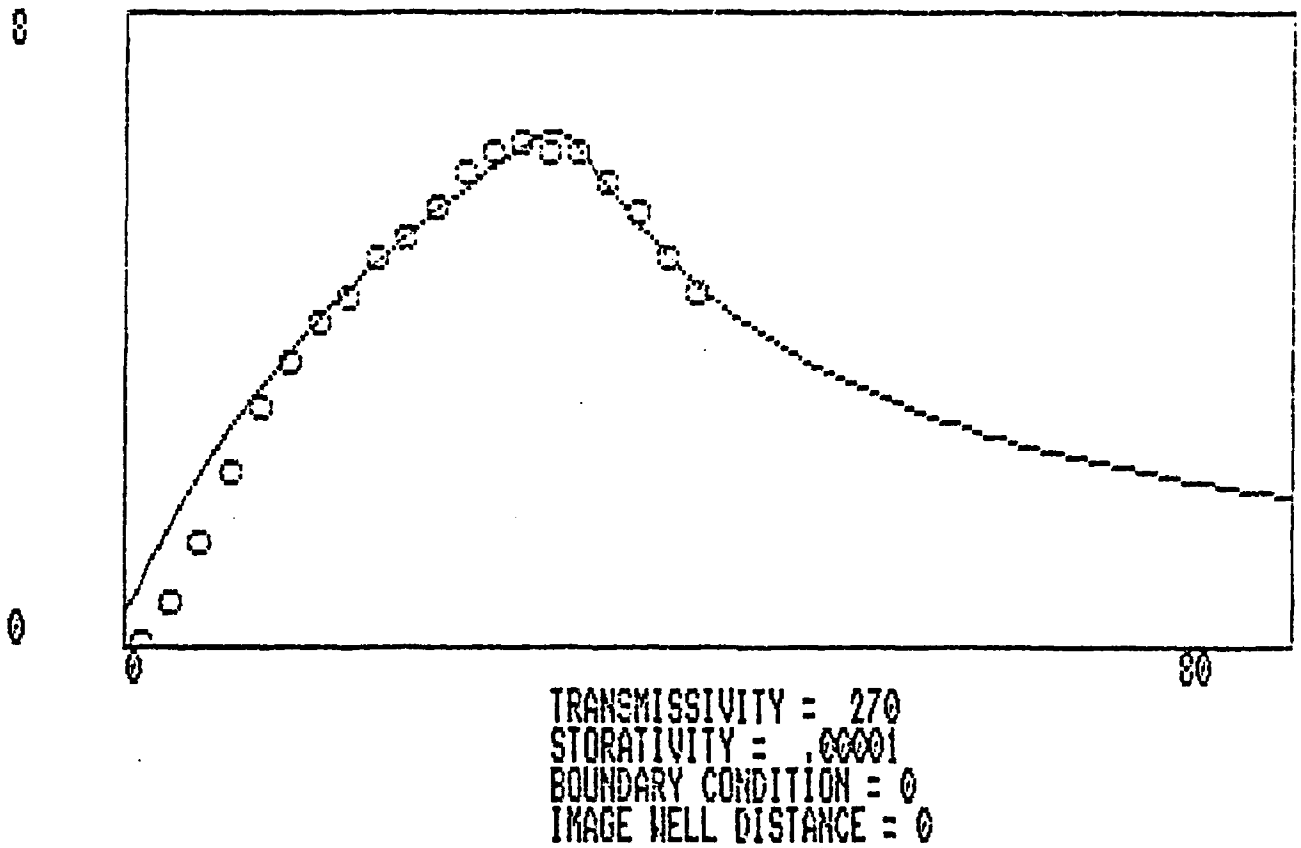
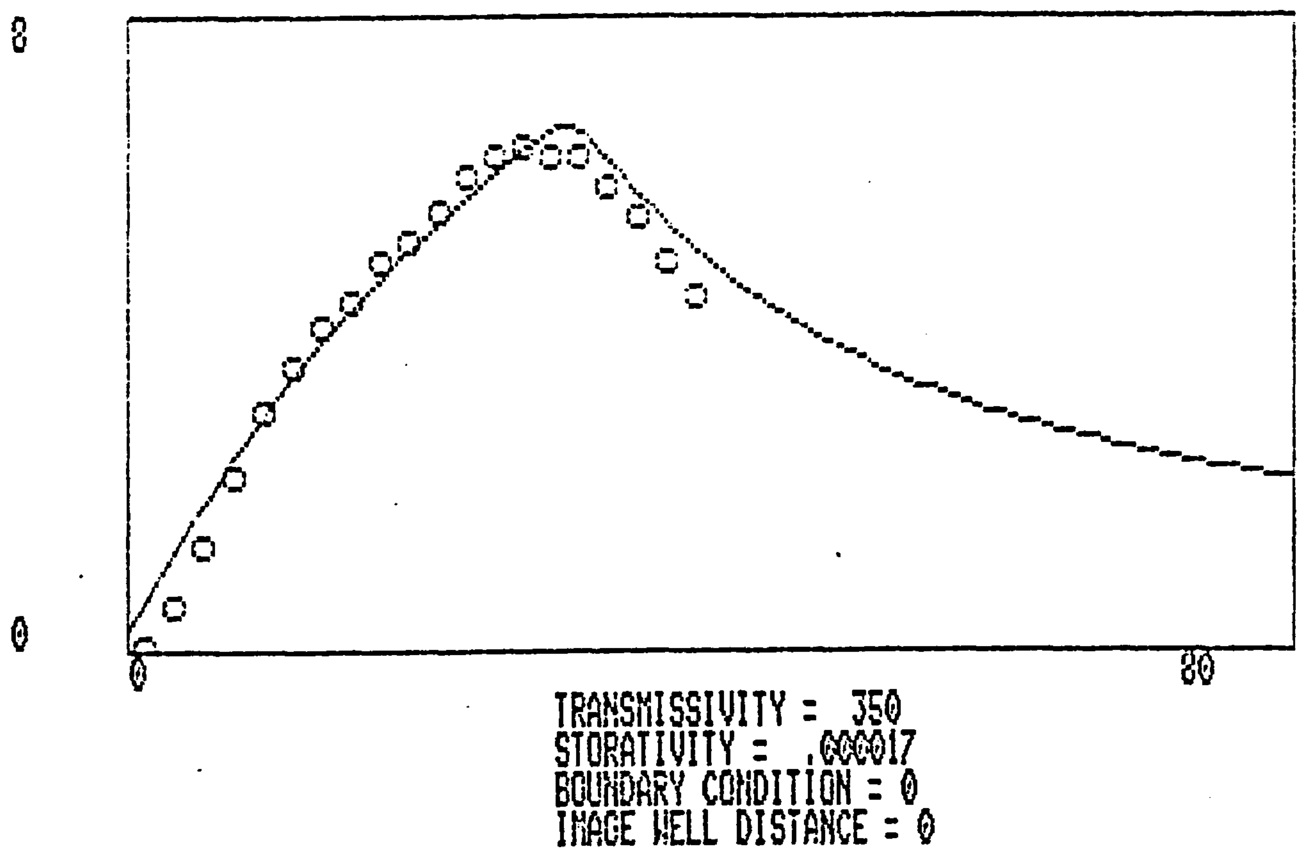


FIGURE 12. "BEST FIT" CURVE FOR DC-20C DRILLING RESPONSE
SEEN AT DB-14 (Q = 115 gpm)



APPENDIX A

FLOW RATE - TIME INPUT DATA
(Figure 1A - RRL-17)

Date	Time (days)	Fluid Loss (gal)	Time Period (days)	Q (cu.ft/d)
02/01/85	0	456	1	61
02/02/85	1	0	3	0
02/05/85	4	432	1	58
02/06/85	5	588	1	79
02/07/85	6	3092	1	413
02/08/85	7	4926	1	659
02/09/85	8	0	2	0
02/11/85	10	3007	1	402
02/12/85	11	0	1	0
02/13/85	12	3409	1	456
02/14/85	13	5021	1	671
02/15/85	14	1619	1	216
02/16/85	15	0	2	0
02/18/85	17	1679	1	224
02/19/85	18	2561	1	342
02/20/85	19	3000	1	401
02/21/85	20	0	4	0
02/25/85	24	1489	1	199
02/26/85	25	4770	1	638
02/27/85	26	6324	1	845
02/28/85	27	6372	1	852
03/01/85	28	1722	1	230
03/02/85	29	0	1	0
03/03/85	30	7806	1	1044
03/04/85	31	0	1	0
03/05/85	32	1248	1	167
03/06/85	33	0	1	0

HYDRAULIC HEAD FIELD DATA
(Figure 1B - DC-20C)

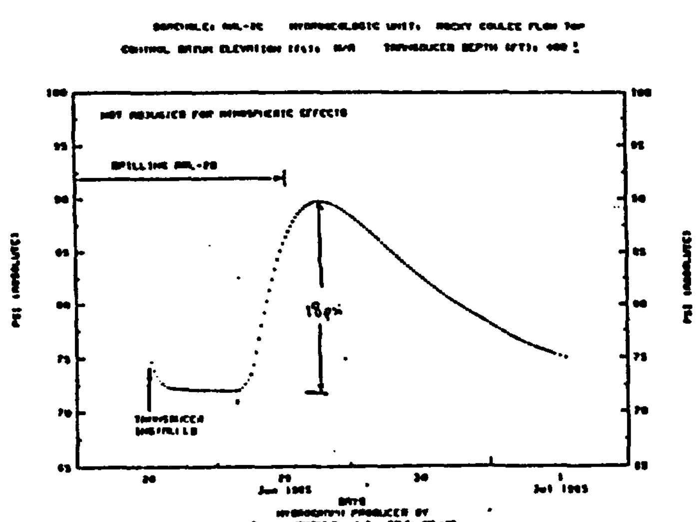
Date	Time (days)	Hydraulic Head (ft)	Buildup (ft)
02/01/85	0	405.3	0
02/03/85	2	405.3	0
02/05/85	4	405.3	0
02/07/85	6	405.3	0
02/09/85	8	405.6	0.3
02/11/85	10	405.8	0.5
02/13/85	12	405.7	0.4
02/15/85	14	405.9	0.6
02/17/85	16	405.9	0.6
02/19/85	18	405.9	0.6
02/21/85	20	406.1	0.8
02/23/85	22	405.9	0.6
02/25/85	24	405.8	0.5
02/27/85	26	405.9	0.6
03/01/85	28	406.6	1.3
03/03/85	30	406.5	1.2
03/05/85	32	406.7	1.4
03/07/85	34	406.2	0.9
03/09/85	36	406.0	0.7
03/11/85	38	405.8	0.5
03/13/85	40	405.7	0.4
03/15/85	42	405.7	0.4
03/17/85	44	405.6	0.3
03/19/85	46	405.6	0.3
03/21/85	48	405.6	0.3
03/23/85	50	405.5	0.2
03/25/85	52	405.5	0.2
03/27/85	54	405.5	0.2
03/29/85	56	405.5	0.2
03/31/85	58	405.5	0.2

HYDRAULIC HEAD FIELD DATA
(Figure 3 - RRL-2C)

Date	Time (hrs)	Time (days)	Hydraulic Head (psia)	Hydraulic Head (ft)	Buildup (ft)
06/28/85	18:00	1.750	72.0	166.2	0.0
06/29/85	00:00	2.000	72.0	166.2	0.0
06/29/85	03:00	2.125	72.0	166.1	-0.1
06/29/85	06:00	2.250	73.6	169.9	3.7
06/29/85	09:00	2.375	81.0	186.9	20.7
06/29/85	12:00	2.500	87.0	200.7	34.5
06/29/85	15:00	2.625	88.7	204.6	38.4
06/29/85	18:00	2.750	89.9	207.4	41.2
06/29/85	21:00	2.875	89.3	205.9	39.7
06/30/85	00:00	3.000	88.5	204.2	38.0
06/30/85	06:00	3.250	85.7	197.8	31.6
06/30/85	12:00	3.500	82.7	190.9	24.7
06/30/85	18:00	3.750	80.2	185.1	18.9
07/01/85	00:00	4.000	78.2	180.5	14.3
07/01/85	06:00	4.250	76.5	176.6	10.4
07/01/85	12:00	4.500	75.2	173.6	7.4

FLOW RATE - TIME INPUT DATA
(Figure 3 - RRL-2B)

Date	Time (days)	Fluid Loss (bbls)	Time Period (days)	Q (cu ft/d)
06/29/85	2	68	1	380
06/30/85	3	0		0

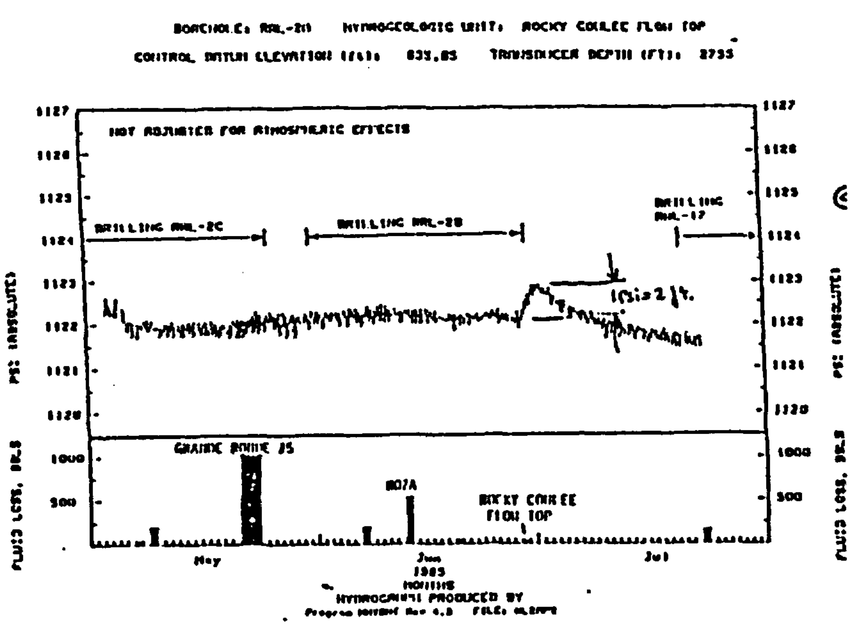


HYDRAULIC HEAD FIELD DATA
(Figure 4 - RRL-2A)

Date	Time (days)	Hydraulic Head (psia)	Hydraulic Head (ft)	Buildup (ft)
06/27/85	1	1122.1	2588.8	0
06/29/85	3	1122.5	2589.6	0.83
07/01/85	5	1122.9	2590.4	1.61
07/03/85	7	1122.6	2589.8	0.99
07/05/85	9	1122.3	2589.2	0.41
07/07/85	11	1122.2	2588.9	0.09
07/09/85	13	1122.0	2588.5	-0.33
07/11/85	15	1121.9	2588.3	-0.53
07/13/85	17	1121.8	2588.0	-0.74
07/15/85	19	1121.8	2588.0	-0.81
07/17/85	21	1121.7	2587.8	-0.99
07/19/85	23	1121.7	2587.8	-0.99
07/21/85	25	1121.6	2587.6	-1.16
07/22/85	26	1121.6	2587.6	-1.16

FLOW RATE - TIME INPUT DATA
(Figure 4 - RRL-2B)

Date	Time (days)	Fluid Loss (bbls)	Time Period (days)	Q (cu ft/d)
06/29/85	2.5	68	1	380
06/30/85	3.5	0		0



Hydrograph borehole RRL-2A, Rocky Coulee Flow Top, May through July, 1985

HYDRAULIC HEAD FIELD DATA
(Figures 5 and 6 - DC-20C)

Date	Time (days)	PSI (abs)	Hydraulic Head (ft)	Buildup (ft)
September 29, 1985	1	577.38	1332.6	0
September 30, 1985	2	577.38	1332.6	0
October 1, 1985	3	577.77	1333.5	0.9
October 2, 1985	4	577.99	1334.0	1.4
October 3, 1985	5	578.21	1334.5	1.9
October 4, 1985	6	578.38	1334.9	2.3
October 5, 1985	7	578.12	1334.3	1.7
October 6, 1985	8	577.86	1333.7	1.1
October 7, 1985	9	577.73	1333.4	0.8
October 8, 1985	10	577.69	1333.3	0.7
October 9, 1985	11	577.69	1333.3	0.7
October 10, 1985	12	577.60	1333.1	0.5
October 11, 1985	13	577.60	1333.1	0.5
October 12, 1985	14	577.56	1333.0	0.4
October 13, 1985	15	577.51	1332.9	0.3
October 14, 1985	16	577.47	1332.8	0.2
October 15, 1985	17	577.47	1332.8	0.2
October 16, 1985	18	577.47	1332.8	0.2
October 17, 1985	19	577.47	1332.8	0.2
October 18, 1985	20	577.47	1332.8	0.2
October 19, 1985	21	577.47	1332.8	0.2
October 20, 1985	22	577.47	1332.8	0.2
October 21, 1985	23	577.47	1332.8	0.2
October 22, 1985	24	577.17	1332.1	-0.5
October 23, 1985	25	576.91	1331.5	-1.1
October 24, 1985	26	576.73	1331.1	-1.5
October 25, 1985	27	576.60	1330.8	-1.8
October 26, 1985	28	576.60	1330.8	-1.8
October 27, 1985	29	576.86	1331.4	-1.2
October 28, 1985	30	576.97	1331.6	-1

FLOW RATE - TIME INPUT DATA
(Figures 5 and 6 - DC-23W)

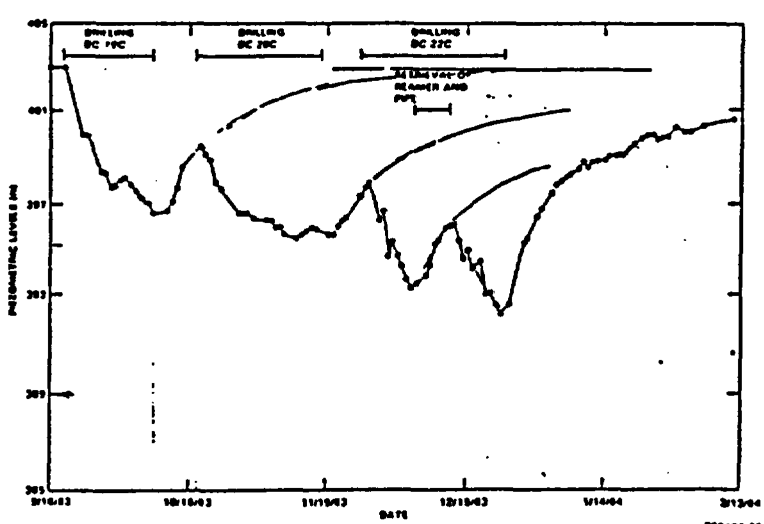
Date	Time (days)	Bbls	Time Period (days)	Q (cu.ft./d
September 29, 1985	1	367	1	2060
September 30, 1985	2	5483	1	30800
October 1, 1985	3	7183	1	40300
October 2, 1985	4	7793	1	43800
October 3, 1985	5	7300	1	41000
October 4, 1985	6	0	17	0
October 21, 1985	23	-3067	1	-17200
October 22, 1985	24	-6400	3	-35900
October 25, 1985	27	-3733	1	-21000
October 26, 1985	28	0	1	0

HYDRAULIC HEAD FIELD DATA
(Figure 7 - DB-14)

Date	Time (days)	Hydraulic Head (ft)	Buildup (ft)
09/16/83	1	402.9	0
09/18/83	3	402.9	0
09/22/83	7	400.2	2.65
09/24/83	9	399.9	3
09/26/83	11	399.2	3.65
09/28/83	13	398.8	4.1
09/30/83	15	398.6	4.3
10/02/83	17	398.2	4.65
10/04/83	19	397.6	5.25
10/06/83	21	397.3	5.6
10/08/83	23	396.9	6
10/10/83	25	396.6	6.3
10/12/83	27	396.7	6.2
10/14/83	29	397.6	5.25
10/16/83	31	398.9	3.93
10/18/83	33	399.2	3.65

FLOW RATE - TIME INPUT DATA
(Figure 7 - DC-19C)

Date	Time (days)	Fluid Loss (gpm)	Time Period (days)	Q (cu ft/d)
09/19/83	4	40	20	7700
10/09/83	24	0		0



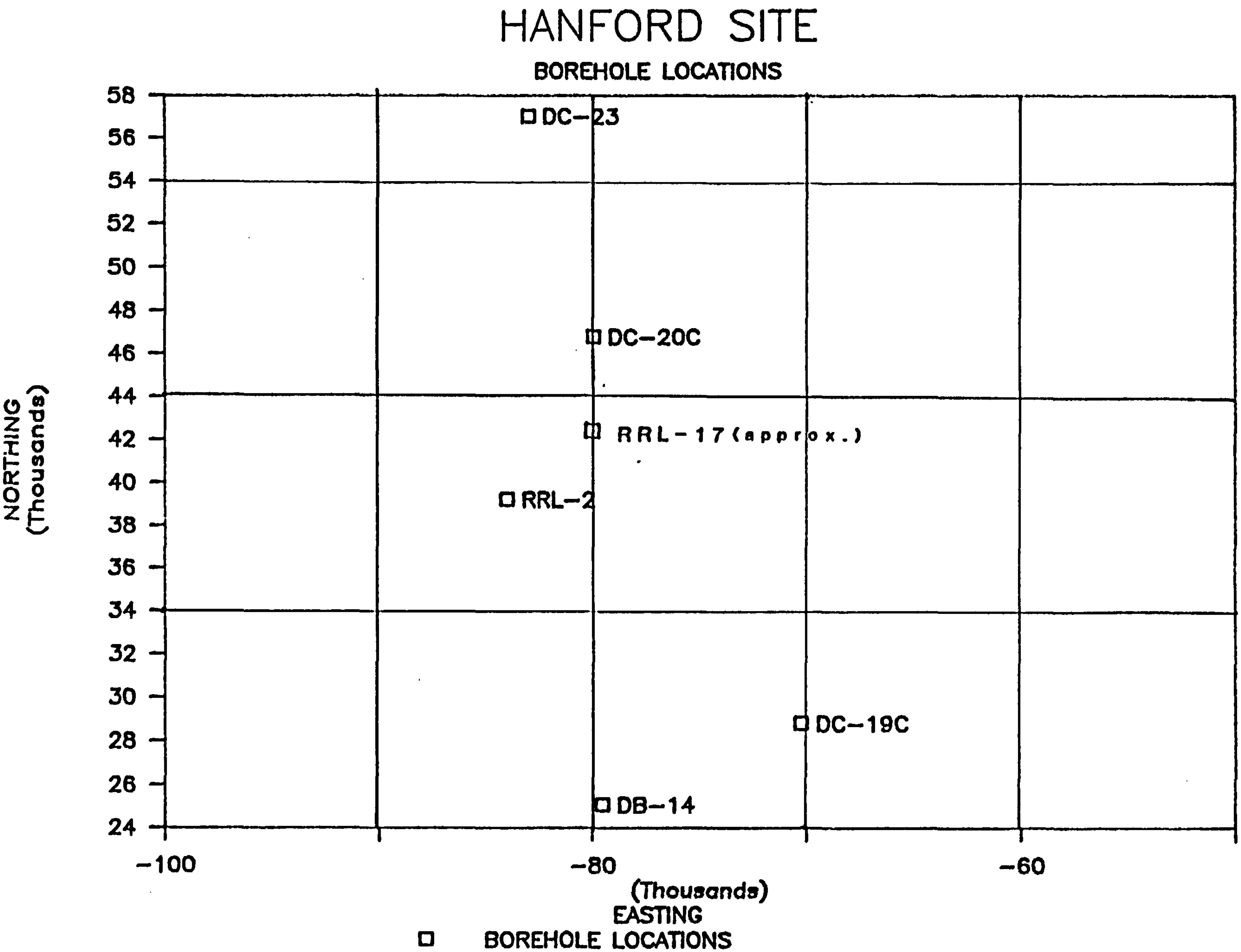
HYDRAULIC HEAD FIELD DATA
(Figure 10 - DB-14)

Date	Time (days)	Hydraulic Head (ft)	Hydraulic Head (pseudo)	Buildup (ft)
10/18/83	1	399.6	399.6	0.0
10/20/83	3	399.2	399.7	0.5
10/22/83	5	398.7	400.0	1.3
10/24/83	7	398.1	400.3	2.2
10/26/83	9	397.6	400.6	3.0
10/28/83	11	397.2	400.8	3.6
10/30/83	13	396.8	400.9	4.1
11/01/83	15	396.6	401.0	4.4
11/03/83	17	396.3	401.2	4.9
11/05/83	19	396.2	401.4	5.2
11/07/83	21	395.9	401.5	5.6
11/09/83	23	395.6	401.6	6.0
11/11/83	25	395.5	401.8	6.3
11/13/83	27	395.5	401.9	6.4
11/15/83	29	395.6	401.9	6.3
11/17/83	31	395.6	401.9	6.3
11/19/83	33	396.3	402.2	5.9
11/21/83	35	396.8	402.3	5.5
11/23/83	37	397.4	402.3	4.9
11/25/83	39	397.9	402.4	4.5

FLOW RATE - TIME INPUT DATA
(Figure 10 - DC-20C)

Date	Time (days)	Fluid Loss (bbls)	Time Period (days)	Q (cu ft/d)
10/15/83	-3	60	28	11500
11/12/83	28	0		0

APPENDIX B


HANFORD SITE
BOREHOLE LOCATIONS
NORTHING (Thousands)
58
56
54
52
50
48
46
44
42
40
38
36
34
32
30
28
26
24
DC-23
DC-20C
RRL-17 (approx.)
RRL-2
DC-19C
DB-14
-100
-80
-60
(Thousands)
EASTING
BOREHOLE LOCATIONS