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Analysis of Well ER-EC-1 Testing, Western Pahute Mesa-Oasis Valley FY 2000 Testing Program

Revision No.: 0

September 2002

Prepared for U.S. Department of Energy under Contract No. DE-AC08-97NV13052.

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IT CORPORATION
P.O. Box 93838
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Approved by: Signature Approved Date: 9-13-02

Janet N. Wille, UGTA Project Manager
IT Corporation

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List of Acronyms and Abbreviations

bgs	Below ground surface
BN	Bechtel Nevada
BOD	Biological Oxygen Demand
C	Carbon
CAU	Corrective Action Unit
CD	Compact disc
Cl	Chlorine
DIC	Dissolved inorganic carbon
DO	Dissolved oxygen
DOE	U.S. Department of Energy
DOP	Detailed Operating Procedure
DRI	Desert Research Institute
EC	Electrical conductivity
ESP	Electrical Submersible Pump
FMP	Fluid Management Plan
fpm	Feet per minute
FS	Full scale
ft	Foot (feet)
ft^2/d	Square feet per day
FY	Fiscal year
gpd/ft	Gallon per day per foot
gpm	Gallon per minute
H_2O	Water
He	Helium
HSU	Hydrostratigraphic unit
hp	Horsepower
hz	Hertz
in.	Inch(es)
K	Hydraulic conductivity
ITLV	IT Corporation, Las Vegas
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
LiBr	Lithium bromide

List of Geologic Terms

m	Meter
mL	Milliliter
mg/L	Milligrams per liter
NDEP	Nevada Division of Environmental Protection
NDWS	Nevada Drinking Water Standards
nm	Nanometers
NNSA/NV	National Nuclear Security Administration Nevada Operations Office
NTU	Nephelometric turbidity unit
od	Outside diameter
pCi/L	Picocuries per liter
psi	Pounds per square inch
psig	Pounds per square inch gauge
PXD	Pressure transducer
redox	Reduction oxidation
rev/sec	Revolutions per second
S	Storage coefficient
SQP	Standard Quality Practice
SWL	Static water level
T	Transmissivity
UGTA	Underground Test Area
UNLV-HRC	University of Nevada, Las Vegas - Harry Reid Center
VSD	Variable speed drive
WDHTP	Well Development and Hydraulic Testing Plan
WPM-OV	Western Pahute Mesa-Oasis Valley
°C	Degree Celsius
µg/L	Micrograms per liter
µmhos/cm	Micromhos per centimeter

1.0 Introduction

This report documents the analysis of the data collected for Well ER-EC-1 during the Western Pahute Mesa - Oasis Valley (WPM-OV) well development and testing program that was conducted during fiscal year (FY) 2000. The data collection for that program is documented in Appendix A, *Western Pahute Mesa - Oasis Valley, Well ER-EC-1 Data Report for Development and Hydraulic Testing*.

1.1 Well ER-EC-1

Well ER-EC-1 is one of eight groundwater wells that were tested as part of FY 2000 activities for the U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Operations Office (NNSA/NV), Underground Test Area (UGTA) Project. Figure 1-1 shows the location of Well ER-EC-1 and the other WPM-OV wells. Drilling and well construction information has been documented in the *Completion Report for Well ER-EC-1, December 2000* (DOE/NV, 2000).

Hydraulic testing and groundwater sampling were conducted at Well ER-EC-1 to provide information on the hydraulic characteristics of hydrostratigraphic units (HSUs) and the chemistry of local groundwater. Well ER-EC-1 is constructed with three completion intervals which are isolated from each other by blank casing sections with annular seals. The completion intervals extend over large vertical distances and access different HSUs and/or lithologies. Figures illustrating the well construction and lithology are provided in Section 3.0. The testing and sampling activities were designed to assess the completion intervals individually.

1.2 WPM-OV Testing Program

The testing program included:

1. Discrete pressure measurements for each completion interval
2. Well development and step-drawdown tests
3. Flow logging at three pumping rates
4. Collection of discrete groundwater sample(s) with a downhole sampler
5. Eight-day, constant-rate pumping test and subsequent recovery

6. Collection of composite groundwater characterization samples
7. Flow measurements and water quality parameter logging under natural gradient flow

1.3 Analysis Objectives and Goals

The testing program was designed to provide information about the local hydrologic conditions and HSU hydraulic parameters for use in the Corrective Action Unit (CAU)-scale flow and transport model. In addition, groundwater quality information from samples collected was intended for use in geochemistry-based analyses of hydrologic conditions and groundwater flow, as well as to detect the presence of any radionuclides. The primary objective for this analysis was to evaluate all of the data collected and to derive the maximum information about the hydrology. A secondary objective was to evaluate the functionality of the well design for use in future investigation and testing activities, and also evaluate this well for use in future monitoring.

General goals for the analysis were: determine the discrete head for each completion interval and the resultant vertical gradient profile, determine representative hydraulic parameter(s) for the formation(s) in each completion interval, and determine representative groundwater quality for the formation(s) in each completion interval. With regard to the well, specific goals included determination of the well hydraulics of the multiple completion interval design under both natural gradient and pumping conditions, and the effectiveness of development and testing methodologies.

Section 2.0 of this report discusses the analysis of the nonpumping natural-gradient well hydrology, and evaluates opportunities for deriving hydraulic parameters for the completion intervals. Section 3.0 discusses the well hydraulics during pumping and the flow logging results. Hydraulic parameters for the well in general, and for the upper completion interval in particular, are presented. This section is completed with comments on working with these deep, multiple completion wells. Section 4.0 discusses the groundwater samples that were collected and the analytical results, as well as how this information fits into the general geochemistry of the groundwater in the area. Finally, concerns pertinent to the future use of Well ER-EC-1 for monitoring are discussed.

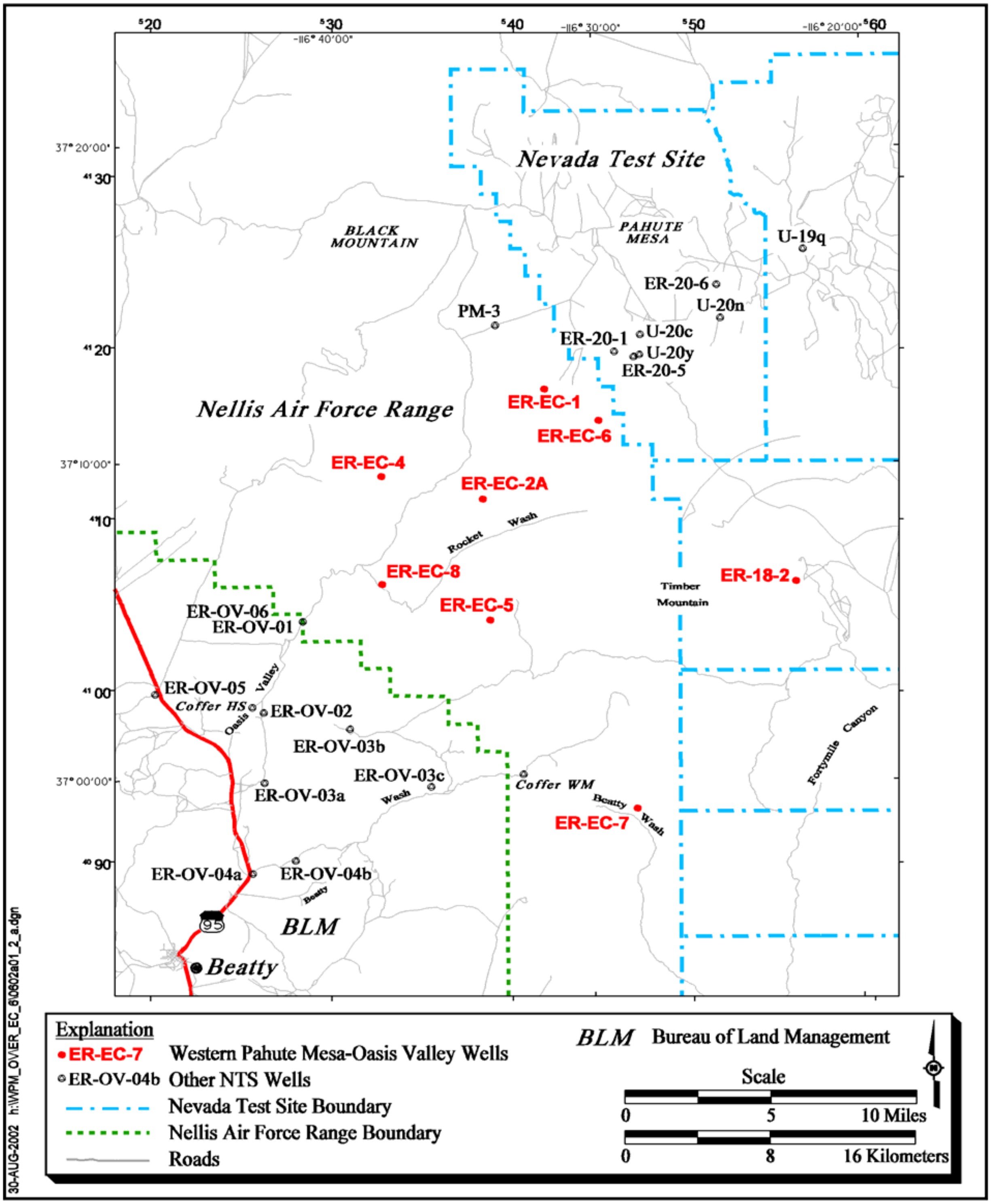


Figure 1-1
Location Map for WPM-OV ER Wells

2.0 Equilibrium Well Hydraulics

This section discusses aspects of well hydraulics for Well ER-EC-1 in the equilibrium, nonpumping condition relating to the individual completion intervals. This material updates the initial analyses of data in Appendix A and further develops some of the concepts and concerns that were presented.

The well is constructed with three separate completion intervals composed of alternating slotted casing joints and blank casing joints. The completion intervals are isolated from each other outside the well casing by cement annular seals. Within a completion interval, all the slotted casing joints (often referred to as screens) are connected by continuous gravel pack in the annulus outside the well casing. Downhole flow features are often discussed with reference to individual screens. The convention for referencing screens is by the consecutive number (e.g., first, second, third) of the screen from the top of the completion interval.

2.1 Composite Equilibrium Water Level

Table A.2-2 in Section A.2.0 of Appendix A presents all of the measurements of the composite water level (i.e., depth to water) made during the testing program. The measurements reported in that table are very consistent. There was no information collected during the testing program to indicate that these values are not representative.

2.2 Barometric Efficiency

The barometric efficiency of the well is used in the analyses of the hydraulic tests to refine the analyses and produce more accurate results. The importance of determining the correct value for barometric efficiency is somewhat dependent on the magnitude of the drawdown of the well during testing; the greater the drawdown, the less important the barometric correction. However, in circumstances where small-scale water level changes are being interpreted, correction for barometric variation during the monitoring period can be important. This is particularly important when making decisions based on short or sparse records.

The methodology used for determining barometric efficiency overlays the barometric pressure record over the water level record after converting the barometric data to consistent units and inverting the trace. The processed barometric trace is trended and scaled until a best-fit match to the water level record is determined. The trending removes any water level trend not due to barometric response; the scaling factor is equal to the barometric efficiency. This method assumes that the water level in the well is in equilibrium with the groundwater head, and that long-term trends in groundwater levels can be represented by a linear trend. The final requirement for applying this methodology is that the record must include changes in barometric pressure longer than diurnal and semidiurnal fluctuations with magnitude substantially greater than those fluctuations. This requirement is necessary to separate the barometric response of the well from earth tide-related fluctuations.

Three water level monitoring records were evaluated for use in determining barometric efficiency: (1) the long-term predevelopment water level monitoring record, (2) a section of record following water level recovery after well development, and (3) the upper-interval monitoring record collected during the discrete interval head measurements. The first two records were found to be unsuitable. Examination of these records found that the records are dominated by semidiurnal variations in both the PXD pressure and barometric pressure that track closely and obscure the general barometric pressure response.

The pressure transducer (PXD) record for the water level in the long-term water level monitoring record (see Figure 2-1) shows anomalous behavior. There are also gaps in the record that are due to intermittent PXD failure. The apparent water level fluctuation is several times greater than the barometric variation. This is the only long-term equilibrium monitoring record collected compositing the response of all three completion intervals. The record after well development and before the start of the constant-rate test was also evaluated for barometric efficiency (see Figure 2-2). However, this section of the record is only three and one-half days long, and during this time there was no substantial variation of the barometric pressure. The evaluation also found that the water level was still equilibrating, so it was not possible to detrend the entire record with a linear trend. The apparent water level fluctuation in this record is slightly greater than the barometric variation. The mechanism for the water level variation exceeding the barometric pressure variation in these records is not known.

The record of the upper-interval water level monitoring during the bridge-plug measurements, shown in Figure 2-3, can be interpreted according to the methodology described above and yields an apparent barometric efficiency of 85 percent. This record differs from the other two records in that it contains a barometric change over several days of much greater amplitude than the semidiurnal daily fluctuations. The derived barometric efficiency is specific to the upper completion interval, and it is not known exactly how it relates to the composite barometric efficiency of the entire well.

These analyses indicate the need for long-term monitoring records that include substantial changes in barometric pressure. There is a greater likelihood that a long-term record will meet the criteria for analysis. The well needs to be in basic equilibrium with the groundwater system during collection of the record, and this should be ascertained from the record, not assumed. A detailed evaluation of the record as it is collected is required to determine if these criteria are met since specific details of each record will determine its usability. Different wells are more or less sensitive to earth-tide effects, and a simple rule-of-thumb for determining the requirements for a record cannot be offered prior to collecting the record other than that 30 days is the necessary minimum to provide full definition of earth tides.

The methodology used here for determining barometric efficiency is improved over the calculation presented in Section A.3.4.1 of Appendix A.

2.3 Completion-Interval Heads

Table 2-1 contains head values for the composite and individual completion intervals for the initial equilibration and at the end of monitoring. The head differences represent the apparent equilibration of the different intervals after isolation of the intervals. Interpretation of the water level and pressure records is discussed below. Head values are presented rounded to the nearest 0.01 ft, and pressure values are reported to the nearest 0.01 psi as recorded by the instrumentation. The accuracy of these values is then evaluated.

Table 2-1
Well ER-EC-1 Composite and Interval-Specific Heads

Location in Well	**Initial Equilibration: Head as Depth Below Ground Surface**		**Change from Composite Head**	**End of Monitoring: Head as Depth Below Ground Surface**		**Accuracy Relative to Composite Head**
	Feet	Meters	Feet	Feet	Meters	Feet
Composite Static Water Level (E tape)	1,855.92	565.68	NA	--	--	NA
Upper Interval (E tape)	1,855.84	565.66	+ 0.08	1,855.78	565.64	+/-0.19[1]
Middle (calculated)	1,857.24	566.09	- 1.32	1,857.24	566.09	+/-0.42[2]
Lower Interval (calculated)	1,856.31	565.80	- 0.28	1,856.18	565.76	+/-0.47[3]

[1] Repeatability of E-tape measurement
[2] Accuracy of PXD plus repeatability of E-tape measurement
[3] Resolution of PXD

The water level measurements made successively with the same e-tape showed a rise in water level of 0.07 feet (ft) after installation of the lower bridge plug. The measurement made immediately after installation of the upper bridge plug was an additional 0.01 ft higher. A water level rise of 0.08 ft was recorded for the upper interval over the following week; however, the relative head actually declined 0.12 ft when the water level was corrected for barometric pressure change. The middle interval pressure declined 0.60 pounds per square inch (psi) over an 8-hour (hr) period and then stayed constant. The lower interval pressure declined 0.12 psi over an 8-hr period, and then increased 0.06 psi over the remainder of the monitoring period. The initial adjustments of the heads were used to calculate the head differences between the completion intervals. The later changes were interpreted to be trends in the heads of the intervals due to general trends in the groundwater system.

The accuracy of the heads computed for the completion intervals is a function of the accuracy of the water level measurements used for the reference heads and the accuracy of the pressure measurements. The e-tape measurements are made to a precision of 0.01 ft, which is the accuracy to which the e-tapes are calibrated. Water level measurements are generally repeatable within 0.1 ft or less per 1,000 ft between independent measurements (complete removal and reinsertion). The e-tapes are calibrated yearly. The calculation of head differences between completion intervals are referenced back to these measurements, so the repeatability of the measurements is the primary inaccuracy.

The specification for accuracy of the PXDs is 0.1 percent of the full-scale measurement and a resolution of 0.008 percent of full scale. Two different PXDs were used. A 1,000 psi unit (SN# 21003) was used for the middle interval measurements, with a nominal accuracy of 1.00 psi (2.33 ft of head) and a resolution of 0.08 psi (0.19 ft of head), and a 2,500 psi unit (SN# 01157) was used for the lower interval measurements with a nominal accuracy of 2.50 psi (5.83 ft of head) and a resolution of 0.20 psi (0.47 ft of head). The resolution specification indicates the incremental ability of the instrumentation to distinguish differences in pressure, and the instrument resolution results in a record showing a band for the time series of readings of width equal to twice the resolution. Differences between successive readings smaller than the resolution are the result of temperature compensation. The pressure values used in these calculations are the central values of the resolution band.

The calibration certificate supplied for SN#21003 indicated that the PXD actually calibrated within 0.23 psi (0.023 percent full scale) or less across the range of operational pressure and temperature. The calibration certificate supplied for SN#01157 indicated that the PXD actually calibrated within -0.27 psi (-0.011 percent full scale) or less across the range of operational pressure and temperature. These potential errors in absolute pressure equate to errors in head of 0.54 and -0.63 ft. The PXDs were accurate to these levels at the time of calibration, but no post-use calibration was run to verify if the PXDs had maintained these better accuracies.

The uncertainty of head difference measurements is related to the stability of the pressure measurement accuracy across the range in pressures measured during the equilibration from one state to another. The calibration of PXD SN#21003 showed errors of 0.09 psi at 500 psi, 0.20 psi at 600 psi, and 0.12 psi at 800 psi at the nearest calibration temperature to the measurement temperature. The maximum variation in the error across this range is 0.11 psi, which is equivalent to 0.26 ft of head. The calibration of PXD SN#01157 showed errors of -0.23 psi at 1,000 psi, and -0.10 psi at 1,250 psi at the nearest calibration temperature to the measurement temperature. The maximum variation in the error across this range is 0.13 psi, which is equivalent to 0.30 ft of head.

The potential error in the head difference between the composite water level and the lower completion interval is the resolution of the PXD, which is greater than the stability error of the calibration. The potential error in the head difference between the composite water level and the middle interval is the sum of the repeatability error of the reference e-tape measurement and the calibration stability of the PXD.

Based on this error analysis, only the decline of the head in the middle completion interval exceeds the uncertainty in the measurements. The calculated changes in the lower interval head and the upper interval head do not exceed the potential error. The head appears to decline from the upper interval to the middle interval, but increases down to the lower interval. This relationship is possible, but there is no other data to support it.

2.4 Variable Density/Viscosity of Water in the Wellbore

The measurements of pressure at various depths in the well have indicated a variation in density of the water with depth that results in a nonlinear pressure-depth relationship. The variation in density is significant, and it is important to use the appropriate composite density when interpreting the bridge-plug pressure measurements to determine the head in a completion interval. The variation of temperature with depth appears to be the primary factor in the density variation. However, there may be other factors such as dissolved gasses and solids, suspended solids that vary with depth, and compressibility of the water. No information was collected that provides any understanding of these other factors, although it was noted during the development that there seemed to be a significant amount of entrained air in the produced water. The viscosity of the water also varies with temperature and perhaps other variables. Both the density and the viscosity variation may affect the flowmeter calibration and consistency of results.

Figure 2-4 shows the result of calculating the theoretical variation in density of water as a function of the temperature variation in the well and water compressibility. The temperature variation was taken from the posttesting ChemTool log. The pressures calculated from this exercise are within about 2.5 psi at the depth of 1,371.76 ft (middle interval bridge plug measurement) and 4.4 psi at a depth of 2,469.23 ft (lower interval bridge plug measurement). Part of this difference is the uncertainty in accounting for the reference pressure of the PXDs, which is not known and was not recorded in the measurement process. The remainder of the difference is due to the other factors mentioned.

2.5 Flow in the Well Under Natural Gradient

Measurement of flow in the well under the natural gradient can be used in conjunction with other information collected to calculate transmissivity (T) values for the individual completion intervals. There are two types of analysis that can be developed, a steady-state analysis using the measurement of the head differences between the completion intervals, and a transient analysis using the pressure adjustment that occurred when the bridge plugs were set. An additional use of the flow measurements are calculation of the total amount of crossflow that had occurred between completion intervals prior to development. This information will be used in evaluation of the effectiveness of development for restoration of natural water quality. If crossflow is allowed to continue, the flow information will provide the basis for estimating future development/purging requirements for sampling of receiving intervals. Temperature logs run under nonpumping conditions also provide information on flow in the well, indicating locations in the borehole of entry and exit of groundwater and direction of flow. The interpretation of the temperature logs is used in conjunction with the flow measurements, providing guidance for locating and interpreting discrete measurements.

2.5.1 Temperature Log

A temperature log was run under nonpumping conditions with the ChemTool approximately 16 days after the constant-rate test. This log is shown in Figure 2-5, along with the temperature log run prior to well completion. The temperature logs give an indication of the entry, direction, and exit of flow from the borehole, but do not provide any rate information. Also shown on this figure are the flow measurements made under natural-gradient flow, which will be discussed in the next section. The precompletion and posttesting temperature logs are very similar in form, but the precompletion log is generally warmer by about 7°F. There are indications of flow in the upper part of the borehole, and in the upper completion interval after completion.

2.5.2 Flow Measurements (Thermal Flow Tool and/or Impeller Log)

Flow in the well under natural gradient (i.e., nonpumping, equilibrium conditions) was measured using the thermal flowmeter after recovery following the constant-rate test. Flow measurements from before and after well construction are tabulated in Table 2-2 and graphically illustrated in Figure 2-5. Prior to well

Table 2-2
Thermal Flow Measurements

Prior to Well Construction		**After the Constant-Rate Test**		**Well Construction**
Depth (ft)	**Flow (gpm)**	**Depth (ft)**	**Flow (gpm)**	**Location**
2,392	0.231	2,290	0	Above upper completion interval
2,590	0.168	2,350	-0.34	Within upper completion interval
2,800	-0.367	2,410	-2.2	Within upper completion interval
3,205	-0.604	2,500	-2.2	Within upper completion interval
3,702	-0.54	2,700	-0.6	Within upper completion interval
4,240	-0.479	3,330	0	Above middle completion interval
4,950	0.177			

+ Indicates upward flow
- Indicates downward flow
gpm - Gallon(s) per minute
ft - Feet

construction, there appeared to be some upward flow in the upper half of the upper completion interval, and downward flow from the upper part of the borehole to the lower part, possibly from shallower lavas to deeper lavas. The uppermost measurement of downward flow before well construction was at a depth within the span of the lowermost screen of the upper completion, and the lowermost completion interval includes the apparent receiving formation. However, in the constructed well, there does not appear to be measurable flow from the upper completion interval downwards to the lower completion intervals. This result does not seem consistent with the general downward flow observed in the open borehole or with the measured downward gradient. However, the completion of the well may have altered conditions that had allowed such flow, or limited the flow to rates below the limits of the tool. Further investigation would help to clarify the situation.

An attempt was also made to measure nonpumping flow with the impeller flowmeter (log ec1mov11) because the flow was at the limit of the range of the thermal flowmeter. The results, shown on Figure 2-5, are very similar to the results of the thermal flowmeter measurements. However, the apparent flow is in the range of the low-flow uncertainty in the measurement according to the analysis of uncertainty that will be presented in Section 3.1.3. It is not clear whether the impeller tool will be generally useful in measuring such low flow rates. The flow rates commonly observed under natural gradients are below the stall speed of the impeller flowmeter, and there is inherent noise in trolling flow logs. In addition, it is suspected that temperature effects on density and viscosity of the water in the borehole may become significant factors affecting the calibration of the flowmeter relative to these low flow rates. There was a considerable temperature gradient in this well, spanning about 50°F from the upper completion interval to the lowermost completion interval. The resultant effect on density will be discussed in Section 2.6.

2.5.3 Derived Hydraulic Properties

Transmissivity of the completion intervals can be calculated from information on the flow from and/or into the completion intervals and the hydraulic gradients associated with the flow. An estimate could be made using the empirical equation $T=2000Q/s_w$ (Driscoll, 1986), where Q is the flow rate in gpm and s_w is the drawdown in feet. The head differences associated with flow to or from each interval would be based on the heads determined for the isolated completion intervals, as presented in Table 2-1. The flows attributed to each interval would be determined from the thermal flowlog measurements. However, the data available for this well do not provide the basis for such estimates. Head differences between completion intervals were not well quantified, and no flows were measured between the completion intervals.

The head change data and the flow data both have substantial relative uncertainty, but could provide general estimates. While these estimates are less specific and accurate than pumping test/flow logging information, they could provide estimates of T and hydraulic conductivity (K) values where better or more specific information will not be acquired.

2.6 Pressure Drawdown Following Setting of Bridge Plugs

The pressure equilibration records for each completion interval following setting the bridge plugs also have the potential for providing information on the transmissivity of the completion interval formation (Earlougher, 1977). These records are shown in Figure A.3-2 and Figure A.3-4 of the data report in Appendix A, and were evaluated for this use. The records were not suitable for this analysis because the pressure declines were primarily defined by data points that resulted from temperature resolution effects.

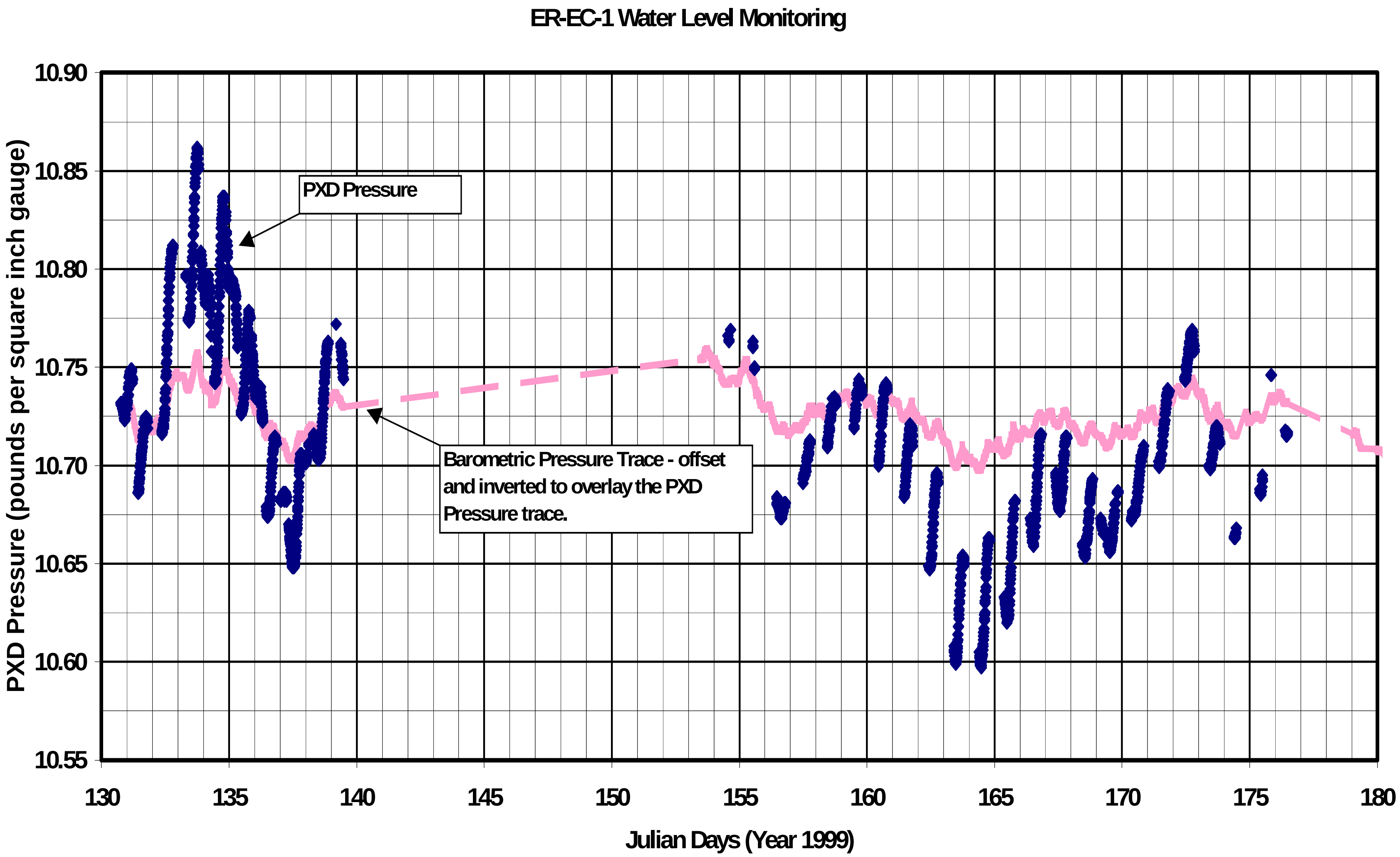


Figure 2-1
Long-Term Water Level Monitoring

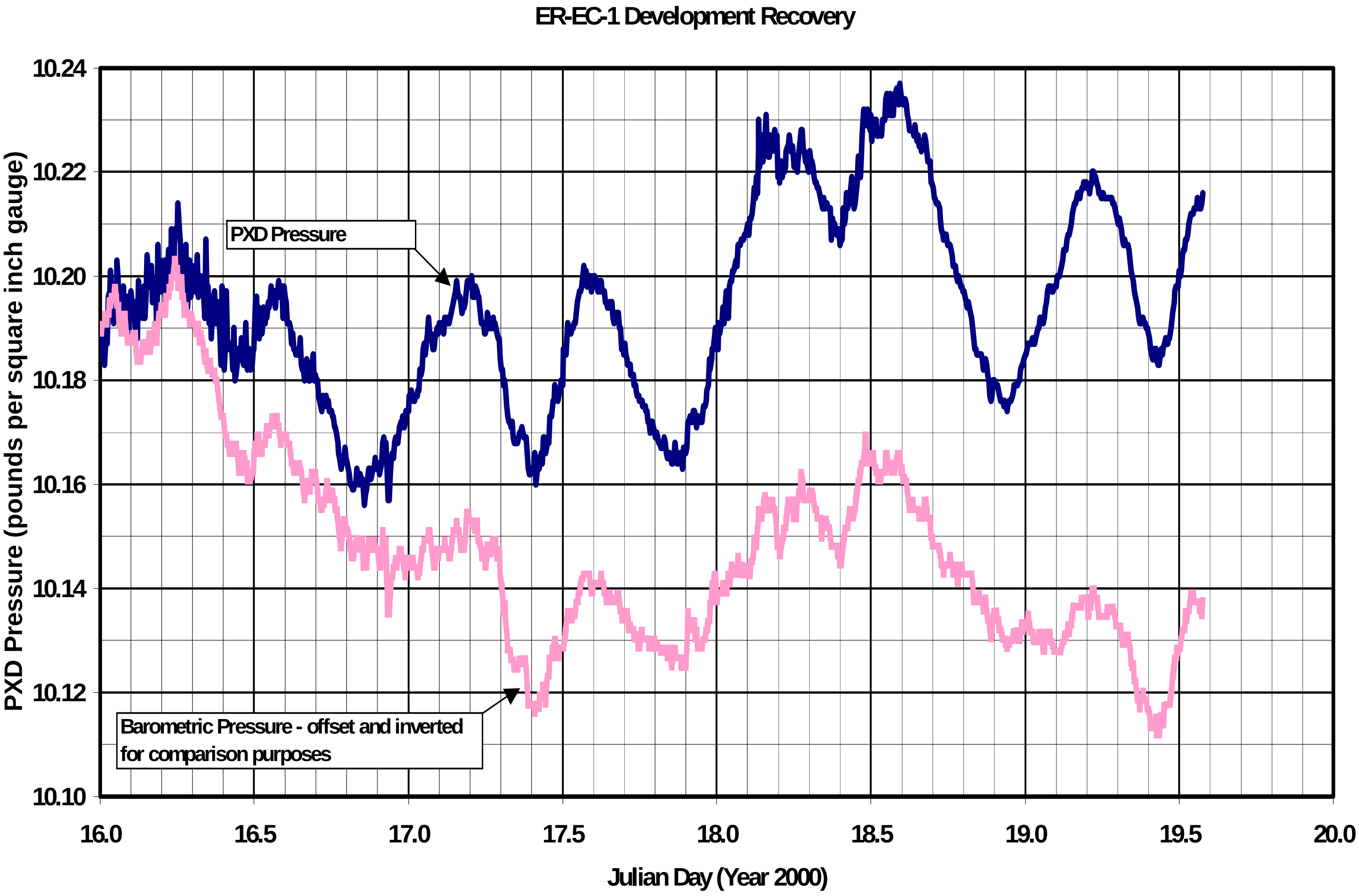


Figure 2-2
Postdevelopment Water Level Record

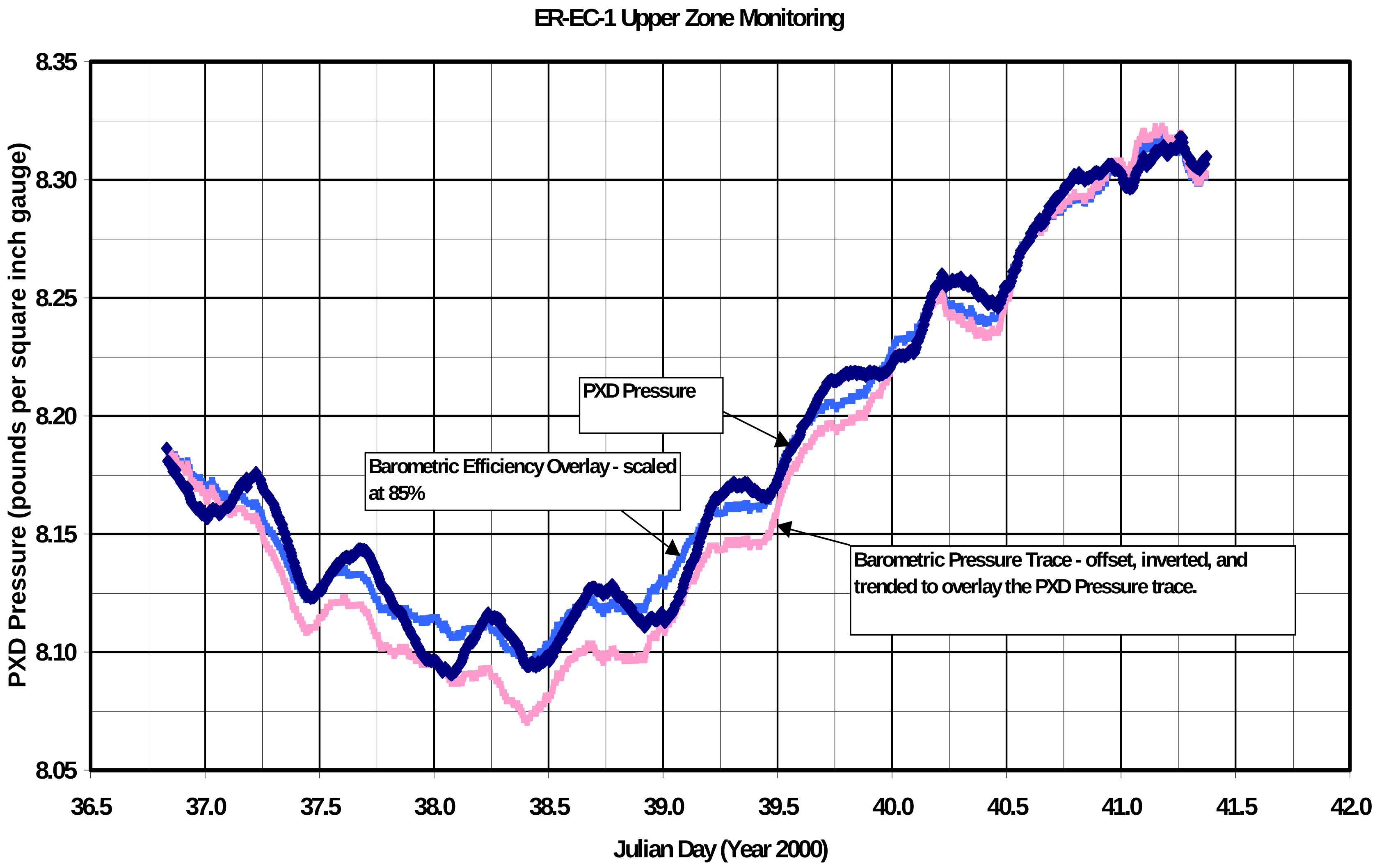


Figure 2-3
Upper Completion Interval Monitoring

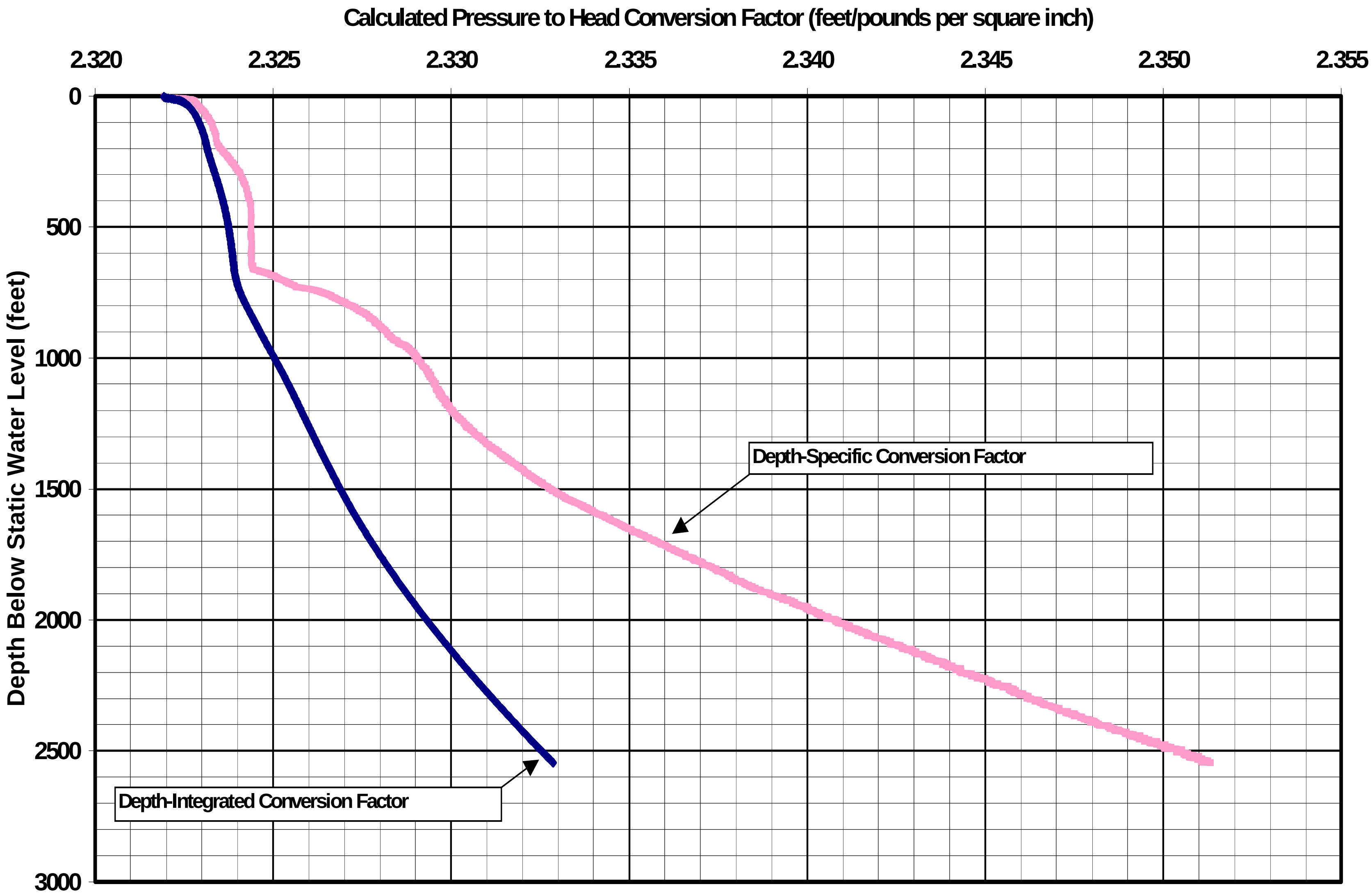


Figure 2-4
Temperature-Dependent Density Variation

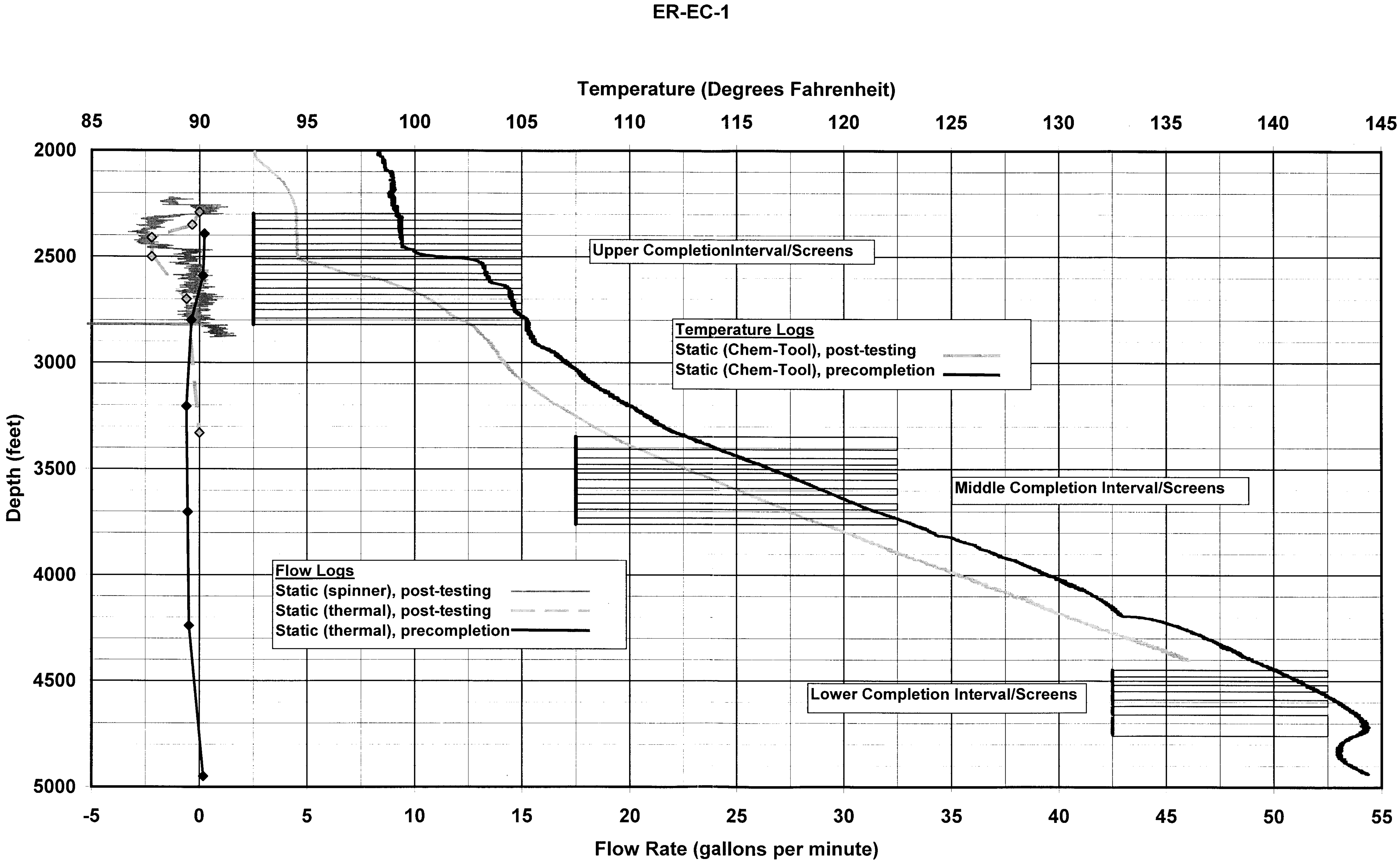


Figure 2-5
Nonpumping Temperature and Flow Logs

3.0 Pumping Well Hydraulics

The hydraulic testing of the well has been analyzed to provide both the transmissivity of the well and hydraulic conductivity of sections of the formation in the upper completion interval. The hydraulic conductivity analysis is based on the flow logging that was conducted during pumping and a detailed analysis of the well losses.

3.1 Measured Discrete Production

One of the significant features of the WPM-OV testing program was the flow logging during pumping to identify the source(s) and distribution of water production in the well. This information will be used in interpreting the well hydraulics and water chemistry. These wells penetrate deeply through a variety of different formations and lithologies and have multiple completions, often in very different materials. Hydraulic testing and composite sampling provides information that is not specific to the differences in completion intervals, and interpretation of the data must often assume that the results pertain in general to all of the completion intervals.

Flow logging in conjunction with the testing and sampling allows the interpretation to be made specific to the origin of the produced water and the specific response of each completion interval, or even part of a completion interval. For example, interpretations of historical hydraulic test data have used the full depth of the saturated section of the wells to assign hydraulic conductivity to the full extent of the formations penetrated in the wells. As discussed later in this section, the flowmeter results show that the producing formation was a fraction of the extent of the completion intervals. Consequently, the derived hydraulic conductivity is substantially greater than the traditional approach would have yielded. The groundwater chemistry analyses can also be assigned more specifically to the depth and formation from which the samples actually came.

Figure 3-1 presents a composite picture of temperature and flow logs for both the static situation and for pumping at 126 gallons per minute (gpm). The static situation was characterized at the end of testing prior to installation of the sampling pump. The pumping case was characterized at the end of development. The smoothest of the four flow logs run at the 126 gpm rate is presented (ec1mov02), but they all show very similar results. Figure 3-2, Figure 3-3, and Figure 3-4 show each of the completion intervals and an example of the flow log for each of the three pumping rates that were used. These figures include depth, lithology, hole diameter, and well construction. Flow log ec1mov01 is presented for 126 gpm, ec1mov06 for 104 gpm, and ec1mov09 for 64 gpm.

3.1.1 Temperature Logs

The difference in the temperature logs between the static and pumping case indicates several things about flow in the well. During pumping at 126 gpm, it appears that there is some flow from the lowermost completion interval to the middle completion interval. This is indicated by the slight rise in temperature uphole from the lowermost interval, and the return to the static temperature log above the middle interval. There does not appear to be any flow, or any change in flow between static and pumping condition in the lower part of the uppermost completion interval. However, the rise in the pumping temperature log in the fifth screen suggests some inflow and upward movement.

3.1.2 Impeller Flow Log Interpretation

During constant-rate pumping, the amount of flow in the well as a function of depth was recorded using a borehole flowmeter. The flowmeter is a spinner device provided by Desert Research Institute (DRI), and was used in both a trolling and stationary mode. A total of 11 logging runs were made at different logging speeds and different pumping rates. In addition, a series of stationary measurements were taken while the well was pumping and the meter held stationary. A listing of these different logging runs is presented in Table A.2-7 and Table A.2-8 of the data report in Appendix A.

The flow logs provide a measure of the water production as a function of depth. This information, along with an estimate of the drawdown in each interval, can be used to calculate the hydraulic conductivity of each segment. This section describes the analysis of the flowmeter measurements in preparation for calculation of interval-specific hydraulic conductivity in Section 3.5.4.

The flowmeter impeller spins in response to water moving through the meter. The rate of revolution is related to water velocity and flow via an equation which accounts for pipe diameter and the trolling speed of the flowmeter. The coefficients of the equation relating the impeller response to the discharge are determined via calibration. In theory, the meter could be calibrated in the laboratory using the same pipe as the well, and no further calibration would be necessary. In reality, the flowmeter response is influenced by a large number of factors specific to an individual well including temperature, pumping rate variation, hole condition, and sediment load. Therefore, it is advantageous to perform a calibration in the well to use for interpretation. For Well ER-EC-1, the calibration of the flowmeter response is determined using flowmeter data collected above the uppermost screen but below the crossover to the nominal 5.5-inch (in.) pipe. In this section of the well, the amount of water flowing upward to the pump should equal the discharge at the land surface. The flowmeter response is calibrated against the measured surface discharge to provide the necessary coefficients to calculate the discharge at any depth in the well as a function of impeller response and logging speed.

3.1.3 Calibration of the Borehole Flowmeter in the Well

The borehole flowmeter measures the velocity of water movement via an impeller that spins in response to water moving past it. Typically, the flowmeter is calibrated in the laboratory, under controlled conditions, to establish a calibration between the impeller response and discharge. The calibration is specific to a certain size pipe and may be different if flow is moving upward or downward through the meter. Hufschmeid (1983) observed significant differences between the meter response to upward and downward flow and established separate calibration equations for those two conditions. Rehfeldt et al. (1989) also observed different flowmeter responses to upward and downward flow, but the differences were not significant enough to warrant separate calibration equations. No data are available from laboratory calibration of the flowmeter used in this study documenting the meter response to flow in different directions. It is assumed that the meter response is similar enough in both directions to allow only one calibration equation to be used.

The borehole flowmeter was calibrated in the well to define a calibration equation specific to the well. This is necessary because the meter response may vary due to: (1) slight changes in the condition of the bearings that support the impeller; (2) differences in the physical characteristics of the fluid (density and viscosity) in the well that may vary due to temperature, dissolved gasses, or suspended solids content; (3) variations in the roughness or diameter of the well pipe; (4) slight variations in the position of the flowmeter relative to the center line of the well; and (5) variations in water flow in the well and the trolling speed of the flowmeter, which may vary among logging runs and affect the flowmeter response. To account for all these variations, the flowmeter is calibrated in the well. The calibration procedure and results are presented in this section.

3.1.3.1 Calibration Procedure

The flowmeter calibration procedure includes preparation of the calibration data and identification of the calibration equation and associated uncertainty.

The well is constructed with a 40-ft long blank section of pipe above the uppermost screen. The pump is located above the blank section; therefore, the flow rate in the upper blank section should be the same as the discharge from the well. For each of the pumping rate and line speed combinations, the flowmeter response is recorded at 0.2-ft intervals along the length of the well including the blank section above the uppermost screen. To avoid end effects, the data observed from a 30-ft interval centered between the ends of the blank section are used to determine the calibration.

Data Preparation

Preparation of the flowmeter calibration data includes the following steps:

- Import the data into a spreadsheet and sort by depth
- Adjust the flow log depths
- Identify the blank intervals
- Extract the data above the top screen for use in the calibration

The flowmeter data, provided in ASCII format as a function of depth, are imported to Excel™. Some of the logging runs are made top to bottom, while others are bottom to top. To maintain consistency, each file is sorted to portray the data from top to bottom.

Differences in depth-reporting equipment leads to errors in reported depths for the logging runs. Logging depths are corrected to match the official well construction diagrams. This is performed by differentiating the log profile to identify locations where flow rates change rapidly. Such changes correspond to changes in the internal diameter of the well such as at the crossover, or to the boundaries of inflow. For simplification purposes, it was assumed that boundaries of inflow are located at the ends of the screens, which may not be correct in every case. However, considering the analysis method used, the impact of this assumption on the results would be negligible.

The flowmeter depths recorded for Well ER-EC-1 were adjusted to ensure that the flowmeter response corresponded to the well construction log. The top and bottom of blank and screened intervals were identified in the flowmeter logs by plotting the rate of change of flow rate versus depth, and recording the locations where flow rate was changing. These depths were compared with the top and bottom of pipe sections in the construction log. Then the depth of the center of each section was calculated and compared between the two logs. The depth correction to match the flowmeter and construction logs was determined from the average difference in the center depth of blank and screened sections.

Figure 3-5 shows the flow log for ec1mov01 and the corresponding differential flow log from depths of 2,240 to 2,500 ft. This depth interval contains the blank casing above the first screen but below the crossover. As can be seen, the transition from the larger casing to the nominal 5.5-in. casing from a depth of 2,258 to 2,261.6 feet is clearly visible. Likewise, the transition from the blank casing to the first screen at a depth of 2,305.4 ft is also apparent. This process was performed for the top four blank sections and the first three screens for each logging run. The depth of the midpoint for each interval from the flow log was compared with the midpoint of the same interval from the construction diagram. The depth correction to match the flowmeter and construction logs was determined from the average differences in the center depth of blank and screened sections of the well. The calculated depth correction was +5.6 ft. This process ensures that the appropriate depth intervals of the flow log are analyzed.

Following depth correction, a 30-ft long section of the borehole flow log data (impeller revolutions per second, line speed, and surface discharge) in the blank section above the uppermost screen were extracted from each of the 11 borehole flowmeter logging runs and from the three logging runs where the flowmeter was held stationary in the blank section while the well was pumped (stationary runs 1, 4, and 9).

Calibration Equation and Uncertainty

Identification of the calibration equation and associated uncertainty includes the following analyses:

1. Multiple linear regression to determine an equation to relate meter response and line speed to measured discharge

2. Estimation of uncertainty using the calibration equation to determine a lower detection limit for the flowmeter

A calibration equation was derived from the data described above in two steps. The first step consisted of a multiple linear regression on the calibration dataset using the flowmeter response (revolutions/second [rev/sec]) as the dependent variable and the line speed (feet/minute [fpm]) and flow rate (gpm) as the independent variables. The second step consisted of expressing the flow rate as a function of the flowmeter response and the line speed by rearranging the equation used to regress the calibration data. The multiple linear regression approach in this work was chosen to provide a method by which the accuracy of the calibration could be quantified.

In this report, the equation used to regress the calibration data is of the form:

$$f = a + b_1 Q + b_2 L_s \tag{3-1}$$

where:

f = Impeller frequency of revolution (rev/sec)
Q = Flow rate (gpm)
L_s = Line speed (fpm)
a = Constant
b_1 and b_2 = Coefficients for the two independent variables

This equation is solved by multiple linear regression of the flow log calibration data. The use of equation (3-1) is advantageous in the multiple linear regression because Q and L_s are statistically independent, which is desirable in regression analysis.

The equation expressing flow rate as a function of flowmeter response and line speed is then derived by rearranging equation (3-1) as follows:

$$Q = c + d_1 f + d_2 L_s \tag{3-2}$$

where:

c = $-a/b_1$
d_1 = $1/b_1$
d_2 = $-b_2/b_1$

The primary advantage of the multiple regression approach is the ability to estimate the prediction error at any point in the response surface. For a given multiple regression on n data points where y is a variable that is dependent on k independent variables noted x_i for i=1 to k, the confidence interval for a specific predicted value of y given specific values of the x_i may be calculated using the following equation (Hayter, 1998):

$$(\hat{y}\big|_{x^*} - t_{\alpha/2,n\text{-}k\text{-}1}\,\text{s.e.}(\hat{y}\big|_{x^*} + \varepsilon),\ \hat{y}\big|_{x^*} + t_{\alpha/2,n\text{-}k\text{-}1}\,\text{s.e.}(\hat{y}\big|_{x^*} + \varepsilon)) \tag{3-3}$$

where the standard error, $\text{s.e.}(\hat{y}\big|_{x^*} + \varepsilon)$, for the case of a single predicted value is given by:

$$\text{s.e.}(\hat{y}\big|_{x^*} + \varepsilon) = \hat{\sigma}\sqrt{1 + x^{*\prime}(X'X)^{-1}x^*} \tag{3-4}$$

and

$\hat{\sigma}$ = Root mean sum of errors between the predicted and measured flow values

X = Matrix of entries that include the number of data points, sums of variables, sums of squared variables, and sums of cross terms

x^* = Vector of independent variables with specific values 1, x_1*, x_2* where the confidence interval is to be estimated

$t_{\alpha/2,n-k-1}$ = Students' t statistic at the α level of significance and n-k-1 degrees of freedom

n = Number of data points

k = Number of independent variables

The prediction of a specific value of y given specific values of the independent variables is more uncertain than the mean y calculated by the regression equation. The prediction uncertainty is a function of how well the regression equation fits the data (the root mean sum of errors), the distance of the specific independent variable values from their means, and the number of data points which influences the value of the t-statistic and the X matrix.

Although equation (3-2) is not solved directly by multiple linear regression, it may be used to calculate downhole flow rates (Q) for each pair of measured flowmeter response and line speed of the calibration dataset. The standard error associated with equation (3-2) may then be calculated using the corresponding root mean sum of errors. The confidence interval for each predicted downhole flow rate is then calculated using equation (3-3). The confidence interval is important because it may be used to represent the bounding error on a given flowmeter measurement.

3.1.3.2 Calibration Results

The calibration dataset derived from the eleven moving and three stationary flow logs consisted of more than 2,569 data points. Each data point consists of discrete measurements of line speed (fpm) and flow rates (gpm) (as discharge measurement recorded at the land surface), and a corresponding measurement of flowmeter response (rev/sec). Table 3-1 contains the values of the coefficients in equations (3-1) and (3-2), the regression model correlation coefficient, the sum of the squared errors, the number of observations, and the standard errors associated with the two equations.

In addition, Table 3-1 contains the 95 percent confidence intervals for specific sets of independent variable values that lead to predicted flow values near zero. The accuracy of the predictions near zero flow are of concern because certain screened sections of the well appear to produce little or no flow. The 95 percent confidence interval determined for specific pairs of flowmeter response and line speed that produced predicted discharge near zero provides an estimate of the measured discharge that is statistically indistinguishable from zero. No analysis for interval hydraulic conductivity was performed for measurements that are statistically indistinguishable from zero. As shown in Table 3-1, the 95 percent confidence interval is approximately 1.87 gpm. Measured flow rates less than 1.87 gpm are considered statistically indistinguishable from zero.

An argument against the flowmeter calibration approach described above is the concern that discharge measured at the land surface at a time, t, may not represent the instantaneous conditions recorded downhole by the flowmeter at that same time. To evaluate this source of uncertainty, a second approach could be used to derive a flowmeter calibration equation using the flow-logging data. In this method, the calibration dataset consists of values of the surface discharge, the line speed, and the flowmeter response averaged over the length of the blank section, or over time in the case of the stationary measurements. The averaged-data approach is conceptually appealing because it eliminates the assumption of a direct link between a downhole response and surface discharge at the same instant in time. However, this approach has a major drawback, it greatly reduces the number of data points.

The averaged-data approach was used for Well ER-EC-1 for comparison purposes. After averaging along the section of blank casing used for flowmeter calibration, the dataset was reduced to 14 sets of measurements, corresponding to the 11 moving logs and the three stationary logs. The coefficients derived from the reduced dataset were nearly identical to those derived from the full calibration dataset. The calculated flow rates using the coefficients from the two methods differed by less than 0.2 gpm over the entire range of values. The primary difference is that the confidence interval near the zero discharge prediction (which differs for various combinations of meter response and line speed) is narrower for the full dataset (1.87 gpm) than for the reduced dataset (2.60 gpm). This is primarily due to the greater number of data points in the full dataset. In fact, the root sum of squared error is smaller for the averaged data than for the full dataset. However, the confidence interval is more concave for the averaged data, and the

Table 3-1
Flowmeter Calibration Results Using all Data and Averaged Data Collected Above the Top Screen

Equations 3-1 and 3-2 Solutions		
	Equation 3-1	Equation 3-2
Constant	-0.0039	0.6878
First dependent variable	0.0057	176.5267
Second dependent variable	-0.0056	0.9835
Multiple R	0.9998	-
Sum of Squared Errors	0.0742	2313.4299
Standard Error	0.00538	0.9495
Number of Observations	2569	2569

95 Percent Confidence Interval for Flow Rates near Zero Based on Equation 3-2

Flow Logging Run	Impeller Rate (rev/sec)	Line Speed (fpm)	Confidence Interval[a] (gpm)
ec1mov01	0.12	-19.37	1.86
ec1mov02	-0.23	41.3	1.87
ec1mov03	0.33	-62.15	1.87
ec1mov04	-0.33	62.57	1.87
ec1mov05	-0.113	21.71	1.87
ec1mov06	0.23	-41.94	1.87
ec1mov07	-0.35	65.23	1.87
ec1mov08	-0.118	21.21	1.87
ec1mov09	0.23	-41.4	1.87
ec1mov10	-0.36	63.57	1.87
ec1mov11	0.1	20.05	1.86

Note: Impeller rate and line speed values were taken from the depth interval of 4,095 to 4,125 ft below ground surface, where flow rates into the well are near zero.

[a] Confidence interval is calculated using equation (3-3) and represents half of the full range of the uncertainty. This confidence interval was used to represent the error associated with low flow rate measurements.

combinations of independent variables that produce near zero discharge are not near the mean of observed values.

3.1.4 Calculation of Flow in the Well as a Function of Depth

Following calibration of the flowmeter, the flowmeter readings were converted to flow rates using the calibration equation (3-2) and the coefficients obtained using the full dataset (Table 3-1). The calibration equation based on the coefficients obtained using the full dataset was used because it produced a smaller 95 percent confidence interval at near-zero flow.

For each moving flow log, and each depth where a flowmeter response and line speed were recorded, the values were inserted into equation (3-2), with the coefficient values provided in Table 3-1, and the flow rate in the well at that depth was calculated. This generated the flow log values used for later analysis.

3.1.5 Resolution Effects of Discrete Screens

The physical arrangement of the screens in this well results in several limitations for resolving the origin of inflow from the aquifer. This well had alternating screens and blank casings in the completion intervals, and the slotting pattern (3-in. slots, 18 per row) for each screen starts 2.5 ft from the end of the casing joint. This construction restricts the location of inflow into the well casing. Since the filter pack is continuous throughout the completion interval, the drawdown is distributed in some manner throughout the filter pack and stresses the aquifer behind the blank casing. This creates more complex flow conditions into the completion intervals than would a continuous screen. There is no good way of determining the extent to which the formation behind the blank casing is contributing. Some qualitative interpretation may be attempted on the flow logs to evaluate the increase in production at the edges of each screen and attribute some of that production to vertical flow from behind the blank casing, but this is speculative. The hydraulics of vertical flow in the filter pack and end effects for the screens are undefined. The main impact of this uncertainty is in determining the appropriate thickness of aquifer to use in calculations of hydraulic conductivity.

3.2 Well Losses

The drawdown observed in the well is comprised of aquifer drawdown and well losses resulting from the flow of water into the well and up to the pump. Aquifer drawdown can be observed directly in observation wells near a pumping well, but such wells were not available near Well ER-EC-1. The step-drawdown test analysis was used to determine the laminar and turbulent losses, and the laminar losses were attributed to aquifer drawdown. Flow losses inside the well were calculated independently, and subtracted from the turbulent losses to evaluate flow losses into the well. This breakdown of the total drawdown into its components provides better understanding of the hydraulics of water production and better estimates of aquifer properties. While there are some uncertainties in the accurate determination of the components of the drawdown, the calculated component values are better estimates of the actual values than the gross drawdown. This analysis provides more accurate results and reveals details of the hydraulics of production.

3.2.1 Step-Drawdown Test

The final step-drawdown test conducted prior to flow logging, on Julian Day 7, was analyzed according to the method of Jacob (Driscoll, 1986) using the Hantush-Bierschenk methodology (Kruseman and de Ridder, 1990). The assumptions and conditions for applying this analysis are: (1) the aquifer is confined, seemingly infinite in extent, homogeneous, isotropic, and of uniform thickness;(2) the initial piezometric surface is horizontal; (3) the well is fully penetrating, and the well receives water through horizontal flow; (4) the well is pumped step-wise at increasing rates; (5) flow to the well is unsteady; and (6) non-linear well losses are appreciable and vary according to Q^2. While the assumptions and conditions about the aquifer and flow in the aquifer are not perfectly satisfied, it is believed that they were sufficiently satisfied during the step-drawdown test to provide a reasonable result. The test was conducted according to the required protocol.

Table 3-2 shows the basic data derived from the step-drawdown test, and Figure 3-6 shows the resultant graph of the data with the equation for the trendline. The equation of the trendline substitutes in the equation for head loss, $s_w = BQ_n + CQ_n^2$ where s_w is the total drawdown in the well, Q_n is the net production rate, B is the linear loss coefficient (trendline constant), and C is the nonlinear loss coefficient (trendline coefficient of x). The linear component of the loss is generally considered to be laminar losses in the aquifer. The turbulent component of the head loss is generally considered to be well losses, which can include flow losses from the aquifer into the wellbore (skin losses), losses in the filter pack and through the screen slots, and flow losses up the casing to the pump. This division of losses will be examined in the next section. The linear and turbulent components of the drawdown for the three flow-logging pumping rates are tabulated in Table 3-2.

Table 3-2
Step-Drawdown Results and Application

Duration Days	Ave Pumping Rate - Q (gallons per minute)	Drawdown s_w (feet)	s_w/Q	Flow Logging Pumping Rate (gallons per minute)	Predicted s_w (feet)	Laminar Losses (feet)	Turbulent Losses (feet)
0.0833	63.08	0.933	0.015	64.73	0.95	0.57	0.38
0.0833	101.63	1.866	0.018	103.58	1.89	0.92	0.97
0.0833	124.73	2.566	0.021	125.95	2.55	1.12	1.43

3.2.2 Evaluation of Components of Head Losses

The components of head loss during production were evaluated separately to correlate them with the distinction of linear and non-linear losses from the step-drawdown test analysis. Evaluation of Reynolds numbers for the various conditions of flow in the well found that most of the flow in the casing had Reynolds numbers indicating turbulent flow, and associated losses would comprise part of the non-linear losses. However, the flow through the filter pack and screens had Reynolds numbers indicating laminar flow, and the associated losses would be included in the linear losses. The head loss for turbulent flow inside the well casing was calculated and found to be substantially less than the non-linear losses determined from the step-drawdown test analysis. The remainder of the turbulent losses may be the result of turbulent flow in the fractures supplying water to the well. Losses through the screen and filter pack were not specifically quantified, but were estimated to be small compared to the total linear losses.

Flow losses inside the well casing were computed based on standard theory of flow in a pipe using the Darcy-Weisbach equation. The slotted sections were assigned friction factors double those of blank pipe (Roscoe Moss Company, [p.225] 1990). Table 3-3 presents a tabulated profile of friction losses showing the cumulative loss at various locations down the well from the pump intake. The flow rates attributed to each screen section of the well were the average of the inflows from the flow logs that were conducted at each pumping rate. The analysis was only taken to the bottom of the 5th screen of the upper completion interval because the analysis of the flow logging indicated that the apparent flow from below that point was in the range of the uncertainty. The flow rates at each point of tabulation for the well screens should have been fairly stable since the well had been pumping for some time and the drawdown did not change substantially during the period of logging. For the best applicability of flow logging data, flow logging should take place only after sufficient continuous pumping at each rate to achieve relatively stable drawdown.

For all three flow logging pumping rates, the calculated turbulent losses for flow in the well casing were less than the turbulent losses calculated in Table 3-2. The remainder of the turbulent losses were apportioned to the screens according to the square of the velocity of the flow through the screen. It is recognized that this approach to determining total well losses is not perfectly accurate, but it is believed to provide a reasonable estimate of the well losses. The results are used to estimate the aquifer drawdown, and this drawdown value is used to calculate hydraulic conductivity for each of the screens. This was particularly significant for this well because the turbulent well losses are a large fraction of the total drawdown.

3.3 Head Distribution Under Pumping

The column in Table 3-3 labeled Cumulative Friction Loss Inside Casing tabulates the loss of head down the well casing due to flow up the casing. These values can be subtracted from the total measured drawdown to calculate the head at each

Table 3-3
Calculated Flow Losses

Location in Well	Flow at Location (gpm)			Cumulative Friction Loss Inside Casing (ft)			Additional Flow Losses Per Screen (ft)			Total Flow Losses at Center of Screen (ft)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Pump Intake	64.71	103.59	125.97									
Bottom of Pump Motor	64.71	103.59	125.97	0.079	0.181	0.256						
Btm of 7 5/8-in Casing - Top of Crossover	64.71	103.59	125.97	0.121	0.279	0.395						
Crossover	64.71	103.59	125.97	0.156	0.359	0.508						
Top of Screen 1	64.71	103.59	125.97	0.160	0.369	0.522	0.11	0.31	0.49	0.29	0.72	1.06
Bottom of Screen 1	31.50	51.64	62.57	0.191	0.441	0.624						
Top of Screen 2	31.50	51.64	62.57	0.200	0.464	0.657	0.01	0.02	0.03	0.21	0.50	0.71
Bottom of Screen 2	23.12	37.97	46.35	0.212	0.492	0.695						
Top of Screen 3	23.12	37.97	46.35	0.217	0.505	0.715	0.04	0.11	0.18	0.26	0.62	0.90
Bottom of Screen 3	4.07	6.56	7.80	0.221	0.513	0.726						
Top of Screen 4	4.07	6.56	7.80	0.221	0.514	0.727	0.00	0.00	0.00	0.22	0.52	0.73
Bottom of Screen 4	1.53	2.33	2.33	0.221	0.514	0.727						
Top of Screen 5	1.53	2.33	2.33	0.221	0.514	0.727	0.00	0.00	0.00	0.22	0.51	0.73
Bottom of Screen 5	0.79	1.17	1.22	0.221	0.514	0.727						

Blank = Not applicable

tabulation point down the casing. For example, during the last flow log run at 126 gpm (Step 3), the drawdown in the well would have been approximately 3.2 ft. This estimate is based on the time since pumping started and the drawdown curve recorded for the constant-rate test run at a similar pumping rate. During flow logging, the PXD was removed to allow access downhole, and drawdown could not be measured directly. At this time, the drawdown in the casing at the top of the first screen would have been about 2.7 ft, and the drawdown at the bottom of the fifth screen would have been about 2.4 ft. The column labeled Total Flow Losses at Center of Screen provides the total calculated flow loss from the aquifer into the casing and up to the intake. Subtracting this value from the total drawdown gives the aquifer drawdown at the center of each screen. The average flow losses across the first screen would have been about 1.06 ft and the flow losses into the casing for the first screen would have been about 0.49 ft, resulting in aquifer drawdown of about 1.49 ft opposite the first screen.

The purpose of these computations is to estimate the actual aquifer drawdown at each pumping rate for each screen. The flow loss values will be used in the flow logging analysis to calculate the hydraulic conductivity attributed to the production from each screen.

3.4 Constant-Rate Test Analysis

The constant-rate test provided data for determining the overall transmissivity of the well. Figure 3-7 shows a graph of the constant-rate drawdown data, and Figure 3-8 shows the recovery data. The drawdown data has a wide band of noise, but the data describes a typical drawdown curve. The noise is thought to be related to problems with the pump that resulted in turbulence or acoustic noise in the well. The constant-rate test was analyzed using the AQTESOLV^{R} program (HydroSOLVE, Inc., 2002). The fitting routine in this software performs a least squares fit that produces a best fit solution (type curve), which simulates the form embedded in the noise.

3.4.1 Single-Porosity Model

The Papadopulos-Cooper model was used to analyze the drawdown response. This model fits a Theis confined model to the data and accounts for casing storage. Casing storage is a significant factor in the early-time drawdown of wells with large diameter casing, often determining an initial stage of drawdown behavior. However, for this well, the magnitude of the drawdown was small and casing storage would only have affected the very early time, up to 0.0003 days. The assumptions and conditions for applying this model are the same as those stated for the Hantush-Biershank analysis in Section 3.2.1, with the addition that water is released from storage instantaneously. Figure 3-9 shows the drawdown data with a linear time scale to show how the model fits the data. The result is a transmissivity (T) of 5,740.9 ft^2/day. This model yields a T value independent of the aquifer thickness. An average K of 19.83 ft/day was determined by dividing by the tested formation thickness (289.5 ft). The type curve appears to fit the late-time data fairly well, but does not simulate the early-time well. The period affected by casing storage for this well is very short and does not affect the fit.

3.4.2 Dual-Porosity Model

The Moench model for dual porosity (1984 [HydroSOLVE, Inc., 1996-2002]) in a fractured aquifer was also used to simulate the aquifer response. This model is consistent with the known geology, and produces an equivalent or better solution fit. The assumptions and conditions for this model are the same as the Papadopulos-Cooper model, with the addition that the aquifer is fractured and acts as a dual-porosity system consisting of low conductivity primary porosity blocks and high conductivity secondary porosity fractures. This assumption is believed to be appropriate based on characterization of the formation during drilling.

This model has many parameters that interact and can produce a variety of solutions, especially without observation well data. In order to determine the most appropriate solution with respect to K (fracture hydraulic conductivity), values for K’ (matrix hydraulic conductivity) and Ss and Ss’ (fracture and matrix-specific storage) were constrained as much as possible. Ranges of possible values for those parameters were determined based upon typical properties for the rock type. Specific storage values were based on typical porosity and compressibility values.

Figure 3-10 shows the type curve for a dual-porosity solution and the resultant parameter values using the extent of the filter pack for the producing section of the upper completion interval for aquifer thickness. The K value was set to 19.83 ft/day, the same as the Papadopulos-Cooper solution. The Ss value had to be allowed much higher than the constraint for the solution to match the slope of the drawdown similar to the Papadopulos-Cooper model, yielding a similar value for the storage coefficient. Figure 3-11 shows the dual-porosity model with the Ss’ value also allowed higher than the constraint, and results in a better fit of the model to the data in the early-time, yielding a lower K value of 16.5 ft/day. Figure 3-12 shows a solution using the combined length of the producing screens (101 ft) rather than of the filter pack for the aquifer thickness. This solution is identical to the first solution, and the resultant K from this analysis is 56.84 ft/day, yielding a T of 5,740.8 ft^2/d.

It is difficult to justify such high values for the specific storage parameters; however, the specific storage values interact inversely with the well radius Rw. The Rw (borehole radius) that was used is 0.6 ft, which is slightly larger than the nominal hole diameter of 0.51 ft (12.25 in bit) based on visual examination of a caliper log. The effective radius of the well may have been substantially larger yet for a variety of reasons. It may be useful to correlate the caliper log to the flow logs and determine a more specific value for Rw for the most productive intervals in the well. However, it appears from the flow logs that much of the flow comes from fractures, and the caliper log probably does not provide adequate information to determine an appropriate Rw for this situation. This problem highlights a limitation of analysis of single-well tests, which apply the drawdown at the Rw of the well. The storage parameters in the models are very sensitive to the value, and there is a lot of uncertainty in specifying an appropriate value.

The difference in these two values for aquifer thickness represents the uncertainty in the length of formation-producing water. Evaluation of the flow logs does not indicate whether production is occurring behind the blank casing in the completion intervals. All production from the formation must enter the well through the slots in the casing, and the flow logging can only quantify the changes in flow along the slotted sections. Any production coming vertically through the filter pack behind the blank casing would enter the well at the ends of the slotted sections, but there has not been any attempt to characterize those portions of the flow. The difference in the fracture hydraulic conductivities derived using the two different aquifer thicknesses will be used later in an analysis of the uncertainty in the derived hydraulic conductivities.

3.5 Interval Transmissivities/Conductivities

The flowmeter data provides a detailed assessment of the sections of the completion intervals producing water for determining the average hydraulic conductivity. In addition, the flowmeter data provide measurements to attribute varying production to the different screened sections. These data provide the basis for determining differences in hydraulic conductivity across different sections of the producing interval. This analysis will be used later in modeling groundwater flow in the corresponding aquifer.

3.5.1 The Borehole Flowmeter Method - Concept and Governing Equations

The borehole flowmeter measures the flow rate inside a well as a function of depth. When measurements are taken during pumping of the well, valuable information is obtained for interpreting the amount of water production coming from each screened interval of the geologic formation being tested. The basic concept and theory for interpreting borehole flowmeter logs is presented in Molz et al. (1989). Their work is based primarily on the previous work of Hufschmeid (1983) and Rehfeldt et al. (1989), who present detailed descriptions of the theory and application of the method.

Conceptually, as a well is pumped, water enters the well along the screen length, and the amount of water flowing inside the well at any depth is a function of the water that has entered the well. In the typical case of a pump located above the well screen, the amount of water flowing in the well will vary from zero at the bottom of the well to the well production rate (Q) above the screened interval. The change in flow rate between any two depths in the well is the amount of water that has been produced from that interval of the well. If certain assumptions are made, this water production profile can be used to estimate the hydraulic conductivity of the aquifer as a function of depth.

After a period of time following the start of pumping, the flow to the well is assumed to be horizontal. Javandel and Witherspoon (1969) used a finite-element model to show that flow to a fully screened well in a confined, layered aquifer eventually became horizontal and that the drawdown in each layer eventually follows the Theis solution. The work of Javandel and Witherspoon (1969) assumes a constant head boundary condition at the well which ignores the effects of head losses in the well, the screen, and the filter pack. Nonetheless, the assumption of horizontal flow is necessary to derive an analytical solution to calculate depth-dependent hydraulic conductivity from the flow in the well.

For each vertical interval in the well, the Cooper and Jacob (1946) equation is assumed to govern the relationship between flow into the well and the aquifer parameters such that:

$$T_i = \frac{Q_i}{4\pi s_i} 1n\left[\frac{2.25 K_i b_i t}{r_w^2 S_i}\right] \tag{3-5}$$

where:

K_i = Hydraulic conductivity of the interval
b_i = Thickness of the interval
T_i = Transmissivity of the interval and is defined by the product $K_i{*}b_i$
s_i = Drawdown in the aquifer for the interval
Q_i = Amount of flow from the interval into the well as determined from the flowmeter measurements
S_i = Storage coefficient for the interval
t = Time since pumping started
r_w = Effective radius of the well

In this form, the equation is difficult to use because the layer storage coefficient is unknown. Kabala (1994) proposed a double flowmeter method to simultaneously estimate K_i and S_i, but later (Ruud and Kabala, 1996) suggested the double flowmeter method produces inaccurate storage values and should not be used. Hufschmeid (1983) and Rehfeldt et al. (1989) assumed that the layer storage coefficient could be defined as a portion of the full storage coefficient, weighted by the transmissivity of each layer.

$$S_i = S\frac{K_i b_i}{Kb} \tag{3-6}$$

where:

S = Storage coefficient of the entire aquifer
K = Average hydraulic conductivity of the aquifer
b = Total aquifer thickness

This assumption amounts to a statement that the hydraulic diffusivity (T/S) of the aquifer is constant with depth. Substituting equation (3-6) into equation (3-5) leads to the equation for calculating the interval transmissivity as presented in Hufschmeid (1983) and Rehfeldt et al. (1989):

$$T_i = \frac{Q_i}{4\pi s_i} \ln\left[\frac{2.25Kbt}{r_w^2 S}\right]$$

(3-7)

The terms within the natural logarithm of equation (3-7) are determined from the full well response and are not dependent on interval-specific values. Molz and Young (1993), Kabala (1994), and Ruud and Kabala (1996) question the constant hydraulic diffusivity assumption and suggest it is a source of significant interpretation errors. Molz et al. (1989) and Molz and Young (1993) suggest that one alternative approach is to simply rely on the work of Javandel and Witherspoon (1969), and define the interval transmissivity as a simple ratio of the interval flow such that:

$$K_i b_i = \frac{Q_i}{Q} Kb$$

(3-8)

Molz and Young (1993) and Molz et al. (1989) fail to recognize that equation (3-8) can be obtained by dividing equation (3-7) by the Cooper-Jacob equation for the full aquifer thickness if one assumes, as did Javandel and Witherspoon (1969), that the drawdown in the well (s) is the same as the layer drawdown, (s_i). Therefore, equation (3-8) is merely a special case of equation (3-7) where the well losses are assumed to be zero. Molz et al. (1989) and Molz and Young (1993) provide a second alternative approach based on the assumption that the specific storage is constant in the aquifer such that:

$$S_i = S\frac{b_i}{b}$$

(3-9)

Substituting equation (3-9) into equation (3-5) leads to an equation for the interval transmissivity of the form:

$$T_i = \frac{Q_i}{4\pi s_i} \ln\left[\frac{2.25K_i bt}{r_w^2 S}\right]$$

(3-10)

The only difference between equations (3-7) and (3-10) is the replacement of K with K_i within the logarithmic term. It is not clear which, if either, storage assumption is correct. To account for uncertainty, hydraulic conductivities were calculated for each storage assumption using equation (3-8) [a special case of equation (3-7) and equation (3-10)].

3.5.2 Calculation Process to Determine Interval Hydraulic Conductivity Values

The steps for calculating the hydraulic conductivity of selected intervals in the well are presented in this section. The process begins with the determination of the average discharge for each screened section of well and ends with the calculation of the interval hydraulic conductivity. The steps are:

1. Selection of specific intervals in the well for which interval hydraulic conductivity is to be calculated

2. Calculation of the interval hydraulic conductivity, which is comprised of three main steps: (1) determine the average discharge for each blank section of well, then determine the total flow contributed by each section of well as the difference of flow in the blank sections above and below; (2) calculate the transmissivity of each screened section using the flowmeter derived flow and the drawdown in each section, corrected for well losses; and (3) determine the uncertainty in hydraulic conductivity values for each screen section resulting from uncertainty in drawdown and contributing thickness.

3.5.3 Selection of Depth Intervals to Calculate Hydraulic Conductivity

To determine the hydraulic conductivity of an interval, the interval must be defined by top and bottom depths so inflow to the well can be determined. Previous applications of the flowmeter method (Rehfeldt et al., 1989; Hufschmeid, 1983; and Molz et al., 1989) calculated hydraulic conductivity at small intervals within fully screened wells in unconfined aquifers. One criterion to determine the size of the interval is to assess the minimum interval necessary to ensure that a statistically significant amount of flow enters the well between one flowmeter measurement and the next. The confidence intervals determined from equation (3-2) suggest that the difference in discharge should be about 3 gpm to be statistically significant. A criterion such as this would produce a variable interval depending on inflow that might be as small as 0.2 ft or as large as 10 ft or more.

In partially penetrating wells, or irregularly screened wells such as ER-EC-1, the horizontal flow assumption may not hold. Cassiani and Kabala (1998) examined flow to a partially penetrating well in an anisotropic confined aquifer where wellbore storage and infinitesimal skin may be present. They showed that, in their example, the flux near the end of the well screen could be exaggerated more than several times compared with elsewhere along the screen. Previous work by Ruud and Kabala (1996, 1997b) also showed that the flux to partially penetrating wells in heterogeneous aquifers can be significantly nonuniform and is a function of the hydraulic conductivity contrast of the adjacent layers. Ruud and Kabala (1997a) also examined the flow to a well in a layered aquifer with a finite skin zone. For their examples, they showed that the horizontal flow assumption inherent in the flowmeter analysis was violated and led to incorrect estimates of interval hydraulic conductivity values. The errors associated with violation of the horizontal flow assumption increase as the layer size decreases (i.e., the smaller the measurement interval). Another factor that may lead to errors is the head loss associated with flow through the borehole flowmeter itself. Ruud et al. (1999) show that head loss caused by the flowmeter can force water to flow in the filter pack outside the well and can lead to errors in measured flow.

For the WPM-OV wells where alternating screen and blank sections are present, the errors in estimated K values may be substantial if the analysis interval is too small. To avoid the need to quantify the potential errors as noted above, the decision was made to interpret the flowmeter response for each screened interval that produced statistically measurable flow. Each screened interval is composed of a 30-ft section of pipe with slots beginning about 2.5 ft from both ends. Therefore, the length of each screened interval is about 25 ft long. Hydraulic conductivity values averaged over 25-ft intervals is expected to be adequate vertical resolution for the CAU-scale and sub CAU-scale models.

3.5.4 Calculation of Hydraulic Conductivity of Each Interval

The transmissivity of each interval is calculated using equations (3-8) and (3-10) prior to determining the hydraulic conductivity. The data requirements and the procedure are described.

3.5.4.1 Data Requirements

For a given pumping rate (Q), Equations (3-8) and (3-10) require a number of parameters to calculate interval transmissivities. These parameters include the following:

- Interval flow rates (Q_i)
- Term $r_w^2 S$.
- Drawdowns (s_w and s_i) at selected times (t)
- Formation transmissivity
- Interval transmissive thicknesses (b_i)

Descriptions of each of these parameters are provided in the following text.

Interval Flow Rates **(*Q_i*)**

The inflow to the well from each screen can be determined from the flow in the well measured in the blank sections of pipe above and below each screen. Within the blank sections of pipe between the screens, the average discharge was determined for a 30-ft interval centered between the ends of the blank section. The average discharge values through the blank casing sections are provided in Table 3-4 for blanks numbered one through eight. The average discharge through

Table 3-4
Average Flow Rates Through the Blank-Casing Sections in gpm During the Flow Logging Runs

Pumping Rate = 126 gpm

Logging Run Blank Number	ec1mov01	ec1mov02	ec1mov03	ec1mov04	Average
1	125.19	126.75	125.46	126.48	125.97
2	63.31	62.82	61.27	62.86	62.57
3	45.83	47.29	44.85	47.42	46.35
4	8.84	7.92	7.26	7.21	7.80
5	3.45	2.46	1.62	1.80	2.33
6	2.22	1.46	0.54	0.65	1.22
7	1.83	1.04	0.11	0.19	0.79
8	5.25	0.88	0.12	-0.29	1.49

Pumping Rate = 104 gpm

Logging Run Blank Number	ec1mov05	ec1mov06	ec1mov07		Average
1	103.48	103.81	103.47		103.59
2	52.30	50.52	52.14		51.65
3	38.52	37.58	37.81		37.97
4	6.87	7.77	5.04		6.56
5	2.31	3.72	0.96		2.33
6	1.16	2.51	-0.16		1.17
7	0.77	2.12	-0.62		0.76
8	0.33	1.94	-1.02		0.42

Pumping Rate = 65 gpm

Logging Run Blank Number	ec1mov08	ec1mov09	ec1mov10		Average
1	64.77	65.70	63.65		64.71
2	32.18	31.72	30.60		31.50
3	22.39	24.15	22.83		23.12
4	4.15	5.66	2.42		4.07
5	1.43	3.10	0.07		1.53
6	0.57	2.49	-0.68		0.79
7	0.28	2.68	-1.15		0.60
8	0.12	1.95	-1.40		0.22

the screened intervals are provided in Table 3-5 for the screens numbered one through seven, beginning with the uppermost intervals. As seen in Table 3-4, the 5th blank is the lowermost blank for which discharge values are consistently statistically different from zero. For the smallest discharge (logging runs 8, 9, and 10), the flow in the 5th blank was not distinguishable from zero. The 95 percent confidence interval of predicted discharge near zero is used to define the intervals for which hydraulic conductivity will be estimated. The 95 percent confidence interval is about 1.87 gpm; therefore, hydraulic conductivity will be determined for the four uppermost screens (Table 3-5). These four screens produce greater than 98 percent of the total flow to the well. If the well could have been pumped at a higher rate, the inflow to the well from lower screens would have been measurable and additional hydraulic conductivity values could have been determined.

The Term $r_w^2 S$.

The product $r_w^2 S$ is required in equation (3-10) and may be estimated using the Cooper-Jacob equation and data from the constant-rate test.

The Cooper-Jacob (1946) equation for flow to a well can be rearranged to produce:

$$\frac{1}{r_w^2 S} = \frac{1}{2.25Tt} \exp\left[\frac{4\pi s T}{Q}\right] \tag{3-11}$$

where:

Q = Discharge from the well
T = Transmissivity
s = Drawdown in the aquifer at the effective radius of the well
S = Storage coefficient
t = Time the drawdown was measured

Using equation (3-11) and known values of Q and T, it is possible to determine an approximate value of the product $r_w^2 S$ for any given time t.

Formation and Interval Drawdowns (s and s_i)

The formation drawdown is the drawdown observed at a given time t since pumping began at a given pumping rate Q, adjusted for well flow losses. Well flow losses were calculated using an average of the “Total Flow Losses at Center of Screen” presented in Table 3-3, weighted by the intervals’ flow rates (Table 3-6). These weighted average well flow losses were subtracted from the total drawdown to obtain an estimate of the formation drawdown for each pumping rate.

Table 3-5
Average Flow Rates Through the Screened Sections in gpm During the Flow Logging Runs of Well ER-EC-1

Pumping Rate = 126 gpm					
Logging Run Screen Number	**ec1mov01**	**ec1mov02**	**ec1mov03**	**ec1mov04**	**Average**
1	61.87	63.93	64.19	63.62	63.40
2	17.49	15.53	16.42	15.45	16.22
3	36.99	39.37	37.59	40.21	38.54
4	5.39	5.45	5.64	5.41	5.47
5	1.23	1.00	1.08	1.15	1.11
6	0.39	0.42	0.43	0.46	0.42
7	-3.42	0.16	-0.01	0.49	-0.70
Pumping Rate = 104 gpm					
Logging Run Screen Number	**ec1mov05**	**ec1mov06**	**ec1mov07**		**Average**
1	51.18	53.29	51.33		51.93
2	13.78	12.94	14.33		13.69
3	31.65	29.81	32.77		31.41
4	4.56	4.05	4.08		4.23
5	1.15	1.21	1.12		1.16
6	0.39	0.39	0.46		0.41
7	0.44	0.19	0.41		0.34
Pumping Rate = 65 gpm					
Logging Run Screen Number	**ec1mov08**	**ec1mov09**	**ec1mov10**		**Average**
1	32.58	33.98	33.05		33.21
2	9.80	7.57	7.77		8.38
3	18.24	18.49	20.42		19.05
4	2.72	2.56	2.34		2.54
5	0.86	0.60	0.75		0.74
6	0.29	-0.18	0.47		0.19
7	0.16	0.73	0.25		0.38

Table 3-6
Calculation of Average Well Losses for Each Pumping Rate

Screen	(1) Flow Rate into Well (gpm)	(2) Total Flow Losses at Center of Screen (ft)	(1) X (2)
Q=126 gpm			
Screen 1	63.33	1.06	67.13169
Screen 2	16.48	0.71	11.70071
Screen 3	37.98	0.9	34.18568
Screen 4	5.49	0.73	4.010431
Screen 5	1.10	0.73	0.806448
Total Flow	124.39		
Weighted Average Flow Loss in the Well =		0.947 ft	
Q=104 gpm			
Screen 1	52.23	0.72	37.60885
Screen 2	13.36	0.5	6.681194
Screen 3	30.73	0.62	19.05323
Screen 4	4.31	0.52	2.239701
Screen 5	1.18	0.51	0.600005
Total Flow	101.81		
Weighted Average Flow Loss in the Well =		0.650 ft	
Q= 64 gpm			
Screen 1	33.28	0.29	9.651828
Screen 2	8.68	0.21	1.823562
Screen 3	18.36	0.26	4.774326
Screen 4	2.64	0.22	0.580914
Screen 5	0.73	0.22	0.161463
Total Flow	63.70		
Weighted Average Flow Loss in the Well =		0.267 ft	

To capture the range of uncertainty associated with drawdowns during the flow logging, two sets of time-drawdown pairs were used. The drawdowns in the well corresponding to a pumping rate of 126 gpm were obtained from the time-drawdown data recorded during the constant-rate test. Drawdowns in the well for the other two pumping rates were estimated using the Cooper-Jacob (1946) equation applied to the whole well. The well transmissivity value derived from the constant-rate test was used in these calculations. The drawdown in the well was calculated for 0.08 and 1.95 days. This period corresponds to the approximate time during which the flow logging was conducted. The formation drawdown was calculated by substrating the weighted average flow loss in the well (shown in Table 3-6) from the well drawdown values described above.

The individual screen's formation drawdown (s_i) at the effective radius of the well are calculated as the drawdown in the well corrected for friction, entrance, and skin losses. These losses have been estimated previously and were presented in Table 3-3 and Table 3-6 as "Total Flow Losses at Center of Screen."

Transmissivity of the Formation

The transmissivity of the formation is the well transmissivity as calculated from the constant-rate test adjusted for well flow losses. An estimate of the formation transmissivity was then derived by multiplying the transmissivity derived from the constant-rate pumping test (Q=126 gpm) by the ratio of the formation drawdown to the well drawdown at t =1.95 days. The well drawdown at 1.95 days is 3.53 ft. As shown in Table 3-6, the average well flow losses at 126 gpm are equal to 0.947 ft. The estimated formation losses are, therefore, equal to 2.58 ft. As a result, the ratio of the formation drawdown to the well drawdown is equal to 0.73. As reported earlier, the transmissivity derived from the constant-rate pumping test is equal to 5740.8 ft^2/d. The derived estimate of formation transmissivity is 7,864 ft^2/d.

Individual Interval's Transmissive Thickness (b_i)

The interval thickness is not precisely known because flow to the screen may be derived, in part, from behind the blank section of pipe above or below the screen. The minimum contributing thickness is assumed to be the length of screen (about 25 ft), and the maximum is assumed to extend above and below the screen to the mid points of the adjacent blank sections for a thickness of as much as 78 ft.

3.5.4.2 Procedure and Results

For equation (3-10), the interval transmissivity is determined using an iterative approach. Equation (3-10) is solved iteratively by estimating K_i, then solving for T_i, dividing by b_i, and then substituting back into the equation. After 10 to 18 iterations, a value of T_i is determined. The Term $r_w^2 S$ is calculated using the formation transmissivity and a pair of known time-drawdown pair. The hydraulic conductivity of each interval is the interval transmissivity from equations (3-8) and (3-10) divided by the interval thickness.

The interval hydraulic conductivities from equations (3-8) and (3-10) are given in Table 3-7 for each of the logging runs and each of the cases considered. For every case considered, the sum of the individual interval transmissivities represent at least 95% of the transmissivity of the formation (well transmissivity derived from the constant-rate test adjusted for flow losses). The amount of transmissivity that is unaccounted for in the calculations is due to well intervals that produced flow rates below the detection level of 1.87 gpm.

Table 3-7
Interval Hydraulic Conductivities Calculated From Flow Logging Data for Well ER-EC-1

Logging Run	Screen	Interval Thickness = Length of Screen				Interval Thickness = Length of Filter Pack			
		Interval Thickness (ft)	Hydraulic Conductivity (ft/d)			Interval Thickness (ft)	Hydraulic Conductivity (ft/d)		
			(Equation 3-10)		(Equation 3-8)		(Equation 3-10)		(Equation 3-8)
			$s_{t=0.08\ d}$[a]	$s_{t=1.95\ d}$[b]	-		$s_{t=0.08\ d}$	$s_{t=1.95\ d}$	-
ec1mov1	Screen 1	25.40	186.70	169.83	151.22	78.32	60.55	55.08	49.05
ec1mov2	Screen 1	25.40	193.97	176.04	156.26	78.32	62.91	57.09	50.68
ec1mov3	Screen 1	25.40	194.79	176.74	156.81	78.32	63.17	57.32	50.86
ec1mov4	Screen 1	25.40	192.73	174.98	155.39	78.32	62.50	56.75	50.40
ec1mov5	Screen 1	25.40	183.92	169.13	152.41	78.32	59.65	54.85	49.43
ec1mov6	Screen 1	25.40	193.36	177.32	159.16	78.32	62.71	57.51	51.62
ec1mov7	Screen 1	25.40	185.12	170.19	153.32	78.32	60.04	55.20	49.73
ec1mov8	Screen 1	25.40	183.74	171.23	156.40	78.32	59.59	55.53	50.73
ec1mov9	Screen 1	25.40	193.12	179.46	163.25	78.32	62.63	58.20	52.95
ec1mov10	Screen 1	25.40	187.22	174.30	158.98	78.32	60.72	56.53	51.56
ec1mov1	Screen 2	25.39	31.50	36.33	42.76	70.56	11.34	13.07	15.39
ec1mov2	Screen 2	25.39	27.20	31.83	37.98	70.56	9.79	11.46	13.67
ec1mov3	Screen 2	25.39	29.12	33.85	40.13	70.56	10.48	12.18	14.44
ec1mov4	Screen 2	25.39	26.98	31.61	37.74	70.56	9.71	11.37	13.58
ec1mov5	Screen 2	25.39	31.23	35.51	41.05	70.56	11.24	12.78	14.77
ec1mov6	Screen 2	25.39	29.02	33.24	38.68	70.56	10.44	11.96	13.92
ec1mov7	Screen 2	25.39	32.93	37.24	42.84	70.56	11.85	13.40	15.41
ec1mov8	Screen 2	25.39	38.87	42.48	47.04	70.56	13.99	15.28	16.93
ec1mov9	Screen 2	25.39	28.34	31.91	36.39	70.56	10.20	11.48	13.10
ec1mov10	Screen 2	25.39	29.30	32.88	37.38	70.56	10.54	11.83	13.45
ec1mov1	Screen 3	25.39	89.73	90.05	90.44	70.57	32.28	32.40	32.54
ec1mov2	Screen 3	25.39	96.65	96.49	96.28	70.57	34.77	34.71	34.64
ec1mov3	Screen 3	25.39	91.40	91.61	91.85	70.57	32.88	32.96	33.05
ec1mov4	Screen 3	25.39	99.01	98.68	98.26	70.57	35.62	35.50	35.35
ec1mov5	Screen 3	25.39	95.05	94.71	94.30	70.57	34.20	34.08	33.93
ec1mov6	Screen 3	25.39	88.82	88.94	89.07	70.57	31.96	32.00	32.05
ec1mov7	Screen 3	25.39	99.40	98.74	97.93	70.57	35.76	35.52	35.23
ec1mov8	Screen 3	25.39	88.64	88.16	87.57	70.57	31.89	31.72	31.51
ec1mov9	Screen 3	25.39	90.19	89.59	88.86	70.57	32.45	32.23	31.97
ec1mov10	Screen 3	25.39	101.57	100.07	98.23	70.57	36.54	36.00	35.34
ec1mov1	Screen 4	24.78	7.23	10.03	13.50	70.04	2.56	3.55	4.78
ec1mov2	Screen 4	24.78	7.35	10.16	13.66	70.04	2.60	3.60	4.83
ec1mov3	Screen 4	24.78	7.68	10.55	14.12	70.04	2.72	3.73	5.00
ec1mov4	Screen 4	24.78	7.26	10.06	13.55	70.04	2.57	3.56	4.79
ec1mov5	Screen 4	24.78	7.95	10.66	13.93	70.04	2.81	3.77	4.93
ec1mov6	Screen 4	24.78	6.81	9.36	12.40	70.04	2.41	3.31	4.39
ec1mov7	Screen 4	24.78	6.88	9.43	12.50	70.04	2.43	3.34	4.42
ec1mov8	Screen 4	24.78	7.94	10.44	13.39	70.04	2.81	3.69	4.74
ec1mov9	Screen 4	24.78	7.33	9.76	12.61	70.04	2.59	3.45	4.46
ec1mov10	Screen 4	24.78	6.51	8.84	11.55	70.04	2.30	3.13	4.09

[a] Drawdown in the well 0.08 day after pumping started
[b] Drawdown in the well 1.95 days after pumping started
ft/d - Feet per day

3.5.5 Sources of Uncertainty

Uncertainty in the interval hydraulic conductivity values comes from primarily two sources: uncertainty in the model and uncertainty in parameters.

The model uncertainty is principally the result of violations of key model assumptions such as the applicability of the Cooper-Jacob equation describing horizontal flow to the well. As Ruud and Kabala (1997a and b), Cassiani and Kabala (1998), and Ruud et al. (1999) note, vertical flow may occur in the vicinity of the well due to heterogeneity, head losses, well skin effects, and partially penetrating screens. Each of these can lead to errors in the calculated interval hydraulic conductivity when using the horizontal flow assumption. Many of the errors due to small-scale vertical flow have been minimized in this work by integrating flowmeter responses over the length of each screened section. Other sources of model uncertainty include the assumed form of the interval storage coefficient. The impact of the latter assumptions are presented in Table 3-7.

The parameter uncertainty comes from uncertainty in the flow rate, the drawdown, and the parameters within the logarithm of equation (3-10). The flow rate determined from the flowmeter and line speed measurements is accurate to within plus or minus 1.87 gpm. This means that flow uncertainty is a small factor for the intervals that produced the most water, but could be a significant factor, up to perhaps 50 percent of the value for Screen 4. The drawdown in the aquifer is uncertain because it relies on corrections for well losses, both inside and outside the well. The well loss corrections are similar down the well, but the impact of the uncertainty will be larger for the screens with low flows, and may be on the order of 50 percent.

The parameters within the logarithmic term are another source of uncertainty. The time at which flowmeter measurements are taken relative to the total time of pumping will influence calculated hydraulic conductivity as will the estimate for the effective radius-storage coefficient product. As seen in equations (3-7) and (3-10), time is a parameter in the equations. If the time of measurement is long after pumping began, the change in drawdown and well hydraulic condition will be small both during the logging run and between logging runs. If one logging run is made too close to the start of pumping, it seems likely that parameters from that run could differ from later runs. Table 3-7 presents the hydraulic conductivity for each interval for each logging run using a range of interval thickness and a range of drawdowns. As can be seen, the differences between logging runs is quite small. Considering, for example, that Runs 1 and 2 were made quite soon after pumping began, and Runs 3 and 4 were taken nearly 18 hours later, it appears that the time of measurement was not a significant source of error in the interpretation. This is consistent with the expectation that the effect of these parameters is not too large because the logarithm has the effect of moderating the impact.

Perhaps the single biggest source of uncertainty is the selection of the length of the transmissive interval for each screen. As was noted earlier, the thickness could vary between 25 and 78 ft. This uncertainty in the thickness of the transmissive interval produces an uncertainty in interval hydraulic conductivity that is about a factor of three.

In summary, the interval hydraulic conductivity values are uncertain, with greater uncertainty associated with the small hydraulic conductivity intervals. The interval hydraulic conductivity values are probably no more accurate than about a factor of 5 to 7. This range is quite good when compared with the range of hydraulic conductivity values presented in the regional groundwater model report (DOE/NV, 1997), where values of hydraulic conductivity for volcanic units ranged over more than seven orders of magnitude.

3.6 Comments on Multiple-Completion Well Design

Several observations have been made about the multiple-completion well design extending over great vertical depth. The very restricted producing interval under the imposed pumping rate resulted in data that only provided definitive information on part of the upper completion interval. A general conclusion can be drawn about the lack of production from the lower intervals, primarily that the hydraulic conductivity of the lower formations must be much less than that of the upper interval. However, there is no information to determine the hydraulic conductivity of those formations. Higher pumping rates may have increased production from lower screens sufficiently to have provided data for hydraulic conductivity analysis.

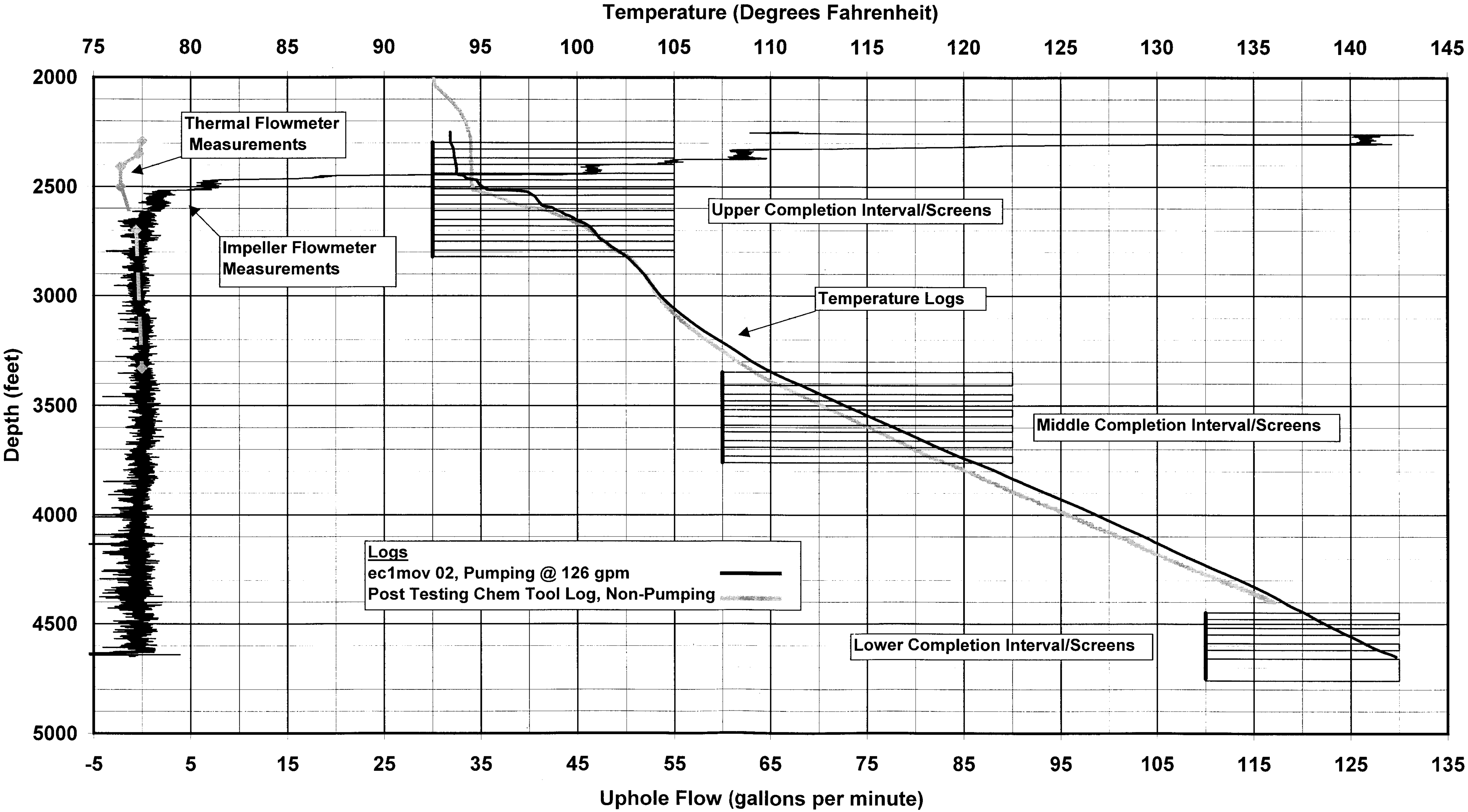


Figure 3-1
Pumping Temperature and Flow Logs

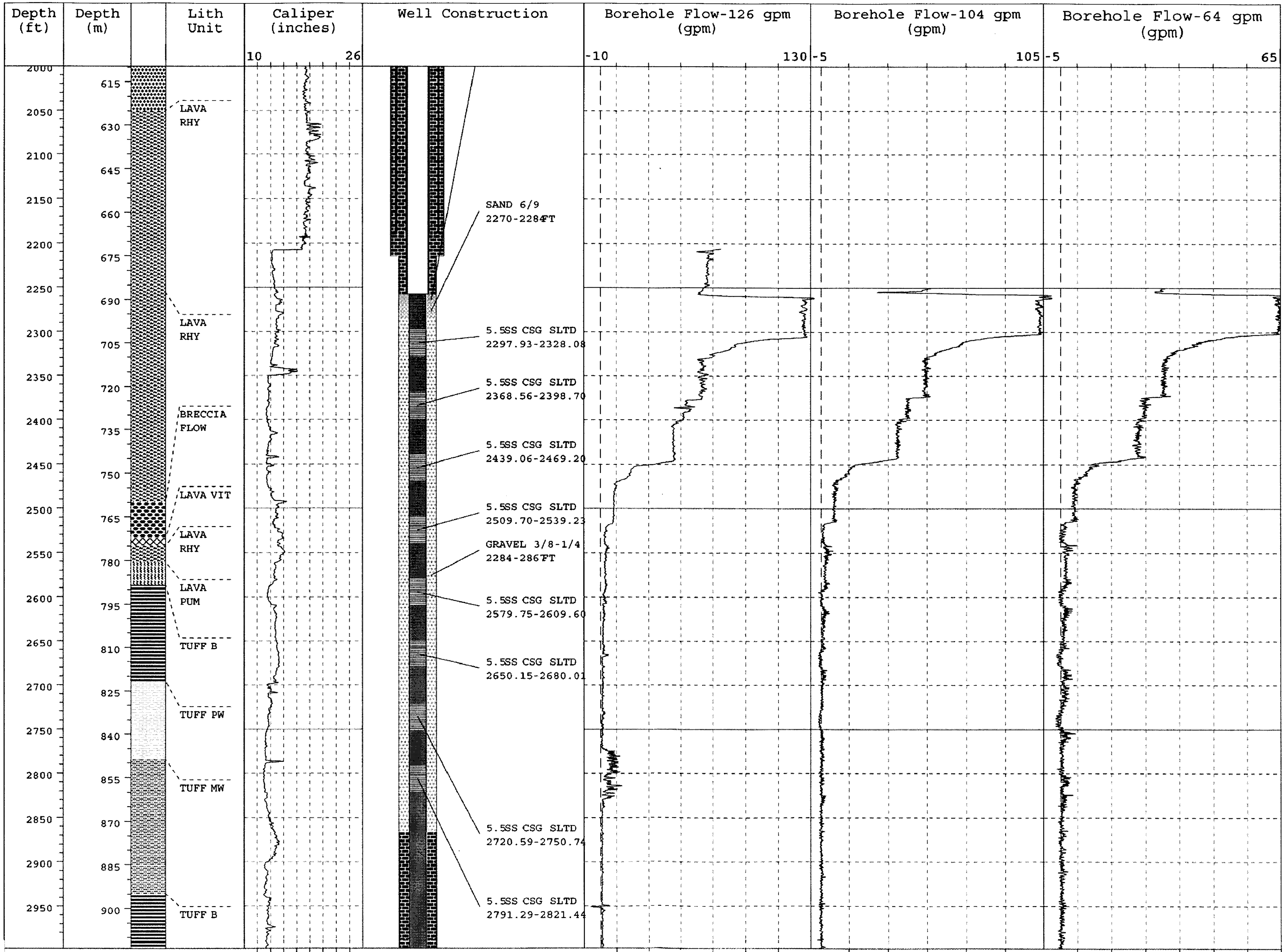


Figure 3-2
Upper Completion Interval

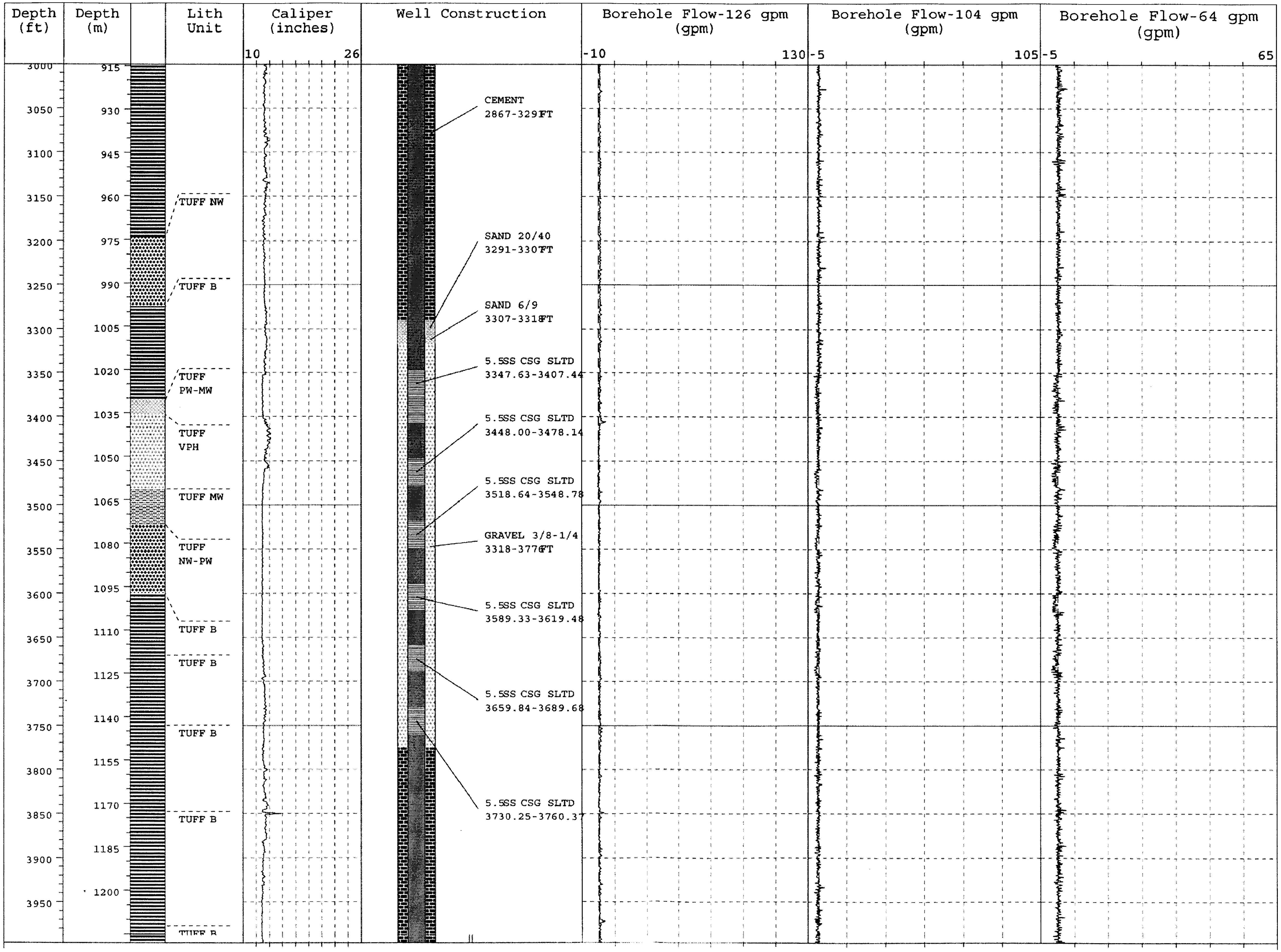


Figure 3-3
Middle Completion Interval

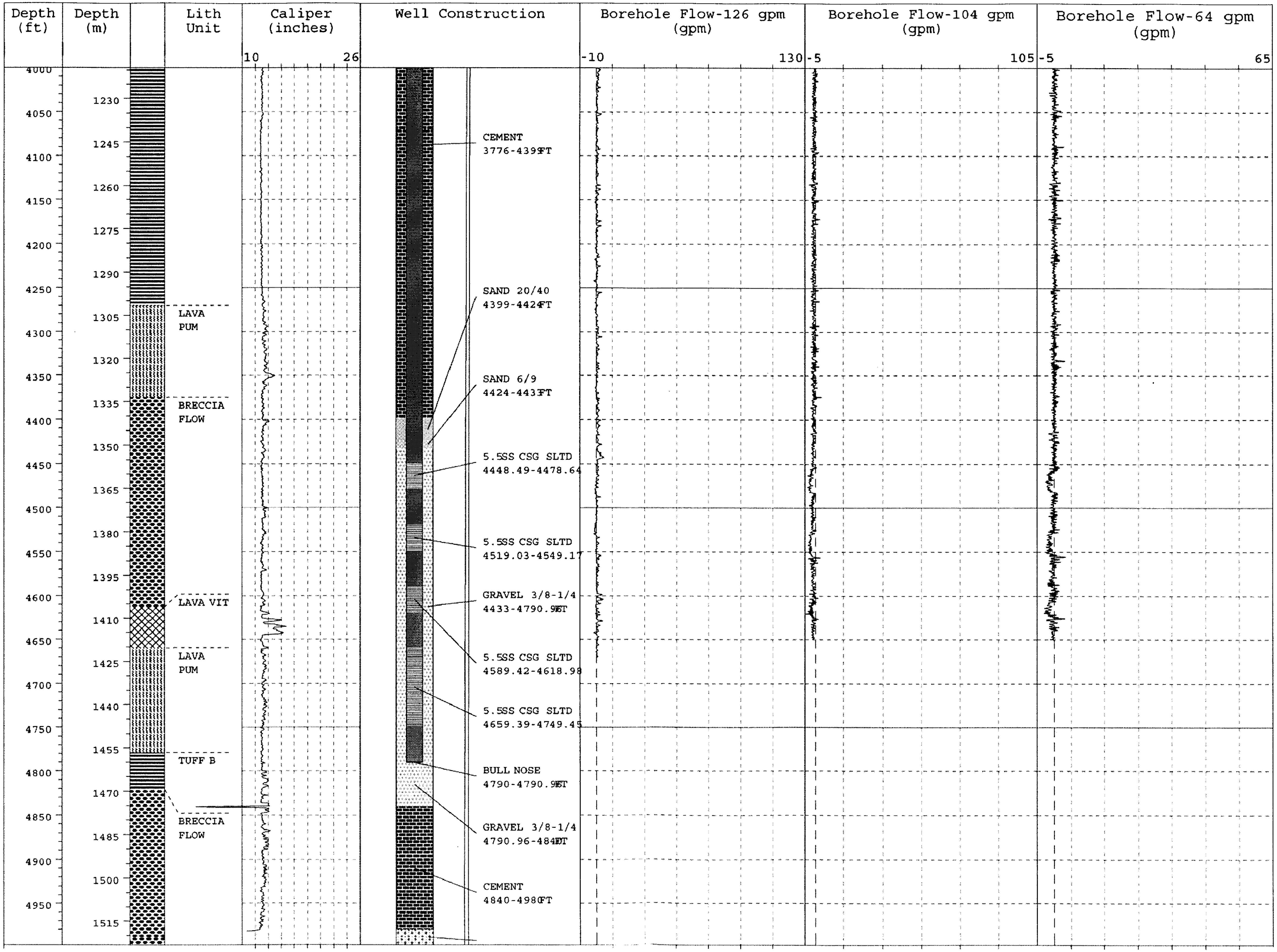


Figure 3-4
Lower Completion Interval

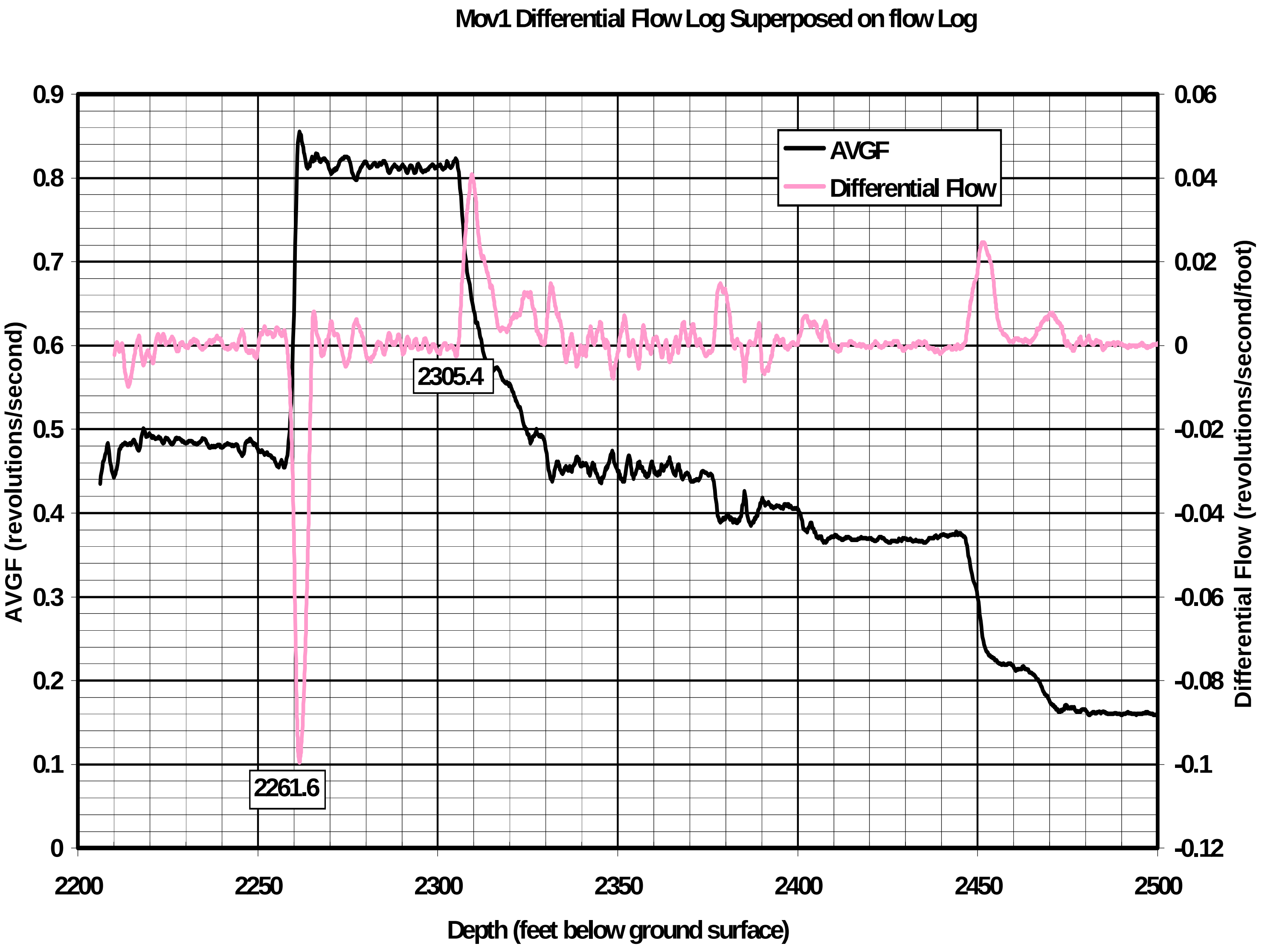


Figure 3-5
Example of Differential Flow Log Superposed on Flow Log (Flow Log ec1mov01)

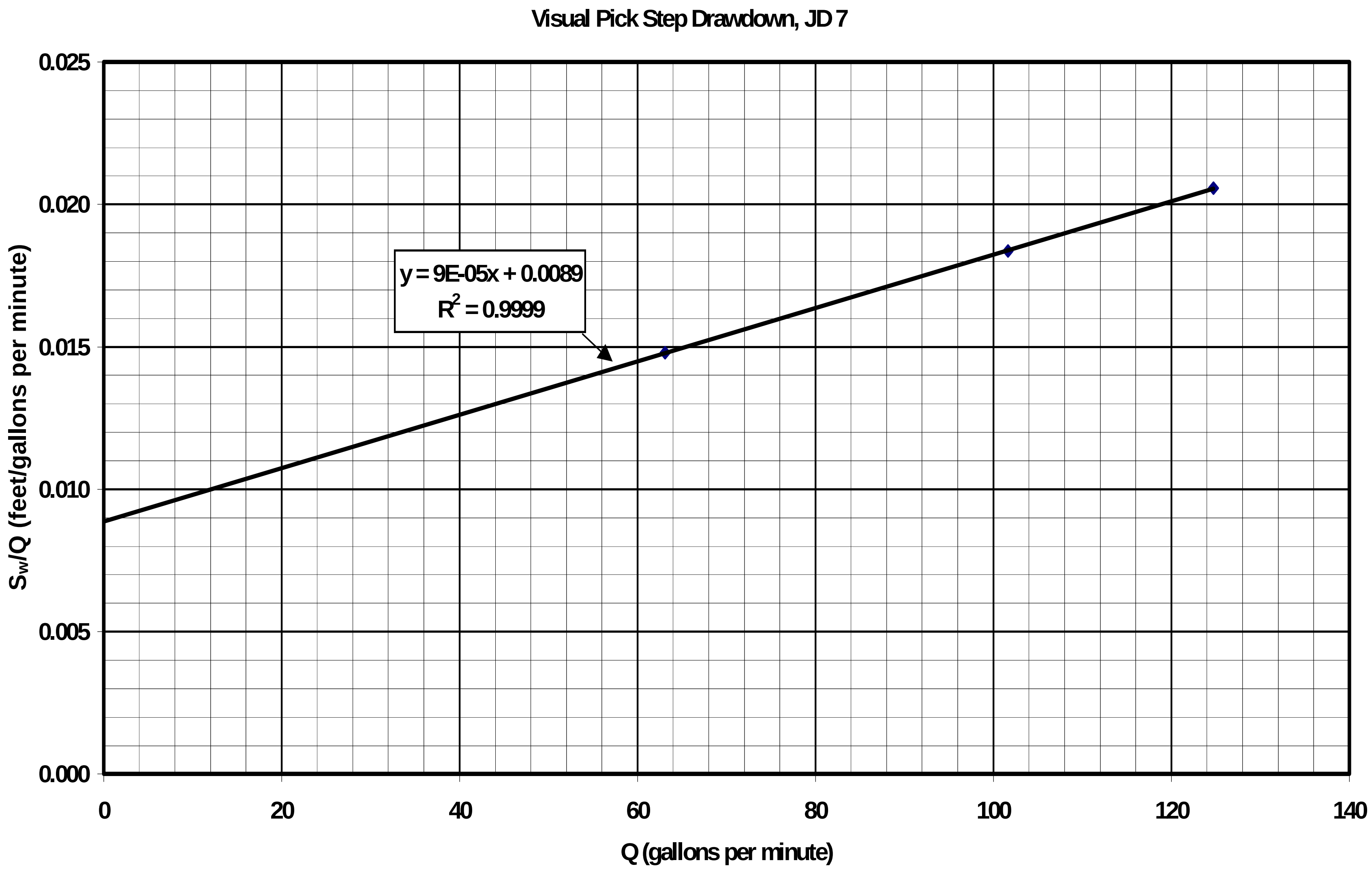


Figure 3-6
Step-Drawdown Analysis

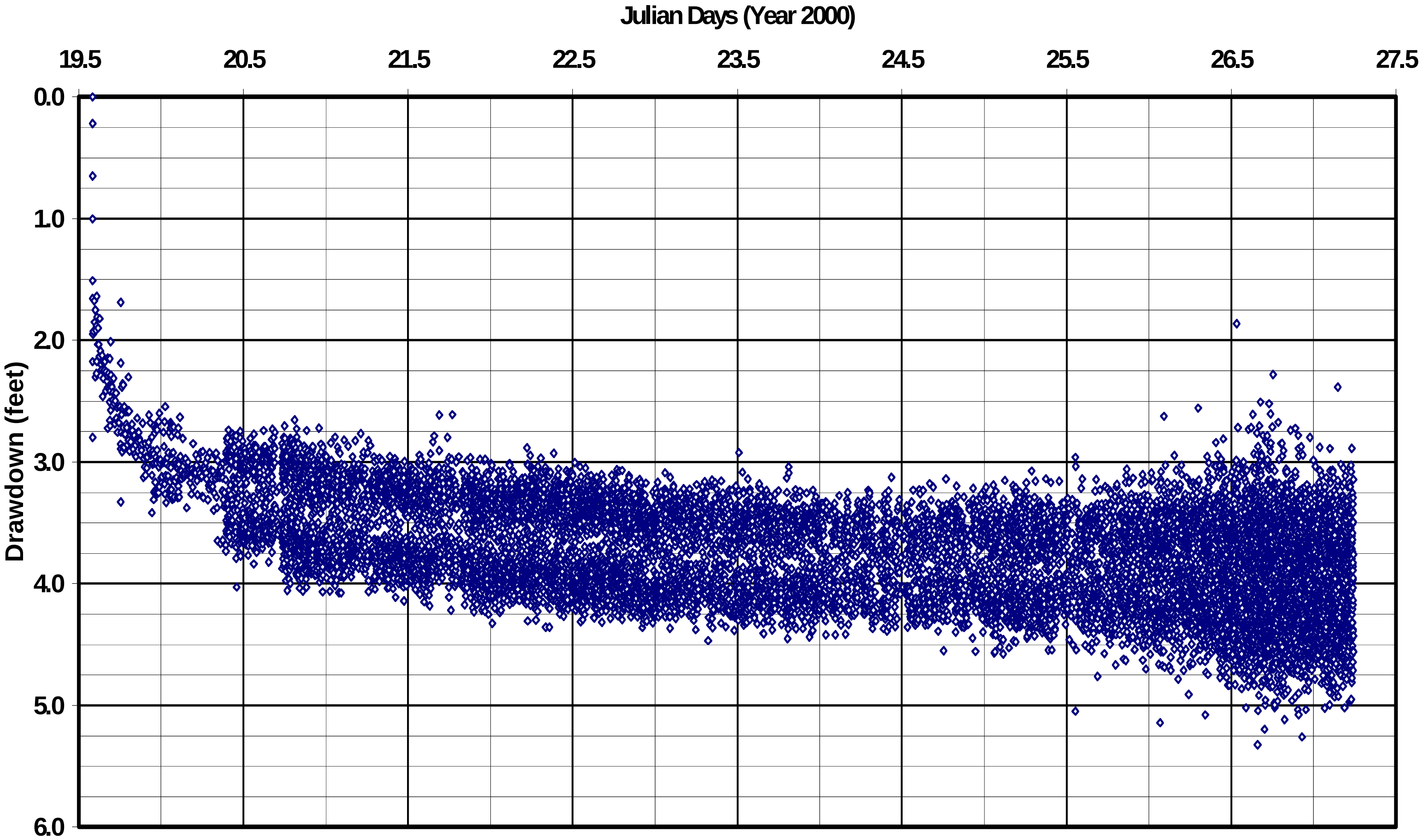


Figure 3-7
Constant-Rate Test Data

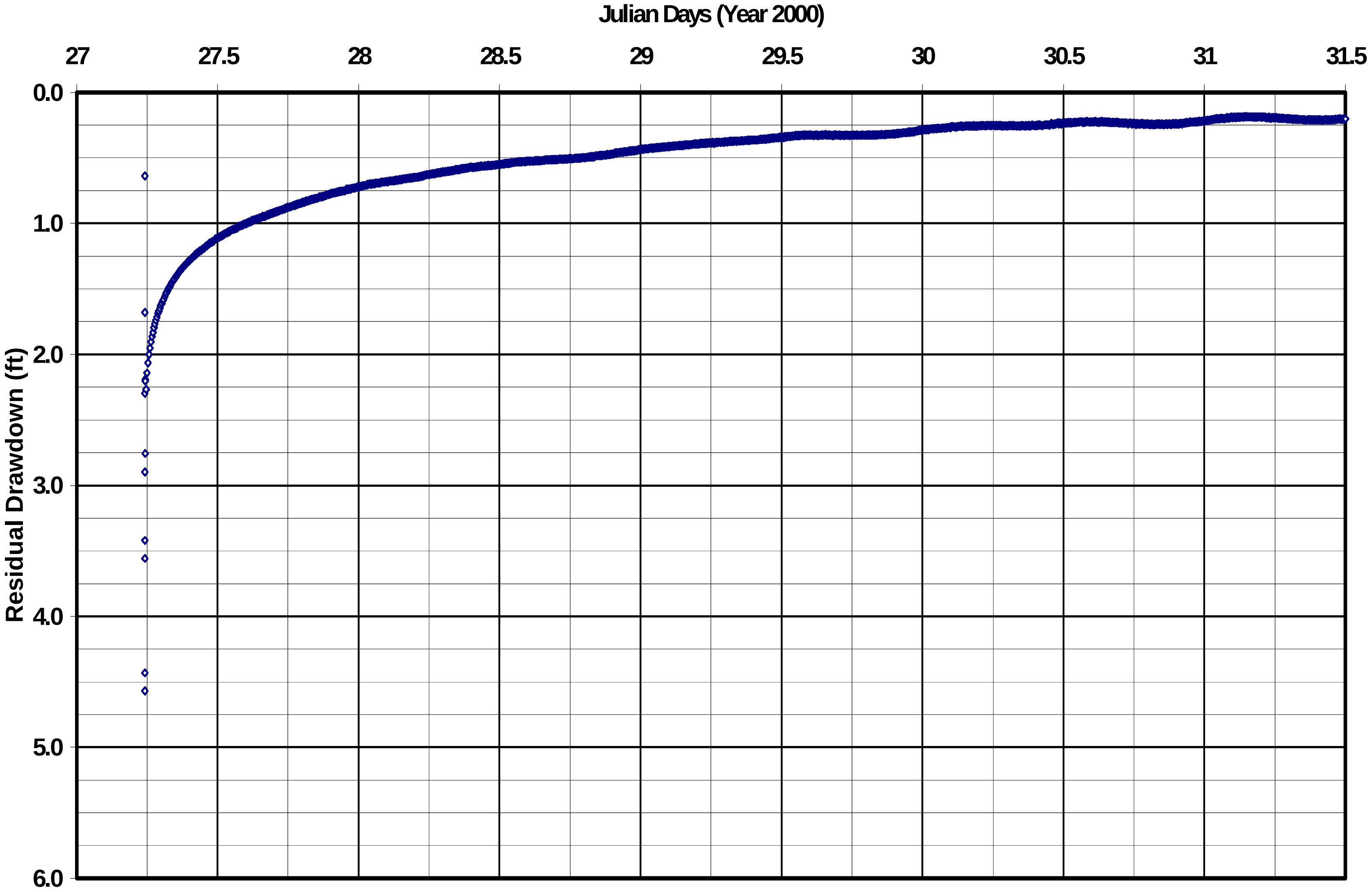


Figure 3-8
Well ER-EC-1 Recovery Data

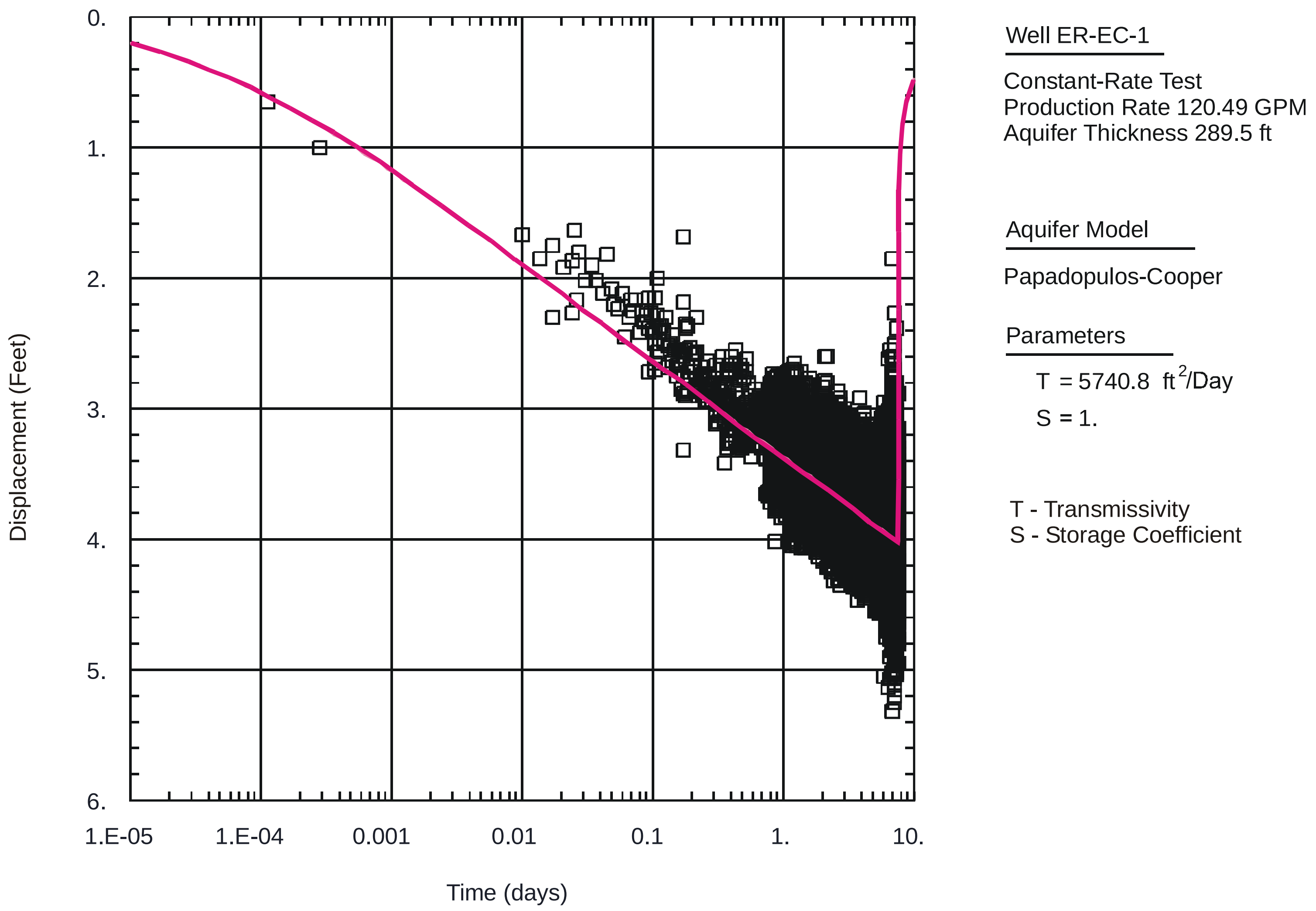
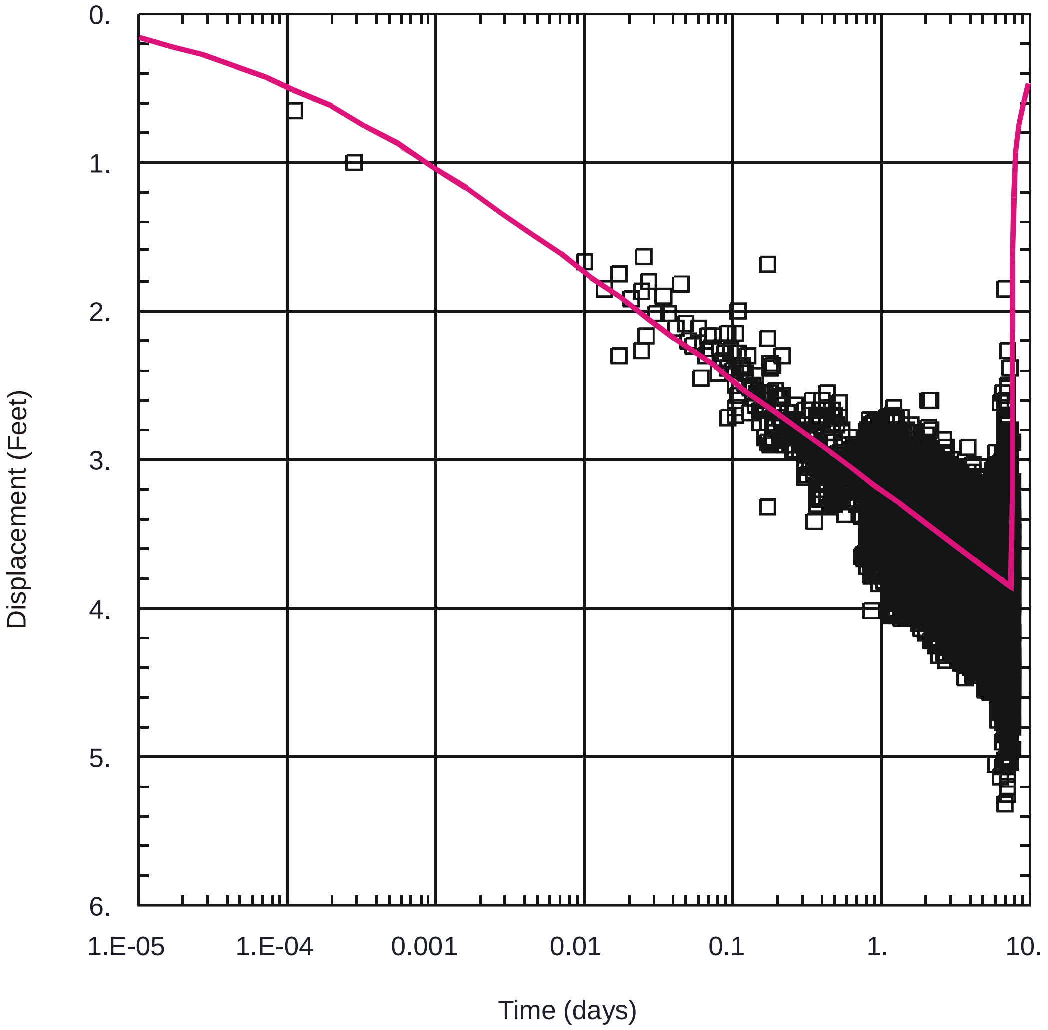


Figure 3-9
Well ER-EC-1 Papadopulos-Cooper Solution



Well ER-EC-1

Constant-Rate Test
Production Rate 120.49 GPM
Aquifer Thickness 289.5 ft

Aquifer Model

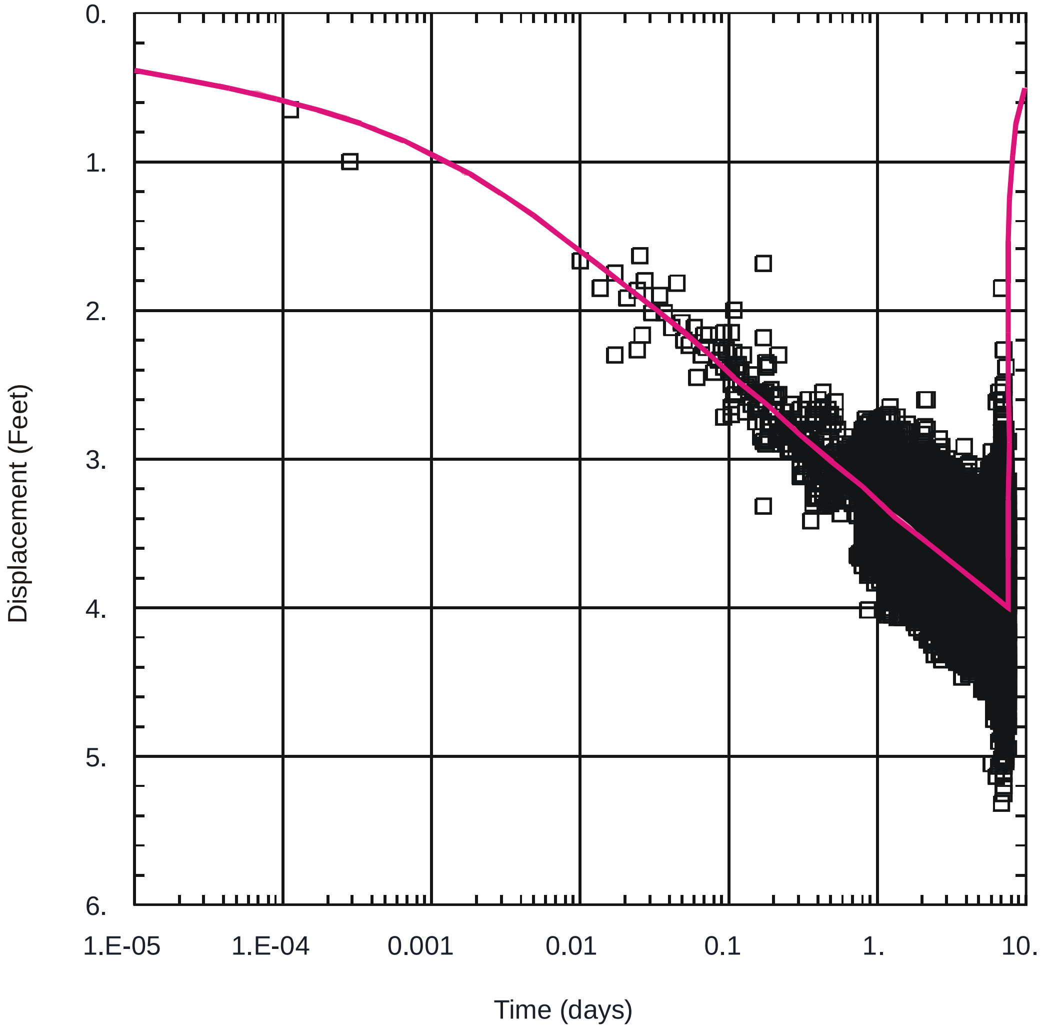
Dual-Porosity:
Moench w/slab blocks

Parameters

K = 19.83 ft/day
Ss = 0.00575 ft^{-1}
K' = 0.005 ft/day
Ss' = 3.4E-06 ft^{-1}
Sw = 0.
Sf = 0.

K - Fracture Hydraulic Conductivity
Ss - Fracture Specific Storage
K' - Matrix Hydraulic Conductivity
Ss' - Matrix Specific Storage
Sw - Well Skin
Sf - Fracture Skin

Figure 3-10
Well ER-EC-1 Moench Dual-Porosity Solution - Filter Pack, Constrained Except for Ss



Well ER-EC-1

Constant-Rate Test
Production Rate 120.49 GPM
Aquifer Thickness 289.5 ft

Aquifer Model

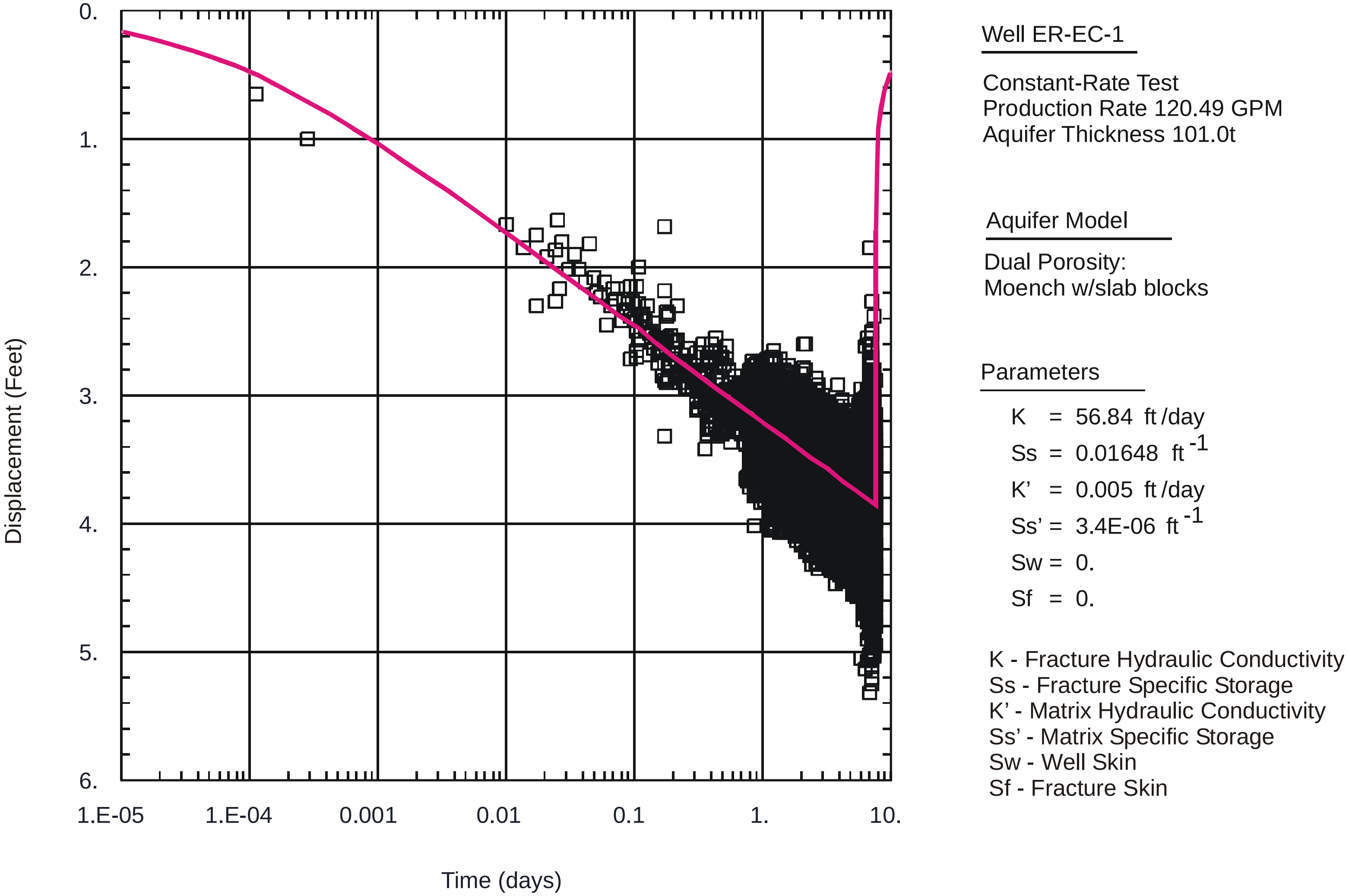
Dual Porosity:
Moench w/slab blocks

Parameters

K = 16.5 ft /day
Ss = 0.0522 ft $^{-1}$
K' = 0.005 ft /day
Ss' = 0.034 ft $^{-1}$
Sw = 0.4744
Sf = 0.1174

K - Fracture Hydraulic Conductivity
Ss - Fracture Specific Storage
K' - Matrix Hydraulic Conductivity
Ss' - Matrix Specific Storage
Sw - Well Skin
Sf - Fracture Skin

Figure 3-11
Well ER-EC-1 Moench Dual-Porosity Solution - Filter Pack, Unconstrained



Well ER-EC-1

Constant-Rate Test
Production Rate 120.49 GPM
Aquifer Thickness 101.0t

Aquifer Model

Dual Porosity:
Moench w/slab blocks

Parameters

K = 56.84 ft/day
Ss = 0.01648 ft^{-1}
K’ = 0.005 ft/day
Ss’ = 3.4E-06 ft^{-1}
Sw = 0.
Sf = 0.

K - Fracture Hydraulic Conductivity
Ss - Fracture Specific Storage
K’ - Matrix Hydraulic Conductivity
Ss’ - Matrix Specific Storage
Sw - Well Skin
Sf - Fracture Skin

Figure 3-12
Well ER-EC-1 Moench Dual-Porosity Solution - Screens

4.0 Groundwater Chemistry

This section presents an evaluation of the analytical results of the groundwater characterization samples collected during the well development and hydraulic testing activities at Well ER-EC-1. Both discrete bailer and well composite samples were collected at this site. The purpose of discrete bailer samples is to collect groundwater samples that would represent the groundwater quality of a subsection of the formation supplying water to the well. The discrete samples are collected at a particular depth under pumping conditions, and only represent the groundwater that had been produced from below that depth. The purpose of the composite groundwater sample is to obtain a sample that was representative of as much of the well as possible. The results from these two different groundwater characterization samples are used to examine the overall groundwater chemistry of the well and to compare the overall groundwater chemistry of this well to that of other wells in the area. The groundwater chemistry results are evaluated to establish whether Well ER-EC-1 was sufficiently developed to restore natural groundwater quality in the formation around the well. Similarities or differences between the two samples can also be evaluated with respect to differences in the water quality of the source formation of the sample water.

4.1 Discussion of Groundwater Chemistry Sampling Results

The groundwater chemistry of Well ER-EC-1 will be discussed in this section, and then compared to the groundwater chemistry of other nearby wells.

4.1.1 ER-EC-1 Groundwater Characterization Sample Results

On January 13, 2000, one discrete bailer sample (#EC-1-011300-1) was obtained from a depth of 2,440 ft below ground surface (bgs) at a pumping rate of 126 gpm. The sample was obtained using a DRI boom, logging truck, and discrete bailer. On February 1, 2000, a composite groundwater characterization sample (#EC-1-020100-1) was collected from the wellhead sampling port after approximately 2.9 x 10^6 gallons of groundwater had been pumped from the well during development and testing activities. The results of these samples are presented in Table ATT 3-1, Table ATT 3-2, and Table ATT 3-3 in Attachment 3 of Appendix A.

Examination of Table ATT 3-1, Attachment 3, Appendix A, reveals that both groundwater characterization samples have similar overall analytical results for the total and dissolved metals as well as for the inorganic parameters. From the table, it can be seen that sodium is the predominate cation for both samples, while bicarbonate and sulfate are the predominate anions for both samples. It can also be seen that significant dissolved silica, calcium, potassium, and chloride are present. Closer inspection of the table reveals that both samples have a slightly basic pH and a similar total dissolved solids value. Examination of the table also reveals that a significant number of the analytes in the 'Metals' and 'Radiological Indicator Parameters' sections of the table were not detected at the given minimum detectable limit as indicated by the 'U' qualifier.

Inspection of the 'Age and Migration Parameters' section of Table ATT 3-1, Attachment 3, Appendix A, for the composite groundwater sample reveals several interesting things. For example, LLNL (2000) explained that the helium-3/helium-4 ($^{3}He/^{4}He$) ratio for Well ER-EC-1 ($R=9.25x10^{-7}$) is slightly lower than the atmospheric ratio ($R_a=1.38x10^{-6}$), giving a R/R_a value of 0.67. This implies that the sample contains a significant amount of nonatmospheric ^{4}He. Evidently, elevated ^{4}He concentrations are predominantly derived from the *in situ* α-decay of naturally occurring radioactive elements in the host rock. LLNL (2000) stated that correcting the ^{4}He data for the presence of nonequilibrium "excess-air" (dissolved during recharge), and assuming a ^{4}He in-growth rate of $1.2x10^{9}$ atoms/year, the ^{4}He apparent age for this groundwater is on the order of 2,100 years. However, they state that the error associated with this number is relatively large because the crustal helium flux is poorly constrained for this region. It can also be seen from the table that the carbon-14 (^{14}C) value of dissolved inorganic carbon (DIC) from Well ER-EC-1 is 5.9 percent modern. This results in an uncorrected apparent groundwater age of 23,400 years (LLNL, 2000). This value is an order of magnitude greater than the ^{4}He apparent age. This implies that the DIC has reacted with ^{14}C-absent carbonate minerals present in the aquifer (LLNL, 2000). Finally, LLNL (2000) reported that the ^{36}chlorine (Cl)/Cl ratio for Well ER-EC-1 was $5.46x10^{-13}$. They stated that this value was within the range of values characteristic of environmental samples from the volcanic aquifers in this region, and is notable because the Well ER-EC-1 chloride concentration is high (Table ATT 3-1, Attachment 3, Appendix A) compared to most Pahute Mesa groundwater samples, although a similar value was reported at Well PM-3.

Table ATT 3-2, Attachment 3, Appendix A, presents the results of the colloid analyses for Well ER-EC-1. It can be seen in the table that the discrete bailer sample had a total colloid concentration of $4.04x10^{7}$ particles per milliliter (particles/mL) for colloids in the size range of 50 to 1,000 nanometers (nm). The composite groundwater characterization sample, on the other hand, had a total colloid concentration of $1.02x10^{8}$ particles/mL for colloids in the size range of 50 to 1,000 nm. The total colloid concentration for the discrete bailer groundwater characterization sample is almost half as much as the total colloid concentration for the composite groundwater characterization sample. It can be seen in the table, however, that the discrete bailer sample had the greater colloid concentrations for each particle size range after 90 to 100 nm. Further inspection of the table reveals that the colloid concentrations for each particle size range decrease, in general, as the particle size range increases for both groundwater characterization samples. In addition, it can be seen from the table that the colloid concentrations for the composite groundwater characterization sample decrease, in general, at a slightly greater rate than the colloid concentrations for the discrete bailer sample.

One difference between the two groundwater characterization samples can be seen in the oxidation-reduction (redox) sensitive parameters: iron and manganese. For example, it can be seen in the composite groundwater characterization sample that for the redox-sensitive parameters the total and dissolved analyses have relatively similar values; but for the discrete sample, the total and dissolved analyses have discernible differences. This suggests that possibly there was a redox change in the discrete groundwater characterization sample between when the sample was collected in-hole and when it was filtered.

Overall, the groundwater compositions observed at Well ER-EC-1 are typical for wells that penetrate volcanic rocks. The preliminary lithologic logs indicated that, in fact, the completion intervals for Well ER-EC-1 were in rhyolitic lavas and ash-flow tuffs of the Paintbrush and Crater Flat Groups (DOE/NV, 2000).

4.1.2 Radionuclide Contaminants

Radiologic indicator parameters were not detected in the groundwater characterization samples from Well ER-EC-1.

4.1.3 Comparison of ER-EC-1 Groundwater Chemistry to Surrounding Wells

Table 4-1 presents groundwater chemistry data for Well ER-EC-1 and for recently collected samples from wells in close proximity to Well ER-EC-1. Shown in the table are the analytical results for selected metals, anionic constituents, field measurements, and several radiological parameters. The data in this table were used to construct the trilinear diagram shown in Figure 4-1. Trilinear diagrams are used to show the relative concentrations of major ions in the groundwater. The diamond-shaped plot in the center of Figure 4-1 combines the information from the adjacent cation and anion triangles. The concentrations are expressed in percent milliequivalents per liter and are used to illustrate various groundwater chemistry types and the relationships that may exist between the types. It can be seen from the figure that the dominant cation for Well ER-EC-1 and the nearby wells is sodium, with lesser amounts of calcium and magnesium. Blankennagel and Weir (1973) postulated that diminished calcium concentrations in western Pahute Mesa groundwater might be due to ion exchange reactions within the zeolitized units. Inspection of the anion diagram, however, reveals that there is no one dominant anion type. In fact, the anion concentrations for Well ER-EC-1 are almost equally split between the bicarbonate, chloride, and sulfate anions. It can also be seen from the anion triangle that there is greater spread among the anion concentrations for the other wells in close proximity to Well ER-EC-1. However, the figure clearly shows that groundwater chemistry for Well ER-EC-1 is similar to the surrounding wells and cannot be considered abnormal. The greater concentrations of sulfate and chloride in Well ER-EC-1 may be related to hydrothermal alteration or mineralization along the flow path.

The data in Table 4-1 were also used to construct Figure 4-2. The figure shows the stable oxygen and hydrogen isotope composition of groundwater for

Table 4-1
Groundwater Chemistry Data for Well ER-EC-1 and Surrounding Sites
(Page 1 of 2)

Analyte	ER-EC-1 (Bailer at 2,440 ft bgs) *Total | Dissolved*	ER-EC-1 (Wellhead Composite) *Total | Dissolved*	ER-20-5 #1	ER-20-5 #3	ER-20-6 #1-1	ER-20-6 #1	ER-20-6 #2	ER-20-6 #3	PM-3	PM-3 (3,019 feet)	U-20 WW	U-20a #2 WW
Metals (mg/L)												
Aluminum (Al)	UJ 0.2 | UJ 0.2	U 0.042 | U 0.055	3.1	11		0.31	1.13	< 0.06	0.03	< 0.01	0.0053	< 0.01
Arsenic (As)	B 0.005 | U 0.01	U 0.01 | B 0.0025	0.042	B 0.0085	< 0.01	0.039	0.051	0.016		0.004	0.00589	
Barium (Ba)	B 0.0044 | B 0.0056	B 0.0035 | B 0.0036	< 0.01	B 0.0076	< 0.2	< 0.01		< 0.01	0.004	0.002	0.00008	
Cadmium (Cd)	U 0.005 | U 0.005	UJ 0.005 | UJ 0.005		0.005	< 0.005					< 0.001	< .000016	
Calcium (Ca)	19 | 18	19 | 20	7.18	3.14	6.95	7.1	8.3	10.1	30.1	36	6.8	6.34
Chromium (Cr)	B 0.0056 | B 0.0023	U 0.00092 | U 0.0012		0.0792	0.0422				0.01	0.002	0.00025	
Iron (Fe)	0.55 | U 0.054	0.43 | 0.34	0.39	8.48	0.845	0.12	0.48	0.17	0.24	0.06	0.0767	0.09
Lead (Pb)	0.0074 | U 0.003	U 0.003 | U 0.003	0.001	0.0206	0.003	<0.001	0.001	< 0.001		< 0.005	0.000263	
Lithium (Li)	0.13 | 0.13	0.14 | 0.14	0.09	0.0696	0.0572	0.06	0.06	0.05	0.278		0.063	0.065
Magnesium (Mg)	B 0.37 | B 0.37	B 0.46 | B 0.47	0.27	0.09	0.891	0.57	0.71	0.8	0.79	1.5	0.27	0.24
Manganese (Mn)	B 0.0097 | B 0.002	0.019 | 0.018	0.02	0.305	< 0.015	0.01	0.03	0.04	0.014	0.014	0.0496	0.01
Potassium (K)	8.2 | 8.2	8.2 | 8.3	5.65	3	< 1.95	2.2	3.1	3.6	10.9	10	1.37	2.27
Selenium (Se)	U 0.005 | U 0.005	U 0.005 | U 0.005	< 0.01	< 0.005	< 0.005	< 0.01	< 0.01	< 0.01		< 0.001	0.00051	
Silicon (Si)	24 | 23	24 | 24	38.4	41.7	23.4	26.1	27.2	23.3		63		48
Silver (Ag)	U 0.01 | U 0.01	U 0.01 | U 0.01		< 0.01	< 0.01					< 0.001	< 0.00001	
Sodium (Na)	150 | 150	120 | 120	105	73	59	60.6	61.1	56	140	130	59.5	62.6
Strontium (Sr)	0.023 | 0.023	0.022 | 0.022	0.02	B 0.027	B 0.0148	0.02	0.02	0.03		0.081	0.0263	0.03
Uranium (U)	U 0.2 | U 0.2	U 0.2 | U 0.2	0.014	< 0.5	< 0.5	0.001	0.003	< 0.001			0.002302	
Mercury (Hg)	UJ 0.0002 | UJ 0.0002	UJ 0.0002 | UJ 0.0002	< 0.0002	0.00029	< 0.0002					< 0.1		
Inorganics (mg/L)												
Chloride (Cl)	95	95	21.7	17.8	12.2	12.3	11.6	13.6	93.5	98	11.1	11.2
Fluoride (F)	2.6	2.6	10.1	3.16	2.64	2.93	3.84	2.45	2.5	2.4	2.23	2.7
Bromide (Br)	0.49	0.46	0.103	< 0.25	< 0.25						0.064	
Sulfate (SO4)	120	120	39	35.1	32.2	32.3	31.5	31.8	129	130	31	38.4
pH	J 7.8	J 8.3	8.6	8.8	8.46	8.12	8.16	8.42	8.73	7.9	8.56	7.7
Total Dissolved Solids (TDS)	J 510	500	436	489	227				441	555.6241	166	201
Carbonate (CO3) as CaCO3	U 50	U 10									6.1	
Bicarbonate (HCO3) as CaCO3	130	130	186	109	96	103	112	109	159	150	101	112
Age and Migration Parameters (pCi/L) - unless otherwise noted												
Carbon-12/13 (per mil)	N/A	-4.3	-2.82	-5.75	-7.9+/-0.2	-6.67	-7.28	-7.24			-6.2	-13.47
Carbon-14, Inorganic (pmc)	N/A	5.9	81657	1346		344.23	1068.53	16.31			8.6	15.3
Carbon-14, Inorganic age (years)*	N/A	23400									20260	
Chlorine-36	N/A	1.75E-03		0.01102								
Helium-3/4, measured value (ratio)	N/A	9.25E-07	0.157	0.001		< 0.001	< 0.001	9.27E-07			4.74E-07	
Helium-3/4, relative to air (ratio)	N/A	0.67	114000	723		< 720	<720	0.67			0.34	
Oxygen-18/16 (per mil)	N/A	-14.8	-14.9	-15.1	-15+/-0.2	-14.98	-15	-14.97			-14.7+/-0.2	-14.75
Strontium-87/86 (ratio)	N/A	0.71023+/-0.00001	0.71104+/-6E-5	0.70868+/-3E-5		0.71016	0.71029	0.70974			0.71126	
Uranium-234/238 (ratio)	N/A	0.000209887	0.000165	0.000158		0.000221	0.000138	0.000257			0.000259	
Hydrogen-2/1 (per mil)	N/A	-114	-115	-113	-113+/-1	-115	-110	-115			-113	-114
Radiological Indicator Parameters-Level I (pCi/L)												
Tritium	U -160 +/- 160	U -130 +/- 160	60400000	142000	2310	1700000	944000		16		3.8 +/- 0.93	
Gross Alpha	10.7 +/- 2.2	13.2 +/- 2.6	C 23.7	37.3	C 7.7							0.0053
Gross Beta	6.3 +/- 1.7	8.4 +/- 2.0	C 29.6	24.8	2.1							5.6
Radiological Indicator Parameters-Level II (pCi/L)												
Carbon-14	UJ -80 +/- 180	UJ -30 +/- 180	260	-3.8	25							
Strontium-90	N/A	U 0.06 +/- 0.15	0.5	0.43							0.13	
Plutonium-238	U -0.003 +/- 0.013	U -0.012 +/- 0.015	< 0.062	< 0.31	0.001						0.43	
Plutonium-239	U 0.001 +/- 0.013	U -0.002 +/- 0.013										
Iodine-129	N/A	U 5.0 +/- 6.7	<570	-0.6	0.04							
Technecium-99	N/A	UJ 1.1 +/- 1.9	< 1.88	< 5.17	0.5						3.22	

Table 4-1
Groundwater Chemistry Data for Well ER-EC-1 and Surrounding Sites
(Page 2 of 2)

Analyte	U-20e	U-20f	UE-18r	UE-18t	UE-19fs	UE-20bh #1	UE-20d	UE-20e #1	UE-20f (13,686 feet)	UE-20f (4,543 feet)	UE-20h WW	UE-20j WW
Metals (mg/L)												
Aluminum (Al)	< 0.1	0.26	< 0.06		0.02	0.01	0.09	0.01	0.07	0.07	0.02	0.01
Arsenic (As)			< 0.1			0.0056						
Barium (Ba)			20			0.0005						
Cadmium (Cd)												
Calcium (Ca)	3.6	14	21.5	22.2	11	3.14	8.5	0.2	4.8	4.8	0.6	46
Chromium (Cr)												
Iron (Fe)	0.07	0.04	< 0.02			0.06		0.02	0.56	0.56		4.8
Lead (Pb)			< 0.01			0.0006						
Lithium (Li)	0.06	0.04	0.08		0.02	< 0.1	0.075	0.07			0.08	
Magnesium (Mg)	0.2	0.1	0.92	1	1.6	0.59	0.1			0.1		1.2
Manganese (Mn)	0.14	0.02	< 0.03		0.03	0.004	0.39	< 0.01	0.14	0.14	0.03	
Potassium (K)	2.9	3	3.49	8.16	3	8.72	2.6	2	2	2	1.8	6.4
Selenium (Se)	0.03	0.02	< 0.01			< 0.004	0.01					
Silicon (Si)	40	39	21.6		56	21.8	45	36	47	47	49	44
Silver (Ag)												
Sodium (Na)	73	82	73.1	141	29	87.7	107	83	113	113	64	138
Strontium (Sr)	0.01	0.07	0.08		0.02	0.0009	< 0.01	0.03			< 0.02	
Uranium (U)			0.0035		0.0021	0.001					0.0018	0.0085
Mercury (Hg)												
Inorganics (mg/L)												
Chloride (Cl)	21	15	6.9	64.4	6.3	4.7	24	20	40	40	15	115
Fluoride (F)	2.7	3.7	3		3.6	< 1	3	4.5	5	5	2.7	2.2
Bromide (Br)												
Sulfate (SO4)	35	65	23	10.8	9	14	40	42	48	48	30	135
pH	7.3	8.4	8.05	8.63	8.1	8.26	8.5	8.5		7.2	8.1	7
Total Dissolved Solids (TDS)	200	268	208	776	186		327	245	368	368	231	583
Carbonate (CO3) as CaCO3												
Bicarbonate (HCO3) as CaCO3	120	140	227	331	86	214	192	119	164	164	107	150
Age and Migration Parameters (pCi/L) - unless otherwise noted												
Carbon-12/13 (per mil)			-1.4			-9.2						
Carbon-14, Inorganic (pmc)			6.7+/-0.06			20.95						
Carbon-14, Inorganic age (years)*												
Chlorine-36			0.0001342									
Helium-3/4, measured value (ratio)												
Helium-3/4, relative to air (ratio)			1.128+/-2			0.923+/-2						
Oxygen-18/16 (per mil)			-14.7			-14.7						
Strontium-87/86 (ratio)			0.70909									
Uranium-234/238 (ratio)												
Hydrogen-2/1 (per mil)			-110			-109						
Radiological Indicator Parameters-Level I (pCi/L)												
Tritium			8 +/- 1.9	< 7260		3.2 +/- 1.7						
Gross Alpha						< 3						
Gross Beta		2.1			3.2	3	3.2	9.8			8.8	13
Radiological Indicator Parameters-Level II (pCi/L)												
Carbon-14												
Strontium-90												
Plutonium-238												
Plutonium-239												
Iodine-129												
Technecium-99			< 5									

U = Result not detected at the given minimum detectable limit or activity

B = The result is less than the contract-required detection limit, but greater than the instrument detection limit.

J = The result is an estimated value.

C = Lockheed Analytical Services radiological parameter qualifier - The minimum detectable activity exceeded the Reporting Detection Limit due to residue weight limitations forcing a volume reduction.

N/A = Not Applicable for that sample

mg/L = Milligrams per liter   µg/L = Micrograms per liter   pCi/L = Picocuries per liter

pmc = Percent modern carbon

* = The carbon-14 age presented is not corrected for reactions along the flow path.

Well ER-EC-1 and for selected well sites within ten miles of ER-EC-1. Also plotted on Figure 4-2 are the weighted averages of precipitation for various sites on Buckboard Mesa, Pahute Mesa, Rainier Mesa, and Yucca Mountain based on data from Ingraham et al. (1990) and Milne et al. (1987). As can be seen on the figure, the precipitation data lie along the local and global meteoric water lines of Ingraham et al. (1990) and Craig (1961), respectively. It can also be seen that the values for stable oxygen and hydrogen isotopes for Well ER-EC-1 plot close to those of surrounding wells. This again illustrates that the groundwater chemistry for Well ER-EC-1 is similar to that of the surrounding wells. Note that the groundwater data for these wells lie below the global meteoric water line. In general, groundwater data that fall below the meteoric water line indicate that secondary fractionation has occurred. The isotopic shift in the groundwater data for areas near Pahute Mesa has been ascribed to fractionation during evaporation of rainfall, sublimation of snowpack, or fractionation during infiltration (White and Chuma, 1987). Because of the recent precipitation data plot along the meteoric water line, it appears that fractionation during evaporation of modern precipitation can be ruled out as causing the isotopic shift observed in groundwater data. Another explanation for the lighter isotopic signature is that the recharge areas for the groundwater are located north of Pahute Mesa, or that the waters are ancient and were recharged in a different climatic regime. Rose et al. (1998) report that the oxygen and hydrogen isotope composition of Pahute Mesa groundwater is similar to the composition of groundwater and alpine spring waters in Central Nevada.

4.2 Restoration of Natural Groundwater Quality

A primary purpose for well development was to restore the natural groundwater quality of the the completion intervals so that groundwater samples would accurately represent the water quality of the producing formations. The formation exposed in each completion interval had potentially been affected by drilling and completion operations as well as crossflow from other completion intervals occurring under the natural head gradient.

4.2.1 Evaluation of Well Development

During drilling operations for Well ER-EC-1, the makeup water was tagged with a lithium bromide (LiBr) tracer to help determine such things as the static water level and the water production during drilling. The makeup water was tagged with a LiBr concentration of approximately 10 to 50+ milligrams per liter (mg/L). This relatively high concentration of Br^- ions injected into the well bore provides a potential means to ascertain the effectiveness of the well development. It can be seen in Table ATT 3-1, Attachment 3, Appendix A, that for both the discrete bailer sample and for the composite groundwater sample, the dissolved concentration of Br^- ions was approximately 0.5 mg/L. This value is essentially an order of magnitude lower than the concentration used during drilling, and likely indicates that the well was sufficiently developed to restore groundwater quality back to its natural condition. However, it can be seen in Table 4-1 that these Br^-

concentrations are still somewhat higher than the Br^- concentrations for surrounding sites, potentially indicating some residual effect of drilling operations. This conclusion pertains only to the formation-producing water during pumping.

4.2.2 Evaluation of Flow Between Completion Intervals

Well ER-EC-1 was drilled and completed in April, 1999, with three discrete completion intervals spanning from 2,300 ft to almost 4,800 ft bgs. Flow between completion intervals has not been determined. There are some reasons to suspect that there may be flow under the natural vertical gradient from the uppermost completion interval to the lower completion interval(s). The thermal flowmeter surveys had measured downward flow before completion of the well, but did not determine flow from the uppermost interval downwards after the well completion was installed. The interpretation of the head measurements for the individual completion intervals indicates that the head of the middle interval is lower than the upper interval, and that the head of lowermost interval is also above that of the middle interval. The uncertainty in these measurements is large relative to the gradients, but does support a low gradients to the middle interval. The well has been left with all three completion intervals connected.

4.2.3 Source Formation(s) of Groundwater Samples

As has been discussed in Section 2.5.2, flow logging indicated that almost all of the water produced during development and testing came from the uppermost completion interval. Any production that might have come from the lower completion intervals is less than the uncertainty of the measurements, which is about 2 gpm. Consequently, the source of both the discrete and composite groundwater characterization samples is apparently only the uppermost completion interval. The discrete bailer sample was collected at a depth of 2,400 ft bgs, which corresponds to just below the second screen of the uppermost completion interval of the well and below about 67 percent of the production from the well. Most of the production below this level comes from the third screen, which produces from the same unit of rhyolitic lava as the upper two screens.

No remediation of groundwater quality in the lower completion intervals was effected by these development activities, and no samples were taken that provide any information about groundwater quality in the lower completion intervals.

4.3 Representativeness of Water Chemistry Results

The analytical results from the groundwater characterization samples support the conclusion about the origin of the water. There are no significant geochemical differences between the discrete bailer sample and the composite groundwater sample. This can be interpreted to indicate that the discrete groundwater sample was indeed produced from the same source as the composite sample. The flow logs indicate that most of the production below the level at which the discrete sample was taken was from the upper completion interval, in the same type of formation. A further explanation for the similarity of the samples would be that water quality in the lower completion intervals is the same as the uppermost interval. However, the minimal production from the lower completion intervals would probably not show up as a significant difference in the samples in any case. Consequently, there is no analytical information on the groundwater quality of the lower completion intervals.

4.4 Use of ER-EC-1 for Future Monitoring

As discussed in this section, almost all of the water produced at the highest pumping rate (126 gpm) at which flow logs were run originated from the upper part of the upper completion interval. The same situation was observed at 64 gpm. The permanent sampling pump that was installed after testing has a maximum capacity of about 43 gpm. Consequently, sampling conducted with this pump will also only represent the upper part of the upper completion interval. The direction of natural-gradient flow in the well is downwards, although it was not definitive if there is any substantial flow from the upper completion interval to lower completion intervals. Consequently, the upper part of the upper completion interval should not become contaminated with any foreign water between pumping episodes, and purging requirements for sampling should not include significant effort to restore natural groundwater quality.

The lower intervals cannot be accurately sampled with the pumping methodology used for development and testing. Pumping at higher rates than were used in this testing program may extend the production downwards, but there is no data to indicate what rates may be required to produce substantial amounts of water from the lower intervals. The required rates would probably be very much greater than the rates that have been employed, and flow logging would be required to confirm the production from the lower intervals.

The lower intervals have not been developed and may be receiving water continuously from the upper interval. Consequently, discrete bailer samples taken from the lower intervals may not provide representative samples of those intervals. A method to develop and test those intervals would be required before such samples could be properly evaluated as representative.

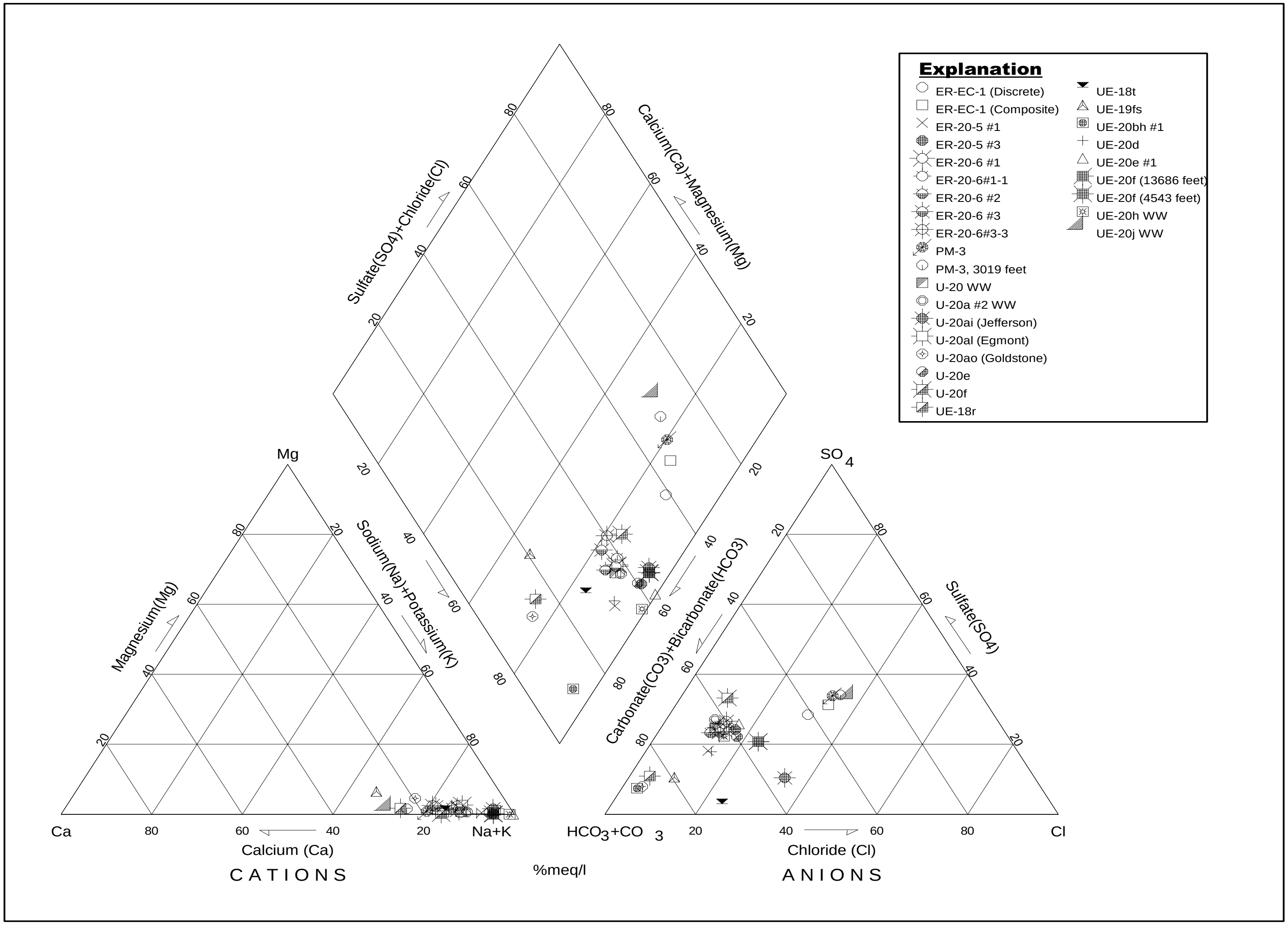


Figure 4-1
Piper Diagram Showing Relative Major Ion Percentages for Groundwater from Well ER-EC-1 and Nearby Wells

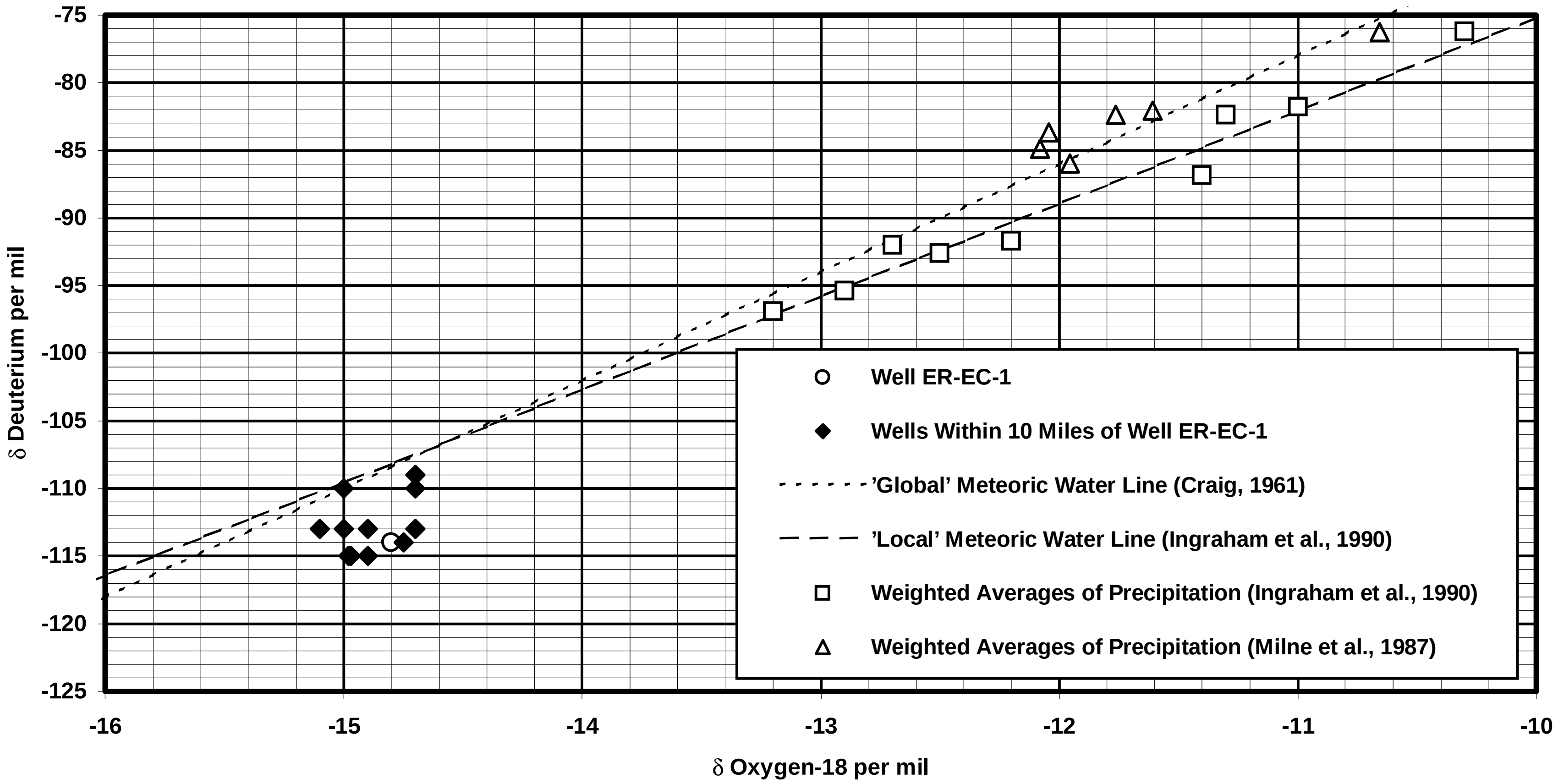


Figure 4-2
Stable Isotope Composition for Well ER-EC-1 and Nearby Wells

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Appendix A

Western Pahute Mesa - Oasis Valley Well ER-EC-1 Data Report for Development and Hydraulic Testing

A.1.0 Introduction

Well ER-EC-1 is one of seven groundwater wells that were completed as part of FY 1999 activities for the NNSA/NV UGTA Project. Figure A.1-1 shows the location of the WPM-OV wells. Hydraulic testing and groundwater sampling were conducted at Well ER-EC-1 to provide information on the hydraulic characteristics of HSUs and the chemistry of local groundwater. Well ER-EC-1 is constructed with multiple completion intervals. The completion intervals access the formation using slotted casing with gravel in the annulus. The completion intervals are separated from each other by blank casing, and isolated with cement seals in the annular space. The completion intervals extend over large vertical distances and access different HSUs.

This document presents the data collected during well development and hydraulic testing for Well ER-EC-1 and the analytic results of groundwater samples taken during this testing.

The objectives of the development and testing program were:

1. Increase the hydraulic efficiency of the well.
2. Restore the natural groundwater quality.
3. Determine the hydraulic parameters of the formations penetrated.
4. Collect discrete samples from specific depths and/or completion intervals to characterize spatial variability in downhole chemistry.
5. Collect groundwater characterization samples to evaluate composite chemistry.

Well ER-EC-1 was the first of the WPM-OV wells to be developed and tested. Activities began in mid-December 1999 and were completed in mid-February 2000. A variety of testing activities were conducted including discrete head measurements for each completion interval, flow logging under ambient conditions and during pumping, a constant-rate pumping test, water quality parameter monitoring, and groundwater sampling at selected depths downhole and of the composite discharge.

A.1.1 ER-EC-1 Specifications and Geologic Interpretation

Drilling and completion specifications for Well ER-EC-1 can be found in the *Completion Report for Well ER-EC-1, December 2000* (DOE/NV, 2000). This report also contains the lithologic and stratigraphic interpretation for this well. The schematic well construction is illustrated in various figures in this report which show logging information.

A.1.2 Development and Testing Plan

Well development consisted of producing water from the well to clean out sediment and drilling-induced fluid to restore the natural productivity and the natural water quality of the formation(s) in the completion intervals. The well was hydraulically stressed and surged to the extent possible to promote the removal of lodged and trapped sediment. Water production was accompanied by both hydraulic response and water quality assessments to evaluate the status of development.

The testing program was structured to develop a complete assessment of the hydrology and groundwater quality of the formations accessed by the well completion. The elements of the testing program can be found in the *Well Development and Hydraulic Testing Plan for Western Pahute Mesa - Oasis Valley Wells,* Rev. 0, November 1999 (WDHTP) (ITLV, 1999d).

The testing activities included: (1) discrete head measurements for each completion interval using bridge plugs equipped with pressure transducers and dataloggers for the lower intervals and a wireline-set pressure transducer for the uppermost interval; (2) flow logging during pumping to determine the extent of the open formation actually producing water and locations of discrete production along the borehole; (3) flow logging under ambient head conditions to determine circulation in the well under the natural gradient; (4) a constant-rate pumping test to determine hydraulic parameters for the formation(s); (5) discrete downhole sampling both under ambient head conditions and during pumping to capture samples that can be determined to represent specific formations or portions of formations; and (6) a composite groundwater characterization sample of water produced during pumping after the maximum possible development.

A.1.3 Schedule

The generic schedule developed for the Well ER-EC-1 testing program was:

1. Measurements of interval-specific hydraulic heads, including monitoring after installation of last bridge plug (estimated 5 days).

2. Installation of well development and hydraulic testing equipment (estimated 2 days).

3. Well development and flow logging (estimated 7 days).
4. Water level recovery (estimated 5 days).
5. Constant-rate pumping test and discrete and groundwater characterization sampling (estimated 10 days).
6. Water level recovery (estimated 5 days).
7. Removal of downhole equipment and water level measurement (estimated 1 day).
8. Thermal flow logging and discrete sampling (estimated 2 days).
9. Installation of dedicated sampling pump and possible groundwater characterization sampling (estimated 4 days).

The history of the testing program at Well ER-EC-1 is shown in Table A.1-1. The discrete interval head measurements were not conducted before the pumping tests because the contract for this work was not available when the testing program was initiated. These measurements were subsequently made after development and the constant-rate test were completed. The work was started before December 1999, but was temporarily suspended between December 25, 1999, and the January 1, 2000. In general, the work proceeded according to the planned schedule. Some additional time was spent on the development phase working through problems with the pump and electrical power system. Discrete downhole sampling was also added at the end of development, and not repeated after thermal flow logging when criteria for sampling were not met.

A.1.4 Governing Documents

Several documents govern the field activities presented in this document. The document describing the overall plan is the WDHTP (ITLV, 1999d). The implementation of the testing plan is covered in *Field Instruction for Western Pahute Mesa - Oasis Valley Well Development and Hydraulic Testing Operations*, Rev. 0, December 1999 (FI) (ITLV, 1999b), as modified by *Technical Change No. 1, 12/22/1999*. This document calls out a variety of Detailed Operating Procedures (DOPs) (ITLV, 1999a) and Standard Quality Practices (SQPs) specifying how certain activities are to be conducted. The work was carried out under the *Site-Specific Health and Safety Plan for Development, Testing, and Sampling of Clean Wells* (ITLV, 1999c).

Table A.1-1
Schedule of Work Performed at ER-EC-1

Activity	Start	Finish
Begin site mobilization	11/29/1999	12/22/1999
Install access line and testing pump	12/16/1999	12/23/1999
Check pump functionality	12/23/1999	12/23/1999
December shutdown	12/24/1999	1/3/2000
Check pump functionality	1/03/2000	1/3/2000
Develop well and conduct step-drawdown testing	1/3/2000	1/10/2000
Flow logging during pumping (impeller flowmeter)	1/10/2000	1/12/2000
Discrete downhole sampling	1/12/2000	1/13/2000
Shut down pump and monitor recovery	1/14/2000	1/19/2000
Constant-rate test	1/19/2000	1/27/2000
Pump shutdown/monitor recovery	1/27/2000	2/1/2000
Check generator/pump function	1/31/2000	1/31/2000
Groundwater characterization sampling	2/1/2000	2/1/2000
Remove test equipment, testing pump, and access line	2/2/2000	2/4/2000
Interval-specific head measurements (bridge plugs)	2/5/2000	2/10/2000
Ambient-condition flow logging (thermal flowmeter)	2/18/2000	2/19/2000
Install sampling pump	3/6/2000	3/10/2000
Test sampling pump for function	3/10/2000	3/10/2000
Demobilize from site	3/13/2000	3/13/2000

A.1.5 Document Organization

This data report is organized in the following manner:

- Section A.1.0: Introduction
- Section A.2.0: Summary of Development and Testing. This chapter presents mostly raw data in the form of charts and graphs. Methodologies for data collection are described, as well as any problems that were encountered. Data is presented under the following topics: water level measurements, interval-specific head measurements, pump installation, well development, flow logging during pumping, constant-rate pumping test, water quality monitoring, groundwater sampling, thermal-flow logging, and ChemTool logging.
- Section A.3.0: Data Reduction and Review. This chapter further refines and reduces the data to present specific results that are derived from the

program objectives. Information is presented on vertical gradients and borehole circulation, intervals of inflow into the well, the state of well development, reducing the data from the constant-rate test, changes in water quality parameters, and representativeness of groundwater samples.

- Section A.4.0: Environmental Compliance. This chapter records the results of the tritium and lead monitoring, fluid disposition, and waste management.
- Section A.5.0: References
- Attachment 1: Manufacturer Pump Specifications for the Testing Pump and the Permanent Sampling Pump.
- Attachment 2: Water Quality Monitoring - Grab Sample Results. This attachment shows the field laboratory results for temperature, electrical conductivity (EC), pH, dissolved oxygen (DO), turbidity and bromide in relation to date/time and gallons pumped.
- Attachment 3: Analytical Results for the Groundwater Characterization Samples. This attachment contains the validated analyses of the groundwater samples.
- Attachment 4: Fluid Management Plan Waiver for the WPM-OV Wells
- Attachment 5: Electronic Data Files Readme.txt. This attachment contains the readme file text included with the electronic data files to explain the raw data files included on the accompanying Compact Disc (CD).

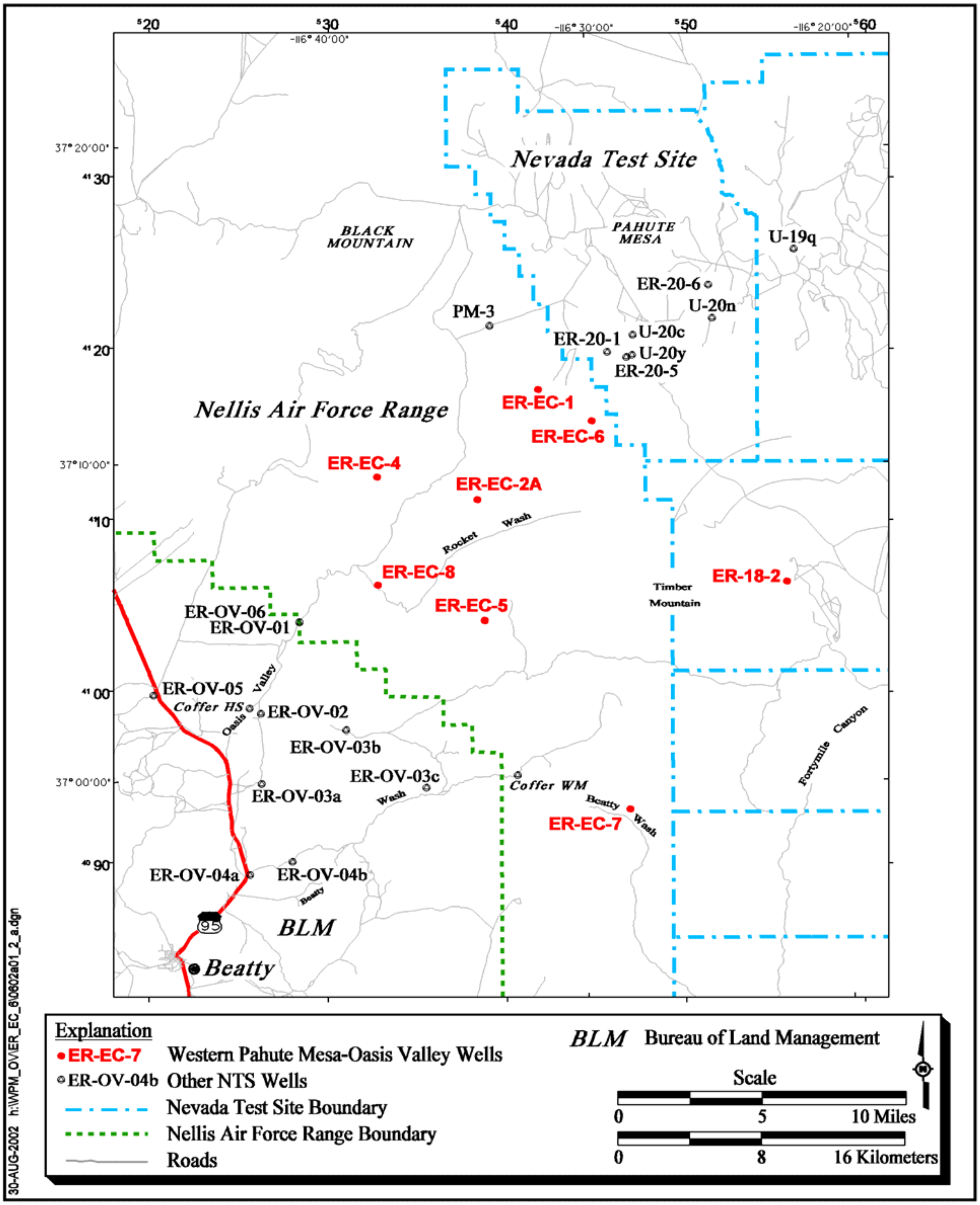


Figure A.1-1
Area Location Map

A.2.0 *Summary of Development and Testing*

This section presents details of the well development and testing activities, the associated data collection activities, and summaries and depictions of the unprocessed data that were collected. The detailed history of Well ER-EC-1 development and testing is shown in Table A.2-1.

A.2.1 Water Level Measurement Equipment

Following is a description of the general equipment used by the IT Corporation, Las Vegas Office (ITLV) for measurements and monitoring during development and testing. Other equipment used for specific parts of the program are described in the appropriate section. Depth-to-water measurements were made with a metric Solinst e-tape equipped with either a conductivity sensor or a float switch. The PXDs were Design Analysis Model H-310 and were vented by means of long rubber hoses between the PXD and the wireline connection. The PXDs employ a silicon strain gauge element and downhole electronics to process the voltage and temperature measurements and output pressure and temperature uphole using SDI 12 protocol. Their rated accuracy is 0.02 percent full scale (FS). Barometric pressure was measured with a Vaisala Model PTA 427A barometer housed with the datalogger. The data was recorded with a Campbell Scientific CR10X datalogger. All equipment was in calibration.

A.2.1.1 Data Presentation

The data are presented primarily using Excel® spreadsheets and graphs. Due to the nature of the data and how the data were recorded in the datalogger program, certain conventions had to be used in formatting the data. The following items explain features of the data presentations:

- The time scale presented for all monitoring is in Julian Days, as recorded by the datalogger. Julian Days are consecutively numbered days starting with January 1 for any year. This format maintains the correspondence of the presentation with the actual data, and presents time as a convenient continuous length scale for analysis purposes.

- The PXD data are presented as the pressure recorded by the datalogger, so that it corresponds to the data files. These data can be processed to various forms of head, with or without barometric correction, as needed, with the appropriate included data. However, various interpretations must be made in using these data, which are subject to revision and

Table A.2-1
Detailed History of Development and Testing Activities

Date	Activities
5/10/1999	ITLV installs 0-15 psi PXD for water level monitoring.
7/16/1999	ITLV removes PXD, completing water level monitoring.
12/7/1999	ITLV installs 0-15 psi PXD for preliminary monitoring.
12/8/1999	ITLV removes PXD and installs 0-75 psi PXD.
12/15/1999	ITLV removes PXD and BN sets up Franks rig for pump installation.
12/16/1999	Finish setting up rig; start installation of 2-3/8 in. access line.
12/20/1999	Land access line at 2,068.64 ft bgs. Assemble pump and start splicing power cable.
12/21/1999	Finish splicing power cable and start pump installation. Suspend operations due to high winds.
12/22/1999	Land pump at 2,029.11 ft bgs; intake at 1,982.96 ft bgs.
12/23/1999	Wire pump. Install 0-75 psi PXD. Operate pump at 58.2 hz (63 gpm) and 60 hz (81 gpm). Pump amperage approaches fuse rating of 200 A on power system.
12/29/1999	Remove PXD.
12/31/1999	ITLV installs 0-30 psi PXD.
1/3/2000	Replace PXD due to failure. Replace power system fuses with 400 A rating. Test pump from minimum (58.7 hz, 61 gpm) to maximum (70 hz, 167.5 gpm) rate. Pump overnight at 125 gpm.
1/4/2000	Test VSD operating modes. Note loss of production for a given hz setting. Test monitoring equipment installations.
1/5/2000	Power/pump problems. Pump representative and electricians troubleshoot system.
1/6-7/2000	Pump for development. Surge well by stopping pump. Use step-drawdown protocol to assess well response.
1/8-10/2000	Power/pump problems cause various shutdowns. Pump for development continuously.
1/10/2000	Remove PXD. DRI begins flow logging during pumping at 126 gpm. Continue pumping overnight.
1/11/2000	DRI flow logs at 104 and 64 gpm.
1/12/2000	DRI finishes flow logging at 64 gpm. DRI attempts to set check valve - problems with equipment. DRI starts discrete downhole sampling at 2,240 ft bgs.
1/13/2000	DRI collects remainder of downhole sample (multiple trips required). DRI sets check valve.
1/14/2000	Install 0-15 psi PXD. Shutdown pump at 04:30. Total of 1,472,969 gallons pumped. Monitor recovery.
1/14-19/2000	Monitor recovery/pretest baseline for constant-rate test.
1/19/2000	Start constant-rate test at 14:00, 120 gpm.
1/19-1/27/2000	Continuous pumping at 120 gpm. Continue monitoring drawdown and water quality.
1/27/2000	Pump shuts down at 05:49, ending test.
1/27-1/31/2000	Monitor recovery.
1/31/2000	BN electricians and generator mechanic check out generator/power system. Start pump at 15:19; shut down at 15:44.
2/1/2000	Start pump at 09:50, 120 gpm, for groundwater characterization sampling. Collect sample. Shut down at 14:54.
2/2/2000	Remove PXD. Remove check valve.
2/3/2000	Remove pump. Note abnormal grinding noise when tested at surface.
2/4/2000	Remove access tubing.
2/5/2000	Set bridge plugs at 4,375 ft bgs (2,500 psi) and at 3,265 ft bgs (1,000 psi). Set 0-15 psi PXD.
2/10/2000	Remove PXD. Remove bridge plugs.
2/17/2000	DRI runs ChemTool log and thermal flow logging tool.
2/18/2000	DRI completes thermal flow logging.
3/6/2000	Begin running dedicated sampling pump.
3/7/2000	Land pump and wire pump to power.
3/10/2000	Finish pump installation; perform successful functionality test.

ITLV - IT Corporation, Las Vegas
PXD - Pressure transducer
psi - Pounds per square inch
BN - Bechtel Nevada
in. - Inch(es)
ft bgs - Feet below ground surface
hz - Cycles per second (hertz)
gpm - Gallons per minute
A - Amps
VSD - Variable speed drive
DRI - Desert Research Institute

reinterpretation. Therefore, the raw data are presented in their original form so that the end-users can make their own interpretation.

- Groundwater pressure measurements are reported as psig (pounds per square inch gauge) since the PXDs used for groundwater pressure monitoring were not absolute. Pressure differences are reported as psi. Atmospheric pressure (i.e., barometric pressure) is reported as mbar (millibars), but is an absolute measurement.

- On graphs showing both PXD data and barometric data, the pressure scales for psi and mbar are closely matched. For presentation convenience, the scales are not exactly proportional, but are sufficiently close that the relative magnitude of the pressure changes is apparent. Complete electronic data files are included on a CD, which allows the user to evaluate barometric changes and aquifer response as desired.

- The data on water density in this report are presented in terms of the conversion factor between vertical height of water column in feet per unit and pressure in psi. This is actually the inverse of weight density expressed in mixed units (feet-square inches/pound). This is a convenient form for use in calculations. Later in the text, the derived densities are discussed in terms of specific gravity.

- The production rates given in the text, shown in figures, and recorded in the data files are the flowmeter readings. During well development, 1 to 3 gpm was diverted to the Hydrolab® before production rate measurement by the flowmeter. The specific flow to the Hydrolab® at any particular time is not known exactly.

A.2.2 Predevelopment Water Level Monitoring

Following completion of Well ER-EC-1, the water level in this well was monitored with a PXD and datalogger for a period of approximately two months to establish the composite head for this well and provide information to determine the barometric efficiency. Figure A.2-1 shows the results of this monitoring. An electronic copy of this data record can be found on the accompanying CD as file EC1-WaterLevel Monitoring.xls.

A.2.3 Depth-to-Water Measurements

A series of depth-to-water measurements were made in ER-EC-1 as part of the various testing activities. Table A.2-2 presents all of the equilibrium, composite water level measurements made during the testing program. Measurements representing a nonequilibrium or noncomposite water level are presented in the appropriate section for the testing activity involved.

Table A.2-2
Equilibrium, Composite Depth-to-Water Measurements

Date	Time	Depth-to-Water bgs		Barometric Pressure (mbar)
		Feet	Meters	
5/10/1999	16:05	1,855.50	565.56	--
7/16/1999	19:05	1,855.48	565.55	--
12/7/1999	11:20	1,855.64	565.60	810.5
12/8/1999	13:33	1,856.00	565.71	861.63
12/31/1999	11:00	1,855.67	565.61	771.52
1/3/2000	12:35	1,856.07	565.73	823.73
2/2/2000	10:32	1,856.11	565.74	825.74
2/5/2000	--	1,855.92	565.68	--
2/10/2000	--	1,855.78	565.64	--

bgs - Below ground surface
mbar - Millibars

A.2.4 Interval-Specific Head Measurements

The hydraulic head of each individual completion interval was measured to provide information on the vertical hydraulic gradients. This was accomplished by isolating the completion intervals from each other with bridge plugs and measuring the pressure or head for each interval. The bridge plugs contained pressure transducers and dataloggers to measure and record the pressure in the interval below the bridge plug. The head change in the uppermost interval was monitored using a PXD installed on a wireline, and the head was measured with an e-tape. The bridge plugs remained in the well for five days after they were set to monitor pressure changes in the intervals. For Well ER-EC-1, this activity was conducted after development and the pumping test because the contract for the service was not available earlier.

A.2.4.1 Bridge Plug Installation and Removal

The procedure for installing the bridge plugs included:

1. Run gauge and basket to 4,448 ft bgs to verify that bridge plugs would fit through casing.
2. Measure the static water level to establish the reference head (head is assumed to be in equilibrium).
3. Run lower bridge plug to set-depth minus 50 ft and set to collect four or more pressure readings.
4. Lower bridge plug to set-depth plus 50 ft and set to collect four or more pressure readings.

5. Raise bridge plug to set-depth, collect four or more pressure readings, then set bridge plug to isolate lower completion interval. Monitor head change in lower interval with internal pressure transducer/datalogger.

6. Measure water level in well to determine head change after setting first plug and establish a new reference head elevation (treated as if stable).

7. Run upper bridge to set-depth minus 50 ft and collect four or more pressure readings.

8. Lower bridge plug to set-depth plus 50 ft and collect four or more pressure readings.

9. Raise bridge plug to set-depth, collect four or more pressure readings, then set bridge plug to isolate middle completion interval. Monitor head change in middle interval with internal pressure transducer/datalogger.

10. Measure water level in well to determine head change and establish a reference head elevation (treated as if stable).

11. Install PXD in uppermost interval and monitor head change in uppermost interval.

12. After five days, measure water level in upper interval, then remove equipment and download dataloggers.

This procedure provides in-well calibration of pressure versus head (i.e., density which is a function of the temperature profile) for use in calculating the head for each isolated interval. No problems were encountered in these operations.

A.2.4.2 Pressure/Head Measurements

The bridge plug/PXD assemblies were supplied and installed by Baker Hughes Corporation on their own wireline. The PXDs were Sunada Model STC8064A with a rated measurement accuracy of 0.1 percent FS. PXDs with various pressure ranges were used to suit the depth of installation. Information was collected by a built-in datalogger recording on a set time interval, which was every 5 minutes following an initial 20-minute delay after the datalogger was started. The datalogger time is in decimal hours. Since there was no data connection to the surface once the bridge plug were set, data could not be read or evaluated until the bridge plugs were retrieved. Five days of monitoring was expected to be sufficient to determine the behavior of the intervals.

Table A.2-3 shows the interval-specific pressure and head measurements, including the calibration data. Graphs of the interval monitoring are included in Section A.3.1.1. Note that the corrected depths for the bridge plugs are somewhat different from the PXD set depths that had been specified and listed in the Morning Reports. The set depths were located by measuring from casing collars, but there was a misunderstanding in the field about the direction of the measurement, up versus down, from the collars. However, there is no problem using the data collected at the actual locations once the location was verified. The location corrections are discussed in Section A.3.1.1. The datalogger files for the pressure transducers can be found on the enclosed CD, labeled as follows: gradient.xls (upper interval), EREC1U.xls (middle interval), and EREC1L.xls (lower interval). A readme.txt file is included in Attachment 5, which describes the data files.

Table A.2-3
Interval-Specific Head Measurements

Interval	Comment	Depth ft bgs	Depth m bgs	PXD Measurement psig
Upper	Final Head (e-tape)	1,855.78	565.64	---
Middle	Reference Head - composite of upper two intervals (e-tape)	1,855.85	565.66	590.94
	Bridge Plug set depth minus 50 ft	3,178.29	968.74	569.54
	Bridge Plug set depth - Final Pressure	3,227.69	983.80	590.34
	Bridge Plug set depth plus 50 ft	3,277.19	998.89	612.52
Lower	Reference Head - composite of all three intervals (e-tape)	1,855.92	565.68	1,069.91
	Bridge Plug set depth minus 50 ft	4,275.76	1,303.25	1,040.59
	Bridge Plug set depth - Final Pressure	4,325.15	1,318.31	1,061.85
	Bridge Plug set depth plus 50 ft	4,374.65	1,333.39	1,081.70

ft bgs - Feet below ground surface
m bgs - Meters below ground surface
psig - Pounds per square inch gauge

A.2.5 Pump Installed for Development and Testing

A high-capacity pump was temporarily installed for well development and testing. This pump was later replaced with a lower capacity, dedicated pump for long-term sampling. The development and testing pump was the highest production-rate pump available that would physically fit into the well and still allow an access line to pass by. The access line was required to guide the flow logging and discrete sampling tools past the pump and into the completion intervals.

A.2.5.1 Pump Installation

The pump installed for development and testing was a Centrilift 86-FC6000 (387 Series) electric submersible consisting of two tandem pump units (01F83184 and 01F83185), with 43 stages each, and a 130-horsepower (hp) motor (375 Series). Attachment 1 contains the manufacturer's performance specifications for this pump. The pump was installed on 2 7/8-in. Hydril tubing, and was landed with the bottom of the motor at 2,029.11 ft bgs, which placed the pump intake at 1,982.96 ft bgs. A model "R" seating nipple was placed just above the pump in the production tubing to allow future installation of a wireline-set check valve. The pump was operated without a check valve during development to allow the water in the production tubing to backflow into the well when the pump was shut down. This was intended to "surge" the well and aid in development. A check valve was installed after development to prevent such backflow prior to the constant-rate pumping test. An Electra Speed 2250-VT Variable Speed Drive (VSD) was used to regulate the production of the pump.

To maintain a constant production rate for testing, the VSD was connected to the transmitter of the Foxboro flowmeter in a feedback loop to supply the VSD with continuous flow rate information. The VSD automatically adjusts the frequency of the power supplied to the pump to maintain a constant production rate. The flowmeter record shows that this worked very well and a constant production rate could be maintained as drawdown progressed.

A.2.5.2 Pump Performance

Initial results from evaluation of the pump performance on January 3, 2000, are shown in Table A.2-4. These production rates are similar to the projected performance supplied by the manufacturer for this pump. However, the following day pump performance began to decline, finally stabilizing on January 6, 2000, at a reduced maximum production rate of 125 gpm at 70 cycles per second (hertz [hz]). The pumping rate was maintained during the constant-rate test at about 120 gpm, and at the end of the test the VSD was running near 70 hz. The VSD shut down the pump at various times throughout development and testing, apparently because of power supply problems and a problematic interaction of the VSD with the generators. Several shutdowns occurred in cold conditions just before dawn and may be related to operating the VSD in extreme temperature conditions. One of these shutdowns prematurely terminated the constant-rate pumping test.

Table A.2-4
Pump Performance

Date	VSD Setting (hz)	Production Rate (gpm)	Wellhead Pressure (psi)	Approximate Drawdown (ft)
1/03/2000	58.7	61	6	NA
1/03/2000	60.0	77	10	1.25
1/03/2000	62.0	102	19	1.7
1/03/2000	64.0	125.8	30	2.5
1/03/2000	66.0	145.1	41	2.9
1/03/2000	68.0	157.5	48	3.3
1/03/2000	70.0	167.5	54	3.9
1/26/2000	69.6	120.4	---	3.86
1/31/2000	69.8	120.0	---	3.9

hz - Hertz, cycles per second
gpm - Gallons per minute
psi - Pounds per square inch
ft - Feet

The cause of the decline in performance was not known and considerable checking of the power system and the pump control system was done. One possibility that was investigated was whether the produced water contained air, entrained and/or dissolved, causing cavitation in the pump and resultant reduced efficiency. An attempt was made to monitor the air content of the produced water. This information is presented in Section A.2.6.2.3. However, no connection was ever established. After the pump was removed from the well, it was noted during testing at the surface that there were abnormal grinding noises in the upper pump unit, which may be related to the reduced production. This pump was subsequently returned to the factory for repair.

A.2.5.3 Turbulence in the Well

Another problem from a data collection standpoint was noise in the PXD drawdown monitoring data. It was thought that the noise may also have been due to air in the produced water causing cavitation, and resulting in turbulence in the well. The noise may be an oscillation of the water surface superimposed on the drawdown response; some such movement of the water surface was observed with an e-tape. However, the frequency and magnitude of the movement was not as great as the noise. This turbulence is attributed to the pump since the noise was not present in the transducer record when the pump was not in operation. The turbulence may be the result of some characteristic of the pump or the pump installation. Similar noise was observed in the drawdown records for the other wells in which this pump was used for testing.

A.2.6 Development

There were two objectives for development activities, improvement of the hydraulic connection of the well completion to the formation and restoration of the natural water quality. Development activities were primarily designed to improve the physical condition of the well completion and borehole. This involved removing drilling fluid and loose sediment left from drilling and well construction to maximize the hydraulic efficiency of the well screen, gravel pack, and the borehole walls. These improvements promote efficient and effective operation of the well and accurate measurement of the hydrologic properties.

Restoration of the natural water quality includes removal of all nonnative fluids introduced by the drilling and construction activities and reversal of any chemical changes that may have occurred in the formation due to the presence of those fluids. This objective of development addresses the representativeness of water quality parameter measurements and chemical analyses of samples taken from the well. Another aspect of this objective was to remove nonnative water from completion intervals receiving water due to natural gradient flow from other intervals and reverse chemical changes that have occurred as a result. Since the well completion cross-connects intervals of different heads and hydraulic conductivities, such natural circulation was presumed to have been occurring since the well was drilled. Measurement of this circulation is addressed later under ambient flow logging with the thermal flowmeter. This would be important for collection of representative discrete downhole samples that are intended to distinguish differences in water quality between completion intervals.

Restoration of natural groundwater quality is mostly a function of the total volume of water produced. Consequently, discrete sampling for groundwater characterization was rescheduled to the end of the development stage. An evaluation of the status of development at the time of sampling will be presented in Section A.3.6.

The history of the development phase for Well ER-EC-1 is shown in Table A.2-1. The generic plan allowed seven days for this phase, but additional time was required to sort out problems with the pump and to adjust the schedule to fit into the overall work scheme for UGTA field activities.

A.2.6.1 Methodology and Evaluation

The basic methodology for hydraulic development was to pump the well at the highest possible rates, and to periodically surge the well by stopping the pump to allow backflow of the water in the pump column. The parameters of the pumping operations, production rates and drawdown responses, were recorded continuously by a datalogger from the production flowmeter and a downhole PXD. During flow logging and discrete-interval sampling, the PXD had to be removed to allow access for the flow logging tool and the discrete bailer. Barometric pressure was also recorded in conjunction with PXD records.

Monitoring during development included a variety of general water quality parameters intended to evaluate both the effectiveness of the development activities and the status of development. These parameters included visual observation of sediment production and turbidity to evaluate removal of sediment, monitoring of drawdown associated with different production rates to evaluate improvement in well efficiency, water quality parameters (temperature, pH, EC, turbidity, and DO), and bromide concentration. The drilling fluid used during drilling was “tagged” with lithium bromide to produce concentrations in the injected fluid ranging from 10 mg/L to over 50 mg/L for injection. The concentration was increased as water production increased to keep the concentration in the produced water at measurable levels. This methodology served to provide a measure of water production during drilling through reference to the dilution of the tracer, and later serves as a measure of development for evaluating the removal of residual drilling fluids from the formation.

A.2.6.2 Hydraulic Development Activities

A PXD was installed in the access tube to monitor the hydraulic response of the well. Information on the PXD installation and calibration is presented in Table A.2-5.

Due to the method of installing these PXDs, there is no exact measurement of the depth of the PXD from the wireline that they are hung on. The vented cables used to install the PXDs are difficult to meter during installation because the cable jackets can move and stretched relative to the interior strain cable. Therefore, the installation depth is calculated by adding the depth of the PXD below water to the measured depth to water. The depth below water is calculated from the pressure

Table A.2-5
PXD Installation Prior to Well Development

Design Analysis H-310 PXD SN 2266, 0-30 psi					
Install Date: 1/3/2000					
Installation Calibration Data: 1/3/2000					
Static water level depth 1,856.07 ft bgs					
Stations	Cal 1[a]	Cal 2	Cal 3	Cal 4	Cal 5
PXD depth ft below TOC[b]	1,690	1,709	1,721	1,733	1,745
PXD psi		0.7360	5.8676	11.0220	16.1690
Delta depth (ft): Cal5 - Cal2					36
Delta psi: Cal5 - Cal2					15.433
Density ft water/psi: delta depth / delta psi (in ft/psi)					2.333
Equivalent ft water: PXD psi (at Cal 5) x density of water (ft/psi)					37.72
Calculated PXD installation depth: static water level + equiv. ft water					1,893.79

ft bgs - Feet below ground surface
TOC - Top of casing
PXD - Pressure transducer
psi - Pounds per square inch

[a] Cal 1 station is above the water table.
[b] PXD depth shown does not include the length of the rubber vent hose.

reading of the PXD at the installation depth using a water density conversion factor determined from the installation calibration. The calibration information is used to check the linearity of the PXD response and determine the density conversion factor from the pressure change/depth change data.

The well was pumped for seven days prior to flow logging. This period was longer than anticipated due to working through problems with the pump, as described previously in Section A.2.5. During that time, development consisted of pumping at rates as great as possible, periodically stopping the pump to surge the well with the backflow from the production tubing. Step-drawdown protocol was used when restarting the pump to assess both well performance and pump performance. Water quality was monitored using both field-lab analyses of grab samples and with a flow-through cell with instrumentation recorded by a datalogger.

A.2.6.2.1 Pumping Rates and Hydraulic Response

Figure A.2-2 shows the datalogger record of the pumping rate and hydraulic response during the development phase. Figure A.2-3 shows the datalogger record of the hydraulic response and the barometric pressure variation. An electronic file of these data can be found on the attached CD with the file name EC1-AqtestComplete.xls. The first two days of the data record show the initial testing of the pump to determine the operating range (see Table A.2-4) and the troubleshooting efforts dealing with declining pump performance. After pump performance stabilized, the pump was generally operated at a rate of 125 gpm for the remainder of the development phase except while conducting step-drawdown protocol. This production rate was close to the reduced maximum rate of the pump, and was limited by pump performance rather than well performance. Drawdown during pumping was less than 4 ft.

As noted in Section A.2.5, the production rate for most of the development phase was considerably less than the maximum rate the pump should have produced. However, the reduced pumping rate probably did not make a significant difference to the end result of development and testing. Even at the maximum rate for the pump production would probably not have extended below the upper completion interval.

A.2.6.2.2 Surging and Step-Drawdown Protocol

Figure A.2-2 and Figure A.2-3 show each instance when the pump was stopped, and also the step-drawdown protocol that was conducted whenever pumping was resumed. The step-drawdown protocol was used whenever the pump was restarted after a period of recovery. Pumping was run for a certain period of time at each of three progressively higher rates: 64 gpm, 104 gpm, and 126 gpm. Drawdowns at the end of the fixed pumping period could then be compared to evaluate the well performance and any improvement in hydraulic efficiency since the last protocol was run. The pump control parameters (frequency and amperage) were also monitored during these steps to keep track of pump performance.

Stopping the pump produced a surging effect in the well, which can be seen in Figure A.2-4. This figure shows a representative instance of surging expanded to illustrate the detail. When the pump is stopped, a brief initial pressure surge dissipates the momentum of the water moving to the pump causing the water in the production casing to backflow through the pump into the well. The water level in the well casing temporarily rises above the head in the formation around the completion because the backflow down the casing is faster than the water in-flow from the formation. This is referred to as a “U-tube” effect. This action produces a reverse head differential which “surges” the well. The surge rapidly dissipates, merging into the recovery curve. This effect was very minor in this well due to the high transmissivity of the formation.

Figure A.2-5 shows a representative closeup of the step-drawdown protocol. The scale has been expanded for this graph, which shows considerable noise in the PXD measurements present while the pump was operating. After pump performance stabilized, the pumping rates for the three steps were standardized at certain VSD settings (power frequencies of approximately 60, 66, and 70 hz), which yielded nominal production rates of approximately 64, 104, and 125 gpm, respectively. Note that there were small variations in frequency settings and resultant production rates throughout the development and testing activities. These three steps were also used for flow logging. The performance of this well did not change much during the development phase and the step-drawdown protocol.

A.2.6.2.3 Other Observations

During development, visual observations were made of the water discharge, primarily whenever the pump was started, to monitor the amount of sediment produced. Log book entries indicated that there was initial reddish-brown turbidity in the water for up to five minutes each time the pump was started, after which the water cleared. In addition, it appeared that the produced water contained some amount of air as entrained bubbles and possibly in the dissolved phase.

The amount of air in the produced water was monitored using an ad hoc field procedure which involved filling a 300-milliliter (mL) biological oxygen demand (BOD) bottle with produced water collected from the sampling port at the wellhead. The bottle was filled from the bottom up with tubing, and tightly stoppered without any trapped air. After about 15 minutes, an air space formed at the top of the bottle. The remaining water volume was measured, and the percent air was calculated from the volume difference. Table A.2-6 shows the results of these measurements. The amount of air so measured was somewhat erratic, varying from a maximum of 3 percent to zero, with 1 percent commonly observed. Temperature and air pressure of the sample bottles were fairly constant throughout the study period. No correlation of production rate with percent air was noted.

A.2.7 Flow Logging During Pumping

Downhole flow logging was conducted after the development phase. Data on the distribution of water production from the different completion intervals would be used to determine the best production rate for constant-rate test, and later in analyzing the hydraulic and analytical data. It was expected that the different completion intervals would not respond uniformly to pumping due to the influence of vertical hydraulic gradients, differences in the hydraulic conductivity of the geologic units, and flow losses along the completion. This is of particular concern in wells such as ER-EC-1 that are completed with multiple completion intervals in different formations. The flow logging directly measured the amount and location of incremental water production downhole.

A.2.7.1 Methodology

The information on water production from each completion interval was collected at different pumping rates to evaluate the linearity of effects for use in later interpretation. The same rates were used as for the step-drawdown protocol during development (64, 104, and 126 gpm), so that results could be directly compared with previous observations.

Flow logging was conducted by the DRI from January 10 to 12, 2000. A complete program of flow logging was run, including both stationary measurements and trolling logs. A temperature log was also recorded in combination with the flow logging to help in identifying production patterns and specific production locations. This was the first well in which this type of downhole flow measurement equipment has been run for the UGTA Project, and new equipment

Table A.2-6
Air in Produced Water

Date	Time	Percent Air	Date	Time	Percent Air
1/06/2000	12:27	2.7	1/09/2000	22:00	0.0
1/06/2000	14:23	0.7	1/10/2000	00:00	0.7
1/06/2000	20:00	0.0	1/10/2000	02:00	1.0
1/06/2000	22:00	1.0	1/10/2000	04:00	0.7
1/07/2000	00:00	0.0	1/10/2000	13:00	1.3
1/07/2000	06:00	0.7	1/10/2000	15:00	1.0
1/07/2000	08:45	1.0	1/10/2000	17:00	1.7
1/07/2000	11:04	0.7	1/10/2000	19:00	1.3
1/07/2000	13:00	1.4	1/10/2000	21:00	0.7
1/07/2000	15:00	0.3	1/10/2000	22:00	1.3
1/07/2000	17:00	1.0	1/11/2000	00:00	1.0
1/07/2000	19:00	0.7	1/11/2000	02:00	1.0
1/07/2000	21:00	0.3	1/11/2000	04:00	1.0
1/07/2000	23:00	0.3	1/11/2000	06:00	1.0
1/08/2000	01:00	0.0	1/11/2000	08:00	1.3
1/08/2000	02:00	0.7	1/11/2000	10:00	1.0
1/08/2000	04:00	1.0	1/11/2000	12:00	0.3
1/08/2000	15:30	1.0	1/11/2000	14:00	1.0
1/08/2000	17:35	0.7	1/11/2000	16:00	1.3
1/08/2000	19:30	1.0	1/11/2000	18:00	0.7
1/08/2000	22:00	0.3	1/11/2000	20:00	0.3
1/09/2000	00:00	0.3	1/11/2000	22:00	0.3
1/09/2000	02:00	0.7	1/12/2000	02:00	1.3
1/09/2000	06:00	0.7	1/12/2000	04:00	1.0
1/09/2000	08:08	1.3	1/12/2000	06:00	0.7
1/09/2000	10:00	1.0	1/12/2000	08:00	1.0
1/09/2000	12:00	0.7	1/12/2000	10:00	0.7
1/09/2000	14:00	1.3	1/13/2000	08:30	1.0
1/09/2000	16:00	0.7	1/13/2000	14:50	0.3
			1/13/2000	17:00	0.3

was being used for the first time. Therefore, a variety of different logging runs at various speeds and directions were tried to evaluate methodology.

A.2.7.1.1 Equipment

The DRI flow-logging system consists of, from top to bottom, (all Computalog™ Flexstak equipment): telemetry cartridge, a centralizer, a temperature tool, another centralizer, and a fullbore flowmeter. This tool string has a maximum diameter of 1 1/16-in., is temperature rated to 176 degrees Celsius (°C), and pressure rated to 17,000 psi. The fullbore flowmeter has a minimum measurement of 5 fpm for a static tool, and a resolution of 0.1 percent.

The fullbore flowmeter has a collapsible impeller that opens to cover a much larger percentage of the casing cross section than a standard fixed-blade impeller. A centralizer centers the tool string in the wellbore. The temperature tool is also run to provide gradient and differential temperature information with high resolution. In conjunction with information from the spinner tool, the temperature tool yields information useful in fluid flow analysis. The fullbore flowmeter needs a minimum of 5-15 fpm of relative velocity to activate the impeller. The minimum flow past the impeller, known as the stall speed, can vary depending on the condition of the impeller/flowmeter.

A.2.7.1.2 Logging Technique

Ten trolling logs were run at different line speeds between the top of the upper screened interval to below the bottom of the lower screened interval. Typically these runs were made in the following order: (1) a down run at 20 fpm, (2) an up run at 40 fpm, and (3) a down run at 60 fpm. This set of three runs was conducted at three different discharge rates requiring a total of nine runs. In addition to the moving logs, static measurements (tool held motionless in the well) were taken above the upper screened interval and between screened intervals.

Calibration is completed by comparing the raw flowmeter readings of counts-per-second to known velocities. Low flow-rate calibration data are obtained from a DRI calibration facility which can produce 0 to 60 gpm flow through 5.5-in. casing. The flow logging tool calibration was also checked on site against the production flowmeter readings at the three pumping rates by measuring uphole velocities in the 5.5-in. casing above the uppermost screen.

A.2.7.2 Flow Logging Results

Table A.2-7 lists the trolling flow logs that were run. Stationary measurements were also taken at locations between completion intervals at the three different flow rates. Table A.2-8 lists these measurements.

The results of the trolling flow logs are presented in Figures A.2-6 through A.2-11. Figure A.2-6 and Figure A.2-7 show flow logs for two different trolling speeds (20 fpm upwards and 40 fpm downwards) at a well production rate of 64 gpm. Figure A.2-8 and Figure A.2-9 depict flow logs for two different trolling speeds (20 fpm upwards and 40 fpm downwards) at a well production rate of 104 gpm. Figure A.2-10 shows the flow log for a trolling speed of 20 fpm downwards at 126 gpm. Figure A.2-11 depicts the temperature log of two discharge rates of 126 and 64 gpm. The optimal logging configuration was determined to be a downwards trolling speed of 20 fpm, providing the least induced noise. However, this configuration was only run at the 126 gpm production rate. The closest alternative logs to 20 fpm for the other two production rates are shown in Figures A.2-6 through A.2-10. Not all of the logs run are shown since the information is repetitive.

Table A.2-7
Listing of Trolling Flow Logs

Run Number	Date of Run	Direction of Run	Run Speed	Surface Discharge	Run Start/Finish
			fpm	gpm	ft bgs
ec1mov01	1/10/2000	DOWN	20	126	2,206.2-4,670.2
ec1mov02	1/10/2000	UP	40	126	4,649.8-2,250
ec1mov03	1/11/2000	DOWN	60	126	2,250-4,649.8
ec1mov04	1/11/2000	UP	60	126	4,642.2-2,250.8
ec1mov05	1/11/2000	UP	20	104	4,642.2-2,250.8
ec1mov06	1/11/2000	DOWN	40	104	2,250-4,649.8
ec1mov07	1/11/2000	UP	60	104	4,742.2-2,250.8
ec1mov08	1/12/2000	UP	20	64	4,642.2-2,250.8
ec1mov09	1/12/2000	DOWN	40	64	2,150-4,649.8
ec1mov10	1/12/2000	UP	60	64	4,642.2-2,250.8
ec1mov11	1/12/2000	DOWN	20	0	2,220-2,879.8

fpm - Feet per minute
gpm - Gallons per minute
ft bgs - Feet below ground surface

Table A.2-8
Listing of Stationary Flow Measurements

Log Run	Pumping Rate gpm	Depth ft bgs
stat1	126	2,275
stat2		3,060
stat3		4,200
stat4	103	2,275
stat5		3,107
stat6		4,200
stat7	64	4,000
stat8		3,100
stat9		2,275

gpm - Gallons per minute
ft bgs - Feet below ground surface

The flow logs show fairly conclusively that about 100 percent of the production in the well was derived from the upper part of the upper completion interval (2,200 to 2,500 ft bgs) regardless of the production rate. The temperature log indicates an in-flow of colder water between 2,200 and 2,500 ft bgs. Then, the temperature gradually increases with depth.

There no flow was measured between the completion intervals. The trolling flow logs indicate that flow from the lower completion intervals uphole did not exceed the threshold relative velocity.

A.2.8 Constant-Rate Test

A constant-rate pumping test was conducted following well development to provide hydraulic response data on well production. Prior to the test, the water level in the well was monitored to observe recovery to ambient head from development pumping and to establish baseline pretest conditions. Pumping for this test commenced on January 19, 2000, and continued for almost eight days until January 27, 2000. The test was terminated by automatic shutdown of the VSD due to a control problem. The barometric efficiency of the well was also determined from the head response to barometric changes during this period. In addition, pumping during the constant-rate test served to continue and complete the development process to restore natural water quality for sampling purposes. Following the pumping period, head recovery was monitored for 4.4 days.

A.2.8.1 Methodology

A continuous datalogger record was captured for barometric pressure and head pressure on the PXD in the well, extending from pretest monitoring through the recovery monitoring. During pumping, the discharge rate of produced water was also recorded continuously. The production rate of the pump was controlled using a feedback loop from the discharge flowmeter to ensure a consistent rate. In addition, water quality was monitored during the constant-rate test with field analyses of grab samples taken daily.

A pumping rate of 120 gpm was chosen for the test. This rate was near the maximum rate the pump was able to achieve in its impaired condition, but left some small amount of upward adjustment of the VSD available. Since one of the requirements for a constant-rate test is to maintain a stable constant-rate, the ability to compensate for factors that might decrease the production rate was important. Experience with this well during development suggested that substantial changes were not expected and there would be a slow, steady drawdown. Some uncertainty existed as to whether the performance of the pump might decline further.

Based on experience during the early part of development, a PXD with a range of 0-15 psi was installed after flow logging for the pretest monitoring and constant-rate test. The lower range maximized the accuracy of the pressure measurements, which are proportional to the overall measurement range of the PXD. The 0-15 psi range provided an appropriate range of measurement for the maximum anticipated drawdown.

The PXD was installed on January 14, 2000, at a calculated depth of 1,879.54 ft bgs based on the calibration performed when the PXD was removed on February 2, 2000. Calibration information could not be obtained during the installation because the PXD was installed after flow logging to monitor the recovery when the water level in the well was not stable. Table A.2-9 shows the PXD installation and calibration data for the constant-rate test.

Table A.2-9
PXD Installation for Constant-Rate Test

Design Analysis H-310 PXD SN 2264, 0-15 psi					
Install Date: 1/14/2000					
Removal Calibration Data: 2/2/2000					
Static Water level depth 1,856.11 ft bgs					
Stations	Cal 1[a]	Cal 2	Cal 3	Cal 4	Cal 5
PXD depth ft below TOC[b]	1,740	1,763	1,769	1,775	1,781
PXD psi		2.3299	4.9254	7.4931	10.05
Delta depth (ft): Cal5 - Cal2					18
Delta psi: Cal5 - Cal2					7.720
Density ft water/psi: delta depth / delta psi (in ft/psi)					2.332
Equivalent ft water: PXD psi (at Cal5) x density of water (ft/psi)					23.43
Calculated PXD installation depth: static water level + equiv. ft water					1,879.54

PXD - Pressure transducer
psi - Pounds per square inch
ft bgs - Feet below ground surface
TOC - Top of casing
[a] Cal1 station is above the water table.
[b] PXD depth shown does not include the length of the rubber vent hose.

A.2.8.2 Hydraulic Data Collection

Figure A.2-12 shows the datalogger record during the constant-rate test pumping period for the pumping rate and the PXD pressure. Figure A.2-13 shows the PXD pressure record and the barometric pressure record for both the pumping period and the recovery period. Pumping started on January 19, 2000 (19.58334 Julian days), and was terminated on January 27, 2000 (27.24254 Julian days). The overall average pumping rate was 120.5 gpm. The pumping rate record appears unsteady with an apparent fluctuation range of about 0.6 gpm in the flowmeter readings. The unsteadiness may be an actual variation in the pumping rate, possibly associated with pump performance, or noise in the magnetic flowmeter data. As mentioned earlier, while the pump was running there was also considerable noise in the PXD measurements thought to be caused by turbulence in the water level resulting from pumping. The production rate data can be found in file EC1-AqtestComplete.xls on the CD.

A.2.9 Water Quality Monitoring

Water quality monitoring of the well discharge was conducted during pumping to provide information on water chemistry and to indicate when natural groundwater conditions predominate in the pumping discharge. Certain parameters such as bromide ion concentration, pH, EC, turbidity and DO were expected to be lower as development progressed, indicating natural groundwater as opposed to the affected well water from drilling. Also, parameter values should stabilize after prolonged pumping and development as more natural groundwater permeates the well environment. During cycles of pumping and shutdown, the parameters were expected to gradually change toward the values observed toward the end of the previous pumping cycle. The extremes of parameter values between the beginning and end of the pumping cycles should diminish as development progresses.

The standard parameters that were monitored during development and testing of Well ER-EC-1 include the following: pH, EC, temperature, turbidity, DO and bromide ion. In addition, lead and tritium were sampled in compliance with the schedule in the Fluid Management Plan (including waivers) (DOE/NV, 1999). In-line monitoring data was collected continuously for all the standard parameters except bromide. Grab samples were obtained every two hours, when possible, and analyzed for all the water quality parameters.

Pumping was initiated on January 3, 2000, at 14:40. In-line monitoring began at 16:10 hours with the installation and operation of a Hydrolab® H20 Multiprobe. The Hydrolab® fed directly to the datalogger, where data could be continuously accessed via a portable laptop computer. Grab sample monitoring was begun on January 4, 2000, at 10:00 hours when the field laboratory was fully operational.

A.2.9.1 Grab Sample Monitoring

Grab samples were obtained from a sample port located on the wellhead assembly. For the development phase, grab samples were collected and analyzed every two hours beginning on January 4 and ending on January 13, 2000, at 19:30 hours after the discrete bailer sample was collected. For the constant-rate pumping test, a grab sample was obtained once a day beginning on January 22 and ending on January 26, 2000.

Grab samples were analyzed using equipment and methodology contained in the DOP ITLV-UGTA-312, “Water Quality Monitoring”; DOP ITLV-UGTA-301, “Fluid Sample Collection”; and DOP ITLV-UGTA-101, “Monitoring and Documenting Well Site Activities.” All instruments were calibrated according to DOP ITLV-UGTA-312 at the beginning of each 12-hour shift, and a calibration check was completed at the end of each shift. The following instruments were used to analyze grab samples:

- YSI 58 (DO)
- YSI 3500 multimeter (for pH, EC and temperature)
- HF Scientific DRT-15C Turbimeter (turbidity)

- Orion 290A (bromide)
- HACH DR100 Colorimeter Kit (lead)

The results of grab sample monitoring have been compiled and are presented in Attachment 2. Two graphs are presented showing water quality parameters versus total discharge in gallons. Figure A.2-14 shows electrical conductivity, pH, and dissolved oxygen. Figure A.2-15 shows turbidity and bromide concentration. The temperature parameter remained fairly constant, varying only a few degrees between 34 and 36°C, and the results are not depicted. Figure A.2-14 shows that pH and EC remained fairly constant throughout the monitoring, showing some fluctuations during the constant-rate test. Dissolved oxygen peaked at 7.0 mg/L, and then decreased to about 4.3 at the end of the constant-rate test. In Figure A.2-15, turbidity was mostly below 0.5 nephelometric turbidity units (NTUs), with occasional peaks up to 8.0 NTUs. Bromide was the most erratic of the parameters, even showing an increase during the constant-rate test. The results of lead and tritium monitoring is presented in Section A.4.0, Environmental Compliance.

A.2.9.2 In-Line Monitoring

In-line monitoring was conducted using a Hydrolab® H2O Multiprobe. The Campbell Scientific datalogger recorded data at various sampling intervals ranging from 5 seconds to 5 minutes. These intervals varied depending on changes in pressure and head. Temperature, EC, pH, turbidity, and DO were recorded continuously when the pump was running between January 3 at 16:10, and January 10, 2000, at 05:00. In-line data were also recorded every two hours on a "Water Quality Data Form," for comparison with grab sample results. The Hydrolab® was calibrated and maintenance was performed at the beginning of operations and every three to four days thereafter according to DOP ITLV-UGTA-312. The Hydrolab® was taken off-line during the constant-rate test because it diverts about 2 to 3 gpm away from the flowmeter, which could cause inaccuracies in the data.

The Hydrolab® data correlated with the grab sample data closely on temperature and pH only. Temperature was about 1 to 2°C higher on the Hydrolab®, which was to be expected since it takes a little time to process grab samples during which temperature can decrease. Electrical conductivity was consistently 50-60 micromhos per centimeter (μmhos/cm) lower on the Hydrolab® data. Turbidity and dissolved oxygen data from the Hydrolab® were recorded incorrectly. Hydrolab® turbidity data was much higher then the grab samples by an average of 130 NTUs. Dissolved oxygen was generally lower then grab samples by at least 5.0 mg/L. The inconsistencies in the in-line Hydrolab® can be attributed to the datalogger misinterpreting data in the S12-01 signal from the Hydrolab®. The in-line data have been saved and are contained in the Excel® file, EC1-AqtestComplete.xls on the CD. The columns labeled as Turbidity and DO have been deleted from the file, otherwise the data has not been modified.

A.2.10 Groundwater Sample Collection

Two types of well samples were collected for characterization of the groundwater in Well ER-EC-1: a discrete bailer sample, and a composite sample from the wellhead.

A.2.10.1 Downhole Discrete Sampling

The purpose of a discrete sample is to target a particular depth interval for sampling under either static or pumping conditions. Discrete sampling is optimally performed after the well has been determined to meet the following criteria: (1) the maximum possible development has occurred for the interval in which the samples will be collected, and (2) a pumping rate can be maintained that will ensure a representative sample of the interval. The discrete sampling interval was determined after initial well development and downhole flow and temperature logging.

On January 13, 2000, one discrete sample was obtained from a depth of 2,440 ft bgs at a pumping rate of 126 gpm. The sample was obtained using a DRI boom, logging truck and discrete bailer. The bailer was decontaminated using the methodology in DOP ITLV-UGTA-500, “Small Sampling Equipment Decontamination,” and SQP ITLV-0405, “Sampling Equipment Decontamination.” An equipment rinsate sample was collected from the decontaminated bailer prior to collection of the discrete sample. The samples were processed according to the following procedures: DOP ITLV-UGTA-302, “Fluid Sample Collection”; SQP ITLV-0402, “Chain of Custody”; and SQP ITLV-0403, “Sample Handling, Packaging, and Shipping.” Samples were immediately stored with ice and transported to a secure refrigerated storage. Sample bottles were obtained for the following laboratories: Paragon, Los Alamos National Laboratory (LANL), University of Nevada, Las Vegas - Harry Reid Center (UNLV-HRC), Lawrence Livermore National Laboratory (LLNL), and DRI.

The final, validated results of the January 13, 2000, discrete sample have been tabulated and are presented in Attachment 3. These results can be compared to the results of the discrete groundwater characterization sample taken during drilling, before well completion. That sample was obtained by discrete bailer at a depth of 2,500 ft bgs (DOE/NV, 2000).

A.2.10.2 Groundwater Composite Sample

The purpose of this sample is to obtain a composite of as much of the well as possible. The composite groundwater characterization sample was collected at the end of the constant-rate pumping test from the sampling port at the wellhead. Since it represents a composite of the whole well, there are two criteria that should be met for the sample to be representative: (1) the sample should be obtained after pumping for the longest time, and (2) the pumping rate should be as high as possible in order to include production from as much of the well completion as possible. From the results of the flow logging, the proportional composition of the composite sample can be determined. As discussed in Section A.2.7.2, the flow logging showed that 100 percent of the production of the well came from the upper screened interval between 2,250 and 2,500 ft bgs, and was not significantly dependent on the discharge rate.

On February 1, 2000, a composite characterization sample was collected from the wellhead sampling port directly into sample bottles. A field duplicate sample was also obtained concurrently. A constant flow rate of 120 gpm was maintained throughout the sampling event. At the time of sampling, approximately 2,900,000 gallons of groundwater had been pumped from the well during development and testing activities. The samples were processed according to the same procedures used for the discrete sampling. The samples were immediately put on ice and transported to a secure refrigerated storage. Samples were collected for the following laboratories: Paragon, LANL, and DRI.

The final, validated results of the February 1, 2000, composite sample have been tabulated and are presented in Attachment 3. Examination of the results show that they are very similar to the January 13, 2000, discrete sample. This was not unexpected as both samples appear to have the same origin in the well completion, the upper section of the upper completion interval.

A.2.11 Thermal Flow and ChemTool Logging

Thermal flow logging was conducted at the very end of the development and testing program to determine flow in the well under ambient or static conditions. The result differs from that of the thermal flow logging conducted in the open borehole before well completion because of the modifications resulting from well completion and well development. The ChemTool provides a depth log of temperature, pH, and EC. The thermal flow logging and ChemTool logging were conducted from February 17 to 18, 2000, by DRI.

A.2.11.1 Methodology

The thermal flow log is a stationary log that can measure vertical flow rates at very low velocities (less then 2 gpm). The flow profile along the well completion is constructed from multiple stationary flow measurements. The ChemTool log is a trolling log that collects data on parameter variation with depth.

A.2.11.2 Results

Table A.2-10 shows the results of the thermal flow logging. A flow of greater than 2 gpm downwards was measured in the interval from 2,400 to 2,600 ft bgs. The thermal flow logging tool has an upper measurement limit of 2 gpm. This result was verified with a trolling log using the fullbore flowmeter running downhole at 20 fpm.

The results of the ChemTool logging are presented in Figure A.2-16. The ChemTool log shows a significant change in parameter values above and below about 2,500 ft bgs. This may be related to changes in the flow regime with depth.

Between 2,500 and 2,600 ft downward flow in the wellbore under the ambient gradient ceased, and inflow to the well during pumping decreased to zero.

Table A.2-10
Thermal Flow Logging Results

Depth ft	Flowmeter[a] gpm
2290	0.000 +/- 0.000
2350	-0.343 +/- 0.082
2410	-2.201 +/- 0.001
2500	-2.201 +/- 3.146
2700	-0.599 +/- 0.269
3330	0.000 +/- 0.000

a - (-) indicates downward flow

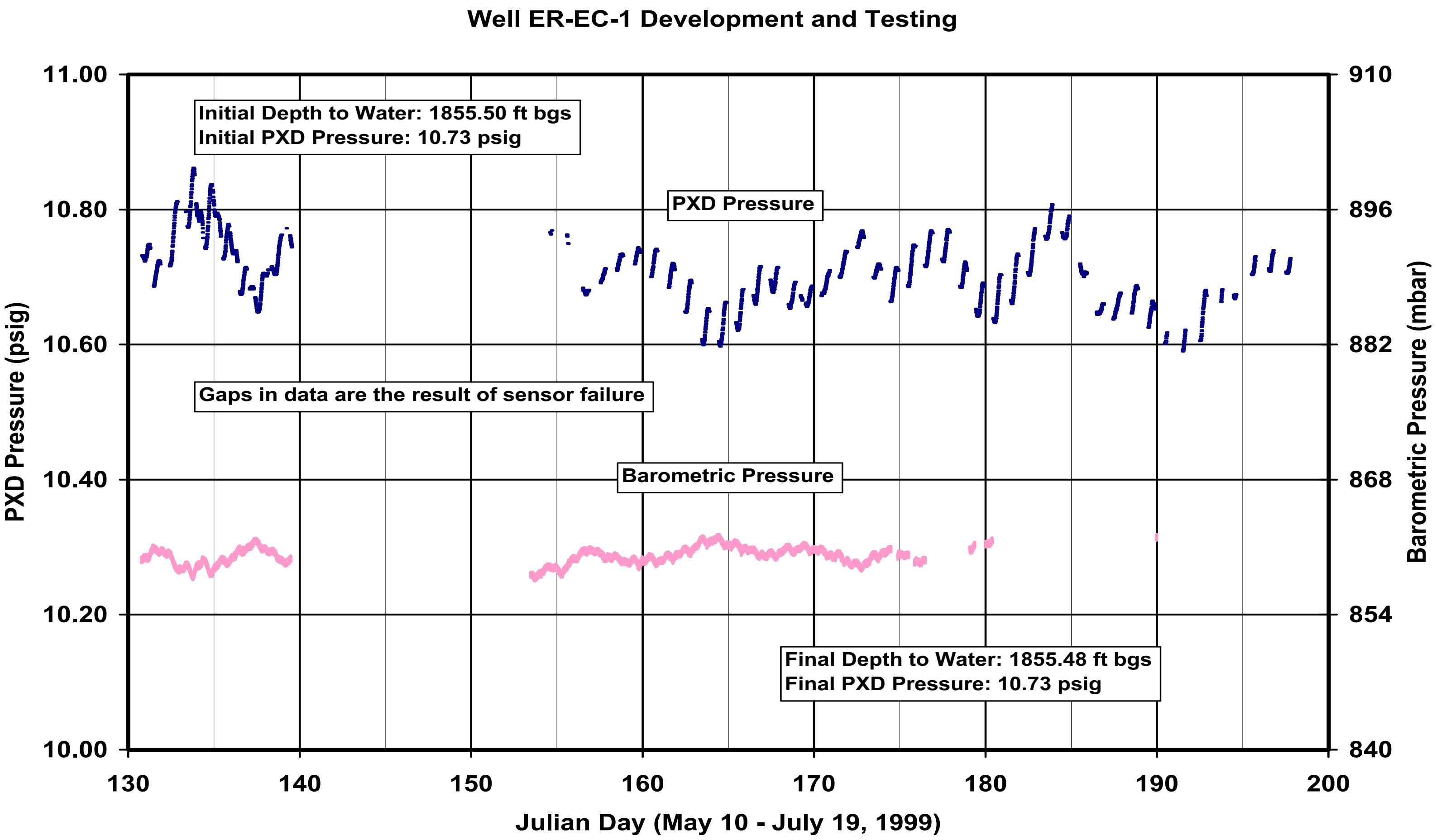
A.2.12 Sampling Pump Installation

On March 9, 2000, a sampling pump was installed in Well ER-EC-1 by Bechtel Nevada (BN) with the assistance of the Electrical Submersible Pump (ESP) Systems representative. The manufacturer’s performance specifications for this pump are presented in Attachment 1. The pump assembly was placed using 2 7/8-in. outside diameter (od) stainless-steel pipe. The bottom of the pump assembly was landed at 2,282.5 ft bgs. The pump intake is located at 2,258.8 ft bgs and the top of the pump assembly is at 2,249.9 ft bgs. The total length of the pump assembly is 32.56 ft. Table A.2-11 summarizes the details of the pump assembly components.

The pump string was landed to a 1-in. landing plate at the wellhead. Figure A.2-17 shows the final wellhead configuration. The pump is controlled via a VSD. On March 10, 2000, a functionality test was conducted on the pump after appropriate wellhead plumbing was attached to the pump string. The discharge was routed to the lined Sump #2. At about 10:15, the pump was started and discharge at the surface commenced approximately 12 minutes later. The pump was run for about 1.5 hours at a discharge rate of between 32 gpm (60 hz and 33 amps) and 43 gpm (72 hz and 40 amps). Approximately 2,500 gals were pumped during the functionality test. No problems were encountered.

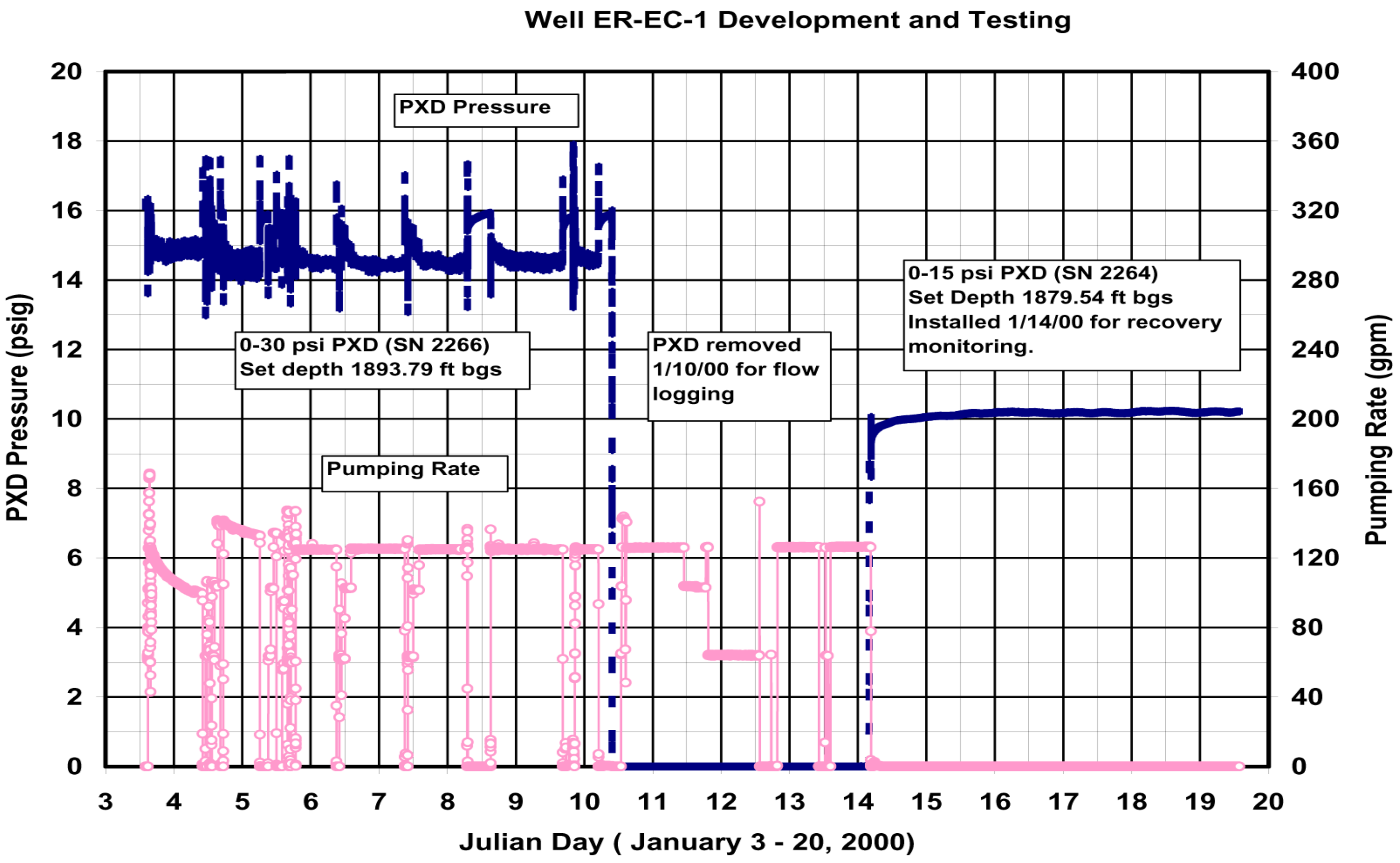
Table A.2-11
Dedicated Sampling Pump

Pump Component	Type/Model	Serial Number	Other Information
Pump	TD 800	2D8I15034	Stage 87
Protector	TR35TD	3B8I07088	None
Motor	CR3THD	1B8I06465	40 Hp, 750 V, 40 amps



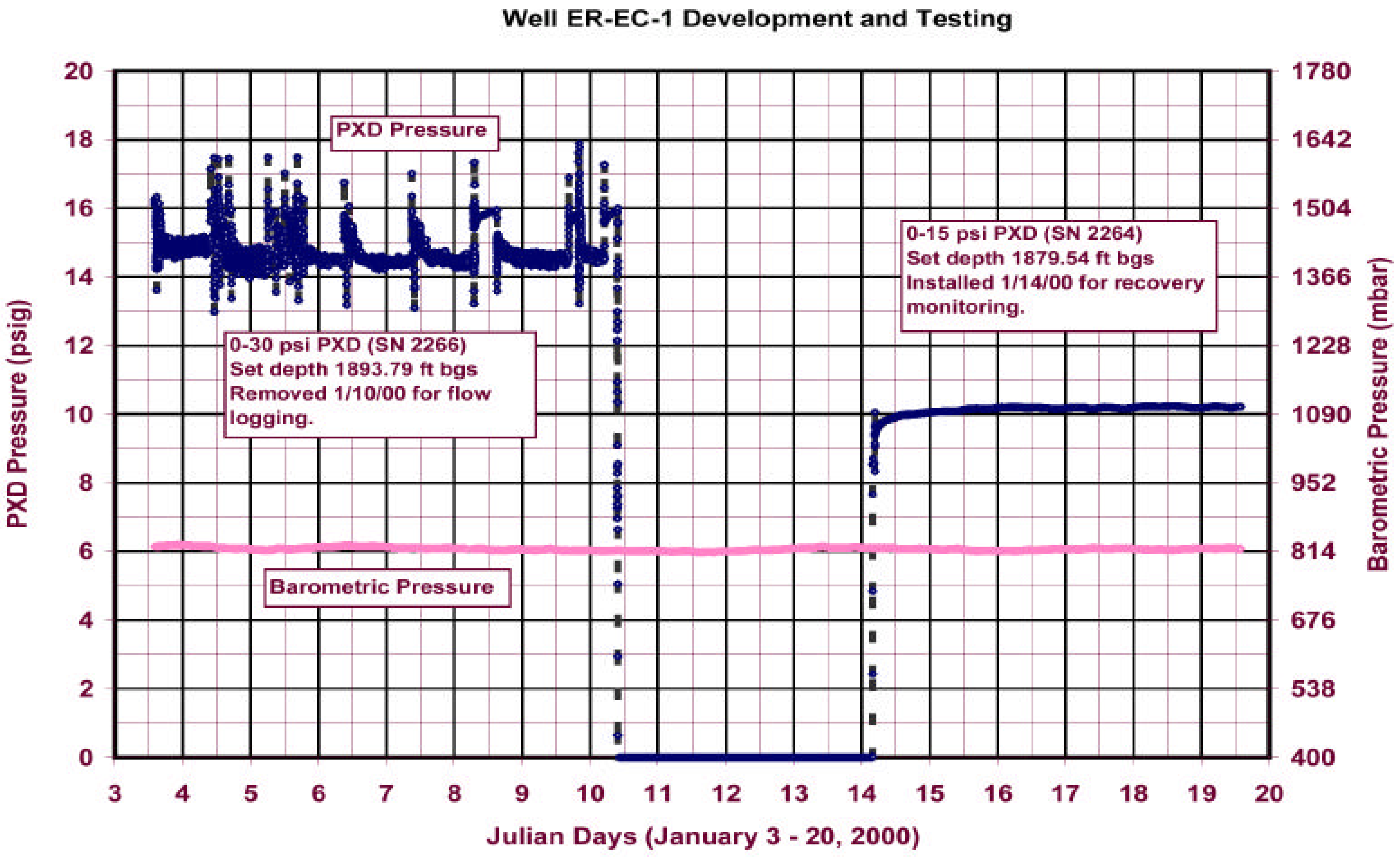
psig- Pounds per square inch gauge
mbar - Millibars
PXD - Pressure transducer
ft bgs - feet below ground surface

Figure A.2-1
Well ER-EC-1 Predevelopment Water Level Monitoring



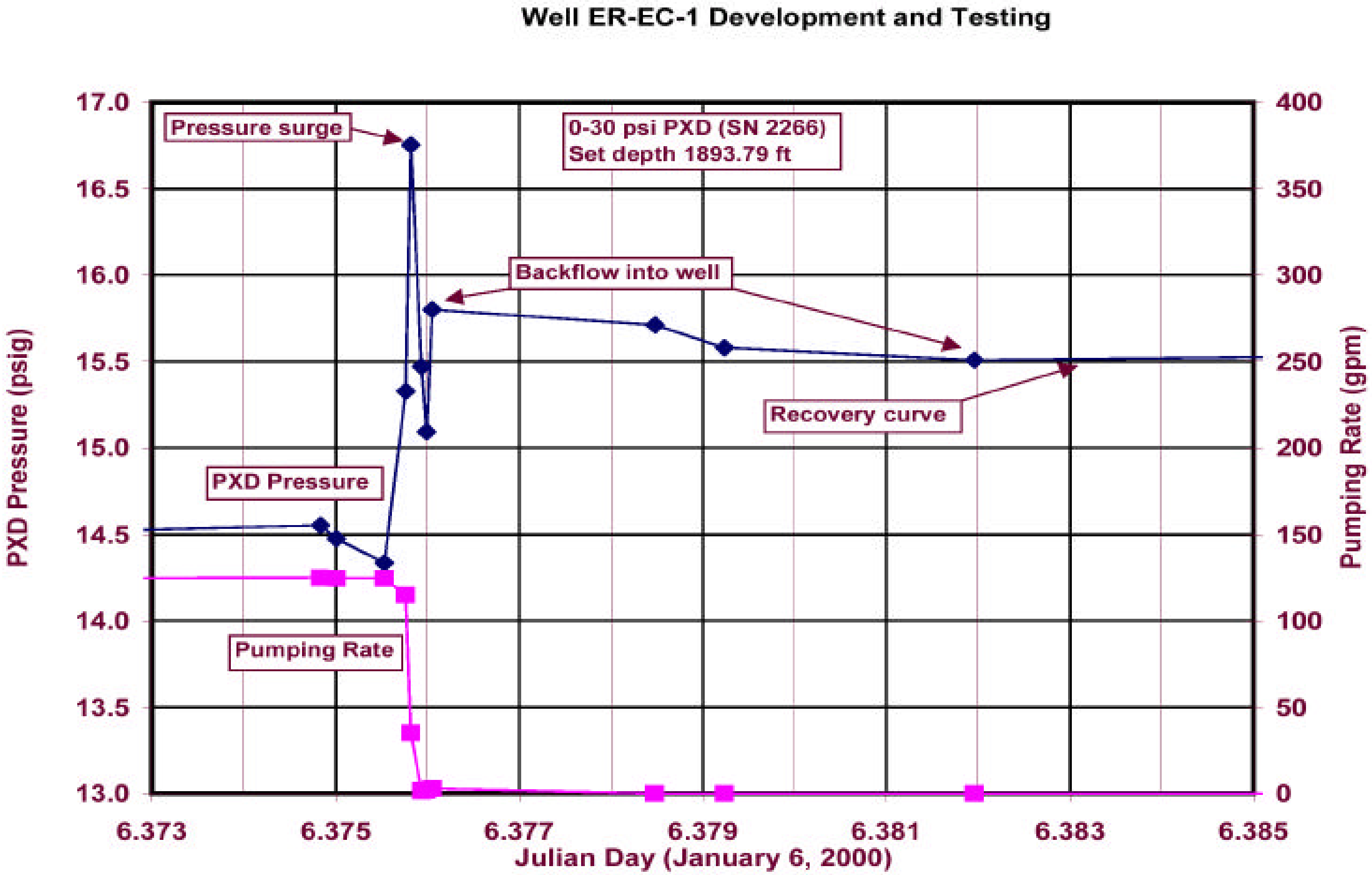
PXD - Pressure transducer
psig - Pounds per square inch gauge
gpm - Gallons per minute
ft bgs - Feet below ground surface

Figure A.2-2
Pumping Rate and Hydraulic Response During Development



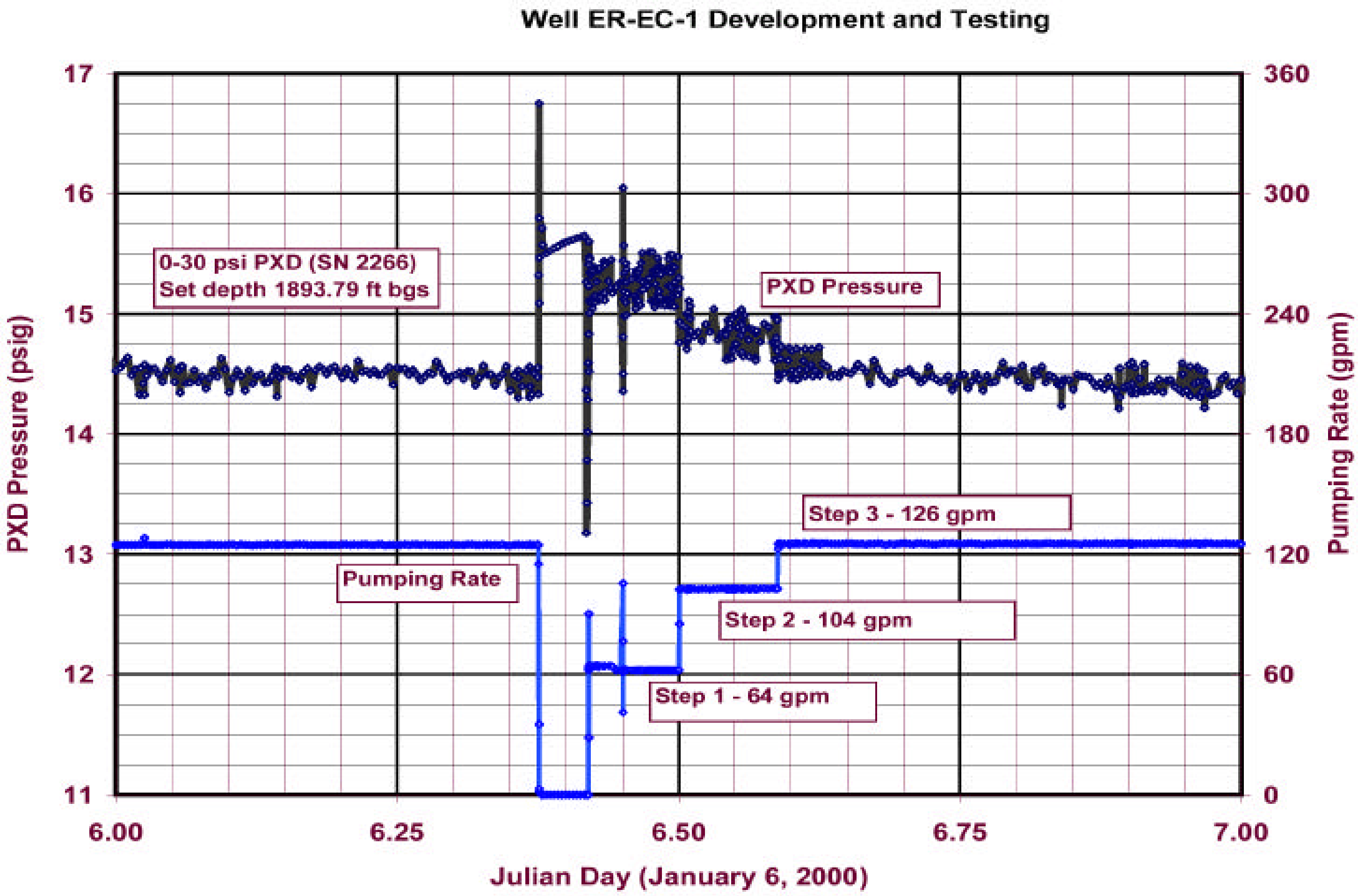
PXD - Pressure transducer
psig - Pounds per square inch gauge
ft bgs - Feet below ground surface
mbar - Millibars

Figure A.2-3
Hydraulic Response and Barometric Pressure During Development



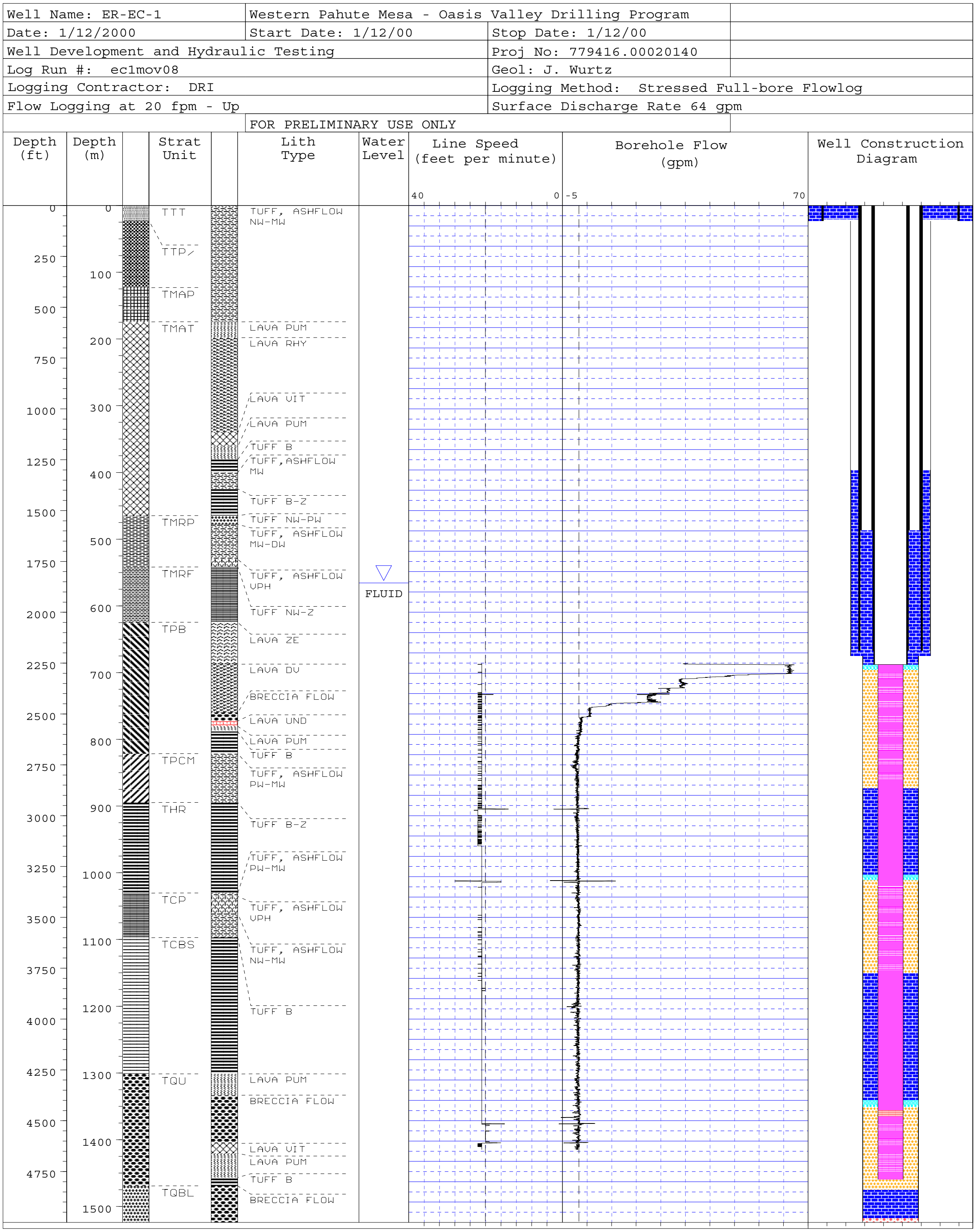
PXD - Pressure transducer
psig - Pounds per square inch gauge
ft bgs - Feet below ground surface
gpm - Gallons per minute

Figure A.2-4
Detail of Surging Action



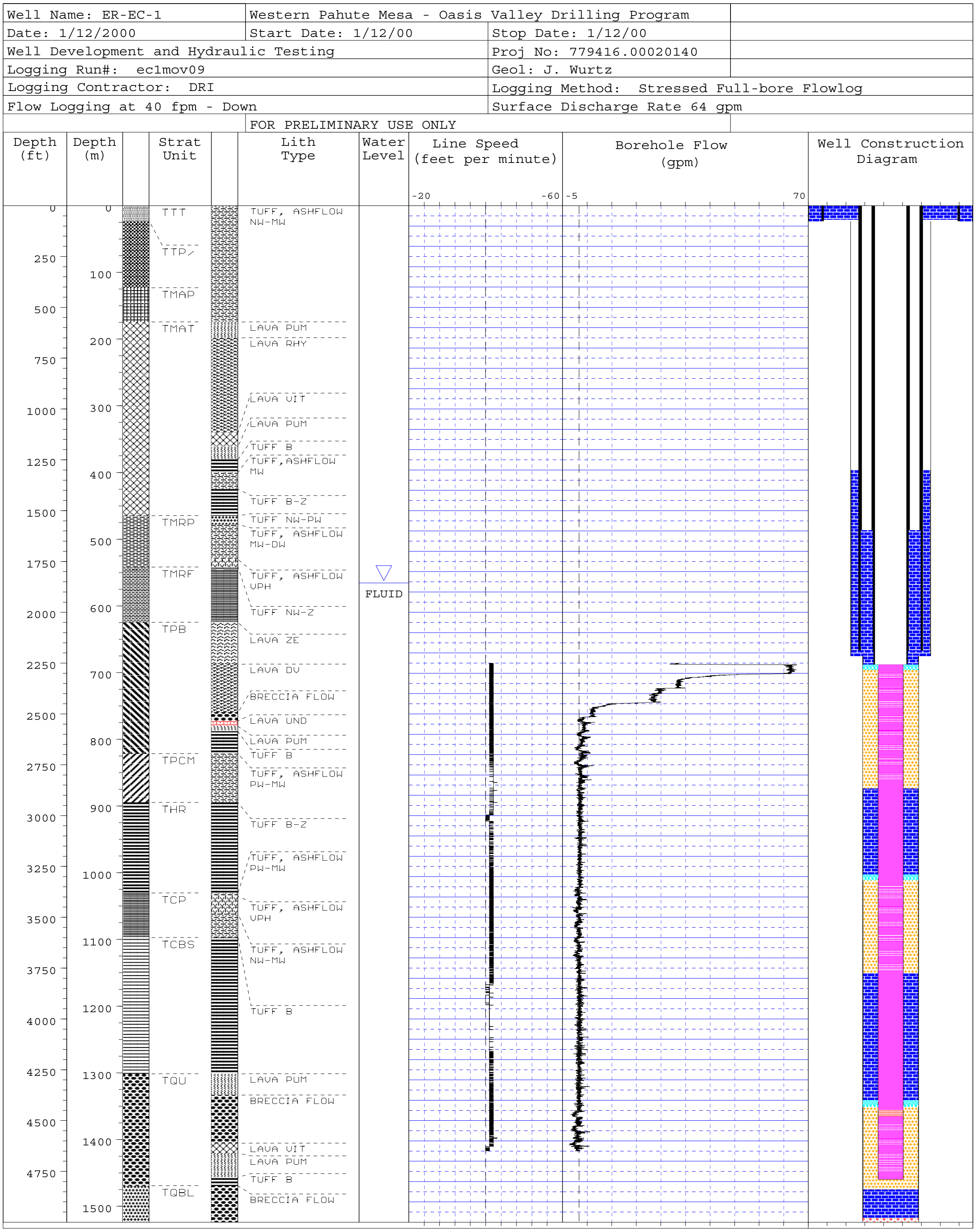
psig - Pounds per square inch gauge
PXD - Pressure transducer
gpm - Gallons per minute
ft bgs - Feet below ground surface

Figure A.2-5
Detail of Step-Drawdown Protocol



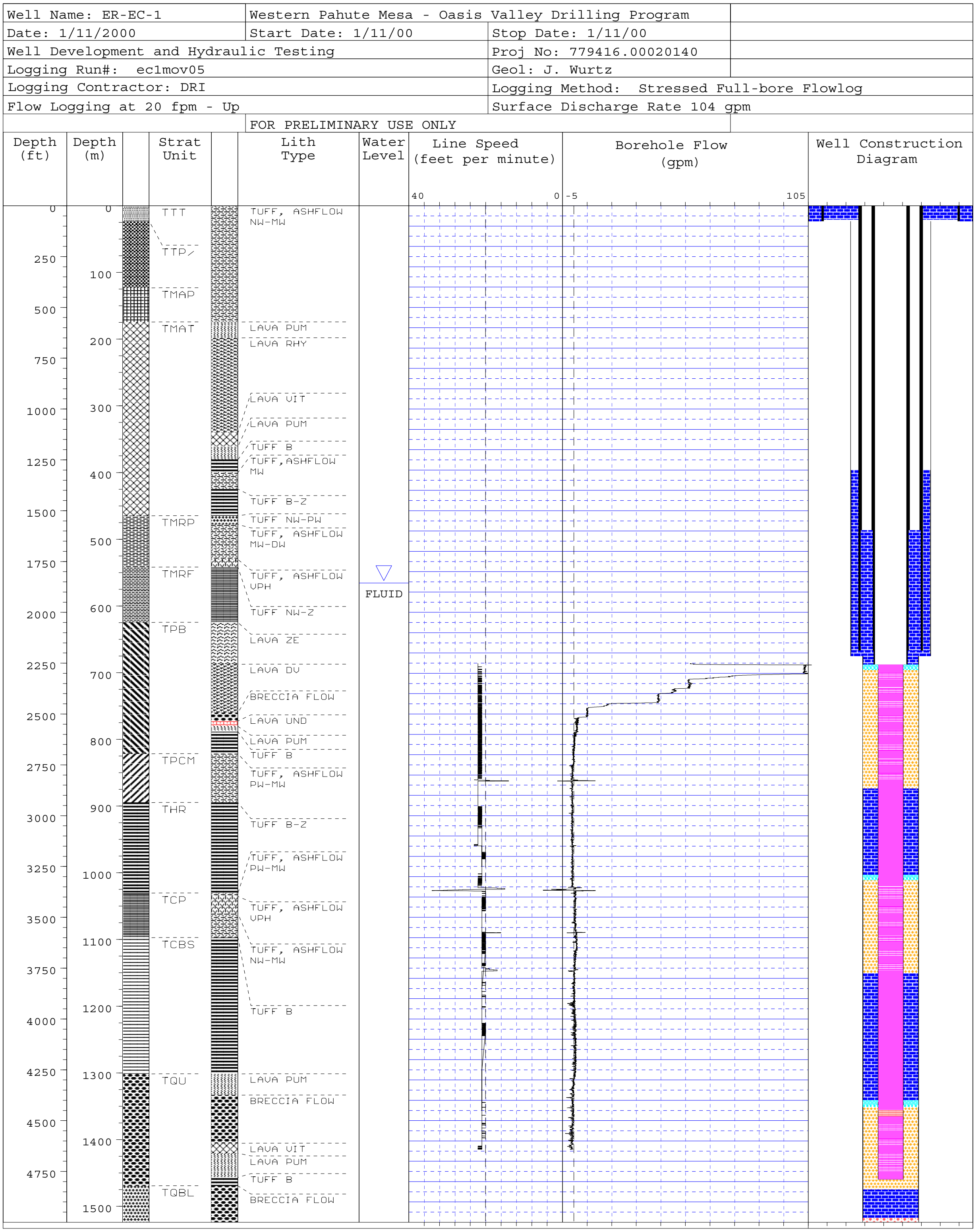
Well Name: ER-EC-1
Western Pahute Mesa - Oasis Valley Drilling Program
Date: 1/12/2000
Start Date: 1/12/00
Stop Date: 1/12/00
Well Development and Hydraulic Testing
Proj No: 779416.00020140
Log Run #: ec1mov08
Geol: J. Wurtz
Logging Contractor: DRI
Logging Method: Stressed Full-bore Flowlog
Flow Logging at 20 fpm - Up
Surface Discharge Rate 64 gpm
FOR PRELIMINARY USE ONLY

Figure A.2-6
Flow Log at 64 gpm Production Rate and 20 fpm Upward Trolling Rate



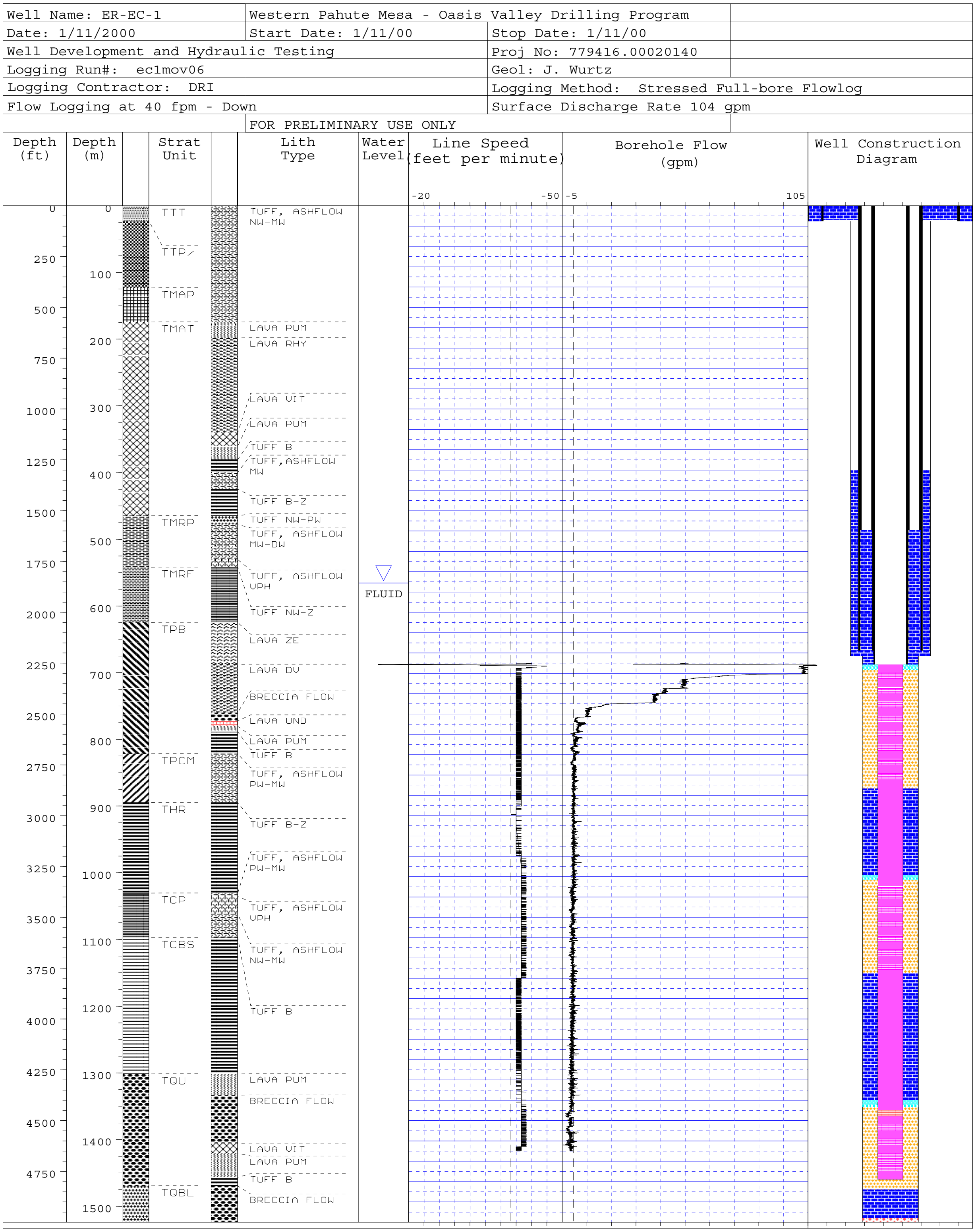
Well Name: ER-EC-1
Western Pahute Mesa - Oasis Valley Drilling Program
Date: 1/12/2000
Start Date: 1/12/00
Stop Date: 1/12/00
Well Development and Hydraulic Testing
Proj No: 779416.00020140
Logging Run#: ec1mov09
Geol: J. Wurtz
Logging Contractor: DRI
Logging Method: Stressed Full-bore Flowlog
Flow Logging at 40 fpm - Down
Surface Discharge Rate 64 gpm
FOR PRELIMINARY USE ONLY

Figure A.2-7
Flow Log at 64 gpm Production Rate and 40 fpm Downward Trolling Rate



Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program	
Date: 1/11/2000	Start Date: 1/11/00	Stop Date: 1/11/00
Well Development and Hydraulic Testing		Proj No: 779416.00020140
Logging Run#: ec1mov05		Geol: J. Wurtz
Logging Contractor: DRI		Logging Method: Stressed Full-bore Flowlog
Flow Logging at 20 fpm - Up		Surface Discharge Rate 104 gpm
	FOR PRELIMINARY USE ONLY	

Figure A.2-8
Flow Log at 104 gpm Production Rate and 20 fpm Upward Trolling Rate



Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program		
Date: 1/11/2000	Start Date: 1/11/00	Stop Date: 1/11/00	
Well Development and Hydraulic Testing		Proj No: 779416.00020140	
Logging Run#: ec1mov06		Geol: J. Wurtz	
Logging Contractor: DRI		Logging Method: Stressed Full-bore Flowlog	
Flow Logging at 40 fpm - Down		Surface Discharge Rate 104 gpm	
	FOR PRELIMINARY USE ONLY		

Figure A.2-9
Flow Log at 104 gpm Production Rate and 40 fpm Downward Trolling Rate

Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program		
Date: 1/10/2000	Start Date: 1/10/00	Stop Date: 1/10/00	
Well Development and Hydraulic Testing		Proj No: 779416.00020140	
Logging Run#: ec1mov01		Geol: J. Wurtz	
Logging Contractor: DRI		Logging Method: Stressed Full-bore Flowlog	
Flow Logging at 20 fpm - Down		Surface Discharge Rate 126 gpm	
	FOR PRELIMINARY USE ONLY		

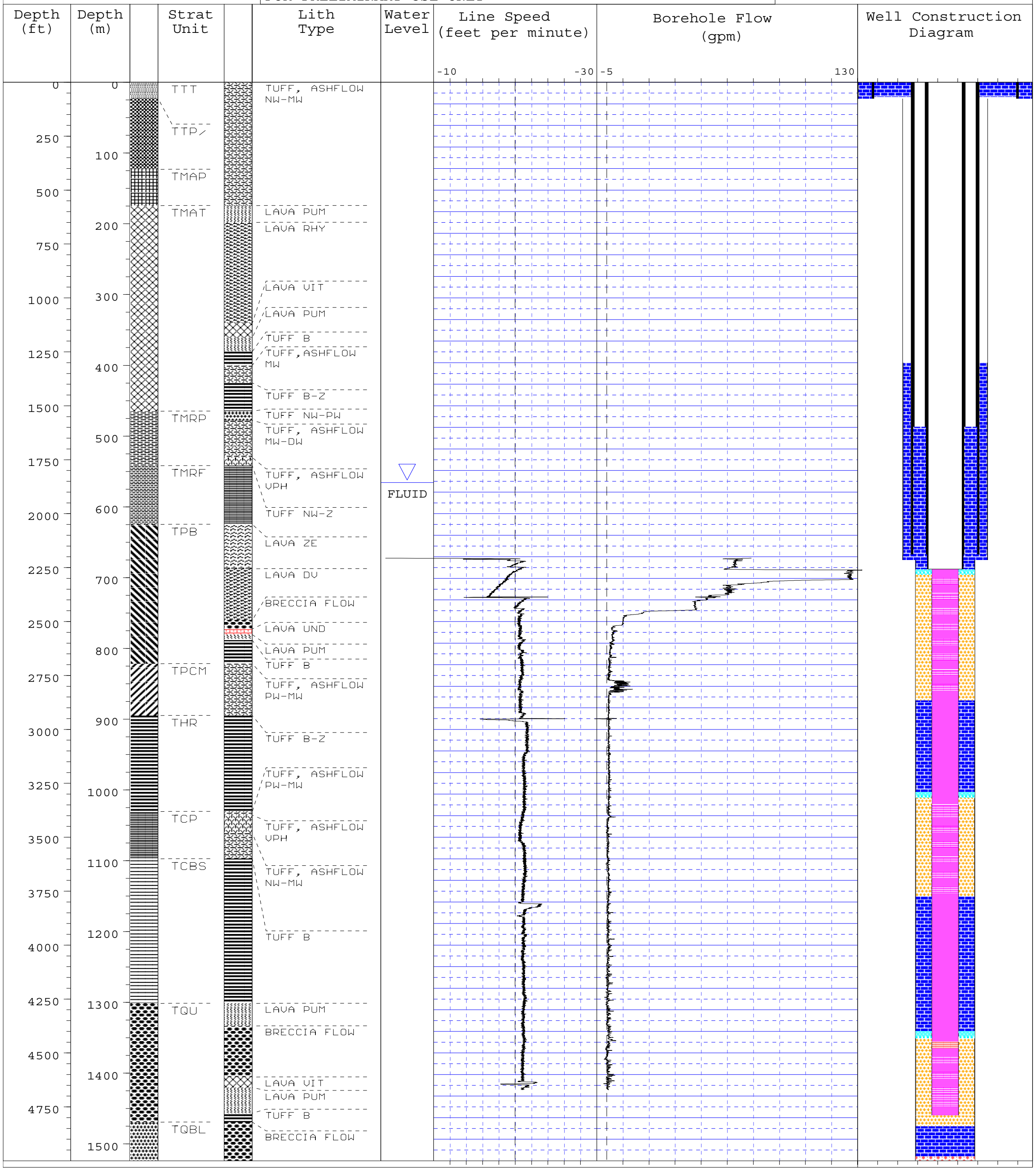
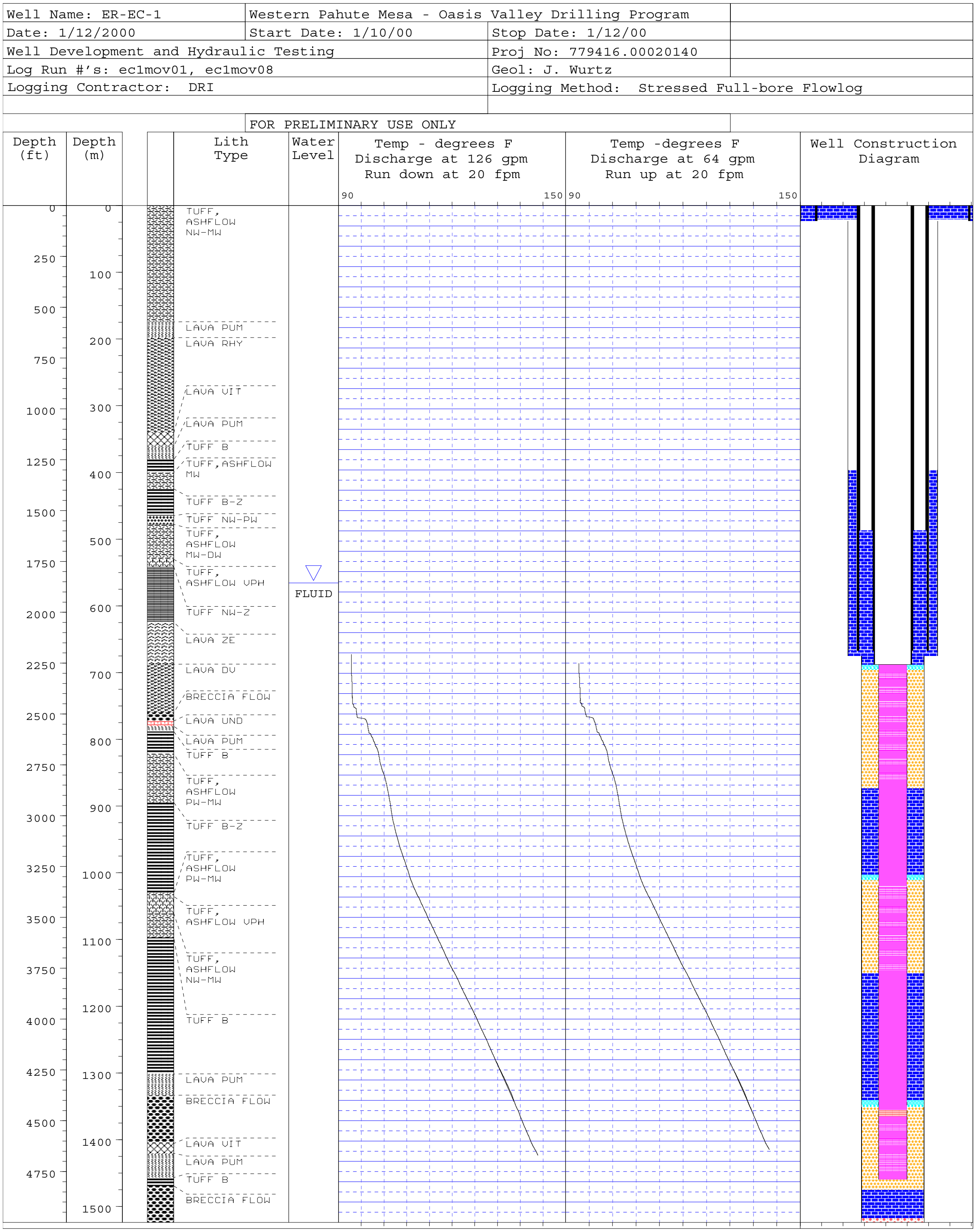


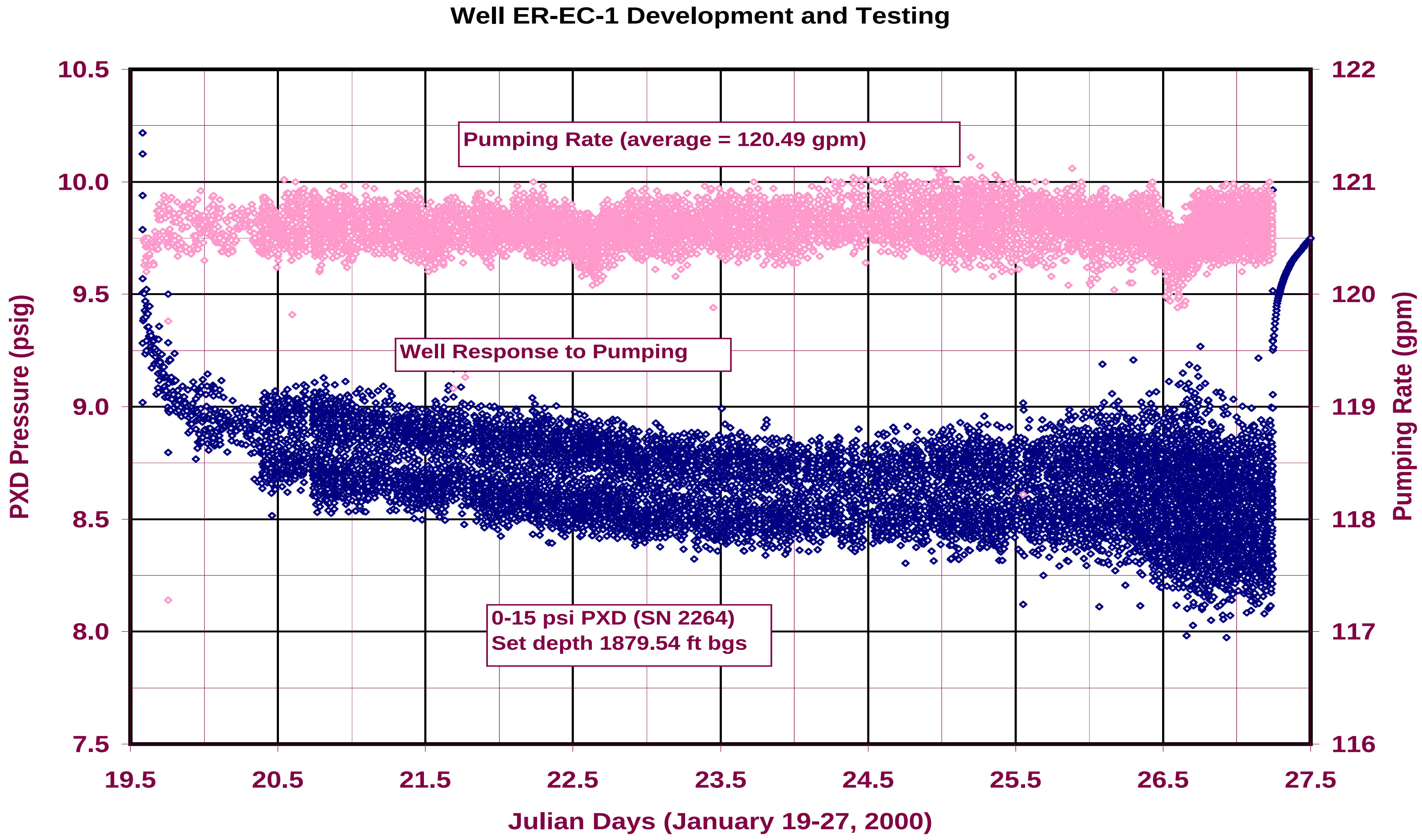
Figure A.2-10
Flow Log at 126 gpm Production Rate and 20 fpm Downward Trolling Rate



Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program	
Date: 1/12/2000	Start Date: 1/10/00	Stop Date: 1/12/00
Well Development and Hydraulic Testing		Proj No: 779416.00020140
Log Run #'s: ec1mov01, ec1mov08		Geol: J. Wurtz
Logging Contractor: DRI		Logging Method: Stressed Full-bore Flowlog

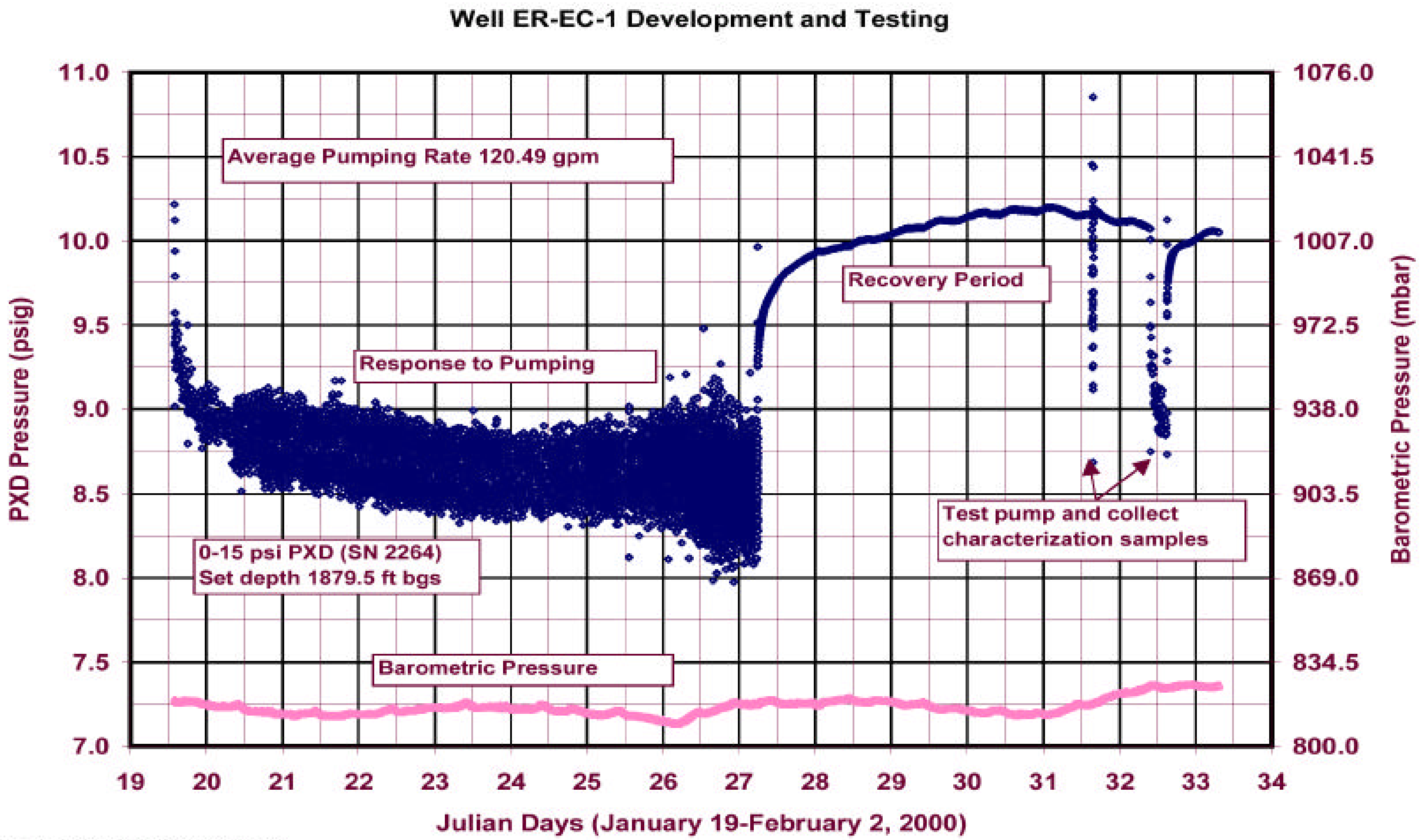
FOR PRELIMINARY USE ONLY

Figure A.2-11
Temperature Logs at 126 gpm and 64 fpm Downward Trolling Rate



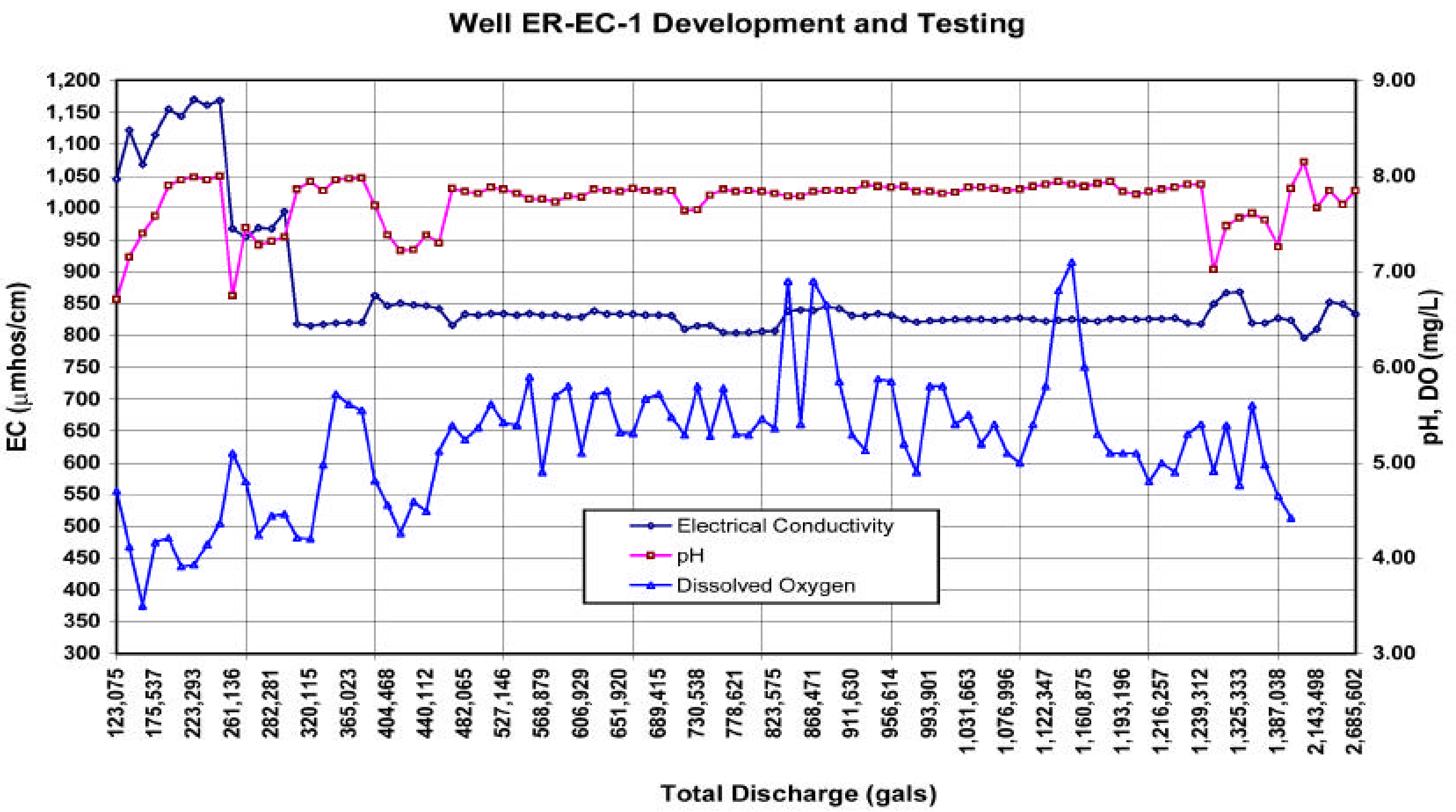
psig - Pounds per square inch gauge
gpm - Gallons per minute
PXD - Pressure transducer
ft bgs - ft below ground surface

Figure A.2-12
Pumping Rate and Hydraulic Response During Constant-Rate Test



psig - Pounds per square inch gauge
gpm - Gallons per minute
mbar - Millibars
PXD - Pressure transducer
ft bgs - feet below ground surface

Figure A.2-13
Hydraulic Response and Barometric Pressure During Constant-Rate Test



µmhos /cm - Micro mhos per centimeter
mg/L - Milligram(s) per liter
gals - gallons

Figure A.2-14
Grab Sample Monitoring for EC, pH, and DO

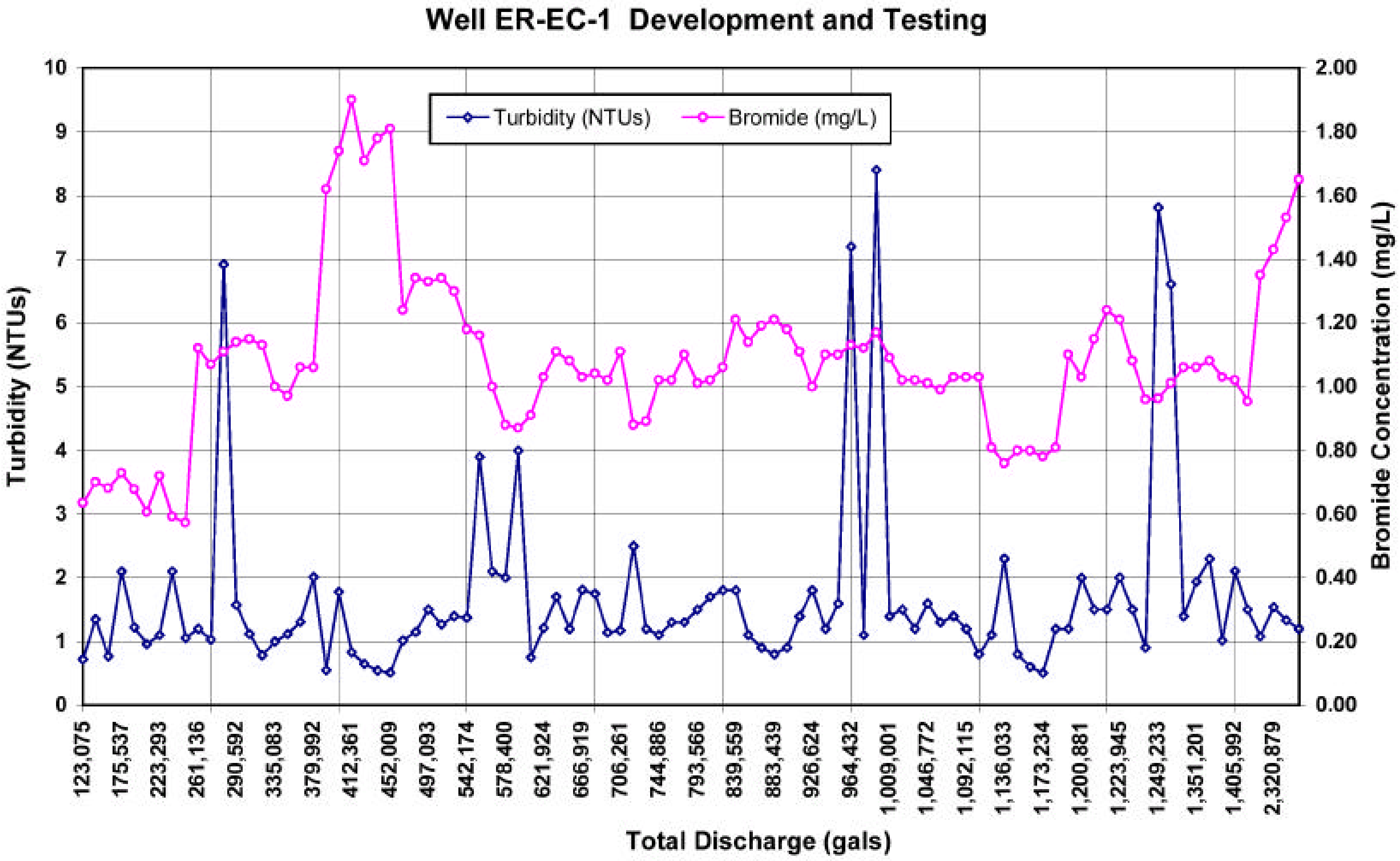
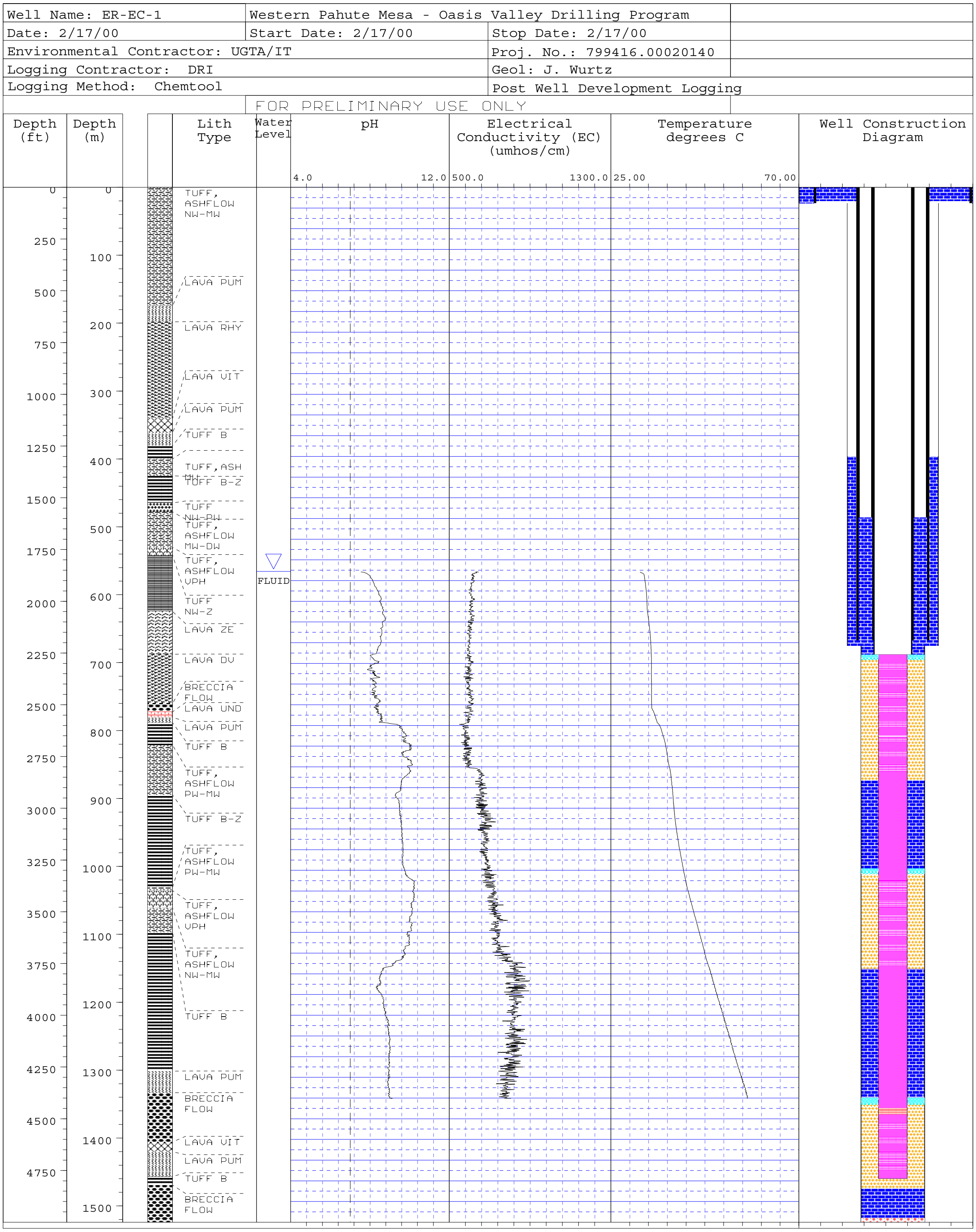


Figure A.2-15
Grab Sample Monitoring for Br^- and Turbidity



Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program	
Date: 2/17/00	Start Date: 2/17/00	Stop Date: 2/17/00
Environmental Contractor: UGTA/IT		Proj. No.: 799416.00020140
Logging Contractor: DRI		Geol: J. Wurtz
Logging Method: Chemtool		Post Well Development Logging

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Figure A.2-16
DRI Chem Tool Logging

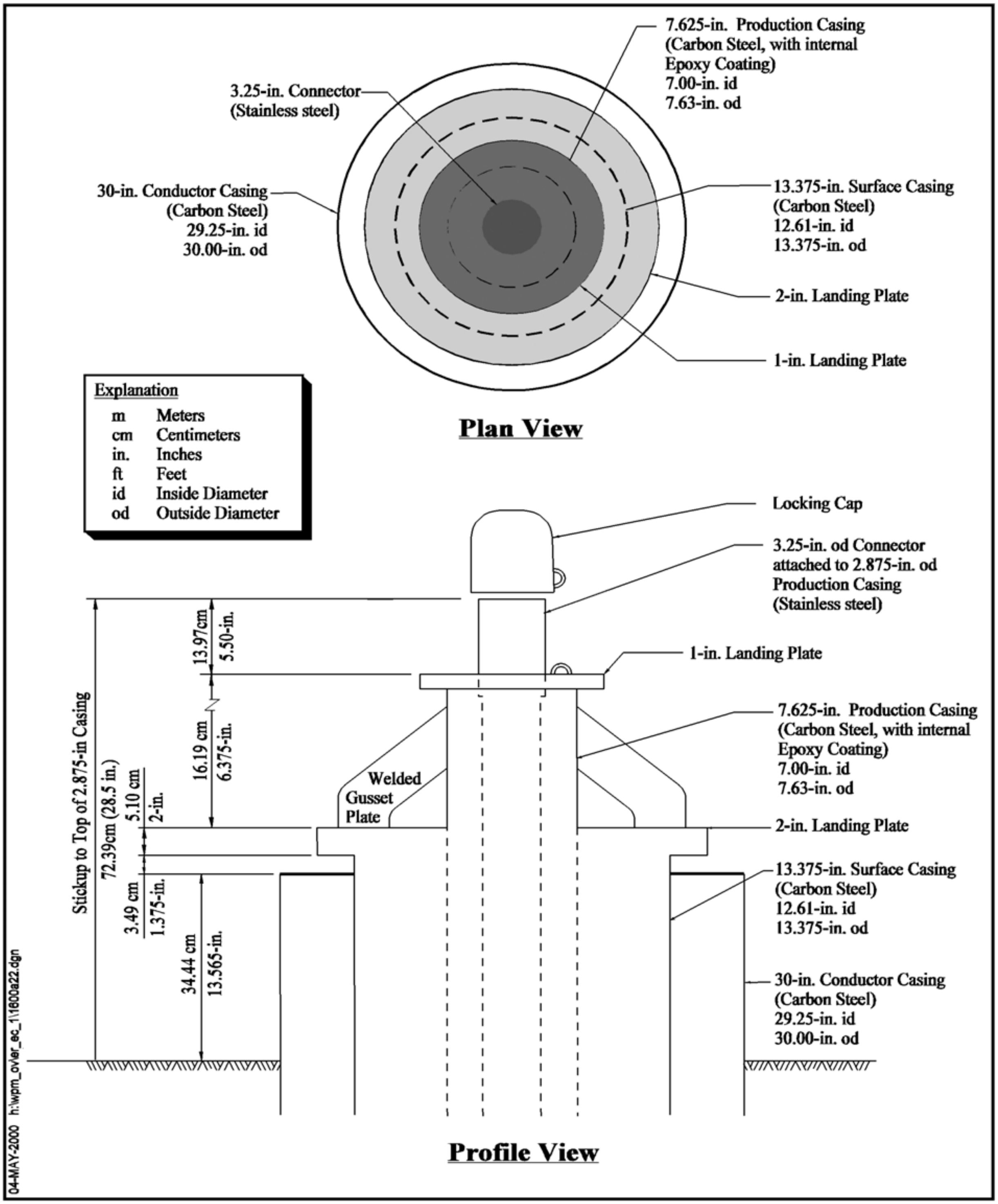


Figure A.2-17
Wellhead Completion Diagram After Sampling Pump Installation

A.3.0 Data Reduction and Review

This section presents basic reduction and processing of data collected during the Well ER-EC-1 development and testing program. Data review and preliminary examination of the results are offered, clarifications of details are provided, and points of interest are noted. Any data interpretations in this section are preliminary and subject to change in future data analysis tasks.

A.3.1 Vertical Gradient and Borehole Circulation

The ambient vertical gradient between completion intervals drives circulation of fluid in the wellbore. The bridge-plug head measurements provide independent measurements of the head in each of the completion intervals. The thermal flow logging provides a direct measure of the associated flow. The composite water level for the well is a density and transmissivity-weighted resultant head showing the effects of flow in the well.

A.3.1.1 Methodology

The head for each of the lower intervals was calculated from the pressure change in the interval when the interval was isolated with a bridge plug. The head was computed by multiplying the pressure change by the composite density of the water in the well above the PXD, and adding that head to the elevation of the PXD. The composite density of the water in the well was computed by dividing the height of the water column above the PXD by the PXD pressure at the set depth measured before setting the bridge plug. Determining the composite density from the actual pressure of the water column was required to calibrate the head calculation to the average density in the water column. Because of the high values of pressure, the calculation of equivalent head was very sensitive to density, which is not specifically known or otherwise measured. This is discussed further in Section A.3.1.4. This method of calculation is insensitive to wireline measurement errors.

The height of the water column was determined from the depth to water measurements (denoted as the reference head) taken after each bridge plug was set. This measurement accommodated any composite head adjustment that occurred after isolating lower interval(s). While there is a chance that this water level may not have completely stabilized, this measurement provides a better estimate of the water column than the total well composite water level. The intervals were monitored for five days or more before the bridge plugs were removed. The PXD pressure was recorded at 5-minute intervals during that time. The well-composite head and the head for the uppermost interval were determined with e-tape measurements. The upper interval was monitored with a PXD set on a wireline.

A.3.1.2 Data Reduction

Graphs of the bridge-plug pressure monitoring records for the lower interval are shown in Figure A.3-1 and Figure A.3-2, and for the middle interval in Figure A.3-3 and Figure A.3-4. Figure A.3-5 shows the PXD monitoring record for the uppermost interval. Since the upper interval was open to atmospheric pressure in the well, the head was affected by barometric pressure changes during the monitoring period. The graph of the upper interval monitoring shows the PXD pressure record and the barometric record for that period, and also a pressure record corrected for barometric change.

These records appear to show an initial rapid equilibration after the bridge plugs were set, and slow trends in the interval head after. Figure A.3-1 and Figure A.3-3 show the pre-set monitoring and adjustments in the pressure in the intervals after setting the bridge plugs. The unsteadiness in the pressure for the calibration data points, especially in Figure A.3-1, was due to the fact that the PXDs had not adjusted to the ambient fluid temperature when those data points were recorded. The PXD temperatures were stable by the time the bridge plugs were set. Figure A.3-2 shows a slow increase in pressure in the lower interval during the later monitoring period, while Figure A.3-4 shows the pressure in the middle interval to be stable after the immediate equilibration. Figure A.3-2 and Figure A.3-4 show that the PXD readings contained noise in the form of fluctuations of a certain amount both above and below a central value; the central values were used as the representative value. Table A.3-1 shows interval-specific head information for Well ER-EC-1 based on the final intervals pressures. The methodology for calculating the head for the middle and lower intervals depends upon the e-tape reference head measurement and the change in PXD pressure from before to after the bridge plug is set, and is insensitive to wireline errors for the PXD set depth.

At the end of the monitoring period, the head of the middle interval was 1.39 ft less than the head of the upper interval, indicating a downward vertical gradient from the upper interval to the middle interval. The head of the lower interval was 0.95 ft higher than the head of the middle interval, indicating an upward vertical gradient from the lower interval to the middle interval. This difference in the direction of the gradient appears inconsistent, although possible. The small differences in calculated head between intervals are within the potential measurement error. The accuracy specification for the PXDs is 0.1 percent FS. Treating the nominal accuracy as measurement uncertainty, the potential uncertainty for the middle interval pressure measurement is +/- 1 psi, and for the lower interval is +/- 2.5 psi. These uncertainties are greater than the measured changes in pressure.

Table A.3-1
ER-EC-1 Interval-Specific Heads

Category	Well Composite	Upper Interval	Middle Interval	Lower Interval
Head - Depth ft bgs	1,855.92	1,855.78	1,857.24	1,856.18
Determination Method	Direct Measurement using e-tape	Direct Measurement using e-tape	Calculated from Bridge Plug Data	Calculated from Bridge Plug Data
Change in Head ft	---	---	-1.39	-0.26
Composite Water Density Conversion Factor ft/psi	---	---	2.32	2.32
Post-Set Pressure psig	---	---	590.34	1,061.85
Pre-Set Pressure psig	---	---	590.94	1,061.96
Reference Head ft	---	---	1,855.85	1,855.92
PXD Set Depth ft	---	---	3,227.70	4,325.20
PXD Serial Number	---	---	21003	01157
PXD Range psig	---	---	0-1000	0-2500

ft - Feet
bgs - Below ground surface
psig - Pounds per square inch gauge
PXD - Pressure transducer

A.3.1.3 Correction of Bridge Plug Set Depths

As mentioned in Section A.2.4, the bridge plug set depths have been corrected from the originally specified set depths. Table A.3-2 shows the specified and the corrected depths. These corrections were supplied by BN Geophysics, who oversaw these measurements. The bridge plugs were located by placing them a specified distance from a reference casing collar that was located downhole based on the casing tallies from well construction. Corrections were required for two reasons. An adjustment was made for the distance from the casing collar that the bridge plug location was referenced to, and an adjustment was made to correct for the calibration error of the wireline measurement. Two different methods were employed to determine the calibration error correction. One method based the calibration error correction on calibration measurements made in a test well, while the other method was based on the error in the measured depth to the reference casing collar. This latter method is thought to be more accurate, and was used to determine the depth reported in Figure A.3-2. The last column in the table shows the difference between the reported calibration correction based on casing collars, and the other method based on the test well calibration.

The requirement for locating the bridge plugs was primarily to place them in the blank casing between completion intervals. They were nominally to be located halfway between completion intervals, and in the middle of a length of blank casing, between the casing joints. The actual set depths of the bridge plugs,

Table A.3-2
Bridge Plug Set Depth Corrections

Location	Specified Depth (ft bgs)	Specified Depth (m bgs)	Corrected Depth (ft bgs)	Corrected Depth (m bgs)	Difference Between Correction Methods (ft)
Lower interval Cal. Depth 1	4,425	1,348.74	4,374.65	1,333.39	+0.43
Lower interval Cal. Depth 2	4,325	1,318.26	4,275.76	1,303.25	+0.42
Lower interval Cal. Depth 3 - Set Depth	4,375	1,333.50	4,325.15	1,318.31	+0.42
Middle interval Cal. Depth 1	3,315	1,010.41	3,277.19	998.89	+0.25
Middle interval Cal. Depth 2	3,215	979.93	3,178.29	968.74	+0.24
Middle interval Cal. Depth 3 - Set Depth	3,265	995.17	3,227.69	983.80	+0.24

ft bgs - Feet below ground surface
m - Meter

although somewhat different from the specified depths, fulfilled those requirements.

A.3.1.4 Composite Water Density

The calculated composite density conversion factors were 2.321 and 2.325 ft water (H_2O)/psi (1.002 and 1.007 in terms of specific gravity corrected for temperature), respectively, for the middle interval and the lower interval. The specific gravity values are based on calculations relative to values for standard temperature-corrected weight density of water (Roberson and Crowe, 1975). These values seem reasonable considering they must accommodate effects of entrained gases, suspended solids, and dissolved solids. The values also compare well with the conversion factor values of 2.333 and 2.332 ft H_2O/psi (specific gravities of 0.994 and 0.995) calculated from the PXD installations for monitoring drawdown. These latter specific gravity values are slightly less, which may reasonably be expected because they apply to the upper part of the water column, which should have less suspended sediment and a greater proportion of entrained gas.

A.3.1.5 Thermal Flow Logging

The thermal flow logging found downward flow in the upper completion interval of 2.2 gpm at 2,410 and 2,500 ft bgs, reduced to 0.6 gpm at 2,700 ft bgs. No flow was measured at 3,300 ft bgs just above the middle completion interval. This flow may be driven by a vertical gradient in the upper completion interval, but the bridge plug measurements did not measure gradient within the completion intervals, only between the completion intervals. The origin of this flow corresponds somewhat to the location of production determined with the flow logging conducted while pumping. The lack of measured flow from the upper to the middle interval and from the lower to the middle interval could indicate that the lower intervals have low hydraulic conductivity, or that the apparent downward gradient is not real. As noted earlier, the apparent gradient is much less than the potential error in the measurements.

A.3.2 Well Development

Well development actions did not appear to have a substantial effect on improving the hydraulic efficiency of the well. Very little sediment was produced, and there was very little apparent improvement in specific capacity (drawdown divided by production rate) of the well during development, as was seen in Figure A.2-2. However, based on the small induced drawdown (less than 4 feet) and the results of the flow logging during pumping, the production rates imposed on this well did not significantly stress the productivity of the well. Consequently, little improvement would be expected.

A.3.3 Flow Logging During Pumping

The flow logging during pumping provided valuable information on the inflow of water to the well that was induced at the pumping rates used for development, testing, and sampling. This information will allow accurate analysis of the hydraulic response, perspective on the effectiveness of this type of well design for accessing the formations over large vertical distance, and representativeness of water samples taken.

A.3.3.1 Optimal Flow Logging Run

The optimal flow logging configuration during pumping is thought to be the downrun at 20 fpm. This configuration maximizes sensitivity of the logging to actual flow and minimizes the effects of trolling on the flow in the well. The logs from this configuration would be preferred for interpretation. However, other configurations are also run to supplement the data. The theory behind this conclusion is explained below.

The rotational response of the impeller is a function of two components, expressed as:

$$R_t=R_{ls}+R_v$$

Where:

R_t is the total rotation rate of the impeller at any depth

R_{ls} is the rotation rate of the impeller due to linespeed, and

R_v is the rotation rate of the impeller due to vertical flow

The greater the line speed, the more R_{ls} contributes to the total response, thereby increasing error due to variable linespeed, depth offset, etc. Logs conducted at 20 fpm, which is well above the stall speed for the fullbore flowmeter, provides for relatively short logging runs (one to two hours), yet minimizes the contribution of R_{ls} and maximizes the response to R_v. Additional runs are conducted at other line speeds in order to address the stall speed of the fullbore flowmeter. Every spinner tool has a minimum velocity required to initiate impeller movement, and a slightly slower velocity at which the impeller will stall. There may be instances in any borehole where flow may be in the same direction and magnitude relative to the direction and line speed of the flowmeter. The impeller would be located in flow moving past the tool at rates below the stall-speed of the tool, despite substantial flow occurring within the well. Logging at different line speeds in different directions under identical conditions shifts the depths within the borehole where this is occurring so that the flow occurring in all depths of the borehole can be logged.

A.3.3.2 Intervals of Inflow

The flow logging during pumping indicates that all of the water being produced was coming from the upper half of the uppermost completion interval. There was no discernible change in the production distribution between the flow log run at a production rate of 64 gpm and 126 gpm, indicating that the production distribution is primarily controlled by the hydraulic conductivity along the borehole within the completion interval rather than factors such as vertical gradient and flow losses.

Figure A.3-6 shows the flow log with temperature for just the upper completion interval at a production rate of 126 gpm, and Figure A.3-7 shows the logs at 64 gpm. These logs indicate that water production was limited to the upper half of the uppermost completion interval. This situation is the result of several factors. The productivity of the formation in the uppermost completion interval resulted in a relatively small amount of drawdown (less than 4 feet). This amount of drawdown can readily be accounted for by the head loss required to bring water into the well and the friction loss required to transport it up to the pump. The latter are estimated to be on the order of 1 foot or so (flow losses along the screen are poorly estimated due to lack of information on the equivalent surface roughness of the screen).

Table A.3-3 shows an approximate tabulation of the cumulative water production at various depths in the upper completion interval based on an interpretation of the graphical log. The results were similar at the two different production rates. There may have been a small amount of production lower in the interval at the higher pumping rate, which would make physical sense.

A.3.4 Constant-Rate Test

The drawdown and recovery data from the constant-rate pumping test have been processed to adjust for the influences of barometric pressure changes. In addition, an example of processing to compensate for the noise in the data is presented. Pressure oscillations that occurred at the start and end of pumping are illustrated to identify some apparent spurious data points at those times.

Table A.3-3
Cumulative Water Production Versus Depth

Depth ft bgs	Pumping Rate	
	64 gpm	126 gpm
2,300	100%	100%
2,325	49%	50%
2,375	42%	40%
2,400	35%	35%
2,470	13%	14%
2,520	5%	5%
2,610	1%	2%
2,670	0%	1%

A.3.4.1 Barometric Efficiency

Barometric efficiency is a measure of the response of the head (water level) in the well to a change in barometric pressure; when barometric pressure rises, the head will be depressed by some fractional amount. Figure A.3-8 shows a segment of the pretest monitoring prior to the constant-rate test (see Figure A.2-2 for the complete record) from which the barometric efficiency was calculated. Table A.3-4 shows the calculation using measurement values extracted from the data file (file EC1-AqtestComplete.xls on the CD). The barometric efficiency was used to apply a correction for barometric pressure variation that occurred during the constant-rate test and recovery period. The drawdown record was processed into the form of “change from starting pressure” at the beginning of pumping. The data points were then adjusted by -74 percent of the barometric change from the initial barometric pressure at the start of the drawdown data.

A.3.4.2 Drawdown Record

Figure A.3-9 shows the resultant record for the pumping period. The pressure drawdown record was converted to an equivalent change in groundwater head using a conversion value for pressure to water head derived from the head measurement and pressure data collected when the pressure transducer was removed after testing. This information is presented in Table A.2-9. The calibration data was collected during removal of the PXD after recording the test because the PXD was set while the well was being pumped, and the water level was not stable to allow collecting data that could be used for calibration. Note the wide band of noise in the record, which was mentioned earlier in Section A.2.7.2. The noise resulted in excessive data collection because the datalogger program records in response to changes in the head exceeding a trigger value. The constant fluctuation of the water level caused the datalogger to record the noise in detail. An interesting effect of the noise in the record is the white zone in the middle of the record, indicating the lack of data points. This is, in fact, approximately the actual drawdown. The recording trigger value in the datalogger routine was set coarsely to cut down on the number of data points recorded, which resulted in a

Table A.3-4
Calculation of Barometric Efficiency

Time Julian Days	PXD Pressure psi	Barometric Pressure mbar
14.42362269	9.8584	821.56
14.55209491	9.9553	818.59
14.83334491	10.012	819.35
Barometric Excursion mbar		-1.86
PXD Excursion psi		0.020
Barometric Efficiency psi/mbar		-0.011
Barometric Efficiency		-0.74

psi - Pounds per square inch
mbar - Millibars
PXD - Pressure transducer

bias to recording the extreme values. However, recording the noise in more detail would have resulted in more data points than could be handled, and more sparse recording may have produced incorrect apparent oscillations.

A.3.4.3 Recovery Record

Figure A.3-10 shows the recovery period corrected for barometric variation.

A.3.4.4 Starting/Stopping Pump Phenomena

An interesting phenomena in both the drawdown and the recovery plots are initial head oscillations following the starting and stopping of the pump, which quickly die out. Figure A.3-11 and Figure A.3-12 show these oscillations on an expanded time scale. The change from the start of the pump to the first minimum takes about 20 seconds, then 15 seconds back to a maximum, and then 10 seconds to a minimum. These oscillations seem to be distinct phenomena from the noise and are presumably related to starting and stopping the pump.

A.3.5 Water Quality

ChemTool logs were run at various stages of ER-EC-1 completion and development activities. Comparisons can be made between the water quality parameters of the well water before well completion and after well development. There are also differences between grab sample results and ChemTool logs.

A.3.5.1 Pre-Completion Versus Postdevelopment

The ChemTool log of downhole water quality parameters was run at the very end of the testing program, and gives another type of picture of the effectiveness of the development and testing activities on water quality restoration. The next three figures show the ChemTool logs that were run following drilling, but prior to well completion, side-by-side with the logs that were run following well development and testing. Figure A.3-13 shows temperature logs, Figure A.3-14 shows the pH logs, and Figure A.3-15 shows EC logs. Included on these figures are lithologic information and well completion details.

The parameters pH and EC give an indication of the representativeness of the water within the well relative to formation water. These logs show that the water below the upper completion has high pH and EC, probably resulting from effects of well completion activities and materials which have not been remediated by pumping. The parameter values for pH in the upper completion interval are similar but a little higher than the values measured after drilling, while the EC values are now significantly lower. These pH values are about what would be expected for these formations, and the lower EC values in this interval also indicate that the water quality has been cleaned up.

A.3.5.2 Grab Sample Results Versus ChemTool Logs

Water quality parameter values measured for grab samples taken from produced water are shown in Attachment 2. The pH values show a rapid adjustment upwards during pumping to a final range of 7.67 to 7.85. The EC values likewise rapidly adjusted, declining to values in the low 800s. These values can be compared to the results of the downhole ChemTool logs shown in Figure A.3-14 and Figure A.3-15. The grab sample results are very similar to the precompletion ChemTool logs, but somewhat different from the postdevelopment ChemTool logs. The postdevelopment ChemTool log in the interval of production shows slightly higher pH (8.0-8.6) than the grab samples. The ChemTool EC values in this interval are considerably lower than the grab sample EC values.

The variation of temperature, pH, and EC with depth in the postdevelopment logs shows a substantial correlation with the upper completion interval, specifically the upper half of the upper completion interval. This can be interpreted to support the results of the flow logs (Section A.3.6), indicating that the origin of produced water was all from the upper half of the upper completion interval. The water in the lower part of this well appears to still reflect effects of well completion activities and materials. It seems doubtful that the water quality in the lower part of the well reflects water quality in the formation around the well, and any natural flow through the well under ambient conditions has not had a substantial effect on remediating this condition. No such flow was measured in the lower part of the well.

A.3.6 Representativeness of Hydraulic Data and Water Samples

A conclusion that can be drawn from the testing of Well ER-EC-1 is that all of the water quality, development, hydraulic testing, and composite sampling must be considered applicable only to the uppermost completion interval. The analysis of the constant-rate test for hydraulic parameters would be applicable only to the section of producing formation. It is not clear whether the lower formation is nonproductive, or whether the pumping stress was not great enough to overcome vertical gradient, production losses, and friction losses.

Likewise, the water quality information obtained, both general parameters and results of laboratory analyses of samples, also must be considered representative only of the formation in the upper part of the upper completion interval. Since no development seemed to have occurred below this level, even discrete samples taken below this could not be considered representative of formation water quality. Future sampling, using the lower-rate dedicated pump, can probably be considered representative of approximately the same interval as has been identified during this testing. There was no significant change in the production distribution identified on the flow logs between the high and low pumping rate.

A.3.7 Development of the Lower Completion Intervals

To affect development in the lower completion intervals, a much greater drawdown requiring a much higher production rate would be necessary to induce production from the lower intervals. To induce flow from the middle completion interval, drawdown would have to additionally exceed the vertical gradient head loss and friction losses from the middle interval. The apparent downward vertical gradient is approximately 1.5 ft from the upper completion interval to the middle completion interval. Friction losses for flow from lower intervals up to the upper completion interval would be proportionately substantial due to the long transport distance. It would be possible to install a pump with greater production capacity, but it would require a pump of greater diameter, which would preclude running flow logs to determine the production distribution. Running the ChemTool after pump removal could give an indication of the effect, but may not be very definitive. Alternatively, some method of isolating production to the lower completion intervals would have to be used to stress and sample them separately.

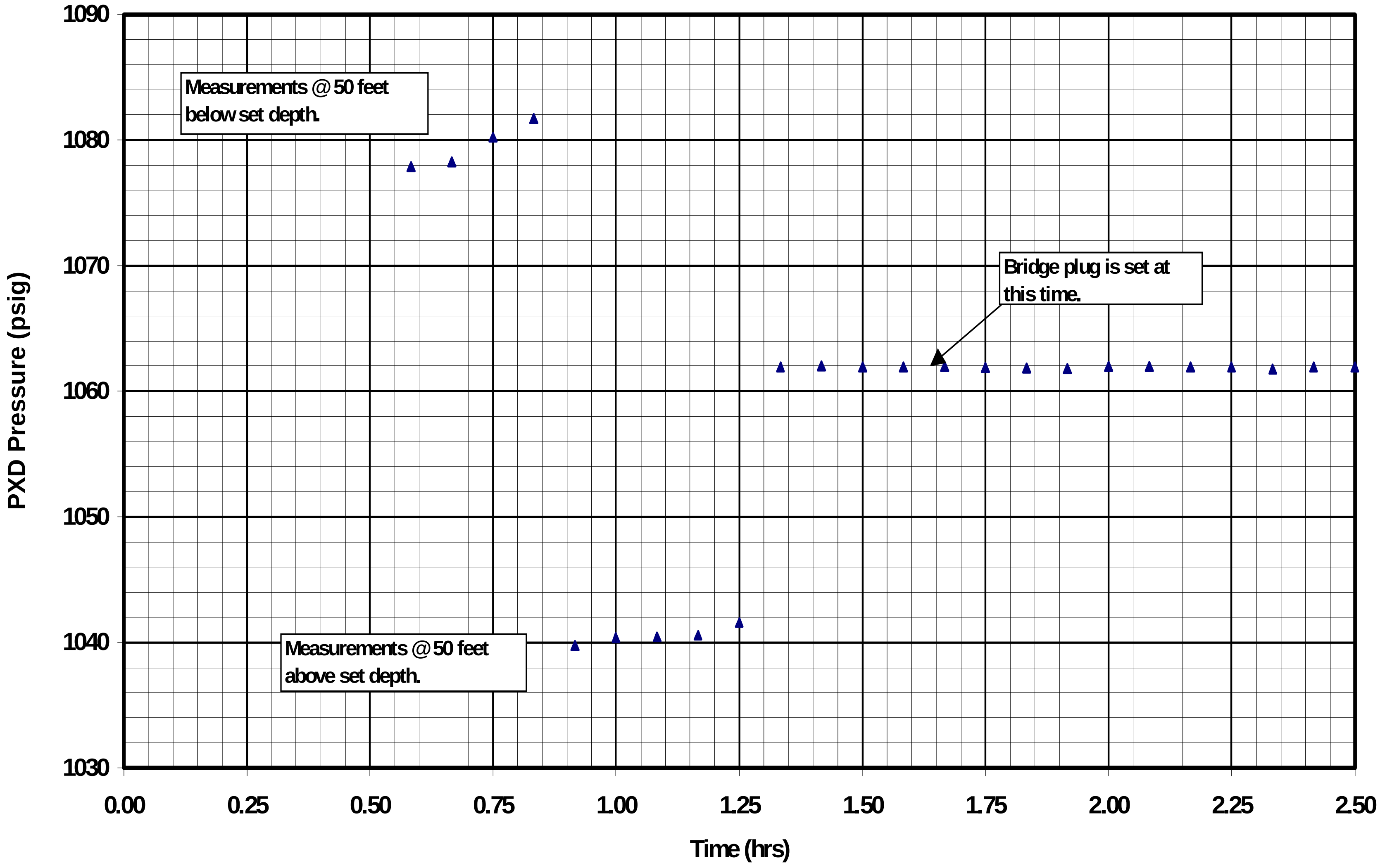


Figure A.3-1
Lower Interval Calibration and Bridge Plug Set

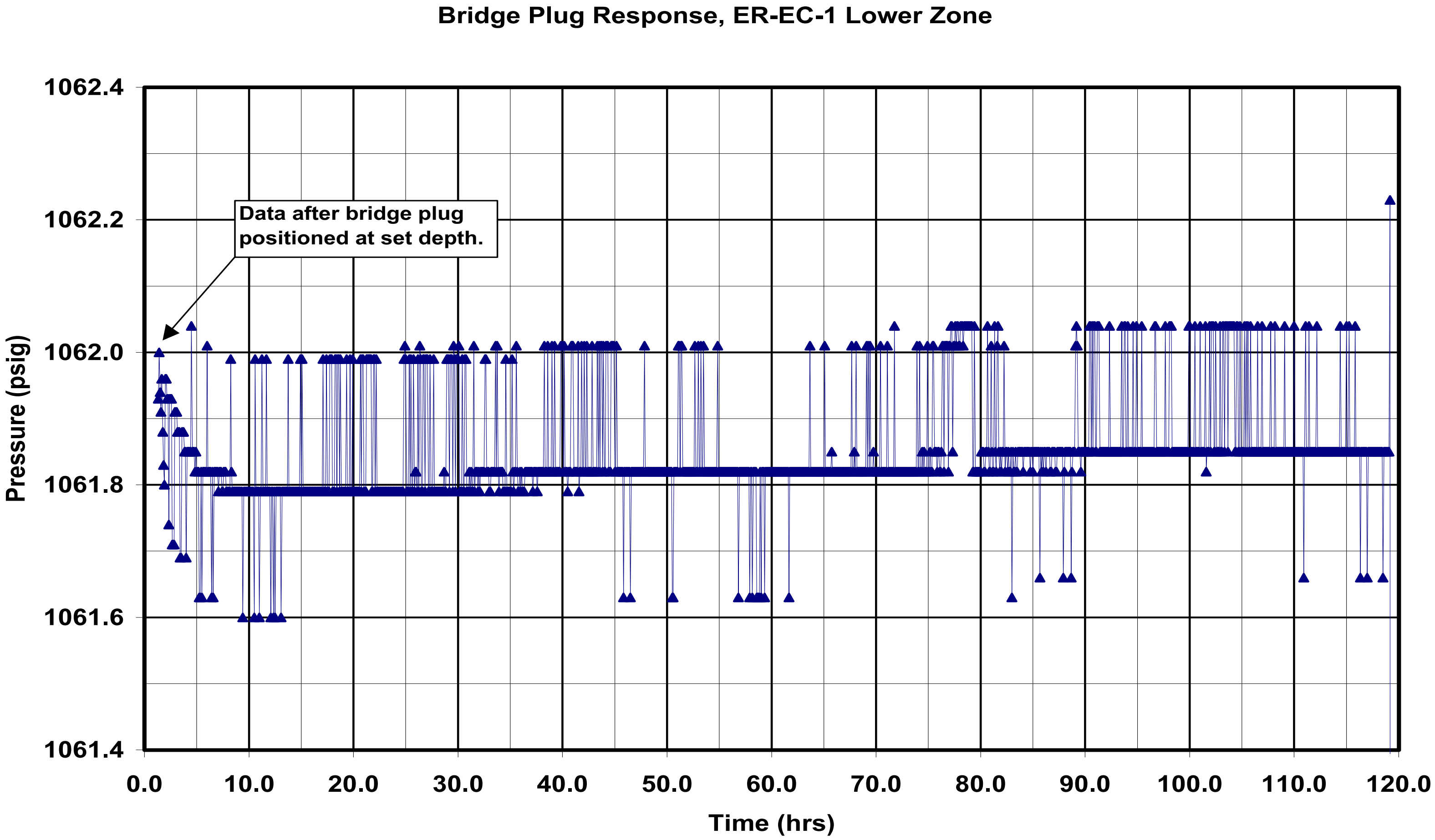


Figure A.3-2
Bridge Plug PXD Response for ER-EC-1 Lower Interval

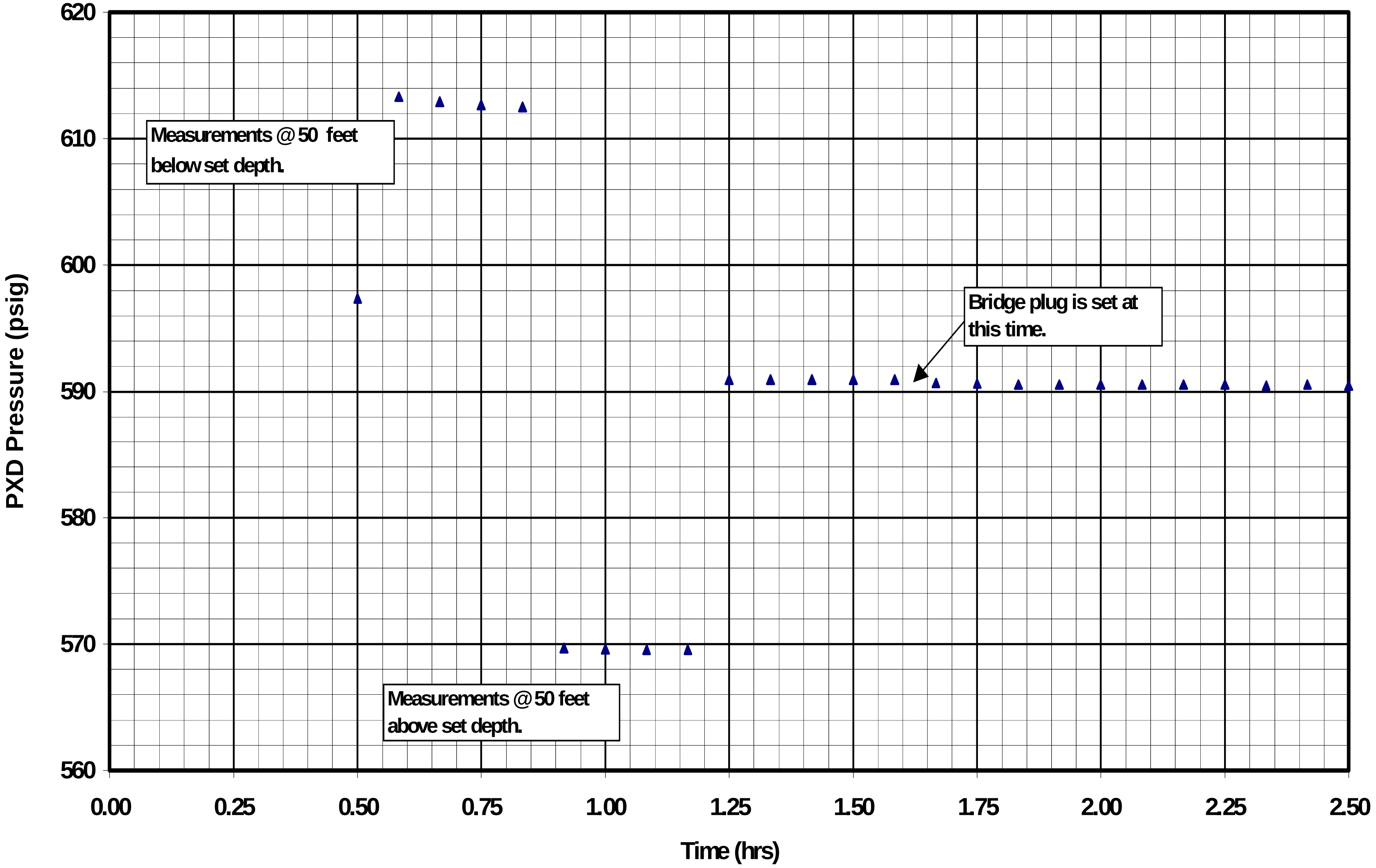


Figure A.3-3
Middle Interval Calibration and Bridge Plug Set

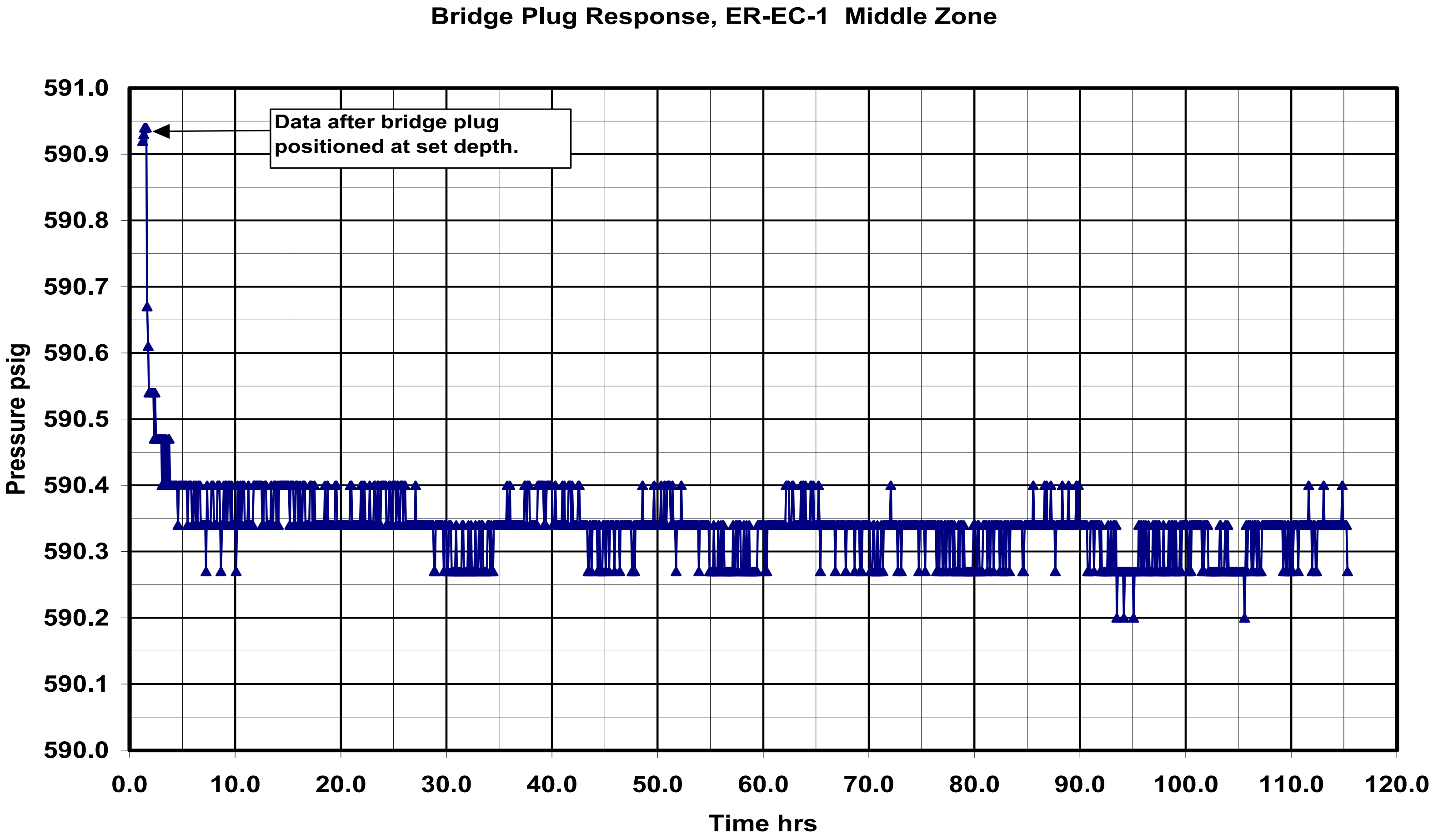
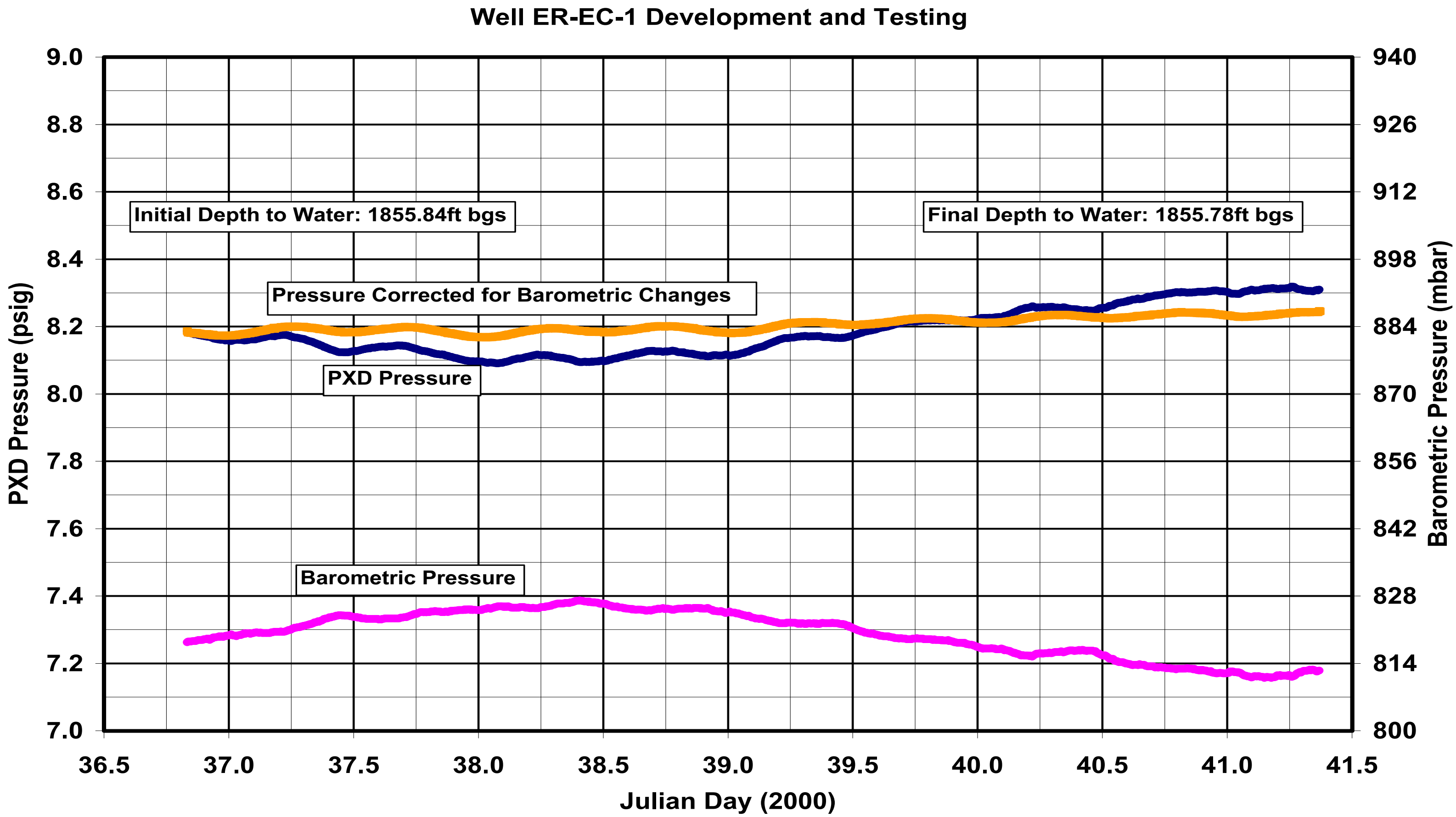


Figure A.3-4
Bridge Plug PXD Response for ER-EC-1 Middle Interval



psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-5
PXD Record for ER-EC-1 Upper Interval

Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program		
Date: 01/10/2000	Start Date: 1/10/2000	Stop Date: 1/10/2000	
Well Development and Hydraulic Testing		Proj No: 779416.00020140	
Log Run #: ec1mov01		Geol: J. Wurtz	
Logging Contractor: DRI		Logging Method: Stressed Full-bore Flowlog	
Flow Logging at 20 fpm -Down		Surface Discharge Rate of 126 gpm	
	FOR PRELIMINARY USE ONLY		

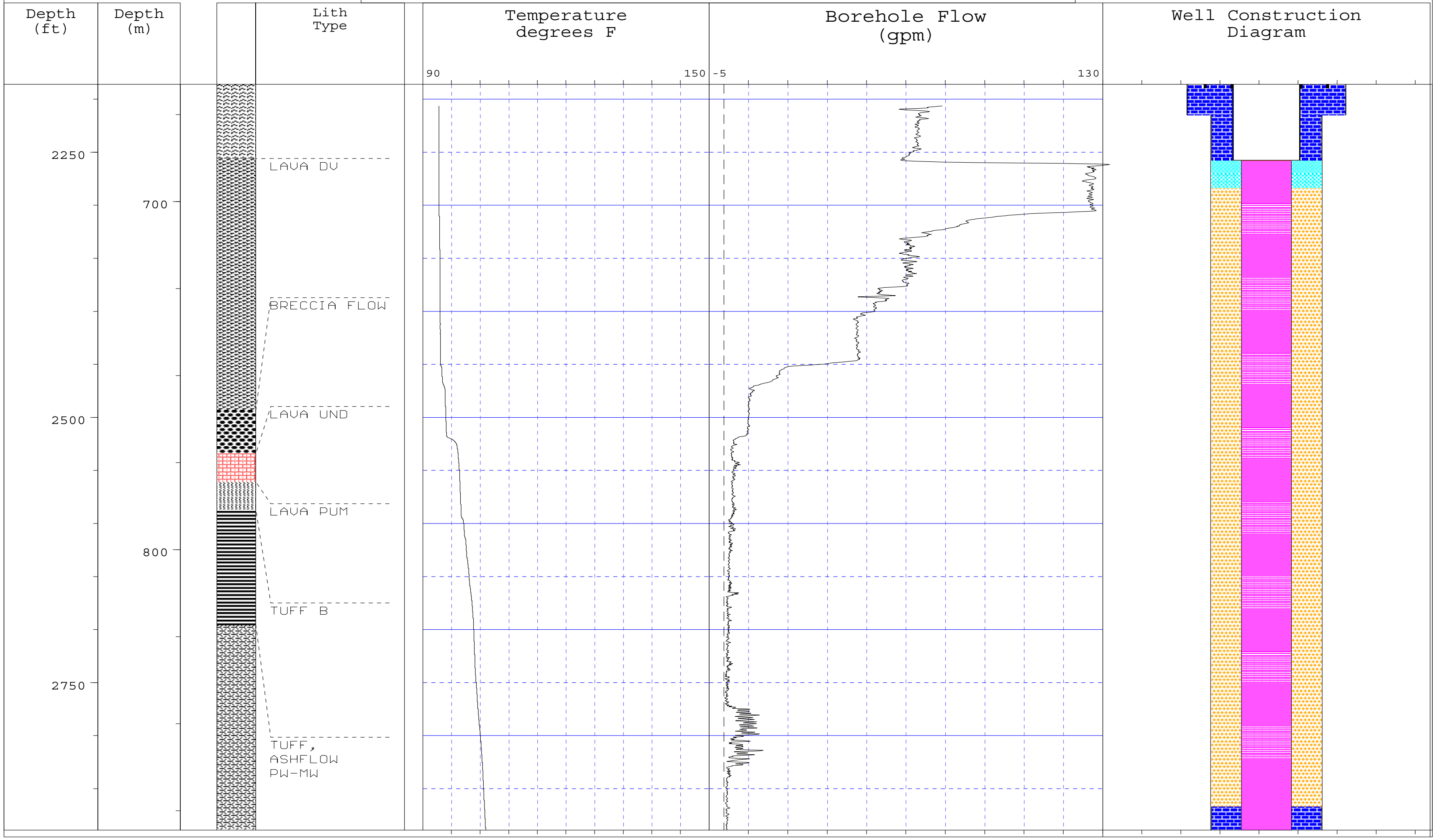


Figure A.3-6
Flow and Temperature Log for the Upper Interval at 126 gpm

Well Name: ER-EC-1
Western Pahute Mesa - Oasis Valley Drilling Program
Date: 1/12/2000
Start Date: 1/12/00
Stop Date: 1/12/00
Well Development and Hydraulic Testing
Proj No: 779416.00020140
Log Run #: ec1mov08
Geol: J. Wurtz
Logging Contractor: DRI
Logging Method: Stressed Full-bore Flowlog
Flow Logging at 20 fpm - Up
Surface Discharge Rate of 64 gpm
FOR PRELIMINARY USE ONLY

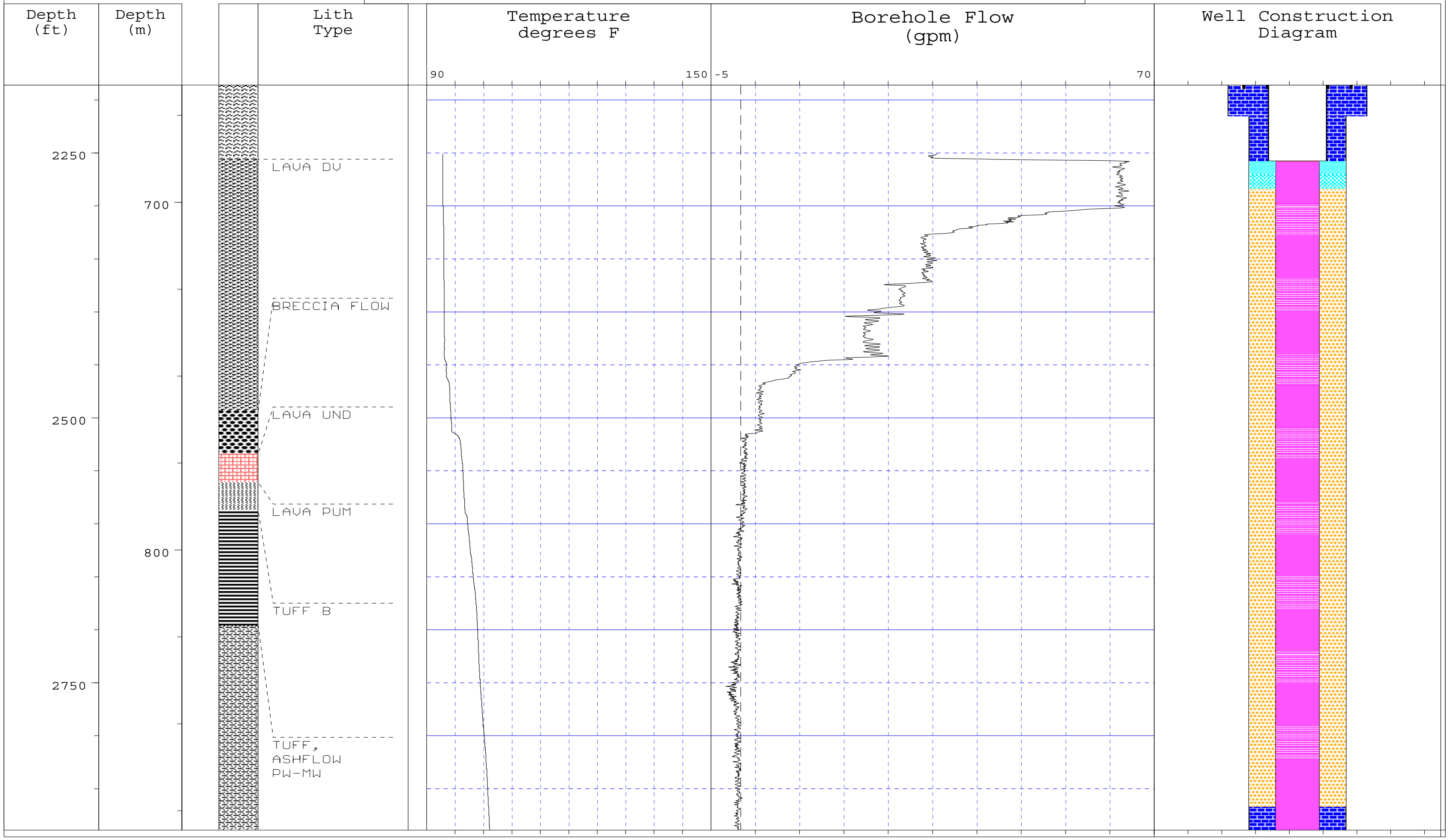
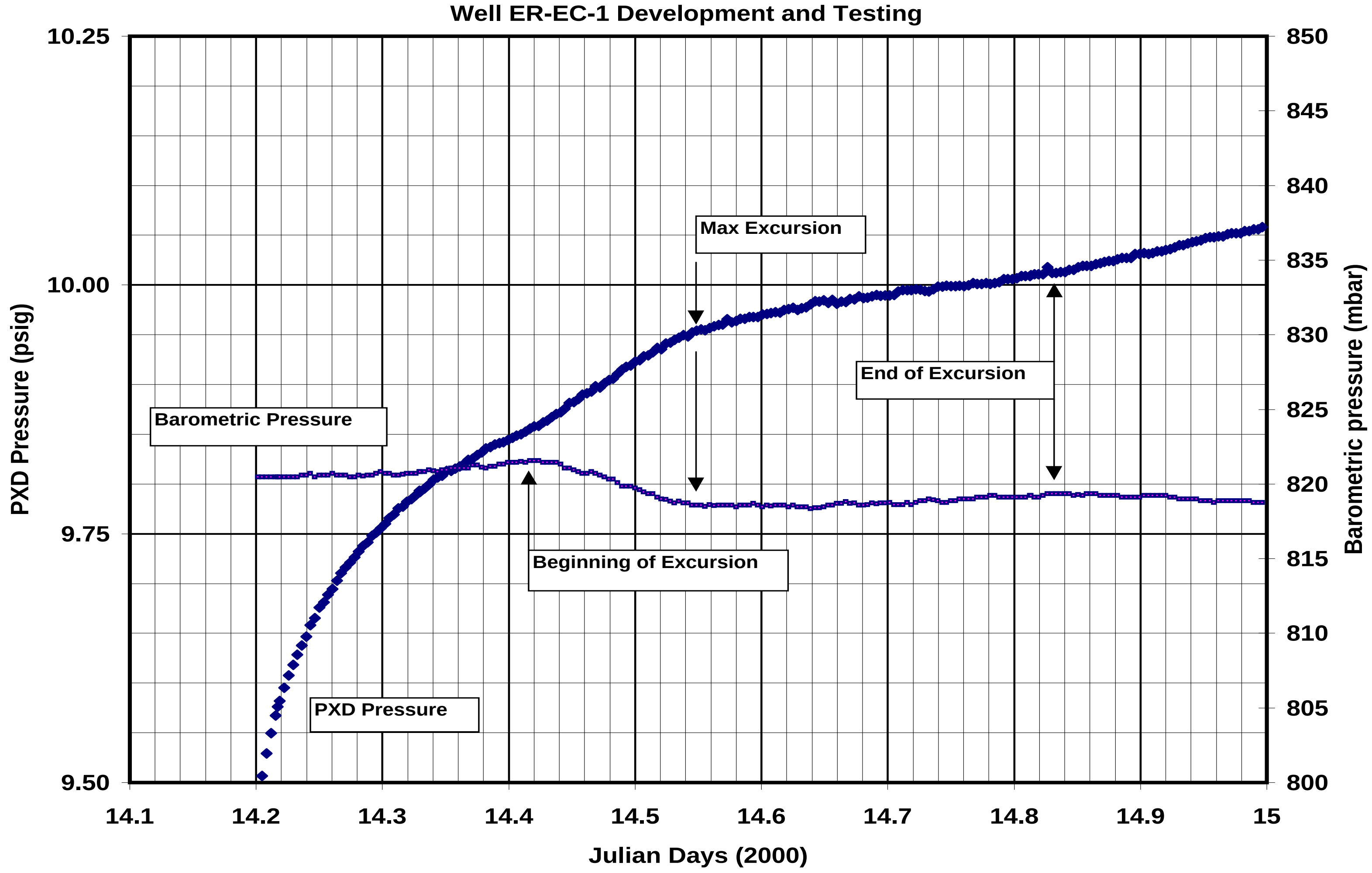


Figure A.3-7
Flow and Temperature Log for the Upper Interval at 64 gpm



psig - Pounds per square inch gauge
PXD - Pressure transducer
mbar - Millibars

Figure A.3-8
Determination of Barometric Efficiency

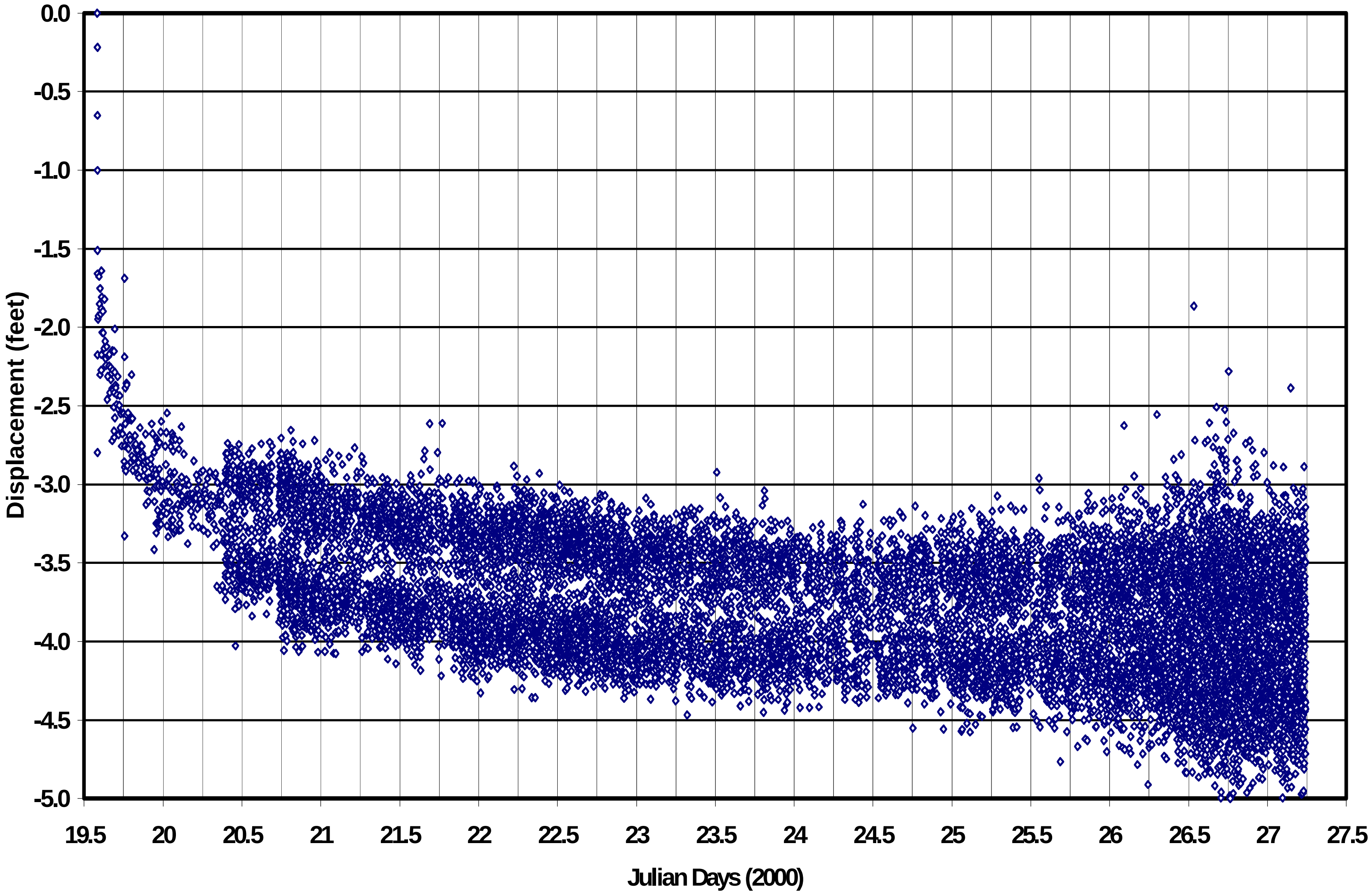


Figure A.3-9
Constant-Rate Pumping Test with Barometric Correction

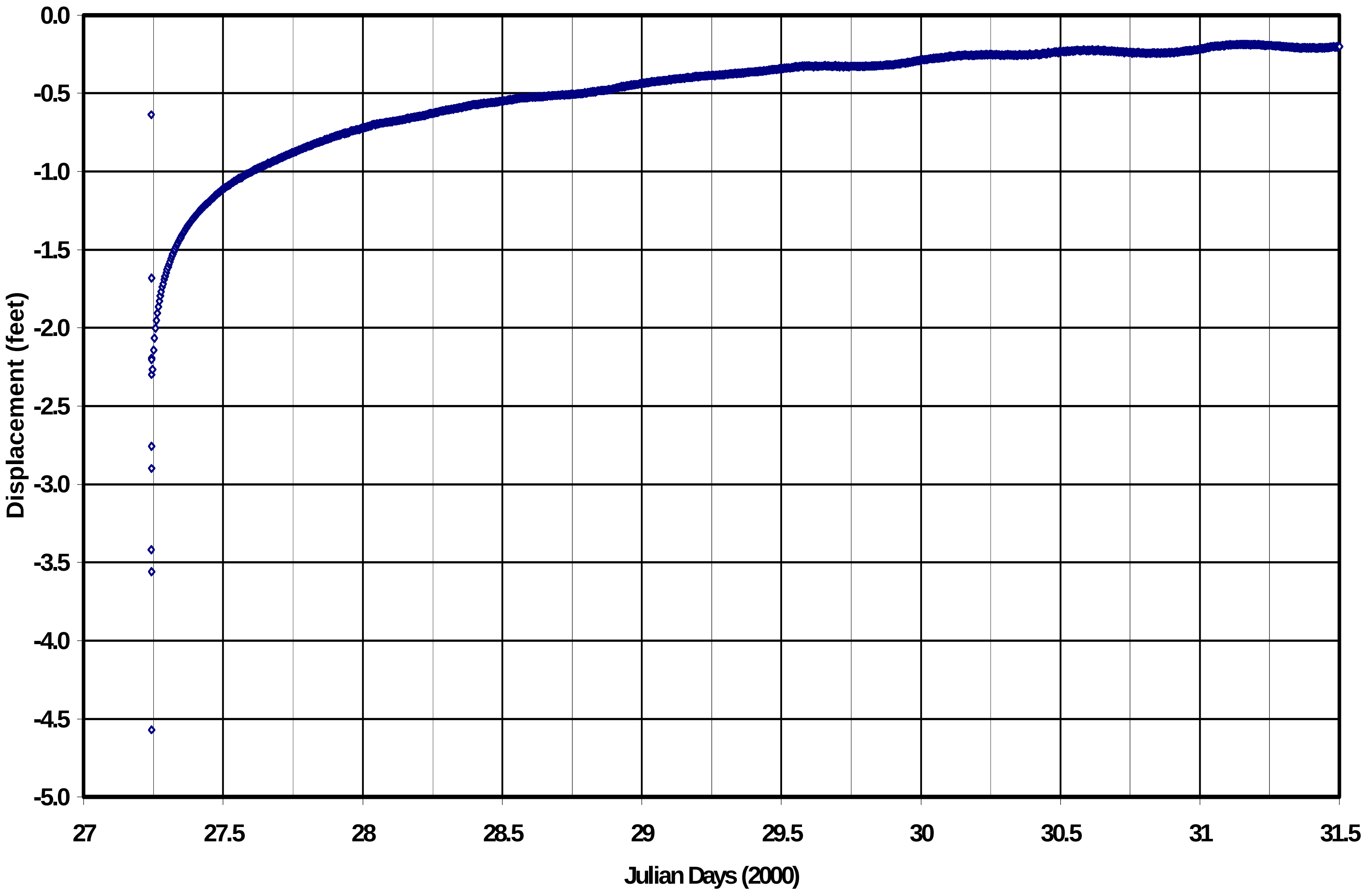


Figure A.3-10
Recovery Period with Barometric Correction

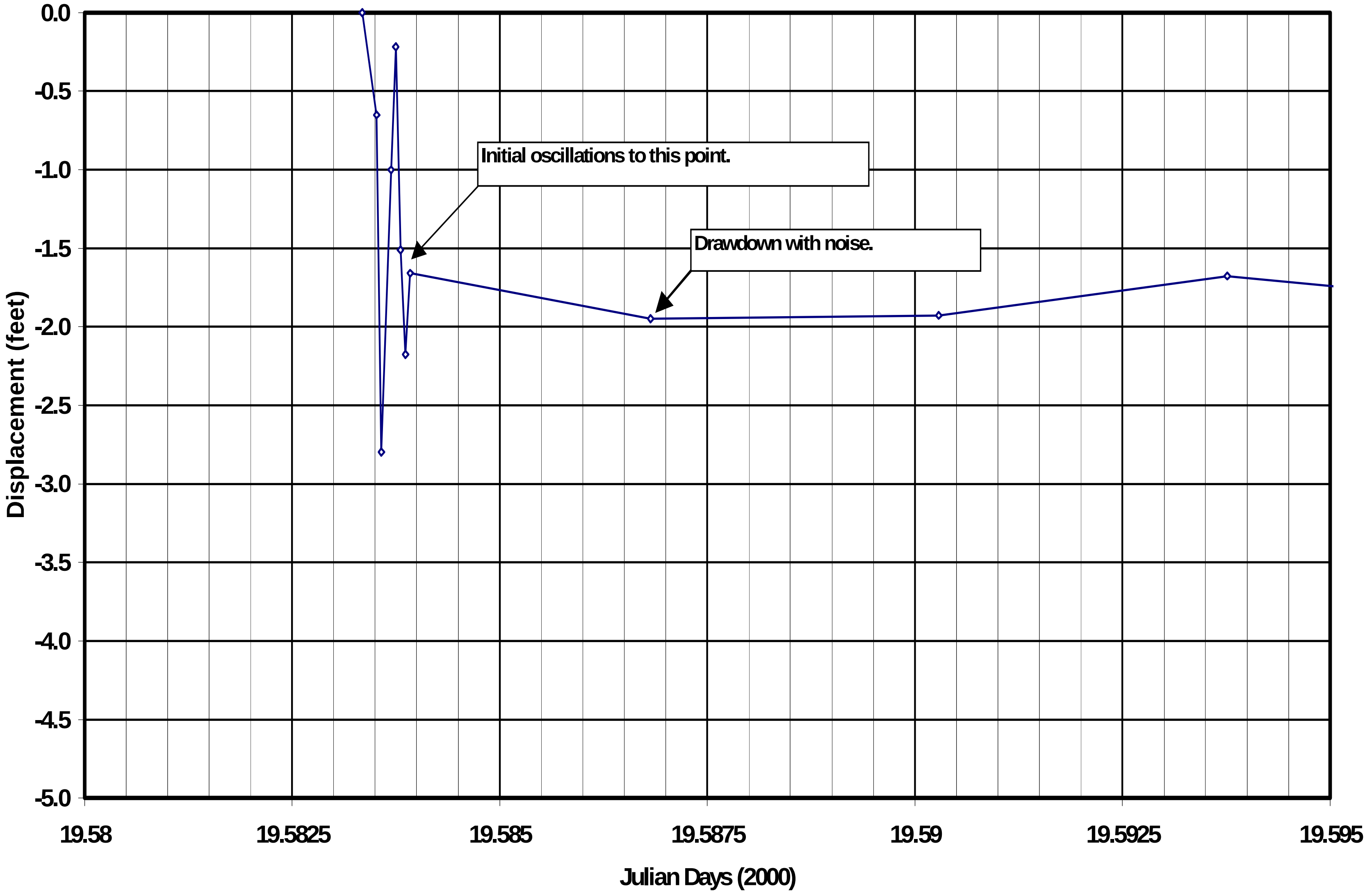


Figure A.3-11
Pressure Oscillations at the Start of the Constant-Rate Test

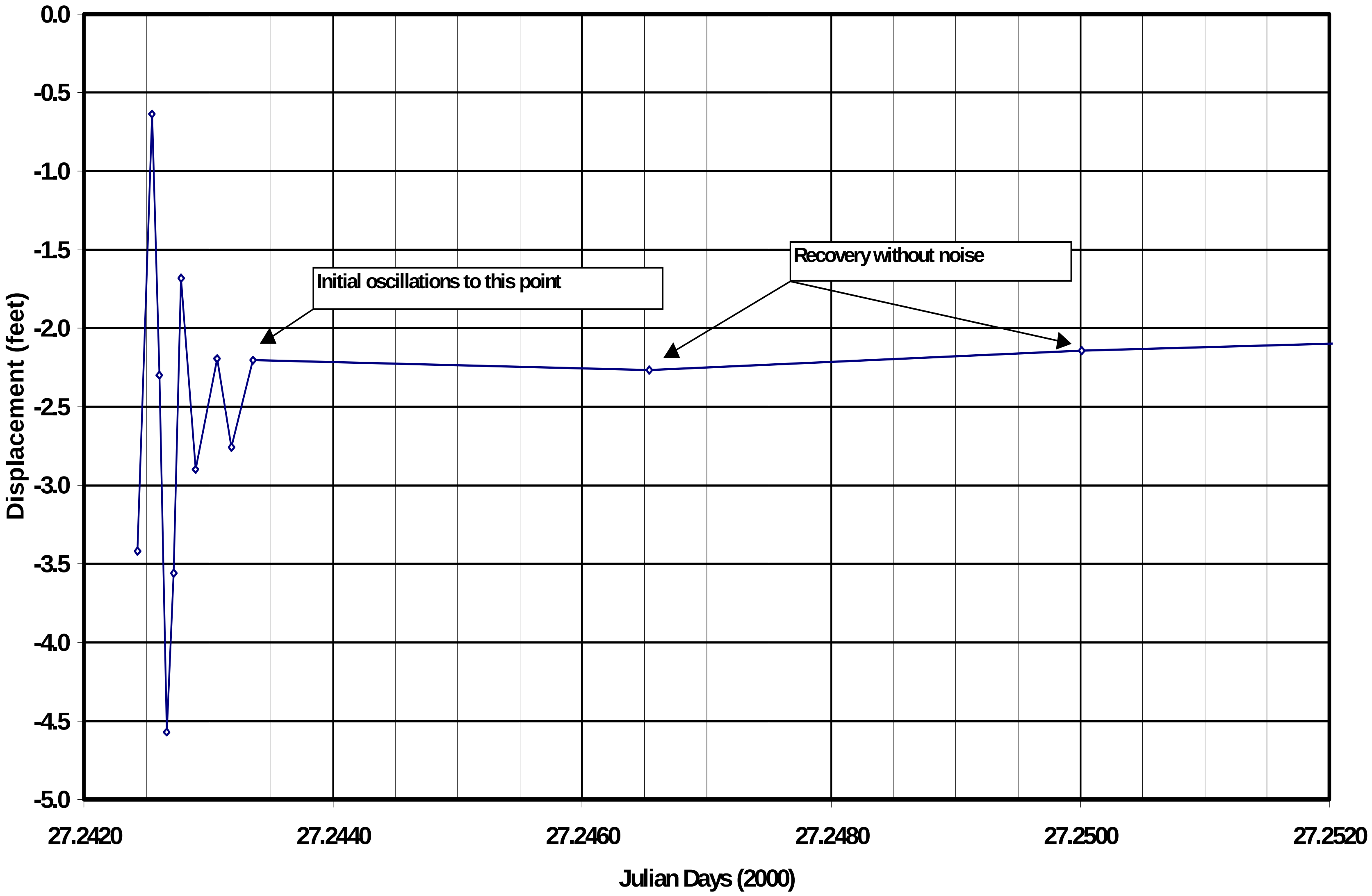
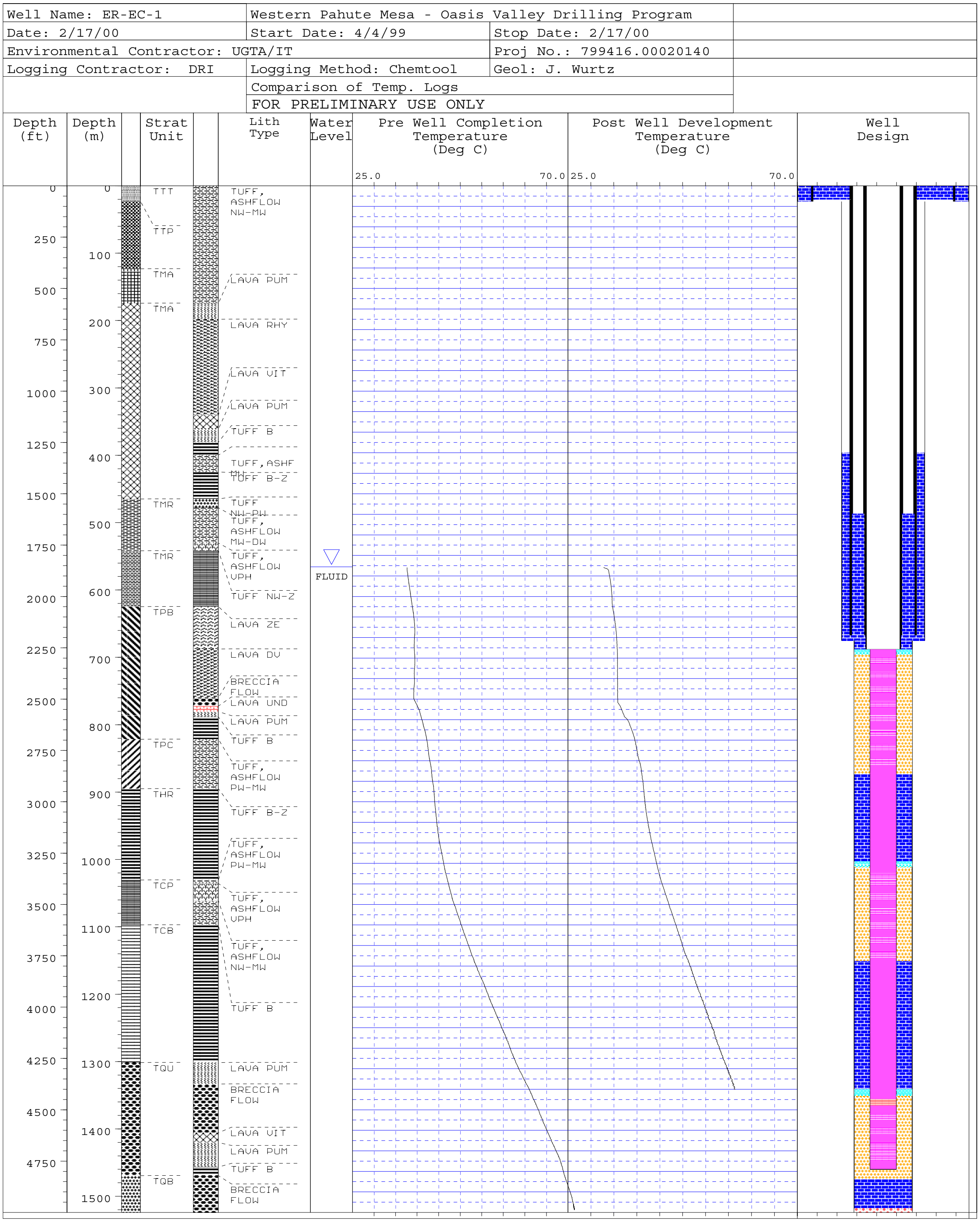
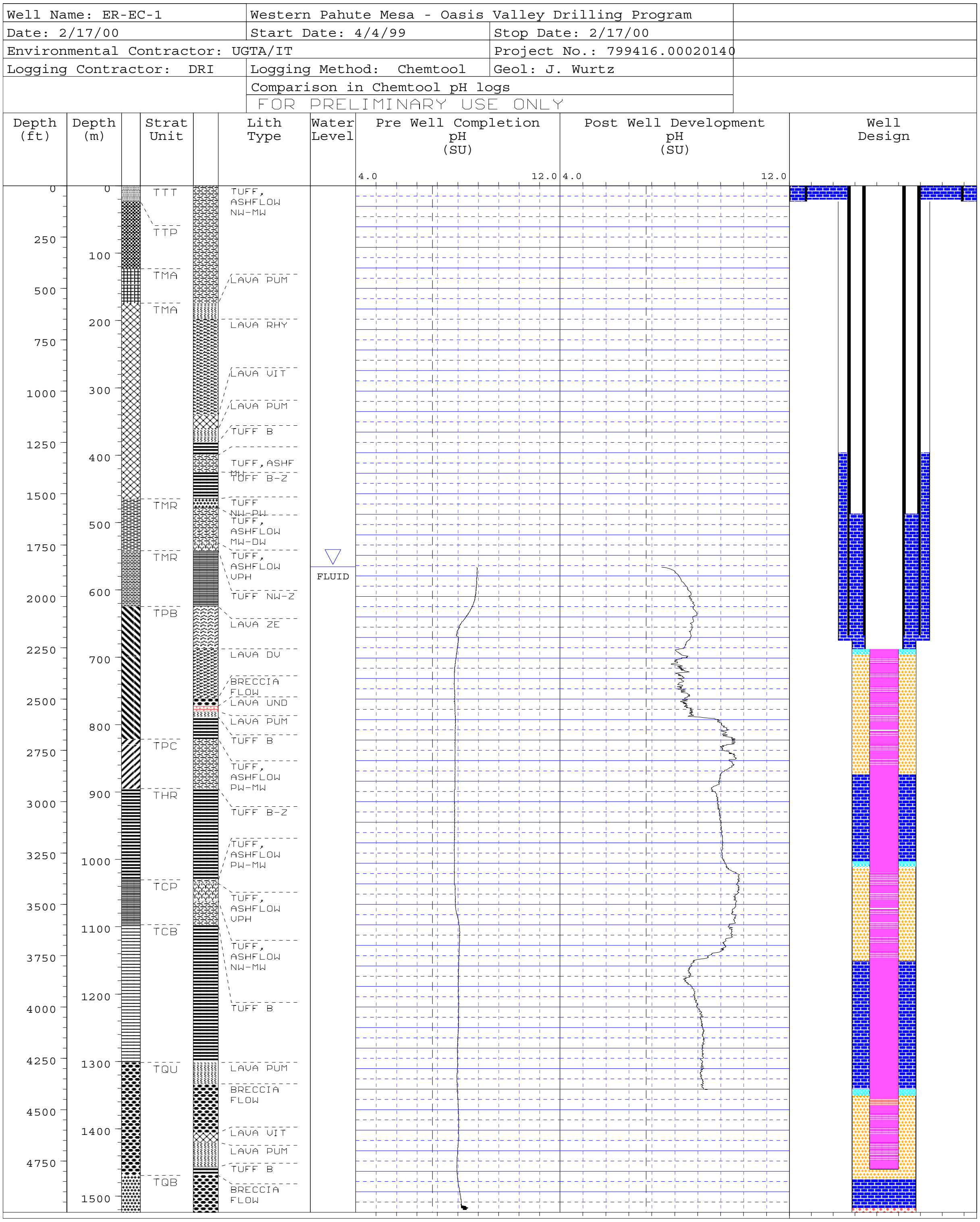


Figure A.3-12
Pressure Oscillations at the Start of the Recovery Period



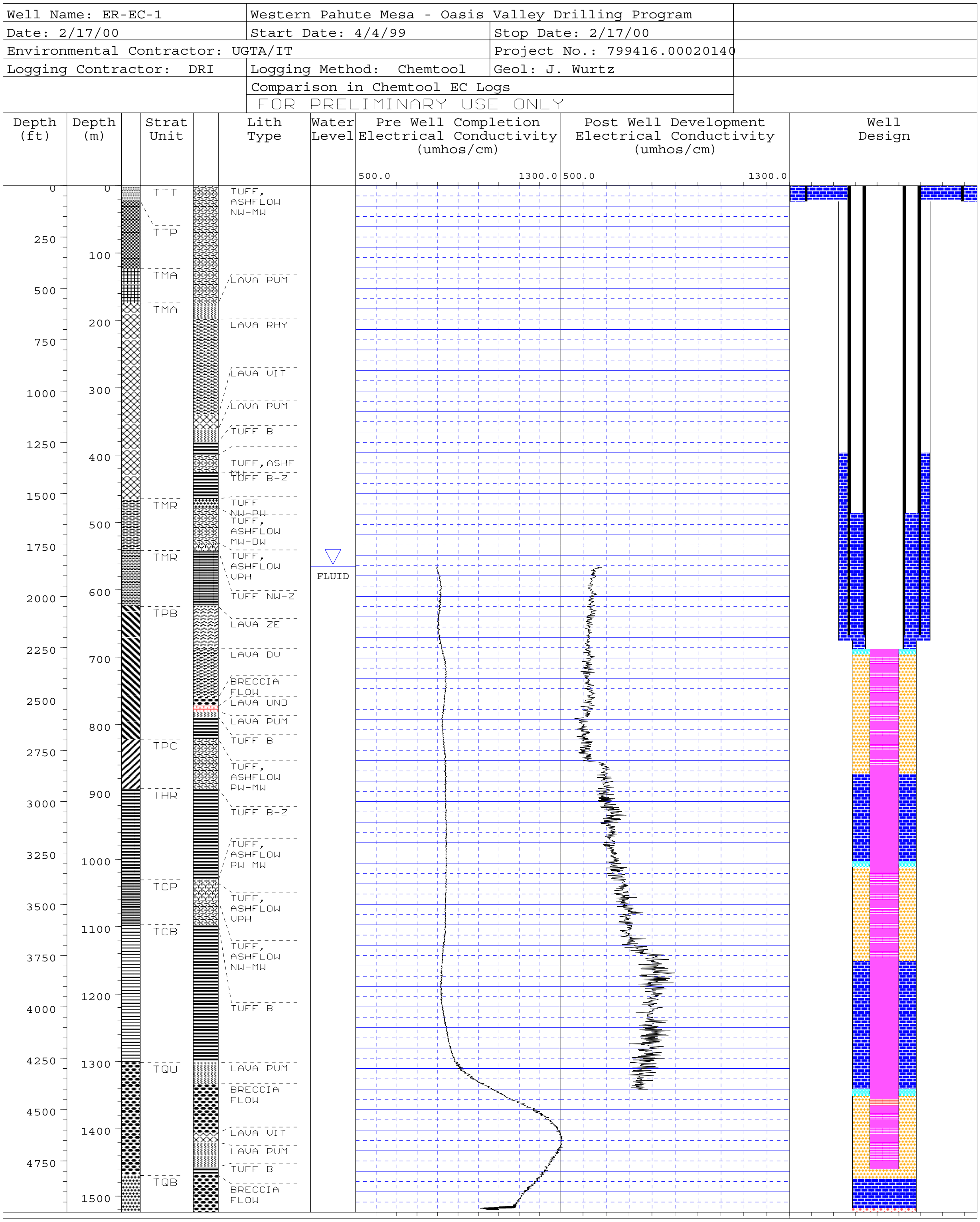
Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program	
Date: 2/17/00	Start Date: 4/4/99	Stop Date: 2/17/00
Environmental Contractor: UGTA/IT		Proj No.: 799416.00020140
Logging Contractor: DRI	Logging Method: Chemtool	Geol: J. Wurtz
	Comparison of Temp. Logs	
	FOR PRELIMINARY USE ONLY	

Figure A.3-13
Temperature Log Prior to Completion Versus Postdevelopment



Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program	
Date: 2/17/00	Start Date: 4/4/99	Stop Date: 2/17/00
Environmental Contractor: UGTA/IT		Project No.: 799416.00020140
Logging Contractor: DRI	Logging Method: Chemtool	Geol: J. Wurtz
	Comparison in Chemtool pH logs	
	FOR PRELIMINARY USE ONLY	

Figure A.3-14
pH Log Prior to Completion Versus Postdevelopment



Well Name: ER-EC-1	Western Pahute Mesa - Oasis Valley Drilling Program	
Date: 2/17/00	Start Date: 4/4/99	Stop Date: 2/17/00
Environmental Contractor: UGTA/IT		Project No.: 799416.00020140
Logging Contractor: DRI	Logging Method: Chemtool	Geol: J. Wurtz
	Comparison in Chemtool EC Logs FOR PRELIMINARY USE ONLY	

Figure A.3-15
EC Log Prior to Completion Versus Postdevelopment

A.4.0 Environmental Compliance

A.4.1 Fluid Management

All fluids produced during well development and hydraulic testing activities were managed according to the *Fluid Management Plan for the Underground Test Area Subproject* (FMP) (DOE/NV, 1999) and associated state-approved waivers. In accordance with the FMP and the waivers, the fluids produced during drilling were monitored and tested for tritium and lead daily. Several samples of water were collected from the sumps and analyzed at a certified laboratory for total and dissolved metals, gross alpha/beta, and tritium. Based on this process knowledge, the DOE/NV requested a waiver for the disposal of fluids produced during well development/hydraulic testing for Wells ER-EC-1, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, ER-EC-8 and ER-18-2. The DOE/NV's proposal was to conduct activities at these well sites under far-field conditions with a reduced frequency of on-site monitoring. In October 1999, the Nevada Division of Environmental Protection (NDEP) granted DOE/NV a waiver to discharge fluids directly to the ground surface during well development, testing, and sampling at the above wells (NDEP, 1999). The waiver was granted under the mandate that the following conditions were satisfied:

- The only fluids allowed to be discharged to the surface are waters from the wells.
- Fluids will be allowed to be discharged to the ground surface without prior notification to NDEP.
- Waters that are heavily laden with sediments need to be discharged to the unlined, noncontaminated basins to allow the sediments to settle out before being discharged to the land surface.
- One tritium and one lead sample from the fluid discharge will be collected every 24 hours for analysis.
- Additional sampling and testing for lead must be conducted at 1 hour and then within 8 to 12 hours after the initial pumping begins at each location. If the field testing results indicate nondetects for lead (less than 50 micrograms per liter [μg/L]), then the sampling may be conducted every 24 hours. If the field testing indicates detectable quantities less than 75 μg/L [5 times the *Nevada Drinking Water Standard* (NDWS)], then sampling must occur every 12 hours until two consecutive nondetects occur. Sampling and testing may then resume on the 24-hour schedule.

- NDEP must be notified within 24 hours if any of the limits in the FMP are exceeded.

A.4.1.1 Water Production and Disposition

At Well ER-EC-1, all fluids from the well development and testing were discharged into unlined Sump #1. Sump #1 serves as an infiltration basin and has an overflow pipe at approximately 6.75 ft from the bottom. On January 5, 2000, at approximately 19:00, the fluid level in Sump #1 reached the overflow pipe and produced fluids that began discharging to the ground surface via a drainage ditch on the north side of Sump #1.

A total of approximately 2,855,000 gallons of groundwater were pumped from Well ER-EC-1 during well development, hydraulic testing, and sampling activities. Table A.4-2 shows the final Fluid Disposition Form for the testing program.

A.4.1.2 Lead and Tritium Monitoring

Lead and tritium samples were collected daily according to the FMP and waivers. Lead analysis was conducted on site in the field laboratory using a HACH DR 100 Colorimeter according to DOP ITLV-UGTA-310, “Field Screening for Lead in Well Effluent.” A tritium sample was collected daily at the sample port of the wellhead. The sample was kept in a locked storage until transported to the BN Site Monitoring Service at the Control Point in Area 6. The sample was analyzed using a liquid scintillation counter.

The NDWS were not exceeded at any time. The highest lead result was 7 μg/L, and the highest tritium activity was 685 picocuries per liter (pCi/L). The complete results of lead and tritium monitoring are presented in Table A.4-2.

A fluid management sample was collected from the active unlined sump at the end of well development and testing activities to confirm on-site monitoring of well effluent. The sample was collected on February 1, 2000, and sent to Paragon. The FMP parameters of total and dissolved metals, gross alpha and beta, and tritium were requested for analysis. The laboratory results are presented in Table A.4-3 and compared to the NDWS.

A.4.2 Waste Management

Wastes generated during well development and testing activities were managed in accordance with the *Underground Test Area Subproject Waste Management Plan, Revision 1* (DOE/NV, 1996); the *Waste Management Field Instructions for the Underground Test Area Subproject* (ITLV, 1997); SQP ITLV-0501, “Control of Hazardous Materials”; and SQP ITLV-0513, “Spill Management.” The following exceptions were added in the *Field Instructions for WPM-OV Well Development and Hydraulic Testing Operations* (IT, 1999b) because chemical and/or radiological contamination was not expected:

Table A.4-1
Fluid Disposition Reporting Form

Site Identification: ER-EC-1
Site Location: Nellis Air Force Range
Site Coordinates: N 4,117,659.67m E 541,730.31m
Well Classification: ER Hydrogeologic Investigation Well
IT Project No: 776706.02080202; 799416.00020150

Report Date: 6/12/00
DOE/NV Subproject Manager: Bob Bangerter
IT Project Manager: Janet Wille
IT Site Representative: Jeff Wurtz
IT Environmental Specialist: Patty Gallo

Well Construction Activity	Activity Duration		#Ops. Days [a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes (m^3)		Infiltration Area (m^3) [d]	Other [c] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids [b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	4/4/99	4/10/99	7	565.7	661.4	149.2	174.9	- - -	- - -	174.9	N/A	Y
Phase I: Saturated-Zone Drilling	4/10/99	4/19/99	8	1,524	1,323	30.11	1,187.7	91.26	9,329	1,187.7	N/A	Y
Phase II: Initial Well Development	1/03/00	1/14/00	12	1,524	- - -	- - -	5,575.3	- - -	- - -	5,575.3	N/A	Y
Phase II: Aquifer Testing	1/19/00	1/27/00	9	1,524	- - -	- - -	5,230.9	- - -	- - -	5,115.7	N/A	Y
Phase II: Final Development	N/A	N/A	-	-	-	-	-	-	-	-	-	-
Cumulative Production Totals to Date:			36	1,524	1,984.4	179.31	12,168.8	91.26	9,329	12,053.6	-	Y

[a] Operational days refer to the number of days that fluids were produced during at least part (>3 hours) of one shift.
[b] Solids volume estimates include calculated added volume attributed to rock bulking factor.
[c] Other refers to fluid conveyance to other fluid management locations or facilities away from the well site, such as vacuum truck transport to another well site.
[d] Ground surface discharge and infiltration within the unlined sump.

NA = Not Applicable; m = meters; m^3 = cubic meters; AIP = Analysis In Process

Total Facility Capacities: Sump #1 (Unlined) = 1,089 m^3 Sump #2 (Lined) = 10,905 m^3

Infiltration Area (assuming very low/no infiltration) = NA m^3

Remaining Facility Capacity (Approximate) as of 3/08/00: Sump #1 = 973.8 m^3 (89.4 %) Sump #2 = 6,837 m^3 (62.7 %)

Current Average Tritium = (Natural Background) pCi/L

IT Authorizing Signature/Date: Janet Wille 6-12-00

Table A.4-2
Results of Tritium and Lead Monitoring at ER-EC-1

Sampling Date	Sample Number	Lead Results[1]	Tritium Results[2]	
		µg/L	dpm**	pCi/L*
12/23/1999	ER-EC-1-122399-01	N/A	0.00	0.00
01/03/2000	ER-EC-1-010300-01	1.0	0.00	0.00
01/03/2000	ER-EC-1-010300-02	N/A	0.00	0.00
01/04/2000	ER-EC-1-010400-01	1.0	2.99	272.2**
01/04/2000	ER-EC-1-010400-RZ1	0.4	0.00	0.00
01/05/2000	ER-EC-1-010500-01	1.0	1.30	117.12
01/06/2000	ER-EC-1-010600-01	0.5	4.67	420.72
01/07/2000	ER-EC-1-010700-01	0.5/0.3	0.88	79.28
01/08/2000	ER-EC-1-010800-01	0.2	4.30	387.39
01/09/2000	ER-EC-1-010900-01	1.0	0.00	0.00
01/10/2000	ER-EC-1-011000-01	<1.0	7.60	684.68
01/11/2000	ER-EC-1-011100-01	<1.0	0.00	0.00
01/12/2000	ER-EC-1-011200-01	<1.0	0.00	0.00
01/13/2000	ER-EC-1-011300-02	1.0	0.00	0.00
01/13/2000	ER-EC-1-011300-03	N/A	2.23	200.90
01/19/2000	EC-1-011900-01	2.0	0.17	15.32
01/20/2000	EC-1-012000-01	1.0	3.34	300.90
01/21/2000	EC-1-012100-01	1.0	0.54	48.65
01/22/2000	EC-1-012200-01	4.0/7.0	0.96	86.49
01/23/2000	ER-EC-1-012300-01	2.0	0.00	0.00
01/24/2000	ER-EC-1-012400-01	7.0	0.00	0.00
01/25/2000	ER-EC-1-012500-01	1.0	0.33	30.4**
01/26/2000	ER-EC-1-012600-01	1.0	0.00	0.00
02/01/2000	EC-1-020100-1	<1.0	0.00	0.00
Nevada Drinking Water Standards:		15.0	- - -	20,000

[1] Lower detection limit 2 ppb.
[2] Lower detection limit 500 to 1,000 pCi/L, depending upon calibration.

*pCi/L derived from the following conversion equation:
dpm/5mL * 1,000 mL/L * 0.45045 pCi/dpm = pCi/L
**Analysis by Bechtel Nevada Site Monitoring Service at the CP in Area 6

dpm - Disintegrations per minute
pCi/L - Picocuries per liter
µg/L - Micrograms per liter

Table A.4-3
Analytical Results of Sump Fluid Management Plan Sample at Well ER-EC-1

Analyte	**CRDL**	**Laboratory**	**NDWS**	**Results of Sump Composite Sample # EC-1-020100-3**
Metals (mg/L)				
				Total | Dissolved
Arsenic	0.01	Paragon	0.05	B 0.0059 | B 0.0035
Barium	0.2	Paragon	2.0	B 0.0031 | B 0.0024
Cadmium	0.005	Paragon	0.005	U 0.005 | U 0.005
Chromium	0.01	Paragon	0.1	B 0.0017 | B 0.0014
Lead	0.003	Paragon	0.015	U 0.003 | U 0.003
Selenium	0.005	Paragon	0.05	U 0.005 | U 0.005
Silver	0.01	Paragon	0.1	U 0.01 | U 0.01
Mercury	0.0002	Paragon	0.002	U 0.0002 | U 0.0002
Analyte	**MDC**	**Laboratory**		**Result | Error**
Radiological Indicator Parameters-Level I (pCi/L)				
Tritium	280	Paragon	20,000	U -40 | +/- 170
Gross Alpha	2.0	Paragon	15	10.1 | +/- 2.2
Gross Beta	2.4	Paragon	50	5.6 | +/- 1.7

U = Result not detected at the given minimum detectable limit or activity
B = Result less than the Practical Quantitation Limit but greater than or equal to the Instrument Detection Limit
CRDL = Contract-Required Detection Limit per Table 5-1 (DOE/NV, 1998)
MDC = Minimum Detectable Concentration, sample-specific
NDWS = *Nevada Drinking Water Standards*
mg/L = Milligrams per liter μg/L = Micrograms per liter pCi/L = Picocuries per liter

- Decontamination rinsate from laboratory and on-site equipment decontamination operations shall be disposed of with fluids in the on-site infiltration basin.

- All disposable sampling equipment and personal protective equipment shall be disposed of as sanitary waste and may be placed directly in on-site receptacles.

As a result of well development and testing activities, two types of waste were generated in addition to normal sanitary waste and decontamination water:

- Hydrocarbon: One drum of hydrocarbon waste was produced containing oily/diesel-stained absorbent pads, rags, and debris.

- Hazardous Waste: Approximately a half gallon of solid hazardous waste was generated from the installation of bridge plugs. This material consists of combustion by-products. This waste was removed from the site and consolidated with the bridge plug waste from other Nevada Test Site WPM-OV well sites. The waste was stored in a Satellite Accumulation Area at Well ER-EC-6 until the waste was transported off site for disposal.

All waste, hydrocarbon and hazardous, shall be disposed of by BN Waste Management once well development operations at the NTS are completed.

A.5.0 References

DOE/NV, see U.S. Department of Energy, Nevada Operations Office.

IT, see IT Corporation.

IT Corporation. 1997. *Waste Management Field Instructions for the Underground Test Area Subproject*, January. Las Vegas, NV.

IT Corporation. 1999a. *Detailed Operating Procedures Underground Test Area Operable Unit*, December. Las Vegas, NV.

IT Corporation. 1999b. *Field Instructions for Western Pahute Mesa - Oasis Valley Well Development and Hydraulic Testing Operations*, Rev. 0, December. Las Vegas, NV.

IT Corporation. 1999c. *Site-Specific Health and Safety Plan for Development, Testing and Sampling of Clean Wells*, October. Las Vegas, NV.

IT Corporation. 1999d. *Well Development and Hydraulic Testing Plan for Western Pahute Mesa - Oasis Valley Wells*, Rev. 0, November. Las Vegas, NV.

NDEP, see Nevada Division of Environmental Protection.

Nevada Division of Environmental Protection. 1999. Letter from P. Liebendorfer (NDEP) to R. Wycoff (DOE/NV) granting a waiver from the FMP for WPM-OV wells and stipulating conditions for discharging fluids, 19 October. Carson City, NV.

Roberson, J.A., and C.T. Crowe. 1975. *Engineering Fluid Mechanics*. Boston, MA: Houghton Mifflin Company.

U.S. Department of Energy, Nevada Operations Office. 1996. *Underground Test Area Subproject Waste Management Plan*, Rev. 1, August. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1998. *Underground Test Area Quality Assurance Project Plan*, Rev. 2, February. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 1999. *Attachment 1 - Fluid Management Plan for the Underground Test Area Subproject* in “Underground Test Area Subproject Waste Management Plan,” Rev. 1, July. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 2000. *Completion Report for Well ER-EC-1*, Rev. 0, December. Las Vegas, NV.

Attachment 1

Manufacturer's Pump Specifications

High-Capacity Testing Pump

[38435] ch-1 pgs-6   Tue Oct 12 13:03:35 1999

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P.06

RFQ # 623 HIGH VOLUME ELECTRIC SUBMERSIBLE PUMP SYSTEMS
BECHTEL NEVADA CORPORATION
YUCCA MOUNTAIN PROJECT
NEVADA TEST SITE
TERRY FLETCHER

CENTRILIFT

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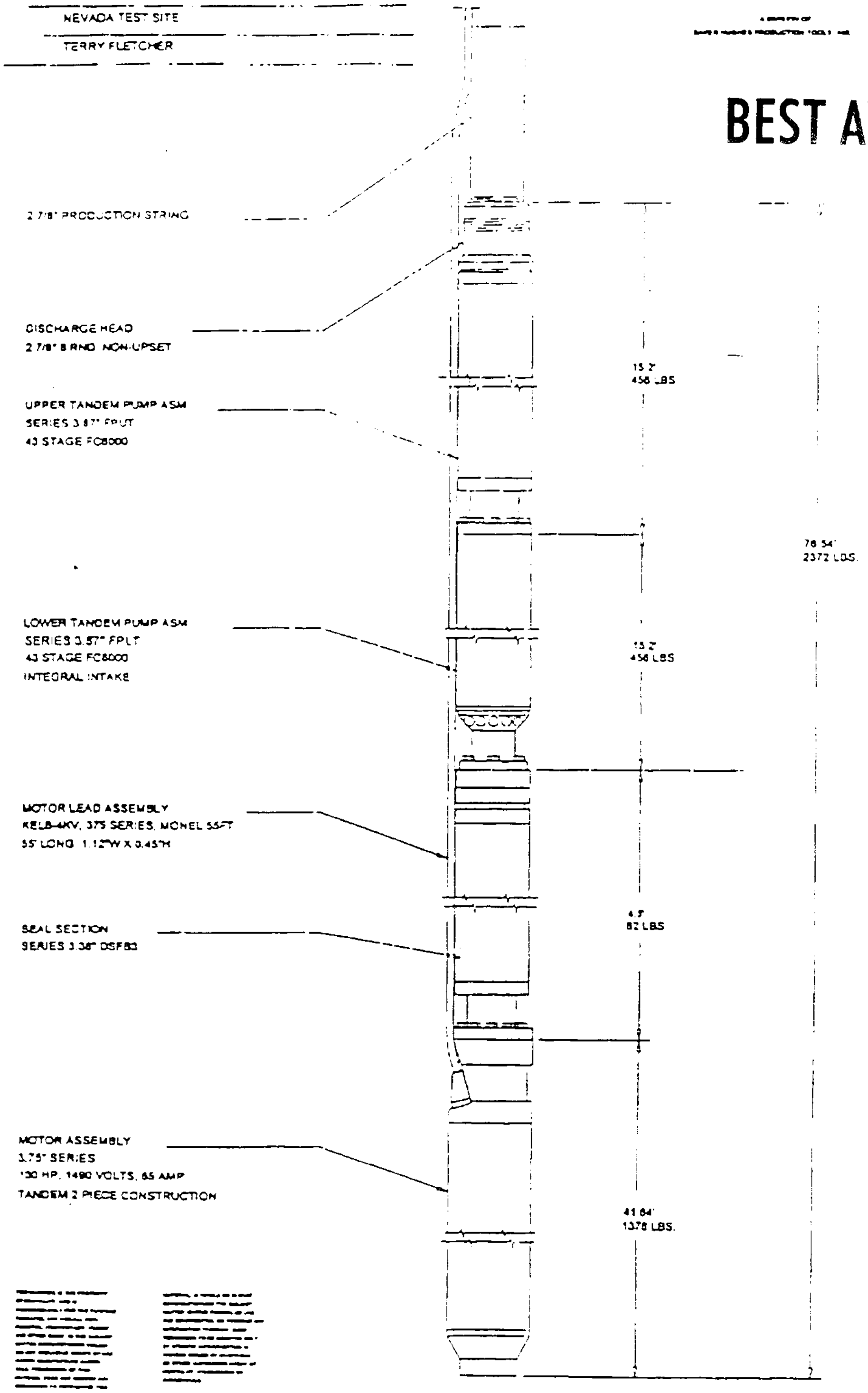

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Centrilift - A Baker Hughes company
(714) 893-8511 (800) 755-8976 (714) 892-9945 FAX (714) 397-0941 MOBILE
5421 Argosy Drive Huntington Beach, CA. 92649
Terry Fletcher- Sales Engineer E- Mail: Terry Fletcher@Centrilift.com

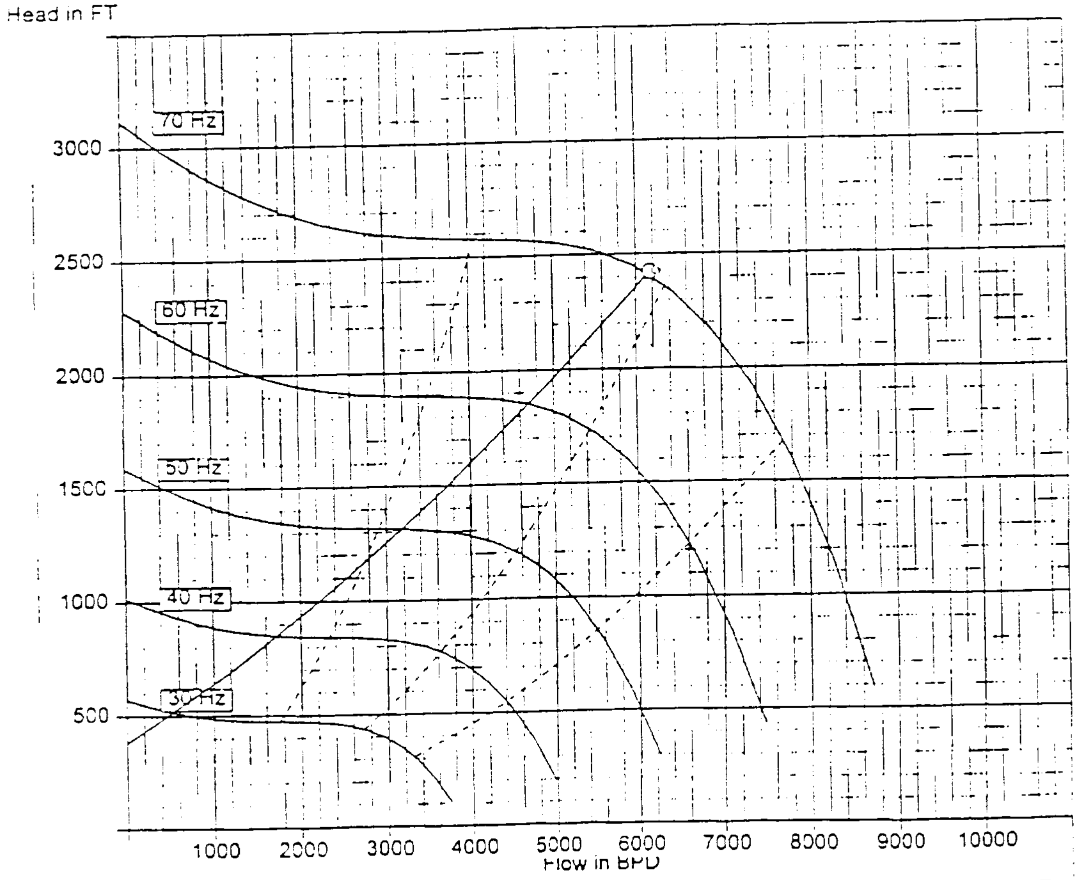
October 11,1999

Project: Nevada Test Site
Customer: Bechtel Nevada
Well: Various
Engineer: Mr. Ken Ortego

Pump: 86-FC6000 [400Series]
Seal: DSFB3 [338Series]
Motor: DMF 130 HP 1490V 55 A [375Series]
Cable: #4 CPNR 3kV ,2080ft
Controller: VSD 2250-VT 260kVA/ 480V/ 313A

60-180 GPM @ 2100' pump setting depth. 42-70 Hz. operation
Slim-line design to accomodate production logging tools *NOTE: Motor ratings at 60Hz
7-5/8" casing internally coated for a drift of 6.83" i.d. * Note: Set VSD to 70.4 Hz

86-FC6000 Series: 400



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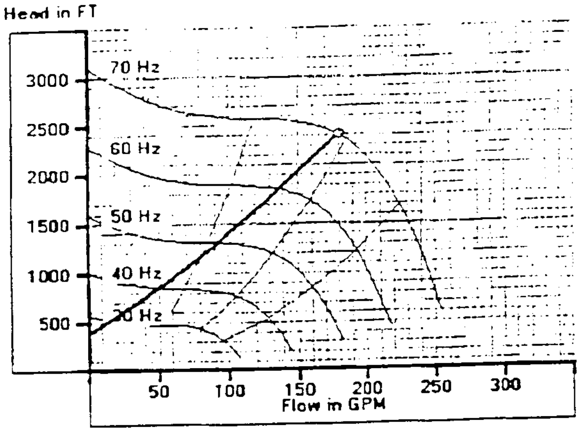
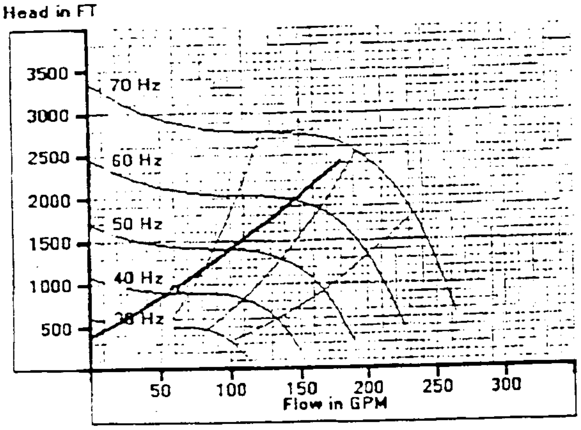
60 G.P.M. TO 180 G.P.M. OPERATION
2100' PUMP SETTING DEPTH





Frequency	Hz	40	45	50	55	60	65	70
Flow at Stock Tank	GPM	56.11	78.17	101	122	142	161	179
Pump Intake Pressure	psi	552	469	383	304	228	158	92
Total Dynamic Head	FT	907	1145	1406	1660	1917	2161	2404
Fluid speed past motor	ft/sec	0.672	0.937	1.211	1.465	1.708	1.931	2.144
Motor Load	%	27.5	38.5	51.38	64.22	77.24	90	103
Motor Amps	A	40.6	40.6	41.24	47.27	53.53	59.81	66.13
Pump RPM	rpm	2352	2646	2938	3210	3473	3726	3969
Surface KVA	kVA	60.92	68.14	77.11	103	134	169	209

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5421 Argosy Drive Huntington Beach, CA. 92649
Terry Fletcher- Sales Engineer E- Mail: Terry Fletcher@Centrilift.com

October 11,1999

Project: Nevada Test Site
Customer: Bechtel Nevada
Well: Various
Engineer: Mr. Ken Ortego

Pump: 86-FC6000 [400Series]
Seal: DSFB3 [338Series]
Motor: DMF 130 HP 1490V 65 A [375Series]
Cable: #4 CPNR 3kV ,2080ft
Controller: VSD 2250-VT 260kVA/ 480V/ 313A

60-180 GPM @ 2100' pump setting depth, 42-70 Hz. operation
Slim-line design to accomodate production logging tools *NOTE: Motor ratings at 60Hz
7-5/8" casing internally coated for a drift of 6.83" i.d. * Note: Set VSD to 70.4 Hz

Input Parameters:

Fluid Properties:
Oil Gravity = 20.0 °API
Water Cut = 100 %
SG water = 1.0 rel to H2O
SG gas = 0.8 rel to air
Sol GOR = 1.0 scf/STB
Prod GOR = 1.0 scf/STB
Bot Hole Temp = 120 °F
Surf Fluid Temp= 120 °F

Gas Impurities:
N2 = 0 %
H2S = 0 %
CO2 = 0 %

Bubble Point Pressure
Pb = 14.7psia

Inflow Performance:
Datum = 2100ft
Perfs V. Depth = 2500ft
Datum Static P = 760psi
Test Flow = 6171BPD
Test Pressure = 86.58psi
PI = 9.14BPD/psi
IPR Method = Composite IPR

Target:
Pump Setting Depth
(vertical) = 2100ft
Desired Flow = 6171BPD
Gas Sep Eff = 90%
Tbg Surf Press = 20.0psi
Csg Surf Press = 0psi

Casing & Tubing: Roughness = 0.0018 in

Casing ID (in)	6.969
Tubing ID (in)	2.441
Vertical Depth (ft)	3000
Measured Depth (ft)	3000

Correlations PVT:

Dead Visc:	**Saturated Visc:**	**UnderSaturated:**	**Gas Visc:**
Beggs & Robinson	Beggs & Robinson	Vasquez & Beggs	Lee
Oil Compress:	**Formation Vol:**	**Z factor:**	**Bubble Point P:**
Vasquez & Beggs	Standings	Hall & Yarborough	Standings

Correlations Multiphase:
Tubing Flow: Hagedorn & Brown
Casing Flow: Hagedorn & Brown

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5421 Argosy Drive Huntington Beach, CA. 92649
Terry Fletcher- Sales Engineer E- Mail: Terry Fletcher@Centrilift.com

October 11,1999

Operating Parameters / Selection:

Design Point:

Desired flow (total) = 6171 BPD
% water = 100.0 %
% Gas into pump = 0.0 %bs /0.0 %
Frequency = 70.4 Hz
GOR into pump= 1.0 scf/STB
TDH = 2422 FT

Pump Selection:

	Intake	Discharge
Pressure	= 86.97 psi	1123 psi
Flowrate	= 6255 BPD	6237 BPD
Specific Gravity	= 0.986 rel-H2O	0.989 rel-H2O
Viscosity	= 0.512Cp	0.534Cp

Pump Selected:
86 stages Type: FC6000 [400 Series]
Shaft HP at 70.4 Hz = 152 (37 %)
Required motor shaft HP at 60.0 Hz = 135

60-180 GPM @ 2100' pump setting depth, 42-70 Hz. operation

Seal Selection:

Well angle at set depth = 0Deg from vertical
No sand present
Pump uses floater-type stages
Motor/Seal Oil type = CL4
Seal Selected : DSFB3 [338 Series]
Options : None

Oil temperature at thrust chamber = 199°F
Chamber Cap Used (Top to Bot)=
22% 25%
Thrust bearing load =62 %
Shaft load = 79 %

Motor Selection:

Terminal Voltage =1766. V
Cable Current =66.6 A
Load acc to N.P. =103.6 %
Shaft Load =54.5 %

Fluid Speed =2.16ft/s
Internal Temp =170°F
Motor Selected: DMF 130 HP 1490V 65 A [375Series]
Options : None

Slim-line design to accomodate production logging tools *NOTE: Motor ratings at 60Hz

Cable Selection:

Surface Length = 50.0ft
Tubing Length = 2080ft
MLE length = 20.0ft
Surface Temp = 75°F

Wellhead Voltage = 1844.4V
Wellhead kVA = 212.8kVA
Voltage Drop = 78.5V
Cond Temp (main) = 179°F
Temp Rating = 205°F

Surface Cable	Main Cable	MLE Cable
#2 CTTF 3kV 50.0ft	#4 CPNR 3kV 2080ft	#6 MLE-KLHTLP 5kV 20.0ft

No comments

Controller Selection:

Input kVA = 169.0kVA
System kW = 162.2kW
Max Ctrl Current = 256.0A
Power Cost/kWH = 0.05$/kW
Total Power Cost = $5840/month

Voltage Input = 480V
Max Well Head Volts = 1844V
Max Frequency = 70.4Hz (6.82V/Hz)
Start Frequency = 10.0Hz
Step-up Trafo = 3.843 ratio
Selected: VSD 2250-V 250kVA/ 480V/ 313A

NEMA 3 design (outdoor use)

— End of Report —

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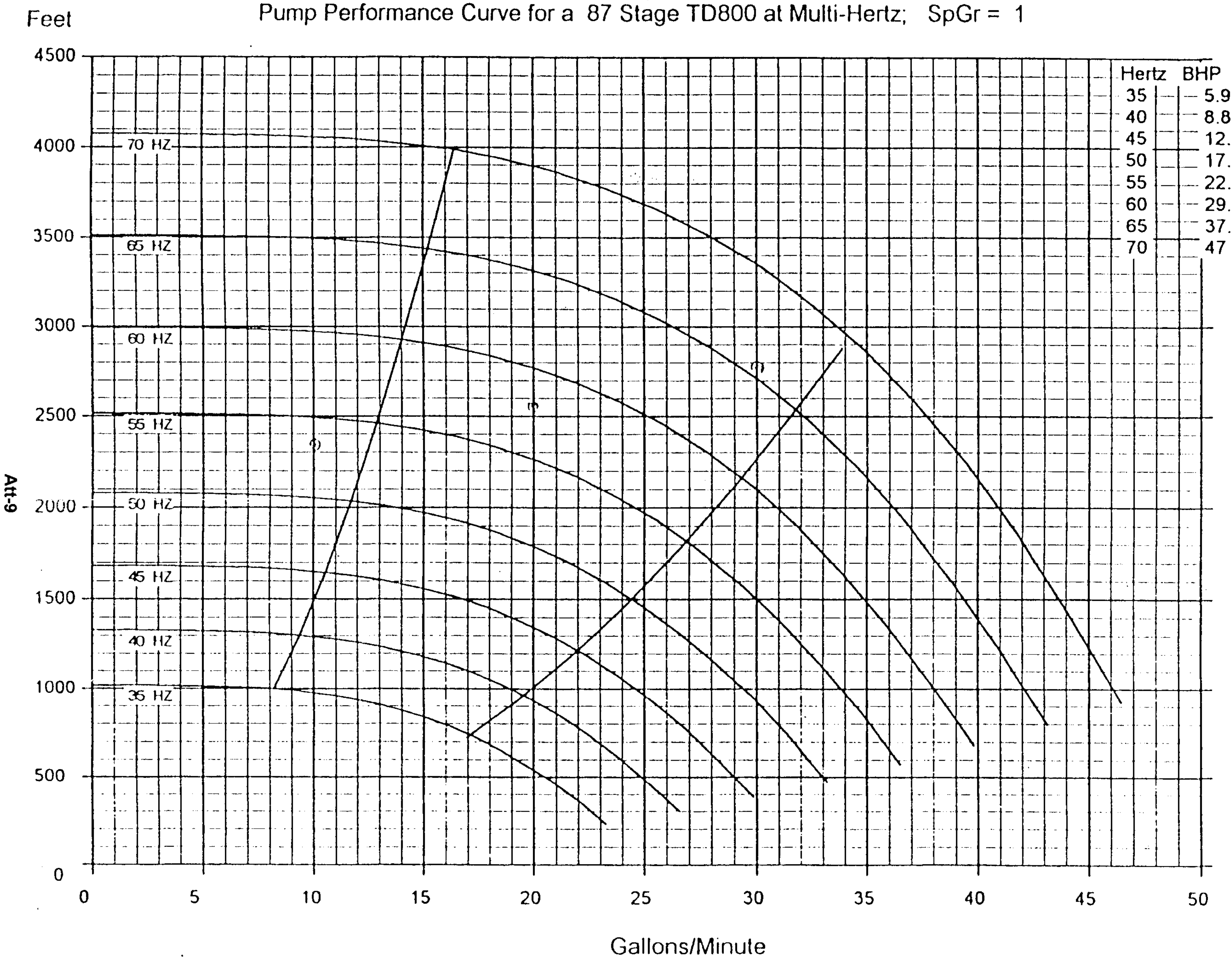
Dedicated Sampling Pump

Plot Program by Electric Submersible Pumps,Inc

4.00 ESP Pumps

Pump Performance Curve for a 87 Stage TD800 at Multi-Hertz; SpGr = 1



Hertz	BHP	NPHP
35	5.9	10.1
40	8.8	13.2
45	12.5	16.7
50	17.1	20.6
55	22.8	24.9
60	29.6	29.6
65	37.7	34.8
70	47	40.3

Att-9

Post-it® Fax Note 7671

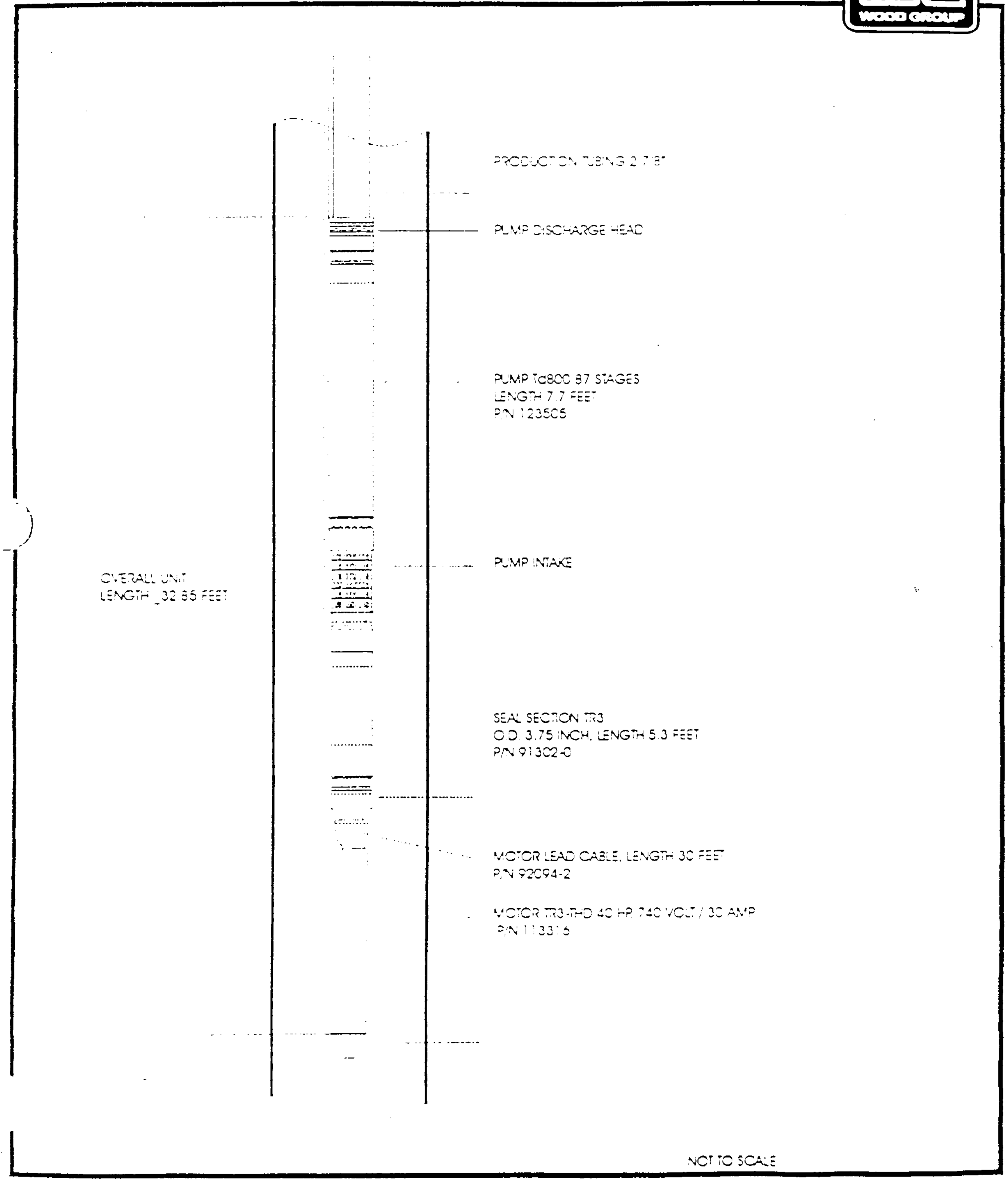
Date 2/16/00	# of pages ▶ 16
To D. SCHWICHTENBERG	From K. CATELLO
Co./Dept.	Co.
Phone #	Phone #
Fax #	Fax #

BEST AVAILABLE COPY

ESP

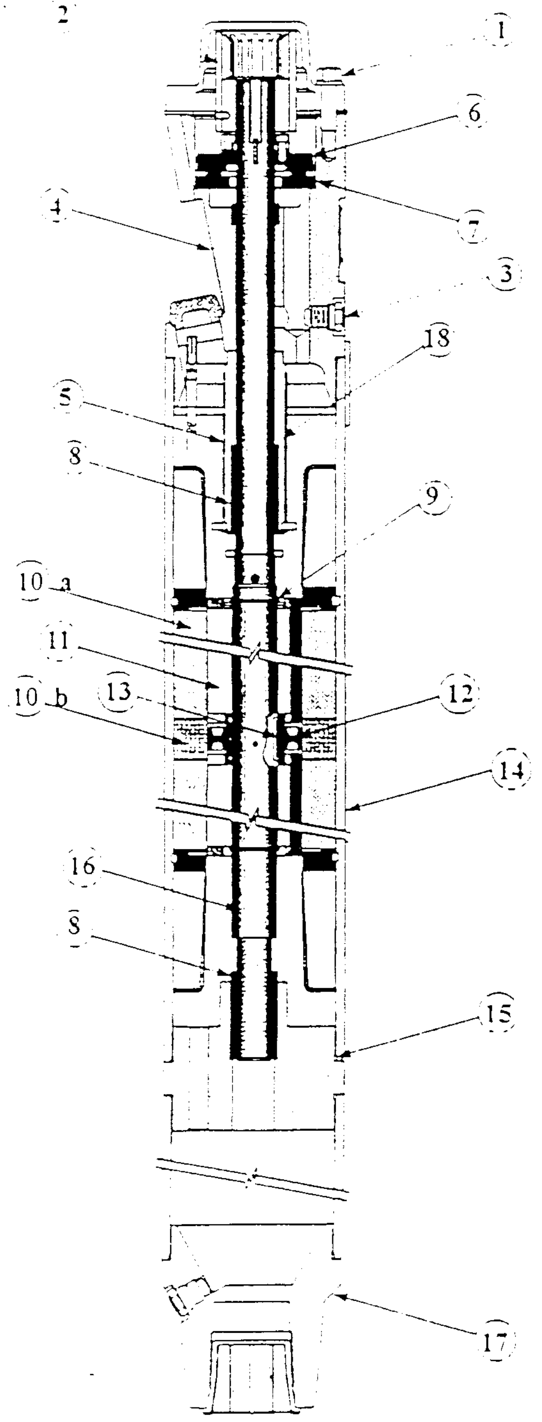
Bechtel Nevada
Las Vegas Nevada
Item Number 0001

WOOD GROUP



BEST AVAILABLE COPY

MOTOR, SINGLE 40HP, 740V 30A



PARTS LIST

ITEM	DESCRIPTION / MATERIAL
1	Unit Bolts Monel K500, UNS N05500
2	Coupling Steel 1042, ASTM 576
3	Vent Plugs Monel K500
4	Head Steel 1042, ASTM 576
5	Lead Guard Synthane
6	Thrust Runner Steel, C1117
7	Thrust Bearing Bronze, SAE 660 MP-481
8	Bushings Bronze 660
9	Snap Rings Beryllium Copper
10	Stator Laminations a)Steel b)Bronze,Silicon
11	Rotor Laminations Steel
12	Rotor Bearing Nitralloy
13	Rotor BearingSleeve Bronze 660
14	Stator Housing Steel 1026, ASTM A513
15	"O" Rings Viton
16	Shaft Steel 4130, ASTM A513, ASTM A519, UNS G41300
17	Base Steel 1042, ASTM 576
18	Guide Tube Steel 1020, ASTM A513,A519, UNS G10200

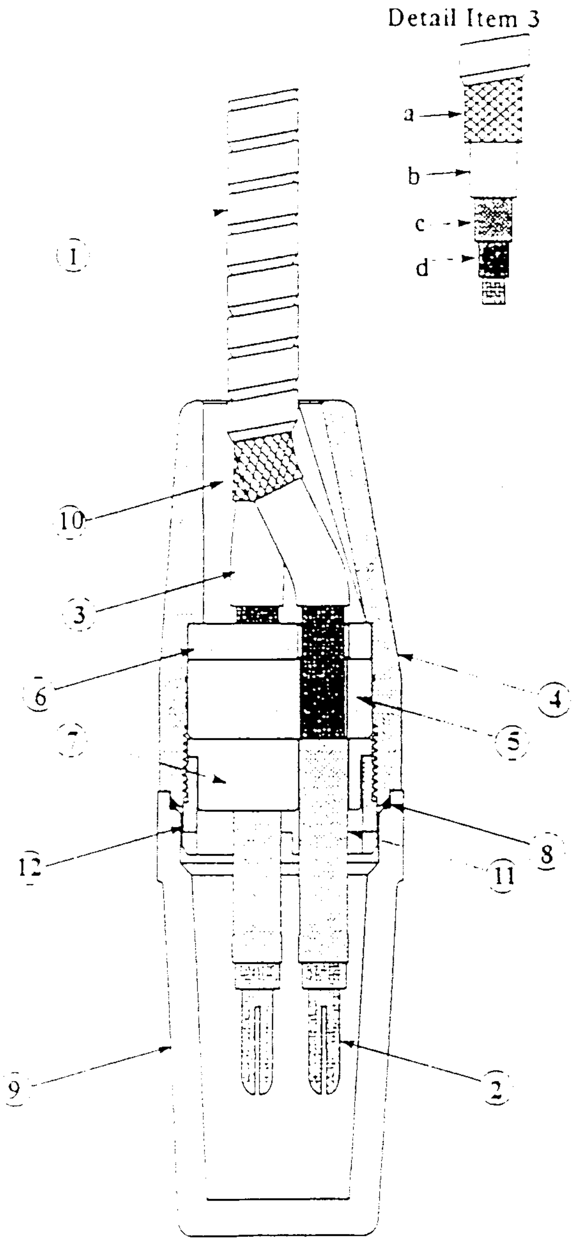
O.D. - 3.75 INCH
LENGTH - 17.7 FEET
WEIGHT - 660 LBS

materials mtr.tr-sgl.cdr

New Release
15 May 1997

BEST AVAILABLE COPY

MLC, Tr3 KEOTB GALV.



PARTS LIST

ITEM	DESCRIPTION / MATERIAL
1	Cable, Flat KEOTB Cable w/ Galv Armor
2	Terminal Beryllium Copper MP1012
3	Insulated Conductor a) Nylon Braid b) Lead Sheath c) EPDM Insulation d) Kapton Tape
4	Pothead Casting Ni-Resist
5	Insulation Block High Dielectric Hypalon
6	Wall, Upper Epoxy Glass G10-11, MP1017-1018
7	Wall, Lower Aluminum 2014
8	O-Ring HSN 75 Duro
9	Shipping Cap Ni-Resist
10	Filler Epoxy, Thermoset
11	Tubing, Shrink Teflon FEP
12	Nut, Compression Steel 1042 ASTM 576

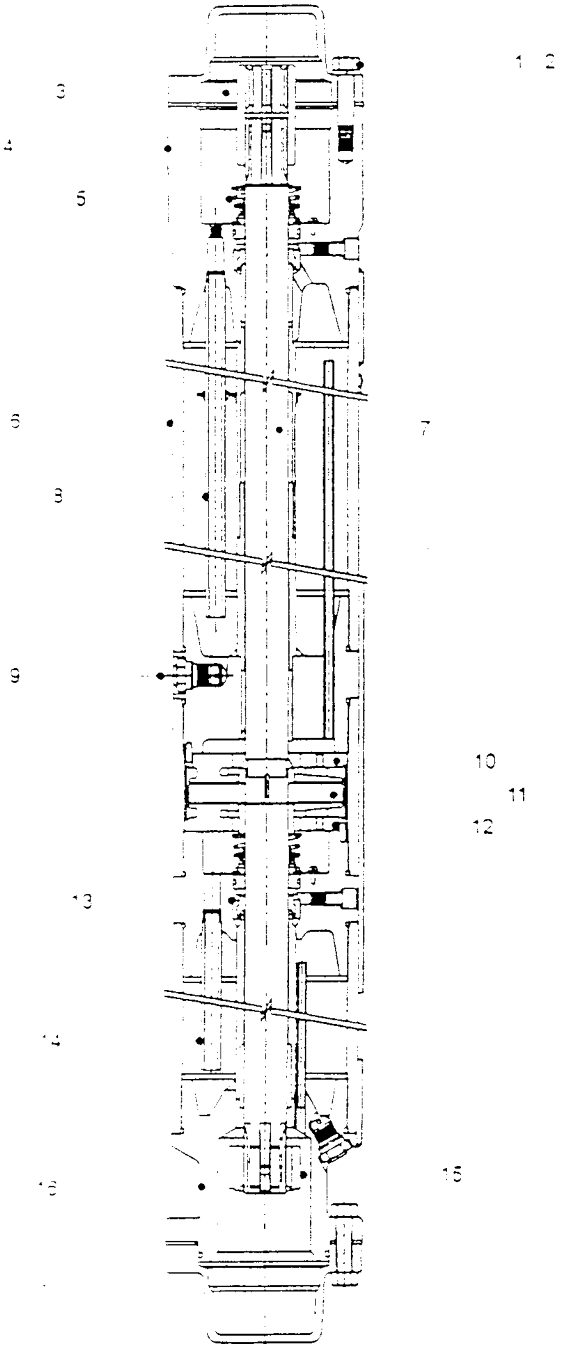
materials mlc,tr3-keib-4kv.car

New Release
27 May 1997

BEST AVAILABLE COPY

ESP

Standard Seal



PARTS LIST

ITEM	DESCRIPTION
1	Screw, Hex Head - Monel
2	Washer, Lock - Monel
3	Coupling - Monel
4	Head, Seal
5	Seal, Mechanical
6	Housing
7	Shaft
8	Breather Tube
9	Valve, Drain/Fill
10	Bearing, Up-Thrust
11	Runner, Thrust
12	Bearing, Down-Thrust
13	Water Shedder
14	Breather Tube
15	Coupling Adapter
16	Base

TYPE TR3
3.75 O.D.
5.3 FT.
Shaft Dia. 1"
Shaft Nitronic 50
Weight 125 lbs.

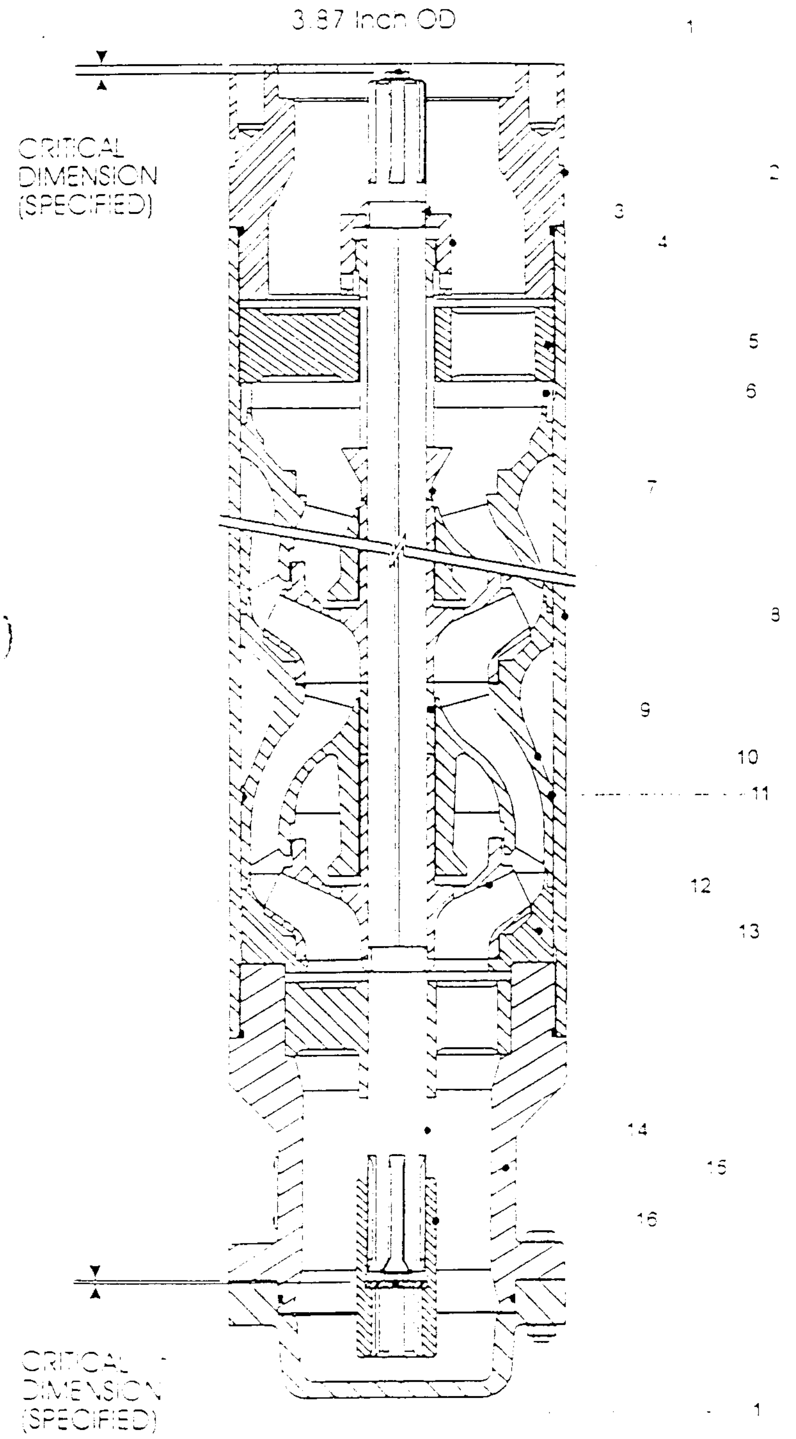
tr-std cdr

BEST AVAILABLE COPY

ESP

Standard Pump (Floater Stage Design)

WG WOOD GROUP



PARTS LIST

ITEM	DESCRIPTION
1	Adj. Nuts & Shims
2	Head, TDM
3	Two Piece Ring
4	Compression Nut, Sleeve & Set Screw
5	Compression Bearing
6	Compression Tube
7	Fluid Director
8	Housing
9	Spacer - Impeller
10	Diffuser
11	O'Ring, Diffuser
12	Impeller
13	Lower Diffuser
14	Shaft
15	Base, TDM S/A
16	Coupling

TD800D
87 STAGE
3.87O.D.
7.8 FT
2 3/8 8RD DISCHARGE
BOLT ON INTAKE

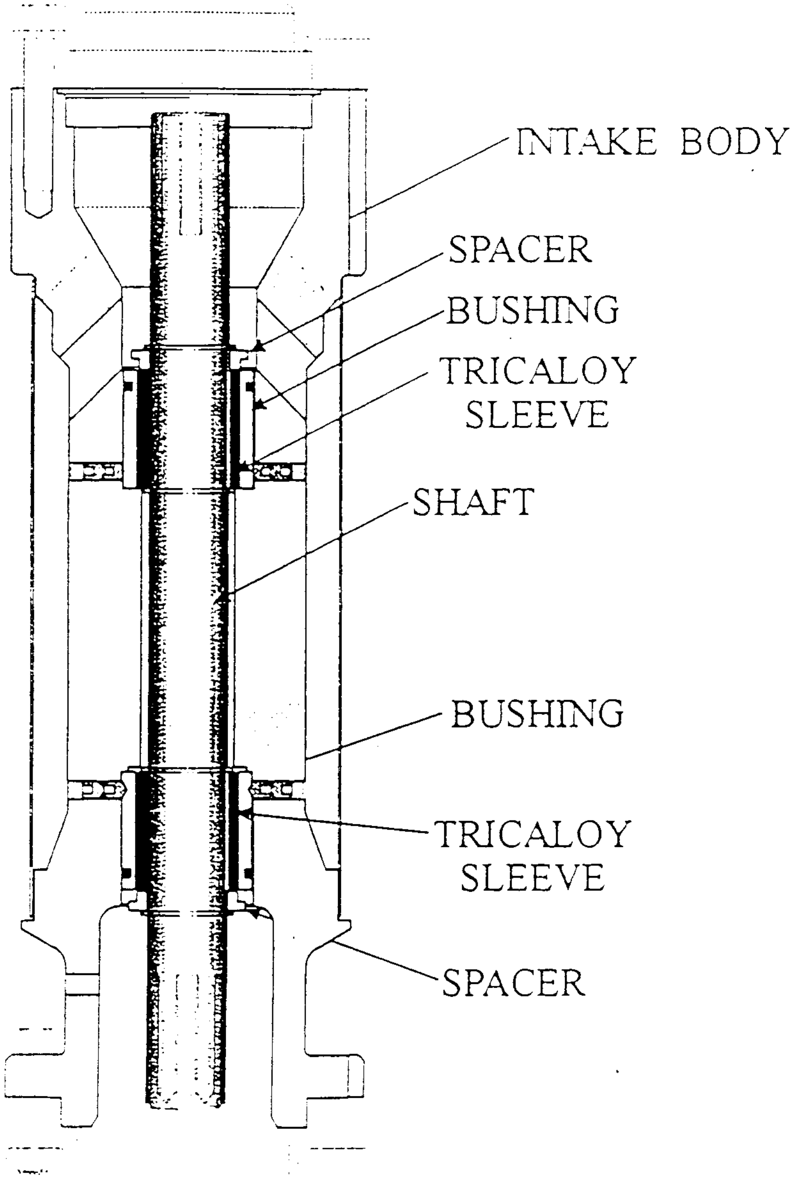
cmp-mix.cdr

BEST AVAILABLE COPY

ESP

3.87 INTAKE

WG WOOD GROUP



Attachment 2

Water Quality Monitoring - Grab Sample Results for Well ER-EC-1

Table ATT 2-1
Water Quality Monitoring Grab Samples for Well ER-EC-1
(Page 1 of 5)

Date	Time hr:min.	Temperature ° C	EC micromhos/ cm	pH	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development Or Testing
1/3/2000	14:49	- - -	- - -	- - -	- - -	- - -	- - -			Begin pumping at various rates
1/4/2000	10:00	34.4	1,045	6.71	4.70	0.7	0.64	99.5	123,075	Well Develop., several pumping/
1/4/2000	15:45	35.0	1,122	7.15	4.12	1.4	0.70	104.0	141,854	recovery sequences
1/4/2000	18:01	34.7	1,068	7.40	3.50	0.8	0.68	140.5	152,330	
1/4/2000	20:48	34.9	1,115	7.58	4.16	2.1	0.73		175,537	
1/4/2000	22:40	34.7	1,155	7.90	4.21	1.2	0.68	136.9	190,775	
1/5/2000	0:40	34.3	1,144	7.96	3.91	1.0	0.61		207,118	
1/5/2000	2:40	34.8	1,170	7.99	3.93	1.1	0.72	134.6	223,293	
1/5/2000	4:40	34.8	1,161	7.96	4.14	2.1	0.59		239,359	
1/5/2000	6:00	35.0	1,169	8.00	4.36	1.1	0.57	132.8	250,012	Pump off between 0610-0902
1/5/2000	10:58	33.3	967	6.75	5.10	1.2	1.12	103.0	261,136	
1/5/2000	11:51	34.2	954	7.46	4.80	1.0	1.07	134.0	267,774	
1/5/2000	14:12	34.4	969	7.28	4.24	6.9	1.11	56.0	270,260	Pump off between 1200-1351
1/5/2000	15:58	33.3	967	7.32	4.44	- - -	1.23	146.9	282,281	
1/5/2000	18:04	34.4	994	7.36	4.46	1.6	1.14		290,592	
1/5/2000	20:10	34.4	818	7.86	4.21	1.1	1.15	125.0	306,400	Establish constant rate of 125 at 1856
1/5/2000	22:00	34.5	815	7.94	4.20	0.8	1.13	124.9	320,115	
1/6/2000	0:00	35.1	817	7.85	4.98	1.0	1.00		335,083	
1/6/2000	2:00	35.2	819	7.96	5.72	1.1	0.97		350,053	
1/6/2000	4:00	34.7	820	7.97	5.61	1.3	1.06	124.7	365,023	
1/6/2000	6:00	35.3	820	7.98	5.55	2.0	1.06	124.9	379,992	
1/6/2000	8:37	35.7	862	7.69	4.81	0.6	1.62		399,347	Pump off between 0900-1000
1/6/2000	10:33	36.0	846	7.38	4.55	1.8	1.74	64.3	404,468	1st step in step-drawdown
1/6/2000	12:27	35.5	851	7.22	4.26	0.8	1.90	102.5	412,361	2nd step in step-drawdown

Table ATT 2-1
Water Quality Monitoring Grab Samples for Well ER-EC-1
(Page 2 of 5)

Date	Time hr:min.	Temperature °C	EC micromhos/cm	pH	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development Or Testing
1/6/2000	14:23	35.8	848	7.23	4.59	0.7	1.71	125.5	424,966	3rd step in step-drawdown
1/6/2000	16:26	36.3	846	7.38	4.49	0.5	1.78		440,112	Maintain constant rate overnight
1/6/2000	18:00	35.1	842	7.30	5.12	0.5	1.81	125.3	452,009	
1/6/2000	20:00	35.8	816	7.87	5.39	1.0	1.24		467,037	
1/6/2000	22:00	36.0	833	7.84	5.24	1.2	1.34	125.3	482,065	
1/7/2000	0:00	35.8	832	7.82	5.37	1.5	1.33		497,093	
1/7/2000	2:00	35.6	834	7.88	5.61	1.3	1.34	125.1	512,116	
1/7/2000	4:00	36.0	834	7.86	5.42	1.4	1.30		527,146	
1/7/2000	6:00	35.9	832	7.82	5.39	1.4	1.18	125.3	542,174	
1/7/2000	8:45	35.2	834	7.76	5.90	3.9	1.16		562,837	Pump off between 0900-1000
1/7/2000	11:04	36.0	832	7.76	4.90	2.1	1.00	63.2	568,879	1st step in step-drawdown
1/7/2000	13:00	35.5	832	7.73	5.70	2.0	0.88	101.4	578,400	2nd step in step-drawdown
1/7/2000	15:00	35.3	829	7.79	5.80	4.0	0.87	125.0	591,957	3rd step in step-drawdown
1/7/2000	17:00	35.7	829	7.78	5.10	0.8	0.91		606,929	Maintain constant rate overnight
1/7/2000	19:00	36.0	838	7.86	5.71	1.2	1.03		621,924	
1/7/2000	21:00	36.1	833	7.85	5.75	1.7	1.11		636,921	
1/7/2000	23:00	35.9	833	7.84	5.32	1.2	1.08	124.9	651,920	
1/8/2000	1:00	36.0	833	7.87	5.31	1.8	1.03		666,919	
1/8/2000	2:00	35.9	832	7.85	5.67	1.8	1.04	124.8	674,418	
1/8/2000	4:00	35.8	832	7.84	5.72	1.1	1.02		689,415	
1/8/2000	6:00	36.0	831	7.85	5.48	1.2	1.11	124.9	706,261	
1/8/2000	15:30	35.1	810	7.64	5.29	2.5	0.88	124.8	714,925	Pump off between 0650-1509
1/8/2000	17:35	36.0	815	7.65	5.80	1.2	0.89	125.1	730,538	Maintain constant rate overnight
1/8/2000	19:30	35.9	816	7.80	5.28	1.1	1.02	124.7	744,886	
1/8/2000	22:00	36.0	805	7.86	5.78	1.3	1.02	124.9	763,643	
1/9/2000	0:00	36.0	804	7.84	5.30	1.3	1.10		778,621	

Table ATT 2-1
Water Quality Monitoring Grab Samples for Well ER-EC-1
(Page 3 of 5)

Date	Time hr:min.	Temperature °C	EC micromhos/cm	pH	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development Or Testing
1/9/2000	2:00	35.9	805	7.85	5.29	1.5	1.01	125.1	793,566	
1/9/2000	4:00	35.8	806	7.84	5.46	1.7	1.02		808,571	
1/9/2000	6:00	35.8	807	7.82	5.36	1.8	1.06	124.8	823,575	
1/9/2000	8:08	36.0	838	7.79	6.90	1.8	1.21		839,559	
1/9/2000	10:00	35.3	840	7.79	5.40	1.1	1.14	125.1	853,565	
1/9/2000	12:00	36.0	839	7.84	6.90	0.9	1.19		868,471	
1/9/2000	14:00	36.0	845	7.85	6.65	0.8	1.21	124.6	883,439	
1/9/2000	16:00	36.1	842	7.85	5.85	0.9	1.18	124.8	898,408	Pump off between 1628-2033
1/9/2000	22:00	36.0	831	7.85	5.29	1.4	1.11	125.0	911,630	
1/10/2000	0:00	36.2	831	7.91	5.13	1.8	1.00		926,624	
1/10/2000	2:00	36.4	834	7.89	5.88	1.2	1.10	125.1	941,619	
1/10/2000	4:00	36.2	832	7.88	5.85	1.6	1.10	125.1	956,614	Pump off between 0459-1250
1/10/2000	13:00	35.7	825	7.89	5.20	7.2	1.13	64.5	964,432	DRI begins flow logging at 1445
1/10/2000	15:00	35.9	821	7.84	4.90	1.1	1.12	142.6	978,808	Pumping in steps, begin at 126
1/10/2000	17:00	35.7	823	7.84	5.80	8.4	1.17	125.9	993,901	
1/10/2000	19:00	35.9	824	7.82	5.80	1.4	1.09		1,009,001	
1/10/2000	21:00	36.2	825	7.83	5.40	1.5	1.02		1,024,106	
1/10/2000	22:00	36.4	825	7.88	5.50	1.2	1.02	125.9	1,031,663	
1/11/2000	0:00	36.2	825	7.88	5.20	1.6	1.01		1,046,772	
1/11/2000	2:00	36.1	824	7.87	5.40	1.3	0.99	125.8	1,061,881	
1/11/2000	4:00	36.0	826	7.85	5.10	1.4	1.03		1,076,996	
1/11/2000	6:00	36.0	827	7.86	5.00	1.2	1.03	125.4	1,092,115	
1/11/2000	8:00	35.9	825	7.89	- - -	0.8	1.03		1,107,233	
1/11/2000	10:00	35.5	822	7.91	5.80	1.1	0.81	125.9	1,122,347	
1/11/2000	12:00	35.6	824	7.94	6.80	2.3	0.76		1,136,033	Decrease pumping rate to 103 at 1100
1/11/2000	14:00	35.9	825	7.91	7.10	0.8	0.80	103.7	1,148,469	

Table ATT 2-1
Water Quality Monitoring Grab Samples for Well ER-EC-1
(Page 4 of 5)

Date	Time hr:min.	Temperature ° C	EC micromhos/ cm	pH	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development Or Testing
1/11/2000	16:00	35.5	824	7.89	6.00	0.6	0.80		1,160,875	
1/11/2000	18:00	35.7	822	7.92	5.30	0.5	0.78	103.1	1,173,234	
1/11/2000	20:00	36.2	826	7.94	5.10	1.2	0.81		1,185,510	Decrease pumping rate to 64 at 1926
1/11/2000	22:00	36.4	826	7.84	5.10	1.2	1.10	64.0	1,193,196	
1/12/2000	0:00	36.2	825	7.81	5.10	2.0	1.03		1,200,881	
1/12/2000	2:00	36.7	826	7.84	4.80	1.5	1.15	64.3	1,208,568	
1/12/2000	4:00	36.8	826	7.86	5.00	1.5	1.24		1,216,257	
1/12/2000	6:00	36.7	827	7.88	4.90	2.0	1.21	64.3	1,223,945	
1/12/2000	8:00	35.9	819	7.91	5.30	1.5	1.08		1,231,629	
1/12/2000	10:00	35.9	818	7.91	5.40	0.9	0.96	64.0	1,239,312	
1/12/2000	12:35	35.9	849	7.02	4.91	7.8	0.96	63.8	1,249,233	
1/12/2000	23:30	- - -	- - -	7.09	- - -	2.1	- - -	126.3	1,283,063	Pump off between 1330-1940
1/13/2000	1:55	35.5	867	7.48	5.39	6.6	1.01	126.3	1,301,357	
1/13/2000	5:06	35.7	868	7.56	4.76	1.4	1.06	126.2	1,325,333	
1/13/2000	8:30	35.1	819	7.61	5.60	1.9	1.06	126.2	1,351,201	Collect bailer sample at 0830-1015
1/13/2000	14:50	34.6	819	7.54	4.98	2.3	1.08		1,370,610	1015-1430 pump off, put in check valve
1/13/2000	17:00	35.1	827	7.26	4.65	1.0	1.03	126.3	1,387,038	Collect bailer sample at 1430-2000
1/13/2000	19:30	34.3	824	7.87	4.42	2.1	1.02		1,405,992	Collect bailer sample at 1430-2000
1/14/2000	4:30	- - -	- - -	- - -	- - -	- - -	- - -		1,472,969	Pump shut down, begin recovery
1/19/2000	14:18	- - -	- - -	- - -	- - -	- - -	- - -	120.5	1,474,345	Begin Constant Rate test
1/22/2000	15:20	N/A	796	8.15	N/A	1.5	0.95	120.2	2,002,428	Constant Rate test, one-a-day testing

Table ATT 2-1
Water Quality Monitoring Grab Samples for Well ER-EC-1
(Page 5 of 5)

Date	Time hr:min.	Temperature ° C	EC micromhos/ cm	pH	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development Or Testing
1/23/2000	10:51	N/A	810	7.67	N/A	1.1	1.35	120.6	2,143,498	Constant Rate test, one-a-day testing
1/24/2000	11:22	N/A	852	7.85	N/A	1.5	N/A	120.6	2,320,879	Constant Rate test, one-a-day testing
1/25/2000	13:08	N/A	849	7.70	N/A	1.3	1.53	120.6	2,507,792	Constant Rate test, one-a-day testing
1/26/2000	13:43	N/A	833	7.85	N/A	1.2	1.65	120.4	2,685,602	Constant Rate test, one-a-day testing

Attachment 3

Water Quality Analyses, Composite Characterization Sample and Discrete Samples

Table ATT 3-1
Analytical Results of Groundwater Characterization Samples
(Page 1 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample Sample # EC-1-011300-1	Results of Wellhead Composite Sample # EC-1-020100-1
Metals (mg/L)				
			Total | Dissolved	**Total | Dissolved**
Aluminum	0.2	Paragon	UJ 0.2 | UJ 0.2	U 0.042 | U 0.055
Arsenic	0.01	Paragon	B 0.005 | U 0.01	U 0.01 | B 0.0025
Barium	0.1	Paragon	B 0.0044 | B 0.0056	B 0.0035 | B 0.0036
Cadmium	0.005	Paragon	U 0.005 | U 0.005	UJ 0.005 | UJ 0.005
Calcium	1	Paragon	19 | 18	19 | 20
Chromium	0.01	Paragon	B 0.0056 | B 0.0023	U 0.00092 | U 0.0012
Iron	0.1	Paragon	0.55 | U 0.054	0.43 | 0.34
Lead	0.003	Paragon	0.0074 | U 0.003	U 0.003 | U 0.003
Lithium	0.01	Paragon	0.13 | 0.13	0.14 | 0.14
Magnesium	1	Paragon	B 0.37 | B 0.37	B 0.46 | B 0.47
Manganese	0.01	Paragon	B 0.0097 | B 0.002	0.019 | 0.018
Potassium	1	Paragon	8.2 | 8.2	8.2 | 8.3
Selenium	0.005	Paragon	U 0.005 | U 0.005	U 0.005 | U 0.005
Silicon	0.05	Paragon	24 | 23	24 | 24
Silver	0.01	Paragon	U 0.01 | U 0.01	U 0.01 | U 0.01
Sodium	1,1,10,10	Paragon	150 | 150	120 | 120
Strontium	0.01	Paragon	0.023 | 0.023	0.022 | 0.022
Uranium	0.2	Paragon	U 0.2 | U 0.2	U 0.2 | U 0.2
Mercury	0.0002	Paragon	UJ 0.0002 | UJ 0.0002	UJ 0.0002 | UJ 0.0002
Inorganics (mg/L) - unless otherwise noted				
Chloride	1,2	Paragon	95	95
Fluoride	.1	Paragon	2.6	2.6
Bromide	.2	Paragon	0.49	0.46
Sulfate	5,10	Paragon	120	120
pH (pH units)	0.1	Paragon	J 7.8	J 8.3
Total Dissolved Solids	20	Paragon	J 510	500
Electrical Conductivity (micromhos/centimeter)	1	Paragon	750	730
Carbonate as CaCO3	50,10	Paragon	U 50	U 10
Bicarbonate as CaCO3	50,10	Paragon	130	130

Table ATT 3-1
Analytical Results of Groundwater Characterization Samples
(Page 2 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Result	Result
Organics (mg/L)				
Total Organic Carbon	1	Paragon	1.9	U 1.0
Redox Parameters (mg/L)				
Total Sulfide	5	Paragon	UJ 5.0	UJ 5.0
Age and Migration Parameters (pCi/L) - unless otherwise noted				
Carbon 13/12 (per mil)	Not Provided	DRI	N/A	-4.3
Carbon-14, Inorganic (pmc)	Not Provided	LLNL	N/A	5.9
Carbon-14, Inorganic age (years)*	Not Provided	LLNL	N/A	23400
Chlorine-36	Not Provided	LLNL	N/A	1.75E-03
Chlorine-36/Cl (ratio)	Not Provided	LLNL	N/A	5.46E-13
Helium-3/4, measured value (ratio)	Not Provided	LLNL	N/A	9.25E-07
Helium-3/4, relative to air (ratio)	Not Provided	LLNL	N/A	6.70E-01
Oxygen-18/16 (per mil)	Not Provided	DRI	N/A	-14.8
Strontium-87/86 (ratio)	Not Provided	LLNL	N/A	0.71023 | 0.00001
Uranium-234/238 (ratio)	Not Provided	LLNL	N/A	0.000209887
Hydrogen-2/1 (per mil)	Not Provided	DRI	N/A	-114
Radiological Indicator Parameters-Level I (pCi/L)				
Gamma Spectroscopy	Sample Specific	Paragon		
Tritium	280	Paragon	U -160 | 160	U -130 | 160
Radiological Indicator Parameters-Level I (pCi/L)				
Gross Alpha	1.4, 1.9	Paragon	10.7 | 2.2	13.2 | 2.6
Gross Beta	2.3, 2.5	Paragon	6.3 | 1.7	8.4 | 2.0
Radiological Indicator Parameters-Level II (pCi/L)				
Carbon-14	300	Paragon	UJ -80 | 180	UJ -30 | 180
Strontium-90	0.25	Paragon	N/A	U 0.06 | 0.15
Plutonium-238	0.041, 0.055	Paragon	U -0.003 | 0.013	U -0.012 | 0.015

Table ATT 3-1
Analytical Results of Groundwater Characterization Samples
(Page 3 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Result	Result
Plutonium-239	0.033, 0.027	Paragon	U 0.001 | 0.013	U -0.002 | 0.013
Iodine-129	11	Paragon	N/A	U 5.0 | 6.7
Technetium-99	3.2	Paragon	N/A	UJ 1.1 | 1.9

U = Result not detected at the given minimum detectable limit or activity
B = Result less than the Practical Quantitation Limit but greater than or equal to the Instrument Detection Limit
J = Estimated value
N/A = Not applicable for that sample
mg/L = Milligrams per liter
pCi/L = Picocuries per liter
pmc = Percent modern carbon

* = The carbon-14 age presented is not corrected for reactions along the flow path.

Table ATT 3-2
Colloid Analyses for Well ER-EC-1

Analyte	**Laboratory**	**Results of Discrete Bailer Sample #EC-1-011300-1**	**Results of Wellhead Composite Sample #EC-1-020100-1**
Colloid Particle Size Range (in nanometer)		Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)
50 - 60	LANL	5.920E+06	3.903E+07
60 - 70	LANL	5.870E+06	2.807E+07
70 - 80	LANL	5.321E+06	1.701E+07
80 - 90	LANL	3.922E+06	7.756E+06
90 - 100	LANL	2.498E+06	3.528E+06
100 - 110	LANL	3.272E+06	1.952E+06
110 - 120	LANL	2.673E+06	1.326E+06
120 - 130	LANL	1.873E+06	7.256E+05
130 - 140	LANL	1.324E+06	3.754E+05
140 - 150	LANL	1.674E+06	4.504E+05
150 - 160	LANL	1.124E+06	4.504E+05
160 - 170	LANL	9.992E+05	2.252E+05
170 - 180	LANL	5.746E+05	2.252E+05
180 - 190	LANL	8.742E+05	2.502E+05
190 - 200	LANL	5.996E+05	5.000E+04
200 - 220	LANL	6.744E+05	1.752E+05
220 - 240	LANL	4.148E+05	7.180E+04
240 - 260	LANL	2.064E+05	4.360E+04
260 - 280	LANL	9.900E+04	2.040E+04
280 - 300	LANL	7.460E+04	9.000E+03
300 - 400	LANL	1.760E+05	1.980E+04
400 - 500	LANL	3.160E+04	3.000E+03
500 - 600	LANL	4.180E+04	3.600E+03
600 - 800	LANL	6.500E+04	1.140E+04
800 - 1,000	LANL	2.620E+04	2.400E+03
>1,000	LANL	5.480E+04	4.800E+03
Total Concentration, Particle Size Range, 50-1,000 nm	LANL	4.04E+07	1.02E+08

Table ATT 3-3
Trace Element Results for Groundwater Characterization Samples
(Page 1 of 2)

Analyte	Laboratory Detection Limit	Laboratory	Qualifier	Results of Discrete Bailer Sample #EC-1-011300-1	UNIT
Ag, Dissolved	0.05	UNLV-HRC	<	0.05	µg/L
Al, Dissolved	0.10	UNLV-HRC		11.4	µg/L
As, Dissolved	0.03	UNLV-HRC		2.95	µg/L
Au, Dissolved	0.057	UNLV-HRC	<	0.057	µg/L
Ba, Dissolved	0.010	UNLV-HRC		4.00	µg/L
Be, Dissolved	0.014	UNLV-HRC		0.023	µg/L
Bi, Dissolved	0.004	UNLV-HRC		0.015	µg/L
Cd, Dissolved	0.004	UNLV-HRC		0.042	µg/L
Ce, Dissolved	2.7	UNLV-HRC		6.8	ng/L
Co, Dissolved	0.004	UNLV-HRC		0.078	µg/L
Cr, Dissolved	0.010	UNLV-HRC		1.95	µg/L
Cs, Dissolved	0.004	UNLV-HRC		1.01	µg/L
Cu, Dissolved	0.010	UNLV-HRC		3.47	µg/L
Ga, Dissolved	5.0	UNLV-HRC		107	ng/L
Ge, Dissolved	0.010	UNLV-HRC		0.860	µg/L
Hf, Dissolved	0.021	UNLV-HRC	<	0.021	µg/L
In, Dissolved	0.006	UNLV-HRC	<	0.006	µg/L
Ir, Dissolved	8.8	UNLV-HRC		23	ng/L
La, Dissolved	3.5	UNLV-HRC		8.4	ng/L
Li, Dissolved	0.009	UNLV-HRC		133	µg/L
Mn, Dissolved	0.01	UNLV-HRC		1.22	µg/L
Mo, Dissolved	0.01	UNLV-HRC		6.56	µg/L
Nb, Dissolved	3.7	UNLV-HRC	<	3.7	ng/L
Ni, Dissolved	0.020	UNLV-HRC		0.610	µg/L
Pb, Dissolved	0.14	UNLV-HRC		0.20	µg/L
Pd, Dissolved	0.024	UNLV-HRC	<	0.024	µg/L
Pt, Dissolved	0.013	UNLV-HRC	<	0.013	µg/L
Rb, Dissolved	0.004	UNLV-HRC		19.0	µg/L
Re, Dissolved	0.007	UNLV-HRC	<	0.007	µg/L
Rh, Dissolved	0.004	UNLV-HRC	<	0.004	µg/L
Ru, Dissolved	0.004	UNLV-HRC	<	0.004	µg/L

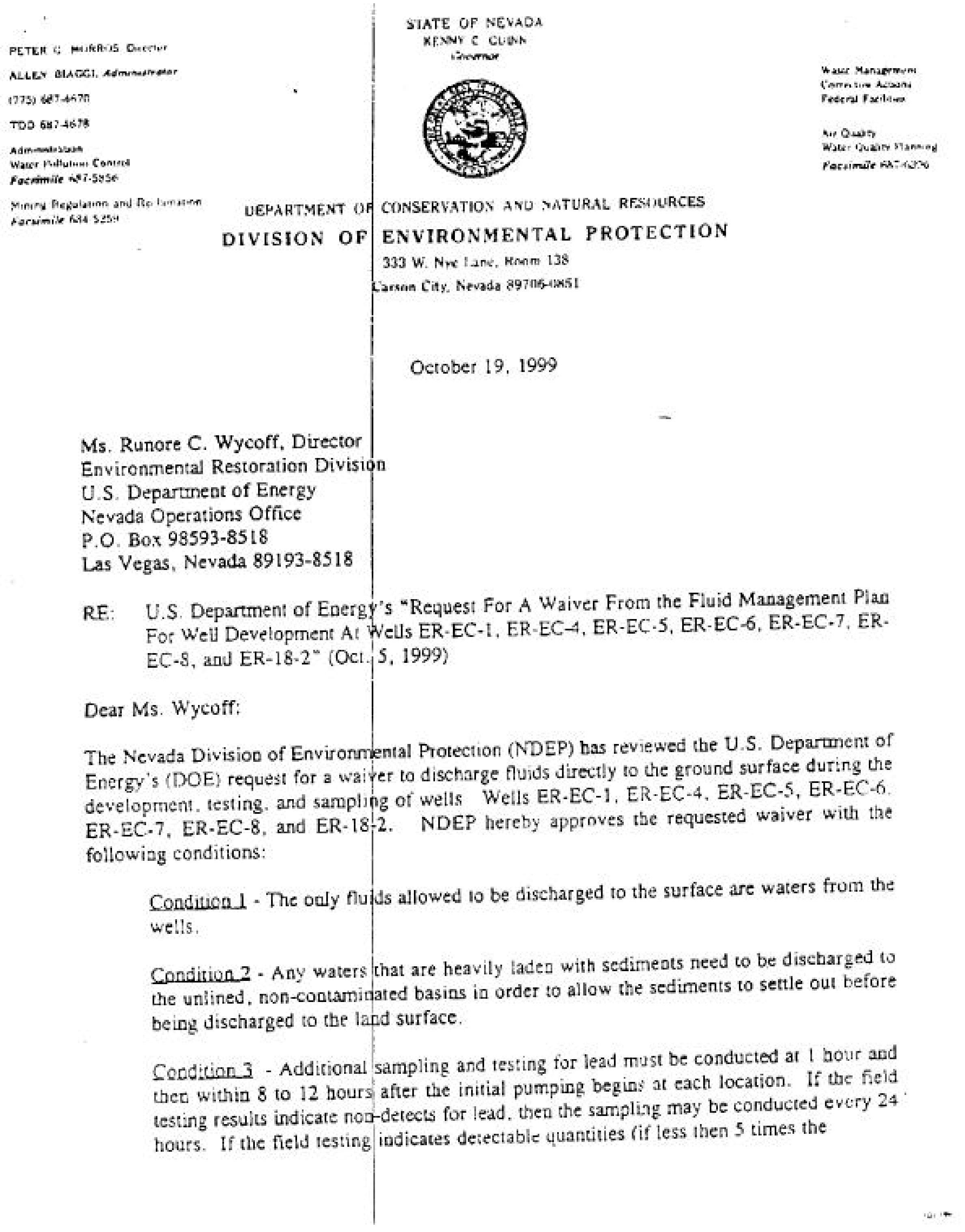
Table ATT 3-3
Trace Element Results for Groundwater Characterization Samples
(Page 2 of 2)

Analyte	Laboratory Detection Limit	Laboratory	Qualifier	Results of Discrete Bailer Sample #EC-1-011300-1	UNIT
Sb, Dissolved	0.005	UNLV-HRC		0.152	µg/L
Se, Dissolved	0.32	UNLV-HRC		1.11	µg/L
Sn, Dissolved	0.006	UNLV-HRC		0.194	µg/L
Sr, Dissolved	0.02	UNLV-HRC		22.0	µg/L
Ta, Dissolved	0.018	UNLV-HRC	<	0.018	µg/L
Te, Dissolved	0.009	UNLV-HRC	<	0.009	µg/L
Ti, Dissolved	0.010	UNLV-HRC		1.08	µg/L
Tl, Dissolved	0.016	UNLV-HRC		1.02	µg/L
U, Dissolved	0.004	UNLV-HRC		7.48	µg/L
V, Dissolved	0.010	UNLV-HRC		2.41	µg/L
W, Dissolved	0.010	UNLV-HRC		1.30	µg/L
Y, Dissolved	0.003	UNLV-HRC		0.019	µg/L
Zn, Dissolved	0.2	UNLV-HRC		60.0	µg/L
Zr, Dissolved	0.026	UNLV-HRC	<	0.026	µg/L

µg/L = Microgram per liter
ng/L = Nanogram per liter
< = Compound was analyzed for, but not detected, above the reported sample quantitation limit. The detection limit (quantitation limit) is reported in the results field.

Attachment 4

Fluid Management Plan Waiver for WPM-OV Wells



PETER G. MORROS, Director
ALLEN BIAGGI, Administrator
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TDD 687-4678

Administration
Water Pollution Control
Facsimile 687-5856

Mining Regulation and Reclamation
Facsimile 684-5259

STATE OF NEVADA
KENNY C. GUINN
Governor

Waste Management
Corrective Actions
Federal Facilities

Air Quality
Water Quality Planning
Facsimile 687-6396

DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
DIVISION OF ENVIRONMENTAL PROTECTION
333 W. Nye Lane, Room 138
Carson City, Nevada 89706-0851

October 19, 1999

Ms. Runore C. Wycoff, Director
Environmental Restoration Division
U.S. Department of Energy
Nevada Operations Office
P.O. Box 98593-8518
Las Vegas, Nevada 89193-8518

RE: U.S. Department of Energy's "Request For A Waiver From the Fluid Management Plan For Well Development At Wells ER-EC-1, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, ER-EC-8, and ER-18-2" (Oct. 5, 1999)

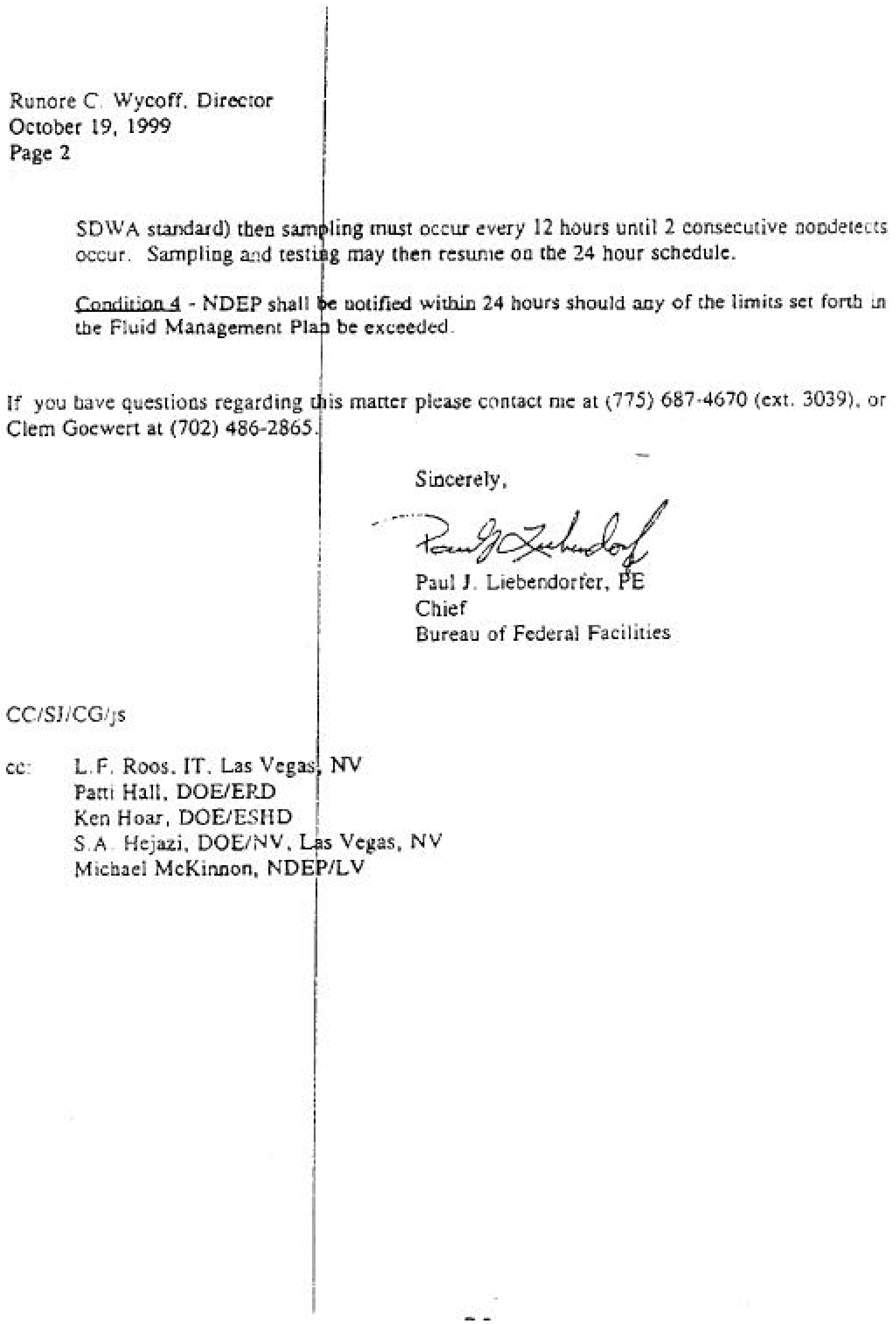
Dear Ms. Wycoff:

The Nevada Division of Environmental Protection (NDEP) has reviewed the U.S. Department of Energy's (DOE) request for a waiver to discharge fluids directly to the ground surface during the development, testing, and sampling of wells Wells ER-EC-1, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, ER-EC-8, and ER-18-2. NDEP hereby approves the requested waiver with the following conditions:

Condition 1 - The only fluids allowed to be discharged to the surface are waters from the wells.

Condition 2 - Any waters that are heavily laden with sediments need to be discharged to the unlined, non-contaminated basins in order to allow the sediments to settle out before being discharged to the land surface.

Condition 3 - Additional sampling and testing for lead must be conducted at 1 hour and then within 8 to 12 hours after the initial pumping begins at each location. If the field testing results indicate non-detects for lead, then the sampling may be conducted every 24 hours. If the field testing indicates detectable quantities (if less then 5 times the



Runore C. Wycoff, Director
October 19, 1999
Page 2

SDWA standard) then sampling must occur every 12 hours until 2 consecutive nondetects occur. Sampling and testing may then resume on the 24 hour schedule.

Condition 4 - NDEP shall be notified within 24 hours should any of the limits set forth in the Fluid Management Plan be exceeded.

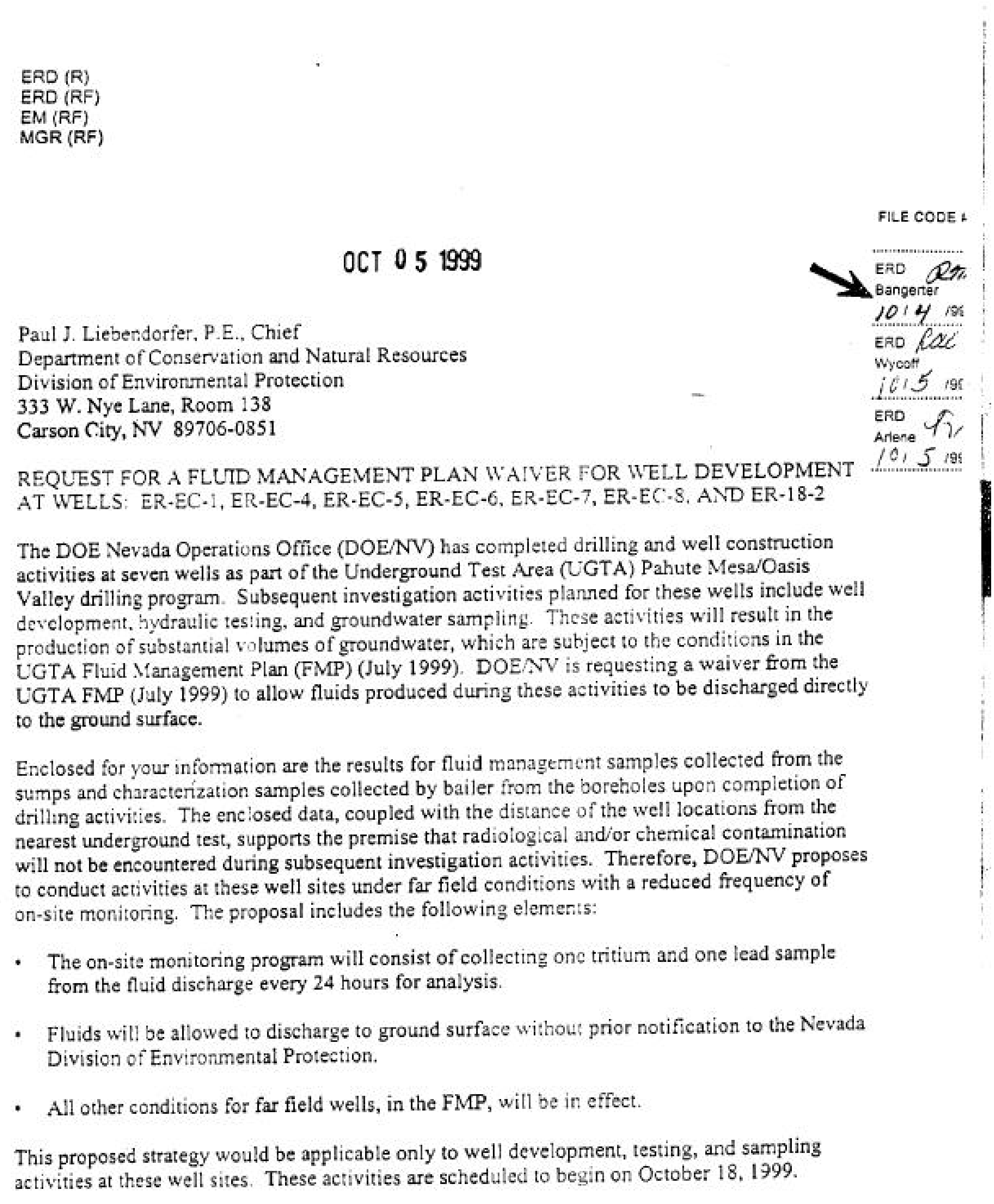
If you have questions regarding this matter please contact me at (775) 687-4670 (ext. 3039), or Clem Goewert at (702) 486-2865.

Sincerely,

Paul J. Liebendorfer, PE
Chief
Bureau of Federal Facilities

CC/SJ/CG/js

cc:
L.F. Roos, IT, Las Vegas, NV
Patti Hall, DOE/ERD
Ken Hoar, DOE/ESHD
S.A. Hejazi, DOE/NV, Las Vegas, NV
Michael McKinnon, NDEP/LV



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ERD (RF)
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ERD
Arlene
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OCT 05 1999

Paul J. Liebendorfer, P.E., Chief
Department of Conservation and Natural Resources
Division of Environmental Protection
333 W. Nye Lane, Room 138
Carson City, NV 89706-0851

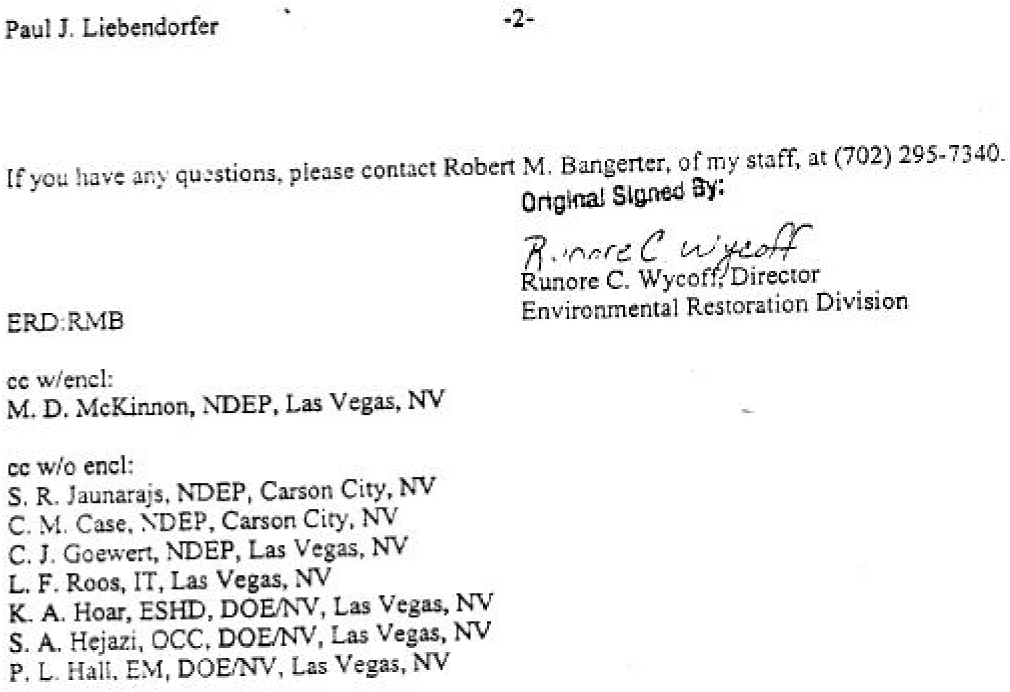
REQUEST FOR A FLUID MANAGEMENT PLAN WAIVER FOR WELL DEVELOPMENT AT WELLS: ER-EC-1, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, ER-EC-8, AND ER-18-2

The DOE Nevada Operations Office (DOE/NV) has completed drilling and well construction activities at seven wells as part of the Underground Test Area (UGTA) Pahute Mesa/Oasis Valley drilling program. Subsequent investigation activities planned for these wells include well development, hydraulic testing, and groundwater sampling. These activities will result in the production of substantial volumes of groundwater, which are subject to the conditions in the UGTA Fluid Management Plan (FMP) (July 1999). DOE/NV is requesting a waiver from the UGTA FMP (July 1999) to allow fluids produced during these activities to be discharged directly to the ground surface.

Enclosed for your information are the results for fluid management samples collected from the sumps and characterization samples collected by bailer from the boreholes upon completion of drilling activities. The enclosed data, coupled with the distance of the well locations from the nearest underground test, supports the premise that radiological and/or chemical contamination will not be encountered during subsequent investigation activities. Therefore, DOE/NV proposes to conduct activities at these well sites under far field conditions with a reduced frequency of on-site monitoring. The proposal includes the following elements:

- The on-site monitoring program will consist of collecting one tritium and one lead sample from the fluid discharge every 24 hours for analysis.
- Fluids will be allowed to discharge to ground surface without prior notification to the Nevada Division of Environmental Protection.
- All other conditions for far field wells, in the FMP, will be in effect.

This proposed strategy would be applicable only to well development, testing, and sampling activities at these well sites. These activities are scheduled to begin on October 18, 1999.



Paul J. Liebendorfer -2-

If you have any questions, please contact Robert M. Bangerter, of my staff, at (702) 295-7340.

Original Signed By:

Runore C. Wycoff

Runore C. Wycoff, Director
Environmental Restoration Division

ERD:RMB

cc w/encl:
M. D. McKinnon, NDEP, Las Vegas, NV

cc w/o encl:
S. R. Jaunarajs, NDEP, Carson City, NV
C. M. Case, NDEP, Carson City, NV
C. J. Goewert, NDEP, Las Vegas, NV
L. F. Roos, IT, Las Vegas, NV
K. A. Hoar, ESHD, DOE/NV, Las Vegas, NV
S. A. Hejazi, OCC, DOE/NV, Las Vegas, NV
P. L. Hall, EM, DOE/NV, Las Vegas, NV

Attachment 5

Electronic Data Files Readme.txt

ER-EC-1 Development and Testing Data Report

This README file identifies the included data files.

Included with this report are 26 files containing data that were collected electronically during the development and testing program for Well ER-EC-1. The .xls data files were originally collected in ASCII format by datalogger, and the data have been imported into Microsoft EXCEL 97 with minimal changes. Files 3, 4 and 5 contain two sheets, a RAW DATA sheet and a PROCESSED DATA sheet. The PROCESSED DATA sheet references the Raw Data sheet and performs basic processing on the data. Please consult the data report for more information on the data.

The files are:

1) EREC1L.xls
   Bridge plug monitoring data for the lower interval.

2) EREC1U.xls
   Bridge plug monitoring data for the middle interval.

3) gradient.xls
   Monitoring data for the upper interval during the bridge plug measurements.

4) EC1-AqtestComplete.xls
   Complete monitoring record of development and testing.

5) EC-1-Water Level Monitoring.xls
   Pre-development monitoring record.

6) DRIFileInfoGeneric.txt
   DRI log head information.

7) ec1mov01, ec1mov02, ec1mov03, ec1mov04, ec1mov05, ec1mov06, ec1mov07, ec1mov08, ec1mov09, ec1mov10, and ec1mov11.txt - DRI flow logs.

8) stat1, stat2, stat3, stat4, stat5, stat6, stat7, stat8, and stat9.txt
   DRI static impeller tool flow measurements.

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