

**Contract No:**

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

**Disclaimer:**

This work was prepared under an agreement with and funded by the U.S. Government. Neither the U. S. Government or its employees, nor any of its contractors, subcontractors or their employees, makes any express or implied:

- 1 ) warranty or assumes any legal liability for the accuracy, completeness, or for the use or results of such use of any information, product, or process disclosed; or
- 2 ) representation that such use or results of such use would not infringe privately owned rights; or
- 3) endorsement or recommendation of any specifically identified commercial product, process, or service.

Any views and opinions of authors expressed in this work do not necessarily state or reflect those of the United States Government, or its contractors, or subcontractors.

## **Electromagnetic Borehole Flowmeter (EBF) Testing in R-area (U)**

Westinghouse Savannah River Company  
Savannah River Site  
Aiken, SC 29808

---



### **Disclaimer**

**This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights. References herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring the United States Government of any agency thereof. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.**

## **Electromagnetic Borehole Flowmeter (EBF) Testing in R-area (U)**

Gregory P. Flach, Frank C. Sappington, W. Pernell Johnson and Robert A.  
Hiergesell

Westinghouse Savannah River Company  
Savannah River Site  
Aiken, SC 29808

---



**Electromagnetic Borehole Flowmeter Testing in R-area (U)**

## Authentication and Approvals:

\_\_\_\_\_  
Gregory P. Flach, Author Date

\_\_\_\_\_  
Frank C. Sappington, Author Date

\_\_\_\_\_  
W. Pernell Johnson, Author Date

\_\_\_\_\_  
Robert A. Hiergesell, Author Date

\_\_\_\_\_  
Mark B. Amidon, Technical Reviewer Date

\_\_\_\_\_  
Mary K. Harris, L4 Manager Date

\_\_\_\_\_  
Joette G. Sonnenberg, L3 Manager Date

## EXECUTIVE SUMMARY

Six constant-rate, multiple-well aquifer tests were recently conducted in R-area to provide site-specific *in situ* hydraulic parameters for assessing groundwater flow and contaminant transport models of R-Reactor Seepage Basins (RRSB) plume migration and RRSB remedial alternatives. The pumping tests were performed in the Upper Three Runs and Gordon aquifers between December 1999 and February 2000. The tests provide reliable estimates of horizontal conductivity averaged over aquifer thickness, and a relatively large horizontal zone of influence. To complement these results, Electromagnetic Borehole Flowmeter (EBF) testing was subsequently performed to determine the vertical variation of horizontal conductivity for RPC-2PR, RPC-3PW, RPT-2PW, RPT-3PW, RPT-4PW and RPT-30PZ. The EBF data generally indicate significant aquifer heterogeneity over the tested screen intervals (Figures 14, 16-18, 20, 22, 24, 26 and 27-31). The vertical variation of groundwater flow in or out of the well screen under ambient conditions was also measured (Figures 13, 15, 19, 21, 23 and 25). These data have implications for contaminant monitoring.

Regarding future deployments, concerns about bypass flow in filter-packed wells have hindered EBF deployment at the SRS. Recently published analyses of bypass flow, the extensions developed in this report, and R-area EBF testing indicate that bypass flow will not be a serious problem in a typical SRS monitoring well. Furthermore, the head losses that drive bypass flow and cause additional flow redistribution effects can be practically eliminated in future deployments by using the 1" EBF for dynamic testing, lower pumping rates with the ½" EBF, or no EBF packer.

This page intentionally left blank

## Contents

Executive summary .....	iii
Tables .....	vi
Figures .....	viii
Appendices .....	x
Introduction .....	1
Borehole flowmeter designs .....	1
Borehole flowmeter testing .....	2
Analysis of borehole flowmeter field data .....	2
Systematic errors due to transient effects .....	5
Systematic errors due to well filter pack .....	9
Systematic errors due to EBF head loss .....	9
Systematic errors due to combined EBF head loss and filter pack .....	10
R-area field experience.....	13
Power supply .....	13
Cable.....	13
Packer .....	13
Uphole electronics .....	14
EBF calibration results .....	14
R-area conductivity profile results .....	15
RPC-1PW .....	15
RPC-2PR .....	15
RPC-3PW .....	17
RPT-2PW .....	18
RPT-3PW .....	19
RPT-4PW .....	19
RPT-30PZ.....	20
Post-test checks for quasi-steady flow conditions .....	20
Comparison of EBF conductivity profiles to Cone Penetration Testing (CPT) data .....	21
Alternative conductivity estimates using Cooper-Jacob analysis.....	21
Considerations and recommendations for future EBF deployment.....	22
Existing SRS monitoring wells .....	22
Contaminant monitoring implications.....	22
Equipment issues.....	23
Optimal EBF testing.....	23
References .....	24



## Tables

Table 1	R-area well information.....	26
Table 2	Peer-reviewed journal publications addressing systematic errors in borehole flowmeter analysis.....	27
Table 3	Constant-head permeameter measurements for FX-50 filter pack.....	28
Table 4	Calibration data for the ½” ID EBF.....	29
Table 5	Calibration data for the 1” ID EBF.....	30
Table 6	Hydraulic conductivity profile and bypass flow estimate for RPC-2PR .....	31
Table 7	Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for ½” EBF, 5 L/min nominal flow and 1 ft increments .....	32
Table 8	Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for ½” EBF, 5 L/min nominal flow and 5 ft increments .....	33
Table 9	Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for ½” EBF, 5 L/min nominal flow and 10 ft increments .....	34
Table 10	Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for 1” EBF, 15 L/min nominal flow and 1 ft increments .....	35
Table 11	Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for 1” EBF, 15 L/min nominal flow and 5 ft increments .....	36
Table 12	Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for 1” EBF, 15 L/min nominal flow and 10 ft increments .....	37
Table 13	Hydraulic conductivity profile and bypass flow estimate for RPT-2PW .....	38
Table 14	Hydraulic conductivity profile and bypass flow estimate for RPT-3PW .....	39
Table 15	Hydraulic conductivity profile and bypass flow estimate for RPT-4PW .....	40
Table 16	Hydraulic conductivity profile and bypass flow estimate for RPT-30PZ.....	41
Table 17	Post-test check for quasi-steady flow conditions at RPC-2PR.....	42
Table 18	Post-test check for quasi-steady flow conditions at RPC-3PW.....	43
Table 19	Post-test check for quasi-steady flow conditions at RPT-2PW.....	44
Table 20	Post-test check for quasi-steady flow conditions at RPT-3PW.....	45
Table 21	Post-test check for quasi-steady flow conditions at RPT-4PW.....	46
Table 22	Post-test check for quasi-steady flow conditions at RPT-30PZ .....	47

**Tables (Continued)**

Table 23	Summary of post-test checks for quasi-steady flow conditions .....	48
----------	--	----

## Figures

Figure 1	Schematic diagram of the Electromagnetic Borehole Flowmeter; reproduced from Molz and Young (1993).....	49
Figure 2	Electromagnetic Borehole Flowmeter (EBF) application of Faraday's Law of Induction; reproduced from Molz and Young (1993) .....	50
Figure 3	Schematic illustration of borehole flowmeter testing; reproduced from Molz and Young (1993) .....	51
Figure 4	Basic geometry and analysis of borehole flowmeter data; reproduced from Molz and Young (1993).....	52
Figure 5	Systematic errors in borehole flowmeter estimation due to transient effects .....	53
Figure 6	Head-loss-induced flow redistribution; reproduced from Dinwiddie and others (1999).....	54
Figure 7	Effect of head-loss-induced flow redistribution for a 4" ID, 20 ft long, nonpacked, well screen; bar graph shows the calculated nondimensional hydraulic conductivity distribution when the true K is 9.1 m/day and the pumping rate is 5 L/min; reproduced from Dinwiddie and others (1999).....	55
Figure 8	Bypass flow through filter pack induced by EBF head loss; reproduced from Dinwiddie and others (1999) .....	56
Figure 9	Bypass flow simulation; reproduced from Dinwiddie and others (1999) .....	57
Figure 10	Constant-head permeameter design and dimensions.....	58
Figure 11	Calibration data and curve for the ½" ID EBF .....	59
Figure 12	Calibration data and curve for the 1" ID EBF .....	59
Figure 13	Ambient flow measurements for RPC-2PR .....	60
Figure 14	Estimated hydraulic conductivity variation for RPC-2PR .....	60
Figure 15	Ambient flow measurements for RPC-3PW .....	61
Figure 16	Estimated hydraulic conductivity variation for RPC-3PW at 1 ft intervals using the ½" and 1" ID EBFs .....	61
Figure 17	Estimated hydraulic conductivity variation for RPC-3PW at 5 ft intervals using the ½" and 1" ID EBFs .....	62
Figure 18	Estimated hydraulic conductivity variation for RPC-3PW at 10 ft intervals using the ½" and 1" ID EBFs .....	62
Figure 19	Ambient flow measurements for RPT-2PW .....	63
Figure 20	Estimated hydraulic conductivity variation for RPT-2PW.....	63

**Figures (cont'd)**

Figure 21	Ambient flow measurements for RPT-3PW .....	64
Figure 22	Estimated hydraulic conductivity variation for RPT-3PW.....	64
Figure 23	Ambient flow measurements for RPT-4PW .....	65
Figure 24	Estimated hydraulic conductivity variation for RPT-4PW.....	65
Figure 25	Ambient flow measurements for RPT-30PZ.....	66
Figure 26	Estimated hydraulic conductivity variation for RPT-30PZ.....	66
Figure 27	Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-average conductivity for RPC-2PR .....	67
Figure 28	Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-average conductivity for RPC-3PW .....	67
Figure 29	Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-average conductivity for RPT-30PZ.....	68
Figure 30	Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-average conductivity for RPT-2PW .....	68
Figure 31	Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-average conductivity for RPT-3PW and RPT-4PW .....	69

## Appendices

Appendix A	RPC-1PW field data .....	A-1
Appendix B	RPC-2PR field data .....	B-1
Appendix C	RPC-3PW field data .....	C-1
Appendix D	RPT-2PW field data .....	D-1
Appendix E	RPT-3PW field data .....	E-1
Appendix F	RPT-4PW field data .....	F-1
Appendix G	RPT-30PZ field data.....	G-1

## Introduction

Six constant-rate, multiple-well aquifer tests were recently conducted in R-area to provide site-specific *in situ* hydraulic parameters for assessing groundwater flow and contaminant transport models of R-Reactor Seepage Basins (RRSB) plume migration and RRSB remedial alternatives (Hiergesell, 1999; WSRC, 2000; Hiergesell and others, 2000). The pumping tests were performed in the Upper Three Runs and Gordon aquifers between December 1999 and February 2000. The tests provide reliable estimates of horizontal conductivity averaged over aquifer thickness, and a relatively large horizontal zone of influence. Table 1 summarizes the findings of Hiergesell and others (2000). To complement these results, Electromagnetic Borehole Flowmeter (EBF) testing was subsequently performed to determine the vertical variation of horizontal conductivity about the average determined from the conventional aquifer testing. This report introduces the borehole flowmeter concept and EBF instrument, summarizes field and calculation procedures, presents EBF test results for 7 R-area wells, and provides recommendations for future application of the technology at the Savannah River Site.

## Borehole flowmeter designs

The term “borehole flowmeter” in this report refers to any instrument that measures the *vertical* flow inside a well casing, whether under ambient or pumping conditions. Various types of borehole flowmeters have been used in field applications, including heat pulse, tracer release and impeller (spinner) designs. Among these, only impeller flowmeters had been commercially available through the 1980s (Molz and others, 1989). Unfortunately, impeller designs contain fragile moving parts and bearings that are susceptible to degradation/clogging by suspended particles, impacts, etc. Young and Waldrop (1989) analyzed impeller flowmeter calibration data and concluded that the calibration curve is very sensitive to the condition of the bearings; therefore, frequent maintenance and calibration are required to ensure accurate data. Even so, most impeller flowmeters did not accurately measure flows below about 5 L/min (Molz and others, 1989).

To remedy these deficiencies, researchers at the Tennessee Valley Authority (TVA) developed, patented and commercialized a robust, highly-sensitive, borehole flowmeter based on electromagnetic principles in the late 1980s and early 1990s. The Electromagnetic Borehole Flowmeter (EBF) operates according to Faraday’s Law of Induction, which states that the voltage induced by a conductor moving at right angles through a magnetic field is directly proportional to the velocity of the moving conductor (Waldrop, 1995). Schematic diagrams of the EBF are shown in Figures 1 and 2 (Molz and Young, 1993). Groundwater acts as the moving conductor, an electromagnet generates the magnetic field, and electrodes measure the induced voltage. The ½” ID EBF has a threshold flowrate of about 5 mL/min, which is 1000 times more sensitive than the typical impeller flowmeter. Flowrates up about 10 L/min can be measured, giving the ½” ID EBF outstanding range. The 1” ID EBF can measure flows from about 40 mL/min to 40 L/min (Waldrop, 1995). Both the ½” and 1” EBF instruments were chosen for aquifer testing in R-area.

## Borehole flowmeter testing

The idea behind borehole flowmeter testing is to relate horizontal conductivity as a function of elevation,  $K(z)$ , to borehole discharge as a function of elevation  $Q(z)$ . The field procedure is schematically illustrated in Figure 3 (Molz and Young, 1993). Under quasi-steady pumping conditions, borehole discharge ( $Q$ ) from the bottom of the screen up to the current flowmeter position is measured as a function of elevation ( $z$ ). As shown in Figure 4, the difference ( $\Delta Q$ ) in borehole discharge  $Q(z)$  between at any two locations is the flowrate of groundwater entering the well casing over that interval. This differential flowrate, minus any ambient flow effects, is proportional to the horizontal conductivity of the aquifer over that interval. Ambient flow refers to horizontal flow through the well screen and vertical flow in the casing under natural, undisturbed conditions. In order to rigorously account for potential ambient flow effects, the standard borehole flowmeter test procedure actually involves two series of measurements:

- 1) under ambient conditions, measure the vertical flowrate inside the well screen at 1 to 2 ft intervals,
- 2) pump (or inject) at a constant rate above the screen zone and borehole flowmeter,
- 3) pause until the drawdown becomes quasi-steady-state,
- 4) under these quasi-steady-state pumping conditions, again measure the vertical flowrate inside the well screen at 1 to 2 ft intervals.

The quasi-steady conditions referred to in step 3) are reported to occur rapidly (e.g. 30 minutes). The ambient flow data is also useful by itself for determining the direction(s) of vertical head gradients in the surrounding aquifer, which has contaminant monitoring implications to be discussed later. Molz and Young (1993) provide a quantitative criterion for determining when quasi-steady conditions have been reached in step 3), and develop methods for analyzing the data as discussed below.

## Analysis of borehole flowmeter field data

Molz and others (1989) and Molz and Young (1993) present two methods for estimating the vertical variation of horizontal conductivity from field measurements of borehole discharge as a function of depth, such as those provided by the EBF (see also Rehfeldt and others (1989)). Both methods assume a fully-penetrating well in a confined aquifer. The first method applies the Cooper-Jacob (1946) method to individual sub-intervals of the well screen to estimate conductivity as a function of vertical position. Alternatively, the relative variation of horizontal conductivity about vertically-averaged  $K$  can be directly related to the EBF measurements of borehole discharge as a function of depth. If the vertical average is known or can be estimated by other means (e.g. pumping test), then the conductivity profile can be determined. The first method produces conductivity estimates from EBF test data alone, but involves a number of uncertain parameters. The second method is simpler and more precise, but requires an independent estimate of average conductivity. In R-area, a conventional pumping test result is available for each

EBF tested well. Therefore, the second approach presented by Molz and Young (1993) is preferred for the present application. Nevertheless, both methods are presented in order to later compare results.

As discussed previously, the field procedure involves measuring the vertical flowrate within the well casing at regular intervals, typically every 1 to 2 ft, first under ambient conditions and then under pumping conditions. The difference between any two readings is the flow entering the well between the two corresponding elevations. A negative value implies that flow is leaving the well. To develop the first method, the Cooper-Jacob equation is applied to each layer as

$$\Delta h_i(r_w, t) = \frac{(\Delta Q_i - \Delta q_i)}{2\pi K_i \Delta z_i} \ln \left( \frac{1.5}{r_w} \sqrt{\frac{K_i \Delta z_i t}{S_{si} \Delta z_i}} \right) \quad (1)$$

where

$\Delta h_i \equiv$  drawdown

$\Delta Q_i - \Delta q_i \equiv$  net differential flow

$\Delta Q_i \equiv$  difference in EBF flow at the top and bottom of the  $i^{\text{th}}$  interval under *pumping* conditions

$\Delta q_i \equiv$  difference in EBF flow at the top and bottom of the  $i^{\text{th}}$  interval under *ambient* conditions

$K_i \equiv$  horizontal conductivity of  $i^{\text{th}}$  layer

$\Delta z_i \equiv$  thickness of  $i^{\text{th}}$  layer

$r_w \equiv$  well bore radius

$t \equiv$  elapsed time

$S_{si} \equiv$  specific storage of  $i^{\text{th}}$  layer

Assuming negligible borehole flowmeter losses under low flow conditions, each layer experiences the same measured drawdown,  $\Delta h$ . The numerical simulations of Javandel and Witherspoon (1969) indicate that the transient drawdown responses of layers in a heterogeneous aquifer quickly merge into a common response described by the Theis solution using averaged aquifer properties. This observation suggests that each layer effectively behaves as if it has the hydraulic diffusivity of the entire aquifer:

$$\frac{K_i \Delta z_i}{S_{si} \Delta z_i} = \frac{T}{S} = v \quad (2)$$



In this expression

$v \equiv$  hydraulic diffusivity of the entire aquifer

$T \equiv$  transmissivity of the entire aquifer

$S \equiv$  storage coefficient (storativity) of the entire aquifer

With this assumption, one of two proposed by Molz and others (1989), equation (1) becomes after solving for  $K_i$

$$K_i = \frac{(\Delta Q_i - \Delta q_i)}{2\pi\Delta z_i\Delta h} \ln \left( \frac{1.5}{r_w} \sqrt{\frac{Tt}{S}} \right) \quad (3)$$

With a prior estimate of aquifer diffusivity ( $T/S$ ), equation (3) provides a direct estimate of horizontal conductivity for the  $i^{\text{th}}$  layer. Fortunately, the Cooper-Jacob estimate is not highly sensitive to the assumed value of  $T/S$  for large times, because diffusivity appears within a square-root and logarithm. However, well inefficiencies introduce significant uncertainty in the drawdown experienced by the formation,  $\Delta h$ .

The data analysis procedure for the second method presented by Molz and Young (1993) is summarized by

$$\frac{K_i}{\bar{K}} = \frac{(\Delta Q_i - \Delta q_i)/\Delta z_i}{\sum_i (\Delta Q_i - \Delta q_i) / \sum_i \Delta z_i} \quad (4)$$

where

$K_i \equiv$  horizontal conductivity of the  $i^{\text{th}}$  interval

$\bar{K} \equiv$  vertically-averaged conductivity

$\Delta Q_i \equiv$  difference in EBF flow at the top and bottom of the  $i^{\text{th}}$  interval under *pumping* conditions

$\Delta q_i \equiv$  difference in EBF flow at the top and bottom of the  $i^{\text{th}}$  interval under *ambient* conditions

$\Delta z_i \equiv$  height of the  $i^{\text{th}}$  interval.

In equation (4),  $(\Delta Q_i - \Delta q_i)$  is the net flowrate induced by pumping and accounts for ambient flow effects. Note that the relative conductivity distribution is equal to the relative distribution of net flow entering the well, which is assumed to occur after the initial transient passes and quasi-steady conditions develop. The basis for this assumption is considered further in the next section.

Both methods, summarized by equations (3) and (4), assume that flow approaching the well is horizontal and driven by a vertically-uniform radial head gradient. Any deviations from this assumption in the flow field will introduce systematic biases in the relative conductivity profile computed from either equation. Therefore, pre-testing consideration should be given to identifying, and minimizing if possible, any conditions that will violate the above assumption. For example, non-horizontal flow will occur in an unconfined aquifer if the drawdown is significant, but can be minimized by pumping at a small rate. A partially-penetrating well screen would also create vertical flows. More subtle sources of vertical flow leading to systematic errors are 1) transient effects in the presence of aquifer heterogeneity, 2) a high conductivity filter pack, and 3) head losses across the EBF. Table 2 summarizes peer-reviewed journal articles dealing with these biases, individually and in combination. Each category is discussed in more detail below.

### **Systematic errors due to transient effects**

The most common method of analysing borehole flowmeter data, described by equation (4), depends on the discharge from each layer being proportional to layer transmissivity. This assumption is not valid at early times when transient storage effects dominate, but becomes increasingly accurate at later times. Systematic errors due to transient effects can be mitigated by waiting until "pseudo-steady" conditions are established. Exactly when such conditions are reached is not entirely clear from the literature, but acceptable criteria have been presented in the literature and are further developed in this section, as discussed below.

The data analysis method is based on Javandel and Witherspoon (1969) who conducted an early numerical study of a two-layer confined aquifer with permeability contrasts up to 100:1. Specific storage was assumed to be constant (Kabala, 1994) so the ratio also applies to hydraulic diffusivity. They found that for non-dimensional times

$$t_D \equiv \frac{1}{u} \equiv \frac{4Tt}{Sr^2} \quad (5)$$

exceeding 400 to 4000 (i.e.  $Tt/Sr^2 > 100$  to 1000), and a non-dimensional radius  $r/b$  exceeding 0.125, the transient drawdown in each layer followed that predicted by Theis (1935) based on average aquifer properties (Javandel and Witherspoon, 1969, Figures 5 and 6). In definition (5) and the non-dimensional radius

$T \equiv$  transmissivity of entire aquifer ( $Kb$ )

$t \equiv$  time

$S \equiv$  storage coefficient

$r \equiv$  radius

$b \equiv$  entire aquifer thickness

They also observed that “cross-flow near the well bore diminishes with time until finally at large values of time the directions of flow are almost horizontal. Under these conditions the radial gradients along the well bore are uniform and constant, and flux into the well within a given layer is simply proportional to the permeability of that layer” (see Javandel and Witherspoon, 1969, Figures 7 and 8). Figures 7 and 8 in Javandel and Witherspoon (1969) are described in terms of dimensional time. Because specific storage is not specified, the equivalent non-dimensional time when

$$Q_i \propto T_i \quad (6)$$

(flow proportional to transmissivity) is unknown from these figures. However, horizontal flow at the well bore radius can be inferred to occur when the layer drawdown curves in Figures 5 and 6 of Javandel and Witherspoon (1969) merge into a common response. At this point, no head differences exist to drive crossflow.

Rehfeldt and others (1989) and Molz and others (1989) interpreted horizontal flow to imply condition (6) for practical purposes. This condition occurs when  $t_D > 400$  to 4000, depending on the permeability contrast between layers and aquifer thickness. At the well bore radius, the criterion is rapidly met. At Savannah River Site (SRS) well RPT-4PW for example, the minimum required time is only

$$t = t_D \frac{S_r^2}{T} = (400 \text{ to } 4000) \frac{(1.5 \times 10^{-3})(5/12 \text{ ft})^2}{0.8 \text{ ft}^2 / \text{min}} = 8 \text{ sec to } 1.3 \text{ min} \quad (7)$$

Analysis of other SRS wells in R-area yields similar results. However, a word of caution is in order. The range of  $r/b$  values considered by Javandel and Witherspoon (1969) is not strictly applicable to a typical SRS well (e.g. RPT-4PW). A common example would be a 10 in borehole and a 40 ft screen, or  $r/b = 0.01$ . This non-dimensional radius is an order of magnitude smaller than considered, and implies a larger non-dimensional time before drawdown follows the Theis solution.

Molz and others (1989) also state that “pseudo steady state conditions” are required to obtain equation (4), and that these occur when  $t_D > 100$ , a less restrictive criterion than  $t_D > 400$ . However in subsequent personal communication (e-mail dated July 12, 2000), Dr. Molz discovered that the intended pseudo-steady-state condition was incorrectly stated in the Molz and others (1989). The error was also reproduced in later papers, such as Molz and Young (1993). Instead of using the well bore radius in equation (5), one should substitute “some estimate of the radius of influence of a flowmeter test” according to Dr. Molz. He does not state a specific formula for radius of influence, but a typical value might be a few feet and produce a dimensional time of at least several minutes before borehole flowmeter testing should begin.

The rigor in assuming that horizontal flow at  $t_D > 400$  to 4000 implies condition (6) is not completely clear, and Kabala (1994) subsequently questioned the calculation method summarized by equation (4). He observed however that “since a horizontal flow regime develops in a layered aquifer in the vicinity of a pumped fully penetrating well long

before the quasi-steady state well response is reached [Javandel and Witherspoon, 1968, 1969], it should be possible to design a methodology, based on the Theis [1935] solution, for interpreting flowmeter tests conducted while the well response is still transient.” Kabala (1994) assumed that, after a brief initial period (e.g.  $t_D > 400$ ), drawdown in each layer can be described by the Theis solution using layer properties and a contribution,  $Q_i$ , to total flow,  $Q$ . Equating this drawdown with the Theis drawdown based on aquifer average properties yields

$$\frac{T_i}{T} = \frac{Q_i}{Q} \frac{W\left(\frac{Sr^2}{4Tt} \frac{T/S}{T_i/S_i}\right)}{W\left(\frac{Sr^2}{4Tt}\right)} = \frac{Q_i}{Q} \frac{W\left(\frac{1}{t_D} \frac{T/S}{T_i/S_i}\right)}{W\left(\frac{1}{t_D}\right)} \equiv \frac{Q_i}{Q} \frac{W(u\gamma)}{W(u)} \equiv \frac{Q_i}{Q} \eta(u, \gamma) \quad (8)$$

In this expression, layer transmissivity is only strictly proportional to layer flow for infinitely long times or diffusivity equal to the aquifer average ( $\gamma = 1$ ). The bias in omitting the factor  $\eta$  in conventional borehole flowmeter data analysis is therefore  $1/\eta$ , which is plotted in Figure 5. Figure 5 is therefore the inverse of Figure 1 in Kabala (1994). Incidentally, the curves in Kabala's figure are mislabeled. The upper curve is actually  $\gamma = 10^{-2}$  while the lower curve is  $\gamma = 10^2$ . In Figure 5, “T/S ratio” in the legend is the quantity

$$\log_{10} \frac{T_i/S_i}{T/S} = \log_{10} \frac{1}{\gamma} \quad (9)$$

So, the upper dashed curve corresponds to a low diffusivity layer with  $\gamma = 10^2$ , while the lower solid curve is high diffusivity and  $\gamma = 10^{-2}$ . Kabala (1994) observed that the bias is still significant at  $t_D = 10^7$ , yet borehole data are commonly analyzed for times as early as  $10^4$ . Figure 5 makes sense qualitatively. Consider for example two layers with identical transmissivity, but differing storage coefficient. At early times the layer with the larger storage coefficient (lower diffusivity) would produce more flow in response to a common drawdown. Using the conventional method of data analysis, equation (4), a larger value of conductivity would be computed for this lower diffusivity layer, due to greater layer flow. Thus the estimate would be biased high, as indicated by Figure 5 for low diffusivity. Conversely, estimates for high diffusivity layers would be biased low. Note that the bias is larger for low diffusivity layers than high T/S layers, contrary to Kabala's (1994, p. 686, 2nd column, last full sentence) statement.

While Kabala (1994) attempted a more rigorous analysis of borehole flowmeter testing, the assumption that each layer can be described by the Theis solution using layer properties is contrary to Javandel and Witherspoon (1969), which showed that each layer eventually follows a *common* Theis solution based on aquifer average properties. Equating the layer and aquifer average Theis solutions in Kabala (1994) implies that  $Q_i$  must change with time, unless diffusivity is constant, which is a violation of the constant  $Q$  assumption of Theis. Therefore, the validity of Figure 5 is unclear. Nevertheless,

Kabala (1994) did establish that condition (6) is at least valid at long times and/or constant diffusivity among layers.

Rudd and Kabala (1996) subsequently performed numerical simulations of borehole flowmeter testing and confirmed that the Theis solution applied to individual layers "does not fully capture the flow dynamics in layered aquifers". The deficiency was attributed to the well face fluxes at layers being transient and vertically non-uniform in their numerical simulations, conditions which violate the assumptions of Theis. Numerical simulations of a two-layer aquifer demonstrated that hydraulic conductivity estimation errors using equation (4) were practically negligible for hydraulic diffusivity contrasts of  $10^{-2} < (T/S)_{\text{layer 1}}/(T/S)_{\text{layer 2}} < 10^2$ ,  $r/b = 0.01$  and  $t_D > 10^3$  in each layer. This result is surprising given the earlier findings of Kabala (1994) which suggested significant biases persisting for relatively long times. Outside this diffusivity range, the biases are not negligible but usually small for high diffusivity layers. This result is good in that borehole flowmeter testing can only measure high conductivity zones with accuracy anyway, once flow measurement errors are considered. A puzzling aspect of Ruud and Kabala (1996) is that any significant estimation errors are always positive. This result is qualitatively contrary to Kabala (1994) and intuition which indicates that equation (4) should underestimate conductivity for high diffusivity layers.

In summary, the minimum practical conditions under which equation (4) is applicable have not been well defined in general. The conventional analysis is rigorously valid only for infinitely long times and/or constant hydraulic diffusivity among layers (Kabala, 1994). The criterion of Rehfeldt and others (1989) and Molz and others (1989)

$$t_D = \frac{4Tt}{Sr_w^2} = \frac{4vt}{r_w^2} > 4 \times 10^2 \text{ to } 4 \times 10^3 \quad (10)$$

is commonly used, but may be non-conservative particularly for aquifers of practical thickness. The work of Ruud and Kabala (1996) suggests that equation (4) can be used with good accuracy for  $t_D > 10^3$  within each layer, aquifer thicknesses satisfying  $b < 100r$  (i.e.  $r/b > 0.01$ ) and reasonable diffusivity contrasts. To apply this criterion before testing, consider a two layer aquifer with an assumed diffusivity contrast ( $v_2/v_1 > 1$ ). For the more stringent layer (#1), the criterion at the well bore radius is

$$\frac{4T_1 t}{S_1 r_w^2} = \frac{4v_1 t}{r_w^2} > 10^3 \quad (11)$$

The diffusivity of layer #1 can be related to average diffusivity and diffusivity ratio as

$$v_1 = v \frac{2}{1 + v_2/v_1} \quad (12)$$

Substituting equation (12) into (11) produces

$$t_D > 1000 \frac{1 + v_2 / v_1}{2} \quad (13)$$

which is generally more conservative than criterion (10). As a third alternative, the corrected criterion of Molz (2000) can be used to define when pseudo-steady conditions are achieved:

$$t_D > 10^2 \left( \frac{r_i}{r_w} \right)^2 \quad (14)$$

Here  $r_i$  is an influence radius measured in feet (m) rather than inches (cm). This criterion would typically be more conservative than (10). A final alternative would be a time beyond which the Theis well function  $W(u)$  is slowly changing on an aquifer average basis, such as

$$t_D > 10^6 \quad (15)$$

which is simply a more conservative version of criterion (10). Equations (10), (13), (14) and (15) provide four possibilities for defining when quasi-steady flow has been reached. The latter three estimates tend to be more conservative. Post-test checks for R-area wells using these criteria are presented later in the report. The safest strategy to minimize systematic errors due to transient effects would be to wait as long as practical after pumping starts before taking borehole flow measurements. In the field, a suggestion would be to wait until the drawdown is observed to be pseudo-steady. Dr. Molz recommends waiting at least 30 minutes after pumping before starting borehole flowmeter testing (Molz, 2000).

### **Systematic errors due to a well filter pack**

Ruud and Kabala (1997) considered the effect of a filter pack annulus on borehole flowmeter estimation under quasi-steady state conditions. In numerical simulations of a two layer aquifer, some groundwater was observed to flow vertically through the filter annulus from the higher conductivity zone and discharge through the well screen adjacent the lower K interval. The artificially-reduced discharge from the high conductivity zone lead to an underestimate of K using equation (4). Conversely, increased discharge from over the screen interval adjacent the low conductivity zone produced an estimate that was biased high. Ruud and others (1999) also considered the effects of a filter pack alone, along the way to analysing the combined effects of a filter pack and flowmeter head losses.

### **Systematic errors due to EBF head loss**

As described by Dinwiddie and others (1999), head losses across the EBF can introduce significant errors in the hydraulic conductivity profile calculated from equation (4). The first of two identified effects for confined aquifers they termed “head-loss-induced flow

redistribution". The second effect involves pump-induced flow bypassing the EBF through the filter pack, and will be discussed in the next section.

The standard calculation procedure for EBF data is based on the assumption that the aquifer is exposed to the same drawdown over the entire well screen length. However, the EBF isolates the portion of the aquifer below the meter from the full drawdown observed at the surface, due to head loss across the meter (Figure 6). That is, the interval below the EBF experiences reduced drawdown. When the head loss caused by flow through the EBF is significant compared to the imposed drawdown, significant biases may be introduced in the calculated relative conductivity profile. Dinwiddie and others (1999) demonstrated that the lower three-quarters of the computed K profile is biased low while the upper quarter is biased high by a greater amount. Head-loss-induced flow redistribution increases with increasing aquifer conductivity for the same pumping rate.

Dinwiddie and others (1999) quantitatively investigated the phenomenon for the ½" ID EBF in a 4" ID, 20 ft long, nonpacked, well screen. Numerical simulations were reported for pumping rates of approximately 20 and 5 L/min, and aquifer conductivities of 0.91, 9.1 and 91 m/day (3, 30 and 300 ft/d). Most of the R-area EBF testing involved 4" wells with active screen lengths of 15 to 40 ft and a pumping rate of roughly 5 L/min. Therefore, the results shown in Figure 16 of Dinwiddie and others (1999), and reproduced here as Figure 7, are most relevant to R-area testing. The aquifer is assumed to have a uniform conductivity of 9.1 m/day (30 ft/day) and the flow rate is 5 L/min. In Figure 7, the calculated K profile is seen to be biased low by as much as 7% in the center, and over-predicted by 27% at the uppermost interval. The biases are demonstrated to increase with increasing aquifer conductivity, and vice versa. The R-area wells that were tested with the EBF have filter packs. Therefore direct comparison of Dinwiddie and others (1999) to the present study has limitations.

Ruud and others (1999) performed similar numerical simulations and observed significant upward flow for the conditions considered. Some flow was observed to leave the well bore just below the flowmeter, enter the aquifer, and then re-enter the well bore just above the flowmeter, thus bypassing the instrument. In wells with a filter pack, bypass flow due to flowmeter head losses is even more significant, as discussed in the next section.

### **Systematic errors due to combined EBF head loss and filter pack**

In wells with a high conductivity filter pack, a second result of head loss across the EBF is bypass flow around the meter, as illustrated in Figures 8 and 9 (Dinwiddie and others, 1999). In this situation, the EBF measures only a fraction of the flow leaving the aquifer below the meter position, generally leading to an under-estimate of the actual conductivity. The exception occurs at the uppermost screen interval, when the EBF passes the top of the screen. Lacking screen above the EBF, bypass flow suddenly ceases and all flow must now pass through the meter. The sudden increase in differential flow for the top interval produces an anomalous high K estimate. Dinwiddie and others (1999) demonstrate that bypass flow increases with filter pack thickness, filter pack conductivity,

and EBF head loss. They also provide a mechanism for estimating bypass flow that can be extended to the R-area test conditions as shown below.

Dinwiddie and others (1999, equation (11)) express bypass flow using a one-dimensional flow concept as

$$Q_{bp}^* = K_{fp} A \frac{\Delta h}{L} \quad (16)$$

where

$Q_{bp}^* \equiv$  bypass flow ( $m^3/day$ )

$K_{fp} \equiv$  filter pack conductivity ( $m/day$ )

$A \equiv$  cross-sectional area of filter pack annulus ( $m^2$ )

$\Delta h \equiv$  head loss across EBF ( $m$ )

$L \equiv$  effective length of bypass flow through filter pack ( $m$ )

Head loss across the 1/2" EBF was determined through laboratory testing to be (Foley, 1997; Dinwiddie and others, 1999)

$$\Delta h = 0.0012Q_m^2 + 0.001Q_m \quad (17)$$

where

$Q_m \equiv$  flow through EBF ( $L/min$ )

The effective filter pack length,  $L$ , can be estimated from numerical simulations performed by Dinwiddie and others (1999). In their simulations, the EBF packer is approximately 5" or 0.127 m in length. For filter pack annular widths of 3.0 and 5.4 cm, the corresponding effective filter pack length was determined through numerical simulations to be 0.18 and 0.21 m, respectively. The effective filter pack length is greater than the EBF packer length because additional distance is required below and above the EBF for the bypass flow to exit and enter the well screen, as shown in Figure 9 (Dinwiddie and others (1999)). Assuming these multi-dimensional end effects are controlled mainly by the filter pack thickness, an effective filter pack length can be easily estimated for other packer lengths.

The packer length and effective filter pack length are related by

$$L = L_{EBF} + \Delta L \quad (18)$$

where



$L \equiv$  effective filter pack length (m)

$L_{\text{EBF}} \equiv$  EBF packer length (m)

$\Delta L \equiv$  length associated with multi-dimensional end effects (m)

For filter pack annular widths of 3.0 and 5.4 cm,  $\Delta L$  is 0.053 (0.18-0.127) and 0.083 (0.21-0.127) m, respectively. Assuming a linear variation,

$$\frac{\Delta L - 0.053 \text{ m}}{t_{\text{fp}} - 3.0 \text{ cm}} = \frac{0.083 - 0.053 \text{ m}}{5.4 - 3.0 \text{ cm}}$$

or

$$\Delta L = 0.053 \text{ m} + 0.0125 \frac{\text{m}}{\text{cm}} (t_{\text{fp}} - 3.0 \text{ cm}) \quad (19)$$

where

$t_{\text{fp}} \equiv$  thickness of filter pack annulus (cm)

For R-area testing,  $L_{\text{EBF}}$  is approximately equal to 7" or 0.178 m. Combining this estimate with equations (18) and (19) yields

$$L_{\text{Rarea}} = 0.231 \text{ m} + 0.0125 \frac{\text{m}}{\text{cm}} (t_{\text{fp}} - 3.0 \text{ cm}) \quad (20)$$

for use in equation (16).

FX-50 was used as the filter pack in the R-area wells that were tested with the EBF. The conductivity of FX-50 was estimated through constant-head permeameter testing using the apparatus depicted in Figure 10. The results of 4 trials are listed in Table 3. The average conductivity is 0.12 cm/s, 330 ft/d or 100 m/d. The filter pack area is simply

$$A = \frac{\pi}{4} (D_o^2 - D_i^2) \quad (21)$$

where  $D_o$  and  $D_i$  are the inner and outer diameters of the filter pack in meters.

Bypass flow can thus be estimated by combining equations (16), (17), (20) and (21) for the ½" ID EBF. The analysis is the same for the 1" ID EBF, except for head loss. Arnold and Molz (2000) determined that head loss across the 1" EBF is about 16 times lower than for the ½" EBF at the same flowrate, based on analysis of a theoretical nozzle flow equation and laboratory experimentation. Therefore, head loss for the 1" EBF can be approximated as 1/16 of the result from equation (17).

Ruud and others (1999) performed similar numerical simulations considering wells without and with a filter pack, and homogeneous and layered aquifers. Head-loss-induced errors increased for wells with a filter pack and layered aquifer properties, compared to a homogeneous aquifer and no filter pack.

### **R-area field experience**

Beyond the basic field procedure described in an earlier section of this report, a number of practical and logistical issues should be considered during field deployment of the EBF. They include items associated with the power supply, cable, packer and uphole electronics. A notable difficulty specific to the equipment deployed at R-area was an ambient air temperature effect on the uphole electronics.

Power supply: Trial and error experience showed that the EBF performance was greatly influenced by the power supply unit, e.g. generator, inverter, etc. The power supply must have a very constant voltage output. Any fluctuations other than small changes in the voltage to the uphole electronics will cause shifts in the meter output readings. This problem can be eliminated by the use of an uninterruptible power supply, a generator with a smooth/constant voltage output, or a power inverter hooked up to a 12 volt power source.

Pumps used during the dynamic testing increase power demand and can also be affected by the power supply. This change in the supply output may affect the actual flows causing changes in the meter output. The generator must be reliable and of the correct size to maintain a constant pump operation. Ideally, separate power supplies would be used for the pump and EBF.

Cable: Two items that would make the unit more user friendly include incorporation of the packer air/nitrogen supply line and incremental foot markings with the electronics cable. Current design requires the addition of a separate air supply line and either a tape or incremental foot markings to be put on the cable by the user. This adds bulk and increases difficulty in handling and deployment time.

The packer supply line and electronics cable must be manually handled by a dedicated field person, in addition to another person who performs most other functions. Lowering and raising the cable can be physically demanding for deep holes. Holding the EBF at a constant, specified depth by hand during testing is tedious. Excess cable must presently be handled by laying it on the ground. As the EBF is advanced deeper into the well, debris such as dirt, grass and/or pine straw can be drawn into the well. These deficiencies could be eliminated with a portable drawworks, such as various models offered by Century Geophysical Corporation that are compatible with contemporary commercial EBF designs.

Packer: The design of the packer includes a stainless steel gear clamp at the top and bottom of the packer. The screw housing on the clamp can be bumped during the insertion of the packer into a well as well as when the packer passes by a joint in the well. If the clamp is bumped/offset a sufficient amount the bladder will leak. This is primarily a

consideration when using the small packer in a 4 inch well where the fit of the deflated packer has a minimal tolerance. Close inspection of the packer is recommended prior to and during each deployment.

Uphole electronics: The uphole electronics box was affected by outside ambient conditions, in that cold temperatures prevented stable display readings. Over the course of two weeks of field testing, it was determined that a steady state "0" reading could not be obtained until the ambient temperature reached approximately 60 °F. Unstable readings occurred during three early morning warm up periods when the temperature was below approximately 60 °F. During the first test the probe was plugged to eliminate any potential for flow through the EBF, lowered into the well, and allowed to warm up for 1 hour per the manufacturers instructions. The instrument display was zeroed and testing started following the appropriate procedural steps. At the completion of the ambient test the instrument had a reading of -0.027 with the probe above the screen in the casing. The probe was removed, plugged, lowered back into the well. With the probe plugged the instrument output was -0.032 and then re-zeroed. At that point the temperature had reached approximately 74 °F. The following dynamic test started at an instrument reading of 0.000 and ended at -0.005.

Similar behavior were observed on two other occasions. During the second occasion the instrument was warmed up for 1 hour and 45 minutes prior to the start of the test and zeroed. At the completion of the test an offset of -0.015 was recorded. A stable reading could not be obtained and testing did not start on the third occasion until the ambient air temperature had reached approximately 60 °F. On all other tests conducted the ambient air temperature had reached a minimum of approximately 60 °F by the end of the warm up period. Following these tests the meter was checked for zero, and observed to read within a few thousands of zero.

The cause of the drift has not been specifically identified. Perhaps a weak electrical component or loose connection was failing at temperatures below approximately 60 °F, but performing reliably at warmer ambient air temperatures. The instrument drift observed during cold mornings was significant compared to the ambient flows being measured. If the ambient flows are of direct interest, future EBF testing should be targeted for ambient air temperatures above 60 °F. However, the instrument noise under cold conditions was generally not significant compared to differential dynamic flows. Therefore if the non-dimensional conductivity profile is of ultimate interest, then ambient air temperature is probably not a significant issue with respect to future deployments.

### **EBF calibration results**

Calibration data for the ½" ID and 1" ID EBF instruments were obtained from the SRS Experimental Thermal Fluids Laboratory (M&TE ID numbers ES020460 and ES020483 dated 3/24/00). Tables 4 and 5 summarize the calibration data for the ½" and 1" EBF instruments respectively. Figures 11 and 12 display the data and chosen calibration curves for the two EBFs. A quadratic functional form forced to go through the origin (0,0) was chosen for the ½" EBF calibration curve. With this selection an instrument

reading of zero corresponds exactly to zero flow. This feature is desirable when interpreting ambient flow data in the field. The ½” EBF calibration model is

$$Q = 0.0024I^2 + 0.7838I \quad (22)$$

where

$Q \equiv$  volumetric flowrate in L/min

$I \equiv$  instrument response

The 1” EBF is typically not used for ambient flow testing, and the calibration data were fit with the linear function

$$Q = 0.9797I + 0.1097 \quad (23)$$

where  $Q$  and  $I$  are defined as before.

### **R-area conductivity profile results**

EBF testing was conducted for seven wells in R-area: RPC-1PW, RPC-2PR, RPC-3PW, RPT-2PW, RPT-3PW, RPT-4PW and RPT-30PZ. For each well that was dynamically tested, the field data were analyzed for vertical variation in horizontal conductivity using equation (4). Bypass flow through the filter pack was estimated from equations (16), (17), (20) and (21). Discussion specific to each well is provided below.

**RPC-1PW:** RPC-1PW is a 2 inch well with a 15 ft screen in the water table. EBF testing was largely unproductive because only about 2 ft of the screen was saturated at the time. Testing was abandoned after the ambient flows were measured initially. Appendix A contains a record of the ambient test results. The ambient flows readings are negative indicating downward flow in the casing, due to a downward head gradient in the aquifer.

**RPC-2PR:** RPC-2PR is a 4 inch well with a fully-penetrating 40 ft screen in the “transmissive” zone. The EBF field data for RPC-2PR are provided in Appendix B. Table 6 shows calculations of the non-dimensional conductivity profile based solely on EBF testing, the dimensional conductivity profile based on EBF and conventional aquifer testing, and an estimate of bypass flow through the filter pack. The differential ambient flow and hydraulic conductivity profiles are plotted in Figures 13 and 14 respectively.

Column (4) in Table 6 lists flow inside the well casing under ambient conditions, measured as a function position with the EBF. A positive value indicates upward flow, and a negative value corresponds to downward flow. Overall the ambient data indicate downward flow through the casing due to a downward head gradient in the aquifer. Column (5) lists differential ambient flow, computed as the difference between adjacent EBF measurements. In this column, a positive value means groundwater is entering the casing (leaving the aquifer) while a negative value means water is flowing out the screen (entering the aquifer). These data are plotted in Figure 13. For RPC-2PR, groundwater is

observed to enter the casing over the upper three-quarters of the screen and leave over the bottom quarter, particularly over the interval centered at 233.39 ft msl (see column (12)).

The non-dimensional or relative hydraulic conductivity distribution,  $K_i/K$ , based on EBF data alone is shown in column (13). The negative values are not physically possible of course. Negative values of  $K_i/K$ , are generally the result of measurement errors and non-ideal test conditions. Expanding on the latter, any artificial reduction in EBF flow when the instrument is passing by a low permeability interval can cause a negative differential net flow in column (9). Examples include a reduction in pump flowrate, which is assumed to be constant in the analysis, and increased flow bypassing the EBF through the filter pack, which also reduces EBF measured flow. These reductions in EBF measured flow are typically small, but can overwhelm the true differential net flow from the aquifer over an interval if the permeability is very low. Therefore, negative values should simply be interpreted as a low permeability zone. The specific cause of negative  $K_i/K$  values for RPC-2PR is not known. From inspection of the field data in Appendix B, one possibility is a slight reduction in pumping rate around 16:00 hours on 3/28/00.

The dimensional conductivity profile is obtained by multiplying column (13) by the average conductivity from conventional aquifer testing. Hiergesell and others (2000) report a best-estimate transmissivity of 0.7655 ft<sup>2</sup>/min for RPC-2PR (Table 1). Hydraulic conductivity averaged over a 40 ft screen length becomes 27.6 ft/d or  $9.72 \times 10^{-3}$  cm/s. The resulting dimensional conductivity profile is shown in columns (14) and (15) of Table 6, and plotted in Figure 14. The aquifer is seen to be quite heterogeneous over the 40 ft interval tested. Several intervals of high conductivity are seen, with the highest value being 158 ft/d or nearly 6 times higher than average. At the other end of the spectrum, several very low conductivity intervals are also observed.

Estimates of filter pack bypass flow are provided in column (17). Bypass flow relative to EBF flow, column (18), is greatest near the top of the screen. This is because the head losses driving bypass flow increase non-linearly with increasing EBF flow, as indicated by equation (3). The maximum ratio is 6.3%. Although any bypass flow is undesirable, this level should not introduce a large bias in the computed conductivity profile. Fortunately, the bypass flow estimates in Table 6 are probably conservatively high, because the filter pack conductivity was assumed to be that of pristine FX-50. In reality, the in-place FX-50 has certainly been “contaminated” with finer-grained sediments and drilling mud, and exhibits a significantly lower conductivity. As evidence, consider the EBF measured flows for the top two positions. At an elevation of 270.89 ft msl, the EBF is centered above the top of the well screen and is measuring the total pumping rate of 4.30 L/min. One foot lower at 269.89 ft msl, the EBF is centered 0.67 ft or 8 inches below the screen top and measuring 4.22 L/min. The difference between these values is the sum of the flow entering the casing through the top few inches of the screen and any bypass flow. Therefore bypass flow cannot be exceeding 0.08 L/min or 2% of EBF flow. While not definitive, these arguments strongly suggest the maximum bypass flow is well under 6% and not a source of large uncertainty.

Coincidentally, the conditions of this test are similar to one of the “head-loss-induced flow redistribution” numerical simulations of Dinwiddie and others (1999), the results of which are displayed in Figure 7. They compare as follows:

<i>Feature</i>	<i>RPC-2PR</i>	<i>Dinwiddie and others (1999) / Figure 6</i>
Conductivity (ft/d)	27.6	29.9
Casing diameter (in)	4	4
Filter pack?	yes	no
Screen length (ft)	40	20

The results shown in Figure 7 suggest that biases on the order of several percent are possible for RPC-2PR due to a head-loss-induced flow redistribution effect.

**RPC-3PW:** This well has a 4 inch casing and a partially-penetrating 40 ft screen in the “lower” aquifer zone of Upper Three Runs aquifer unit (Table 1). Appendix C contains the field data obtained from using both the ½” and 1” EBF instruments for dynamic flow measurements. Data from the ½” EBF are analyzed in Table 7 at 1 ft increments, in the same manner as Table 6 discussed above. The differential ambient flow results are displayed in Figure 15. This figure indicates that flow is mainly entering the casing in the middle of the screen and exiting at the bottom of the screen. Anomalous behavior is observed at the top of the screen where a large negative flow is observed next to a large positive flow. Looking at the ambient flow in column (3) of Table 7, the measurement at 199.98 ft msl is strange in that upward flow in the casing is indicated, whereas all other flows are downward.

The dynamic test results for non-dimensional conductivity are highly variable and contain several negative values. The estimates near 200 ft msl also appear to be aphysical. Looking at the measured flows under dynamic conditions in column (6), an abrupt and unexpected decrease occurred at 199.98 msl. A possible, but highly unlikely, explanation is severe instrument error. The anomaly in the vicinity of 199.98 ft msl occurred at different times under ambient and dynamic conditions, for both the ½” and 1” EBF. Rather, the field data suggest that extraordinarily high bypass flow is occurred at this elevation. Only about ¼ of the anticipated flow is being recorded by the EBF, suggesting that the other ¾ is bypassing the meter. Evidently, filter pack is absent at this elevation creating an extremely low resistance path for flow to bypass the EBF.

Installation of RPC-3PW involved multiple drilling efforts due to lost circulation. Between repeated drilling attempts, addition of special drilling additives in the lost circulation zone, and presence of a persistent lost circulation zone, the filter pack in the suspect area may have settled after well construction. The bentonite seal may have formed a ceiling over the open zone during settling. Intervals of enhanced bypass flow may be occurring elsewhere, although to a lesser degree, and causing the extreme variability and negative conductivity estimates in columns (13) through (15). Nevertheless, the conductivity profile in ft/d is plotted in Figure 16, based on an average conductivity of 47.5 ft/d from conventional aquifer testing (Table 1).

Because much of the variability in Figure 16 is suspected to be an artifact of unusually high bypass flow, the data were re-analyzed over larger intervals in order to smooth the conductivity profile (Tables 8 and 9). The results are plotted in Figures 17 and 18 for 5 and 10 ft intervals respectively. These plots provide more credible estimates of the true conductivity variation, although at a coarser resolution than desired.

The conditions of this test are less similar to those associated with the head-loss-induced flow redistribution results displayed in Figure 7 than for RPC-2PR. They compare as follows:

<i>Feature</i>	<i>RPC-2PR</i>	<i>Dinwiddie and others (1999) / Figure 6</i>
Conductivity (ft/d)	47.5	29.9
Casing diameter (in)	4	4
Filter pack?	yes	no
Screen length (ft)	40	20

Dinwiddie and others (1999) show that biases increase with increasing aquifer conductivity. Therefore, Figure 7 understates the potential head-loss-induced flow redistribution errors for RPC-3PW. Another source of systematic error would be vertical flows caused by partial-penetration of the well screen.

RPC-3PW was also tested at a nominal flow of 15 L/min using the 1" EBF. Tables 10, 11 and 12 present analyses of field data at 1, 5 and 10 ft intervals. The conductivity results are plotted in Figures 16 through 18 along side the ½" EBF results. The 1" EBF conductivity profile at 1 ft resolution has a signature similar to that from the ½" EBF, but shows less variability. The reduced "noise" is probably a result of lower bypass flow for the 1" EBF. Although flowrates are roughly 3 times higher for the 1" EBF compared to the ½" EBF, the head loss is 16 times lower for the 1" EBF at the same flow. Comparing Tables 7 and 10, the net effect is bypass flow for the 1" EBF being only 1/6 of that for the ½" EBF. Therefore, artificial variations in conductivity caused by varying bypass flow conditions should be muted for the 1" EBF compared to the ½" EBF. Figure 16 appears to support this hypothesis. Systematic head-loss-induced flow redistribution errors should also be significantly lower for the 1" EBF results. When the field data are analyzed at coarser 5 ft and 10 ft intervals, even closer agreement is observed between the 1" and ½" EBF results, as shown in Figures 17 and 18.

These results suggest that future dynamic tests should use the 1" EBF, or the ½" EBF at a lower flowrate, to practically eliminate systematic errors due to instrument head loss.

**RPT-2PW:** This is a 4 inch well with a fully-penetrating 15 ft screen in the "transmissive" zone. Average conductivity was estimated from conventional aquifer testing to be 2.30 ft/d (Table 1). The field data presented in Appendix D were analyzed as shown in Table 13. Unlike RPC-2PR and RPC-3PW, the EBF data for RPT-2PW exhibit no anomalies and can be accepted at face value. The differential ambient flows are small compared to those for RPC-2PR and RPC-3PW, probably due to correspondingly low aquifer conductivity. As shown in Figure 19, groundwater was entering the upper half of the screen and leaving the lower half at the time of the ambient

test. This behavior is consistent with a downward gradient in the aquifer. From a contaminant monitoring perspective, this implies that only groundwater from the upper 7 ft of the screened interval would tend to be sampled, despite the 15 ft screen length.

The conductivity profile is shown in Figure 20. Because the formation conductivity is much lower than the value assumed in Figure 7, head-loss-induced flow redistribution effects are minimal. On the other hand, the borehole diameter for this well was 12 rather than 10 inches as for the preceding wells, which creates a larger annulus of the high conductivity filter pack. Therefore, higher bypass flow is predicted as shown in columns (17) and (18) of Table 13. As was done for RPC-2PR, an upper bound on bypass flow can be computed from the uppermost pair of EBF flows. The result is

$$\left( \frac{Q_{bp}}{Q_{EBF}} \right)_{\max} = \frac{4.01 - 3.74}{4.01} \times 100\% = 6.7\% \quad (24)$$

which is lower than 8.2% in Table 13. Therefore, the estimates shown in columns (17) and (18) are certainly too high. As mentioned previously, the conductivity of the in-place filter pack is undoubtedly much lower than the measured value of 100 m/d for pristine FX-50.

**RPT-3PW:** This is a 4 inch well with a partially-penetrating 40 ft screen in the “lower” UTR aquifer zone. Average conductivity was estimated from conventional aquifer testing to be 5.44 ft/d (Table 1). The field data presented in Appendix E were analyzed as shown in Table 14. The differential ambient flow results in Figure 21 show that groundwater enters the upper third of the screen and exits the bottom two-thirds. A few of the computed conductivities in columns (14) and (15) of Table 14 are slightly negative due to measurement errors and/or non-ideal test conditions. These values should be interpreted as low conductivity. As shown in Figure 22, EBF testing reveals an interval of very high conductivity compared to the average. Because dynamic testing was performed with the 1” EBF, head losses were minimal. Maximum bypass flow is estimated to be only 1.2% of EBF flow. Head-loss-induced flow redistribution errors are probably insignificant, considering usage of the 1” EBF and relatively low aquifer conductivity.

**RPT-4PW:** This is a 6 inch well with a partially-penetrating 40 ft screen in the Gordon aquifer. Average conductivity was estimated from conventional aquifer testing to be 44.6 ft/d (Table 1). The field data presented in Appendix F were analyzed as shown in Table 15. The current EBF system has a 250 ft cable, which unfortunately limited high-resolution EBF testing to the upper 13 ft of the screen. The bottom 27 ft are necessarily treated as a single interval in the analysis. Considering the precision of the ½” EBF, the ambient data indicate zero flow in the upper 13 ft (Figure 23). The dynamic test results indicate a slightly increasing flowrate as the EBF was raised, which translates into a very low formation conductivity. However, the total pumping rate was also increasingly at the same time. In fact, EBF flow at all elevations appears to be simply measuring the actual pumping rate. Within instrument tolerance, no flow entered the casing over the top 13 ft during both ambient and dynamic testing. Either the formation is practically



impermeable or the well is not actually screened over this interval. Figure 24 illustrates the resulting conductivity profile.

**RPT-30PZ:** This is 2 inch water table well with a 40 ft screen in the A and AA horizons. The average conductivity based on conventional aquifer testing is 1.33 ft/d (Table 1). At the time of EBF testing, the water table was about 30½ ft above the bottom of the screen. The field data are presented in Appendix G and analyzed in Table 16. The differential ambient flow results shown in Figure 25 indicate groundwater was entering the casing over the upper three-quarters of the saturated screen and exiting over the lower quarter. For dynamic testing, the pumping was limited to 2 L/min to minimize drawdown. The drawdown was 1½ ft leaving 29 ft of saturated screen. EBF readings were taken every 1 ft up to the final 4 ft, where interference with the pump occurred. In column (6) of Table 16, the total pumping rate of 2.10 L/min was entered at water table elevation during dynamic testing. As seen in Appendix G, the pumping rate fluctuated approximately  $\pm 8\%$  about the mean, causing artificial changes in differential net flow. These variations are apparently responsible for the negative conductivities seen in columns (14) and (15). As shown in Figure 26, much higher than average conductivity is observed near the bottom of the screen.

Systematic errors due to head loss across the EBF are likely to be very small given the low pumping rate and low formation conductivity. A packer is not used with the EBF in a 2 inch ID well because the instrument is nearly 2 inches OD. Therefore, flow can bypass the EBF between the meter and casing. Fortunately, this bypass flow occurs regardless of whether the EBF is positioned in or out of the screen, unlike filter pack bypass flow. Therefore, the EBF still responds linearly to the actual well discharge and the calculations summarized by equation (4) are unaffected. In fact, Arnold and Molz (2000) have proposed using the EBF without a packer in larger diameter wells as a way of practically eliminating head loss.

### **Post-test checks for quasi-steady flow conditions**

The estimated conductivity profiles just presented depend on the flow having reached quasi-steady conditions. Four criteria defining the elapsed time required after pumping to achieve such conditions have been given by equations (10), (13), (14) and (15). Tables 17 through 22 evaluate the four criteria for each R-area well. In these tables, the "Ruud and Kabala (1996)" criterion refers to equation (13), "Molz and others (1989)" to equation (14), "Rehfeldt and others (1989)" to equation (10), and "Flach" refers to equation (15). Among these, criterion (13) based on Ruud and Kabala (1996) is preferred because it has a more rigorous basis than equations (10) and (14) and avoids the probable over-conservatism of equation (15). A reasonable assumption for diffusivity contrast is 100:1, considering that flows associated with intervals with conductivity lower than 1/100 of the most permeable layer cannot be accurately measured. In evaluating hydraulic diffusivity (T/S), the transmissivity (T) and storage coefficient (S) estimates are based on the pumping tests of Hiergesell and others (2000, Table 4). Storage coefficients from pumping tests are more uncertain than transmissivity estimates for a heterogeneous

aquifer (Meier and others, 1998; Sanchez-Vila and others, 1999). Therefore, the diffusivity estimates have similar uncertainty as the storage coefficient estimates.

Table 23 compares the criterion of Ruud and Kabala (1996) assuming a diffusivity contrast of 100:1 to the actual test conditions. Also included are the less conservative measures of Ruud and Kabala (1996) with a 10:1 diffusivity contrast and Rehfeldt and others (1989) ( $t_D > 4000$ ). All tests were conducted beyond the time criterion of Ruud and Kabala (1996) assuming a diffusivity contrast of 100:1, except for RPT-30PZ. However, testing at RPT-30PZ did begin after the two less conservative criteria. Therefore, the EBF conductivity profile results previously presented are valid from the standpoint of having reached pseudo-steady flow.

### **Comparison of EBF conductivity profiles to Cone Penetration Testing (CPT) data**

The dimensional hydraulic conductivity profiles plotted in Figures 14, 18, 20, 22, 24 and 26 are plotted in non-dimensional form in Figures 27 through 31. The non-dimensional profiles are interval conductivity divided by screen-averaged conductivity, column (13) in Tables 6, 12, 13, 14, 15 and 16. The CPT push near RPT-3PW and RPT-4PW did not reach the screen zones for these wells. At the RPC-3PW site, the CPT log barely overlaps the well screen. At RPC-2PR, RPT-2PW and RPT-30PZ, the CPT logs fully overlap the EBF normalized conductivity profiles. In general, EBF conductivity profiles differ significantly from the conductivity variation suggested by the CPT logs. These comparisons demonstrate the value of EBF measurements, and the difficulty in accurately inferring conductivity from CPT tip resistance, sleeve friction, pore pressure and resistivity data.

### **Alternative conductivity estimates using Cooper-Jacob analysis**

Horizontal conductivity can be estimated directly from data taken during EBF testing, provided the pumping rate is held constant and time-drawdown data are recorded in addition to EBF flowrates. Under these conditions, a Cooper-Jacob analysis can be applied to each screen interval as summarized by equation (3). Well losses can be introduced by modifying equation (3) as

$$K_i = \frac{(\Delta Q_i - \Delta q_i)}{2\pi\Delta z_i\Delta hE} \ln\left(\frac{1.5}{r_w} \sqrt{\frac{Tt}{S}}\right) \quad (25)$$

where E is well efficiency, defined to be the theoretical drawdown divided by actual drawdown. If barometric pressure variations are significant, further adjustments to measured drawdown are needed. This approach replaces the need for a prior screen-average conductivity estimate, ideally from a separate multiple well pumping test, with single-well pump testing conducted concurrently with EBF flow measurements. Being a form of single-well aquifer testing, the Cooper-Jacob analysis requires prior estimates for hydraulic diffusivity ( $T/S$ ) and well efficiency (E). Transmissivity (T) can be determined iteratively from the layer estimates of conductivity ( $K_i$ ). Therefore, storage coefficient (S) and well efficiency (E) are fundamentally required. Both are difficult to estimate with

accuracy. However, the Cooper-Jacob estimate is not highly sensitive to the assumed value of storage coefficient for large times, because  $S$  appears within a square-root and logarithm in equation (24). Unfortunately, the same cannot be said for well efficiency because conductivity is inversely proportional to  $E$  in equation (24). Therefore, EBF conductivity estimates from equation (24) have a level of uncertainty similar to conventional single-well pumping test estimates.

The conditions required for Cooper-Jacob analysis were satisfied during EBF testing at RPC-2PR, RPT-2PW and RPT-30PZ. Barometric pressure was not monitored, but probably did not vary substantially over the course of a 1 to 3 hour EBF test. Conductivity calculations using equation (24) are presented in Tables 6, 13 and 14. For these calculations, well efficiency and specific storage coefficient were assumed to be 50% and  $10^{-4}$  ft<sup>-1</sup>. The Cooper-Jacob conductivity estimates are shown in column (23) of that calculation tables. Column (24) is the ratio of the Cooper-Jacob estimate to the prior estimate in column (14) based on prior multiple-well aquifer testing. Similarly, the Cooper-Jacob estimates are averaged over the screen zone is compared to the prior multiple-well test result beneath column (25). For RPC-2PR, the Cooper-Jacob estimates are about half of the estimates based on equation (4) and multiple-well aquifer testing. For RPT-2PW, the agreement is good with the Cooper-Jacob estimate differing by only 12%. For RPT-3PW, the Cooper-Jacob estimates are two times higher than the prior estimates. Contributors to the discrepancy between the average conductivity computed using Cooper-Jacob and the prior multiple-well test include uncertainty in well efficiency and scale differences.

### **Considerations and recommendations for future EBF deployment**

Based on the experience gained in R-area, the following recommendations and considerations for future EBF deployments are stated.

Existing SRS monitoring wells: Concerns about bypass flow in filter-packed wells have hindered EBF deployment at the SRS in the past. Recently published analyses of bypass flow, the extensions developed in this report, and R-area EBF testing indicate that bypass flow will not be a serious problem in a typical SRS monitoring well. Furthermore, the head losses that drive bypass flow and cause additional flow redistribution effects can be practically eliminated in future deployments by using the 1" EBF for dynamic testing, lower pumping rates with the ½" EBF, or no EBF packer.

Contaminant monitoring implications: The differential ambient flow results for R-area indicate that a well screen functions as a "short-circuit" in the presence of a vertical head gradient in the surrounding aquifer. Usually the gradient is downward as a result of surface recharge. Therefore, groundwater enters the casing over the upper portion of the screen and exits the lower portion. This phenomenon has important implications for contaminant monitoring. Specifically, samples taken from the well will be biased towards groundwater that originated from the upper strata. The extent of the bias depends on the relative strength of the horizontal gradient.

Equipment issues: The present EBF system has a number of shortcomings that should ideally be remedied before extensive, routine application of the technology at the SRS. The specific deficiencies have been identified in an earlier section. Improved EBF systems are now commercially available from Quantum Engineering Corporation and Century Geophysical Corporation.

Optimal EBF testing: Future dynamic testing should be done exclusively with the 1" ID EBF in order to minimize systematic errors due to instrument head losses. Pre-test calculations should be performed to estimate bypass flow using the methods described in this report. Based on this analysis, a pumping rate that reduces bypass flow to an insignificant level should be chosen. Additional effort should be made to ensure the pumping rate is constant, and time-drawdown and barometric data are accurately recorded preferably using a pressure transducer and data logger.

## References

- Arnold, K. B. and F. J. Molz, 2000, In-well hydraulics of the Electromagnetic Borehole Flowmeter: Further studies, *Ground Water Monitoring & Remediation*, Winter issue, 52-55.
- Cooper, H. H. and C. E. Jacob, 1946, A generalized graphical method for evaluating formation constants and summarizing well-field history, *Transactions of the American Geophysical Union*, v27, 526-534.
- Dinwiddie, C. L., N. A. Foley and F. J. Molz, 1999, In-well hydraulics of the Electromagnetic Borehole Flowmeter, *Ground Water*, v37 n2, 305-315.
- Foley, N. A., 1997, Pressure distribution around an electromagnetic borehole flowmeter in an artificial well, M. S. thesis, Department of Environmental Systems Engineering, Clemson University.
- Hiergesell, R. A., 1999, Test plan for conducting aquifer tests near R area reactor, WSRC-RP-99-00419.
- Hiergesell, R. A., W. E. Jones and M. K. Harris, 2000, Results of aquifer tests performed near R-area, SRS, WSRC-TR-2000-00180.
- Javandel, I., and P. A. Witherspoon, 1969, A method for analyzing transient flow in multilayered aquifers, *Water Resources Research*, v5 n4, 856-869.
- Kabala, Z. J., 1994, Measuring distributions of hydraulic conductivity and specific storativity by the double flowmeter test, *Water Resources Research*, v30 n3, 685-690.
- Meier, P. M., J. Carrera and X. Sanchez-Vila, 1998, An evaluation of Jacob's method for the interpretation of pumping tests in heterogeneous formations, *Water Resources Research*, v34 n5, 1101-1025.
- Molz, F. J., 2000, personal communication, e-mail dated 7/12.
- Molz, F. J., R. H. Morin, A. E. Hess, J. G. Melville and O. Guven, 1989, The impeller meter for measuring aquifer permeability variations: evaluation and comparison with other tests, *Water Resources Research*, v25 n7, 1677-1683.
- Molz, F. J. and S. C. Young, 1993, Development and application of borehole flowmeters for environmental assessment, *The Log Analyst*, v3, Jan.-Feb., 13-23.
- Rehfeldt, K. R., P. Hufschmied, L. W. Gelhar and M. E. Schaefer, 1989, The borehole flowmeter technique for measuring hydraulic conductivity variability, report, Electric Power Research Institute, Palo Alto CA.
- Riha, B., 1993, Predicting saturated hydraulic conductivity for unconsolidated soils from commonly measured textural properties, M.S. thesis, Clemson University, 87 p.

Ruud, N. C., and Z. J. Kabala, 1996, Numerical evaluation of flowmeter test interpretation methodologies, *Water Resources Research*, v32 n4, 845-852.

Ruud, N. C., and Z. J. Kabala, 1997, Numerical evaluation of the flowmeter test in a layered aquifer with a skin zone, *Journal of Hydrology*, v203, 101-108.

Ruud, N. C., Z. J. Kabala and F. J. Molz, 1999, Evaluation of flowmeter-head loss effects in the flowmeter test, *Journal of Hydrology*, v224, 55-63.

Sanchez-Vila, X., P. M. Meier and J. Carrera, 1999, Pumping tests in heterogeneous aquifers: An analytical study of what can be obtained from their interpretation using Jacob's method, *Water Resources Research*, v35 n4, 943-952.

Theis, C. V., 1935, The relationship between the lowering of piezometric surface and the rate and duration of discharge using ground-water storage, *Trans. Amer. Geophys. Union*, v16, 519.

Waldrop, W. R., 1995, A summary of hydrogeologic studies with the Electromagnetic Borehole Flowmeter, report QEC T-102, Quantum Engineering Corporation, 112 Tigitsi Lane, Loudon, Tennessee, 37774, 615-458-0506.

WSRC, 2000, Field summary report for installation of pumping and observation wells in R Area, WSRC-RP-2000-4058.

Young, S. C. and W. R. Waldrop, 1989, An electromagnetic borehole flowmeter for measuring hydraulic conductivity variability, in Molz, F. J., O. Guven and J. G. Melville eds., *Proceedings of the conference on new field techniques for quantifying the physical and chemical properties of heterogeneous aquifers*: Water Resources Research Institute, Auburn University, Alabama.

Table 1 R-area well information.

Well	SRS N (ft)	SRS E (ft)	Pad Elevation (ft msl)	TOC Elev (ft msl)	Top of Screen (ft msl)	Bottom of Screen (ft msl)	Screen Length (ft)	Borehole Diameter (in)	Casing Diameter (in)	Filter Pack	Hydro- stratigraphic unit	Unit Thickness (ft)	Average Trans- missivity (ft <sup>2</sup> /min)	Average Conductivity (ft/d)
RPC-1PW	57938.27	74187.63	305.24	307.56	285.41	270.41	15	8	2	FX-50			-	
RPC-2PR	57918.93	73976.10	309.02	311.51	270.56	230.56	40	10	4	FX-50	transmissive	39	0.679	24.4
RPC-3PW	57913.93	74069.58	307.58	309.14	202.25	162.25	40	10	4	FX-50	"lower" UTR	101	1.75	25.0
RPT-2PW	56089.13	76789.92	287.66	289.91	209.33	194.33	15	12	4	FX-50	transmissive	15	0.024	2.3
RPT-3PW	56127.15	76565.66	287.64	289.83	138.31	98.31	40	10	4	FX-50	"lower" UTR	74	0.102	2.0
RPT-4PW	56106.15	76566.26	287.50	289.72	55.77	15.77	40	10	6	FX-50	Gordon	86	0.871	14.6
RPT-30PZ	56067.92	76753.77	287.52	289.66	272.19	232.19	40	8	2	FX-50	A/AA	34	0.038	1.4

Table 2      Peer-reviewed journal publications addressing systematic errors in borehole flowmeter analyses.

Transient flow	Filter pack	Flowmeter head losses	References
×			Molz and others (1989) Kabala (1994) Ruud and Kabala (1996)
	×		Ruud and Kabala (1997) Ruud and others (1999)
		×	Dinwiddie and others (1999)
	×	×	Dinwiddie and others (1999) Ruud and others (1999)



Table 3 Constant-head permeameter measurements for FX-50 filter pack.

Approx. Start Time	Bucket Vol. (L)	Fill Time		Total Time (sec)	Flow (l/min)	Flow (ft <sup>3</sup> /min)	Water Level WL (ft)		Sand Column Height SC (ft)	Water Column HeightW C (ft)	$\Delta H$	Head Grad.	A=Pi R <sup>2</sup> (ft <sup>2</sup> )	K=Q/iA (ft/min)	K (cm/s)	K (ft/d)	K (m/d)
		Min.	Sec.				Initial	Final									
9:58	16.80	13	53	833	1.21	0.0427	0.1823	0.1823	0.5469	0.7812	1.3281	2.428	0.075	0.233	0.118	336	102
10:52	16.80	14	20	860	1.17	0.0414	0.1875	0.1875	0.5469	0.7760	1.3229	2.419	0.075	0.227	0.115	326	99
11:44	16.80	14	29	869	1.16	0.0410	0.1875	0.1875	0.5469	0.7760	1.3229	2.419	0.075	0.224	0.114	323	98
16:04	16.80	14	8	848	1.19	0.0420	0.1979	0.1979	0.5469	0.7656	1.3125	2.400	0.075	0.232	0.118	334	102
														average	0.116	330	100

Table 4 Calibration data for the 1/2" ID EBF.

Calibration Data				Calculated Data						$y = 0.0024x^2 + 0.7838x$		
Instrument Response	Water Temp (C)	Water Weight (lbs)	Time Duration (min)	Mass Flow (lbs/min)	Water Density (lb/ft <sup>3</sup> )	Volume Flow (ft <sup>3</sup> /min)	Volume Flow (Actual) (LPM)	Act-Inst Resp	% Error	Calibrated Meter Flow Rate	Act-Cal Mtr Flow	% Error
0.00							0	0.000		0.000	0.000	
0.029	21.5	0.685	10.00533	0.0685	62.2877	0.0011	0.0311	0.002	6.89	0.023	0.008	27.01
0.036	21.9	0.670	10.0065	0.0670	62.2826	0.0011	0.0304	-0.006	18.25	0.028	0.002	7.30
0.073	22.0	0.667	5.004333	0.1332	62.2813	0.0021	0.0606	-0.012	20.51	0.057	0.003	5.52
0.089	21.8	0.814	5.0035	0.1627	62.2839	0.0026	0.0740	-0.015	20.32	0.070	0.004	5.67
0.506	19.4	4.510	5.009167	0.9003	62.3135	0.0144	0.4091	-0.097	23.68	0.397	0.012	2.91
0.506	19.5	4.500	5.008333	0.8985	62.3123	0.0144	0.4083	-0.098	23.93	0.397	0.011	2.71
0.552	22.2	2.935	3.006833	0.9761	62.2787	0.0157	0.4438	-0.108	24.38	0.433	0.010	2.35
1.007	19.0	17.830	10.01183	1.7809	62.3181	0.0286	0.8092	-0.198	24.44	0.792	0.017	2.16
1.019	20.5	18.020	10.00867	1.8004	62.3003	0.0289	0.8183	-0.201	24.52	0.801	0.017	2.09
4.010	20.8	35.100	5.0065	7.0109	62.2966	0.1125	3.1867	-0.823	25.84	3.182	0.005	0.16
4.030	19.6	35.260	5.0085	7.0400	62.3111	0.1130	3.1992	-0.831	25.97	3.198	0.002	0.05
6.955	21.2	60.990	5.008333	12.1777	62.2916	0.1955	5.5357	-1.419	25.64	5.567	-0.032	0.57
9.860	21.2	52.470	3.0105	17.4290	62.2916	0.2798	7.9227	-1.937	24.45	7.962	-0.039	0.49
9.875	20.5	53.070	3.004667	17.6625	62.3003	0.2835	8.0278	-1.847	23.01	7.974	0.054	0.67
10.015	21.4	53.480	3.005833	17.7921	62.2890	0.2856	8.0881	-1.927	23.82	8.090	-0.002	0.03

Table 5 Calibration data for the 1" ID EBF.

Calibration Data				Calculated Data				Calibrated Meter Flow				
Instrument Response	Water Temp (C)	Water Weight (lbs)	Time Duration (min)	Mass Flow (lbs/min)	Water Density (lb/ft^3)	Volume Flow (ft^3/min)	Volume Flow (Actual) (LPM)	Act-Inst Resp	% Error	$y = 0.9797x + 0.1097$		
										Calibrated Meter Flow Rate (L/min)	Act-Cal Mtr Flow (L/min)	% Error
0.00							0	0.00		0.110	-0.110	
0.10	19.0	2.070	5.0065	0.4135	62.3181	0.0066	0.1879	0.09	46.77	0.208	-0.020	10.5
0.10	18.8	2.070	5.006	0.4135	62.3204	0.0066	0.1879	0.09	46.77	0.208	-0.020	10.5
0.10	19.0	2.075	5.0075	0.4144	62.3181	0.0066	0.1883	0.09	46.89	0.208	-0.019	10.3
1.00	22.2	7.255	3.0075	2.4123	62.2787	0.0387	1.0968	0.10	8.83	1.089	0.007	0.7
1.00	22.2	7.280	3.011	2.4178	62.2787	0.0388	1.0993	0.10	9.03	1.089	0.010	0.9
1.00	22.40	7.260	3.006667	2.4146	62.2760	0.0388	1.0979	0.10	8.92	1.089	0.009	0.8
10.02	19.2	66.290	3.0035	22.0709	62.3158	0.3542	10.0289	0.01	0.09	9.926	0.103	1.0
10.23	19.6	68.090	3.0035	22.6702	62.3111	0.3638	10.3020	0.07	0.70	10.132	0.170	1.7
10.40	19.8	68.800	3.005	22.8952	62.3087	0.3674	10.4047	0.00	0.04	10.299	0.106	1.0
20.12	19.2	130.060	3.004667	43.2860	62.3158	0.6946	19.6690	-0.45	2.29	19.821	-0.152	0.8
20.15	19.6	131.500	3.008333	43.7119	62.3111	0.7015	19.8640	-0.29	1.44	19.851	0.013	0.1
20.51	19.8	134.010	3.0075	44.5586	62.3087	0.7151	20.2495	-0.26	1.29	20.203	0.046	0.2
30.00	19.6	161.780	2.509	64.4799	62.3111	1.0348	29.3016	-0.70	2.38	29.501	-0.199	0.7
30.15	19.8	162.290	2.505667	64.7692	62.3087	1.0395	29.4342	-0.72	2.43	29.648	-0.213	0.7
30.30	20.0	163.240	2.5075	65.1007	62.3063	1.0448	29.5860	-0.71	2.41	29.795	-0.209	0.7
35.00	20.0	150.470	2.004167	75.0786	62.3063	1.2050	34.1206	-0.88	2.58	34.399	-0.279	0.8
35.00	19.8	150.510	2.005167	75.0611	62.3087	1.2047	34.1113	-0.89	2.61	34.399	-0.288	0.8
35.00	20.0	156.560	2.007833	77.9746	62.3063	1.2515	35.4367	0.44	1.23	34.399	1.038	2.9

Table 6 Hydraulic conductivity profile and bypass flow estimate for RPC-2PR.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft <sup>3</sup> /min)	Differential Ambient Flow, Δq (ft <sup>3</sup> /min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft <sup>3</sup> /min)	Net Pumping Flow, Q - q (ft <sup>3</sup> /min)	Differential Net Flow, Δ(Q - q) (ft <sup>3</sup> /min)	Differential Net Flow Δ(Q - q) (ft <sup>3</sup> /min)	Layer Thickness Δz (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>base</sub> b(ΔQ <sub>i</sub> -Δq <sub>i</sub> )/(Q <sub>p</sub> Δz)	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cm/s)	Check Δz*K <sub>i</sub> /K <sub>base</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>bp</sub> /Q <sub>EBF</sub> )	Clock Time	Elapsed Time (min)	Water Level (ft)	dh (ft)	Cooper-Jacob K (ft/d)	Ratio	KΔz
37.03	270.89	-0.00044	-0.00002	-0.00017	4.30	0.15178	0.15179	0.00289	0.00289	0.67	270.22	1.14	27.9	9.85E-03	7.618E-01	0.27	0.063	14:30	30	33.85	0.80	12.9	0.46	8.60
38.03	269.89	0.00449	0.00016	0.00005	4.22	0.14906	0.14890	0.01314	0.01314	1.00	269.39	3.46	84.7	2.99E-02	3.463E+00	0.26	0.062	14:33	33	33.85	0.80	39.4	0.46	39.35
39.03	268.89	0.00315	0.00011	0.00010	3.85	0.13588	0.13577	0.00354	0.00354	1.00	268.39	0.93	22.8	8.06E-03	9.342E-01	0.22	0.058	14:37	37	33.85	0.80	10.7	0.47	10.70
40.03	267.89	0.00024	0.00001	-0.00001	3.74	0.13223	0.13223	0.00046	0.00046	1.00	267.39	0.12	3.0	1.05E-03	1.222E-01	0.21	0.056	14:40	40	33.86	0.81	1.4	0.47	1.41
41.03	266.89	0.00047	0.00002	0.00004	3.73	0.13178	0.13176	-0.00007	-0.00007	1.00	266.39	-0.02	-0.4	-1.50E-04	-1.740E-02	0.21	0.056	14:42	42	33.86	0.81	-0.2	0.47	-0.20
42.03	265.89	-0.00059	-0.00002	0.00006	3.73	0.13181	0.13183	-0.00049	-0.00049	1.00	265.39	-0.13	-3.1	-1.11E-03	-1.285E-01	0.21	0.056	14:44	44	33.86	0.81	-1.5	0.47	-1.49
43.03	264.89	-0.00230	-0.00008	-0.00004	3.74	0.13223	0.13232	-0.00056	-0.00056	1.00	264.39	-0.15	-3.6	-1.28E-03	-1.483E-01	0.21	0.056	14:46	46	33.86	0.81	-1.7	0.47	-1.72
44.03	263.89	-0.00129	-0.00005	0.00010	3.76	0.13283	0.13288	-0.00015	-0.00015	1.00	263.39	-0.04	-1.0	-3.52E-04	-4.080E-02	0.21	0.056	14:48	48	33.86	0.81	-0.5	0.48	-0.48
45.03	262.89	-0.00406	-0.00014	0.00005	3.76	0.13289	0.13303	0.00049	0.00049	1.00	262.39	0.13	3.2	1.12E-03	1.302E-01	0.21	0.057	14:50	50	33.86	0.81	1.5	0.48	1.53
46.03	261.89	-0.00540	-0.00019	0.00010	3.75	0.13235	0.13254	0.00442	0.00442	1.00	261.39	1.17	28.5	1.01E-02	1.166E+00	0.21	0.056	14:52	52	33.86	0.81	13.7	0.48	13.73
47.03	260.89	-0.00831	-0.00029	0.00013	3.62	0.12782	0.12812	0.00246	0.00246	1.00	260.39	0.65	15.8	5.59E-03	6.480E-01	0.20	0.055	14:54	54	33.86	0.81	7.7	0.48	7.67
48.03	259.89	-0.01200	-0.00042	0.00032	3.55	0.12523	0.12566	0.00329	0.00329	1.00	259.39	0.87	21.2	7.47E-03	8.663E-01	0.19	0.054	14:56	56	33.86	0.81	10.3	0.49	10.29
49.03	258.89	-0.02118	-0.00075	0.00008	3.44	0.12162	0.12237	0.00180	0.00180	1.00	258.39	0.47	11.6	4.09E-03	4.745E-01	0.18	0.053	14:58	58	33.85	0.80	5.7	0.49	5.66
50.03	257.89	-0.02330	-0.00082	-0.00004	3.39	0.11975	0.12057	-0.00078	-0.00078	1.00	257.39	-0.21	-5.0	-1.78E-03	-2.065E-01	0.18	0.052	15:00	60	33.85	0.80	-2.5	0.49	-2.47
51.03	256.89	-0.02215	-0.00078	0.00022	3.41	0.12057	0.12136	0.00211	0.00211	1.00	256.39	0.56	13.6	4.80E-03	5.564E-01	0.18	0.052	15:03	63	33.85	0.80	6.7	0.49	6.71
52.03	255.89	-0.02834	-0.00100	0.00012	3.35	0.11825	0.11925	-0.00022	-0.00022	1.00	255.39	-0.06	-1.4	-4.94E-04	-5.724E-02	0.17	0.051	15:06	66	33.85	0.80	-0.7	0.50	-0.69
53.03	254.89	-0.02484	-0.00088	0.00013	3.36	0.11859	0.11946	-0.00010	-0.00010	1.00	254.39	-0.03	-0.6	-2.21E-04	-2.559E-02	0.17	0.052	15:08	68	33.85	0.80	-0.3	0.50	-0.31
54.03	253.89	-0.02839	-0.00100	0.00019	3.36	0.11856	0.11956	0.00912	0.00912	1.00	253.39	2.40	58.8	2.07E-02	2.404E+00	0.17	0.052	15:10	70	33.85	0.80	29.2	0.50	29.20
55.03	252.89	-0.03365	-0.00119	0.00035	3.09	0.10925	0.11044	0.00551	0.00551	1.00	252.39	1.45	35.5	1.25E-02	1.453E+00	0.15	0.048	15:13	73	33.86	0.81	17.6	0.50	17.58
56.03	251.89	-0.04361	-0.00154	0.00002	2.93	0.10339	0.10493	0.00321	0.00321	1.00	251.39	0.85	20.7	7.29E-03	8.452E-01	0.14	0.046	15:16	76	33.87	0.82	10.2	0.49	10.19
57.03	250.89	-0.04416	-0.00156	0.00004	2.84	0.10017	0.10173	0.00352	0.00352	1.00	250.39	0.93	22.7	8.00E-03	9.280E-01	0.13	0.045	15:19	79	33.87	0.82	11.1	0.49	11.15
58.03	249.89	-0.04537	-0.00160	0.00021	2.74	0.09660	0.09821	0.00191	0.00191	1.00	249.39	0.50	12.3	4.34E-03	5.038E-01	0.12	0.044	15:22	82	33.88	0.83	6.0	0.49	6.03
59.03	248.89	-0.05127	-0.00181	-0.00012	2.68	0.09448	0.09629	0.00151	0.00151	1.00	248.39	0.40	9.7	3.43E-03	3.975E-01	0.12	0.043	15:25	85	33.88	0.83	4.7	0.49	4.74
60.03	247.89	-0.04777	-0.00169	0.00021	2.64	0.09310	0.09479	0.00173	0.00173	1.00	247.39	0.46	11.2	3.94E-03	4.574E-01	0.11	0.043	15:27	87	33.89	0.84	5.4	0.49	5.44
61.03	246.89	-0.05381	-0.00190	-0.00015	2.58	0.09115	0.09305	0.00094	0.00094	1.00	246.39	0.25	6.1	2.14E-03	2.478E-01	0.11	0.042	15:32	92	33.90	0.85	2.9	0.48	2.93
62.03	245.89	-0.04958	-0.00175	0.00018	2.56	0.09036	0.09211	0.00005	0.00005	1.00	245.39	0.01	0.3	1.09E-04	1.269E-02	0.11	0.042	15:37	97	33.91	0.86	0.9	0.48	0.15
63.03	244.89	-0.05461	-0.00193	0.00004	2.55	0.09014	0.09206	0.00321	0.00321	1.00	244.39	0.85	20.7	7.29E-03	8.451E-01	0.11	0.042	15:39	99	33.91	0.86	9.9	0.48	9.88
64.03	243.89	-0.05572	-0.00197	0.00004	2.46	0.08689	0.08886	0.00644	0.00644	1.00	243.39	1.70	41.5	1.46E-02	1.699E+00	0.10	0.040	15:42	102	33.92	0.87	19.8	0.48	19.78
65.03	242.89	-0.05684	-0.00201	0.00004	2.28	0.08041	0.08242	0.00249	0.00249	1.00	242.39	0.66	16.1	5.67E-03	6.578E-01	0.09	0.038	15:45	105	33.92	0.87	7.6	0.47	7.63
66.03	241.89	-0.05795	-0.00205	0.00001	2.21	0.07788	0.07992	0.00097	0.00097	1.00	241.39	0.26	6.3	2.21E-03	2.558E-01	0.08	0.037	15:47	107	33.93	0.88	3.0	0.47	2.96
67.03	240.89	-0.05837	-0.00206	0.00001	2.18	0.07689	0.07895	0.00314	0.00314	1.00	240.39	0.83	20.2	7.13E-03	8.269E-01	0.08	0.037	15:49	109	33.93	0.88	9.5	0.47	9.53
68.03	239.89	-0.05879	-0.00208	0.00001	2.09	0.07374	0.07582	0.01411	0.01411	1.00	239.39	3.72	90.9	3.21E-02	3.720E+00	0.08	0.036	15:54	114	33.94	0.89	42.6	0.47	42.59
69.03	238.89	-0.05921	-0.00209	0.00007	1.69	0.05961	0.06171	0.02175	0.02175	1.00	238.39	5.73	140.2	4.94E-02	5.734E+00	0.05	0.031	15:57	117	33.94	0.89	65.8	0.47	65.79
70.03	237.89	-0.06119	-0.00216	-0.00010	1.07	0.03780	0.03996	0.00203	0.00203	1.00	237.39	0.53	13.1	4.61E-03	5.342E-01	0.03	0.023	16:01	121	33.94	0.89	6.1	0.47	6.15
71.03	236.89	-0.05834	-0.00206	-0.00007	1.82	0.03587	0.03793	0.00227	0.00227	1.00	236.39	0.60	14.6	5.16E-03	5.989E-01	0.02	0.023	16:04	124	33.94	0.89	6.9	0.47	6.90
72.03	235.89	-0.05640	-0.00199	-0.00010	0.95	0.03367	0.03566	0.00249	0.00249	1.00	235.39	0.66	16.1	5.67E-03	6.573E-01	0.02	0.022	16:07	127	33.94	0.89	7.6	0.47	7.59
73.03	234.89	-0.05369	-0.00190	-0.00038	0.89	0.03127	0.03317	0.00959	0.00959	1.00	234.39	2.53	61.8	2.18E-02	2.529E+00	0.02	0.021	16:10	130	33.94	0.89	29.3	0.47	29.28
74.03	233.89	-0.04300	-0.00152	-0.00110	0.62	0.02206	0.02357	0.01897	0.01897	1.00	233.39	5.00	122.3	4.31E-02	5.002E+00	0.01	0.018	16:14	134	33.94	0.89	58.1	0.47	58.05
75.03	232.89	-0.01193	-0.00042	-0.00005	0.12	0.00418	0.00460	0.00105	0.00105	1.00	232.39	0.28	6.8	2.39E-03	2.770E-01	0.00								

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft <sup>3</sup> /min)	Differential Ambient Flow, Δq (ft <sup>3</sup> /min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft <sup>3</sup> /min)	Net Pumping Flow, Q - q (ft <sup>3</sup> /min)	Differential Net Flow, Δ(Q - q) (ft <sup>3</sup> /min)	Differential Net Flow Δ(Q - q) (ft <sup>3</sup> /min)	Layer Thickness Δz <sub>i</sub> (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>cur</sub> b(ΔQ-Δq)/ (Q <sub>0</sub> Δz <sub>i</sub> )	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cm/s)	Check Δz* <sup>2</sup> K <sub>i</sub> /K <sub>cur</sub>	Estimated bypass flow (L/min)	Estimated flow ratio (Q <sub>0</sub> q/Q <sub>0</sub> q <sub>EBF</sub> )
106.16	202.98	-0.00022	-0.00001	0.00001	5.34	0.18863	0.18864	-0.00044	-0.00044	0.27	202.11	-0.35	-8.8	-3.10E-03	-9.380E-02	0.41	0.076
107.16	201.98	-0.00050	-0.00002	0.00001	5.35	0.18906	0.18908	0.00045	0.00045	1.00	201.48	0.10	2.4	8.37E-04	9.508E-02	0.41	0.076
108.16	200.98	-0.00086	-0.00003	-0.00113	5.34	0.18860	0.18863	0.14506	0.14506	1.00	200.48	30.77	767.6	2.71E-01	3.077E+01	0.41	0.076
109.16	199.98	0.03106	0.00110	0.00131	1.26	0.04467	0.04357	-0.11300	-0.11300	1.00	199.48	-23.97	-598.0	-2.11E-01	-2.397E+01	0.03	0.026
110.16	198.98	-0.00606	-0.00021	0.00013	4.43	0.15636	0.15657	-0.01377	-0.01377	1.00	198.48	-2.92	-72.9	-2.57E-02	-2.920E+00	0.29	0.065
111.16	197.98	-0.00970	-0.00034	0.00031	4.81	0.17000	0.17034	-0.00057	-0.00057	1.00	197.48	-0.12	-3.0	-1.06E-03	-1.210E-01	0.33	0.069
112.16	196.98	-0.01854	-0.00065	-0.00005	4.82	0.17025	0.17091	-0.00386	-0.00386	1.00	196.48	-0.82	-20.4	-7.21E-03	-8.186E-01	0.34	0.070
113.16	195.98	-0.01726	-0.00061	-0.00010	4.93	0.17416	0.17477	0.00157	0.00157	1.00	195.48	0.33	8.3	2.92E-03	3.320E-01	0.35	0.071
114.16	194.98	-0.01441	-0.00051	0.00015	4.89	0.17269	0.17320	-0.00328	-0.00328	1.00	194.48	-0.69	-17.3	-6.12E-03	-6.950E-01	0.34	0.070
115.16	193.98	-0.01854	-0.00065	0.00004	4.98	0.17583	0.17648	0.00525	0.00525	1.00	193.48	1.11	27.8	9.79E-03	1.113E+00	0.36	0.071
116.16	192.98	-0.01961	-0.00069	-0.00007	4.83	0.17054	0.17123	0.00027	0.00027	1.00	192.48	0.06	1.4	5.11E-04	5.807E-02	0.34	0.070
117.16	191.98	-0.01755	-0.00062	-0.00008	4.82	0.17034	0.17096	0.00125	0.00125	1.00	191.48	0.27	6.6	2.34E-03	2.661E-01	0.34	0.070
118.16	190.98	-0.01534	-0.00054	0.00012	4.79	0.16916	0.16971	0.00475	0.00475	1.00	190.48	1.01	25.2	8.88E-03	1.008E+00	0.33	0.069
119.16	189.98	-0.01876	-0.00066	0.00004	4.65	0.16429	0.16495	0.00019	0.00019	1.00	189.48	0.04	1.0	3.58E-04	4.062E-02	0.31	0.067
120.16	188.98	-0.01983	-0.00070	-0.00005	4.65	0.16406	0.16476	-0.00205	-0.00205	1.00	188.48	-0.43	-10.8	-3.82E-03	-4.338E-01	0.31	0.067
121.16	187.98	-0.01848	-0.00065	-0.00010	4.71	0.16615	0.16680	-0.00045	-0.00045	1.00	187.48	-0.10	-2.4	-8.39E-04	-9.531E-02	0.32	0.068
122.16	186.98	-0.01578	-0.00056	0.00015	4.72	0.16670	0.16725	0.00053	0.00053	1.00	186.48	1.38	34.5	1.22E-02	1.384E+00	0.32	0.068
123.16	185.98	-0.02005	-0.00071	0.00017	4												

106.89	Top of Screen Depth from TOC (ft)		<i>Filter pack:</i>	QP (ft3/min) 0.18859	40.00 b (ft)	Avg K/K <sub>bar</sub> 1.000000
146.89	Bottom of Screen Depth from TOC (ft)	0.254	Do (m)	QP (L/min) 5.34		(Should be exactly 1)
40.00	Screen Length (ft)	0.102	Di (m)	uncorr QP 5.34		
309.14	TOC Elevation (ft)	0.043	Area (m^2)			
1.75	T pump (ft2/min)	7.62	Thickness (cm)			
101	Formation thickness (ft)	100	Conductivity, K <sub>sp</sub> (m/d) FX-50			
25.0	K pump (ft/d)		EBF:			
8.80E-03	K pump (cm/s)	0.178	L <sub>EBF</sub> (m)			
			<i>Bypass flow:</i>			
		0.111	ΔL (m)			
		0.289	L (m)			

Table 8 Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for ½" EBF, 5 L/min nominal flow and 5 ft increments.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft <sup>3</sup> /min)	Differential Ambient Flow, Δq <sub>i</sub> (ft <sup>3</sup> /min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft <sup>3</sup> /min)	Net Pumping Flow, Q - q (ft <sup>3</sup> /min)	Differential Net Flow, Δ(Q <sub>i</sub> - q <sub>i</sub> ) (ft <sup>3</sup> /min)	Adjusted? Differential Net Flow Δ(Q <sub>i</sub> - q <sub>i</sub> ) (ft <sup>3</sup> /min)	Layer Thickness Δz <sub>i</sub> (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>bar</sub> = b(ΔQ <sub>i</sub> -Δq <sub>i</sub> )/(Q <sub>p</sub> Δz <sub>i</sub> )	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cm/s)	Check Δz*K <sub>i</sub> /K <sub>bar</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>bp</sub> /Q <sub>EBF</sub> )
106.16	202.98	-0.00022	-0.00001	0.00033	5.34	0.18863	0.18864	0.01830	0.01830	4.27	200.11	0.91	43.2	1.52E-02	3.881E+00	0.41	0.076
111.16	197.98	-0.00970	-0.00034	0.00035	4.81	0.17000	0.17034	-0.00090	-0.00090	5.00	195.48	-0.04	-1.8	-6.37E-04	-1.899E-01	0.33	0.069
116.16	192.98	-0.01961	-0.00069	-0.00004	4.83	0.17054	0.17123	0.00443	0.00443	5.00	190.48	0.19	8.9	3.15E-03	9.394E-01	0.34	0.070
121.16	187.98	-0.01848	-0.00065	0.00213	4.71	0.16615	0.16680	0.02475	0.02475	5.00	185.48	1.05	49.9	1.76E-02	5.250E+00	0.32	0.068
126.16	182.98	-0.07868	-0.00278	0.00088	3.94	0.13927	0.14205	0.00451	0.00451	5.00	180.48	0.19	9.1	3.21E-03	9.563E-01	0.23	0.059
131.16	177.98	-0.10353	-0.00366	0.00005	3.79	0.13389	0.13754	0.00630	0.00630	5.00	175.48	0.27	12.7	4.48E-03	1.336E+00	0.22	0.057
136.16	172.98	-0.10490	-0.00370	-0.00087	3.61	0.12754	0.13124	0.04603	0.04603	5.00	170.48	1.95	92.8	3.27E-02	9.762E+00	0.20	0.055
141.16	167.98	-0.08027	-0.00283	-0.00268	2.33	0.08238	0.08522	0.08517	0.08517	5.73	165.11	3.15	149.7	5.28E-02	1.806E+01	0.09	0.039
147.16	161.98	-0.00434	-0.00015		0.00	-0.00011	0.00004	0.18859	0.18859								
106.89	Top of Screen Depth from TOC (ft)				Filter pack:				QP (ft <sup>3</sup> /min)	0.18859	40.00 b (ft)	Avg K <sub>i</sub> /K <sub>bar</sub> 1.000000					
146.89	Bottom of Screen Depth from TOC (ft)				0.254	Do (m)			QP (L/min)	5.34		(Should be exactly 1)					
40.00	Screen Length (ft)				0.102	Di (m)			uncorr QP	5.34							
309.14	TOC Elevation (ft)				0.043	Area (m <sup>2</sup> )											
1.32	T pump (ft <sup>2</sup> /min)				7.62	Thickness (cm)											
47.5	K pump (ft/d)				100	Conductivity, K <sub>gp</sub> (m/d) FX-50											
1.68E-02	K pump (cm/s)					EBF:											
					0.178	L <sub>EBF</sub> (m)											
						Bypass flow:											
					0.111	ΔL (m)											
					0.289	L (m)											

**Table 9** Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for ½" EBF, 5 L/min nominal flow and 10 ft increments.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft³/min)	Differential Ambient Flow, Δq <sub>i</sub> (ft³/min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft³/min)	Net Pumping Flow, Q - q (ft³/min)	Differential Net Flow, Δ(Q <sub>i</sub> - q <sub>i</sub> ) (ft³/min)	Differential Net Flow Δ(Q <sub>i</sub> - q <sub>i</sub> ) (ft³/min)	Layer Thickness Δz <sub>i</sub> (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>bar</sub> = b(ΔQ <sub>i</sub> -Δq <sub>i</sub> )/ (Q <sub>p</sub> Δz <sub>i</sub> )	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cm/s)	Check Δz*K <sub>i</sub> /K <sub>bar</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>bp</sub> /Q <sub>EBF</sub> )	
106.16	202.98	-0.00022	-0.00001	0.00068	5.34	0.18863	0.18864	0.01740	0.01740	9.27	197.61	0.40	18.9	6.68E-03	3.691E+00	0.41	0.076	
116.16	192.98	-0.01961	-0.00069	0.00209	4.83	0.17054	0.17123	0.02918	0.02918	10.00	187.98	0.62	29.4	1.04E-02	6.190E+00	0.34	0.070	
126.16	182.98	-0.07868	-0.00278	0.00093	3.94	0.13927	0.14205	0.01081	0.01081	10.00	177.98	0.23	10.9	3.84E-03	2.292E+00	0.23	0.059	
136.16	172.98	-0.10490	-0.00370	-0.00355	3.61	0.12754	0.13124	0.13120	0.13120	10.73	167.61	2.59	123.2	4.35E-02	2.783E+01	0.20	0.055	
147.16	161.98	-0.00434	-0.00015		0.00	-0.00011	0.00004	0.18859	0.18859									
106.89	Top of Screen Depth from TOC (ft)					Filter pack:			QP (ft³/min) 0.18859		40.00 b (ft)		Avg K <sub>i</sub> /K <sub>bar</sub> 1.000000					
146.89	Bottom of Screen Depth from TOC (ft)					0.254	Do (m)	QP (L/min) 5.34						(Should be exactly 1)				
40.00	Screen Length (ft)					0.102	Di (m)	uncorr QP 5.34										
309.14	TOC Elevation (ft)					0.043	Area (m^2)											
1.32	T pump (ft²/min)					7.62	Thickness (cm)											
47.5	K pump (ft/d)					100	Conductivity, K <sub>gp</sub> (m/d) FX-50											
1.68E-02	K pump (cm/s)						EBF:											
						0.178	L <sub>EBF</sub> (m)											
							Bypass flow:											
						0.111	ΔL (m)											
						0.289	L (m)											

Table 10 Hydraulic conductivity profile and bypass flow estimate for RPC-3PW for 1" EBF, 15 L/min nominal flow and 1 ft increments.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft <sup>3</sup> /min)	Differential Ambient Flow, Δq <sub>i</sub> (ft <sup>3</sup> /min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft <sup>3</sup> /min)	Net Pumping Flow, Q - q (ft <sup>3</sup> /min)	Differential Net Flow, Δ(Q <sub>i</sub> - q) (ft <sup>3</sup> /min)	Adjusted?	Layer Thickness Δz <sub>i</sub> (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>bar</sub> , b(ΔQ <sub>i</sub> -Δq <sub>i</sub> ) (Q <sub>p</sub> Δz <sub>i</sub> )	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cm/s)	Check Δz <sup>2</sup> K <sub>i</sub> /K <sub>bar</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>bp</sub> /Q <sub>EBF</sub> )
									Differential Net Flow Δ(Q <sub>i</sub> - q) (ft <sup>3</sup> /min)								
106.16	202.98	-0.00022	-0.00001	0.00001	14.56	0.51412	0.51413	-0.00243	-0.00243	0.27	202.11	-0.72	-34.0	-1.20E-02	-1.907E-01	0.17	0.012
107.16	201.98	-0.00050	-0.00002	0.00001	14.63	0.51654	0.51656	-0.00140	-0.00140	1.00	201.48	-0.11	-5.2	-1.84E-03	-1.095E-01	0.17	0.012
108.16	200.98	-0.00086	-0.00003	-0.00113	14.67	0.51793	0.51796	0.23013	0.23013	1.00	200.48	18.05	857.5	3.03E-01	1.805E+01	0.17	0.012
109.16	199.98	0.03106	0.00110	0.00131	8.18	0.28892	0.28782	-0.21198	-0.21198	1.00	199.48	-16.62	-789.9	-2.79E-01	-1.662E+01	0.06	0.007
110.16	198.98	-0.00606	-0.00021	0.00013	14.15	0.49959	0.49981	-0.00878	-0.00878	1.00	198.48	-0.69	-32.7	-1.15E-02	-6.882E-01	0.16	0.012
111.16	197.98	-0.00970	-0.00034	0.00031	14.39	0.50824	0.50859	0.00073	0.00073	1.00	197.48	0.06	2.7	9.54E-04	5.691E-02	0.17	0.012
112.16	196.98	-0.01854	-0.00065	-0.00005	14.36	0.50720	0.50786	-0.00099	-0.00099	1.00	196.48	-0.08	-3.7	-1.30E-03	-7.783E-02	0.17	0.012
113.16	195.98	-0.01726	-0.00061	-0.00010	14.39	0.50824	0.50885	0.00183	0.00183	1.00	195.48	0.14	6.8	2.41E-03	1.435E-01	0.17	0.012
114.16	194.98	-0.01441	-0.00051	0.00015	14.34	0.50651	0.50702	-0.00291	-0.00291	1.00	194.48	-0.23	-10.9	-3.83E-03	-2.285E-01	0.17	0.012
115.16	193.98	-0.01854	-0.00065	0.00004	14.42	0.50928	0.50993	0.00100	0.00100	1.00	193.48	0.08	3.7	1.31E-03	7.842E-02	0.17	0.012
116.16	192.98	-0.01961	-0.00069	-0.00007	14.39	0.50824	0.50893	0.00007	0.00007	1.00	192.48	0.01	0.3	9.58E-05	5.716E-03	0.17	0.012
117.16	191.98	-0.01755	-0.00062	-0.00008	14.39	0.50824	0.50886	0.00077	0.00077	1.00	191.48	0.06	2.9	1.01E-03	6.037E-02	0.17	0.012
118.16	190.98	-0.01534	-0.00054	0.00012	14.37	0.50755	0.50809	0.00368	0.00368	1.00	190.48	0.29	13.7	4.84E-03	2.889E-01	0.17	0.012
119.16	189.98	-0.01876	-0.00066	0.00004	14.27	0.50375	0.50441	-0.00177	-0.00177	1.00	189.48	-0.14	-6.6	-2.32E-03	-1.386E-01	0.17	0.012
120.16	188.98	-0.01983	-0.00070	-0.00005	14.32	0.50548	0.50618	0.00074	0.00074	1.00	188.48	0.06	2.8	9.72E-04	5.800E-02	0.17	0.012
121.16	187.98	-0.01848	-0.00065	-0.00010	14.30	0.50478	0.50544	-0.00060	-0.00060	1.00	187.48	-0.05	-2.2	-7.84E-04	-4.676E-02	0.17	0.012
122.16	186.98	-0.01578	-0.00056	0.00015	14.32	0.50548	0.50603	0.00573	0.00573	1.00	186.48	0.45	21.4	7.53E-03	4.493E-01	0.17	0.012
123.16	185.98	-0.02005	-0.00071	0.00017	14.15	0.49959	0.50030	0.00086	0.00086	1.00	185.48	0.07	3.2	1.14E-03	6.776E-02	0.16	0.012
124.16	184.98	-0.02497	-0.00088	0.00089	14.12	0.49856	0.49944	0.01502	0.01502	1.00	184.48	1.18	56.0	1.97E-02	1.178E+00	0.16	0.011
125.16	183.98	-0.05026	-0.00177	0.00100	13.67	0.48264	0.48442	0.01560	0.01560	1.00	183.48	1.22	58.1	2.05E-02	1.223E+00	0.15	0.011
126.16	182.98	-0.07868	-0.00278	0.00078	13.20	0.46604	0.46882	0.01029	0.01029	1.00	182.48	0.81	38.3	1.35E-02	8.065E-01	0.14	0.011
127.16	181.98	-0.10089	-0.00356	0.00015	12.88	0.45497	0.45853	-0.00188	-0.00188	1.00	181.48	-0.15	-7.0	-2.47E-03	-1.471E-01	0.14	0.011
128.16	180.98	-0.10502	-0.00371	-0.00007	12.93	0.45670	0.46041	0.00111	0.00111	1.00	180.48	0.09	4.1	1.46E-03	8.709E-02	0.14	0.011
129.16	179.98	-0.10296	-0.00364	0.00007	12.90	0.45566	0.45930	-0.00076	-0.00076	1.00	179.48	-0.06	-2.8	-9.95E-04	-5.938E-02	0.14	0.011
130.16	178.98	-0.10481	-0.00370	-0.00005	12.92	0.45635	0.46005	0.00385	0.00385	1.00	178.48	0.30	14.3	5.06E-03	3.019E-01	0.14	0.011
131.16	177.98	-0.10353	-0.00366	-0.00001	12.82	0.45255	0.45620	0.00797	0.00797	1.00	177.48	0.62	29.7	1.05E-02	6.249E-01	0.13	0.010
132.16	176.98	-0.10318	-0.00364	0.00001	12.59	0.44459	0.44823	0.00103	0.00103	1.00	176.48	0.08	3.8	1.35E-03	8.059E-02	0.13	0.010
133.16	175.98	-0.10347	-0.00365	0.00009	12.56	0.44355	0.44721	0.00371	0.00371	1.00	175.48	0.29	13.8	4.88E-03	2.913E-01	0.13	0.010
134.16	174.98	-0.10603	-0.00374	-0.00002	12.45	0.43975	0.44349	0.00348	0.00348	1.00	174.48	0.27	13.0	4.57E-03	2.728E-01	0.13	0.010
135.16	173.98	-0.10546	-0.00372	-0.00002	12.36	0.43629	0.44001	0.00244	0.00244	1.00	173.48	0.19	9.1	3.21E-03	1.915E-01	0.13	0.010
136.16	172.98	-0.10490	-0.00370	-0.00016	12.29	0.43387	0.43757	0.01227	0.01227	1.00	172.48	0.96	45.7	1.61E-02	9.618E-01	0.12	0.010
137.16	171.98	-0.10041	-0.00355	-0.00005	11.94	0.42176	0.42530	0.00524	0.00524	1.00	171.48	0.41	19.5	6.88E-03	4.106E-01	0.12	0.010
138.16	170.98	-0.09906	-0.00350	-0.00054	11.80	0.41657	0.42007	0.07250	0.07250	1.00	170.48	5.68	270.1	9.53E-02	5.685E+00	0.11	0.010
139.16	169.98	-0.08368	-0.00295	-0.00002	9.76	0.34462	0.34757	0.02458	0.02458	1.00	169.48	1.93	91.6	3.23E-02	1.928E+00	0.08	0.008
140.16	168.98	-0.08311	-0.00293	-0.00010	9.06	0.32006	0.32299	0.01428	0.01428	1.00	168.48	1.12	53.2	1.88E-02	1.120E+00	0.07	0.008
141.16	167.98	-0.08027	-0.00283	0.00007	8.66	0.30587	0.30871	0.00443	0.00443	1.00	167.48	0.35	16.5	5.83E-03	3.475E-01	0.06	0.007
142.16	166.98	-0.08212	-0.00290	-0.00040	8.54	0.30138	0.30427	0.02358	0.02358	1.00	166.48	1.85	87.9	3.10E-02	1.849E+00	0.06	0.007
143.16	165.98	-0.07073	-0.00250	-0.00035	7.88	0.27820	0.28070	0.04255	0.04255	1.00	165.48	3.34	158.6	5.59E-02	3.337E+00	0.05	0.007
144.16	164.98	-0.06083	-0.00215	-0.00049	6.68	0.23599	0.23814	0.05895	0.05895	1.00	164.48	4.62	219.7	7.75E-02	4.623E+00	0.04	0.006
145.16	163.98	-0.04701	-0.00166	-0.00063	5.03	0.17753	0.17919	0.06359	0.06359	1.00	163.48	4.99	236.9	8.36E-02	4.986E+00	0.02	0.005
146.16	162.98	-0.02921	-0.00103	-0.00088	3.24	0.11457	0.11560	0.11158	0.11158	0.73	162.61	11.93	567.0	2.00E-01	8.749E+00	0.01	0.003
147.16	161.98	-0.00434	-0.00015		0.11	0.00387	0.00403	0.51010	0.51010								
106.89	Top of Screen Depth from TOC (ft)					Filter pack:		QP (ft <sup>3</sup> /min) 0.51010	40.00 b (ft)		Avg K <sub>i</sub> /K <sub>bar</sub> 1.000000						
146.89	Bottom of Screen Depth from TOC (ft)				0.254	Do (m)		QP (L/min) 14.45			(Should be exactly 1)						
40.00	Screen Length (ft)				0.102	Di (m)		uncorr QP 14.45									
309.14	TOC Elevation (ft)				0.043	Area (m^2)											
1.32	T pump (ft <sup>2</sup> /min)				7.62	Thickness (cm)											
47.5	K pump (ft/d)				100	Conductivity, K <sub>sp</sub> (m/d) FX-50											
1.68E-02	K pump (cm/s)					EBF:											
					0.178	L <sub>EBF</sub> (m)											
					0.111	Bypass flow:											
					0.289	ΔL (m)											
						L (m)											



36

WSRC-TR-2000-00170, Rev. 0, Electromagnetic Borehole Flowmeter Testing in R-area (U)

WSRC-TR-2000-00170, Rev. 0, Electromagnetic Borehole Flowmeter Testing in R-area (U)

37

Table 13 Hydraulic conductivity profile and bypass flow estimate for RPT-2PW.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft <sup>3</sup> /min)	Differential Ambient Flow, Δq (ft <sup>3</sup> /min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft <sup>3</sup> /min)	Net Pumping Flow, Q - q (ft <sup>3</sup> /min)	Differential Net Flow, Δ(Q - q) (ft <sup>3</sup> /min)	Differential Net Flow Δ(Q - q) (ft <sup>3</sup> /min)	Layer Thickness Δz <sub>i</sub> (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>bar</sub> b(ΔQ-Δq)/ (Q <sub>0</sub> Δz <sub>i</sub> )	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cm/s)	Check Δz*K <sub>i</sub> /K <sub>bar</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>0</sub> /Q <sub>EBF</sub> )	Clock Time	Elapsed Time (min)	Water Level (ft)	dh (ft)	Cooper- Jacob K <sub>i</sub> (ft/d)	Ratio	KΔz
80.58	209.33	0.00000	0.00000	0.00006	4.01	0.14153	0.14153	0.00924	0.00924	1.00	208.83	0.98	2.3	7.98E-04	9.787E-01	0.33	0.082	14:40	110	36.65	8.10	2.6	1.13	2.56
81.58	208.33	-0.00157	-0.00006	0.00006	3.74	0.13223	0.13229	0.01896	0.01896	1.00	207.83	2.01	4.6	1.63E-03	2.009E+00	0.29	0.077	14:37	107	36.65	8.10	5.2	1.13	5.24
82.58	207.33	-0.00314	-0.00011	0.00014	3.21	0.11322	0.11333	0.00457	0.00457	1.00	206.83	0.48	1.1	3.93E-04	4.840E-01	0.22	0.068	14:33	103	36.65	8.10	1.3	1.13	1.26
83.58	206.33	-0.00705	-0.00025	0.00017	3.07	0.10852	0.10877	0.01036	0.01036	1.00	205.83	1.10	2.5	8.92E-04	1.098E+00	0.20	0.066	14:30	100	36.65	8.10	2.8	1.12	2.84
84.58	205.33	-0.01176	-0.00042	0.00019	2.78	0.09799	0.09840	0.00882	0.00882	1.00	204.83	0.93	2.2	7.59E-04	9.342E-01	0.17	0.061	14:23	93	36.65	8.10	2.4	1.12	2.40
85.58	204.33	-0.01724	-0.00061	0.00003	2.52	0.08898	0.08959	0.00854	0.00854	1.00	203.83	0.91	2.1	7.36E-04	9.052E-01	0.14	0.057	14:21	91	36.64	8.09	2.3	1.11	2.32
86.58	203.33	-0.01803	-0.00064	0.00003	2.28	0.08041	0.08105	0.00479	0.00479	1.00	202.83	0.51	1.2	4.12E-04	5.071E-01	0.12	0.052	14:19	89	36.62	8.07	1.3	1.11	1.30
87.58	202.33	-0.01881	-0.00066	-0.00003	2.14	0.07560	0.07626	0.00708	0.00708	1.00	201.83	0.75	1.7	6.10E-04	7.507E-01	0.11	0.050	14:17	87	36.61	8.06	1.9	1.11	1.93
88.58	201.33	-0.01803	-0.00064	-0.00003	1.94	0.06854	0.06918	0.01047	0.01047	1.00	200.83	1.11	2.6	9.01E-04	1.109E+00	0.09	0.047	14:14	84	36.59	8.04	2.8	1.11	2.84
89.58	200.33	-0.01724	-0.00061	-0.00006	1.65	0.05810	0.05871	0.01265	0.01265	1.00	199.83	1.34	3.1	1.09E-03	1.341E+00	0.07	0.042	14:10	80	36.56	8.01	3.4	1.11	3.43
90.58	199.33	-0.01568	-0.00055	-0.00008	1.29	0.04550	0.04606	0.00938	0.00938	1.00	198.83	0.99	2.3	8.08E-04	9.942E-01	0.05	0.036	14:08	78	36.55	8.00	2.5	1.11	2.54
91.58	198.33	-0.01332	-0.00047	-0.00014	1.03	0.03621	0.03668	0.01056	0.01056	1.00	197.83	1.12	2.6	9.10E-04	1.119E+00	0.03	0.031	14:05	75	36.53	7.98	2.9	1.11	2.85
92.58	197.33	-0.00941	-0.00033	-0.00028	0.73	0.02578	0.02612	0.02390	0.02390	1.00	196.83	2.53	5.8	2.06E-03	2.533E+00	0.02	0.026	14:01	71	36.49	7.94	6.5	1.11	6.46
93.58	196.33	-0.00157	-0.00006	-0.00006	0.06	0.00216	0.00221	0.00136	0.00136	1.00	195.83	0.14	0.3	1.17E-04	1.437E-01	0.00	0.015	13:58	68	36.45	7.90	0.4	1.11	0.37
94.58	195.33	0.00000	0.00000	0.00014	0.02	0.00086	0.00086	0.00008	0.00008	0.42	195.12	0.02	0.0	1.70E-05	8.802E-03	0.00	0.014	13:56	66	36.43	7.88	0.1	1.11	0.02
95.00	194.91	-0.00392	-0.00014	-0.00014	0.02	0.00064	0.00077	0.00077	0.00077	0.58	194.62	0.14	0.3	1.15E-04	8.212E-02	0.00	0.014	13:53	63	36.4	7.85	0.4	1.10	0.21
95.58	194.33	0.00000	0.00000	created data	0.00	0.00000	0.00000	0.14153	0.14153															
80.58	Top of Screen Depth from TOC (ft)				Filter pack:				QP (ft3/min)	0.14153	15.00 b (ft)		Avg K/K <sub>bar</sub> 1.000000				r <sub>w</sub> (in)	6	Avg Cooper-Jacob K				2.57	
95.58	Bottom of Screen Depth from TOC (ft)				0.305	Do (m)				QP (L/min)	4.01		(Should be exactly 1)				b (ft)	15	Ratio				1.12	
15.00	Screen Length (ft)				0.102	Di (m)				uncorr QP	4.01						K (ft/d)	2.6						
289.91	TOC Elevation (ft)				0.065	Area (m^2)											S <sub>w</sub> (1/ft)	1.0E-04						
0.024	T pump (ft2/min)				10.16	Thickness (cm)											T (ft^2/d)	39						
15	Formation thickness (ft)				100	Conductivity, K <sub>qp</sub> (m/d) FX-50											S (unitless)	1.5E-03						
2.3	K pump (ft/d)					EBF:											T/S (ft^2/d)	2.60E+04						
8.13E-04	K pump (cm/s)				0.178	L <sub>EBF</sub> (m)											Start of pumping	12:50						
					0.143	Bypass flow:											Water level (ft)	28.55						
					0.320	ΔL (m)											Well efficiency	50%						
						L (m)																		

Table 14 Hydraulic conductivity profile and bypass flow estimate for RPT-3PW.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft <sup>3</sup> /min)	Differential Ambient Flow, Δq (ft <sup>3</sup> /min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft <sup>3</sup> /min)	Net Pumping Flow, Q - q (ft <sup>3</sup> /min)	Differential Net Flow, Δ(Q - q) (ft <sup>3</sup> /min)	Differential Net Flow Δ(Q - q) (ft <sup>3</sup> /min)	Layer Thickness Δz (ft)	Mid-point Elevation (ft)	K <sub>z</sub> /K <sub>bar</sub> b(ΔQ - Δq)/(Q <sub>p</sub> Δz)	K <sub>z</sub> (ft/d)	K <sub>z</sub> (cm/s)	Check Δz <sup>2</sup> K <sub>z</sub> /K <sub>bar</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>bypass</sub> /Q <sub>EBF</sub> )	Clock Time	Elapsed Time (min)	Water Level (ft)	dh (ft)	Cooper-Jacob K (ft/d)	Ratio	KΔz
151.48	138.35	0.00000	0.00000	0.00456	14.16	0.49994	0.49994	0.01204	0.01204	0.96	137.83	1.01	2.0	7.05E-04	9.633E-01	0.16	0.012	14:38	166	61.27	7.70	4.1	2.06	3.94
152.48	137.35	-0.12926	-0.00456	0.00033	13.69	0.48334	0.48790	-0.00137	-0.00137	1.00	136.85	-0.11	-0.2	-7.67E-05	-1.096E-01	0.15	0.011	14:35	163	61.26	7.69	-0.4	2.06	-0.45
153.48	136.35	-0.13866	-0.00490	0.00011	13.72	0.48437	0.48927	0.00300	0.00300	1.00	135.85	0.24	0.5	1.68E-04	2.402E-01	0.15	0.011	14:33	161	61.25	7.68	1.0	2.06	0.98
154.48	135.35	-0.14179	-0.00501	0.00053	13.63	0.48126	0.48627	0.01089	0.01089	1.00	134.85	0.87	1.7	6.10E-04	8.713E-01	0.15	0.011	14:30	158	61.23	7.66	3.6	2.06	3.57
155.48	134.35	-0.15666	-0.00553	0.00011	13.31	0.46984	0.47538	-0.00288	-0.00288	1.00	133.85	-0.23	-0.5	-1.61E-04	-2.303E-01	0.14	0.011	14:27	155	61.22	7.65	-0.9	2.06	-0.94
156.48	133.35	-0.15980	-0.00564	0.00014	13.38	0.47261	0.47825	0.00436	0.00436	1.00	132.85	0.35	0.7	2.44E-04	3.487E-01	0.15	0.011	14:23	151	61.20	7.63	1.4	2.06	1.43
157.48	132.35	-0.16371	-0.00578	0.00044	13.26	0.46811	0.47389	0.01270	0.01270	1.00	131.85	1.02	2.0	7.12E-04	1.016E+00	0.14	0.011	14:16	144	61.17	7.60	4.2	2.06	4.16
158.48	131.35	-0.17623	-0.00622	0.00116	12.88	0.45497	0.46119	0.02963	0.02963	1.00	130.85	2.37	4.7	1.66E-03	2.370E+00	0.14	0.011	14:12	140	61.15	7.58	9.7	2.06	9.70
159.48	130.35	-0.20910	-0.00738	0.00251	12.01	0.42418	0.43156	0.05422	0.05422	1.00	129.85	4.34	8.6	3.04E-03	4.338E+00	0.12	0.010	14:07	135	61.13	7.56	17.7	2.06	17.74
160.48	129.35	-0.28029	-0.00990	0.00287	10.41	0.36745	0.37735	0.05767	0.05767	1.00	128.85	4.61	9.2	3.23E-03	4.614E+00	0.09	0.009	14:03	131	61.11	7.54	18.9	2.06	18.85
161.48	128.35	-0.36160	-0.01277	0.00207	8.69	0.30691	0.31968	0.04359	0.04359	1.00	127.85	3.49	6.9	2.44E-03	3.488E+00	0.06	0.007	13:59	127	61.10	7.53	14.2	2.06	14.24
162.48	127.35	-0.42021	-0.01484	0.00099	7.40	0.26125	0.27608	0.01284	0.01284	1.00	126.85	1.03	2.0	7.20E-04	1.028E+00	0.05	0.006	13:55	123	61.08	7.51	4.2	2.05	4.19
163.48	126.35	-0.44833	-0.01583	0.00019	7.01	0.24741	0.26324	-0.00054	-0.00054	1.00	125.85	-0.04	-0.1	-3.02E-05	-4.312E-02	0.04	0.006	13:52	120	61.07	7.50	-0.2	2.05	-0.18
164.48	125.35	-0.45380	-0.01602	-0.00006	7.02	0.24776	0.26378	0.00386	0.00386	1.00	124.85	0.31	0.6	2.16E-04	3.088E-01	0.04	0.006	13:49	117	61.06	7.49	1.3	2.05	1.26
165.48	124.35	-0.45223	-0.01597	0.00011	6.91	0.24395	0.25992	-0.00011	-0.00011	1.00	123.85	-0.01	0.0	-6.18E-06	-8.825E-03	0.04	0.006	13:46	114	61.05	7.48	0.0	2.05	-0.04
166.48	123.35	-0.45536	-0.01608	0.00006	6.91	0.24395	0.26003	0.00479	0.00479	1.00	122.85	0.38	0.8	2.68E-04	3.830E-01	0.04	0.006	13:44	112	61.04	7.47	1.6	2.05	1.56
167.48	122.35	-0.45692	-0.01613	0.00025	6.77	0.23911	0.25524	0.00044	0.00044	1.00	121.85	0.04	0.1	2.49E-05	3.550E-02	0.04	0.006	13:41	109	61.03	7.46	0.1	2.05	0.14
168.48	121.35	-0.46395	-0.01638	-0.00008	6.75	0.23842	0.25480	0.00735	0.00735	1.00	120.85	0.59	1.2	4.12E-04	5.878E-01	0.04	0.006	13:39	107	61.02	7.45	2.4	2.05	2.39
169.48	120.35	-0.46161	-0.01630	0.00019	6.55	0.23115	0.24745	0.00119	0.00119	1.00	119.85	0.10	0.2	6.67E-05	9.526E-02	0.04	0.006	13:36	104	61.00	7.43	0.4	2.05	0.39
170.48	119.35	-0.46707	-0.01649	-0.00019	6.51	0.22977	0.24626	0.00088	0.00088	1.00	118.85	0.07	0.1	4.96E-05	7.079E-02	0.04	0.006	13:34	102	60.98	7.41	0.3	2.05	0.29
171.48	118.35	-0.46161	-0.01630	-0.00022	6.49	0.22908	0.24537	0.00057	0.00057	1.00	117.85	0.05	0.1	3.17E-05	4.533E-02	0.04	0.006	13:31	99	60.96	7.39	0.2	2.05	0.18
172.48	117.35	-0.45536	-0.01608	-0.00011	6.48	0.22873	0.24481	-0.00127	-0.00127	1.00	116.85	-0.10	-0.2	-7.13E-05	-1.019E-01	0.04	0.006	13:29	97	60.95	7.38	-0.4	2.05	-0.41
173.48	116.35	-0.45223	-0.01597	-0.00066	6.52	0.23011	0.24608	0.00896	0.00896	1.00	115.85	0.72	1.4	5.02E-04	7.172E-01	0.04	0.006	13:27	95	60.93	7.36	2.9	2.05	2.91
174.48	115.35	-0.43349	-0.01531	-0.00055	6.28	0.22181	0.23712	0.01404	0.01404	1.00	114.85	1.12	2.2	7.87E-04	1.123E+00	0.03	0.005	13:24	92	60.91	7.34	4.6	2.05	4.56
175.48	114.35	-0.41786	-0.01475	-0.00036	5.90	0.20832	0.22307	0.01108	0.01108	1.00	113.85	0.89	1.8	6.21E-04	8.866E-01	0.03	0.005	13:22	90	60.90	7.33	3.6	2.04	3.60
176.48	113.35	-0.40771	-0.01440	-0.00047	5.60	0.19760	0.21199	0.00635	0.00635	1.00	112.85	0.51	1.0	3.56E-04	5.090E-01	0.03	0.005	13:20	88	60.89	7.32	2.1	2.04	2.06
177.48	112.35	-0.39443	-0.01393	-0.00055	5.43	0.19171	0.20564	0.00782	0.00782	1.00	111.85	0.63	1.2	4.38E-04	6.253E-01	0.03	0.005	13:18	86	60.88	7.31	2.5	2.04	2.53
178.48	111.35	-0.37880	-0.01338	-0.00039	5.22	0.18445	0.19783	0.01284	0.01284	1.00	110.85	1.03	2.0	7.19E-04	1.027E+00	0.02	0.005	13:16	84	60.87	7.30	4.2	2.04	4.16
179.48	110.35	-0.36786	-0.01299	-0.00102	4.87	0.17200	0.18499	0.02109	0.02109	1.00	109.85	1.69	3.3	1.18E-03	1.687E+00	0.02	0.004	13:13	81	60.86	7.29	6.8	2.04	6.82
180.48	109.35	-0.33894	-0.01197	-0.00102	4.30	0.15193	0.16390	0.02316	0.02316	1.00	108.85	1.85	3.7	1.30E-03	1.853E+00	0.02	0.004	13:11	79	60.85	7.28	7.5	2.03	7.48
181.48	108.35	-0.31001	-0.01095	-0.00094	3.68	0.12979	0.14074	0.01962	0.01962	1.00	107.85	1.57	3.1	1.10E-03	1.570E+00	0.01	0.003	13:09	77	60.83	7.26	6.3	2.03	6.33
182.48	107.35	-0.28342	-0.01001	-0.00022	3.15	0.11111	0.12112	0.00472	0.00472	1.00	106.85	0.38	0.7	2.64E-04	3.775E-01	0.01	0.003	13:07	75	60.82	7.25	1.5	2.03	1.52
183.48	106.35	-0.27716	-0.00979	-0.00017	3.02	0.10662	0.11640	0.00259	0.00259	1.00	105.85	0.21	0.4	1.45E-04	2.070E-01	0.01	0.003	13:05	73	60.80	7.23	0.8	2.03	0.83
184.48	105.35	-0.27247	-0.00962	-0.00055	2.95	0.10419	0.11381	0.00920	0.00920	1.00	104.85	0.74	1.5	5.15E-04	7.361E-01	0.01	0.003	13:02	70	60.78	7.21	3.0	2.03	2.97
185.48	104.35	-0.25683	-0.00907	-0.00240	2.71	0.09555	0.10461	0.02143	0.02143	1.00	103.85	1.71	3.4	1.20E-03	1.714E+00	0.01	0.003	12:59	67	60.75	7.18	6.9	2.03	6.90
186.48	103.35	-0.18876	-0.00666	-0.00249	2.17	0.07652	0.08318	0.02117	0.02117	1.00	102.85	1.69	3.4	1.19E-03	1.694E+00	0.00	0.002	12:56	64	60.73	7.16	6.8	2.03	6.81
187.48	102.35	-0.11830	-0.00418	-0.00119	1.64	0.05784	0.06202	0.01849	0.01849	1.00	101.85	1.48	2.9	1.04E-03	1.479E+00	0.00	0.002	12:54	62	60.71	7.14	5.9	2.02	5.94
188.48	101.35	-0.08462	-0.00299	-0.00058	1.15	0.04054	0.04353	0.00750	0.00750	1.00	100.85	0.60	1.2	4.20E-04	6.000E-01	0.00	0.002	12:51	59	60.69	7.12	2.4	2.02	2.41
189.48	100.35	-0.06817	-0.00241	-0.00075	0.95	0.03362	0.03603	0.01182	0.01182	1.00	99.85	0.95	1.9	6.62E-04	9.454E-01	0.00	0.001	12:49	57	60.67	7.10	3.8	2.02	3.79
190.48	99.35	-0.04702	-0.00166	-0.00166	0.64	0.02255	0.02421	0.02421	0.02421	1.04	98.83	1.86	3.7	1.30E-03	1.937E+									

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft³/min)	Differential Ambient Flow, Δq <sub>i</sub> (ft³/min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft³/min)	Net Pumping Flow, Q - q (ft³/min)	Differential Net Flow, Δ(Q <sub>i</sub> - q <sub>i</sub> ) (ft³/min)	<i>Adjusted?</i> Differential Net Flow Δ(Q <sub>i</sub> - q <sub>i</sub> ) (ft³/min)	Layer Thickness Δz <sub>i</sub> (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>bar</sub> = b(ΔQ <sub>i</sub> -Δq <sub>i</sub> )/ (Q <sub>p</sub> Δz <sub>i</sub> )	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cms/s)	Check Δz*K <sub>i</sub> /K <sub>bar</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>bp</sub> /Q <sub>EBF</sub> )
233.82	55.90	0.00000	0.00000	-0.00008	13.55	0.47845	0.47845	0.00073	0.00073	0.87	55.33	0.07	1.0	3.64E-04	6.129E-02	0.13	0.009
234.82	54.90	0.00235	0.00008	-0.00006	13.53	0.47780	0.47772	-0.00133	-0.00133	1.00	54.40	-0.11	-1.6	-5.71E-04	-1.111E-01	0.13	0.009
235.82	53.90	0.00392	0.00014	0.00014	13.57	0.47918	0.47905	-0.00014	-0.00014	1.00	53.40	-0.01	-0.2	-5.95E-05	-1.157E-02	0.13	0.009
236.82	52.90	0.00000	0.00000	0.00000	13.57	0.47918	0.47918	0.00000	0.00000	1.00	52.40	0.00	0.0	0.00E+00	0.000E+00	0.13	0.009
237.82	51.90	0.00000	0.00000	0.00000	13.57	0.47918	0.47918	0.00069	0.00069	1.00	51.40	0.06	0.8	2.98E-04	5.784E-02	0.13	0.009
238.82	50.90	0.00000	0.00000	0.00000	13.55	0.47849	0.47849	-0.00035	-0.00035	1.00	50.40	-0.03	-0.4	-1.49E-04	-2.892E-02	0.13	0.009
239.82	49.90	0.00000	0.00000	0.00014	13.56	0.47884	0.47884	0.00194	0.00194	1.00	49.40	0.16	2.4	8.33E-04	1.620E-01	0.13	0.009
240.82	48.90	-0.00392	-0.00014	-0.00014	13.50	0.47676	0.47690	-0.00055	-0.00055	1.00	48.40	-0.05	-0.7	-2.38E-04	-4.627E-02	0.13	0.009
241.82	47.90	0.00000	0.00000	0.00000	13.52	0.47745	0.47745	-0.00104	-0.00104	1.00	47.40	-0.09	-1.3	-4.46E-04	-8.676E-02	0.13	0.009
242.82	46.90	0.00000	0.00000	0.00000	13.55	0.47849	0.47849	0.00208	0.00208	1.00	46.40	0.17	2.5	8.93E-04	1.735E-01	0.13	0.009
243.82	45.90	0.00000	0.00000	0.00000	13.49	0.47642	0.47642	0.00104	0.00104	1.00	45.40	0.09	1.3	4.46E-04	8.676E-02	0.13	0.009
244.82	44.90	0.00000	0.00000	0.00000	13.46	0.47538	0.47538	0.00035	0.00035	1.00	44.40	0.03	0.4	1.49E-04	2.892E-02	0.13	0.009
245.82	43.90	0.00000	0.00000	0.00000	13.45	0.47503	0.47503	0.00069	0.00069	1.00	43.40	0.06	0.8	2.98E-04	5.784E-02	0.13	0.009
246.82	42.90	0.00000	0.00000	0.00000	13.43	0.47434	0.47434	0.47434	0.47434	27.13	29.33	1.46	21.3	7.52E-03	3.966E+01	0.13	0.009
273.95	15.77	0.00000	0.00000	created date	0.00	0.00000	0.00000										
233.95	Top of Screen Depth from TOC (ft)					Filter pack:			QP (ft3/min) 0.47845		40.00 b (ft)		Avg K/K <sub>bar</sub>		1.000000		
273.95	Bottom of Screen Depth from TOC (ft)					0.254	Do (m)		QP (L/min) 13.55		(Should be exactly 1)						
40.00	Screen Length (ft)																

Table 16 Hydraulic conductivity profile and bypass flow estimate for RPT-30PZ.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
Depth Below TOC (ft)	Elevation (ft-msl)	Ambient Flow (L/min)	Ambient Flow, q (ft³/min)	Differential Ambient Flow, Δq <sub>i</sub> (ft³/min)	Pump Induced Flow (L/min)	Pump Induced Flow, Q (ft³/min)	Net Pumping Flow, Q - q (ft³/min)	Differential Net Flow, Δ(Q <sub>i</sub> - q) (ft³/min)	Adjusted? Differential Net Flow Δ(Q <sub>i</sub> - q) (ft³/min)	Layer Thickness Δz <sub>i</sub> (ft)	Mid-point Elevation (ft)	K <sub>i</sub> /K <sub>bar</sub> = b(ΔQ <sub>i</sub> -Δq <sub>i</sub> )/ (Q <sub>p</sub> Δz <sub>i</sub> )	K <sub>i</sub> (ft/d)	K <sub>i</sub> (cms/s)	Check Δz* K <sub>i</sub> /K <sub>bar</sub>	Estimated bypass flow (L/min)	Estimated bypass flow ratio (Q <sub>bp</sub> /Q <sub>EBF</sub> )
27.47	262.19	0.00000	0.00000	0.00000													
28.30	261.36	0.00000	0.00000	0.00003	2.10	0.07415	0.07415	0.01285	0.01285	3.17	259.78	1.60	2.8	1.00E-03	5.085E+00	0.05	0.026
28.47	261.19	-0.00078	-0.00003	0.00003													
29.47	260.19	-0.00157	-0.00006	0.00006													
30.47	259.19	-0.00314	-0.00011	-0.00003													
31.47	258.19	-0.00235	-0.00008	0.00011	1.73	0.06121	0.06130	-0.00395	-0.00395	1.00	257.69	-1.56	-2.8	-9.79E-04	-1.565E+00	0.04	0.023
32.47	257.19	-0.00549	-0.00019	0.00008	1.84	0.06506	0.06525	0.00025	0.00025	1.00	256.69	0.10	0.2	6.28E-05	1.004E-01	0.04	0.023
33.47	256.19	-0.00784	-0.00028	-0.00003	1.83	0.06472	0.06500	-0.00093	-0.00093	1.00	255.69	-0.37	-0.7	-2.29E-04	-3.666E-01	0.04	0.023
34.47	255.19	-0.00705	-0.00025	0.00003	1.86	0.06567	0.06592	0.00059	0.00059	1.00	254.69	0.23	0.4	1.46E-04	2.334E-01	0.04	0.024
35.47	254.19	-0.00784	-0.00028	-0.00003	1.84	0.06506	0.06533	-0.00410	-0.00410	1.00	253.69	-1.62	-2.9	-1.01E-03	-1.622E+00	0.04	0.023
36.47	253.19	-0.00705	-0.00025	0.00017	1.96	0.06919	0.06943	-0.00008	-0.00008	1.00	252.69	-0.03	-0.1	-2.02E-05	-3.234E-02	0.05	0.025
37.47	252.19	-0.01176	-0.00042	0.00000	1.96	0.06910	0.06952	-0.00138	-0.00138	1.00	251.69	-0.54	-1.0	-3.41E-04	-5.447E-01	0.05	0.024
38.47	251.19	-0.01176	-0.00042	0.00011	2.00	0.07048	0.07089	0.00542	0.00542	1.00	250.69	2.15	3.8	1.34E-03	2.145E+00	0.05	0.025
39.47	250.19	-0.01489	-0.00053	0.00017	1.84	0.06495	0.06547	0.00127	0.00127	1.00	249.69	0.50	0.9	3.13E-04	5.006E-01	0.04	0.023
40.47	249.19	-0.01959	-0.00069	0.00011	1.80	0.06351	0.06421	0.00267	0.00267	1.00	248.69	1.05	1.9	6.60E-04	1.055E+00	0.04	0.023
41.47	248.19	-0.02273	-0.00080	0.00025	1.72	0.06074	0.06154	0.00211	0.00211	1.00	247.69	0.83	1.5	5.21E-04	8.332E-01	0.04	0.022
42.47	247.19	-0.02978	-0.00105	0.00006	1.65	0.05838	0.05943	-0.00078	-0.00078	1.00	246.69	-0.31	-0.6	-1.94E-04	-3.102E-01	0.04	0.022
43.47	246.19	-0.03135	-0.00111	0.00017	1.67	0.05911	0.06022	-0.00087	-0.00087	1.00	245.69	-0.34	-0.6	-2.15E-04	-3.430E-01	0.04	0.022
44.47	245.19	-0.03605	-0.00127	0.00014	1.69	0.05981	0.06108	0.00042	0.00042	1.00	244.69	0.17	0.3	1.05E-04	1.671E-01	0.04	0.022
45.47	244.19	-0.03997	-0.00141	0.00003	1.68	0.05925	0.06066	0.00081	0.00081	1.00	243.69	0.32	0.6	2.01E-04	3.218E-01	0.04	0.022
46.47	243.19	-0.04075	-0.00144	0.00017	1.65	0.05841	0.05985	0.00062	0.00062	1.00	242.69	0.24	0.4	1.53E-04	2.448E-01	0.04	0.022
47.47	242.19	-0.04545	-0.00160	0.00039	1.63	0.05762	0.05923	0.00281	0.00281	1.00	241.69	1.11	2.0	6.95E-04	1.110E+00	0.04	0.022
48.47	241.19	-0.05642	-0.00199	0.00039	1.54	0.05443	0.05642	0.00247	0.00247	1.00	240.69	0.98	1.7	6.11E-04	9.766E-01	0.03	0.021
49.47	240.19	-0.06739	-0.00238	0.00025	1.46	0.05157	0.05395	0.00140	0.00140	1.00	239.69	0.55	1.0	3.47E-04	5.547E-01	0.03	0.020
50.47	239.19	-0.07444	-0.00263	0.00022	1.41	0.04992	0.05255	0.00123	0.00123	1.00	238.69	0.49	0.9	3.05E-04	4.880E-01	0.03	0.020
51.47	238.19	-0.08071	-0.00285	0.00000	1.37	0.04847	0.05132	0.00238	0.00238	1.00	237.69	0.94	1.7	5.88E-04	9.403E-01	0.03	0.019
52.47	237.19	-0.08071	-0.00285	-0.00058	1.31	0.04609	0.04894	0.01560	0.01560	1.00	236.69	6.17	10.9	3.86E-03	6.170E+00	0.02	0.019
53.47	236.19	-0.06426	-0.00227	-0.00028	0.88	0.03108	0.03334	0.00938	0.00938	1.00	235.69	3.71	6.6	2.32E-03	3.711E+00	0.01	0.015
54.47	235.19	-0.05642	-0.00199	-0.00014	0.62	0.02197	0.02396	0.00136	0.00136	1.00	234.69	0.54	1.0	3.37E-04	5.387E-01	0.01	0.013
55.47	234.19	-0.05250	-0.00185	-0.00011	0.59	0.02075	0.02260	0.00281	0.00281	1.00	233.69	1.11	2.0	6.95E-04	1.110E+00	0.01	0.012
56.47	233.19	-0.04937	-0.00174	-0.00174	0.51	0.01805	0.01980	0.01938	0.01938	1.00	232.69	7.67	13.6	4.80E-03	7.667E+00	0.01	0.012
57.47	232.19	0.00000	0.00000		0.01	0.00042	0.00042										
17.47	Top of Screen Depth from TOC (ft)					Filter pack:		QP (ft³/min) 0.07374		29.17 b (ft)				Avg K/K <sub>bar</sub>		1.000000	
57.47	Bottom of Screen Depth from TOC (ft)				0.203	Do (m)		QP (L/min) 2.09								(Should be exactly 1)	
30.85	Saturated Screen Length (ft)				0.051	Di (m)		uncorr QP 2.09									
289.66	TOC Elevation (ft)				0.030	Area (m²)											
0.038	T pump (ft²/min)				7.62	Thickness (cm)											
1.77	K pump (ft/d)				100	Conductivity, K <sub>gp</sub> (m/d) FX-50											
6.26E-04	K pump (cm/s)					EBF:											
26.62	Water Level Depth from TOC (ft) - 12/20/99				0.178	L <sub>EBF</sub> (m)											
28.30	Water Level Depth from TOC (ft) -					Bypass flow:											
	EBF dynamic testing				0.111	ΔL (m)											
					0.289	L (m)											

Table 17 Post-test check for quasi-steady flow conditions at RPC-2PR.

**Post-test check for valid EBF application (pseudo-steady state & minimal bypass flow)**

<b>Site</b>		RPC-2PR					
<b>Formation properties</b>		<b>Ruud and Kabala (1996) pseudo-steady criterion</b>					
estimated K (ft/d)	25	1.0E+03	Non-dimensional time, $t_D$				
estimated $S_s$ (1/ft)	2.5E-04	Diffusivity contrast	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
thickness b (ft)	40	1:1	0.0	0.0	0.6	37.5	
estimated T (ft <sup>2</sup> /d)	1000	10:1	0.0	0.1	3.4	206.3	
estimated S	1.0E-02	100:1	0.0	0.5	31.6	1893.8	
diffusivity $\nu = T/S$ (ft <sup>2</sup> /d)	1.0E+05	1000:1	0.2	5.2	312.8	18768.8	
<b>Well properties</b>		<b>Molz and others (1989) pseudo-steady criterion</b>					
borehole diameter (in)	10	<i>(but using assumed influence radius per personal comm.)</i>					
Casing diameter (in)	4	1.0E+02	Non-dimensional time, $t_D$				
Borehole radius (in)	5	Influence radius, r (ft)	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
Casing radius (in)	2	1	0.0	0.0	0.4	21.6	
Borehole radius (m)	0.1270	2	0.0	0.0	1.4	86.4	
Casing radius (m)	0.0508	5	0.0	0.2	9.0	540.0	
Annulus area (m <sup>2</sup> )	0.043	10	0.0	0.6	36.0	2160.0	
Annulus thickness (cm)	7.62	20	0.1	2.4	144.0	8640.0	
Filter pack conductivity (m/d)	100	<b>Rehfeldt and others (1989) and Flach criteria</b>					
<b>EBF properties</b>		Non-dimensional time, $t_D$	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
$L_{EBF}$ (m)	0.178	4.0E+02	0.0	0.0	0.3	15.0	10:1
<b>Bypass properties</b>		4.0E+03	0.0	0.0	2.5	150.0	100:1
$\Delta L$ (m)	0.111	4.0E+04	0.0	0.4	25.0	1500.0	$r/b < 0.125$
L (m)	0.289	1.0E+06	0.4	10.4	625.0	37500.0	long time
<b>Bypass flow estimate</b>		<b>1/2" EBF</b>				<b>1" EBF</b>	
Pumping rate, QP (L/min)		Pumping rate, QP (gal/min)	Bypass (L/min)	Ratio	Bypass (L/min)	Ratio	
0.2		0.05	0.00	1.3%	0.00	0.1%	
0.5		0.13	0.01	1.6%	0.00	0.1%	
1		0.26	0.02	2.3%	0.00	0.1%	
2		0.53	0.07	3.5%	0.00	0.2%	
5		1.32	0.36	7.2%	0.02	0.4%	
10		2.64	1.33	13.3%	0.08	0.8%	
20		5.28	5.12	25.6%	0.32	1.6%	
4.3	test block		0.27	6.3%	0.02	0.4%	

Table 18 Post-test check for quasi-steady flow conditions at RPC-3PW.

**Post-test check for valid EBF application (pseudo-steady state & minimal bypass flow)**

<b>Site</b>		RPC-3PW					
<b>Formation properties</b>		<b>Ruud and Kabala (1996) pseudo-steady criterion</b>					
estimated K (ft/d)	25	1.0E+03	Non-dimensional time, $t_D$				
estimated $S_s$ (1/ft)	1.0E-04	Diffusivity contrast	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
thickness b (ft)	101	1:1	0.0	0.0	0.3	15.0	
estimated T (ft <sup>2</sup> /d)	2525	10:1	0.0	0.0	1.4	82.5	
estimated S	1.0E-02	100:1	0.0	0.2	12.6	757.5	
diffusivity $v = T/S$ (ft <sup>2</sup> /d)	2.5E+05	1000:1	0.1	2.1	125.1	7507.5	
<b>Well properties</b>		<b>Molz and others (1989) pseudo-steady criterion</b>					
borehole diameter (in)	10	<i>(but using assumed influence radius per personal comm.)</i>					
Casing diameter (in)	4	1.0E+02	Non-dimensional time, $t_D$				
Borehole radius (in)	5	Influence radius, r (ft)	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
Casing radius (in)	2	1	0.0	0.0	0.1	8.6	
Borehole radius (m)	0.1270	2	0.0	0.0	0.6	34.6	
Casing radius (m)	0.0508	5	0.0	0.1	3.6	216.0	
Annulus area (m <sup>2</sup> )	0.043	10	0.0	0.2	14.4	864.0	
Annulus thickness (cm)	7.62	20	0.0	1.0	57.6	3456.0	
Filter pack conductivity (m/d)	100	<b>Rehfeldt and others (1989) and Flach criteria</b>					
<b>EBF properties</b>		Non-dimensional time, $t_D$	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
$L_{EBF}$ (m)	0.178	4.0E+02	0.0	0.0	0.1	6.0	10:1
<b>Bypass properties</b>		4.0E+03	0.0	0.0	1.0	60.0	100:1
$\Delta L$ (m)	0.111	4.0E+04	0.0	0.2	10.0	600.0	$r/b < 0.125$
L (m)	0.289	1.0E+06	0.2	4.2	250.0	15000.0	long time
<b>Bypass flow estimate</b>		<b>1/2" EBF</b>		<b>1" EBF</b>			
Pumping rate, QP (L/min)		Pumping rate, QP (gal/min)	Bypass (L/min)	Ratio	Bypass (L/min)	Ratio	
0.2		0.05	0.00	1.3%	0.00	0.1%	
0.5		0.13	0.01	1.6%	0.00	0.1%	
1		0.26	0.02	2.3%	0.00	0.1%	
2		0.53	0.07	3.5%	0.00	0.2%	
5		1.32	0.36	7.2%	0.02	0.4%	
10		2.64	1.33	13.3%	0.08	0.8%	
20		5.28	5.12	25.6%	0.32	1.6%	
5.34		test block	0.41	7.6%	0.03	0.5%	
14.56		test block	2.76	18.9%	0.17	1.2%	



Table 19 Post-test check for quasi-steady flow conditions at RPT-2PW.

**Post-test check for valid EBF application (pseudo-steady state & minimal bypass flow)**

Site RPT-2PW

**Formation properties**

estimated K (ft/d)	2.3
estimated $S_s$ (1/ft)	1.5E-05
thickness b (ft)	15
estimated T (ft <sup>2</sup> /d)	34.5
estimated S	2.3E-04
diffusivity $\nu = T/S$ (ft <sup>2</sup> /d)	1.5E+05

**Ruud and Kabala (1996) pseudo-steady criterion**

1.0E+03	Non-dimensional time, $t_D$			
Diffusivity contrast	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)
1:1	0.0	0.0	0.6	35.2
10:1	0.0	0.1	3.2	193.7
100:1	0.0	0.5	29.6	1778.5
1000:1	0.2	4.9	293.8	17626.3

**Well properties**

borehole diameter (in)	12
Casing diameter (in)	4
Borehole radius (in)	6
Casing radius (in)	2
Borehole radius (m)	0.1524
Casing radius (m)	0.0508
Annulus area (m <sup>2</sup> )	0.065
Annulus thickness (cm)	10.16
Filter pack conductivity (m/d)	100

**Molz and others (1989) pseudo-steady criterion***(but using assumed influence radius per personal comm.)*

1.0E+02	Non-dimensional time, $t_D$			
Influence radius, r (ft)	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)
1	0.0	0.0	0.2	14.1
2	0.0	0.0	0.9	56.3
5	0.0	0.1	5.9	352.2
10	0.0	0.4	23.5	1408.7
20	0.1	1.6	93.9	5634.8

**Rehfeldt and others (1989) and Flach criteria**

Non-dimensional time, $t_D$	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
4.0E+02	0.0	0.0	0.2	14.1	10:1
4.0E+03	0.0	0.0	2.3	140.9	100:1
4.0E+04	0.0	0.4	23.5	1408.7	$r/b < 0.125$
1.0E+06	0.4	9.8	587.0	35217.4	long time

**EBF properties** $L_{EBF}$  (m) 0.178**Bypass properties** $\Delta L$  (m) 0.143  
L (m) 0.320**Bypass flow estimate**

		<b>1/2" EBF</b>		<b>1" EBF</b>	
Pumping rate, QP (L/min)	Pumping rate, QP (gal/min)	Bypass (L/min)	Ratio	Bypass (L/min)	Ratio
0.2	0.05	0.00	1.7%	0.00	0.1%
0.5	0.13	0.01	2.2%	0.00	0.1%
1	0.26	0.03	3.1%	0.00	0.2%
2	0.53	0.10	4.8%	0.01	0.3%
5	1.32	0.49	9.8%	0.03	0.6%
10	2.64	1.83	18.3%	0.11	1.1%
20	5.28	7.03	35.2%	0.44	2.2%
4.01	test block	0.33	8.2%	0.02	0.5%

Table 20 Post-test check for quasi-steady flow conditions at RPT-3PW.

**Post-test check for valid EBF application (pseudo-steady state & minimal bypass flow)**

<b>Site</b>		RPT-3PW					
<b>Formation properties</b>		<b>Ruud and Kabala (1996) pseudo-steady criterion</b>					
estimated K (ft/d)	2	1.0E+03	Non-dimensional time, $t_D$				
estimated $S_s$ (1/ft)	5.0E-06	Diffusivity contrast	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
thickness b (ft)	74	1:1	0.0	0.0	0.2	9.4	
estimated T (ft <sup>2</sup> /d)	148	10:1	0.0	0.0	0.9	51.6	
estimated S	3.7E-04	100:1	0.0	0.1	7.9	473.4	
diffusivity $v = T/S$ (ft <sup>2</sup> /d)	4.0E+05	1000:1	0.1	1.3	78.2	4692.2	
<b>Well properties</b>		<b>Molz and others (1989) pseudo-steady criterion</b>					
borehole diameter (in)	10	<i>(but using assumed influence radius per personal comm.)</i>					
Casing diameter (in)	4	1.0E+02	Non-dimensional time, $t_D$				
Borehole radius (in)	5	Influence radius, r (ft)	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
Casing radius (in)	2	1	0.0	0.0	0.1	5.4	
Borehole radius (m)	0.1270	2	0.0	0.0	0.4	21.6	
Casing radius (m)	0.0508	5	0.0	0.0	2.3	135.0	
Annulus area (m <sup>2</sup> )	0.043	10	0.0	0.2	9.0	540.0	
Annulus thickness (cm)	7.62	20	0.0	0.6	36.0	2160.0	
Filter pack conductivity (m/d)	100	<b>Rehfeldt and others (1989) and Flach criteria</b>					
<b>EBF properties</b>		Non-dimensional time, $t_D$	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
$L_{EBF}$ (m)	0.178	4.0E+02	0.0	0.0	0.1	3.8	10:1
<b>Bypass properties</b>		4.0E+03	0.0	0.0	0.6	37.5	100:1
$\Delta L$ (m)	0.111	4.0E+04	0.0	0.1	6.3	375.0	$r/b < 0.125$
L (m)	0.289	1.0E+06	0.1	2.6	156.3	9375.0	long time
<b>Bypass flow estimate</b>		<b>1/2" EBF</b>				<b>1" EBF</b>	
Pumping rate, QP (L/min)		Pumping rate, QP (gal/min)	Bypass (L/min)	Ratio	Bypass (L/min)	Ratio	
0.2		0.05	0.00	1.3%	0.00	0.1%	
0.5		0.13	0.01	1.6%	0.00	0.1%	
1		0.26	0.02	2.3%	0.00	0.1%	
2		0.53	0.07	3.5%	0.00	0.2%	
5		1.32	0.36	7.2%	0.02	0.4%	
10		2.64	1.33	13.3%	0.08	0.8%	
20		5.28	5.12	25.6%	0.32	1.6%	
14.16		test block	2.61	18.4%	0.16	1.2%	

Table 21 Post-test check for quasi-steady flow conditions at RPT-4PW.

**Post-test check for valid EBF application (pseudo-steady state & minimal bypass flow)**

Site RPT-4PW

**Formation properties**

estimated K (ft/d)	14.6
estimated $S_s$ (1/ft)	1.6E-05
thickness b (ft)	86
estimated T (ft <sup>2</sup> /d)	1255.6
estimated S	1.4E-03
diffusivity $\nu = T/S$ (ft <sup>2</sup> /d)	9.1E+05

**Ruud and Kabala (1996) pseudo-steady criterion**

1.0E+03	Non-dimensional time, $t_D$				
Diffusivity contrast	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
1:1	0.0	0.0	0.1	4.1	
10:1	0.0	0.0	0.4	22.6	
100:1	0.0	0.1	3.5	207.5	
1000:1	0.0	0.6	34.3	2056.8	

**Well properties**

borehole diameter (in)	10
Casing diameter (in)	6
Borehole radius (in)	5
Casing radius (in)	3
Borehole radius (m)	0.1270
Casing radius (m)	0.0762
Annulus area (m <sup>2</sup> )	0.032
Annulus thickness (cm)	5.08
Filter pack conductivity (m/d)	100

**Molz and others (1989) pseudo-steady criterion***(but using assumed influence radius per personal comm.)*

1.0E+02	Non-dimensional time, $t_D$				
Influence radius, r (ft)	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
1	0.0	0.0	0.0	2.4	
2	0.0	0.0	0.2	9.5	
5	0.0	0.0	1.0	59.2	
10	0.0	0.1	3.9	236.7	
20	0.0	0.3	15.8	946.8	

**Rehfeldt and others (1989) and Flach criteria**

Non-dimensional time, $t_D$	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
4.0E+02	0.0	0.0	0.0	1.6	10:1
4.0E+03	0.0	0.0	0.3	16.4	100:1
4.0E+04	0.0	0.0	2.7	164.4	$r/b < 0.125$
1.0E+06	0.0	1.1	68.5	4109.6	long time

**EBF properties** $L_{EBF}$  (m) 0.178**Bypass properties**
 $\Delta L$  (m) 0.079  
 L (m) 0.257
**Bypass flow estimate**

Pumping rate, QP (L/min)	Pumping rate, QP (gal/min)	1/2" EBF		1" EBF	
		Bypass (L/min)	Ratio	Bypass (L/min)	Ratio
0.2	0.05	0.00	1.1%	0.00	0.1%
0.5	0.13	0.01	1.4%	0.00	0.1%
1	0.26	0.02	1.9%	0.00	0.1%
2	0.53	0.06	3.0%	0.00	0.2%
5	1.32	0.31	6.1%	0.02	0.4%
10	2.64	1.14	11.4%	0.07	0.7%
20	5.28	4.38	21.9%	0.27	1.4%
13.55	test block	2.05	15.1%	0.13	0.9%

Table 22 Post-test check for quasi-steady flow conditions at RPT-30PZ.

**Post-test check for valid EBF application (pseudo-steady state & minimal bypass flow)**

<b>Site</b>		RPT-30PZ					
<b>Formation properties</b>		<b>Ruud and Kabala (1996) pseudo-steady criterion</b>					
estimated K (ft/d)	1.6	1.0E+03	Non-dimensional time, $t_D$				
estimated $S_s$ (1/ft)	7.5E-05	Diffusivity contrast	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
thickness b (ft)	34	1:1	0.0	0.0	1.9	112.5	
estimated T (ft <sup>2</sup> /d)	54.4	10:1	0.0	0.2	10.3	618.8	
estimated S	2.6E-03	100:1	0.1	1.6	94.7	5681.3	
diffusivity $v = T/S$ (ft <sup>2</sup> /d)	2.1E+04	1000:1	0.7	15.6	938.4	56306.3	
<b>Well properties</b>		<b>Molz and others (1989) pseudo-steady criterion</b>					
borehole diameter (in)	8	<i>(but using assumed influence radius per personal comm.)</i>					
Casing diameter (in)	2	1.0E+02	Non-dimensional time, $t_D$				
Borehole radius (in)	4	Influence radius, r (ft)	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
Casing radius (in)	1	1	0.0	0.0	1.7	101.3	
Borehole radius (m)	0.1016	2	0.0	0.1	6.8	405.0	
Casing radius (m)	0.0254	5	0.0	0.7	42.2	2531.3	
Annulus area (m <sup>2</sup> )	0.030	10	0.1	2.8	168.8	10125.0	
Annulus thickness (cm)	7.62	20	0.5	11.3	675.0	40500.0	
Filter pack conductivity (m/d)	100	<b>Rehfeldt and others (1989) and Flach criteria</b>					
<b>EBF properties</b>		Non-dimensional time, $t_D$	Time, t (d)	Time, t (hr)	Time, t (min)	Time, t (s)	
$L_{EBF}$ (m)	0.178	4.0E+02	0.0	0.0	0.8	45.0	10:1
<b>Bypass properties</b>		4.0E+03	0.0	0.1	7.5	450.0	100:1
$\Delta L$ (m)	0.111	4.0E+04	0.1	1.3	75.0	4500.0	$r/b < 0.125$
L (m)	0.289	1.0E+06	1.3	31.3	1875.0	#####	long time
<b>Bypass flow estimate</b>		<b>1/2" EBF</b>				<b>1" EBF</b>	
Pumping rate, QP (L/min)		Pumping rate, QP (gal/min)	Bypass (L/min)	Ratio	Bypass (L/min)	Ratio	
0.2		0.05	0.00	0.9%	0.00	0.1%	
0.5		0.13	0.01	1.2%	0.00	0.1%	
1		0.26	0.02	1.6%	0.00	0.1%	
2		0.53	0.05	2.5%	0.00	0.2%	
5		1.32	0.26	5.1%	0.02	0.3%	
10		2.64	0.95	9.5%	0.06	0.6%	
20		5.28	3.66	18.3%	0.23	1.1%	
2.1		test block	0.05	2.6%	0.00	0.2%	

Table 23 Summary of post-test checks for quasi-steady flow conditions.

<b>SiteID</b>	<b>Ruud and Kabala (1996) with 100:1 diffusivity contrast</b>	<b>Ruud and Kabala (1996) with 10:1 diffusivity contrast</b>	<b>Rehfeldt and others (1989)</b>	<b>Approximate EBF start (min)</b>	<b>Approximate EBF finish (min)</b>
RPC-2PR	32 min	3.4 min	2.5 min	30 min	2.5 hr
RPC-3PW - 1/2" EBF	13 min	1.4 min	1.0 min	15 min	2.5 hr
RPC-3PW - 1" EBF	14 min	1.4 min	1.0 min	15 min	2 hr
RPT-2PW	30 min	3.2 min	2.3 min	1 hr	2 hr
RPT-3PW	7.9 min	0.9 min	0.6 min	50 min	3 hr
RPT-4PW	3.5 min	0.4 min	0.3 min	20 min	1.5 hr
RPT-30PZ	1.6 hr	10 min	7.5 min	1 hr	2 hr

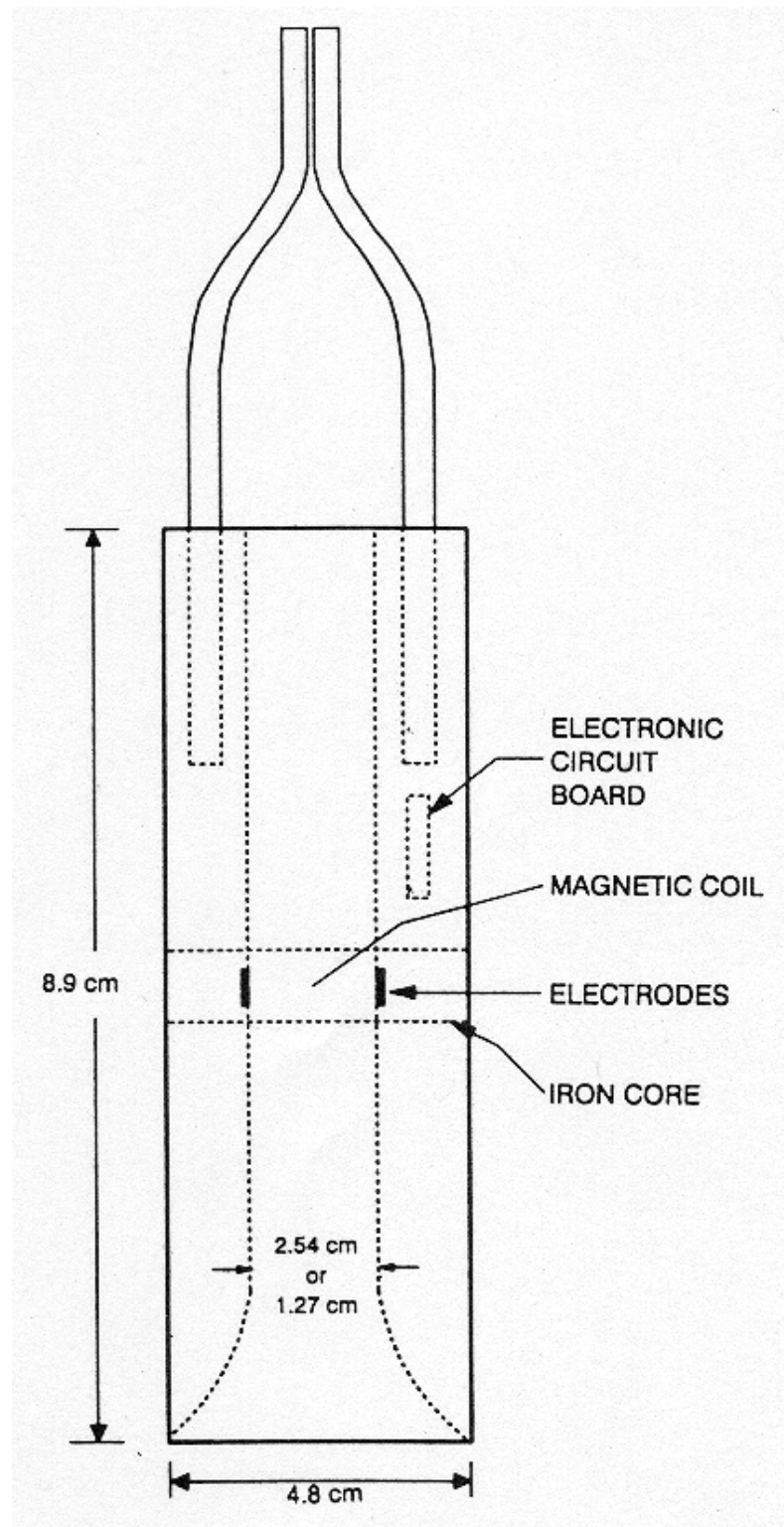


Figure 1 Schematic diagram of the Electromagnetic Borehole Flowmeter; reproduced from Molz and Young (1993).

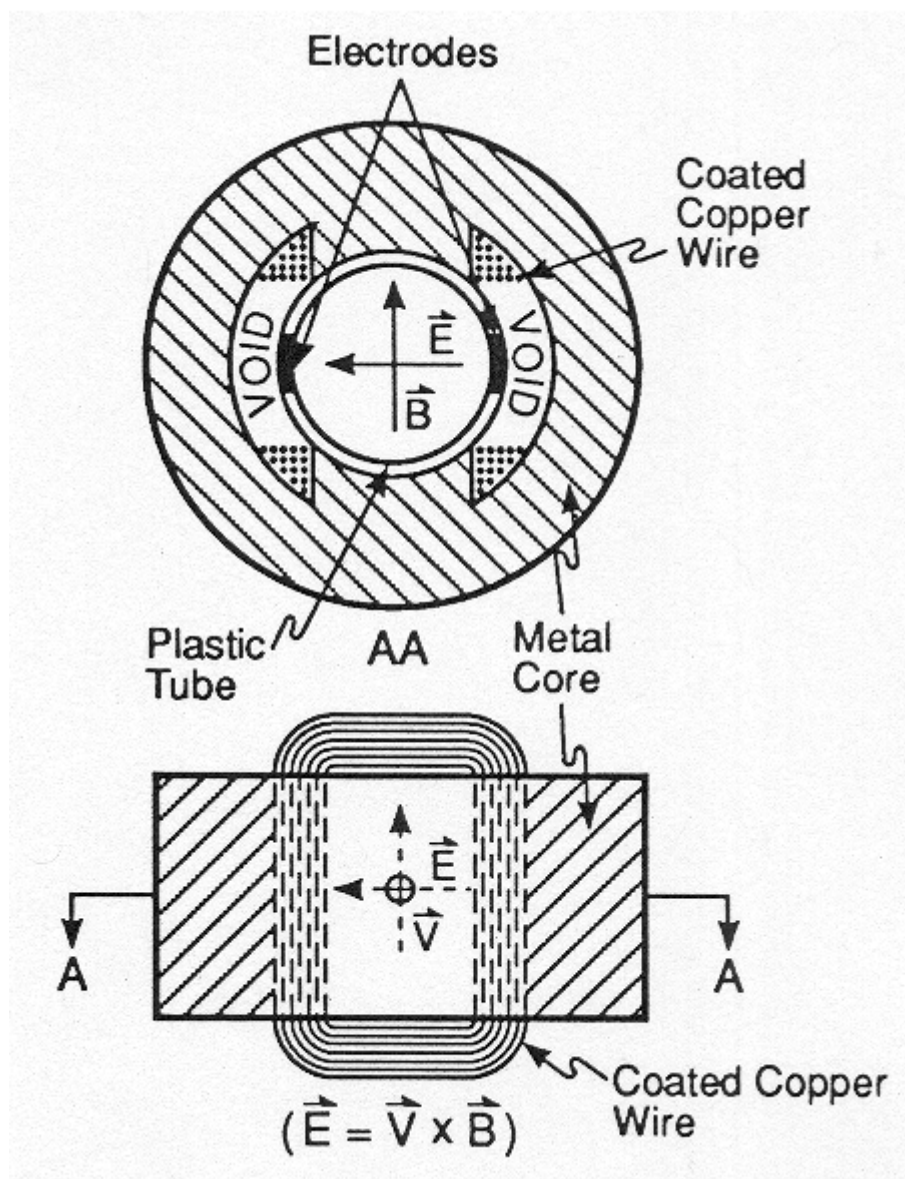


Figure 2 Electromagnetic Borehole Flowmeter (EBF) application of Faraday's Law of Induction; reproduced from Molz and Young (1993).

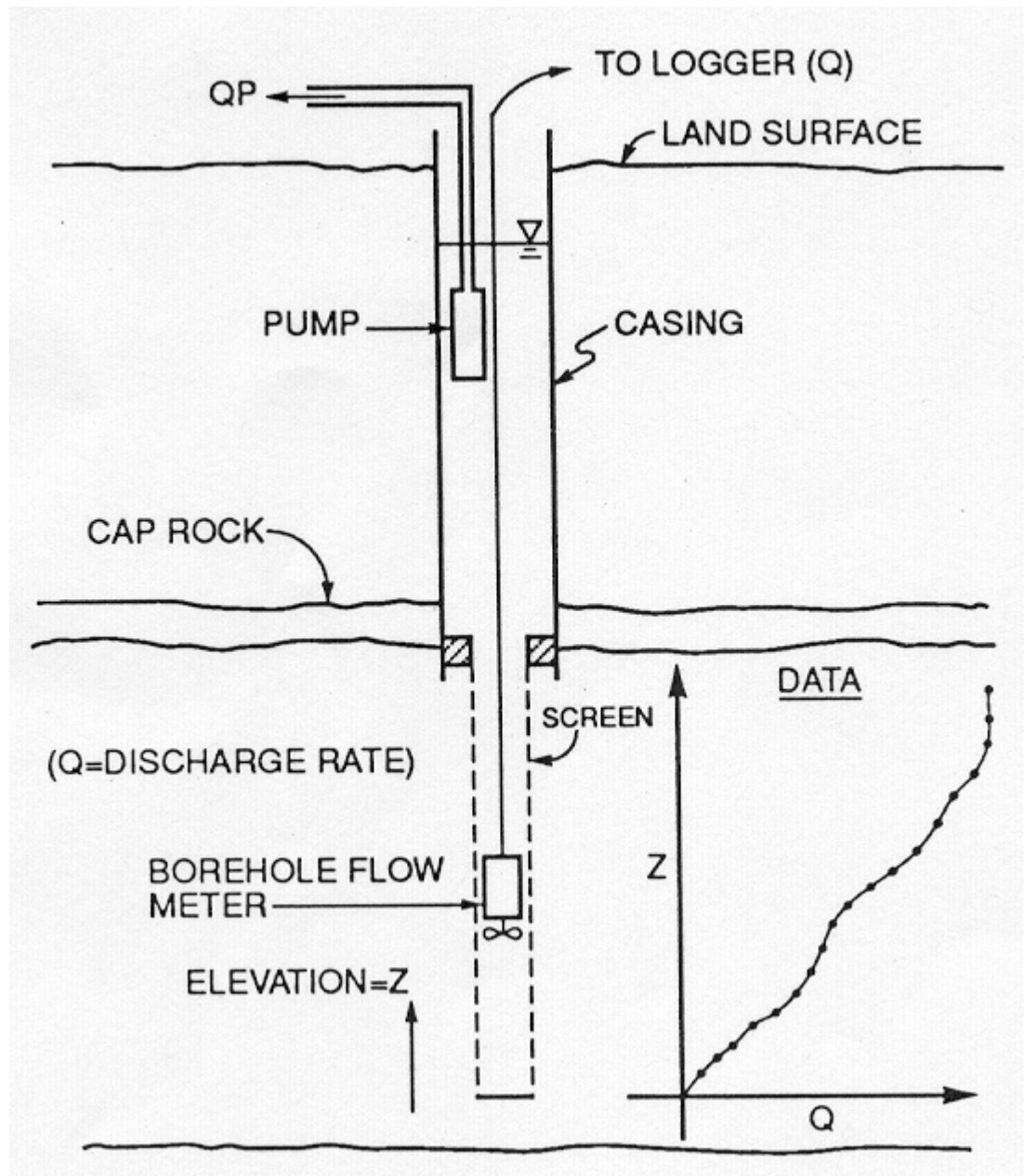


Figure 3 Schematic illustration of borehole flowmeter testing; reproduced from Molz and Young (1993).



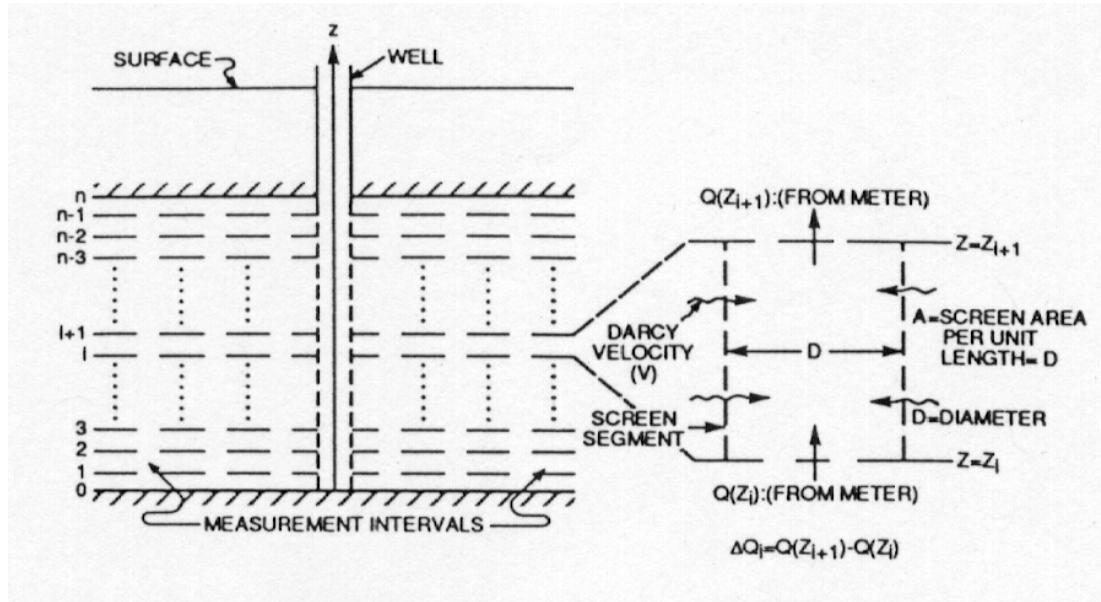


Figure 4 Basic geometry and analysis of borehole flowmeter data; reproduced from Molz and Young (1993).

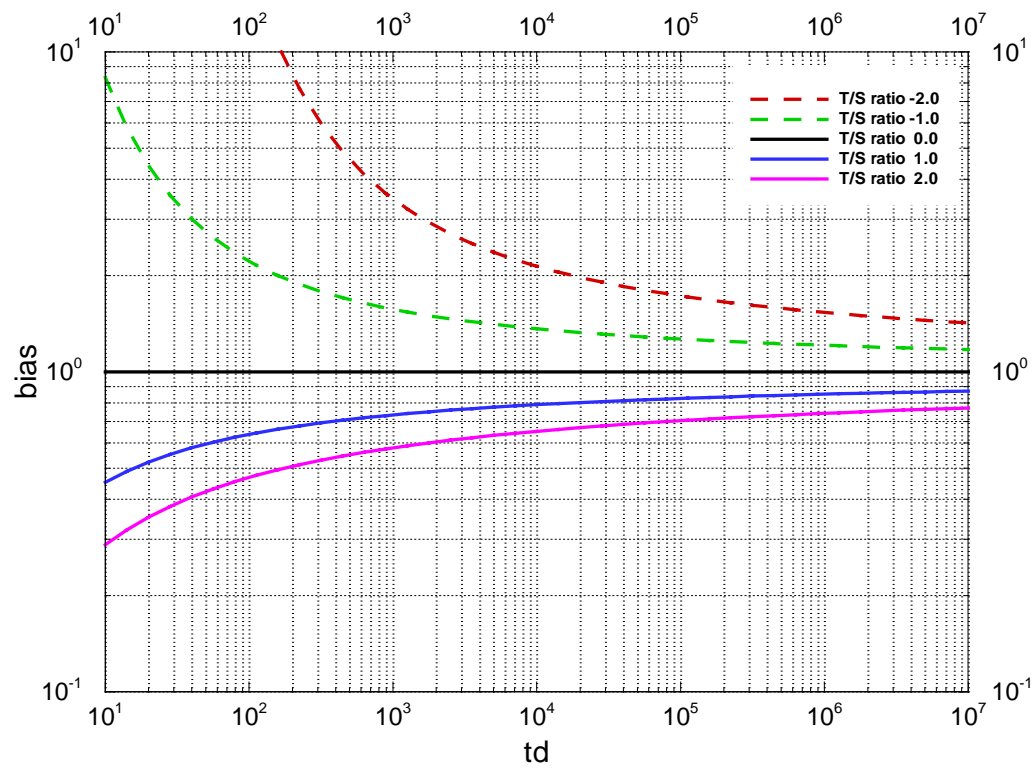


Figure 5 Systematic errors in borehole flowmeter estimation due to transient effects.

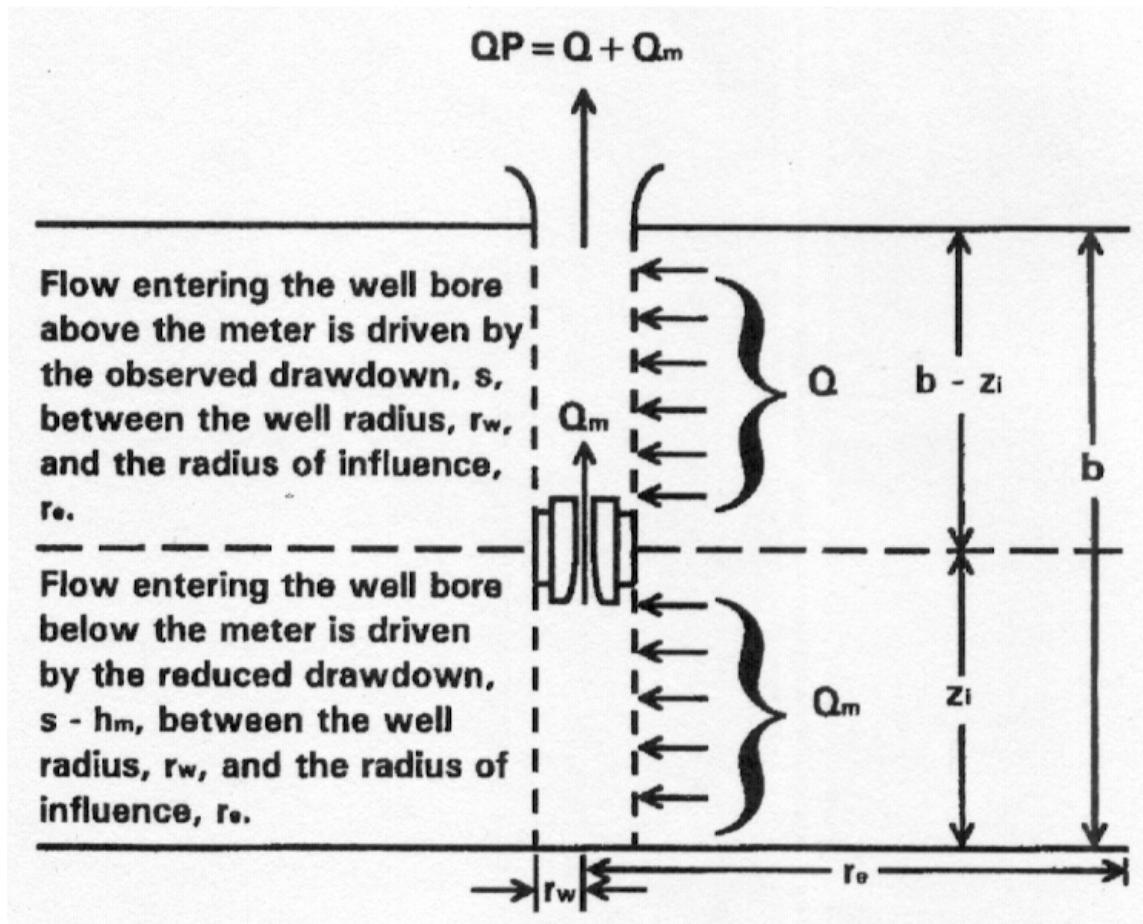


Figure 6 Head-loss-induced flow redistribution; reproduced from Dinwiddie and others (1999).

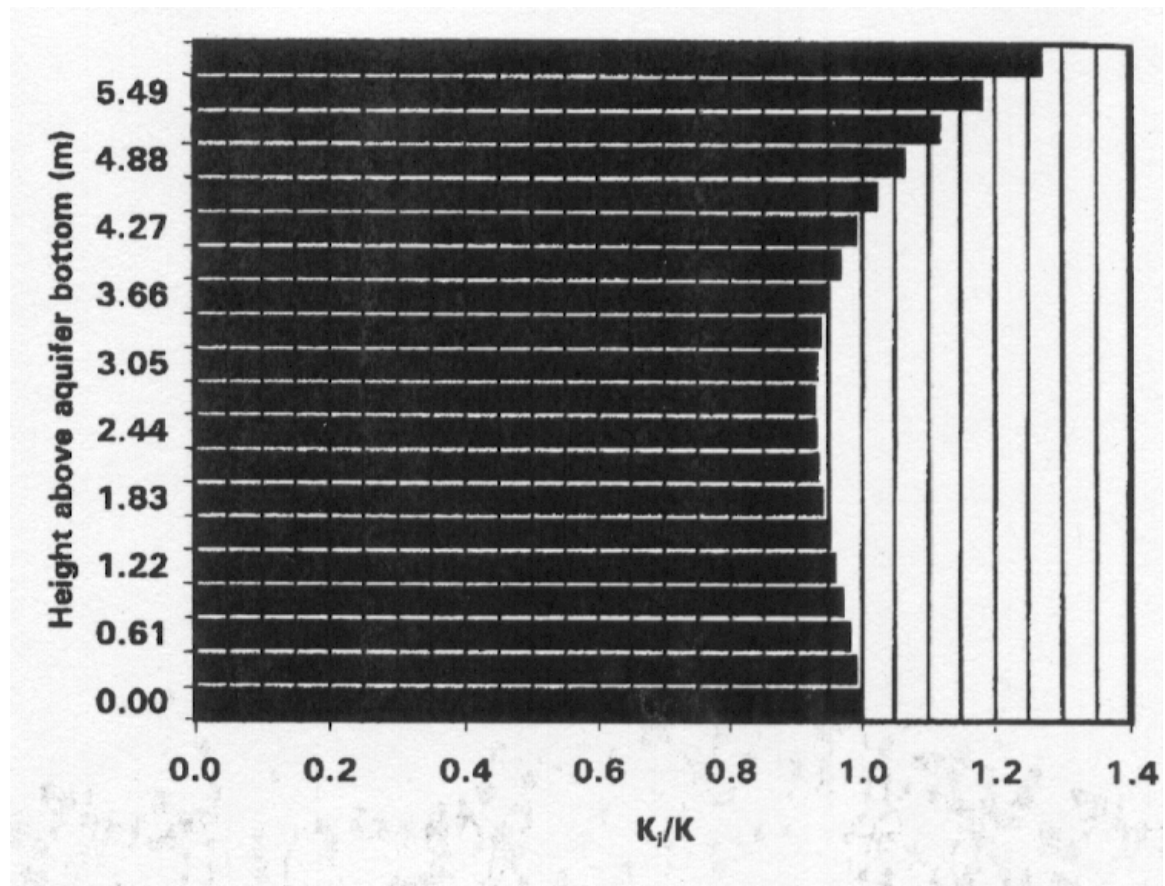


Figure 7 Effect of head-loss-induced flow redistribution for a 4" ID, 20 ft long, nonpacked, well screen; bar graph shows the calculated nondimensional hydraulic conductivity distribution when the true  $K$  is 9.1 m/day and the pumping rate is 5 L/min; reproduced from Dinwiddie and others (1999).

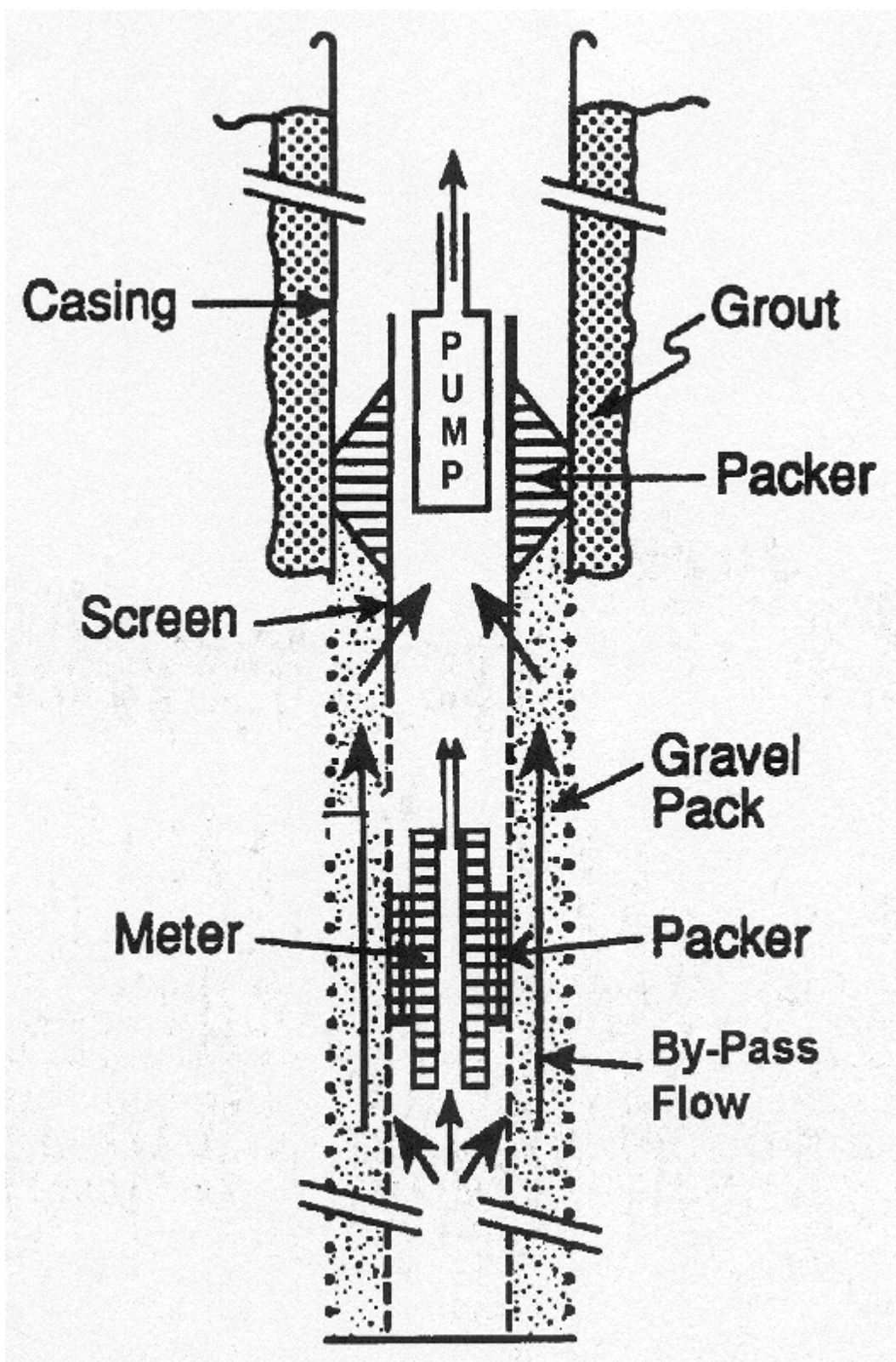


Figure 8 Bypass flow through filter pack induced by EBF head loss; reproduced from Dinwiddie and others (1999).

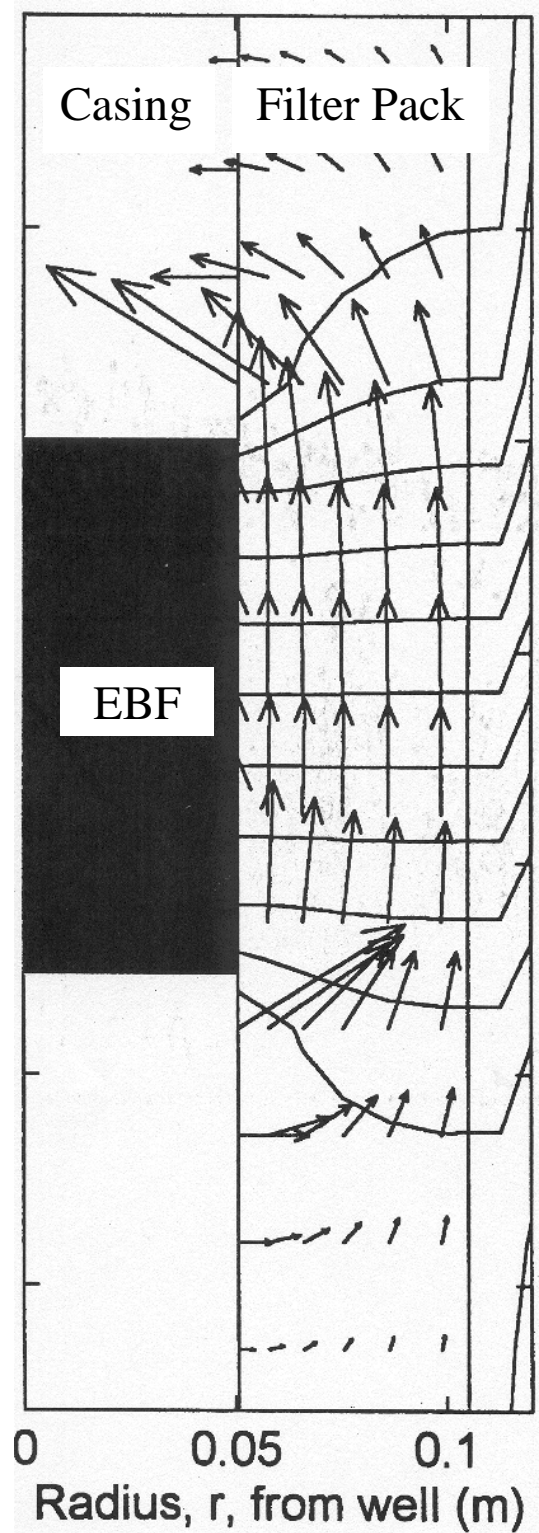


Figure 9 Bypass flow simulation; modified from Dinwiddie and others (1999).

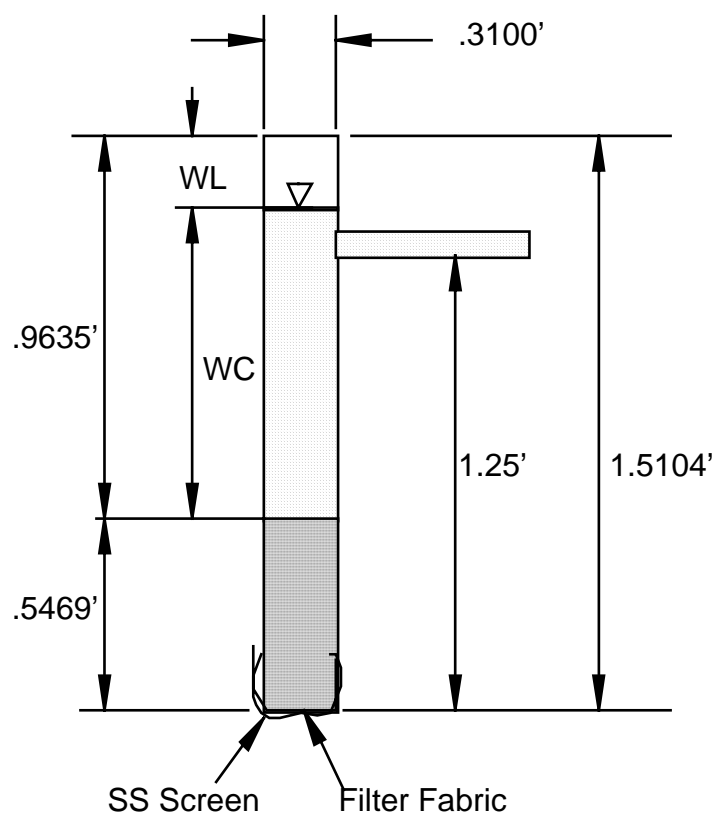


Figure 10 Constant-head permeameter design and dimensions.

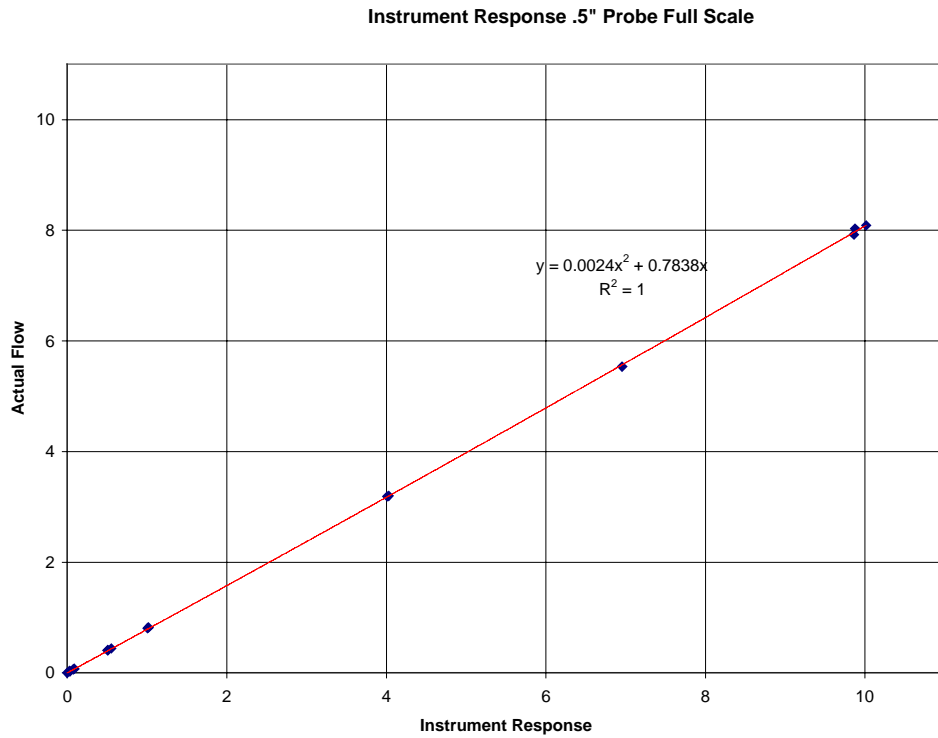


Figure 11 Calibration data and curve for the 1/2" ID EBF.

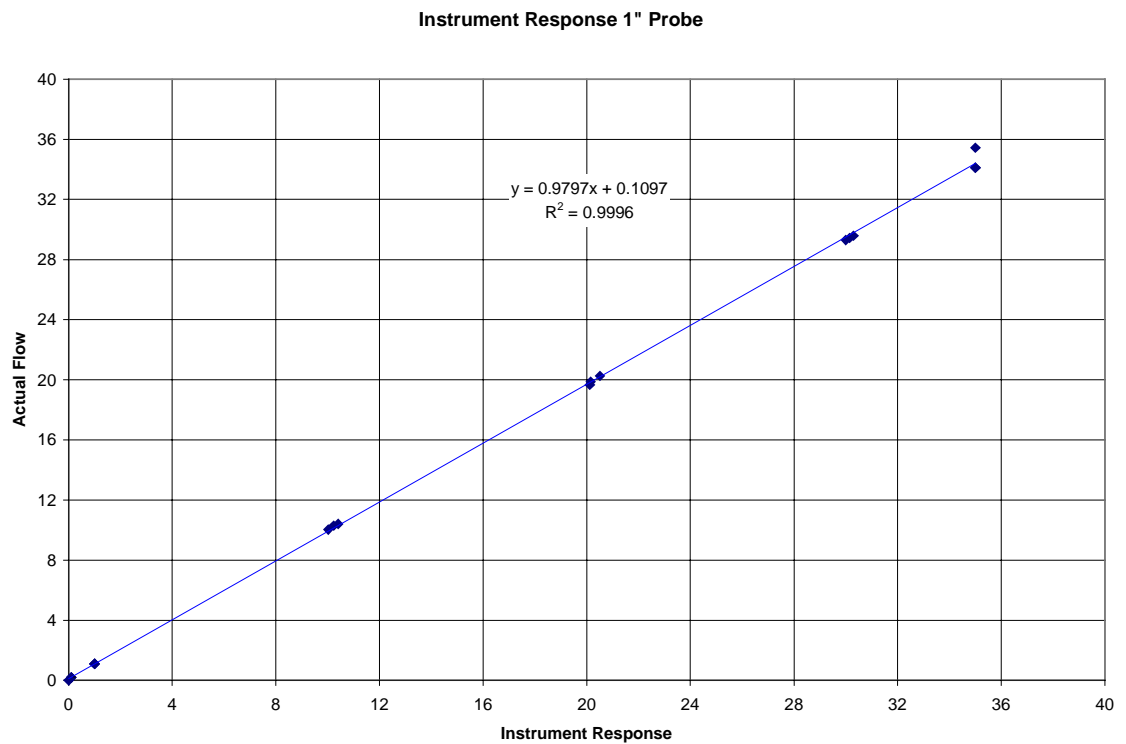


Figure 12 Calibration data and curve for the 1" ID EBF.



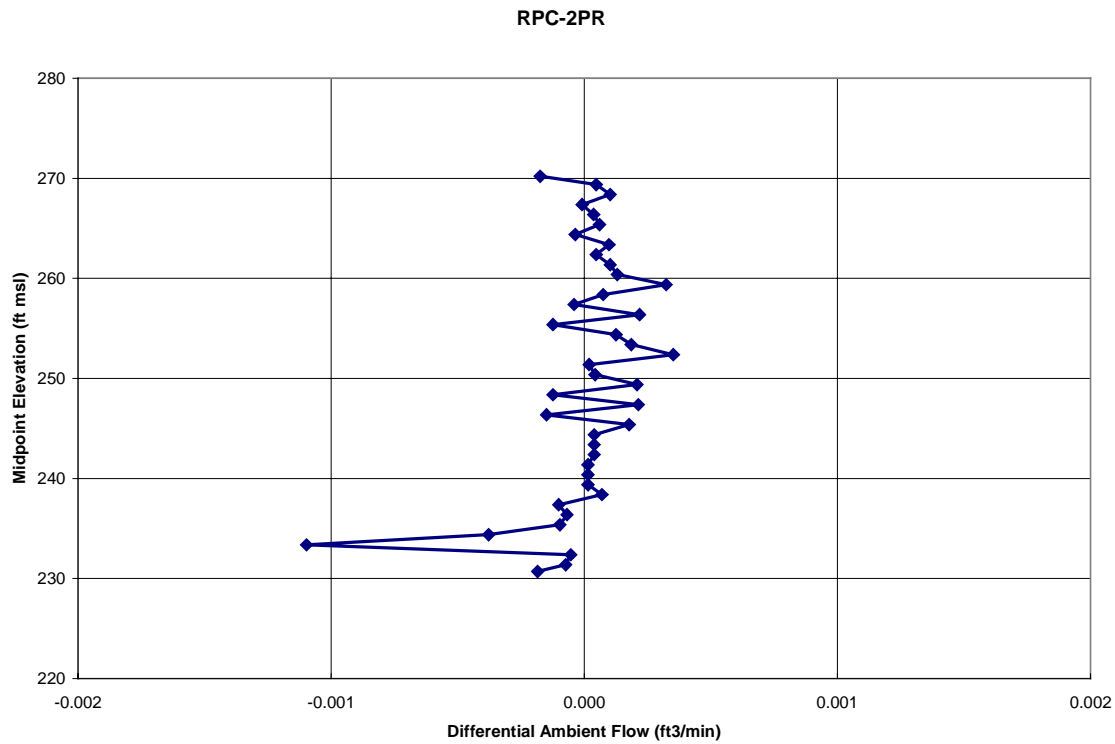


Figure 13 Ambient flow measurements for RPC-2PR.

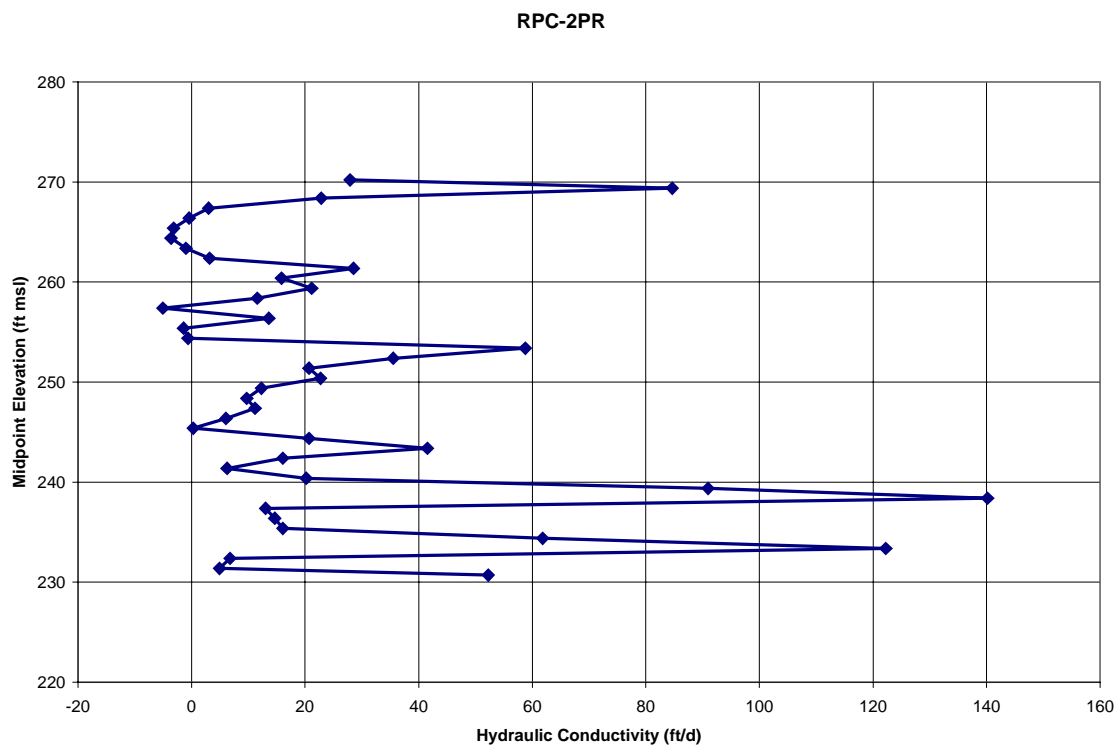


Figure 14 Estimated hydraulic conductivity variation for RPC-2PR.

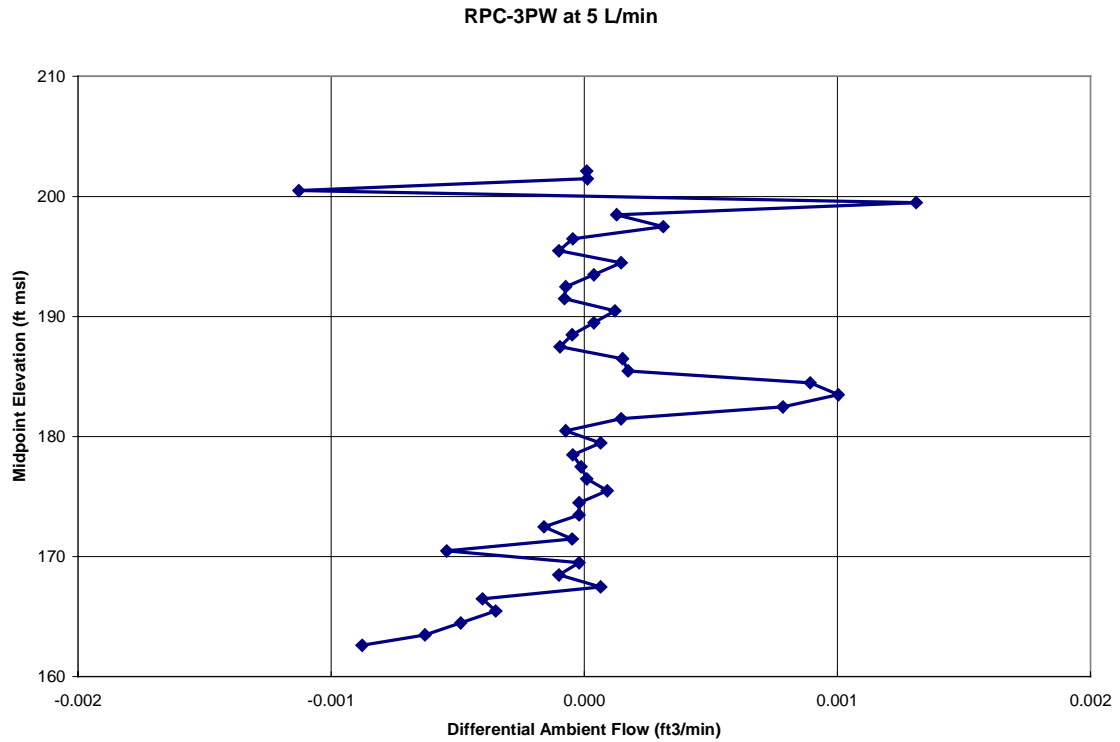


Figure 15 Ambient flow measurements for RPC-3PW.

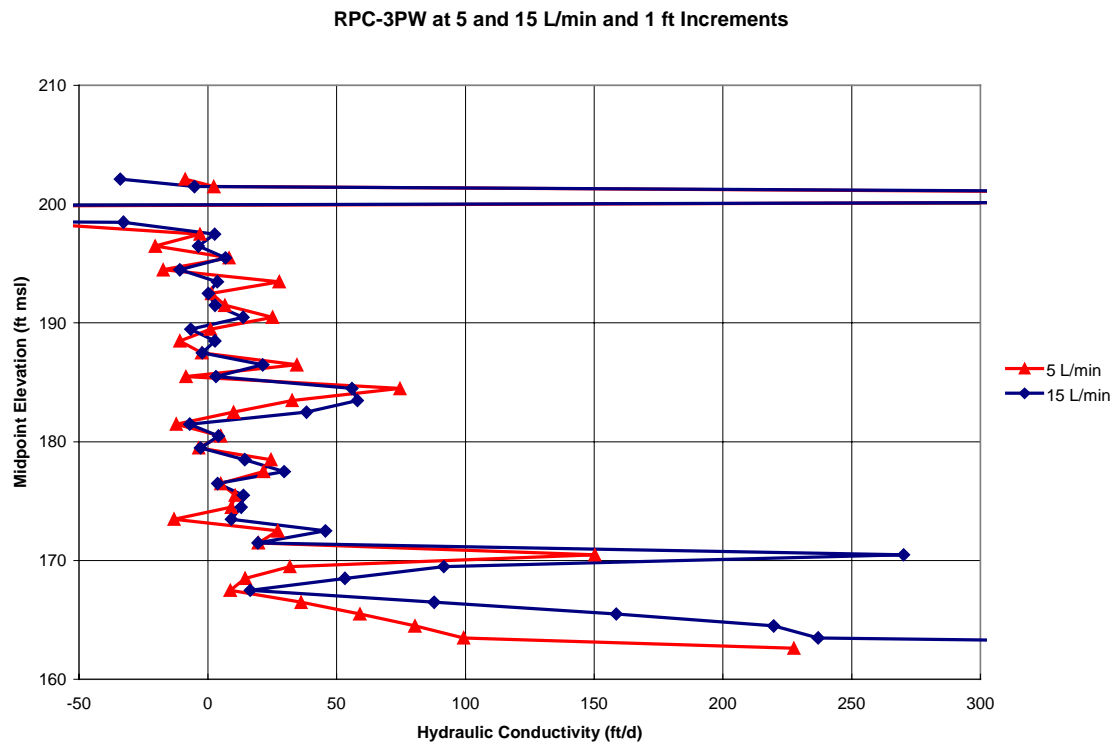


Figure 16 Estimated hydraulic conductivity variation for RPC-3PW at 1 ft intervals using the 1/2" and 1" ID EBFs.

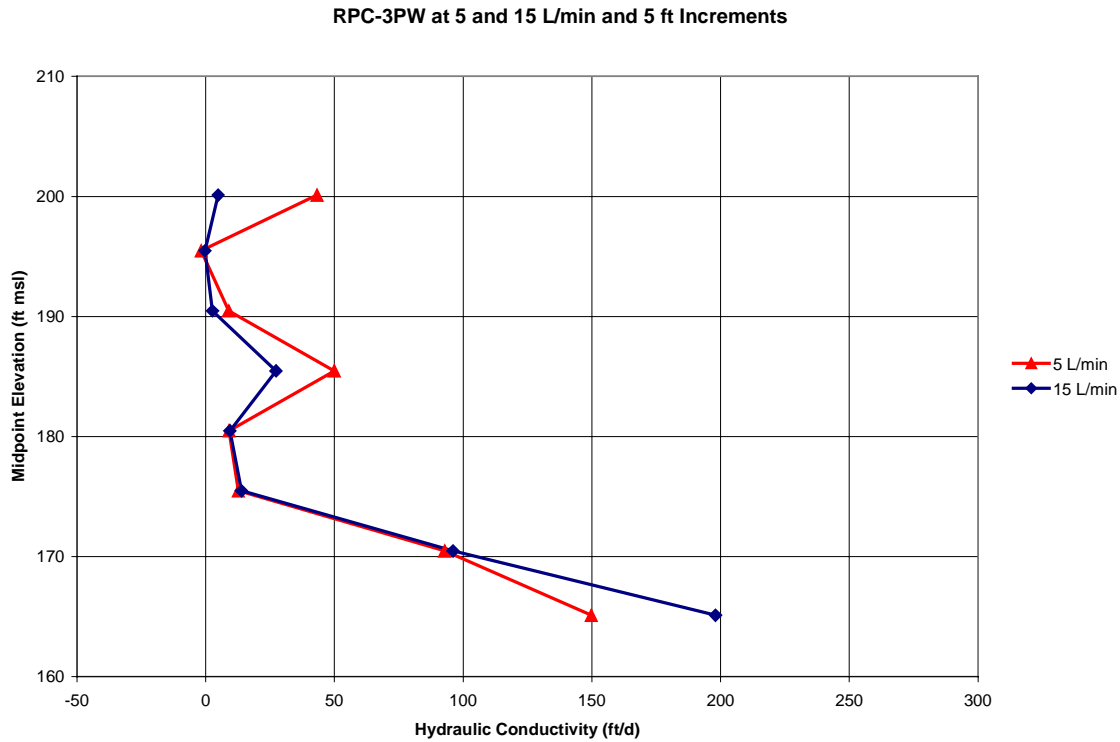


Figure 17 Estimated hydraulic conductivity variation for RPC-3PW at 5 ft intervals using the ½" and 1" ID EBFs.

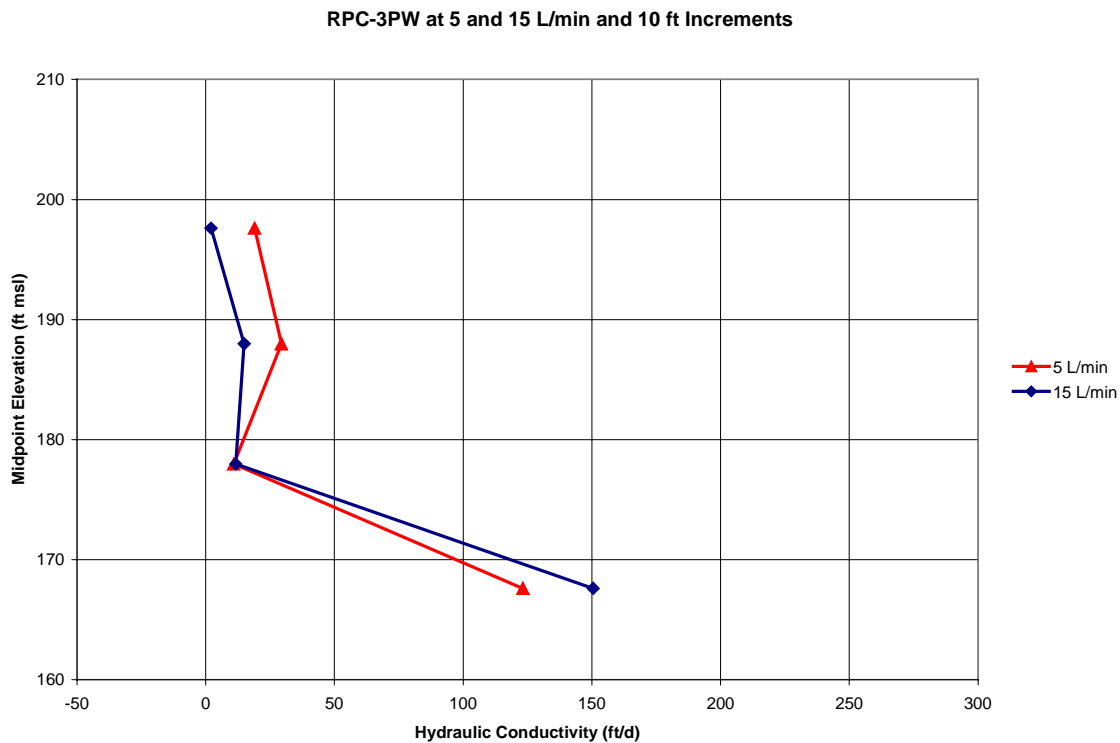


Figure 18 Estimated hydraulic conductivity variation for RPC-3PW at 10 ft intervals using the ½" and 1" ID EBFs.

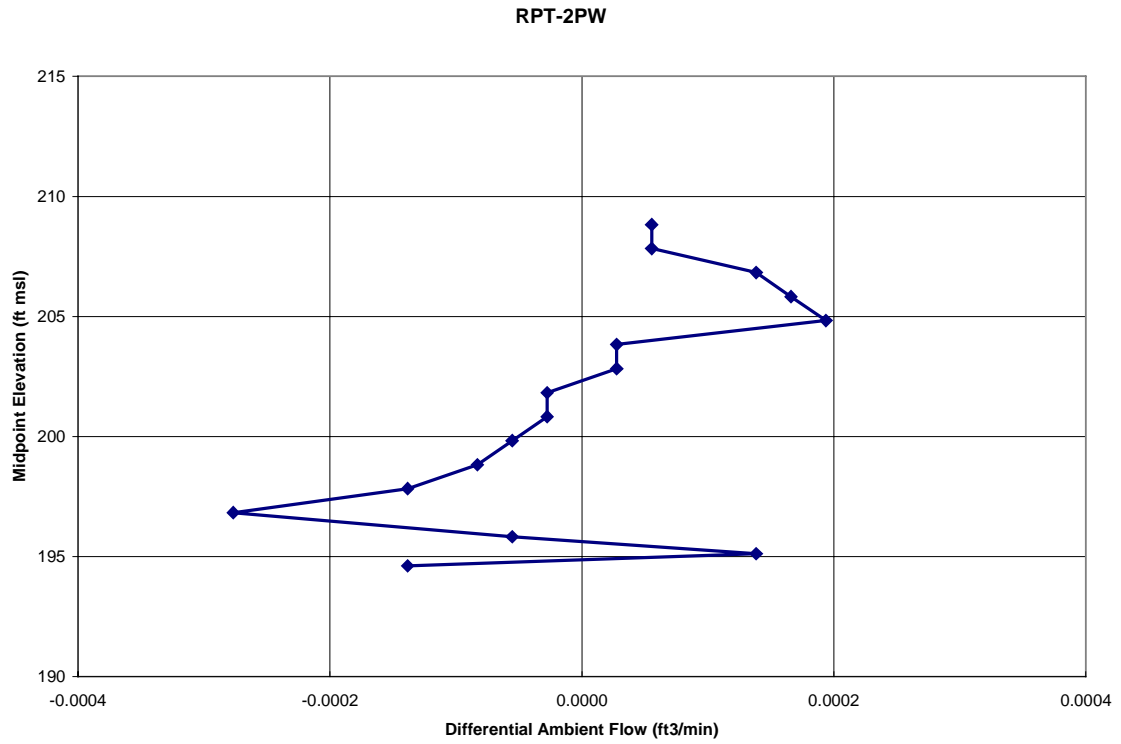


Figure 19 Ambient flow measurements for RPT-2PW.

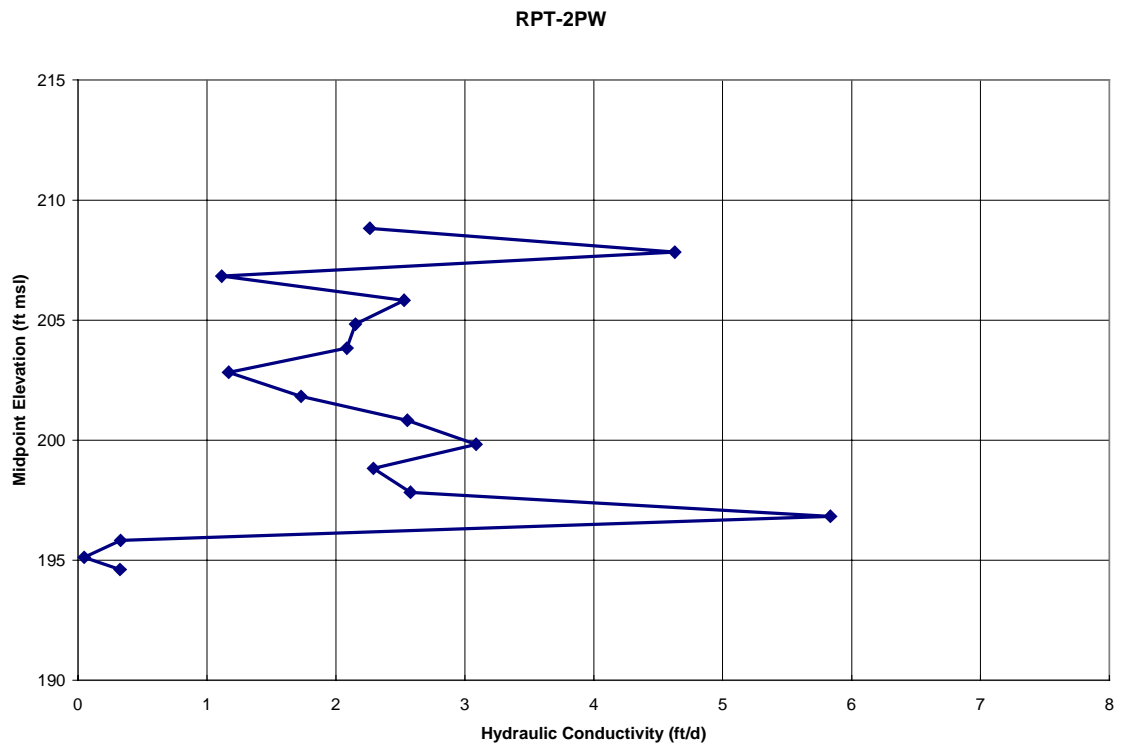


Figure 20 Estimated hydraulic conductivity variation for RPT-2PW.

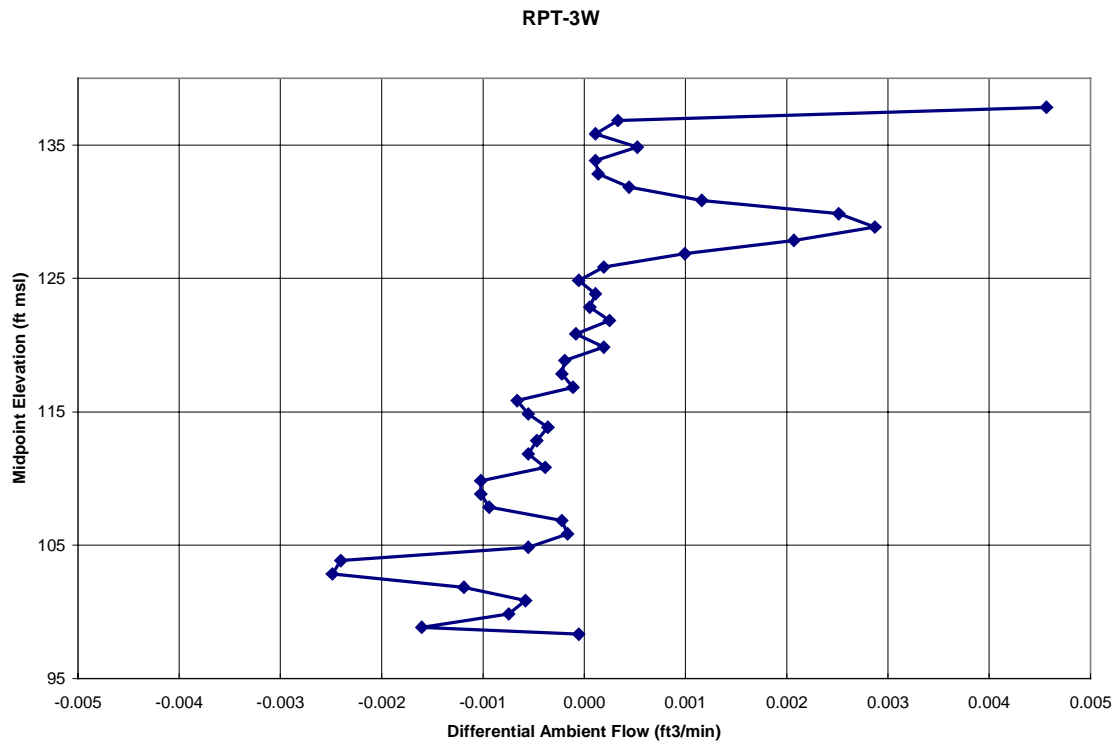


Figure 21 Ambient flow measurements for RPT-3PW.

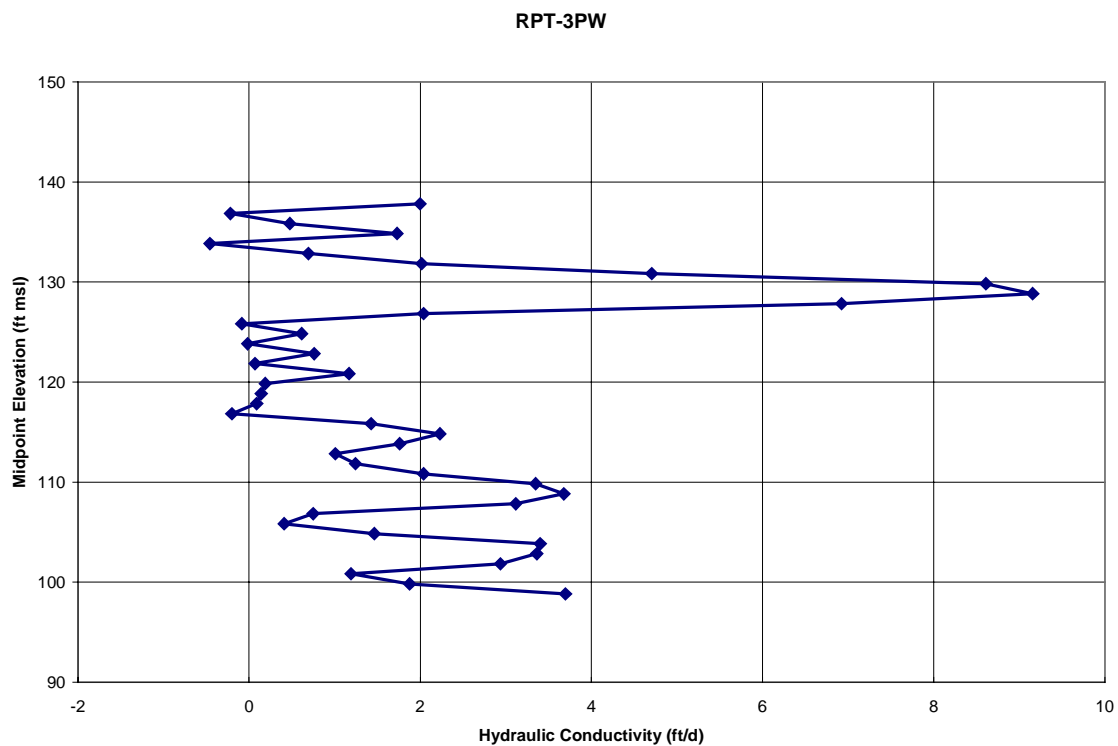


Figure 22 Estimated hydraulic conductivity variation for RPT-3PW.

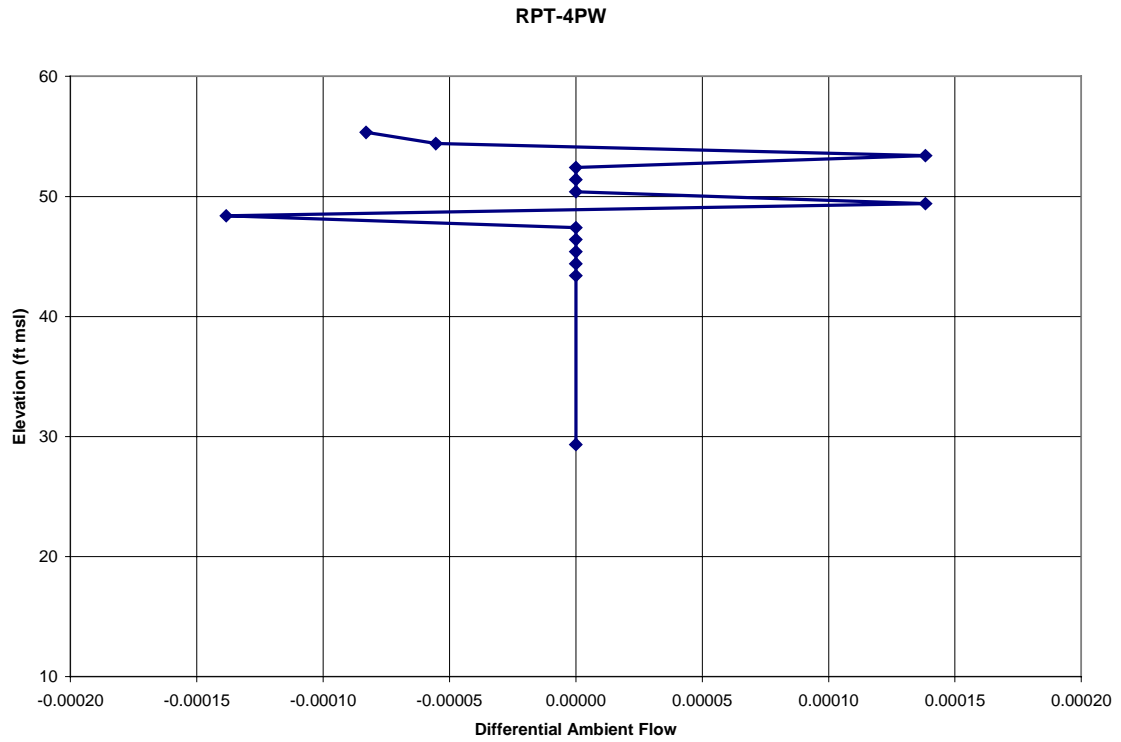


Figure 23 Ambient flow measurements for RPT-4PW.

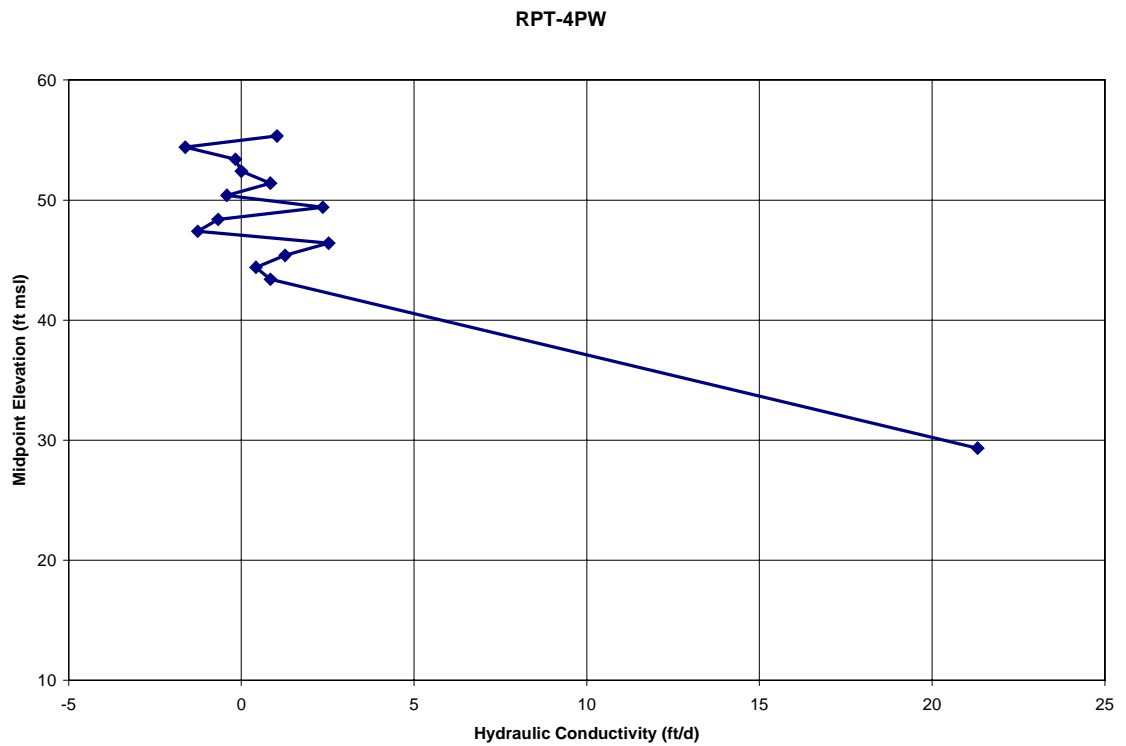


Figure 24 Estimated hydraulic conductivity variation for RPT-4PW.

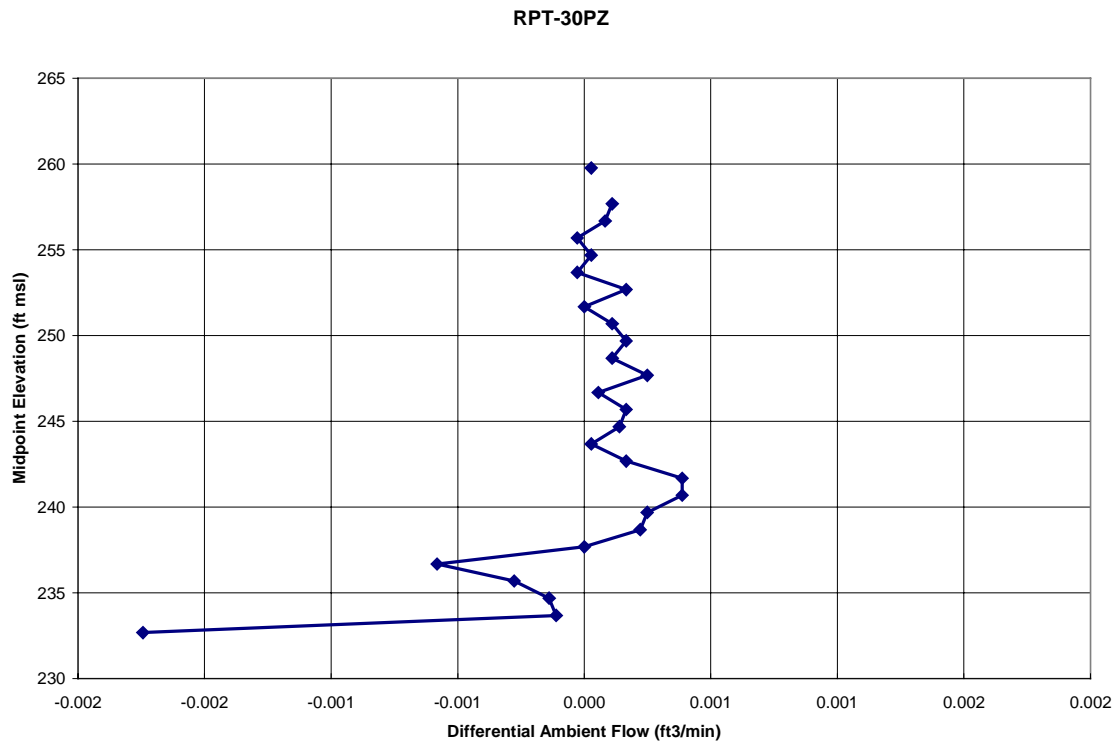


Figure 25 Ambient flow measurements for RPT-30PZ.

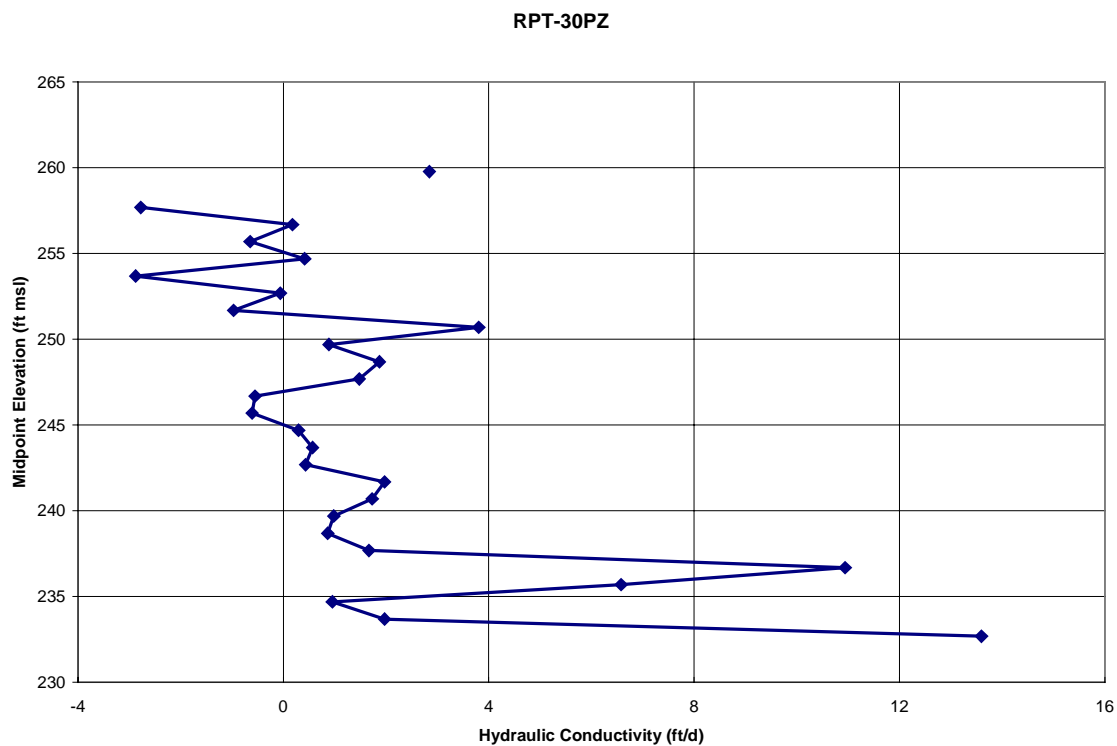


Figure 26 Estimated hydraulic conductivity variation for RPT-30PZ.

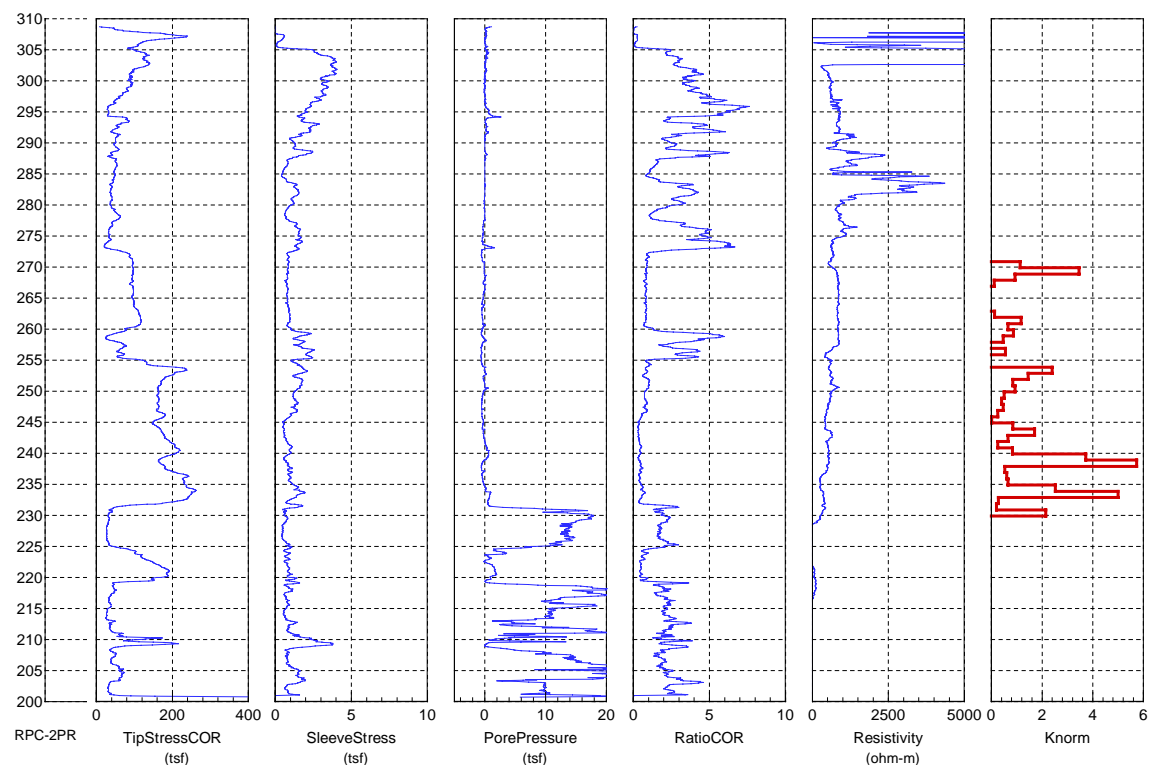


Figure 27 Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-averaged conductivity for RPC-2PR.

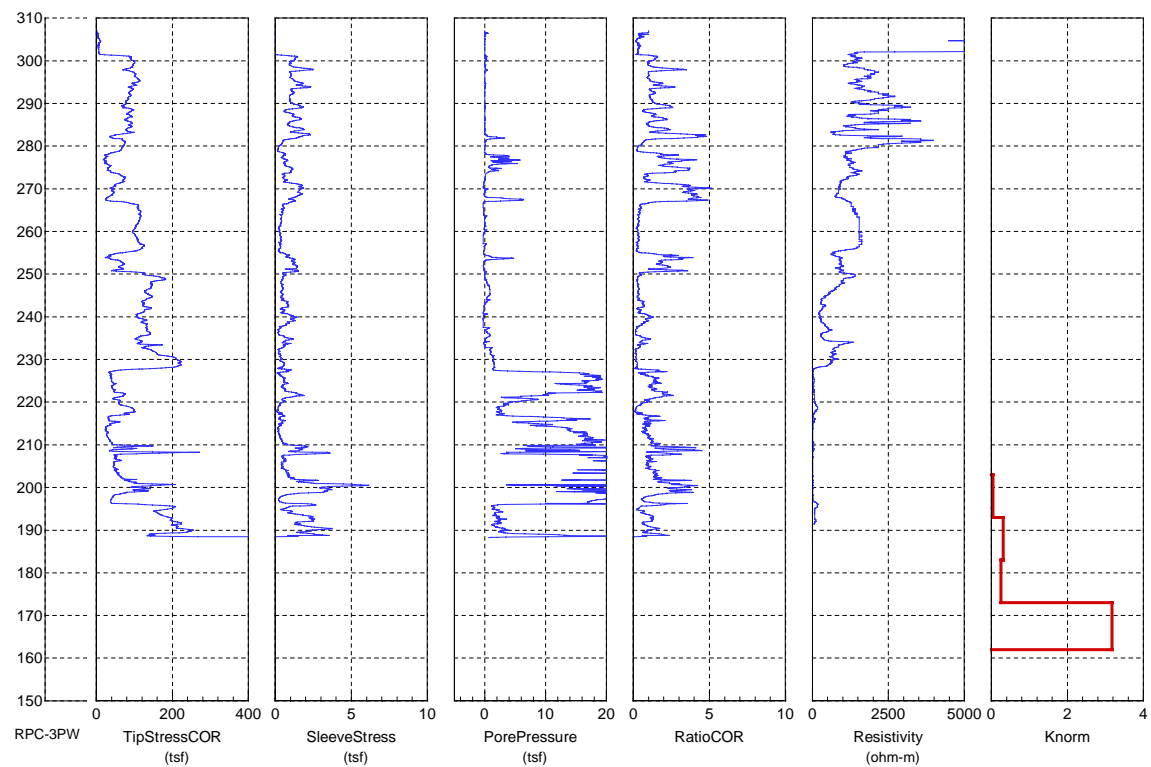


Figure 28 Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-averaged conductivity for RPC-3PW.



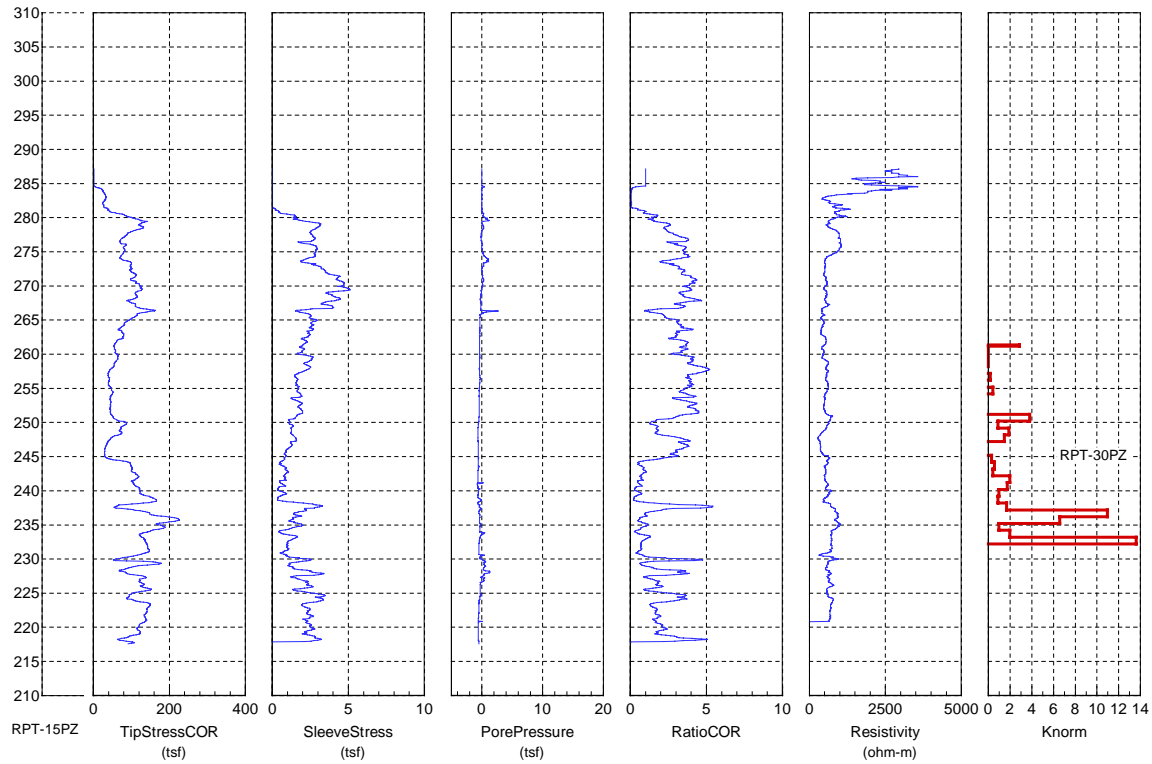


Figure 29 Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-averaged conductivity for RPT-30PZ.

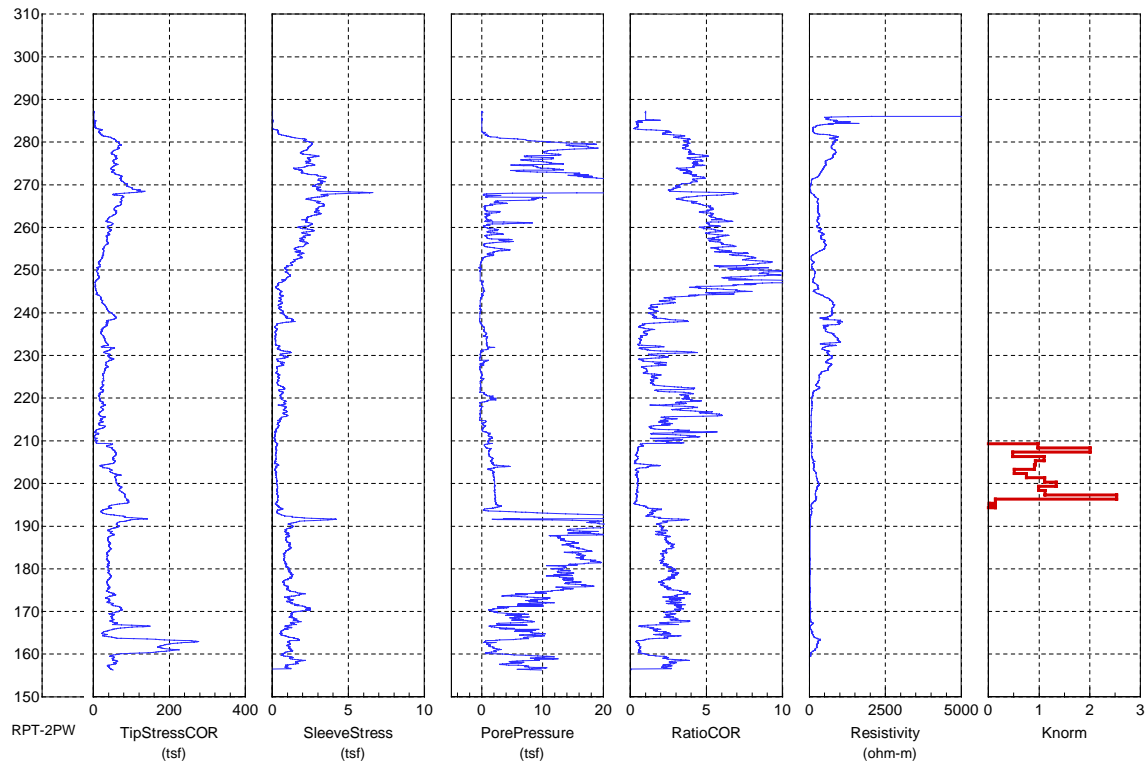


Figure 30 Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-averaged conductivity for RPT-2PW.

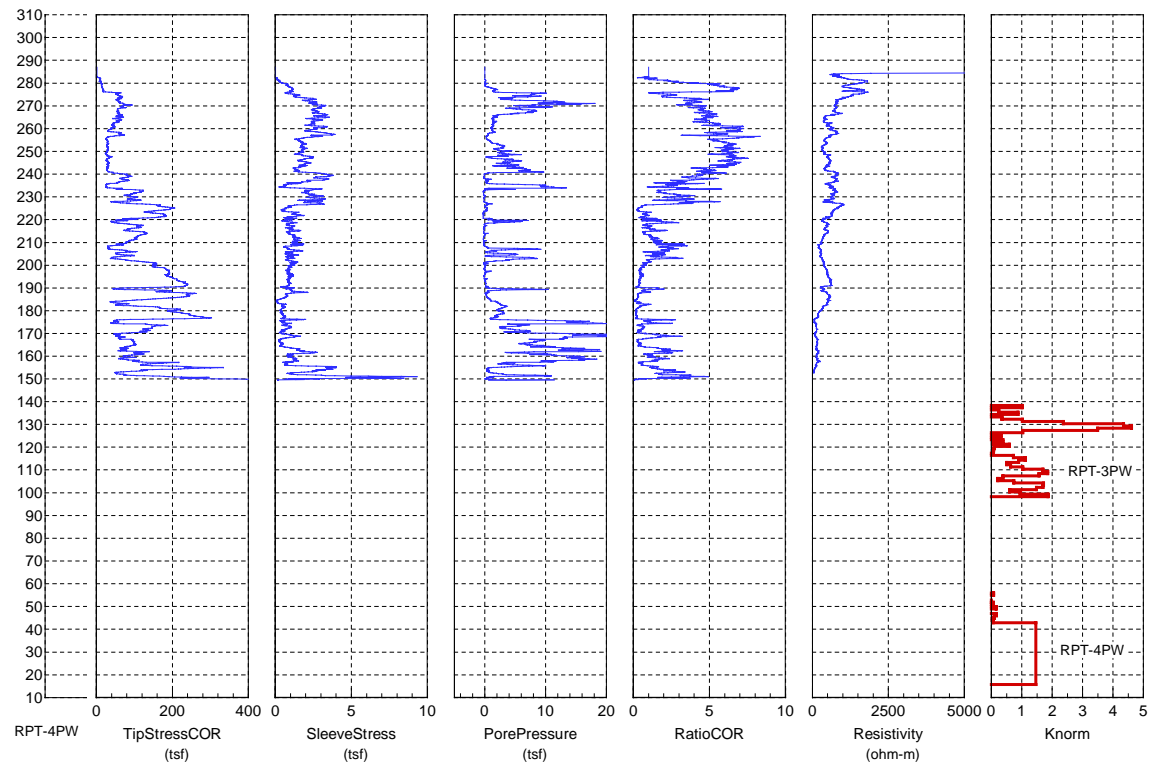


Figure 31 Comparison of CPT data to EBF horizontal conductivity distribution relative to screen-averaged conductivity for RPT-3PW and RPT-4PW.

This page intentionally left blank

**Appendix A – RPC-1PW field data**

Well ID	Top of Screen From Grade (ft)	Bottom of Screen From Grade (ft)	Screen Length (ft)	Casing Diameter (inch)	Approx. Water Level From TOC (ft)	Survey Elev. TOC (ft-msl)	Survey Elev. Conc Pad (ft-msl)	TOC to Conc Pad (ft)
<b>RPC-1PW</b>	19.5	34.5	15	2	32.7	307.56	305.24	2.32

	Probe Date	.5" 3/27/00	.5" 3/27/00
Station	Depth Below Toc	Ambient Instrument Response	$y = 0.0024x^2 + 0.7838x$ Ambient Calibrated Flow (l/min)
4			
3			
2	34.82'	-0.035	-0.0274
1	35.82'	-0.029	-0.0227
0	36.82'	-0.018	-0.0141

Time	Water Level (ft)
10:40	32.65

3/28/00

Ambient

14:30-15:30 Warm up meter set to 0.000

This page intentionally left blank

## Appendix B – RPC-2PR field data

Well ID	Top of Screen From Grade (ft)	Bottom of Screen From Grade (ft)	Screen Length (ft)	Casing Diameter (inch)	Approx. Water Level From TOC (ft)	Survey Elev. TOC (ft-msl)	Survey Elev. Conc Pad (ft msl)	TOC to Conc Pad (ft)	Pad Thickness (ft)	Top of Screen From TOC (ft)	Bottom of Screen From TOC (ft)	Top of Screen Elevation (ft)	Bottom of Screen Elevation (ft)
RPC-2PR	35	75	40	4	33.1	307.92	305.89	2.03	0.33	37.36	77.36	270.56	230.56

Ambient Corrected for "0"									
Station	Probe Date	.5" 3/28/00		.5" 3/28/00		.5" 3/28/00		.5" 3/28/00	.5" 3/28/00
		Time	Ambient Instrument Response	Delta Time min	Ambient Instrument Response Corrected for "0"	Time	Dynamic Instrument Response	0.0024x2 + 0.7838x Ambient Calibrated Flow (l/min)	0.0024x2 + 0.7838x Dynamic Calibrated Flow
41	36.03	13:06	-0.027	164	0.02916	0.002		0.0017	
40	37.03	13:02	-0.029	160	0.02844	-0.001	16:30	5.395	-0.0004
39	38.03	12:58	-0.022	156	0.02773	0.006	16:25	5.300	0.0045
38	39.03	12:54	-0.023	152	0.02702	0.004	16:17	4.838	0.0032
37	40.03	12:50	-0.026	148	0.02631	0.000	16:14	4.710	0.0002
36	41.03	12:46	-0.025	144	0.02560	0.001	16:10	4.694	0.0005
35	42.03	12:44	-0.026	142	0.02524	-0.001	16:07	4.695	-0.0006
34	43.03	12:43	-0.028	141	0.02507	-0.003	16:04	4.710	-0.0023
33	44.03	12:39	-0.026	137	0.02436	-0.002	16:01	4.731	-0.0013
32	45.03	12:36	-0.029	134	0.02382	-0.005	15:57	4.733	-0.0041
31	46.03	12:32	-0.030	130	0.02311	-0.007	15:54	4.714	-0.0054
30	47.03	12:28	-0.033	126	0.02240	-0.011	15:49	4.555	-0.0083
29	48.03	12:24	-0.037	122	0.02169	-0.015	15:47	4.464	-0.0120
28	49.03	12:20	-0.048	118	0.02098	-0.027	15:45	4.337	-0.0212
27	50.03	12:16	-0.050	114	0.02027	-0.030	15:42	4.271	-0.0233
26	51.03	12:13	-0.048	111	0.01973	-0.028	15:39	4.300	-0.0222
25	52.03	12:08	-0.055	106	0.01884	-0.036	15:37	4.218	-0.0283
24	53.03	12:05	-0.050	103	0.01831	-0.032		4.230	-0.0248
23	54.03	12:02	-0.054	100	0.01778	-0.036		4.229	-0.0284
22	55.03	11:58	-0.060	96	0.01707	-0.043	15:27	3.901	-0.0336
21	56.03	11:54	-0.072	92	0.01636	-0.056	15:25	3.694	-0.0436
20	57.03	11:50	-0.072	88	0.01564	-0.056		3.580	-0.0442
19	58.03	11:47	-0.073	85	0.01511	-0.058	15:19	3.454	-0.0454
18	59.03	11:44	-0.080	82	0.01458	-0.065	15:16	3.379	-0.0513
17	60.03	11:41	-0.075	79	0.01404	-0.061		3.330	-0.0478
16	61.03	11:37	-0.082	75	0.01333	-0.069	15:10	3.261	-0.0538
15	62.03	11:28	-0.075	66	0.01173	-0.063	15:08	3.233	-0.0496
14	63.03	11:20	-0.080	58	0.01031	-0.070	15:06	3.225	-0.0546
13	64.03	11:12	-0.080	50	0.00889	-0.071	15:03	3.110	-0.0557
12	65.03	11:04	-0.080	42	0.00747	-0.073	15:00	2.880	-0.0568
11	66.03	10:56	-0.080	34	0.00604	-0.074	14:58	2.790	-0.0580
10	67.03	10:53	-0.080	31	0.00551	-0.074	14:56	2.755	-0.0584
9	68.03	10:50	-0.080	28	0.00498	-0.075	14:54	2.643	-0.0588
8	69.03	10:47	-0.080	25	0.00444	-0.076	14:52	2.140	-0.0592
7	70.03	10:44	-0.082	22	0.00391	-0.078	14:50	1.360	-0.0612
6	71.03	10:42	-0.078	20	0.00356	-0.074	14:48	1.291	-0.0583
5	72.03	10:39	-0.075	17	0.00302	-0.072	14:46	1.212	-0.0564
4	73.03	10:36	-0.071	14	0.00249	-0.069		1.126	-0.0537
3	74.03	10:34	-0.057	12	0.00213	-0.055	14:42	0.795	-0.0430
2	75.03	10:32	-0.017	10	0.00178	-0.015		0.151	-0.0119
1	76.03	10:26	-0.014	4	0.00071	-0.013	14:37	0.115	-0.0104
0	77.03	10:24	-0.011	2	0.00036	-0.011	14:33	0.090	-0.0083
-1	78.03	10:22	-0.004	0	0.00000	-0.004	14:30	-0.001	-0.0031

3/28/00			
Time	Water Level (ft)	Bucket 16.8L Fill in (sec)	Field Measured Flow (L/min)
7:52	33.15		
9:30	33.14'		
13:52	33.05'		
14:17	33.85'		
14:22	33.85'	233.5	4.32
14:27		236	4.27
14:30	33.85'		
14:45	33.86'		
15:00		231.5	4.35
15:08	33.85'		
15:27		234	4.31
15:55	33.94'		
16:02		235	4.29
16:23			
16:25		234	4.31
16:31		234	4.31

3/28/00 Ambient

Warm up 9:10-10:00 - meter set to 0.000

13:22 Probe removed / plugged reading -0.032 reset to 0.000

Times in *italics* for ambient test estimated

Dynamic

16:40 Probe removed / plugged reading 0.000

Correction for "0"

Start Time - Stop Time = 180 min

Total Delta "0" = -.032

This page intentionally left blank

## Appendix C – RPC-3PW field data

Well ID	Top of Screen From Grade (ft)	Bottom of Screen From Grade (ft)	Screen Length (ft)	Casing Diameter (inch)	Approx. Water Level From TOC (ft)	Survey Elev. TOC (ft-msl)	Survey Elev. Conc Pad (ft-msl)	TOC to Conc Pad (ft)	Pad Thickness (ft)	Top of Screen From TOC (ft)	Bottom of Screen From TOC (ft)	Top of Screen Elevation (ft)	Bottom of Screen Elevation (ft)
RPC-3PW	105	145	40	4	53.7	309.14	307.58	1.56	0.33	106.89	146.89	202.25	162.25

Ambient Corrected for "0"													
Station	Probe Date	.5" 3/29/00		.5" 3/29/00			.5" 3/30/00		1.0" 3/31/00		.5" 3/29/00	.5" 3/30/00	1.0" 3/31/00
		Time	Ambient Instrument Response	Delta Time min	Delta (ml)	Ambient Instrument Response Corrected for "0"	Time	Dynamic Flow 1 Instrument Response	Time	Dynamic Flow 2 Instrument Response	0.0024x2 + 0.7838x Ambient Calibrated Flow (l/min)	0.0024x2 + 0.7838x Dynamic Calibrated Flow (l/min)	y = 0.9797x + 0.1097 Dynamic Calibrated Flow (l/min)
42	105.16	12:32	-0.015	164	0.01500	0.00000					0.0000		
41	106.16	12:29	-0.015	161	0.01473	-0.00027	16:39	6.679	10:49	14.75	-0.0002	5.3421	14.56
40	107.16	12:25	-0.015	157	0.01436	-0.00064	16:36	6.694		14.82	-0.0005	5.3543	14.63
39	108.16	12:20	-0.015	152	0.01390	-0.00110	16:32	6.678	10:44	14.86	-0.0009	5.3412	14.67
38	109.16	12:17	0.026	149	0.01363	0.03963	16:29	1.606		8.24	0.0311	1.2650	8.18
37	110.16	12:13	-0.021	145	0.01326	-0.00774	16:23	5.555	10:39	14.33	-0.0061	4.4281	14.15
36	111.16	12:06	-0.025	138	0.01262	-0.01238	16:20	6.031	10:35	14.58	-0.0097	4.8144	14.39
35	112.16	12:03	-0.036	135	0.01235	-0.02365	16:16	6.040	10:33	14.55	-0.0185	4.8217	14.36
34	113.16	11:59	-0.034	131	0.01198	-0.02202	16:12	6.176	10:30	14.58	-0.0173	4.9323	14.39
33	114.16	11:55	-0.030	127	0.01162	-0.01838	16:08	6.125	10:25	14.53	-0.0144	4.8908	14.34
32	115.16	11:52	-0.035	124	0.01134	-0.02366	16:03	6.234	10:22	14.61	-0.0185	4.9795	14.42
31	116.16	11:48	-0.036	120	0.01098	-0.02502	15:58	6.050	10:18	14.58	-0.0196	4.8298	14.39
30	117.16	11:44	-0.033	116	0.01061	-0.02239	15:54	6.043	10:15	14.58	-0.0175	4.8241	14.39
29	118.16	11:42	-0.030	114	0.01043	-0.01957	15:49	6.002	10:13	14.56	-0.0153	4.7908	14.37
28	119.16	11:38	-0.034	110	0.01006	-0.02394	15:45	5.832	10:10	14.45	-0.0188	4.6528	14.27
27	120.16	11:34	-0.035	106	0.00970	-0.02530	15:42	5.824	10:08	14.50	-0.0198	4.6463	14.32
26	121.16	11:31	-0.033	103	0.00942	-0.02358		5.897	10:06	14.48	-0.0185	4.7055	14.30
25	122.16	11:25	-0.029	97	0.00887	-0.02013		5.916	10:04	14.50	-0.0158	4.7210	14.32
24	123.16	11:20	-0.034	92	0.00841	-0.02559		5.683	10:00	14.33	-0.0201	4.5318	14.15
23	124.16	11:17	-0.040	89	0.00814	-0.03186	15:41	5.733	9:57	14.30	-0.0250	4.5724	14.12
22	125.16	11:14	-0.072	86	0.00787	-0.06413	15:39	5.209	9:54	13.84	-0.0503	4.1479	13.67
21	126.16	11:11	-0.108	83	0.00759	-0.10041	15:37	4.957	9:52	13.36	-0.0787	3.9443	13.20
20	127.16	11:07	-0.136	79	0.00723	-0.12877	15:34	4.863	9:50	13.04	-0.1009	3.8684	12.88
19	128.16	11:04	-0.141	76	0.00695	-0.13405	15:31	4.939	9:46	13.09	-0.1050	3.9297	12.93
18	129.16	11:00	-0.138	72	0.00659	-0.13141	15:27	4.908	9:45	13.06	-0.1030	3.9047	12.90
17	130.16	10:56	-0.140	68	0.00622	-0.13378	15:23	4.929	9:42	13.08	-0.1048	3.9217	12.92
16	131.16	10:52	-0.138	64	0.00585	-0.13215	15:21	4.768	9:40	12.97	-0.1035	3.7917	12.82
15	132.16	10:46	-0.137	58	0.00530	-0.13170	15:18	4.625	9:37	12.74	-0.1032	3.6764	12.59
14	133.16	10:42	-0.137	54	0.00494	-0.13206	15:16	4.591	9:35	12.71	-0.1035	3.6490	12.56
13	134.16	10:39	-0.140	51	0.00466	-0.13534	15:13	4.517	9:32	12.60	-0.1060	3.5894	12.45
12	135.16	10:36	-0.139	48	0.00439	-0.13461	15:11	4.457	9:28	12.50	-0.1055	3.5411	12.36
11	136.16	10:33	-0.138	45	0.00412	-0.13388	15:07	4.545	9:26	12.43	-0.1049	3.6119	12.29
10	137.16	10:30	-0.132	42	0.00384	-0.12816	15:05	4.370	9:24	12.08	-0.1004	3.4710	11.94
9	138.16	10:27	-0.130	39	0.00357	-0.12643	15:02	4.241	9:22	11.93	-0.0991	3.3673	11.80
8	139.16	10:23	-0.110	35	0.00320	-0.10680	14:59	3.257	9:20	9.85	-0.0837	2.5783	9.76
7	140.16	10:20	-0.109	32	0.00293	-0.10607	14:55	3.044	9:18	9.14	-0.0831	2.4081	9.06
6	141.16	10:16	-0.105	28	0.00256	-0.10244	14:50	2.950	9:16	8.73	-0.0803	2.3331	8.66
5	142.16		-0.107	24	0.00220	-0.10480	14:47	2.889	9:14	8.60	-0.0821	2.2844	8.54
4	143.16	10:07	-0.092	19	0.00174	-0.09026	14:45	2.660	9:13	7.93	-0.0707	2.1019	7.88
3	144.16	10:03	-0.079	15	0.00137	-0.07763	14:43	2.275	9:11	6.71	-0.0608	1.7956	6.68
2	145.16	9:59	-0.061	11	0.00101	-0.05999	14:40	1.750	9:10	5.02	-0.0470	1.3790	5.03
1	146.16	9:56	-0.038	8	0.00073	-0.03727	14:36	1.100	9:08	3.20	-0.0292	0.8651	3.24
0	147.16	9:53	-0.006	5	0.00046	-0.00554	14:30	-0.004	9:07	0.00	-0.0043	-0.0031	0.11
-1	148.16	9:48	-0.005	0	0.00000	-0.00500	14:28	-0.004	9:05	0.00	-0.0039	-0.0031	0.11

3/29/00 Ambient

Warm up 7:43-9:30 - meter set to 0.000  
12:35 Probe removed / plugged reading -0.015 reset to 0.000  
Station 38 reading reverified  
Ambient "0" correction =.015/164= 0.000091463 ml/min

3/30/00 Dynamic

Warm up 13:00-14:04 - meter set to 0.000  
17:05 Probe removed / plugged reading -0.005

3/31/00 Dynamic

Warm up 7:24-8:24 - meter set to 0.000



3/29/00

Time	Water Level (ft)	Time to Fill Bucket 16.8L (sec)	Field Measured Flow (L/min)
7:42	53.7'		
10:25	53.7'		
13:20	53.75'		

3/30/00

13:00	53.65'		
14:20	53.72'		
14:25	53.72'	196	5.14
14:28		195	5.17
14:30	53.74'		
15:06	53.74'		
15:30		193	5.22
16:00	53.82'		
16:07		193	5.22
16:43		194	5.20
16:44	53.79'		

3/31/00

7:30	53.69'		
8:40	53.87'		
8:46		70	14.40
8:47	53.88'		
8:53		70	14.40
8:57		69	14.61
9:02	53.88'	69	14.61
9:32	53.92'	69.5	14.50
10:01	53.95'		
10:13	53.95'		
10:20		69	14.61
10:50	53.96		
10:52		69.5	14.50
10:59	53.7		

## Appendix D – RPT-2PW field data

Well ID	Top of Screen From Grade (ft)	Bottom of Screen From Grade (ft)	Screen Length (ft)	Casing Diameter (inch)	Approx. Water Level From TOC (ft)	Survey Elev. TOC (ft-msl)	Survey Elev. Conc Pad (ft-msl)	TOC to Conc Pad (ft)	Pad Thickness (ft)	Top of Screen From TOC (ft)	Bottom of Screen From TOC (ft)	Top of Screen Elevation (ft)	Bottom of Screen Elevation (ft)
<b>RPT-2PW</b>	78	93	15	4	28.6	289.91	287.66	2.25	0.33	80.58	95.58	209.33	194.33

	Probe Date	.5" 4/5/00	.5" 4/5/00	.5" 4/5/00	.5" 4/5/00
Station	Depth Below TOC (FT)	Time	Ambient Instrument Response	Time	Dynamic Instrument Response
	70.00			14:47	5.032
16	79.58	12:45	0.000	14:44	5.030
15	80.58	12:40	0.000	14:40	5.036
14	81.58	12:38	-0.002	14:37	4.71
13	82.58	12:35	-0.004	14:33	4.041
12	83.58	12:33	-0.009	14:30	3.875
11	84.58	12:32	-0.015	14:23	3.503
10	85.58	12:30	-0.022	14:21	3.184
9	86.58	12:27	-0.023	14:19	2.88
8	87.58	12:24	-0.024	14:17	2.709
7	88.58	12:21	-0.023	14:14	2.458
6	89.58	12:18	-0.022	14:10	2.086
5	90.58	12:16	-0.020	14:08	1.636
4	91.58	12:14	-0.017	14:05	1.303
3	92.58	12:12	-0.012	14:01	0.929
2	93.58	12:10	-0.002	13:58	0.078
1	94.58	12:09	0.000	13:56	0.031
0	95.00	12:07	-0.005	13:53	0.023

4/5/00			
Time	Water Level (ft)	Bucket 16.8L Fill in (sec)	Field Measured Flow (L/min)
7:40	28.59		
12:46	28.55		
13:05	35.30		
13:09	35.70		
13:13	35.85		
13:19	36.00		
13:27	36.13		
13:34	36.20		
13:47	36.40		
13:50		249	4.05
14:06	36.53		
14:12		251	4.02
14:21		252	4.00
14:24	36.65		
14:49		252.5	3.99
14:50			

3/31/00

Ambient

95.00 Lowest possible position probe/ packer could be set  
 Warm up 9:30-12:05 - meter set to 0.000  
 Station 16 in casing "0" verified at 0.000

Dynamic

Dynamic test with .5" probe followed ambient rezero not required  
 15:00 Probe removed and plugged reading -0.004

This page intentionally left blank

## Appendix E – RPT-3PW field data

Well ID	Top of Screen From Grade (ft)	Bottom of Screen From Grade (ft)	Screen Length (ft)	Casing Diameter (inch)	Approx. Water Level From TOC (ft)	Survey Elev. TOC (ft-msl)	Survey Elev. Conc Pad (ft-msl)	TOC to Conc Pad (ft)	Pad Thickness (ft)	Top of Screen From TOC (ft)	Bottom of Screen From TOC (ft)	Top of Screen Elevation (ft)	Bottom of Screen Elevation (ft)
RPT-3PW	149	189	40	4	53.6	289.83	287.64	2.19	0.33	151.52	191.52	138.31	98.31

Station	Probe Date	1.0" 4/3/00		.5" 4/3/00		1.0" 4/3/00	.5" 4/3/00	4/3/00			
	Depth Below TOC (ft)	Time	Dynamic Instrument Response	Time	Ambient Instrument Response	$y = 0.9797x + 0.1097$ Dynamic Calibrated Flow (l/min)	$0.0024x^2 + 0.7838x$ Ambient Calibrated Flow (l/min)	Time	Water Level (ft)	Bucket fill 16.8L in (sec)	Field Measured Flow (L/min)
41	150.48	14:41	14.34	17:47	0.000	14.159	0.0000	11:51	53.57		
40	151.48	14:38	14.34	17:43	0.000	14.159	0.0000	12:00	59.7		
39	152.48	14:35	13.86	17:39	-0.165	13.688	-0.1293	12:13	60.25		
38	153.48	14:33	13.89	17:36	-0.177	13.718	-0.1387	12:16		71	14.20
37	154.48	14:30	13.8	17:33	-0.181	13.630	-0.1418	12:23		70.5	14.30
36	155.48	14:27	13.47	17:30	-0.200	13.306	-0.1567	12:24	60.38		
35	156.48	14:23	13.55	17:27	-0.204	13.385	-0.1598	12:33	60.51		
34	157.48	14:16	13.42	17:24	-0.209	13.257	-0.1637	12:36		71	14.20
33	158.48	14:12	13.04	17:22	-0.225	12.885	-0.1762	12:40	60.6		
32	159.48	14:07	12.15	17:19	-0.267	12.013	-0.2091	12:50	60.67		
31	160.48	14:03	10.51	17:16	-0.358	10.406	-0.2803	12:53		71	14.20
30	161.48	13:59	8.76	17:14	-0.462	8.692	-0.3616	13:02		71	14.20
29	162.48	13:55	7.44	17:12	-0.537	7.399	-0.4202	13:10	60.85		
28	163.48	13:52	7.04	17:10	-0.573	7.007	-0.4483	13:21	60.9		
27	164.48	13:49	7.05	17:08	-0.580	7.017	-0.4538	13:22		71	14.20
26	165.48	13:46	6.94	17:05	-0.578	6.909	-0.4522	13:32	60.96		
25	166.48	13:44	6.94	17:02	-0.582	6.909	-0.4554	13:42	61.03		
24	167.48	13:41	6.80	16:59	-0.584	6.772	-0.4569	13:56		71	14.20
23	168.48	13:39	6.78	16:57	-0.593	6.752	-0.4639	14:08	61.13		
22	169.48	13:36	6.57	16:55	-0.590	6.546	-0.4616	14:39		71	14.20
21	170.48	13:34	6.53	16:53	-0.597	6.507	-0.4671	14:41	61.27		
20	171.48	13:31	6.51	16:51	-0.590	6.488	-0.4616	15:28	54.6		
19	172.48	13:19	6.50	16:49	-0.582	6.478	-0.4554	15:42	54.47		
18	173.48	13:27	6.54	16:46	-0.578	6.517	-0.4522	15:57	54.3		
17	174.48	13:24	6.30	16:44	-0.554	6.282	-0.4335	16:23	54.26		
16	175.48	13:22	5.91	16:42	-0.534	5.900	-0.4179	16:45	54.19		
15	176.48	13:20	5.60	16:40	-0.521	5.596	-0.4077	17:04	54.13		
14	177.48	13:18	5.43	16:38	-0.504	5.429	-0.3944	17:52	54.07		
13	178.48	13:16	5.22	16:36	-0.484	5.224	-0.3788				
12	179.48	13:13	4.86	16:34	-0.470	4.871	-0.3679				
11	180.48	13:11	4.28	16:33	-0.433	4.303	-0.3389				
10	181.48	13:09	3.64	16:31	-0.396	3.676	-0.3100				
9	182.48	13:07	3.10	16:30	-0.362	3.147	-0.2834				
8	183.48	13:05	2.97	16:29	-0.354	3.019	-0.2772				
7	184.48	13:02	2.90	16:27	-0.348	2.951	-0.2725				
6	185.48	12:59	2.65	16:25	-0.328	2.706	-0.2568				
5	186.48	12:56	2.10	16:23	-0.241	2.167	-0.1888				
4	187.48	12:54	1.56	16:21	-0.151	1.638	-0.1183				
3	188.48	12:51	1.06	16:20	-0.108	1.148	-0.0846				
2	189.48	12:49	0.86	16:18	-0.087	0.952	-0.0682				
1	190.48	12:46	0.54	16:16	-0.060	0.639	-0.0470				
0	191.48	12:44	0.00	16:14	-0.002	0.110	-0.0016				
-1	192.48	12:42	0.00	16:12	-0.002	0.110	-0.0016				

4/3/00

Dynamic

Warm up 10:42-11:42 1" probe meter set to 0.000

Ambient

Warm up 14:50-15:50 1/2" probe meter set to 0.000

17:47 After final reading probe raised into casing and "0" at 0.000

This page intentionally left blank

## Appendix F – RPT-4PW field data

Well ID	Top of Screen From Grade (ft)	Bottom of Screen From Grade (ft)	Screen Length (ft)	Casing Diameter (inch)	Approx. Water Level From TOC (ft)	Survey Elev. TOC (ft-msl)	Survey Elev. Conc Pad (ft- msl)	TOC to Conc Pad (ft)	Pad Thickness (ft)	Top of Screen From TOC (ft)	Bottom of Screen From TOC (ft)	Top of Screen Elevation (ft)	Bottom of Screen Elevation (ft)
RPT-4PW	231.4	271.4	40	6	94.00	289.72	287.5	2.22	0.33	233.95	273.95	55.77	15.77

Station	Probe Date	.5" 3/31/00		1.0" 4/3/00		.5" 3/31/00	1.0" 4/3/00
		Time	Ambient Instrument Response	Time	Dynamic Instrument Response	$y = 0.0024x2 + 0.7838x$ Dynamic Calibrated Flow (l/min)	$y = 0.9797x + 0.1097$ Dynamic Calibrated Flow (l/min)
44				10:35	13.72		13.55
42	233.82						
41	234.82						
40	235.82	17:10	0.005	10:24	13.74	0.0039	13.57
39	236.82	17:06	0.000	10:18	13.74	0.0000	13.57
38	237.82	17:00	0.000	10:12	13.74	0.0000	13.57
37	238.82	16:55	0.000	10:06	13.72	0.0000	13.55
36	239.82	16:50	0.000	10:01	13.73	0.0000	13.56
35	240.82	16:45	-0.005	9:55	13.67	-0.0039	13.50
34	241.82	16:44	0.000	9:51	13.69	0.0000	13.52
33	242.82	16:20	0.000	9:47	13.72	0.0000	13.55
32	243.82	16:07	0.000	9:43	13.66	0.0000	13.49
31	244.82	16:01	0.000	9:40	13.63	0.0000	13.46
30	245.82	15:56	0.000	9:35	13.62	0.0000	13.45
29	246.82	15:54	0.000	9:30	13.60	0.0000	13.43
n/a	n/a		n/a		n/a		
n/a	n/a		n/a		n/a		
0	0		0		0		

3/31/00			
Time	Water Level (ft)	Time to fill Bucket 16.8L (sec)	Field Measured Flow (L/min)
11:59	94.00		
16:53	94.00		

4/3/00			
Time	Water Level (ft)	Time to fill Bucket 16.8L (sec)	Field Measured Flow (L/min)
8:02	94.00'		
9:11	96.20'		
9:14		75.5	13.35
9:21		75	13.44
9:25	96.17'		
9:29		75	13.44
9:30	96.20'		
9:42	96.20'		
9:49		75	13.44
10:02	96.20'		
10:16		74.5	13.53
10:22	96.23'		
10:33		74.5	13.53

3/31/00

Ambient

Warm up 12:08-13:19 - meter set to 0.000  
station 41 After final reading probe raised into casing and "0" at 0.003  
250' Cable could only reach to Station 29 of the screen

4/3/00

Dynamic

Warm up 8:00-8:59 1" probe meter set to 0.000  
250' Cable could only reach to Station 29 of the screen

This page intentionally left blank

## Appendix G – RPT-30PZ field data

Well ID	Top of Screen From Grade (ft)	Bottom of Screen From Grade (ft)	Screen Length (ft)	Casing Diameter (inch)	Approx. Water Level From TOC (ft)	Survey Elev. TOC (ft-msl)	Survey Elev. Conc Pad (ft-msl)	TOC to Conc Pad (ft)	Pad Thickness (ft)	Top of Screen From TOC (ft)	Bottom of Screen From TOC (ft)	Top of Screen Elevation (ft)	Bottom of Screen Elevation (ft)
<b>RPT-30PZ</b>	15	55	40	2	26.8	289.66	287.52	2.14	0.33	17.47	57.47	272.19	232.19

Station	Depth Below TOC (ft)	Probe Date	.5" 4/5/00		.5" 4/6/00		.5" 4/5/00	.5" 4/6/00
			Ambient Time	Ambient Instrument Response	Dynamic Time	Dynamic Instrument Response	$y = 0.0024x2 + 0.7838x$ Ambient Calibrated Flow (l/min)	$y = 0.0024x2 + 0.7838x$ Dynamic Calibrated Flow (l/min)
30	27.47	17:25	0.000				0.0000	
29	28.47	17:23	-0.001				-0.0008	
28	29.47	17:21	-0.002				-0.0016	
27	30.47	17:20	-0.004				-0.0031	
26	31.47	17:18	-0.003		12:52	2.197	-0.0024	1.7336
25	32.47	17:16	-0.007		12:51	2.334	-0.0055	1.8425
24	33.47	17:15	-0.010		12:50	2.322	-0.0078	1.8329
23	34.47	17:13	-0.009		12:48	2.356	-0.0071	1.8600
22	35.47	17:11	-0.010		12:47	2.334	-0.0078	1.8425
21	36.47	17:08	-0.009		12:41	2.481	-0.0071	1.9594
20	37.47	17:06	-0.015		12:40	2.478	-0.0118	1.9570
19	38.47	17:04	-0.015		12:30	2.527	-0.0118	1.9960
18	39.47	17:03	-0.019		12:25	2.330	-0.0149	1.8393
17	40.47	17:02	-0.025		12:23	2.279	-0.0196	1.7987
16	41.47	17:01	-0.029		12:22	2.180	-0.0227	1.7201
15	42.47	16:58	-0.038		12:21	2.096	-0.0298	1.6534
14	43.47	16:57	-0.040		12:19	2.122	-0.0313	1.6740
13	44.47	16:55	-0.046		12:17	2.147	-0.0360	1.6939
12	45.47	16:54	-0.051		12:15	2.127	-0.0400	1.6780
11	46.47	16:52	-0.052		12:14	2.097	-0.0408	1.6542
10	47.47	16:50	-0.058		12:13	2.069	-0.0455	1.6320
9	48.47	16:48	-0.072		12:12	1.955	-0.0564	1.5415
8	49.47	16:47	-0.086		12:11	1.853	-0.0674	1.4606
7	50.47	16:45	-0.095		12:10	1.794	-0.0744	1.4139
6	51.47	16:43	-0.103		12:09	1.742	-0.0807	1.3727
5	52.47	16:41	-0.103		12:07	1.657	-0.0807	1.3053
4	53.47	16:39	-0.082		12:05	1.119	-0.0643	0.8801
3	54.47	16:38	-0.072		12:04	0.792	-0.0564	0.6223
2	55.47	16:36	-0.067		12:03	0.748	-0.0525	0.5876
1	56.47	16:35	-0.063		12:01	0.651	-0.0494	0.5113
0	57.47	16:33	0.000		12:00	0.015	0.0000	0.0118
-1	58.47	16:31	0.000		11:58	0.000	0.0000	0.0000

4/5/00				
Time	Water Level (ft)	Graduated Cylinder Readings (ml)	Time (sec)	Field Measured Flow (L/min)
13:29	26.8			
16:04	26.75			
17:30	26.75			

4/6/00				
Time	Water Level (ft)	Graduated Cylinder Readings (ml)	Time (sec)	Field Measured Flow (L/min)
10:52	26.73			
11:00	28.74			
11:04	28.68			
11:21	28.42			
11:37	28.25			
11:52	28.39			
11:54	28.40			
11:57		1970	51.5	2.30
12:08		2000	57.5	2.09
12:09	28.25			
12:14		1990	57.0	2.09
12:17	28.30			
12:23		1980	56.5	2.10
12:31		2000	55.0	2.18
12:32	28.35			
12:40		1990	55.0	2.17
12:48		2000	58.0	2.07
12:52		2000	59.5	2.02

4/5/00 Ambient  
Warm up 16:00 - 16:30 meter set to 0.000 +/- 0.001  
station 30 After final reading probe raised into casing and "0" at 0.000

4/5/00 Dynamic  
Warm up 8:20 - 10:38 meter set to 0.000 +/- 0.001  
Station 26 probe at the bottom of the pump



This page intentionally left blank