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January 8, 1986

009/2.3/Meetings.001
RS-NMS-85-009
Communication No. 11

U.S. Nuclear Regulatory Commission
Division of Waste Management
Geotechnical Branch
MS 623-SS
Washington, DC 20555

Attention: **Mr. Jeff Pohle, Project Officer**
Technical Assistance in Hydrogeology - Project B (RS-NMS-85-009)

Re: **BWIP Document Review - SD-BWI-TP-040**

Dear Mr. Pohle:

Per our telephone conversation of January 7, 1986, please find attached the Nuclear Waste Consultants/Terra Therma Inc. document review of the draft Test Plan for Multiple-Well Hydraulic Testing of Selected Hydrogeologic Units at the RRL-2 Site, Basalt Waste Isolation Project, Reference Repository Location (SD-BWI-TP-040). This document review was inadvertently omitted from the trip report for the December NRC/DOE Hydrology Workshop (NWC Communication No. 9, dated December 20, 1985), to which it should have been Attachment 2. Nuclear Waste Consultants regrets this ommission and any inconvenience it may have caused the NRC staff.

Because of the urgency of Mr. Weber's request for this review, I am sending one copy of this report directly to you by express, with the balance of the required copies to follow under separate cover by regular mail. If you have any questions about this matter, please contact me immediately.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Mark J. Logsdon

Mark J. Logsdon, Project Manager

Att: NWC/TTI Document Review - SD-BWI-TP-040

cc: US NRC - Director, NMSS (ATTN PSB)
DWM (ATTN Division Director)
Barry Bromberg, Contract Administrator
WMGT (ATTN Branch Chief)
Lyle Davis, WWL
M. Galloway, TTI
R. Knowlton, DBS

8603140376 860108
PDR WMRES EECNWCI
D-1021 PDR

2744

See D1021 1/8/86
TO: J. Pohle
"BWIP" Document
SD-BWI-TP-040

TERRA THERMA, INC.

WATER CONSULTANTS AND ENGINEERS

1.0 INTRODUCTION

FILE NO: NWC-009/2.3/REV001

DOCUMENT: TEST PLAN FOR MULTIPLE-WELL HYDRAULIC TESTING OF SELECTED HYDROGEOLOGIC UNITS AT THE RRL-2 SITE, BASALT WASTE ISOLATION PROJECT, REFERENCE REPOSITORY LOCATION (DOE Doc No. SD-BWI-TP-040) by Randolph Stone, P.M. Rogers, A.H. Lu, and R.W. Bryce, Dated 1985.

REVIEWER: Fred Marinelli, Michael Galloway (Terra Therma, Inc.) and Mark Logsdon (Nuclear Waste Consultants).

DATE REVIEW COMPLETED: December 6, 1985

DATE APPROVED: NWC - Mark J. Logsdon, Project Manager 12/18/85

2.0 SUMMARY OF DOCUMENT AND REVIEW CONCLUSIONS

2.1 SUMMARY OF DOCUMENT

DOE Document No. SD-BWI-TP-040 provides a detailed description of the planned stress testing of various hydrostratigraphic units at the BWIP site. The document describes the facilities and procedures to be used in the large scale testing and provides the results of pre-analyses of the tests. In addition, plans and procedures for a convergent tracer test and water quality sampling are included in the document.

2.2 SUMMARY OF REVIEW CONCLUSIONS

In general, the document provides a fairly complete report on the test plans and pre-analyses of the expected hydraulic responses. The nature of the report suggests that DOE and its contractors have spent considerable time designing the proposed test series with the obvious intention of generating valid data.

In addition to several specific technical comments which are provided in section 4.0, the consensus of the reviewers is that the test plan does not emphasize the importance of a large scale test to determine the regional significance of leakage and the effects of hydrologic boundaries. A "large scale" test is planned, but seems to be de-emphasized in the document. The need to assess the system performance in response to planned stresses (repository placement) is an important component of STP 1.1, which envisioned a large-scale (both temporal and spatial) test to achieve this goal.

3.0 SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM

Performance modeling is critical to any performance assessment of the BWIP site. However, the prerequisite to performance modeling is the observation of hydraulic responses in the basaltic framework to stresses of sufficient magnitude to mirror probable responses due to repository placement. STP 1.1 recognized this need and therefore placed testing emphasis on large-scale stresses at the expense of small- to mid-scale tests.

4.0 DETAILED REVIEW (PROBLEMS, DEFICIENCIES AND LIMITATIONS)

4.1 LARGE-SCALE STRESS TEST

A major goal of testing is to provide a large-scale stress to the basalt aquifer system to determine its regional hydraulic response. Such a response may provide information on the regional significance of leakage and the effects of hydrologic boundaries. In order to provide a regional stress to the system, emphasis should be placed on long term-pumping of a high transmissivity flow top. Predicted transmissivities are greatest in the Umtanum and Grande Ronde 5 flow tops. Thus, it may be advisable to place emphasis on testing these units (as opposed to the Rocky Coulee).

4.2 PUMPING EQUIPMENT

The document gives the impression of prescribing specific types of pumping equipment for each test interval. Prior to drilling, uncertainty will exist in hydraulic properties of flow tops at the RRL-2B site and thus, in the optimal pumping rates needed to stress each test interval. Discharge rates observed during short-term air-lift pumping of each test interval (see Comment 3) will provide estimates of the optimal pumping rate for testing. Once an optimal pumping rate is established, a pump equipment option can be selected to perform the test.

The document states that a pump capable of producing a maximum of 200 GPM will be used in the test of the Grande Ronde 5 flow top. However, if 300 meters (m) of drawdown are to be achieved during this test, the size will have to be based on a preliminary value of transmissivity to be determined by a short-term pump test of this interval. Table 2 of the reviewed document indicates that measured transmissivities in the Grande Ronde 5 flow top range from 0.005 to 77 m^2/day; the maximum being in the vicinity of the RRL-2 site. For a transmissivity of this magnitude, a flow rate of 12,600 m^3/day (2300 GPM) would be required to produce 300 m of drawdown in 50 days. Therefore, it is suggested that the pump be sized on the basis of the results of a short-term test and the desired pumping drawdown, rather than a pre-selection based on a geometric mean value for tests performed at different locations.

4.3 WELL DEVELOPMENT/PRETEST

According to Jackson et al (1984), each test interval will be rotary drilled with clear water. During drilling, a hydraulic buildup in excess of 40 meters will be imposed on the test interval (distance from static water level to ground surface). As a result, infiltration of drilling fluids and cuttings into the formation may occur. Infiltration of cuttings may cause well inefficiency, thereby reducing well pumping rates. A discussion of well development prior to testing was not found in the document.

To develop each test interval after drilling, we suggest that short-term air-lift pumping be performed. The purpose of this pumping would be to remove cuttings from the formation and recover a portion of drilling fluid injected during the drilling process. Air-lift pumping may be performed by lowering a riser pipe with air-line to about 300 meters below the static water level. Water levels and/or downhole pressure should be monitored during the short-term test. Observed discharge rate and hydraulic response during the pumping and recovery can be used to calculate preliminary aquifer specific yield and therefore provide estimates of the optimal pumping rate during long-term testing.

4.4 FLOW-TESTING OF THE COHASSETT FLOW TOP

The document suggests that long-term testing will not be considered in the Cohassett flow top due to its assumed low transmissivity. However, analyses conducted by Terra Therma indicates that the geometric mean of transmissivity assumed by RHO (0.019 m^2/d) would produce a significant hydraulic response at RRL-2C after 50 days of pumping (Refer to Appendix A). Since hydraulic properties of the Cohassett flow interior and flow top are of considerable interest in performance modelling, we suggest that a long-term pump test in the Cohasssett flow top be considered if aquifer/aquitard properties are such that a test of this type is feasible. The decision to perform this test should be made after determination of preliminary aquifer parameters obtained during well development (see Comment 3).

Uncertainty in leaky aquifer analyses is reduced in situations where substantial departure from the theoretical Theis response is observed. For a given set of aquitard parameters, this departure will be greater when pumping a lower transmissivity aquifer. Thus, from the standpoint of determining aquitard vertical hydraulic conductivity, pumping of low transmissivity flow tops may provide valuable information (provided that a response can be measured in observation piezometers). For this reason, we suggest that long-term pumping of the Cohassett flow top be given serious consideration. The decision to perform this test should be based on information measured during well development rather than assumed values.

4.5 UTILITY OF RATIO TEST FOR BULK KV EVALUATION

Completion of piezometers within flow interiors will, under some circumstances, allow for application of the Neuman-Witherspoon ratio method. Although this method may provide valuable information on aquitard properties, the following limitations should be recognized.

1. The ratio method provides only spot measurements of aquitard properties associated with a relatively narrow column of aquitard material extending primarily from the aquitard/aquifer boundary to the observation piezometer. As such, the ratio method does not provide aquitard properties integrated over a large area.

2. Since the ratio method only provides aquitard diffusivity, a unique value of vertical hydraulic conductivity can not be determined. Uncertainty in calculated vertical hydraulic conductivity will be related to uncertainty in aquitard specific storage, which could approach an order of magnitude.

3. Lag time resulting from borehole compliance, even in a closed piezometer, could result in an underestimation of aquitard diffusivity and hence calculated vertical hydraulic conductivity. Underestimates of vertical hydraulic conductivity are nonconservative from the standpoint of performance assessment (Refer to Appendix C).

The Hantush-Jacob r/B method and Hantush modified method provide aquitard parameters integrated over a large area. It is our position that such bulk parameter values are more suitable for site performance modeling (compared to those obtained from the ratio method).

4.6 TEST LENGTH

The testing program should emphasize flexibility in the pumping duration of each test. In low transmissivity zones, pumping should be continued until departures from the theoretical Theis response resulting from leakage are well defined, or until the lack of departure is verified. For high transmissivity zones, pumping duration should be sufficiently long to assure that potential hydrologic boundaries have been interecepted. In both cases, criteria need to be developed for determining when pumping should be terminated.

4.7 QUASI-THREE DIMENSIONAL MODEL

Considerable uncertainty exists in values of vertical hydraulic conductivity within basalt flow interiors. During large-scale testing, aquitard vertical hydraulic conductivity (and hence leakage) will have significant influence on determining the radius of influence of the test and whether or not potential hydrologic boundaries are intercepted. In addition to the six cases considered for the quasi-three-dimensional model, we suggest that additional runs be performed using different values of aquitard vertical hydraulic conductivity in order to assess the sensitivity of regional response to this parameter.

4.8 TRANSIENTS DUE TO TESTING

Pump testing of a flow top and subsequent drilling to the next flow top will impose hydraulic transients that are not likely to be fully dissipated before the next interval is ready to be tested. In general, testing can be initiated if existing transients can be reliably extrapolated through the test pumping and recovery periods. This will require monitoring of hydraulic head in all piezometers and observation wells until a baseline for the next test can be established. Criteria need to be developed to form a basis for deciding when a testing baseline exists and when the next test can be initiated.

4.9 MONITORING SITES

In order to qualitatively record regional responses to drilling, well development and testing, we suggest that other existing wells be added to the described monitoring system. These wells can be fitted with relatively unsophisticated recording devices (such as Stevens recorders) and be used with sufficiently long recording periods to minimize chart changing. The advantage of using these additional wells is that they will provide backup information to those wells already included in the monitoring network, over a larger area than otherwise might be available. Additionally, qualitative data collected from numerous wells can be used to qualify interpretations of responses in fully instrumented wells. For example, without being able to look at the response characteristics of numerous wells, it may be difficult to distinguish between leakage and boundary effects.

4.10 TRACER TEST INDUCED TRANSIENTS IN ADJACENT AQUITARDS

Introduction of tracers into an aquifer will be accomplished by momentary injection of chemicals and formation water, with hydraulic build-ups on the order of 250 meters (820 ft). Since this procedure will be performed while the ratio test is in progress, the potential exists for the aquifer pressure "spike" to cause hydraulic transients in adjacent aquitards that could potentially interfere with ratio test monitoring.

Preliminary analyses by Terra Therma suggest that such aquitard transients may persist long after the aquifer pressure "spike" has dissipated. In some cases, the magnitude of aquitard build-up may be on the order of meters and the pressure perturbation may persist throughout the remainder of the testing period (Refer to Appendix B).

4.11 TRACER TEST PLAN

Use of the reinterpreted McCoy Canyon (DC 7/8) tracer test to pre-analyze RRL-2 tracer test is probably the best available approach, and staging subsequent test designs based on the results of the new tests is a good plan. As with the comments on preserving flexibility with respect to the pumping capacities, substantial flexibility should be preserved for these tests:

1. Leonhart et al. (1985) do not report that effective porosity (n) was .002 - .003. The paper reports that the effective thickness (nb) was .002 - .003. While the dynamic temperature log can be interpreted to imply a thin zone, Leonhart et al. conclude that, "the range of possible contributing zone thicknesses is very broad." In this case, it is reasonable for BWIP to be prepared for considerably different behavior, even if the dispersivity and effective porosity properties of the Rocky Coulee are close to those of the McCoy Canyon.

2. Given that apparent dispersion values are probably related to the degree of heterogeneity in the tested formation, it may be that the dispersion in the Rocky Coulee is qualitatively different from that in the McCoy Canyon. In advance of the test, there is no basis either way, so the pretest analysis is probably the best approach. BWIP might do well to consider a continuous monitoring system using their flow-through cell system (e.g., electrode measurements for Br and fluorescence measurements for SCN) to assure that they are prepared for tracer breakthrough.

4.12 TRACER TEST RATIONALE

The document does not set out a complete rationale for the tracer test, particularly with respect to dispersivity. As pointed out by Leonhart et al. (1985), the estimate of the dispersivity obtained in the McCoy Canyon experiment, "is probably not representative of dispersivity required to model regional-scale transport." Based on the scale relationships of longitudinal dispersivity developed by Lallemand-Barres and Peaudecerf (1979), it seems unlikely that the RRL-2 experiments will clearly define an "asymptotic macrodispersivity", either. Thus, some discussion is needed to determine how these experiments will fit with other data that BWIP considers necessary for collection.

Two questions arise as to whether the design of the tracer test in fact qualitatively reflects the physics of flow and transport that will likely occur under post-emplacement conditions.

1. In the design-basis convergent test, are the streamlines properly accounted for to assure that lateral dispersion is negligable with respect to longitudinal disperson?

2. For a Norton/Knapp type porosity model for fractured media (or even a heterogeneous porous media), do the high velocities associated with the imposed gradients produce a tracer behavior that is qualitatively different from the tracer behavior that would exist under ambient conditions?

4.13 GEOCHEMISTRY

There is little doubt that the proposed program will generate a great deal of intrinsically interesting hydrogeochemical data. However, from this document, it is very hard to identify the data need(s) that would lead to such a very large list of parameters. The section on geochemistry would substantially benefit from a presentation of the rationale for the proposed testing, even if that rationale is only qualitative at this time.

5.0 RECOMMENDATIONS

The recommendations which arise out of this review are as follows:

1. The NRC staff should be prepared to review the revised version of the DOE test plan. A revised version could reflect both DOE/Rockwell statements and NRC review team comments which were made at the December hydrology meeting, and would therefore, be important for determining the intended

nature of the tests.

2. Many of the technical comments listed in Section 4.0 are intended as recommendations to DOE, based on information provided in the Draft Test Plan. We would hope that these recommendations are to be addressed in the revised plan. Based on comments made by DOE at the December hydrology meeting, we recognize that some of the review concerns were considered by DOE, but were not specifically discussed in the Draft Test Plan.

APPENDIX A

TECHNICAL MEMORANDUM

From: Fred Marinelli Date: December 20, 1985

To: Adrian Brown
Mike Galloway

Re: Pre-analysis of Large-Scale Testing at the RRL-2 Site

INTRODUCTION

As discussed in the BWIP document entitled, "Test Plan for Multiple-Well Hydraulic Testing of Selected Hydrogeologic Units at the RRL-2 Site ...." (SD-BWI-TP-040), Rockwell Hanford Operations (RHO) plans to conduct a series of multiple-borehole hydraulic tests in three Grande Ronde flow tops at the RRL-2 site. The purpose of these tests is (1) to observe the regional response of the basalt sequence to a large hydraulic stress and (2) to measure in situ hydraulic properties of basalt materials. The former is primarily intended to to identify the presence of hydrologic boundaries and to assess the significance of leakage on the regional scale. The latter is intended to measure flow top hydraulic parameters such as transmissivity, storativity, and effective porosity; and also the properties of flow interiors including vertical hydraulic conductivity.

In order to evaluate test design and performance, RHO has conducted pre-analyses that include axisymetric and quasi-three-dimensional modeling. The purpose of this modeling has been to:

1. Evaluate the feasibity of conducting large-scale tests in selected Grande Ronde flow tops.

2. Optimize the location of observation wells and piezometers.

3. Estimate the time required to conduct each test including pumping and recovery periods.

4. Assess the utility of standard analysis techniques for interpreting and analyzing test data obtained at the RRL-2 site.

Quasi-three dimensional modeling included sensitivity studies to assess the effects variable flow top transmissivity on regional hydraulic response. This modeling, however, did not consider the regional effects associated with variable vertical hydraulic conductivity of flow interiors. Axisymetric modeling included the effects of vertical hydraulic conductivity, but only in the near-field.

Modeling conducted by RHO has provided valuable information concerning the performance of large-scale tests at the RRL-2 site. However, we feel that there are several issues that may require additional analysis. These include:

1. Sensitivity of regional hydraulic response to vertical hydraulic conductivity of flow interiors.

2. Feasibility of conducting a multiple-borehole test in the Cohassett flow top.

3. To what extent hydrologic boundaries can be identified through the use of large-scale tests.

4. The degree to which unidentified background trends in hydraulic head will affect test analysis.

This memorandum presents preliminary calulations performed by Terra Therma to assess the above issues. The primary purpose, at this stage, is to outline the analysis techniques and present preliminary results and interpretations. More detailed study of this subject will require additional sensitivity analyses to assess hydraulic impacts for a variety of conditions potentially existing in the Reference Repositiory Location.

APPROACH

Aquifer drawdown in response to pumping is calculated using the modified Hantush (1960) leaky aquifer solution. The final Hantush solution can be difficult to evaluate because (1) two different asymptotic equations are given for early and late times, (2) the resulting equations are difficult to evaluate, often necessitating the use of tables, and (3) no solution is available for intermediate times. To circumvent these problems, a computer program has been written for the IBM-PC that evaluates aquifer drawdown by numerical inversion of the LaPlace solution to the boundary value problem. The program is based on the Stelfest algorithm and makes use of equations described in Moench and Ogata (1984). This approach results in an efficient algorithm that can evaluate the modified Hantush solution for all times. Comparison of tables of values with the numerical results indicates that the program is generally accurate to four significant figures.

Since the program allows for incorporation of an image well, the effects of a hydrologic boundary can be simulated, as well as recovery following termination of pumping. Effects of a background trend on actual water level changes can also be incorporated. Program results are graphed using an HP-7475A plotter to produce a standard 3 X 5 logarithmic plot of drawdown vs. time. For plots attached to this memorandum, circles represent the leaky aquifer resonse and triangles show water level changes incorporating the background trend. The plotting subroutine contains a provision for plotting the theoretical Theis response to provide a means for assessing the significance of leakage and/or hydrologic boundaries on aquifer drawdown.

In addition to basic assumptions generally associated with well hydraulic problems, the modified Hantush (1960) leaky aquifer solution assumes that (refer to Figure 1):

1. Aquitards above and below the pumped aquifer are a source of water to the pumping well.

2. The aquitards are capable of ground water storage.

3. The top of the upper aquitard and bottom of the lower aquitard are maintained at constant head (zero draw-down). These correspond to boundaries "A" and "B" in Figure 1.

For the basalt sequence at Hanford, flow tops are considered to correspond with aquifers and flow interiors are assumed to behave as aquitards.

EFFECTS OF AQUITARD VERTICAL HYDRAULIC CONDUCTIVITY

Cases 1 through 3 (refer to attached plots) consider the hydraulic response at RRL-2C as a result of pumping the Rocky Coulee Flow Top at RRL-2B. Subcase "A" assumes the same aquitard hydraulic conductivity (K') as that adopted by RHO for their quasi-three-dimensional model. Subcase "B" shows the effects of of a K' value which is one order of magnitude higher. Case 1 is based on RHO's best guess transmissivity for the Rocky Coulee Flow Top, while cases 2 and 3 are related to RHO's assumed upper and lower bound transmissivities, respectively.

Results of the Rocky Coulee simulations indicate that the effects of leakage (i.e., departures from the Theis curve) are greater for aquitards with higher vertical hydraulic conduct-ivities and also for aquifers with lower transmissivities. The results also show that a relatively high unidentified background trend of 0.3 meters per month would not have a significant effect on test analysis at the RRL-2C piezometer.

FEASIBILITY OF A MULTIPLE-BOREHOLE TEST IN THE COHASSETT FLOW TOP

RHO did not consider a multiple well test in the Cohassett flow top because of its apparent low transmissivity. Cases 4 through 6 show the predicted response at RRL-2C resulting from pumping the Cohassett Flow Top at RRL-2B. In all cases, a measurable response would be predicted after 10 ten days of pumping. It is thus concluded that a large-scale pump test in the Cohassett Flow Top is potentially feasible. Results also indicate that a relatively high unidentified background trend of 0.3 meters per month would not affect test analysis, except possibly for case 6B (low transmissivity; high aquitard hydraulic conductivity).

IDENTIFICATION OF HYDROLOGIC BOUNDARIES

Pumping a high transmissivity flow top may create a regional hydraulic response in which hydrologic boundaries are intercepted. Cases 7 through 9 consider a situation where the proposed Yakima structure affects a pump test conducted in the Grande Ronde 5 Flow Top. This simulation considers hydraulic response at DC-22 resulting from pumping at RRL-2B. Case 7 assumes RHO's best guess value of aquifer transmissivity. Since transmissivities considerable higher than this value have been measured in the Grande Ronde 5 Flow Top at the RRL-2 site, cases 8 and 9 consider higher transmissivty values. Results show that boundary effects would occur in all cases considered. However, it would be difficult to distinguish the presence of a boundary in case 7 (lowest transmissivity). Reasults also indicate that a moderate unidentified background trend of 0.03 meters per month would not significantly affect test analysis.

EFFECTS OF BACKGROUND TRENDS

In our estimate, unidentified background trends are not likely to exceed 0.03 meters per month. As discussed in previous sections, background trends of this magnitude are not expected to have a significant effect on test analsis.

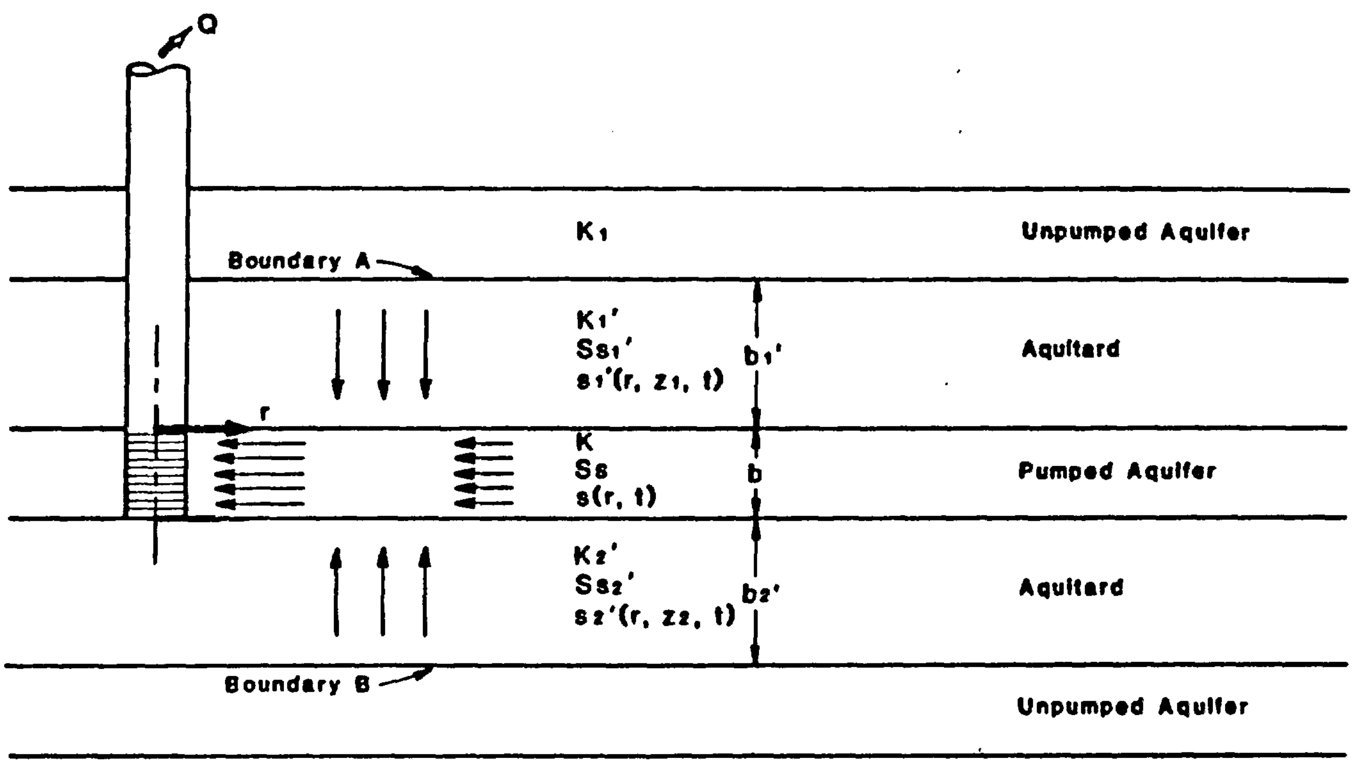
REFERENCES

Hantush, M.S. 1960. Modification of the theory of leaky aquifers. J. Geophys. Res., vol 65, no 11, pp 3713-3725.

Moench, A. and A. Ogata. 1984. Analysis of constant discharge wells by numerical inversion of LaPlace transform solutions. In; Groundwater Hydraulics; J. Rosenshein and G.D. Bennett editors; Amer. Geophys. Union, Water Resources Monograph 9, Washington DC, pp 146-170.

MATHEMATICAL MODEL

Figure 1



NOMENCLATURE

K = aquifer horizontal hydraulic conductivity ($L\ T^{-1}$)

Ss = aquifer specific storage (L^{-1})

b = aquifer thickness (L)

s = aquifer drawdown (L)

K' = aquitard vertical hydraulic conductivity ($L\ T^{-1}$)

Ss' = aquitard specific storage (L^{-1})

b' = aquitard thickness (L)

s' = aquitard drawdown (L)

r = radial distance (L)

t = time since beginning of pumping (T)

DIMENSIONLESS PARAMETERS

$$\frac{r}{B} = r\left(\sqrt{\frac{1}{Kb}\left(\frac{K_1'}{b_1'} + \frac{K_2'}{b_2'}\right)}\right)$$

$$\beta = \frac{r}{4b}\left(\sqrt{\frac{K_1'\,Ss_1'}{K\,Ss}} + \sqrt{\frac{K_2'\,Ss_2'}{K\,Ss}}\right)$$

$$u = \frac{Ss\,r^2}{4Kt}$$

CASE:

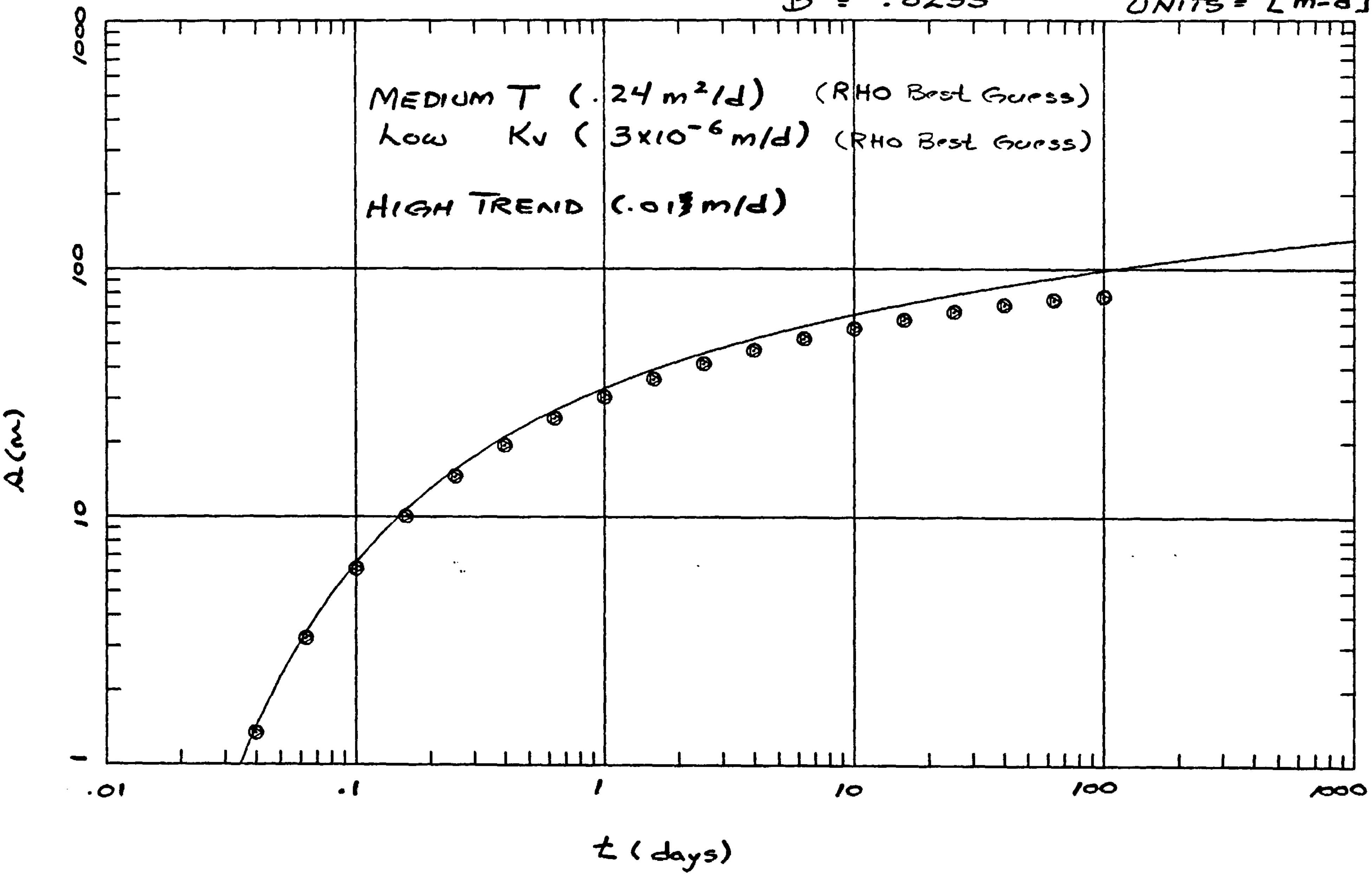
TEST INTERVAL: ROCKY COULEE
OBSERVATION WELL: RRL-2C
PUMPING WELL: RRL-2B

BOUNDARY: NONE

Q = 43.6
T = .24
S = 10^{-5}
r_o = 76
r/B = .0711
β = .0255

TREND = .01

UNITS = [m-d]



TEST INTERVAL: Rocky Coulee

PUMPING WELL: RRL-2B

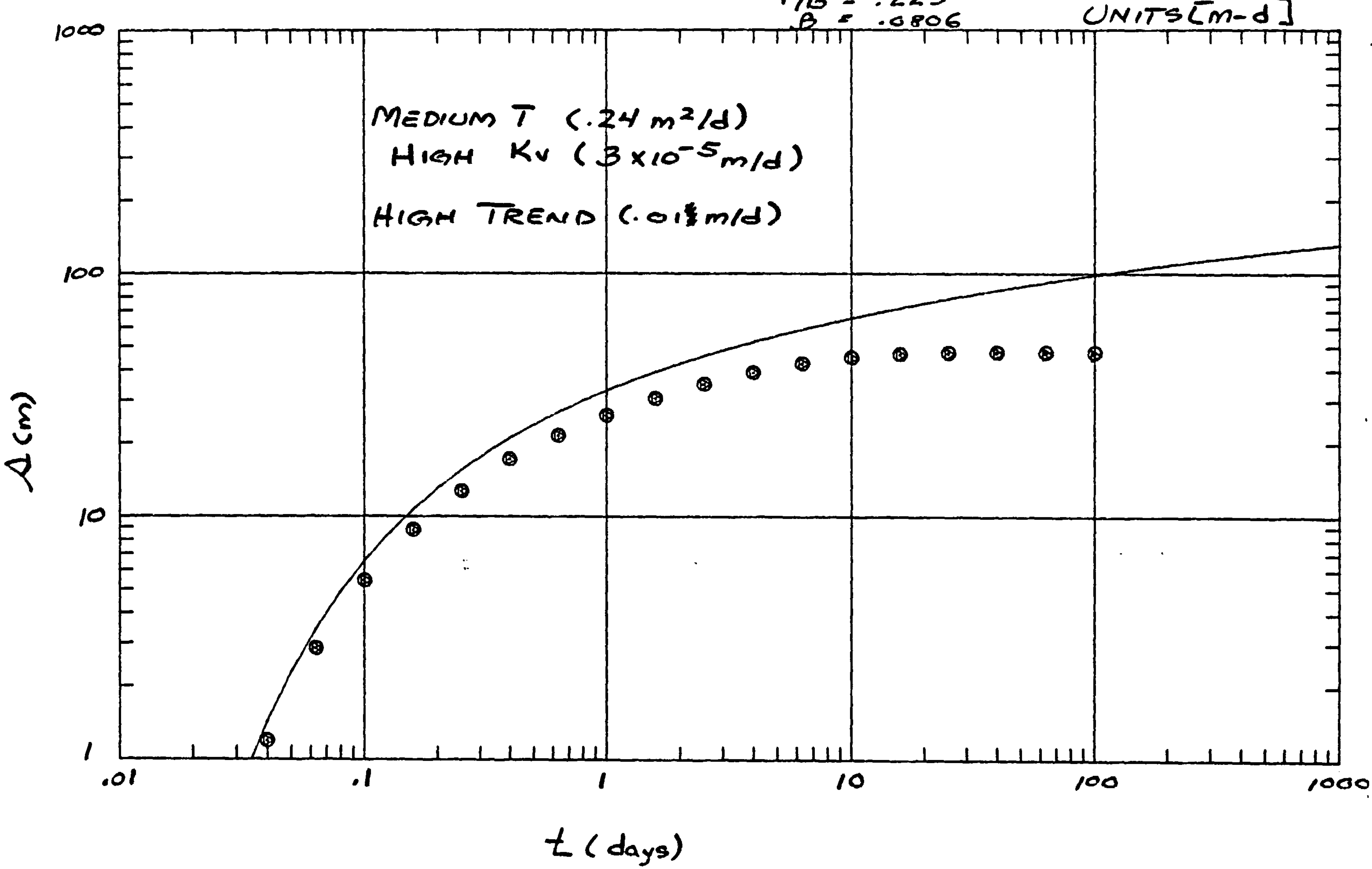
OBSERVATION WELL: RRL-2C

BOUNDARY: NONE

$Q = 43.6$
$T = .24$
$S = 10^{-5}$
$r_o = 76$
$r/B = .225$
$\beta = .0806$

CASE: 1B

TREND = .01

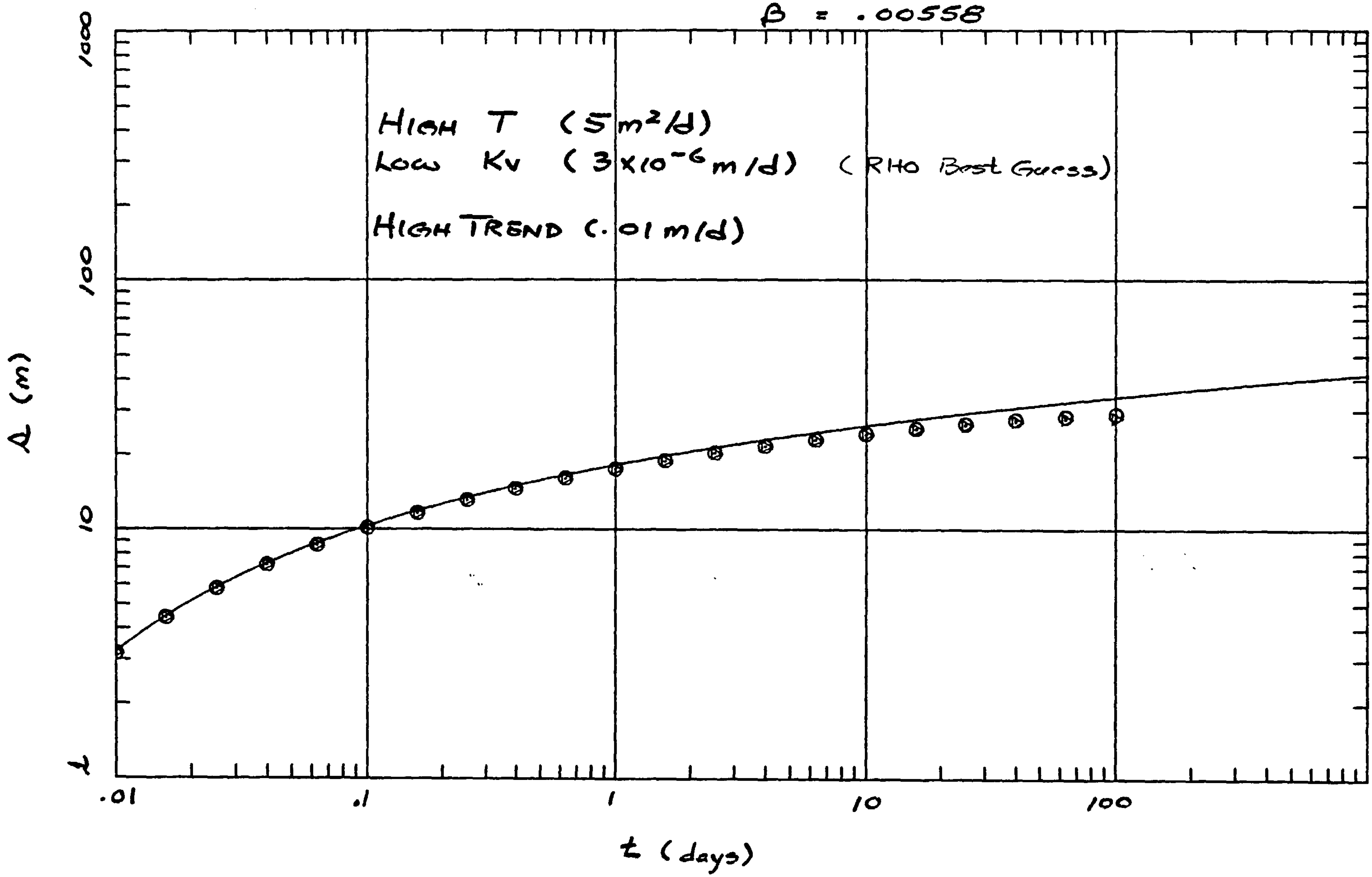


TEST INTERVAL: ROCKY COULEE
PUMPING WELL: RRL-2B
OBSERVATION WELL: RRL-2C

BOUNDARIES: NONE

$Q = 217$
$T = 5.0$
$S = 10^{-5}$
$r_o = 76$
$r/B = .0156$
$\beta = .00558$

TREND = + .01



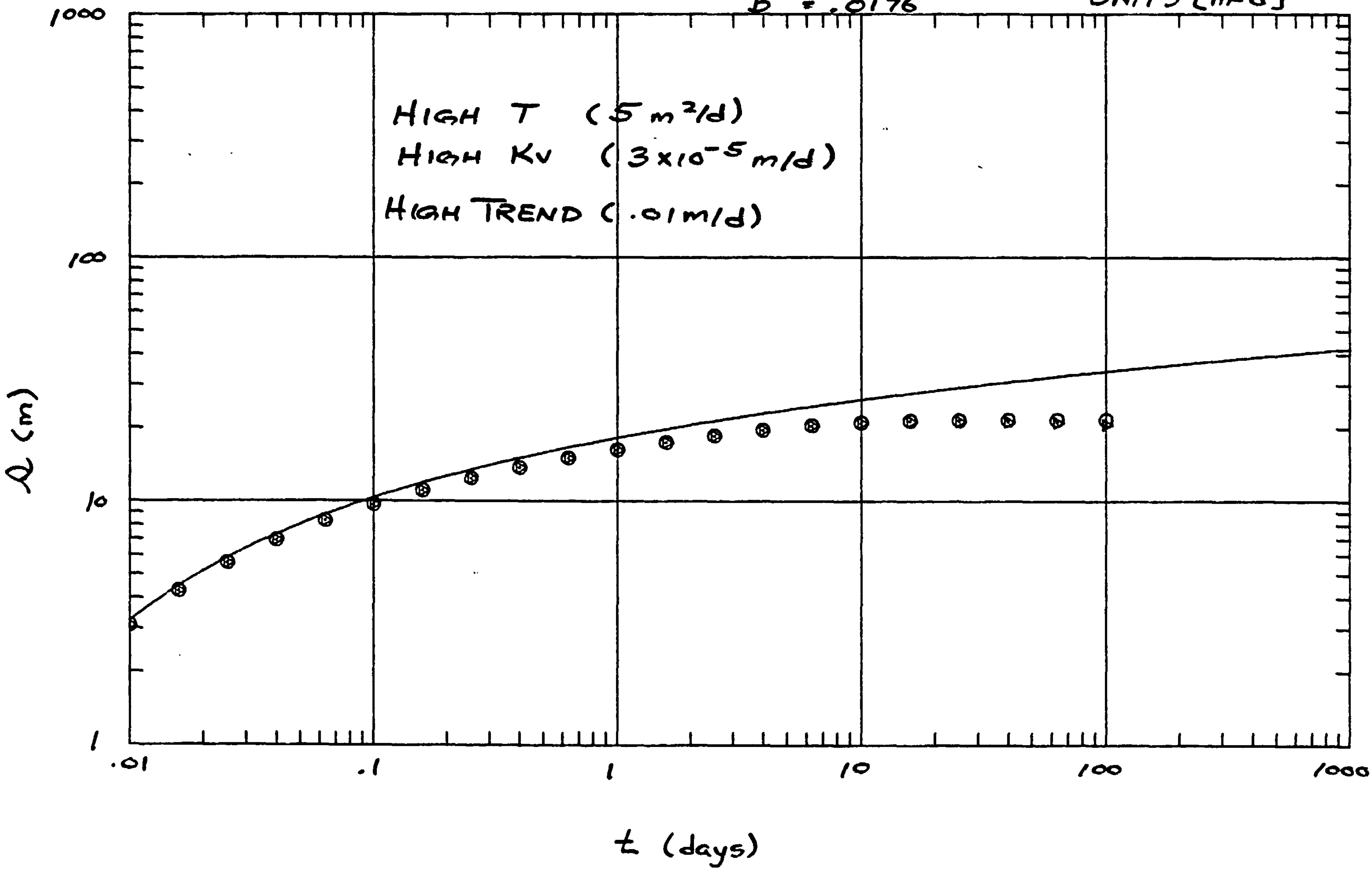
TEST INTERVAL : ROCKY COULEE
PUMPING WELL : RRL-2B
OBSERVATION WELL : RRL-2C
BOUNDARY : NONE

Q = 217
T = 5
S = 10^{-5}
r_0 = 76
r/B = .0493
B = .0176

CASE : 2B

TREND = +0.01

UNITS [m-d]

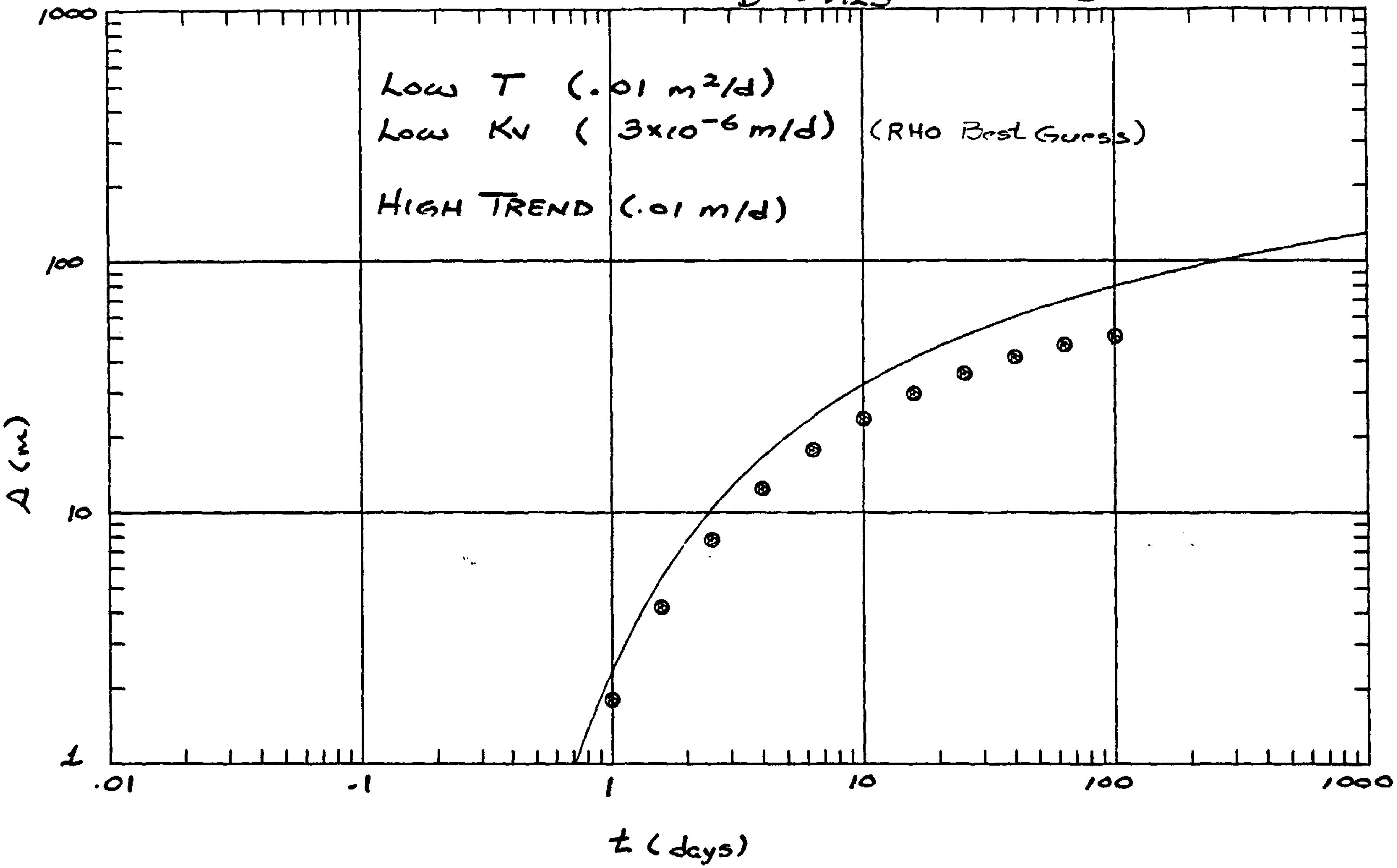


TEST INTERVAL: ROCKY COULEE
PUMPING WELL: RRL-2B
OBSERVATION WELL: RRL-2C
BOUNDARY: NONE

$Q = 2.72$
$T = 0.01$
$S = 10^{-5}$
$r_o = 76$
$r/B = .348$
$\beta = .125$

TREND = + 0.01

UNITS: [m-d]



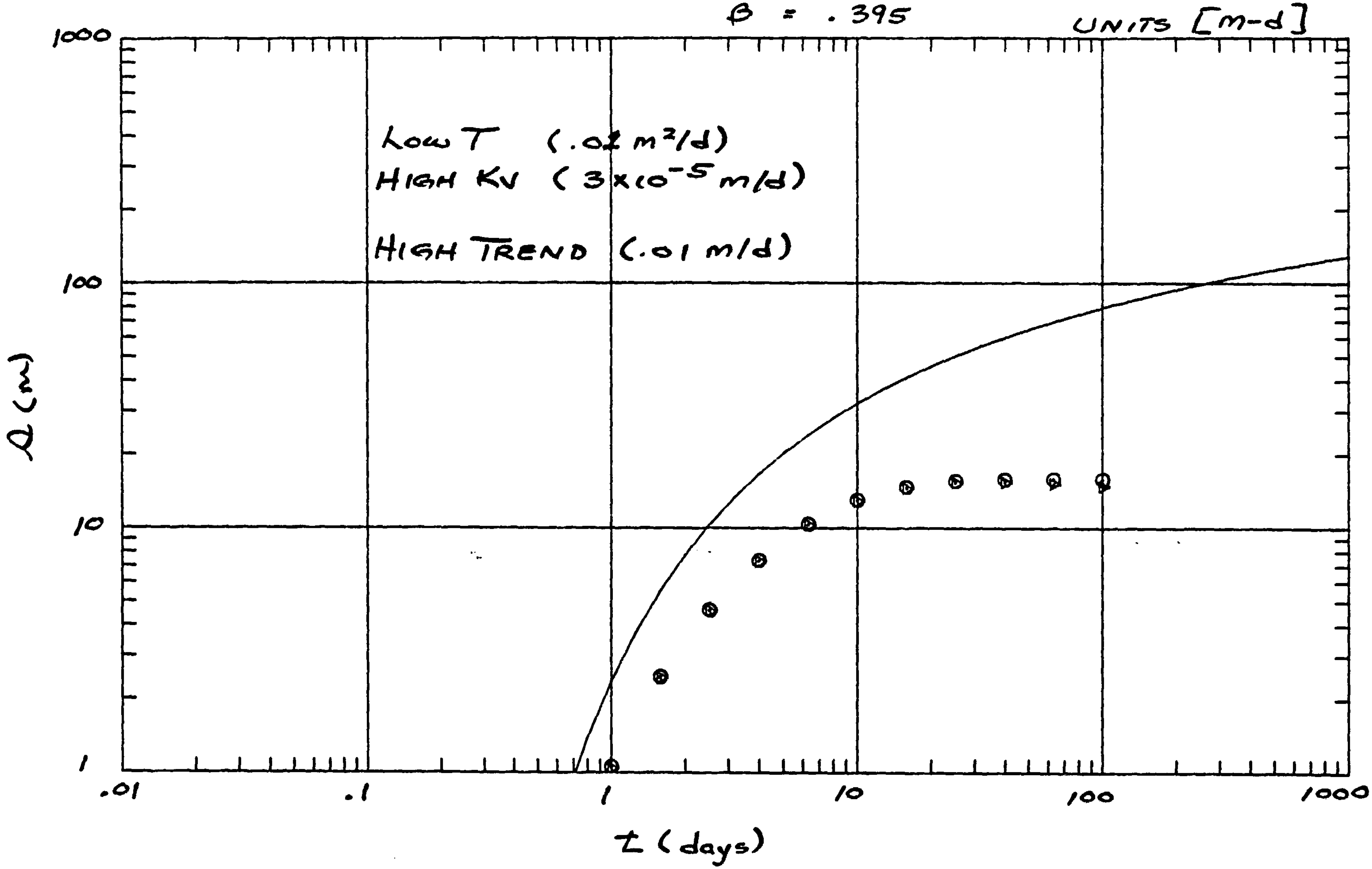
TEST INTERVAL : ROCKY COULEE
PUMPING WELL : RRL-2B
OBSERVATION WELL : RRL-2C

BOUNDARY : NONE

$Q = 2.72$
$T = .01$
$S = 10^{-5}$
$r_o = 76$
$r/B =$ ~~[illegible]~~ 1.1
$\beta = .395$

CASE : [illegible]

TREND = + 0.01



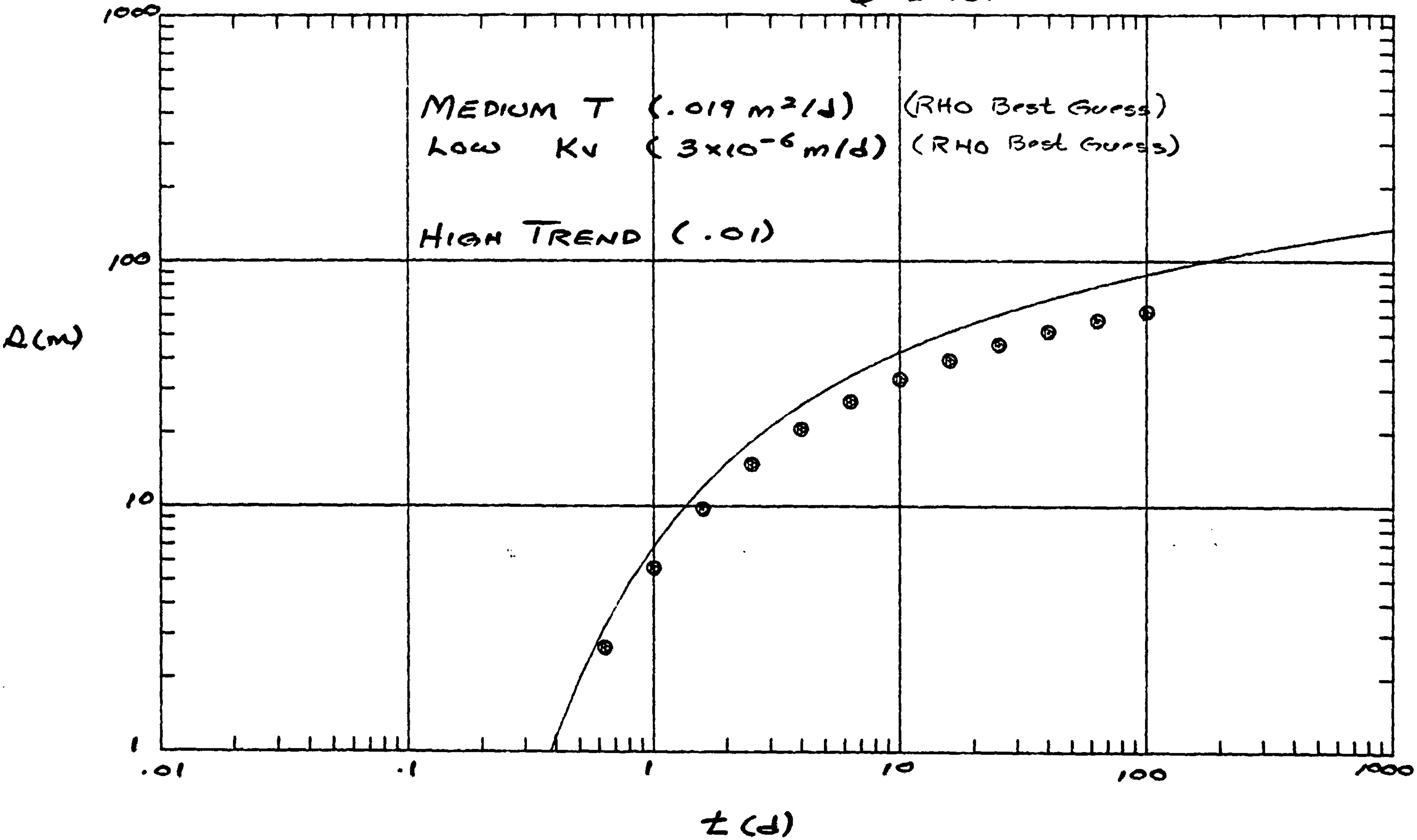
CASE: 4A

TEST INTERVAL: COHASSET
PUMPING WELL: RRL-2B
OBSERVATION WELL: RRL-2C

BOUNDARY: NONE

Q = 4.9
T = .019
S = 10^{-5}
r = 76
r/B = .215
β = .0906

TREND = .01

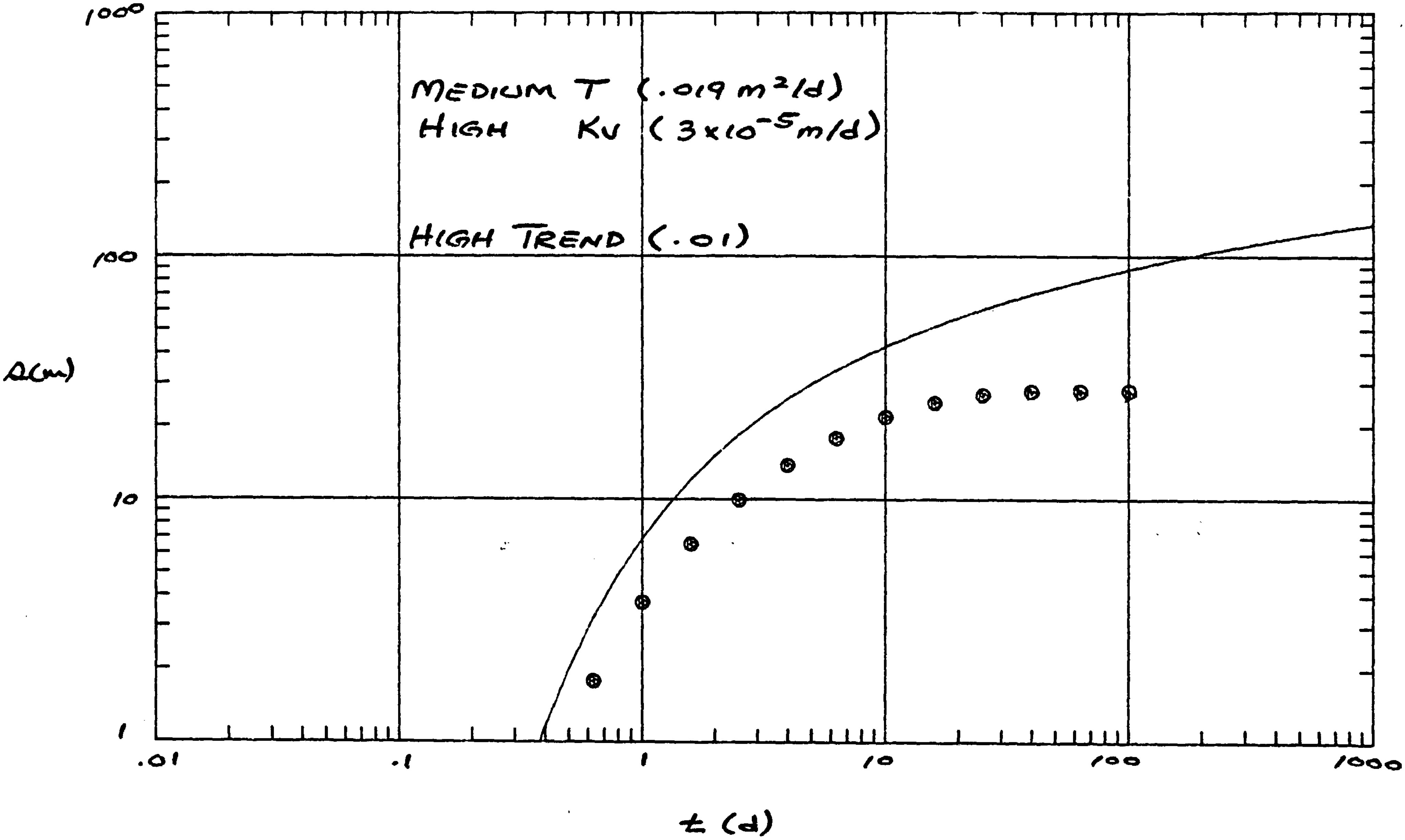


TEST INTERVAL: CULEBRA (COHASSETT)
PUMPING WELL: RRL-2B
OBSERVATION WELL: RRL-2C

Q = 4.9
T = .019
S = 10^{-5}
r = 76
r/B = .680
β = .286

CASE: 4B

TREND = .01

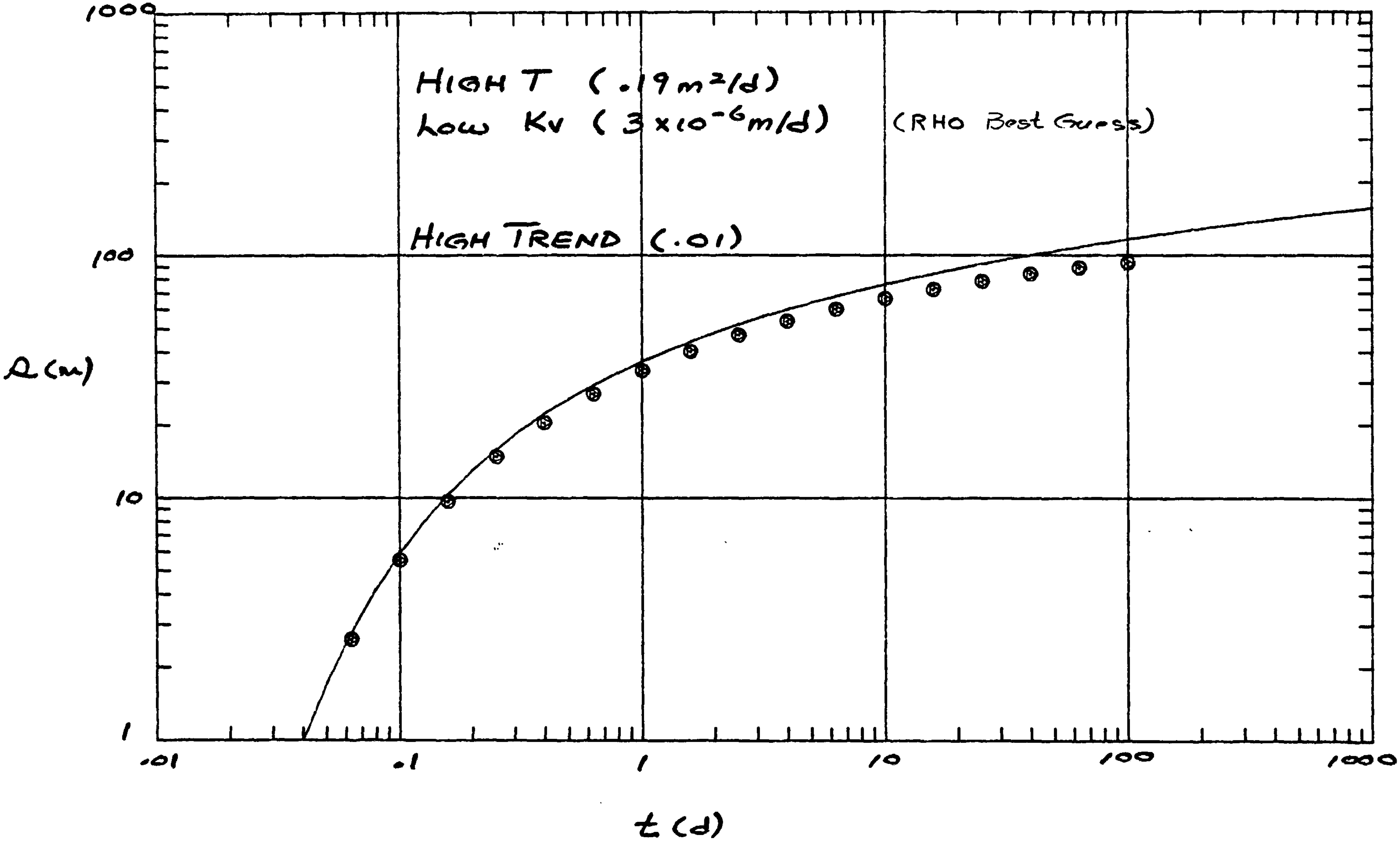


TEST INTERVAL: COHASSETT
PUMPING WELL: RRL-2B
OBSERVATION WELL: RRL-2C
BOUNDARY: NONE

Q = 42.1
T = .19
S = 10^{-5}
r = 76
r/B = .068
β = .0286

CASE: 5A

TREND = .01

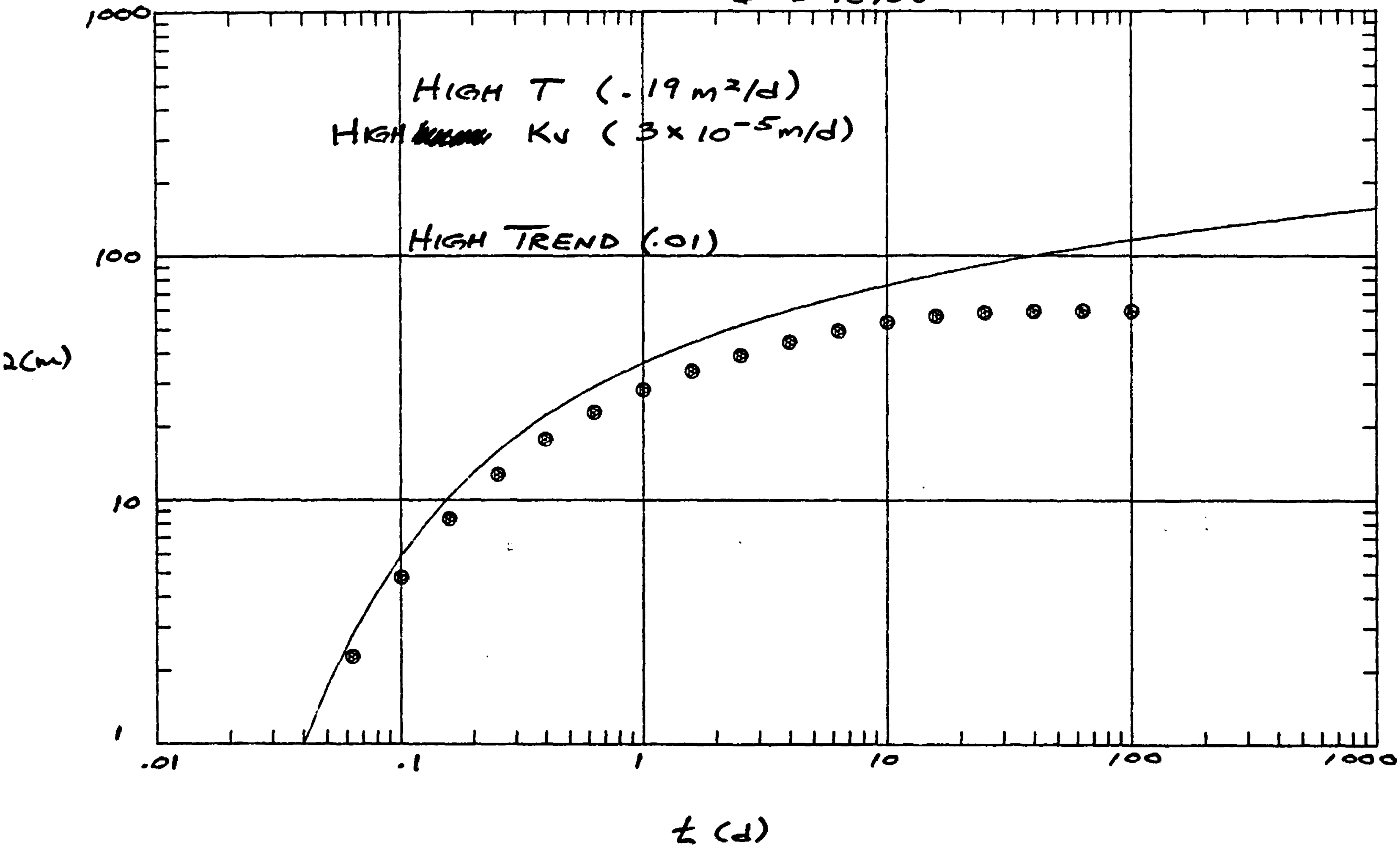


TEST INTERVAL: COHASSETT
PUMPING WELL: RRL-2B
OBSERVATON WELL: RRL-2C
BOUNDARY: NONE

Q = 42.1
T = .19
S = 10^{-5}
r = 76
r/B = .215
B = .0906

CASE: 5B

TREND = .01

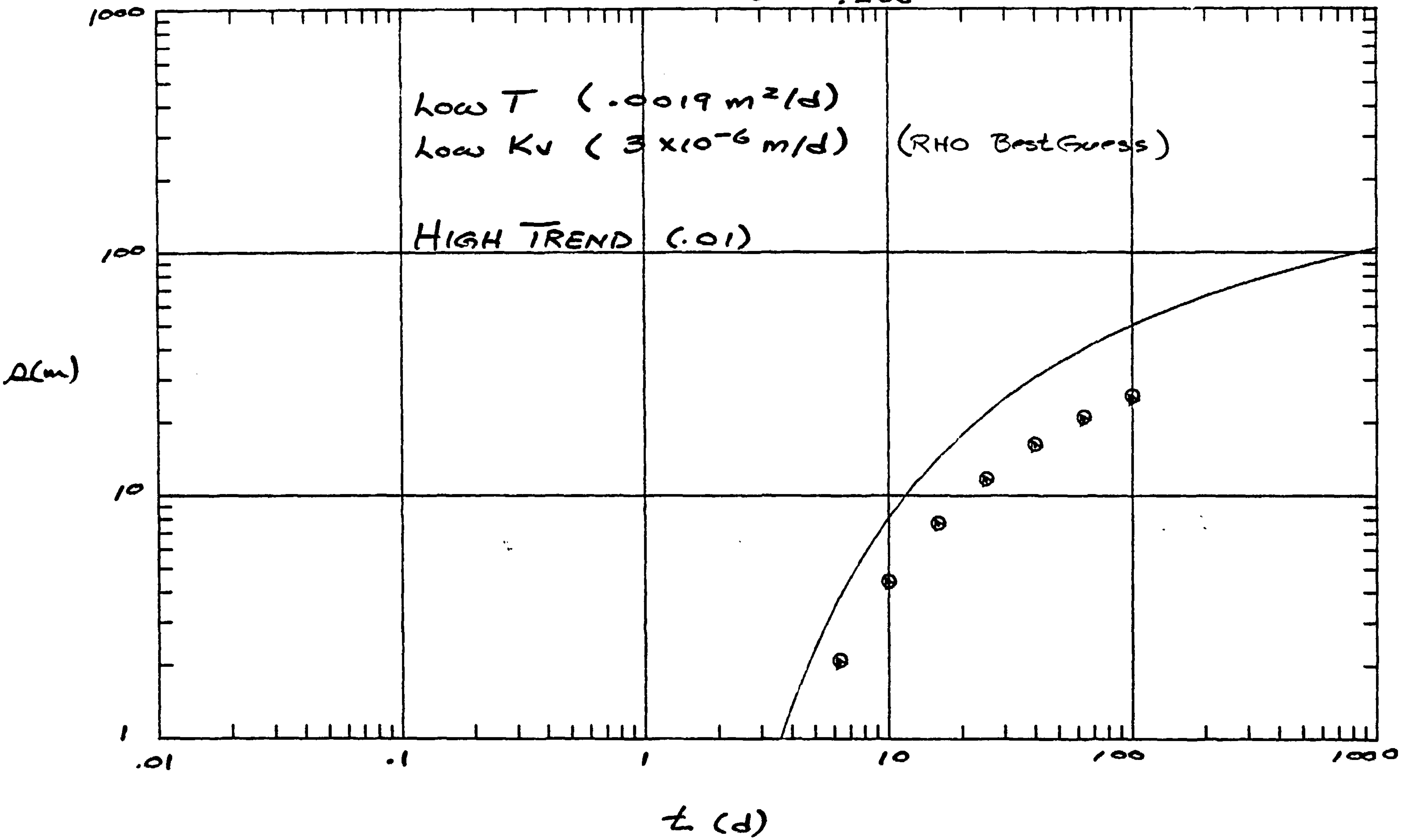


TEST INTERVAL: COHASSETT
PUMPING WELL: RRL-2B
OBSERVATION WELL: RRL-2C
BOUNDARY: NONE

Q = .579
T = .0019
S = 10^{-5}
r = 76
r/B = .680
β = .286

CASE: 6A

TREND = 0.01

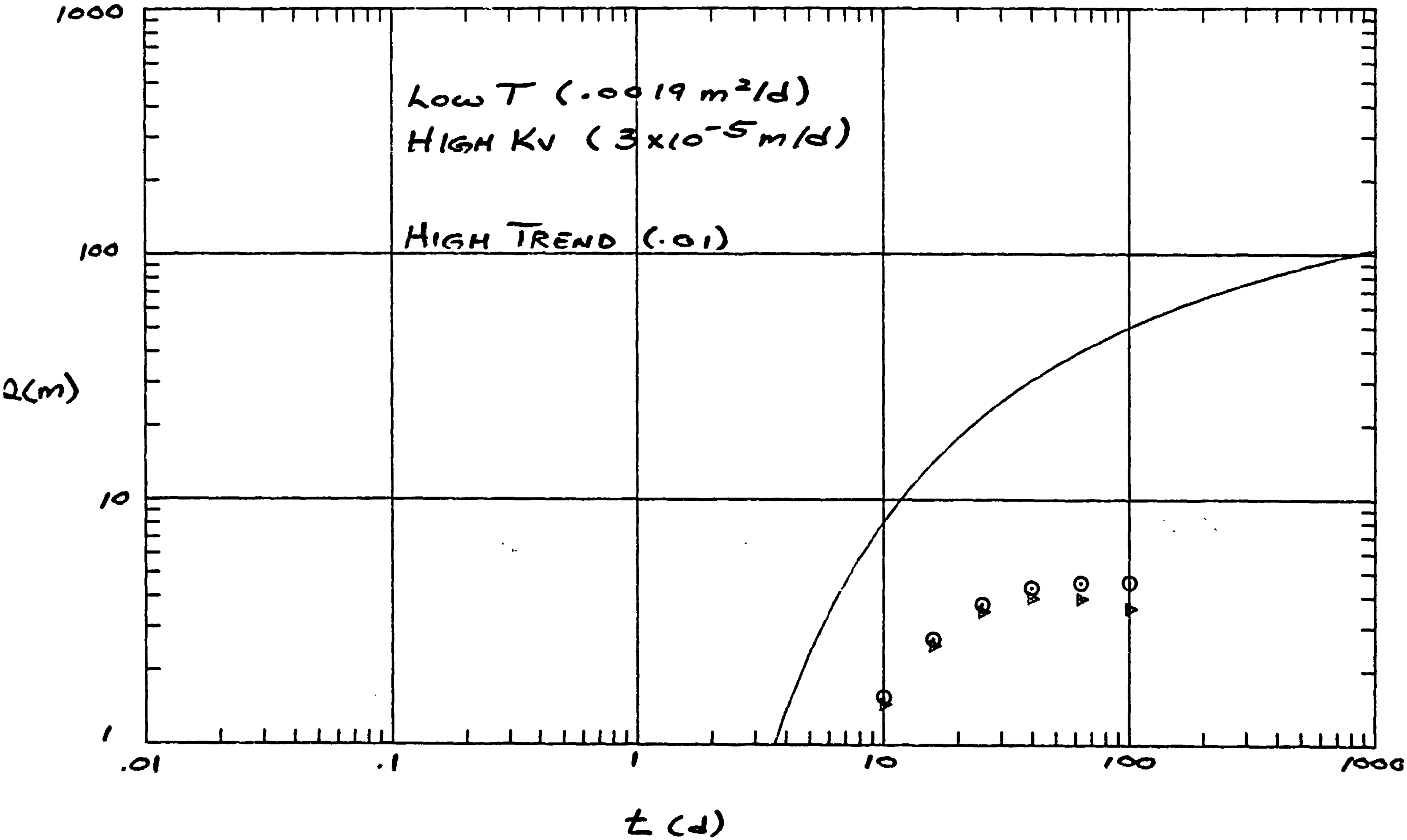


TEST INTERVAL: COHASSETT
PUMPING WELL: RRL-2B
OBSERVATION WELL: RRL-2C
BOUNDARY: NONE

$Q = .579$
$T = .0019$
$S = 10^{-5}$
$r = 76$
$r/B = 2.15$
$\beta = .906$

CASE: 6B

TREND = .01



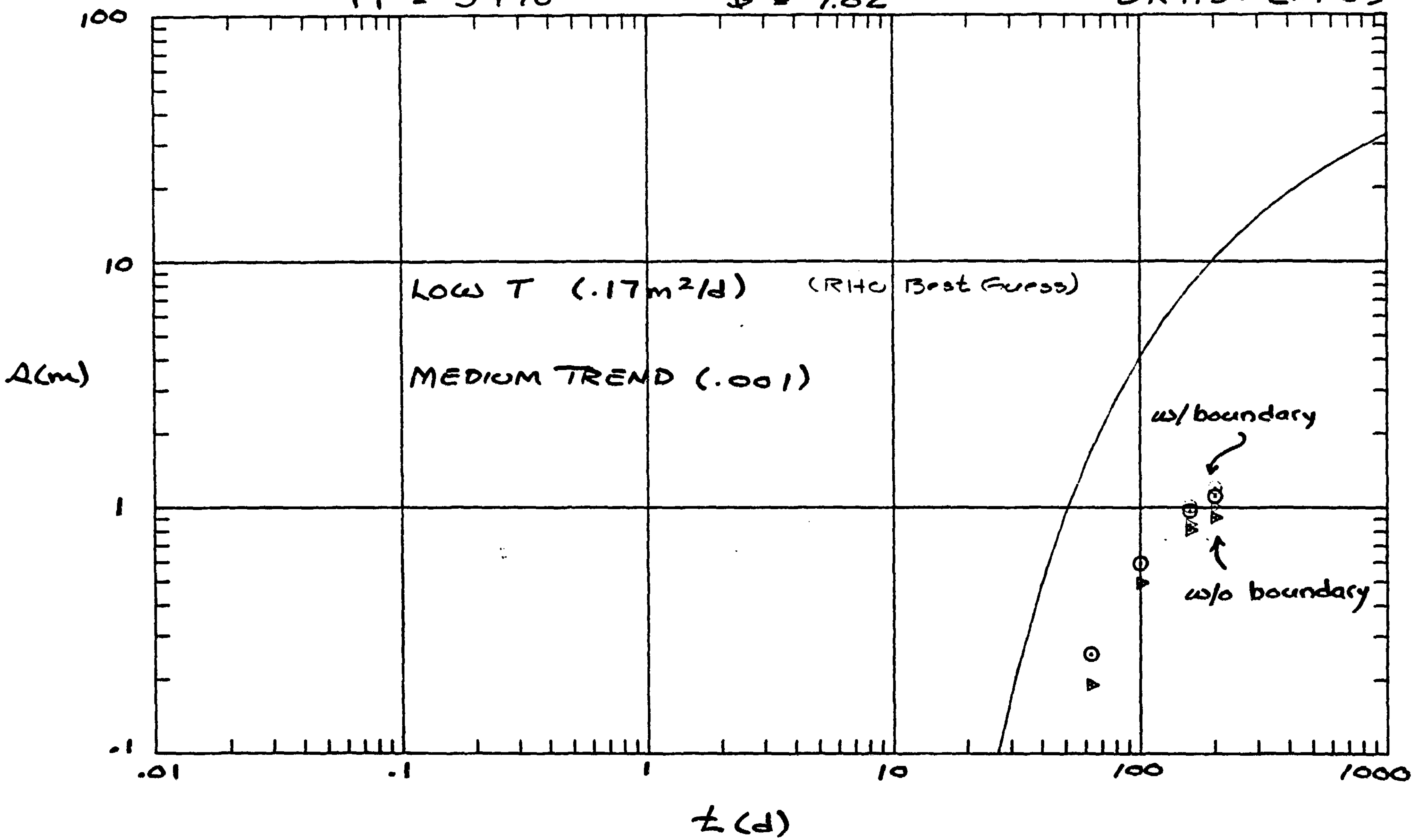
TEST INTERVAL: GR5
PUMPING WELL: RRL-2B
OBSERVATION WELL: DC-22
BOUNDARY: IMPERMEABLE
r_i = 5470

Q = 38.1
T = .17
S = 10^{-5}
r = 2570
r/B = 2.97
β = 1.02

CASES: 7A, 7B

TREND = +0.001

UNITS: [m-d]



TEST INTERVAL: GR 5

PUMPING WELL: RRL-2B

OBSERVATION WELL: [redacted] DC-22

BOUNDARY : IMPERMEABLE

$r_i = 5470$

$Q = 334$

$T = 1.7$

$S = 10^{-5}$

$r = 2570$

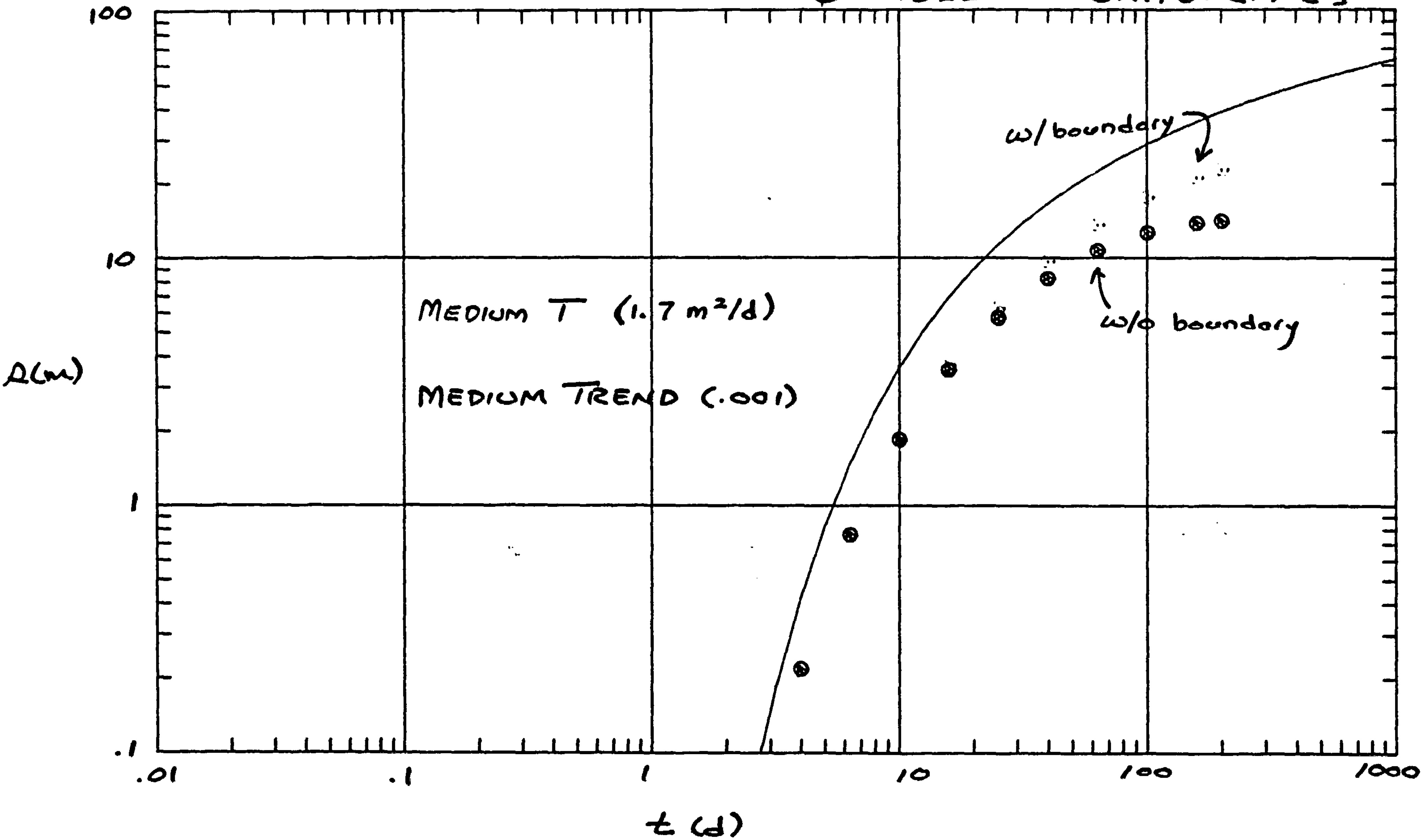
$r/B = .939$

$\beta = .322$

CASES: 8A, 8B

TREND = + 0.001

UNITS: [m-d]



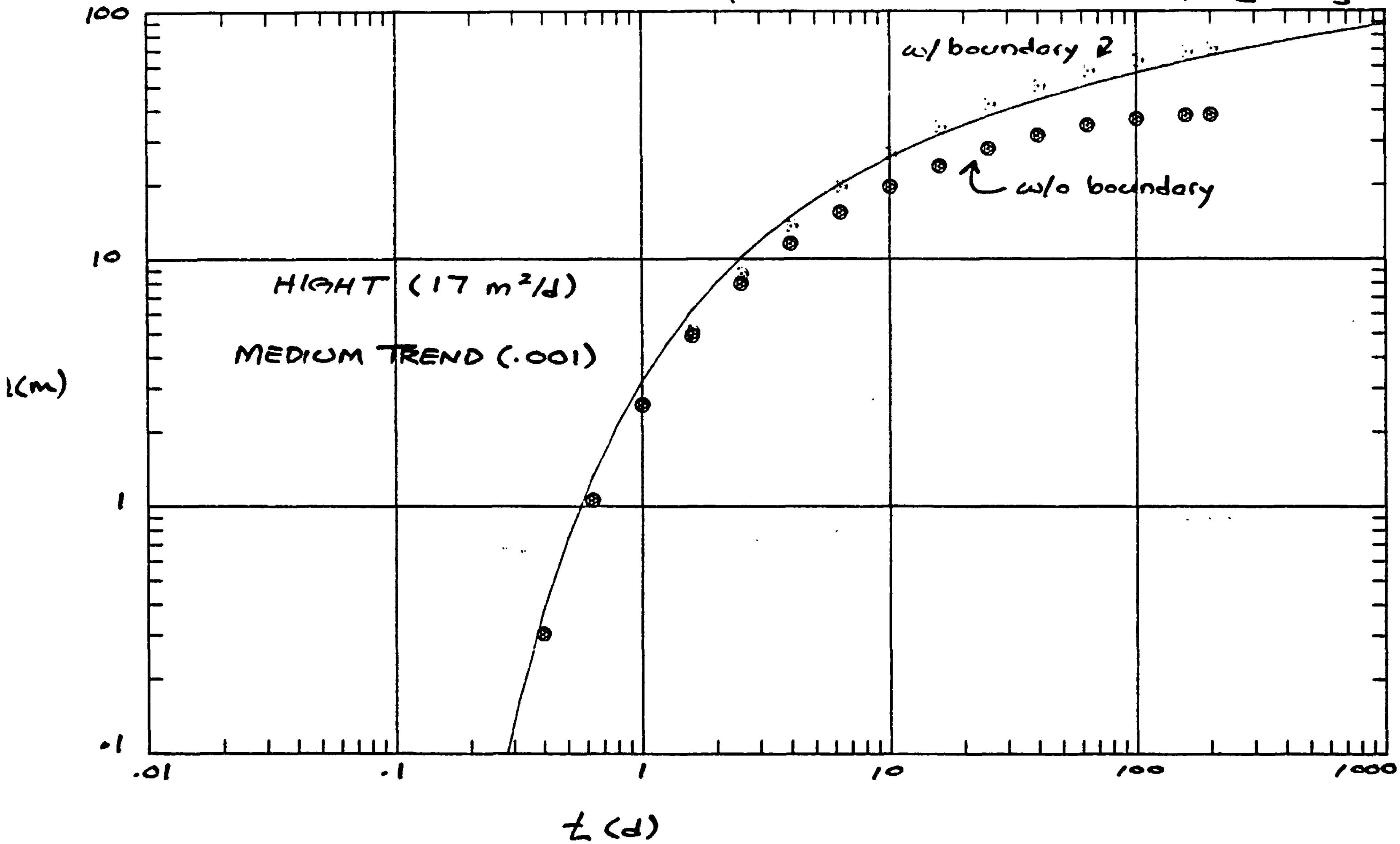
TEST INTERVAL: GR5
PUMPING WELL: RRL-2B
OBSERVATION WELL: DC-22
BOUNDARY: IMPERMEABLE
$r_i = 5470$

$Q = 2980$
$T = 17$
$S = 10^{-5}$
$r = 2570$
$r/B = .297$
$\beta = .102$

CASES: 9A, 9B

TREND: + 0.001

UNITS: [m-d]



APPENDIX B

TECHNICAL MEMORANDUM

From: Fred Marinelli Date: December 20, 1985

To: Adrian Brown
Mike Galloway

Re: Analysis of Hyraulic Response in the Rocky Coulee Flow Interior Resulting from Tracer Injection in the Rocky Coulee Flow Top

INTRODUCTION

As discussed in the BWIP document entitled, "Test Plan for Multiple-Well Hydraulic Testing of Selected Units at the RRL-2 Site ...." (SD-BWI-TP-040), Rockwell Hanford Operations (RHO) plans to conduct a series of multiple borehole hydraulic/tracer tests in three Grande Ronde flow tops. An important aspect of the test plan is to measure hydraulic properties of basalt flow interiors by application of the "ratio method" (Neuman and Witherspoon, 1972). This method involves pumping an aquifer (flow top) at a centrally located production well and measuring associated hydraulic responses within the aquifer and in adjacent aquitards (flow interiors). The testing technique requires installation of piezometers in both the aquifer and adjacent aquitards, preferably at the same radial distance from the production well. Using RRL-2B as a production well, these requirements are satisfied by multiple piezometer completions existing at RRL-2C.

In addition to hydraulic testing, RHO plans to simultaneously conduct convergent tracer tests. These tests will involve slug injection of tracers at the aquifer piezometers and monitoring tracer concentrations in groundwater discharged from the production well. Introduction of tracers into the aquifer will be accomplished by momentary injection of chemicals and formation water with hydraulic buildups on the order of 250 meters (820 feet). Since this procedure might be performed while the ratio test is in progress, the following question arises:

> Will the momentary head increase in the aquifer caused by tracer injection result in a transient aquitard response that could potentially interfere with monitoring for the ratio test?

This memorandum presents preliminary calculations to assess the significance hydraulic perturbations in the Rocky Coulee Flow Interior caused by tracer injection in the Rocky Coulee Flow Top.

At this stage, the primary purpose is to outline the analysis technique and present preliminary results and interpretations. More detailed study of this subject will require additional sensitivity analyses to assess aquitard impacts under a variety of conditions potentially existing at the RRL site.

APPROACH

Analyses presented in this memorandum are based on the physical model illustrated in Figure 1. The physical system consists of an aquifer situated between two aquitards. For the case considered herein, the aquifer corresponds to the Rocky Coulee Flow Top and the upper and lower aquitards correspond to the Grande Ronde 2 and Rocky Coulee Flow Interiors, respectively. Formation water with tracer is momentarily injected into the aquifer through an observation borehole. This causes an increase in head (hydraulic buildup) in the aquifer that rapidly decays after injection is terminated. Hydraulic buildup at the interface between the Rocky Coulee Flow Top and Interior creates a pressure perturbation that propogates downward into the aquitard. Since aquifer buildup decays after tracer injection is terminated, it is expected that pressure perturbations in the aquitard will also dissipate with time.

To quantify dissipation of hydraulic transients in the aquitard, use has been made of the analytical model shown in Figure 2. The flow region considered in this model represents a vertical column of aquitard material and corresponds to the shaded portion of the aquitard in Figure 1. Flow in the aquitard is assumed to be one-dimensional and vertical, which is considered a reasonable assumption provided that the ratio of aquifer to aquitard hydraulic conductivity exceeds two orders of magnitude (Neuman and Witherspoon, 1969). Such permeability contrasts are expected to exist in the basalt sequence within the Pasco Basin. The lower boundary of the aquitard is assumed to be maintained at constant head (zero buildup) and the upper boundary (adjacent to the aquifer) experiences time-varying hydraulic buildup which is approximated by a step function. An example of an arbitrary step function is shown in Figure 3.

Hydraulic buildup in the aquitard resulting from an instantaneous change in head at the aquifer boundary can be expressed by the following general equation (adapted from Carslaw and Jaeger, 1959; p 310):

$$s'(z,t) = so * F(tD,zD)$$

$$\text{where: } F(tD,zD) = \sum_{i=0}^{\text{inf}} \left\{ \text{erf}\, \frac{(2i+1)+(1-zD)}{2*SQR(tD)} - \text{erf}\, \frac{(2i+1)-(1-zD)}{2*SQR(tD)} \right\}$$

$$tD = \frac{a'\ t}{B^2}$$

$$a' = \frac{K'}{Ss'}$$

$$zD = z/B$$

s' = aquitard hydraulic buildup [L]
z = vertical coordinate [L]
t = time [T]
so = aquifer hydraulic buildup at time t = 0 [L]
tD = dimensionless time [ ]
zD = dimensionless distance [ ]
a' = aquitard hydraulic diffusivity [L^2/T]
K' = aquitard hydraulic conductivity [L/T]
Ss' = aquitard specific storage [1/L]
B = aquitard thickness [L]

and erf is the error function. The above equation is commonly referred to as the "consolidation equation" in civil engineering literature.

For the case where aquifer buildup is represented as a series of discrete steps (Figure 3), the rule of superposition can be utilized to produce the following equation:

$$s'(z,t) = s1 * F(tD1,zD) + \sum_{n=2}^{N} [sn - s(n-1)] * F(tDn,zD)$$

where: $$tDn = \frac{a'\ (t-tn)}{Ss'\ B^2}$$

sn = aquifer buildup during the nth step [L]
tn = time at beginning of the nth step [T]
N = total number of steps [ ]

The above equation is evaluated using a computer program written for the IBM-PC. The program prompts the user for aquitard hydraulic properties and requires an external file to define the step function for aquifer buildup. Aquitard drawdown for the specified dimensionless distance (zD) is then computed based on an inputted value of time (t).

APPLICATION TO THE ROCKY COULEE FLOW INTERIOR

The analytical approcach described above was applied to conditions expected during injection of tracer into the Rocky Coulee Flow Top. For this analysis, it was assume that tracer and formation water would be injected for a period of one hour, during which hydraulic head in the aquifer would be increased by 250 meters. After termination of tracer injection, it was further assumed that the imposed hydraulic buildup would decrease linearly to zero during the next hour. Hydraulic buildup in the aquifer is illustrated in Figure 4, along with the approximating step function used for the analysis.

Assumed aquitard properties for the Rocky Coulee Flow Interior were consistant with those used by RHO in the review document for axisymetric modeling. These parameters are summarized below:

a' = 0.91 m^2/d (lower bound)
 = 9.1 m^2/d (best guess)
 = 91.0 m^2/d (upper bound)

B = 26.8 m

Hydrographs of buildup vs. time at the midpoint of the aquitard (zD = .5) are shown in Figure 5 for the three values of hydraulic diffusivity given above. Although tracer injection is assumed to affect the aquifer for a period of only two hours (Figure 4), analytical results indicate that associated pressure perturbations in the aquitard would exist considerably longer. For the "best guess" hydraulic diffusivity value of 9.1 m^2/d, a maximum buildup of 0.73 meters is observed in the aquitard approximately 3.25 days after tracer injection. Hydraulic buildup slowely dissipates after this peak, but is still significant 20 days after injection. For the upper bound diffusivity of 91 m^2/d, buildup reaches a peak of 7.3 meters within several hours after injection, but the aquitard response does not fully dissipate until 6 days after injection. In the low diffusivity case, aquitard heads increase very slowely throughout the simulated time period, but do not exceed 0.1 meters at 30 days.

DISCUSSION

Analyses presented herein indicate that hydraulic buildups associated with tracer injection can potentially affect ratio test monitoring within basalt flow interiors. Although hydraulic effects in flow tops are expected to be short-lived, pressure perturbations in adjacent flow interiors may be significant and exhibit considerable time-lag. As a result, the following recommendations are made concerning the performance of tracer tests at the RRL-2 site:

1. It may be advisable to develop a tracer injection methodology that does not produce excessive buildups in the affected flow top. This might be accomplished by injecting tracer through a small-diameter tube which is sealed in the riser pipe just above the test interval

using an inflatible packer. Such equipment would minimize the volume of water injected into the flow top and thus minimize hydraulic buildup during injection.

2. Tracer injection should not be initiated until complete ratio test responses have been identified in RRL-2C piezometers. External aquitard perturbations after this time are likely to have only a minimal affect on ratio test analyses. However, subsequent hydraulic responses associated with tracer injection could complicate interpretations regarding the evaluation of background trends.

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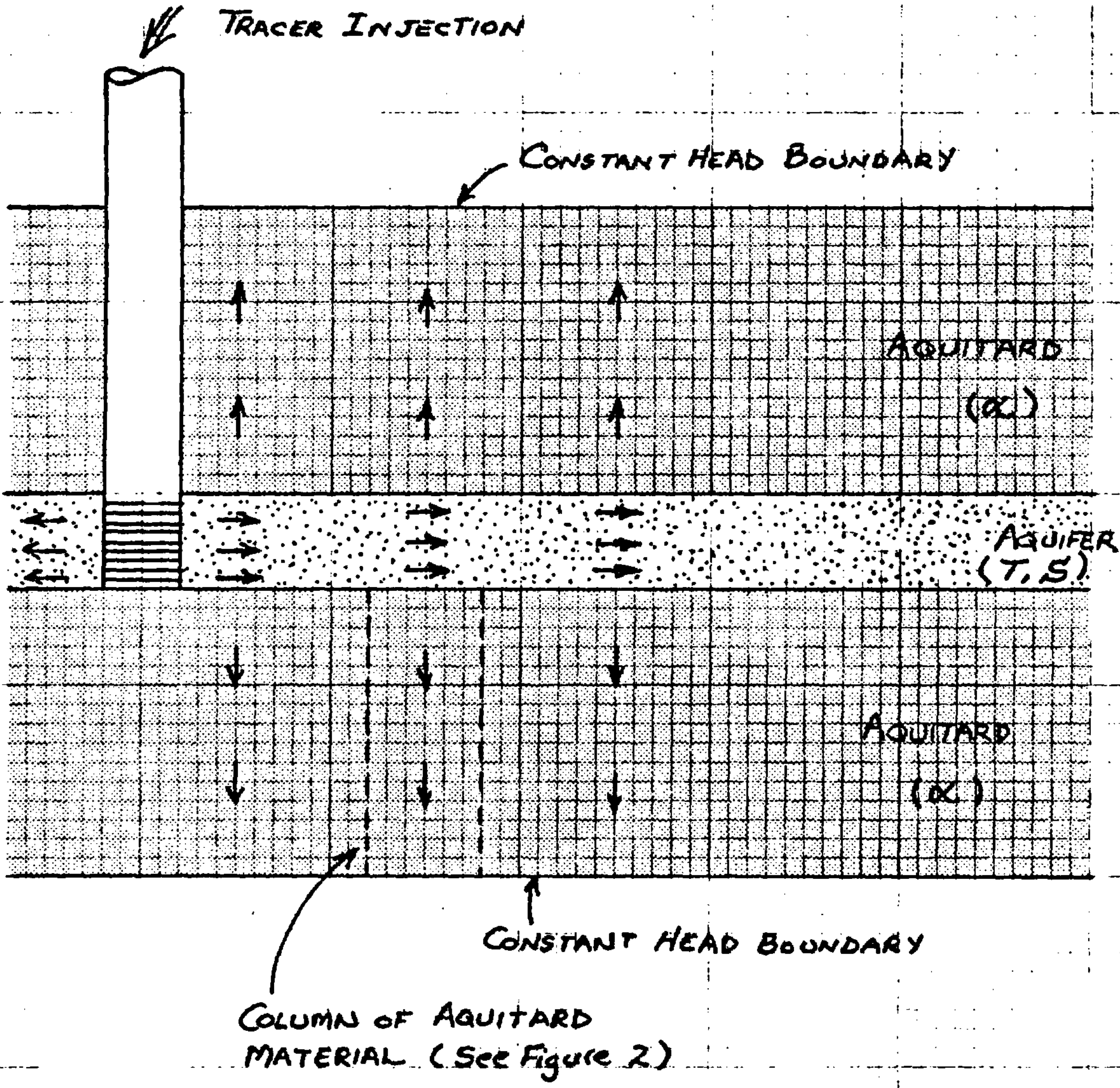

FIGURE 1. PHYSICAL MODEL

46 0703

K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.

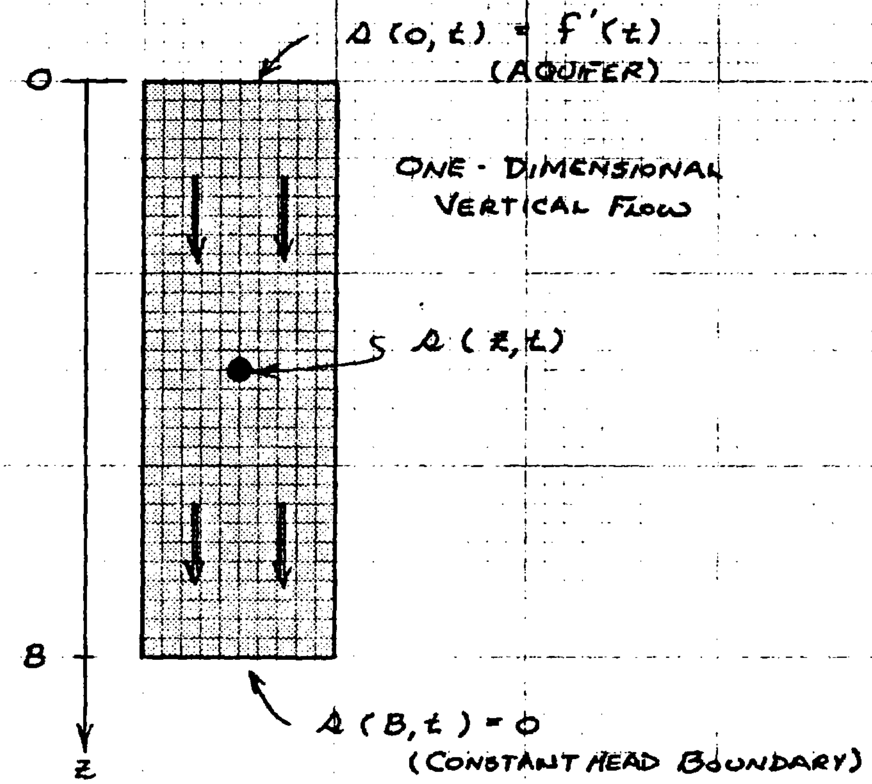

FIGURE 2 ANALYTICAL MODEL

46 0703

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO.

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K&E 10 X 10 TO THE INCH • 7 X 10 INCHES
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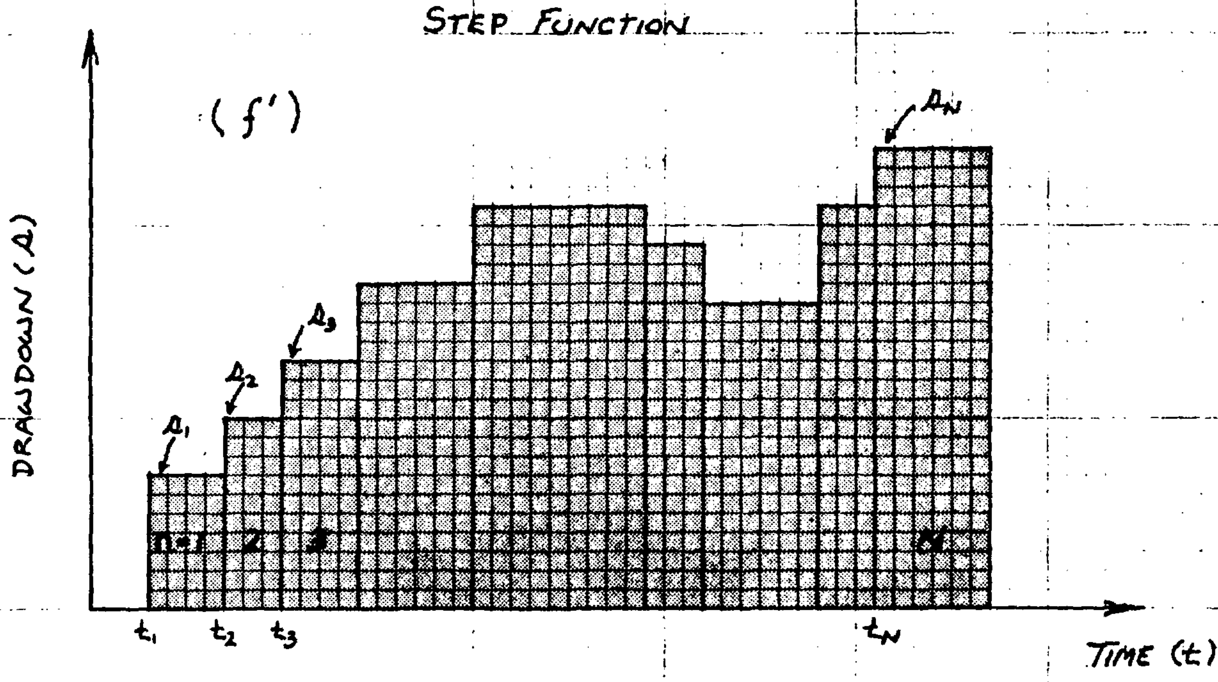
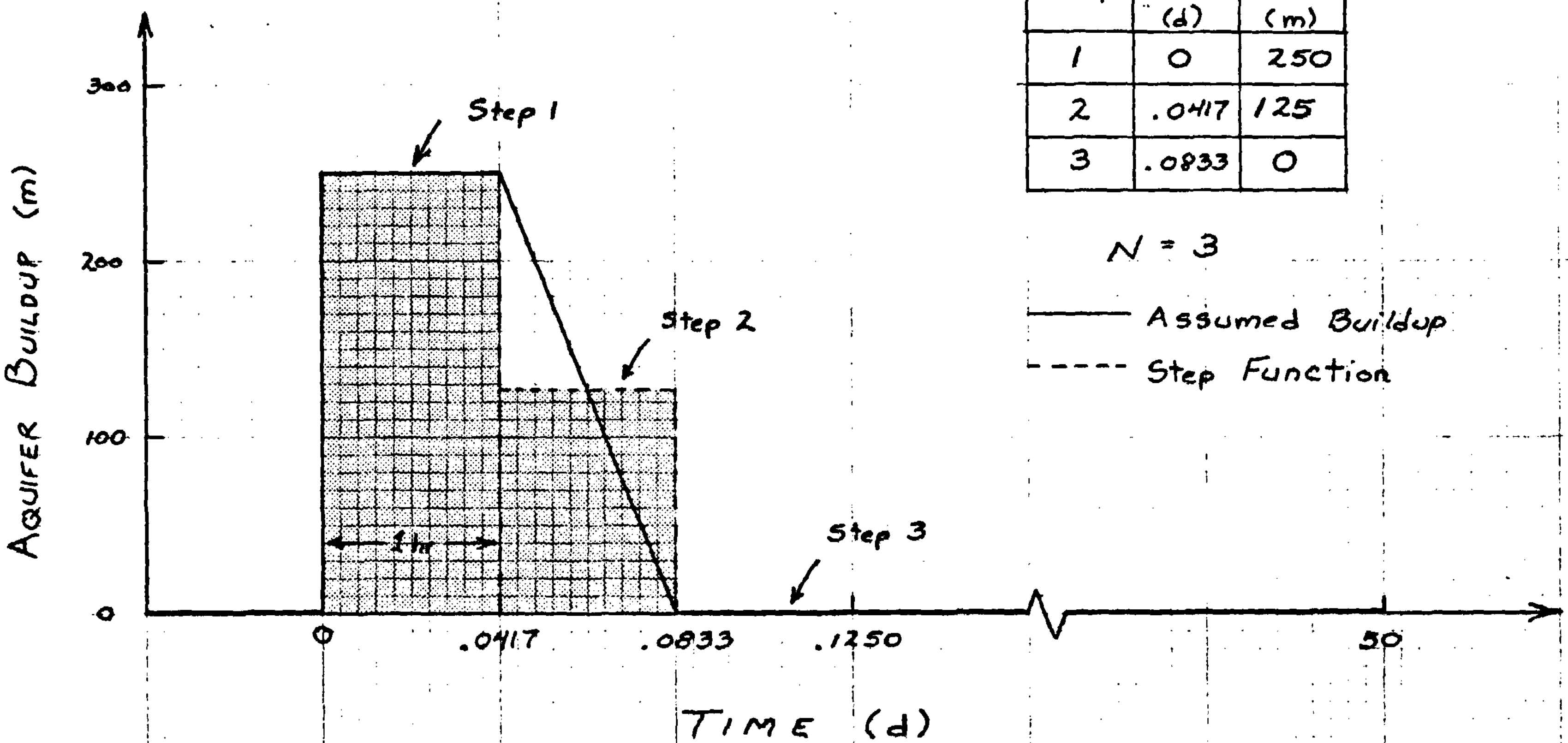
FIGURE 3. BOUNDARY CONDITION FOR ANALYTICAL SOLUTION



$\boxed{f(t) = s_n}$ for $t_n < t \leq t_{n+1}$; $n = 1, 2, 3 \ldots N$

K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 0703

FIGURE 4. ASSUMED AQUIFER BUILDUP



EXPLANATION

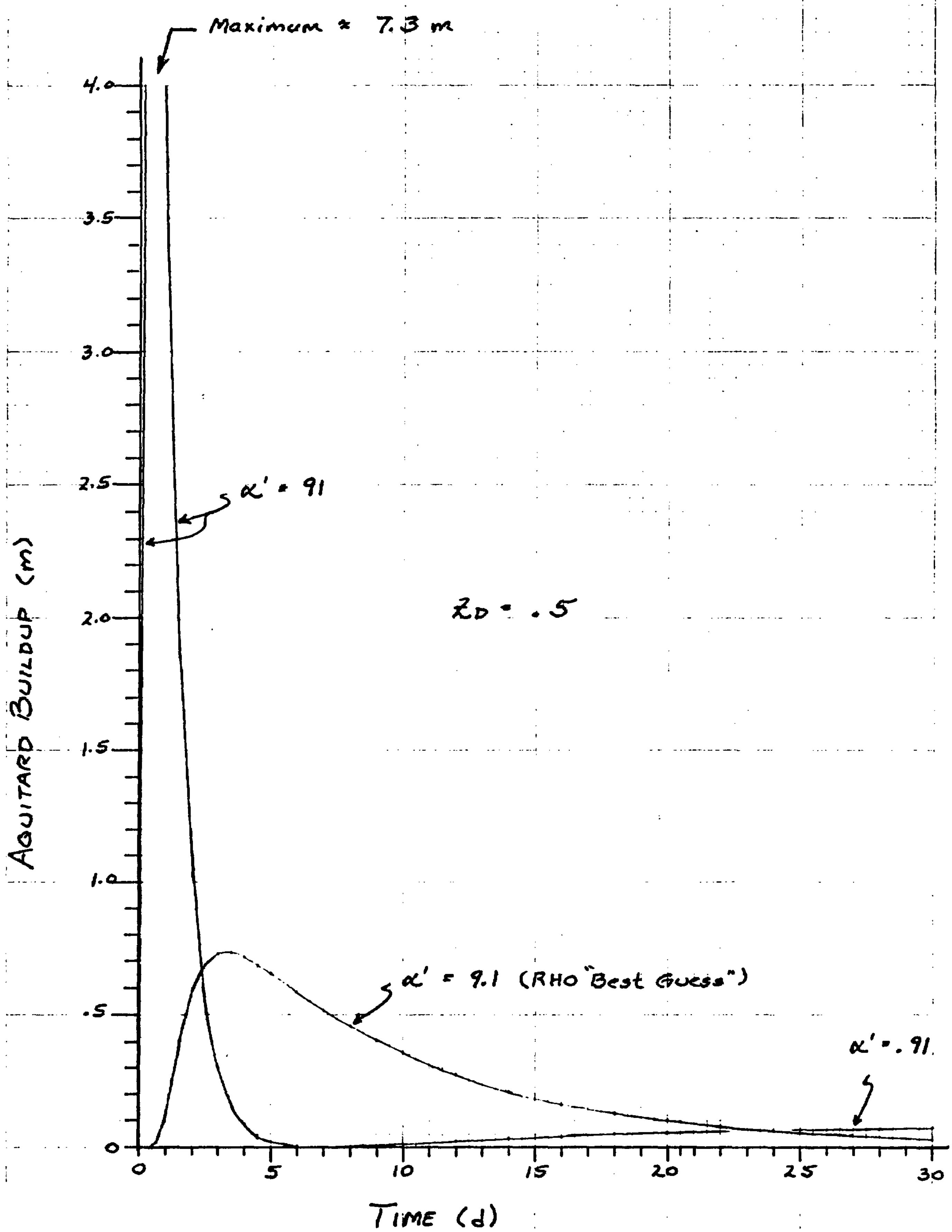
Step	t_r (d)	Q_r (m)
1	0	250
2	.0417	125
3	.0833	0

N = 3

—— Assumed Buildup

- - - - Step Function

FIGURE 5. BUILDUP AT MIDPOINT OF AQUITARD (Z_D = 0.5)



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APPENDIX C

TECHNICAL MEMORANDUM

From: Fred Marinelli

To: Adrian Brown
Mike Galloway

December 20, 1985

Re: Time-Lag in Flow Interior Piezometers

INTRODUCTION

As discussed in the BWIP document entitiled, "Test Plan for Multiple-Well Hydraulic Testing of Selected Hydrogeologic Units at the RRL-2 Site ....", Rockwell Hanford Operations (RHO) plans to conduct ratio tests (Neuman and Witherspoon, 1972) by pumping from a basalt flow top and measuring associated hydraulic responses within the flow top and also in adjacent flow interiors. An important aspect of ratio tests is to accurately measure the aquitard (flow interior) response using piezometers. It is well known that piezometers can experience time-lag when completed in low permeability materials. To reduce time-lag, RHO plans to use closed piezometer systems in which the riser pipe is sealed by a pneumatic packer and hydraulic responses are measured using a downhole electrical pressure transducer. While this design would be acceptable in most geologic situations, the extremely low permeability of dense basalt might still result in time-lag effects that could potentially affect ratio test monitoring.

The effects of time-lag are a major concern in interpreting ratio test data. Test analysis, as presented in Neuman and Witherspoon (1972), is highly sensitive to the time at which the initial aquitard response first arrives at the piezometer. If piezometer time-lag results in an overestimation of the actual response time, calculated hydraulic diffusivity will be less than that actually existing within the aquitard. For performance modeling at the BWIP site, underestimates in the diffusity of dense basalt will result in underestimates of vertical hydraulic conductivity, leading to nonconservative performance assessment calculations.

APPROACH

For calculations performed herein, it is assumed that the time required for recovery of a pulse test is comparable to the time-lag of the installation. In a pulse test, an instantaneous pressure differential is induced between the piezometer and the formation. Re-equilibriation of hydraulic head inside the piezometer is related to the time required for the pressure perturbation to dissipate into the formation. These conditions are mathematically analogous to a situation where an instantaneous pressure change occurs within the formation adjacent to the piezometer. Thus, equations describing pulse test recovery are directly applicable to piezometer response due to a change in formation pressure.

Hydraulic drawdown in a piezometer, experienced after an instantaneous decrease in formation pressure, is given by the following equation (adapted from Bredehoeft and Papadopulos, 1980):

$$s/so = F(a,B) \tag{1}$$

where:

$$a = \frac{PI\ rs^2\ Ss\ L}{Cb} \tag{2}$$

$$B = \frac{PI\ K\ L\ t}{Cb} \tag{3}$$

s = piezometer drawdown [L]
so = initial formation drawdown [L]
F = dimensionless drawdown function [ ]
PI = 3.14159
rs = borehole radius [L]
Ss = specific storage [1/L]
L = piezometer length [L]
Cb = wellbore compressibility [L^2]
K = horizontal hydraulic conductivity [L/T]
t = recovery time [T]

Wellbore compressibility (Cb) is defined as the volume of fluid added to the wellbore per unit increase in hydraulic head. For an open piezometer, Cb is equal to cross-sectional area of the riser pipe. In a closed system, wellbore compressibity is related to the compressibility of borehole fluids and the compliance of downhole equipment (such as expandible packers). For an ideal closed piezometer, a minimum value of Cb is obtained by assuming that wellbore compressibility is related solely to the compressibility of water. In this case:

$$Cb = Yw\ Vw\ Cw \tag{4}$$

where: Yw = specific weight of water [M/L^2/T^2]
Vw = volume of water in piezometer [L^3]
Cw = compressibility of water [LT^2/M]

As discussed by Neuzil (1982), effective wellbore compressibility of real piezometer installations is generally higher than what can be attributed solely to water compressibity. Based on studies reported by Neuzil (1982) and Marinelli and Rowe (1985), it is reasonable to assume that effective Cb is a factor of 2 to 10 times higher that given by the above equation. The actual factor depends on characteristics of the piezometer installation and the borehole fluids.

According to the solution given above, an infinite time is required to achieve complete recovery. For practical purposes, however, it can be assumed that piezometer time-lag is approximately equal to the time required for 90 percent recovery. This corresponds to:

$$s/so = F(a,B90) = 0.1$$

Values of a and B corresponding to a dimensionless drawdown of 0.1 were obtained by linear interpolation from tables provided in Cooper et al (1967), Papadopulos et al (1973), and Bredehoeft and Papadopulos (1980). These values (B90 vs. log[a]) are plotted in Figure 1. Linear regression of the data results in the following empirical relationship:

$$B90 = -1.57 \log(a) + 2.06 \tag{5}$$

Given the value of a, B90 can be calculated. Time required for 90 percent recovery is then determined using the following equation:

$$t90 = \frac{B90\ Cb}{PI\ K\ L} \tag{6}$$

where: t90 = time at 90 percent recovery [T]

APPLICATION TO THE ROCKY COULEE FLOW INTERIOR

Estimates of time-lag for the Rocky Coulee Flow Interior piezometer at RRL-2C were made using the equations given above. These calculations were based on the following parameter values obtained either from the RRL-2 test plan or other relevant technical literature:

rs = .156 m
Ss = 3.6 E-07 1/m
L = 7.01 m
Yw = 1000 N/m^3
Cw = 4.26 E-09 m^2/N

The following range of horizontal hydraulic conductivities were considered, corresponding to RHO's "best guess" value for the Rocky Coulee Flow Interior plus or minus one order of magnitude:

Kh = 3.0 E-08 m/d (lower bound)
= 3.0 E-07 m/d (RHO "best guess")

$= 3.0$ E-06 m/d (upper bound)

To obtain minimum (least conservative) values of piezometer time-lag, wellbore compressibility was calculated based on the compressibility of water. The volume of water inside the closed piezometer was calculated to be 0.148 m^3. This corresponds to the pore volume of a sand pack with 30% porosity and the internal volume of a 23 meter length of riser pipe, but excludes the volume taken up by other riser pipes within the monitoring installation. Using equation (4), the minimum value of wellbore compressibity was calculated to be:

$$Cb(min) = 6.30 \text{ E-07 m}^2$$

and by equation (2), the corresponding value of a was:

$$a = .306$$

Using the empirical relationship in equation (5), B90 was estimated to be:

$$B90 = 2.87$$

Finally, based on an assumed value of horizontal hydraulic conductivity, the time required for 90 percent recovery (assumed equal to time-lag) was computed using equation (6). Figure 2 shows predicted piezometer time-lags, corresponding to a wellbore compressibility of 6.30 E-07 m^2, for the range of horizontal hydraulic conductivity considered.

As previously disscussed, wellbore compressibility based solely on the properties of water tends to underestimate the effective compressibility of the piezometer installation, leading to underestimates of time-lag. To perform more realistic time-lag calculations, wellbore compressibility was increased to 1.9 E-06 m^2. This is a factor of about 3 times greater than the value used in previous calcluations. Using the procedure previously described, B90 was estimated to be 3.62, and predicted time-lags were calculated by equation (6). Figure 2 shows calculated time-lag for the hydraulic conductivity range of interest. We feel these values are more realistic than those asociated with the lower value of wellbore compressibility. As shown in Figure 2, a time lag of one day is estimated for RHO's "best guess" horizontal hydraulic conductivity of 3.0 E-07 m/d. However, if the actual horizontal hydraulic conductivity of dense basalt were as low as 3.0 E-08 m/d, the predicted time-lag could approach 10 days. For an upper-bound horizontal hydraulic conductivity of 3.0 E-06 m/d, the time-lag is 0.1 day.

Pre-analyses conducted by RHO predict initial ratio test responses in the Rocky Coulee Flow Interior ranging from 2 to 50 days (NRC-DOE, 1985), and our analyses suggest that piezometer time-lag could range from 0.1 to 10 days. Thus, considering the range of conditions potentialy existing at the RRL-2 site, piezometer time-lag may or may not be significant factor in interpreting and anlayzing ratio test data. In cases where time-lag is significant, standard ratio test analyses may lead underestimates in vertical hydralulic conductivity, which are nonconservative from the standpoint of performance modeling.

FIELD MEASUREMENT OF TIME-LAG

Since time-lag can be thought of as the time required for recovery of a pulse test, actual field measurement of time-lag for a piezometer installation can be accomplished by performing a standard pulse test and directly measuring (or extrapolating) the time for 90 percent recovery. Piezometers at the RRL-2C site are constructed in such a way that pulse tests can be easily performed. A possible procedure for conducting pulse tests is as follows:

1. Install pressure transducer and pneumatic packer (within the riser pipe) just above the monitored interval.

2. Expand packer and monitor pressure until static conditions prevail or a background trend is well estabilihed.

3. Add a volume of water to the riser pipe, creating a hydraulic head differential between the piezometer and the column of water above the packer. The exact height of water column can be measured by steel tape.

4. Momentarily deflate and inflate the packer to create an instantaneous pressure change within the piezometer.

5. Monitior pressure within the piezometer installation and measure (or extrapolate) the time required for 90 percent recovery.

DISCUSSION

After a ratio test is performed, the time of the initial response in the piezometer can be compared to the measured or computed time-lag of the installation. If the facility time-lag is sufficiently less than the initial response time, it can be concluded that time-lag effects need not be considered in interpreting and analyzing ratio test data. If, however, time-lag is comparable to the initial response time, corrections to the data may be required in order to predict the true aquitard response. In extreme cases, piezometer response may be dominated by time-lag effects. This might occur in situations where vertical hydraulic conductivity is relatively high, but the associated (rapid) aquitard response can not be measured due to time-lag effects. In this case, it may only be possible to calcluate a lower bound value of vertical hydraulic conductivity using the ratio method.

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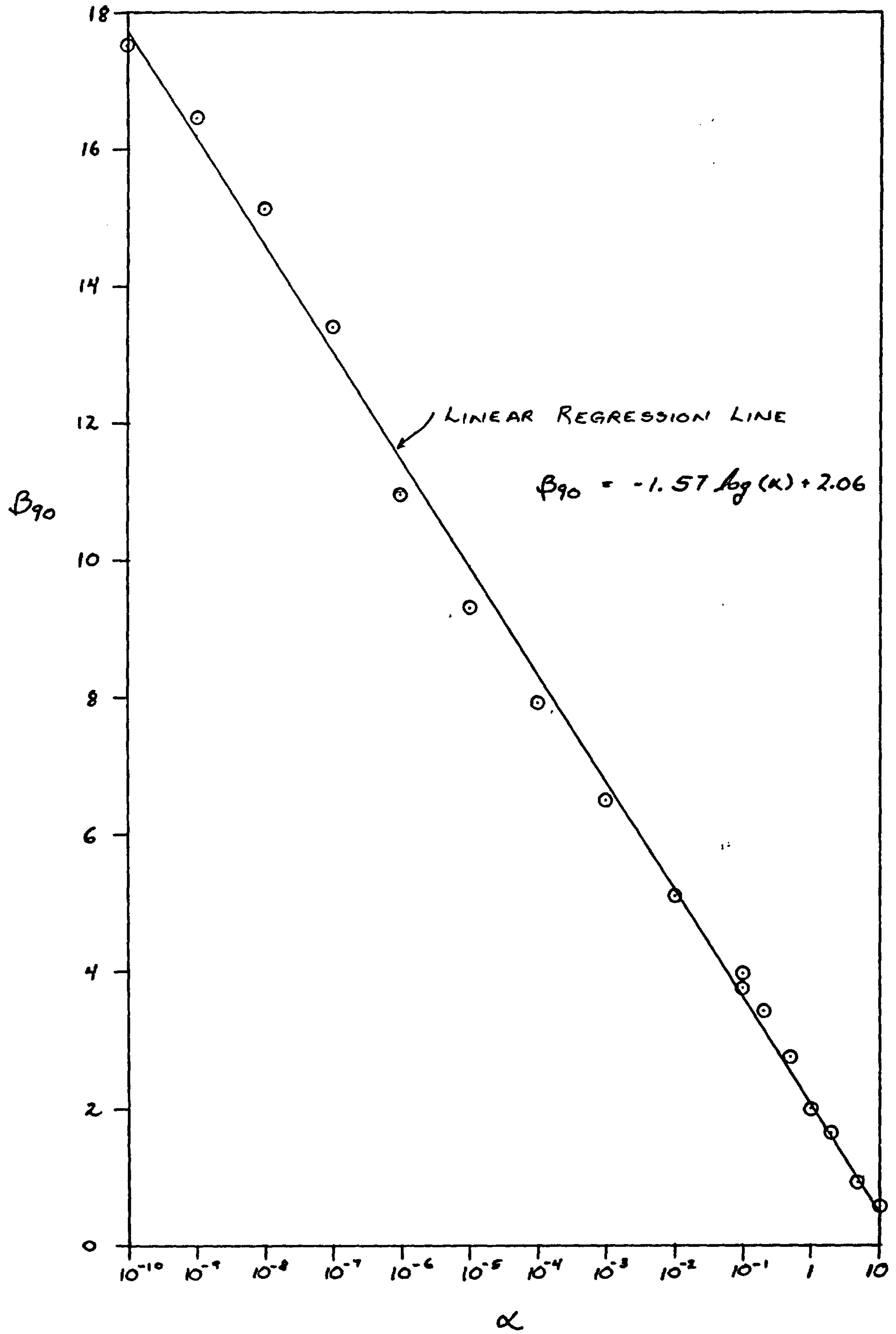
FIGURE 1. RELATIONSHIP BETWEEN β and α For 90 PERCENT RECOVERY ($F(\alpha, \beta) = 0.1$)



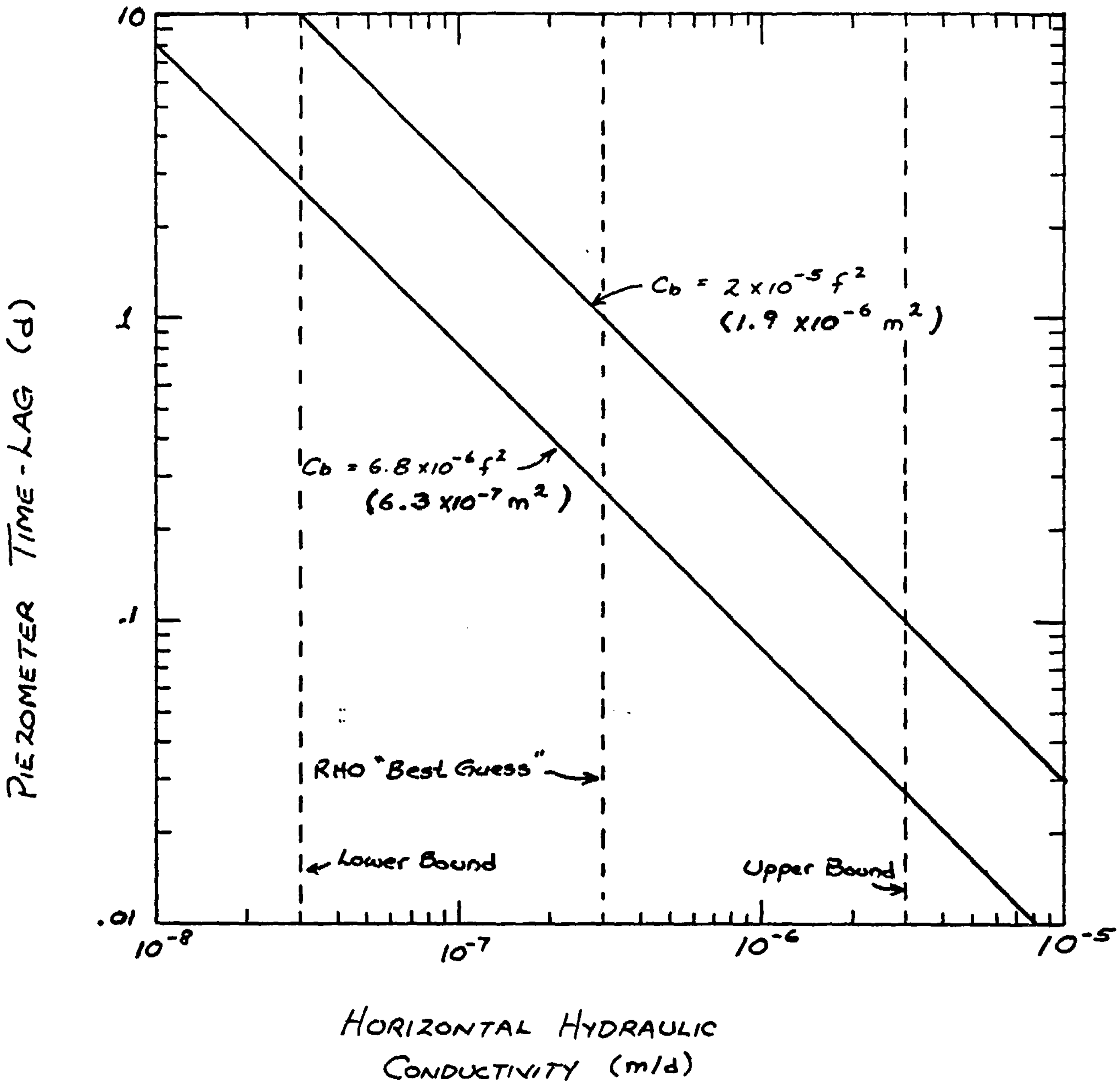


FIGURE 2 PREDICTED TIME-LAG IN ROCKY COULEE FLOW INTERIOR PIEZOMETER AT RRL-2C