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Analysis of Well ER-EC-6 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
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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
Br	Bromide
C	Carbon
CAU	Corrective Action Unit
CD	Compact disc
Cl	Chlorine
$\delta^{13}C$	Delta carbon-13
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
FI	Field Instruction
FMP	Fluid Management Plan
fpm	Feet per minute
FS	Full scale
ft	Foot (feet)
ft/d	Feet per day
ft^2/d	Square feet per day
FY	Fiscal year
gpm	Gallon per minute
He	Helium
hp	Horsepower
HSU(s)	Hydrostratigraphic unit(s)
hz	Hertz

List of Acronyms and Abbreviations *(continued)*

in.	Inch(es)
ITLV	IT Corporation, Las Vegas
K	Hydraulic conductivity
LANL	Los Alamos National Laboratory
Li	Lithium
LiBr	Lithium bromide
LLNL	Lawrence Livermore National Laboratory
mg/L	Milligram per liter
NDEP	Nevada Division of Environmental Protection
NDWS	*Nevada Drinking Water Standards*
nm	Nanometer
NNSA/NV	U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office
NTU	Nephelometric turbidity units
od	Outside diameter
particles/mL	Particle per milliliter
pCi/L	Picocuries per liter
psi	Pound per square inch
psig	Pounds per square inch gauge
PXD	Pressure transducer
rev/sec	Revolution per second
S	Storage coefficient
SQP	Standard Quality Practice
Sr	Strontium
T	Transmissivity
TDH	Total dynamic head
UGTA	Underground Test Area
UNLV-HRC	University of Nevada, Las Vegas - Harry Reid Center
VSD	Variable speed drive

List of Acronyms and Abbreviations *(continued)*

WDHTP	Well Development and Hydraulic Testing Plan
WPM-OV	Western Pahute Mesa-Oasis Valley
°C	Degrees 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-6 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-6 Data Report for Development and Hydraulic Testing*.

1.1 Well ER-EC-6

Well ER-EC-6 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 the WPM-OV wells. Drilling and well construction information has been documented in the *Completion Report for Well ER-EC-6*, May 2000 (DOE/NV, 2000).

Hydraulic testing and groundwater sampling were conducted at Well ER-EC-6 to provide information on the hydraulic characteristics of hydrostratigraphic units (HSUs) and the chemistry of local groundwater. Well ER-EC-6 is constructed with four 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 two pumping rates
4. Collection of discrete groundwater sample(s) with a downhole sampler
5. 10-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-6 for monitoring are discussed.

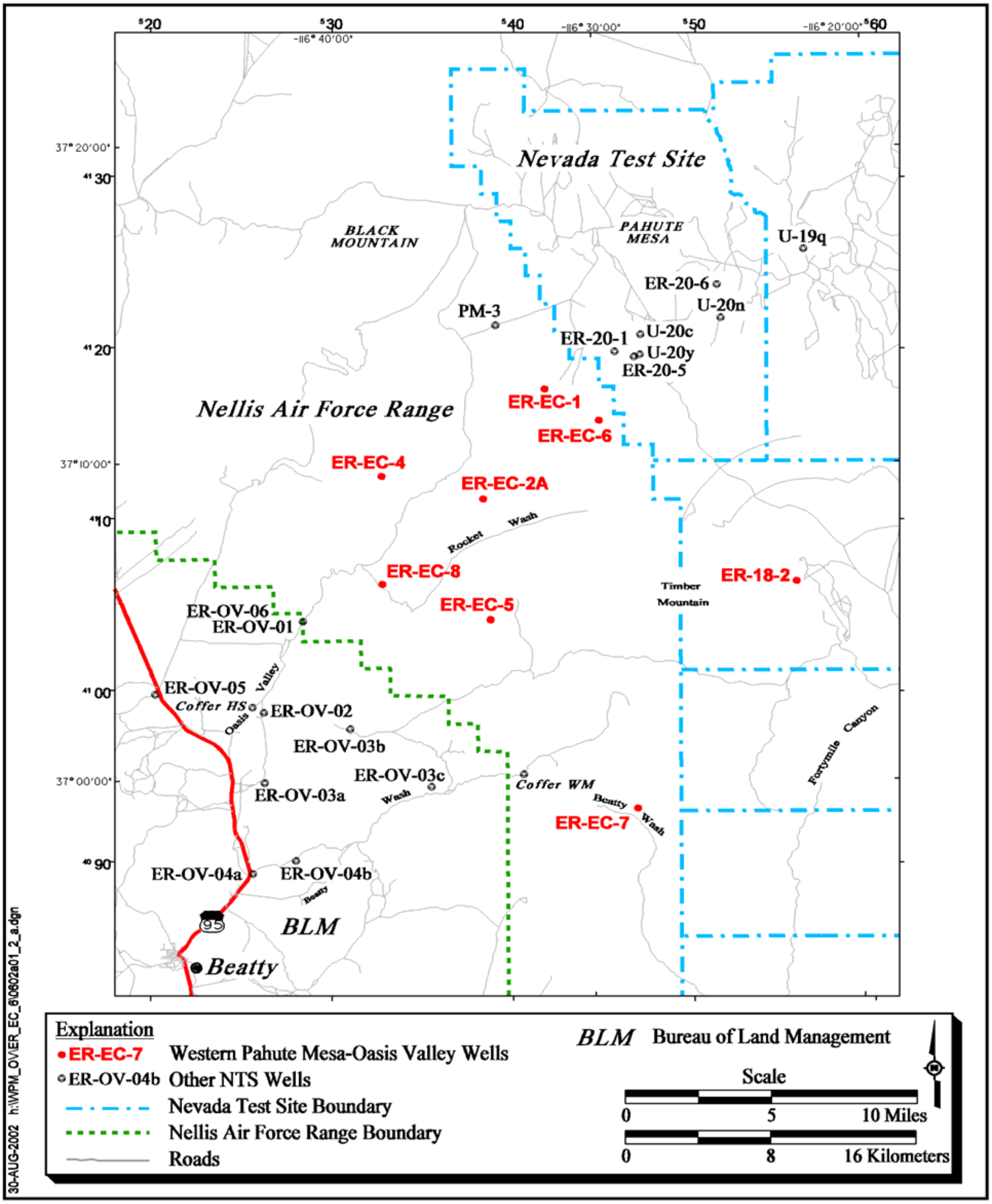


Figure 1-1
Location Map for WPM-OV ER Wells

2.0 Equilibrium Well Hydraulics

This section discusses many aspects of well hydraulics for Well ER-EC-6 in the equilibrium, nonpumping condition relating to the individual completion intervals. This material updates the initial analysis of the data in Appendix A and further develops some of the concepts and concerns that were presented.

The well is constructed with four separate completion intervals, each composed of alternating slotted and blank casing joints. The completion intervals are isolated from each other outside the well casing by cement annular seals. Within a completion interval, the slotted casing joints (commonly referred to as screens) access a continuous gravel pack in the annulus outside the well casing. Features of downhole flow 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 (depth-to-water) made during the testing program. The measurements reported in that table are very consistent, and 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 the correction for barometric efficiency to the test analysis is 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 requiring accurate knowledge of the status of a well relative to equilibrium with the natural state of the groundwater system, the refinement offered by correcting a water level monitoring record for barometric efficiency can be important. This is particularly important when making decisions based on a short or sparse record.

The methodology used for determining barometric efficiency involves overlaying 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 then adjusted with a linear trend and scaled until a best-fit match to the water level record is determined. The trend is added to remove the effect of any trend in the water level not due to barometric response. The scaling factor is equal to the barometric efficiency. This method assumes that the well is in basic 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 to a record is that the record must contain changes in barometric pressure longer than 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 responses.

The long-term predevelopment water level monitoring record, shown in Figure 2-1, was used to determine barometric efficiency. Examination of this record in detail finds both responses to barometric pressure variation and the semidiurnal peaks of earth tide effects. Figure 2-2 shows the barometric record inverted, trended, and scaled, yielding a barometric efficiency of 0.83. Figure 2-3 presents the pressure transducer (PXD) record corrected for barometric pressure variation, showing the actual trend in the head of the formation during the monitoring period. The head increase was countered by an increase in barometric pressure during this monitoring period.

2.3 Completion Interval Heads

Table 2-1 contains the head values for the composite and individual completion intervals following equilibration of the different intervals to the isolation of the interval. For this well, the heads in each interval were stable after equilibration. Interpretation of the water level and pressure records is discussed below. Head values are presented rounded to the nearest 0.01 feet (ft) and pressure values are reported to the nearest 0.01 psi as recorded by the instrumentation. The accuracy of these head values is then evaluated.

Table 2-1
Well ER-EC-6 Composite and Interval-Specific Head Measurements

Location in Well	**Head as Depth Below Ground Surface**		**Change from Composite Head**
	Feet	Meters	Feet
Composite Static Water Level (e-tape)	1,425.95	434.63	--
Upper Interval (e-tape)	1,425.83	434.59	+ 0.12
Upper-Middle (calculated)	1,426.39	434.76	- 0.44
Lower-Middle (calculated)	1,427.74	435.18	- 1.79
Lower Interval (calculated)	1,431.40	436.29	-5.45

Water level measurements were made successively as each bridge plug was installed using the same e-tape. The measurements indicate a rise in water level of 0.07 ft after installation of the lower bridge plug, an additional rise of 0.07 ft after installation of the lower-middle bridge plug, and a further rise of 0.05 ft immediately after installation of the upper bridge plug. These differences in water level could be measurement uncertainty or adjustment of the composite head as a result of the progressive isolation of lower completion intervals. The progressive rise of the water level after installation of each bridge plug is consistent with the downward gradient that was derived from the bridge plug pressure measurements and the downward flow. The water level for the upper interval after 5 days of monitoring had declined 0.07 ft. All of these changes are within the range that could result from barometric changes between measurements.

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 an precision of 0.01 ft, which is the accuracy to which the e-tapes are calibrated. Water level measurements are generally repeatable within 0.10 ft or less per 1,000 ft between independent measurements. The e-tapes are calibrated yearly. The determination of the head differences between completion intervals are referenced back only to these measurements; consequently, the repeatability of the measurements is the primary concern.

During the 5 days of monitoring, approximately 120 hours total, the head in the upper interval rose 0.12 ft, and the heads in the lower intervals declined. The upper-middle interval declined 0.25 pound per square inch (psi) (equivalent to about 0.44 ft) over a period of about 50 hours. The head in the lower-middle interval declined 0.80 psi (equivalent to about 1.79 ft) over about 38 hours. The lower interval declined 2.33 psi (equivalent to about 5.45 ft) over about 27 hours. The pressures used to calculate the interval heads are the central values of stable pressure after the initial decline.

The specification for accuracy of the PXDs is 0.1 percent of the full-scale measurement. Three different PXDs were used. A 750-psi unit (SN# 21014) was used for the upper-middle interval measurements, with nominal accuracy of 0.75 psi (1.75 ft of head) and resolution of 0.06 psi (0.14 ft of head); a 1,000-psi unit (SN# 21003) was used for the lower-middle interval measurements, with nominal accuracy of 1.0 psi (2.33 ft of head) and 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 nominal accuracy of 2.5 psi (5.83 ft of head) and 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# 21014 indicated that the PXD actually calibrated within 0.20 psi (0.47 ft of head)) or less across the range of operational pressure and temperature. The calibration certificate supplied for SN# 21003 indicated that the PXD actually calibrated within 0.23 psi (0.54 ft of head) 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 (0.63 ft of head) or less across the range of operational pressure and temperature. 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# 21014 showed errors of 0.10 psi @ 150 psi, 0.02 psi @ 300 psi, and -0.07 psi @ 375 psi at the nearest calibration temperature to the measurement temperature. The maximum variation in the error across this range is 0.17 psi, which is equivalent to 0.40 ft of head. The calibration of PXD SN# 21003 showed errors of 0.09 psi @ 500 psi, 0.20 psi @ 600 psi, and 0.12 psi @ 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 @ 1,000 psi, and -0.10 psi @ 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 (0.47 ft), which is greater than the stability error of the calibration. This is much less than the calculated difference of -5.45 ft. The potential error in the head difference between the composite water level and the lower-middle interval is the sum of the repeatability error of the reference e-tape measurement (+/-0.14 ft) and the calibration stability of the PXD (+0.26 ft), which is greater than the resolution. The sum of these errors (0.40 to 0.12 ft) is also much less than the calculated head difference of -1.79 ft. The potential error in the head difference between the composite water level and the upper-middle interval is the sum of the repeatability error of the reference e-tape measurement (0.14 ft) and the calibration stability of the PXD (0.40 ft), which exceeds the calculated head difference.

The head appears to decline progressively from the upper interval to the lower interval. Based on the error analysis, the calculated decline of the head in the lower middle and lower completion intervals exceed the uncertainty in the measurements. The head in the lower-middle interval is 1.39 to 1.67 ft below the composite water level, and the head in the lower interval is 4.98 to 5.92 ft below the composite water level.

2.4 Variable Density of Water in the Wellbore

The measurements of pressure at various depths in the well indicate 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 and can be shown to account for most of the variation. However, there may be other factors such as dissolved gasses and solids and suspended solids that vary with depth, and compressibility of the water that produce the remainder of the density variation. No information was collected on any of these other factors. 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 includes the effect of compressibility. The temperature profile was taken from the posttesting ChemTool log, shown in Figure 3-1. The pressures calculated from this exercise are within +0.15 psi of the PXD measurement at a depth of 691.30 ft below the water surface (upper-middle bridge-plug measurement), -4.79 psi at a depth of 1,941.14 ft (lower-middle interval bridge-plug measurement), and -2.93 psi at a depth of 2,896.14 ft (lower interval bridge-plug measurement). The difference between calculated and actual includes the uncertainty due to accuracy of the PXD measurements and the uncertainty in the reference pressure of the PXDs, which is not known accurately. The accuracy uncertainties for the PXD pressure measurements exceed the discrepancy for the uppermost measurement, but are less than the discrepancy for the lower two measurements. The remainder of the difference is due to factors affecting the water density profile.

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: (1) a steady-state analysis using the measurement of the head differences between the completion intervals and (2) 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 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 Desert Research Institute (DRI) ChemTool approximately 26 days after the constant-rate test. This log is shown in Figure 3-1. The temperature logs provide evidence to support the identification of the entry, direction, and exit of flow from the borehole, but does not provide any rate information. There is very little indication of substantial inflows or outflows from the borehole or specific locations of inflows/outflows.

2.5.2 Flow Measurements (Thermal Flow Tool)

Flow in the well under natural gradient (i.e., nonpumping, equilibrium conditions) was measured using the DRI thermal flowmeter after recovery following the constant-rate test. The flow measurements are tabulated in Table 2-2. Prior to well construction, there appeared to be steady downward flow of about 1 gallon per minute (gpm) to a depth of 3,690+ ft, and then decreasing flow to the bottom of the well. In the well completion, there appears to be flow downwards from the upper completion interval to the lower completion intervals, but at a reduced rate of about 0.2 gpm. The flow goes to zero below the lower-middle completion interval. Based on these measurements, there is no substantial flow into the upper-middle completion interval or into the lower interval. The 0.2 gpm appears to exit the well in the lower-middle completion interval.

Table 2-2
Thermal Flow Measurements

Depth (ft)	Flow (gpm)	Location
1,661	-0.580 +/- 0.067	Within upper completion interval
1,900	- 0.162 +/- 0.061	Below upper completion interval
2,011	- 0.197 +/- 0.001	Above upper-middle completion interval
2,551	- 0.211 +/- 0.071	Below upper-middle completion interval
3,820	0.000 +/- 0.000	Below lower-middle completion interval

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

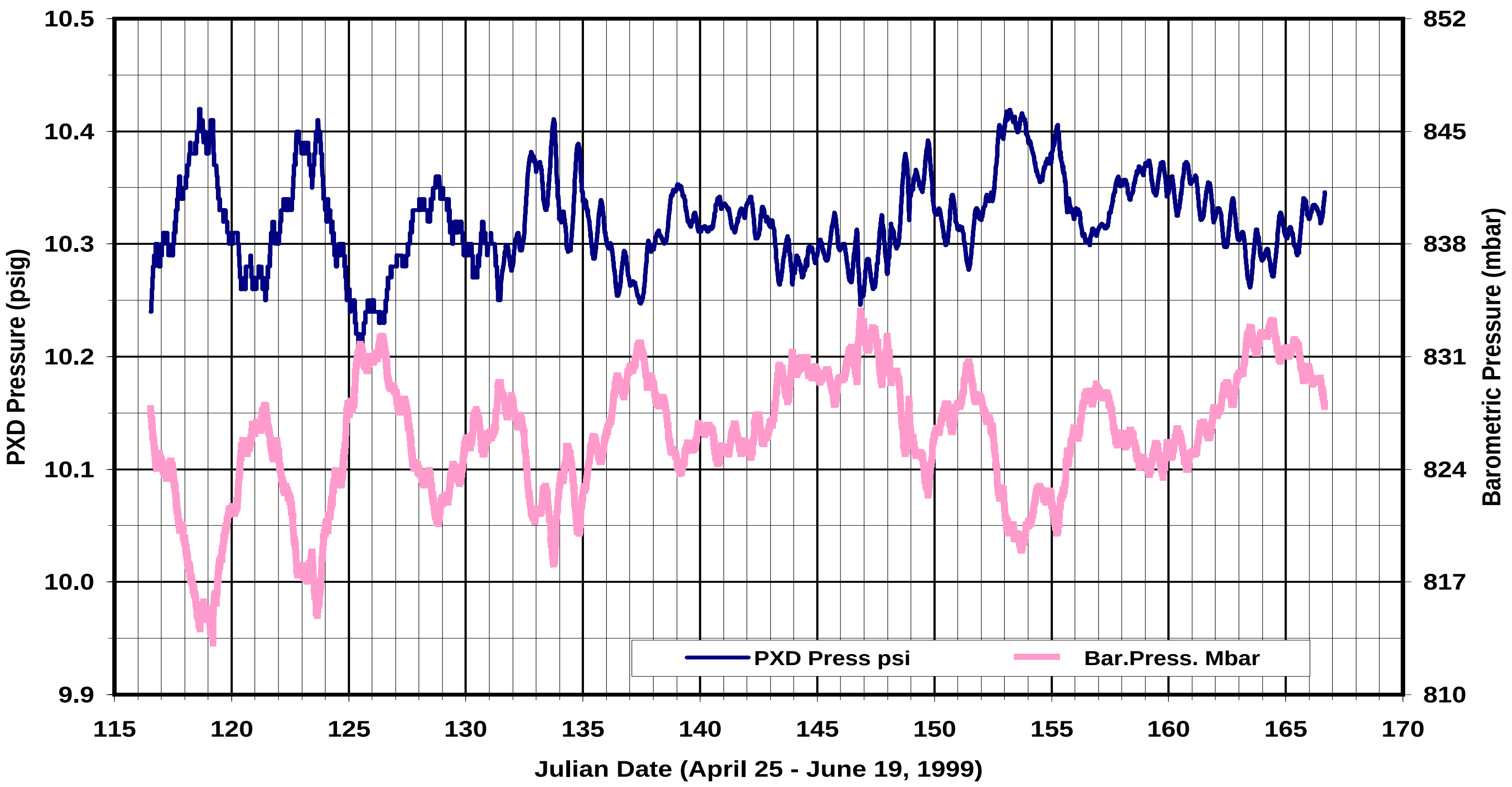
2.6 Pressure Drawdown Following Setting of Bridge Plugs

The pressure equilibration records for each completion interval following setting the bridge plugs have the potential for providing information on the transmissivity of the completion interval formation. The methodology is referred to as pressure falloff analysis (Earlougher, 1977) and is analogous to a Cooper-Jacob straight-line analysis for time-drawdown (Krueseman and de Ridder, 1990). The pressure falloff analysis also requires measurement of the prior flow rate into the completion interval resulting from the head difference. This information is derived from the thermal flow log measurements. The difference in measurements above and below a completion interval are considered flow into the interval.

Figure A.3-2, Figure A.3-4, and Figure A.3-6 in Appendix A show the pressure equilibration records. The equilibration of the upper-middle interval, shown in Figure 2-5, was rapid and defined by only three data points. Figure 2-6 shows the record of the lower-middle interval and Figure 2-7 shows the lower interval record, plotted as pressure versus log time. Resolution effects from the instrumentation produces bands in the data, and two different resolution effects are evident, that of the pressure sensor and that of the temperature correction.

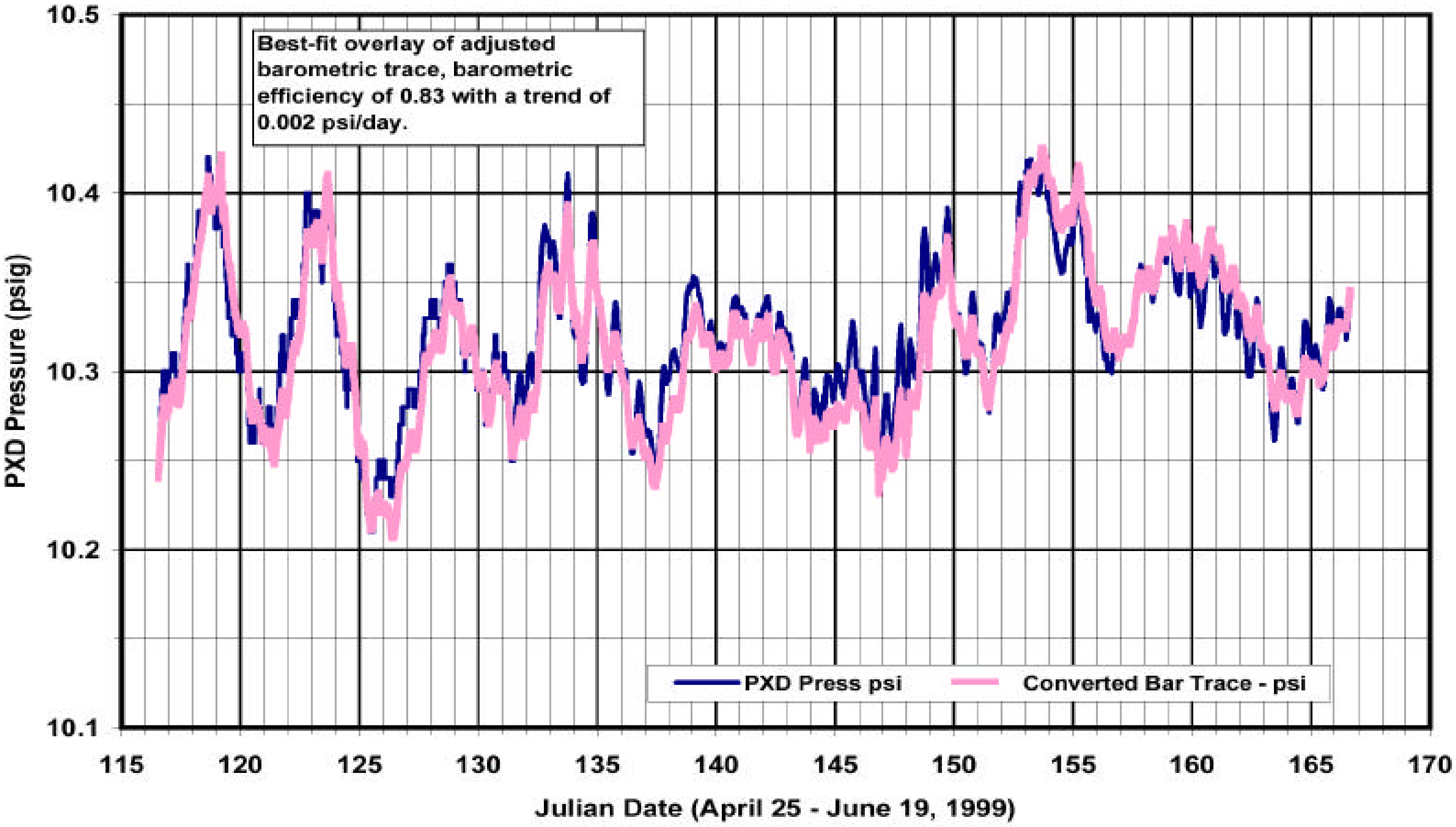
However, a logarithmic trend is evident in the pressure decline, and the trend is calculated. The thermal flow measurements (Table 2-2) only indicate flow into the lower-middle completion interval. The pressure declines observed for the other two completion intervals suggest that they also were receiving inflow, but flows were not clearly indicated by the thermal flow measurements.

Using the pressure falloff decline per log cycle of time and the apparent inflow rate of 0.2 gpm to the lower-middle interval in the Cooper-Jacob equation results in a transmissivity value of 16.44 square feet per day (ft^2/d). Assuming this applies to the lower-middle completion interval (overall length 428 ft) yields a hydraulic conductivity of 0.012 feet per day (ft/d).



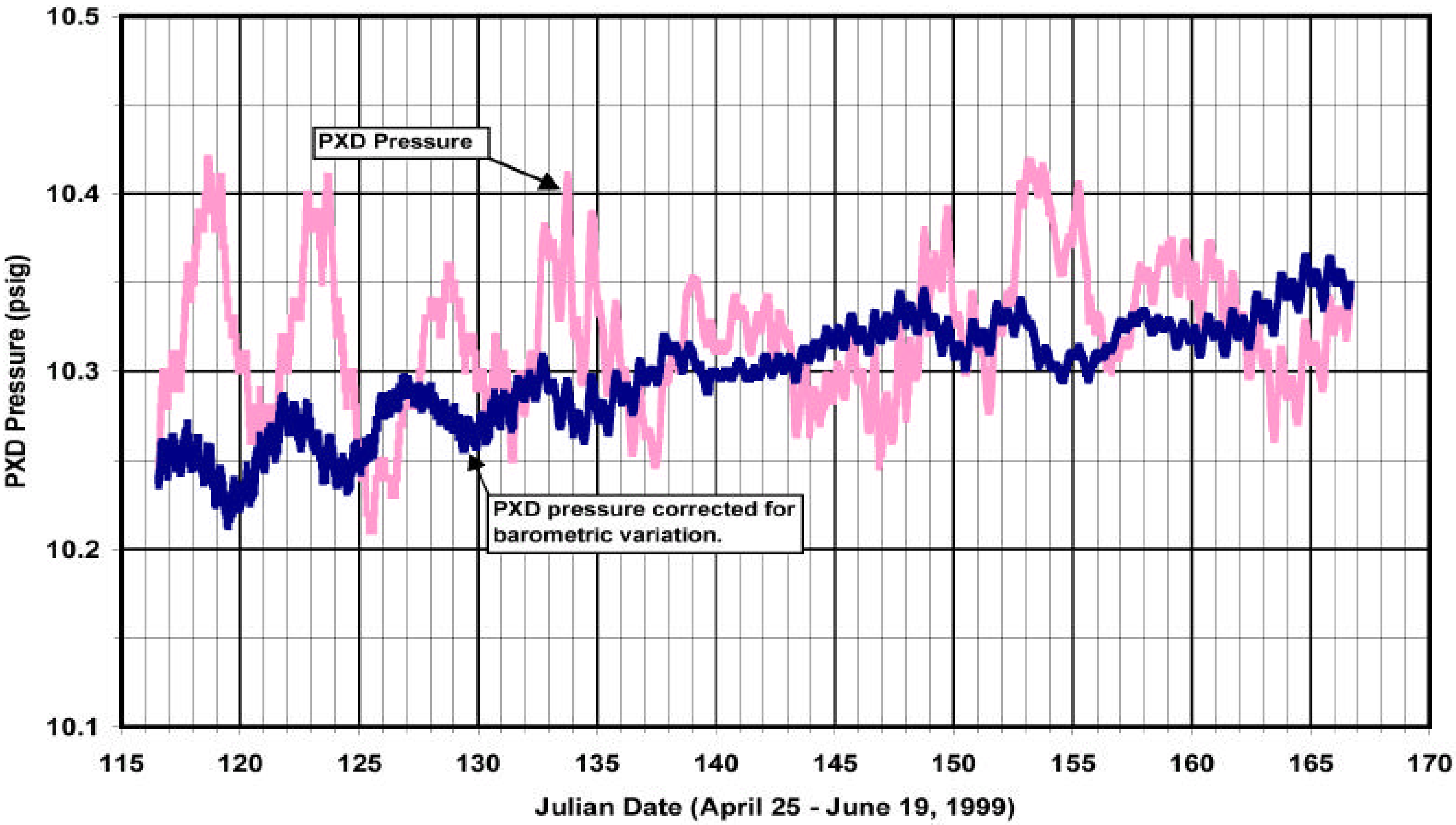
psig - Pounds per square inch gauge
mbar - Millibars
PXD - Pressure transducer

Figure 2-1
Long-Term Water Level Monitoring



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

Figure 2-2
Barometric Efficiency Overlay



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

Figure 2-3
Barometric-Corrected Monitoring Record

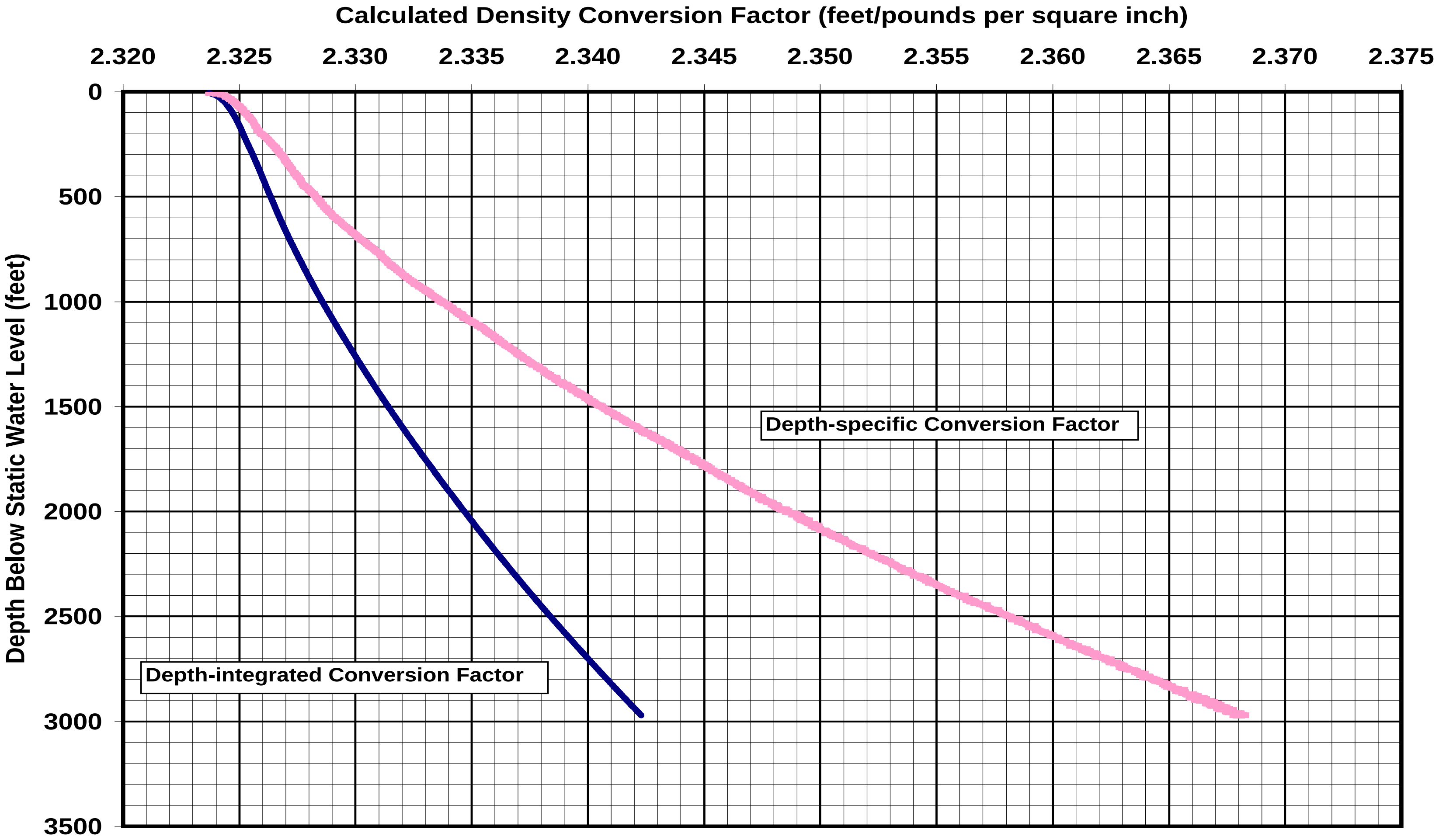
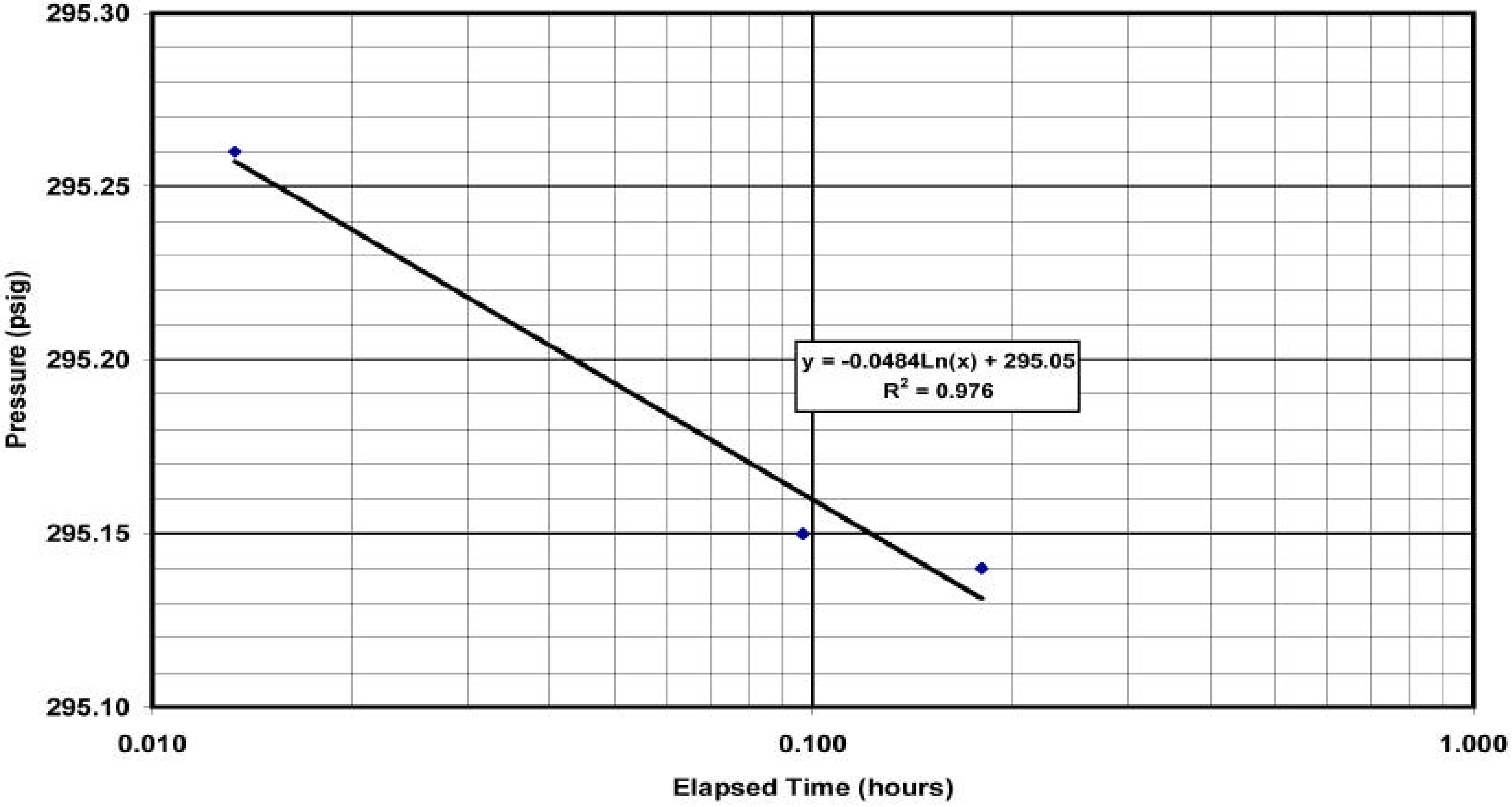
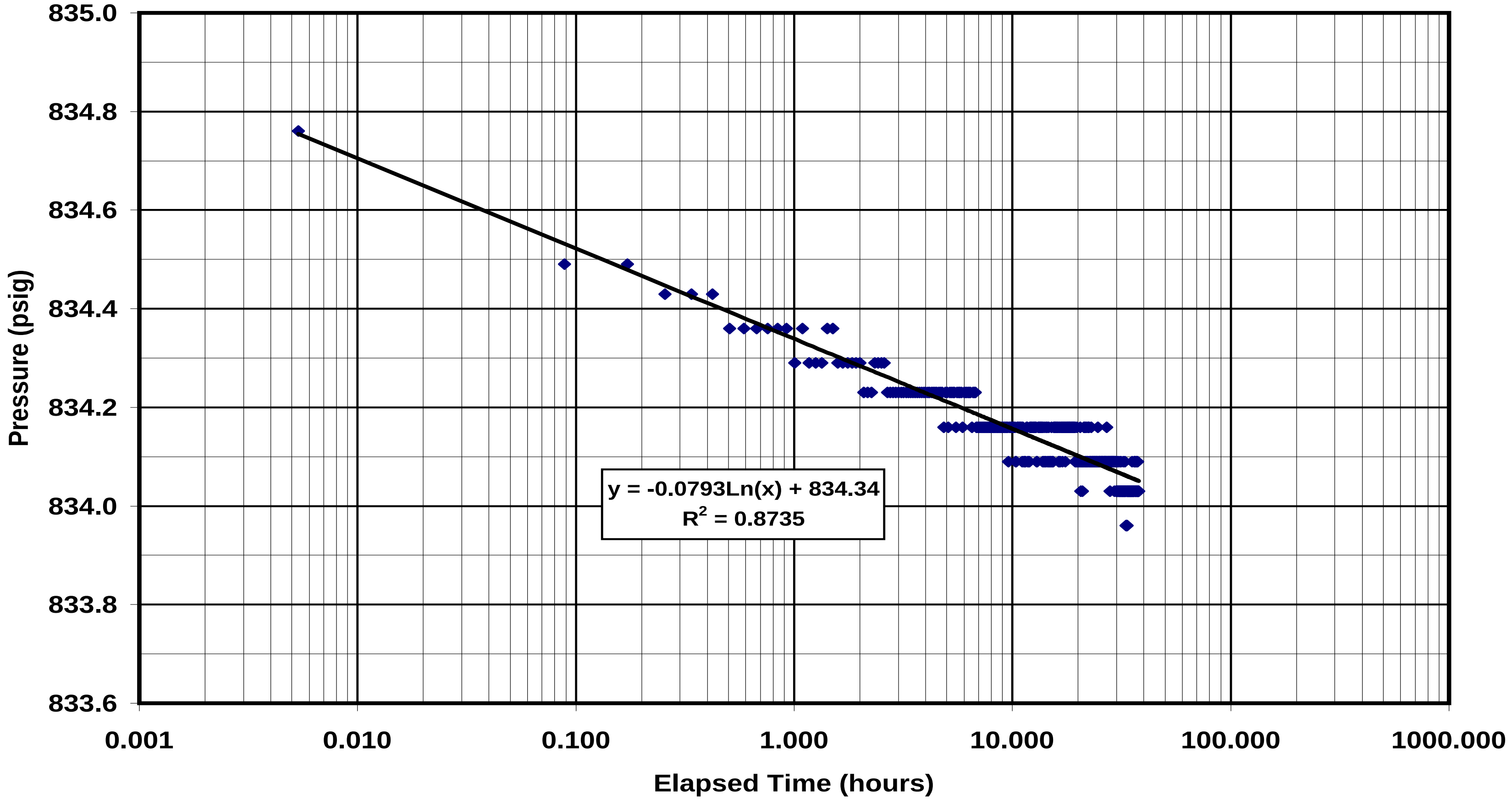


Figure 2-4
Temperature-Dependent Density Variation



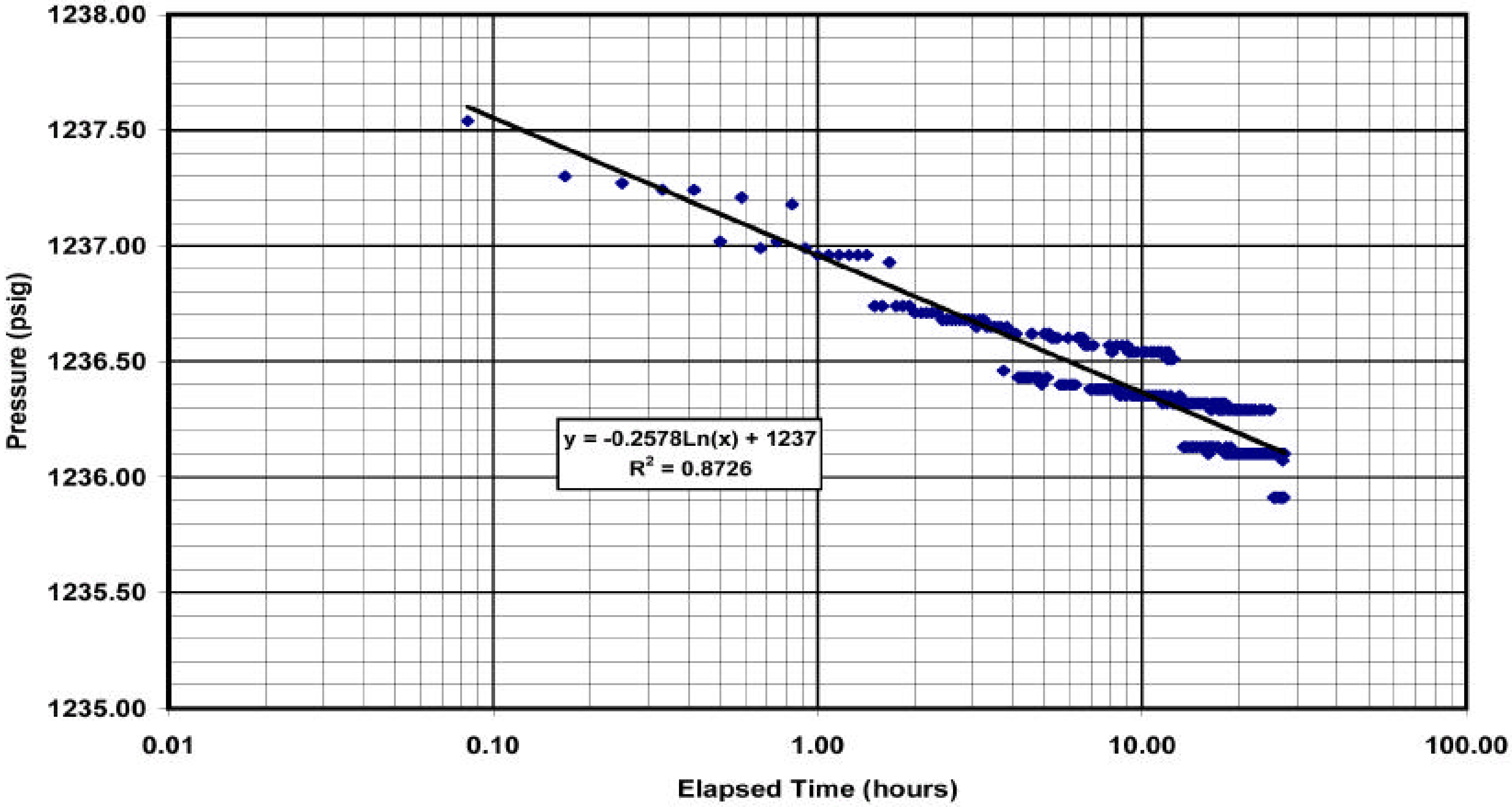
psig - Pounds per square inch gauge

Figure 2-5
Upper-Middle Completion Interval Pressure Decline



psig - Pounds per square inch gauge

Figure 2-6
Lower-Middle Completion Interval Pressure Decline



psig - Pounds per square inch gauge

Figure 2-7
Lower Completion Interval Pressure Decline

3.0 Pumping Well Hydraulics

The hydraulic testing for this well has been analyzed to determine the average hydraulic conductivity of the formation that was tested and the variation of hydraulic conductivity for specific sections of the formation in the upper completion interval. This latter analysis is based on flow logging that was conducted during pumping. Well losses were not analyzed due to the lack of a broad-range step-drawdown test; however, linear flow losses would be a relatively negligible fraction of the overall drawdown.

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 is used in interpreting the well hydraulics and water chemistry. These wells penetrate a variety of different formations and lithologies and have multiple completions, often in very different lithologies. Hydraulic testing and composite sampling provides information that is not specific to any of the completion intervals, and interpretation of the data must assume that the results pertain in general to all of the completion intervals.

Flow logging in conjunction with 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 small 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 the well completion, temperature logs for both the static situation and for pumping at 68 gpm, and a flow log during pumping. 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. Figure 3-2, Figure 3-3, and Figure 3-4 show the completion intervals and examples of the flow logs for each of the two pumping rates that were used. These figures include depth, lithology, hole diameter, and well construction. Flow log “ec6mov1” is presented for 68 gpm, and “ec6mov4” for 62 gpm. These two logs are representative of the logging results at the two production rates and generally show that most of the production originated in the upper completion interval. The flow values shown are the DRI field values. The analysis presented in later sections determines more accurately the distribution of production during pumping.

3.1.1 Temperature Logs

The temperature log during pumping distinctly shows the effect of inflows from the upper two screens of the upper completion interval. These inflows dominate the upward flow, rapidly bringing the temperature in line with the static temperature at that depth. This interpretation is consistent with the flow log shown. The difference in the temperature profiles between the static and pumping cases indicates that, while pumping at 68 gpm, there is some flow upwards from the lower completion intervals, mostly from the two middle intervals. This is indicated by the general rise in the temperature profile uphole from the lower interval, and the distinct temperature increases at the top of each of the middle intervals.

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 DRI, and was used in both a trolling and stationary mode. A total of six 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 at one depth. A summary of these different logging runs is presented in Table 3-1.

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 3.4.4.

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-6, 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

Table 3-1
Summary of Impeller Flow Logs

Run Number	Direction of Run	Line Speed (fpm)	Pumping Rate (gpm)	Run Start/Finish (ft bgs)
ec6mov1	Up	20	68	3,852 - 1,582
ec6mov2	Down	40	68	1,575 - 3,851
ec6mov3	Up	60	68	3,902 - 1,579
ec6mov4	Down	20	62	3,851 - 1,581
ec6mov5	Up	40	62	1,580 - 3,850
ec6mov6	Down	60	62	1,580 - 3,856
erec6stat1	Stationary	0	68	1,607
erec6stat2	Stationary	0	68	2,032
erec6stat3	Stationary	0	68	2,972
erec6stat4	Stationary	0	62	1,607
erec6stat5	Stationary	0	62	2,032
erec6stat6	Stationary	0	62	2,972

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

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 from well to well 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 from well to well 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 in the upper part of this blank section; therefore, the flow rate in the portion of this blank section located below the pump 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 spreadsheets
- Sort the data by depth
- Match the flow logs to well construction
- 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. An effort is made to correct logging depths to match the official well construction diagrams. Typically, this is performed by differentiating the log profile to identify locations where flow rates are changing 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-6 were adjusted to ensure that the flowmeter response matched the well construction. The top and bottom of blank and screened intervals were identified in the flowmeter logs by plotting the rate of change of flowmeter response versus depth, and recording the locations where the flowmeter response 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 ec6mov1 and the corresponding differential flow log from depths of 1,580 to 1,780 ft. This depth interval contains the blank casing above the first screen. Each peak on the curve shown in Figure 3-5 represents a change in flowmeter response, which corresponds to a transition from one type of interval to another. For example, the transition from the larger casing to the nominal 5.5-inch casing is clearly visible at a depth of 1,586.2 ft. Likewise, the transition from the blank casing to the first screen at a depth of 1,632.2 ft is also apparent. This process was performed for the top two blank sections and the first two 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. A 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 +1.4 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 six borehole flowmeter logging runs and from the two logging runs where the flowmeter was held stationary in the blank section while the well was pumped (stationary runs 1 and 4).

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 x=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, 1996):

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

where the standard error, $\text{s.e.}\left(y\big|_{x^*}+\varepsilon\right)$, 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

σ = 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 original calibration dataset consisted of approximately 1,595 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). A small number of data points (26), displaying an unexpected behavior probably caused by line speed variations, were eliminated from the calibration dataset. The final calibration dataset included 1,569 points.

Table 3-2 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.

Table 3-2
Flowmeter Calibration Results Using all Data Collected Above the Top Screen at Well ER-EC-6

Equations 3-1 and 3-2 Solutions		
	Equation 3-1	**Equation 3-2**
Constant	-0.0146	2.5555
First dependent variable	0.00570	175.3764
Second dependent variable	-0.0055	0.9608
Multiple R	0.9995	-
Sum of Squared Errors	0.0485	1491.484
Standard Error	0.0056	0.9759
Number of Observations	1569	1569

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)**
ec6mov1	-0.102	22.601	2.12
ec6mov2	0.219	-40.27	2.15
ec6mov3	-0.347	63.213	2.15
ec6mov4	-0.1	21.464	2.13
ec6mov5	0.235	-42.341	2.15
ec6mov6	-0.338	61.042	2.16

Note: Impeller rate and line speed values were taken from depths greater than 3,800 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.

In addition, Table 3-2 contains the 95 percent confidence intervals for specific sets of independent variable values that lead to predicted flow near zero. The accuracy of the predictions near zero flow are of concern because most of the well below the upper two screens appears 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 3-2, the 95 percent confidence interval is 2.16 gpm. Measured flow rates less than 2.16 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.

This averaged-data approach could not be used for Well ER-EC-6 because of the limited number of logging runs (8). After averaging along the section of blank casing used for flowmeter calibration, only eight data points corresponding to each of the logging runs would remain for use in the multiple regression. This number is too small to yield reliable results. This method was, however, used for Well ER-EC-1; the dataset was reduced to 14 sets of measurements, which were used to derive a second calibration equation. The regression coefficients derived from the detailed and reduced datasets were nearly identical. 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 was that the confidence interval near the zero discharge prediction was narrower for the full dataset than when average values were used. Based on the case of Well ER-EC-1, it will be assumed that the time lag between the discharge measured at the land surface and the flow recorded by the flowmeter for Well ER-EC-6 has a negligible impact on the flowmeter calibration.

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 3-2). For each moving flow log, each depth where a flowmeter response and line speed were recorded, the values were inserted into equation (3-2), with the coefficient values from the first method, 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. First, the arrangement of alternating screens and blank casings create more complex flow conditions in the completion intervals than a continuous screen would. 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. However, there is no information available to determine 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. An alternative approach would be to run an oxygen activation flow log, which can evaluate flow behind casing. The main impact of this situation is the uncertainty in determining the appropriate thickness of aquifer to use in calculations of hydraulic conductivity.

3.2 Well Losses

The drawdown observed in a 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-6. Total drawdown may be broken down into its components to better understand the hydraulics of water production and derive better estimates of aquifer parameters. The basic apportionment of losses between aquifer drawdown and flow losses is made using the analysis of a step-drawdown test to determine the linear versus non-linear elements of the drawdown response. The step-drawdown test run on this well included three steps, 67.9, 65.3, and 60.8 gpm. This range was restricted by the minimum rate the pump could be operated and the maximum drawdown that was available above the pump. The data from such similar pumping rates does not sufficiently characterize the response to accurately derive the flow loss equation. Consequently, flow loss analysis was not conducted. However, the correction for flow losses in determining aquifer parameter values for Well ER-EC-6 would not substantially change the derived values. The head losses associated with flow up the well at 68 gpm are not a significant proportion of the total drawdown. The external turbulent losses at this low rate would probably also be a small fraction of the more than 60 feet of drawdown that occurred.

3.3 Constant-Rate Test Analysis

The constant-rate test provided data for determining the overall transmissivity of the well. Figure 3-6 shows a graph of the constant-rate drawdown data and the recovery data. The drawdown data has a wide band of noise which 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® program (HydroSOLVE, Inc., 1996-2002).

The Moench model for dual porosity (1984 [HydroSOLVE, Inc., 1996-2002]) in a fractured aquifer was 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: (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; (6) nonlinear well losses are appreciable and vary according to Q^2; (7) water is released from storage instantaneously; and (8) the aquifer is fractured and acts as a dual-porosity system consisting of low conductivity primary porosity blocks and high conductivity secondary porosity fractures. 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 assumption about the fracture nature of the formation 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 3-7 shows the type curve for a dual-porosity solution and the resultant parameter values using the extent of the filter pack (143 ft) for the producing section of the upper completion interval for aquifer thickness. This solution yields a K of 1.80 ft/day with an associated T of 257 ft^2/d. Figure 3-8 shows a solution using the combined length of the producing screens (51 ft) rather than of the filter pack for the aquifer thickness. This solution is very similar to the first solution, with a resultant K of 5.21 ft/day, yielding a T of 266 ft^2/d.

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.

3.4 Interval Hydraulic Conductivities

The flowmeter data provides an accurate assessment of the thickness of aquifer-producing water for determining the average hydraulic conductivity. In addition, the flowmeter data provides measurements to attribute varying production to the different screens. 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 flow in that aquifer.

3.4.1 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):

$$T_i = \frac{Q_i}{4\pi s_i} \ln\left[\frac{2.25Kbt}{r_w^2 S}\right] \tag{3-7}$$

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:

$$K_i b_i = \frac{Q_i}{Q} Kb \tag{3-8}$$

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) do provide a second alternative approach based on the assumption that the specific storage is constant in the aquifer such that:

$$S_i = S\frac{b_i}{b} \tag{3-9}$$

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

$$T_i = \frac{Q_i}{4\pi s_i} \ln\left[\frac{2.25K_i bt}{r_w^2 S}\right] \tag{3-10}$$

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 equations (3-8) and (3-10).

3.4.2 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.

3.4.3 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; 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 (3-3) suggest that the difference in discharge should be greater than 2.16 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-6, 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. 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) 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 interval. 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 hydraulic conductivity 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 the slotted portion of each screened interval is about 25 ft long. Hydraulic conductivity values averaged over 25-ft intervals are expected to provide adequate vertical resolution for the CAU-scale and sub CAU-scale models.

3.4.4 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.

3.4.4.1 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^2S.
- 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. These average discharge values are tabulated in Table 3-3 for the blanks numbered one through eight, beginning with the uppermost blank which is situated above the uppermost screen. Flow from the formation through a given screen was then calculated as the difference in flow between two consecutive blank sections. As seen in Table 3-4, the second screen is the lowermost screen for which discharge values are consistently statistically different from zero (greater than 2.16 gpm). 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 2.16 gpm; therefore, hydraulic conductivity will be determined for the two uppermost screens. These two screened intervals produce most of the total flow to the well (greater than approximately 90 percent of the total discharge). 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^2S.

The product r_w^2S 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:

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

Table 3-3
Average Flow Rates Through the Blank Casing Sections in gpm During the Flow Logging of Well ER-EC-6

Pumping Rate = 68 gpm				
Blank Number	**Logging Run**			
	ec6mov1	**ec6mov2**	**ec6mov3**	**Average**
1	69.13	66.64	69.54	68.43
2	13.14	12.09	11.54	12.25
3	6.76	6.40	6.01	6.39
4	5.39	5.25	4.89	5.18
5	4.76	5.04	4.06	4.62
6	4.59	4.71	4.07	4.46
7	4.16	4.28	3.65	4.03
8	4.08	4.07	3.26	3.80

Pumping Rate = 62 gpm				
Blank Number	**Logging Run**			
	ec6mov4	**ec6mov5**	**ec6mov6**	**Average**
1	62.80	64.59	62.14	63.17
2	12.53	12.99	10.31	11.94
3	6.55	7.67	5.19	6.47
4	5.67	6.53	4.11	5.44
5	4.58	6.05	3.49	4.71
6	4.79	5.80	3.39	4.66
7	3.92	5.53	3.04	4.16
8	4.11	5.41	2.88	4.13

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^2S for any given time t.

Table 3-4
Average Flow Rates Through the Screened Sections in gpm During the Flow Logging of Well ER-EC-6

Pumping Rate = 68 gpm				
Screen Number	Logging Run			
	ec6mov1	ec6mov2	ec6mov3	Average
1	55.99	54.55	58.00	56.18
2	6.38	5.69	5.53	5.87
3	1.37	1.15	1.12	1.21
4	0.63	0.21	0.82	0.55
5	0.17	0.34	-0.01	0.17
6	0.44	0.42	0.42	0.43
7	0.08	0.21	0.39	0.23
Pumping Rate = 62 gpm				
Screen Number	Logging Run			
	ec6mov4	ec6mov5	ec6mov6	Average
1	50.27	51.60	51.82	51.23
2	5.98	5.31	5.12	5.47
3	0.88	1.14	1.09	1.04
4	1.09	0.48	0.61	0.73
5	0.00	0.00	0.00	0.00
6	0.87	0.27	0.35	0.49
7	-0.19	0.12	0.16	0.03

Formation and Interval Drawdowns (s and s_i)

In general, the drawdown in the aquifer at the effective radius of the well is calculated as the drawdown in the well corrected for friction, entrance, and skin losses. These losses are considered to be negligible for Well ER-EC-6, as discussed previously in this document.

Two values of drawdown were used for each pumping rate to assess the uncertainty associated with drawdown. These drawdowns were calculated using specific capacity values obtained from the constant-rate test. The drawdowns were calculated for 0.1 and 1 day.

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. As discussed previously in this document, these losses are considered to be negligible for Well ER-EC-6. Well transmissivities derived from the constant-rate tests were used in the calculations.

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 25 feet. This length does not include the nonslotted parts located at both ends of the slotted section. The maximum contributing thickness is assumed to be equal to the relevant lengths of the filter packs, a thickness of as much as 73 ft.

3.4.4.2 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 3-5 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 89 percent of the transmissivity of the formation (well transmissivity derived from 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 2.16 gpm.

3.4.5 Sources of Uncertainty

Uncertainty in the interval hydraulic conductivity values primarily comes from 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 factors 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 3-5.

Table 3-5
Interval Hydraulic Conductivities Calculated From Flow Logging Data for Well ER-EC-6

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)
			$s_{t=0.1\,d}$[a]	$s_{t=1\,d}$[b]	-		$s_{t=0.1\,d}$	$s_{t=1\,d}$	-
ec6mov1	Screen 1	25.39	8.80	8.79	8.49	72.83	3.07	3.07	2.89
ec6mov2	Screen 1	25.39	8.53	8.52	8.24	72.83	2.97	2.97	2.81
ec6mov3	Screen 1	25.39	9.07	9.06	8.73	72.83	3.16	3.16	2.97
ec6mov4	Screen 1	25.39	8.60	8.59	8.31	72.83	3.00	2.99	2.83
ec6mov5	Screen 1	25.39	8.77	8.76	8.47	72.83	3.06	3.06	2.88
ec6mov6	Screen 1	25.39	8.91	8.90	8.59	72.83	3.11	3.10	2.93
ec6mov1	Screen 2	25.38	0.84	0.85	0.97	70.69	0.30	0.30	0.34
ec6mov2	Screen 2	25.38	0.75	0.75	0.87	70.69	0.27	0.27	0.30
ec6mov3	Screen 2	25.38	0.71	0.71	0.82	70.69	0.25	0.26	0.29
ec6mov4	Screen 2	25.38	0.86	0.86	0.98	70.69	0.31	0.31	0.34
ec6mov5	Screen 2	25.38	0.76	0.76	0.88	70.69	0.27	0.27	0.31
ec6mov6	Screen 2	25.38	0.72	0.72	0.83	70.69	0.26	0.26	0.29

[a] Drawdown in the well 0.1 day after pumping started
[b] Drawdown in the well 1 day after pumping started

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 about plus or minus 2.16 gpm. This means that flow uncertainty is a small factor for the intervals that produced the most water, but could be a significant factor, more than perhaps 50 percent of the value, for Screen 2. As shown in Table 3-5, the uncertainty on the calculated hydraulic conductivities due to drawdown uncertainty is small because the drawdowns do not change significantly shortly after pumping begins.

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 equation (3-10), time is a parameter in this equation. 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 3-5 summarized the hydraulic conductivity for each interval for each logging run using a range of interval thicknesses and a range of drawdowns corresponding to different points in time. Also, as shown in Table 3-5, the hydraulic conductivity values were calculated using two methods represented by equation (3-8) and equation (3-10). 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. The values calculated using equation (3-8) and equation (3-10) are very similar, as is expected when flow losses are negligible.

For Well ER-EC-6, the biggest source of uncertainty is the selection of the length of the contributing interval for each screen. As was noted earlier, the thickness could vary between 25 and 73 ft. This uncertainty in the contributing thickness produces an uncertainty in interval hydraulic conductivity that is almost 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 3 to 4 based on the range of calculated values for the two screens. 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.

3.5 Comments on the Testing Program and the Well Design

Several observations can be made about testing multiple-completion well design that extend over great vertical depth. The flow logging during pumping has revealed that production is often limited to just one of the completion intervals and even just specific zones within the completion interval. This information reveals the character of the formation(s) more accurately and provides a much more realistic view of the nature of hydraulic conductivity within the formation(s). A general conclusion can be drawn about the lack of production from the other completion intervals, that the hydraulic conductivity of the formation(s) in those intervals must be much less than that of the productive zones in the upper completion interval.

For Well ER-EC-6, the analysis in Section 3.4.4 found an order-of-magnitude difference in K between the formation opposite the first screen and opposite the second screen of the upper completion interval. Specific production below these screens could not be accurately determined from the noise in the flow measurements below these screens. The analysis presented in Section 2.6 for the lower-middle completion interval yielded a K value that is an order-of-magnitude lower than the K determined for the second screen of the upper completion interval.

When there are great contrasts in the hydraulic conductivity of different sections of formation, the pumping/flow logging testing is dominated by the high conductivity sections and little specific information can be derived for the other sections. The pumping rates that can be imposed with the available pumps result in data that only provide definitive information on parts of the completion intervals. Higher pumping rates may have increased production from lower screens sufficiently to have provided data for hydraulic conductivity analysis, but it is probable that much higher rates would be required to produce meaningful results. The thermal flow log and bridge-plug pressure drawdown information provided an alternate means to get quantitative information on lower conductivity formation(s), but those measurements also had a lower accuracy limit.

The head adjustment data collected during the bridge plug head measurements were used to calculate a hydraulic conductivity for the upper-middle completion interval. There was no data collected during the pumping test to provide this result. While there is no way to check this result, the data and analysis appear reasonable. Further development and application of this methodology may be valuable for use where pumping tests do not produce useful data.

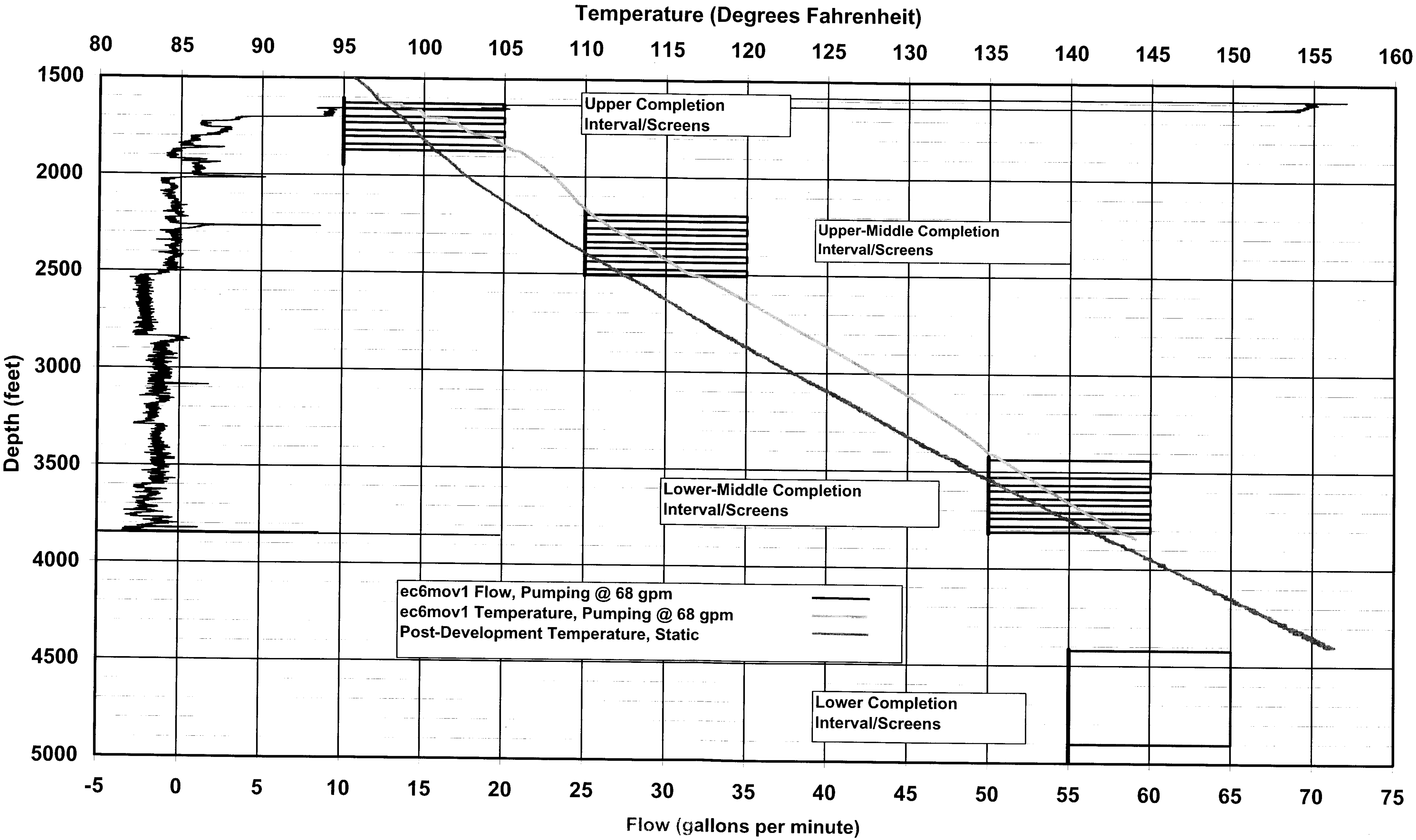


Figure 3-1
Representative Temperature and Flow Logs

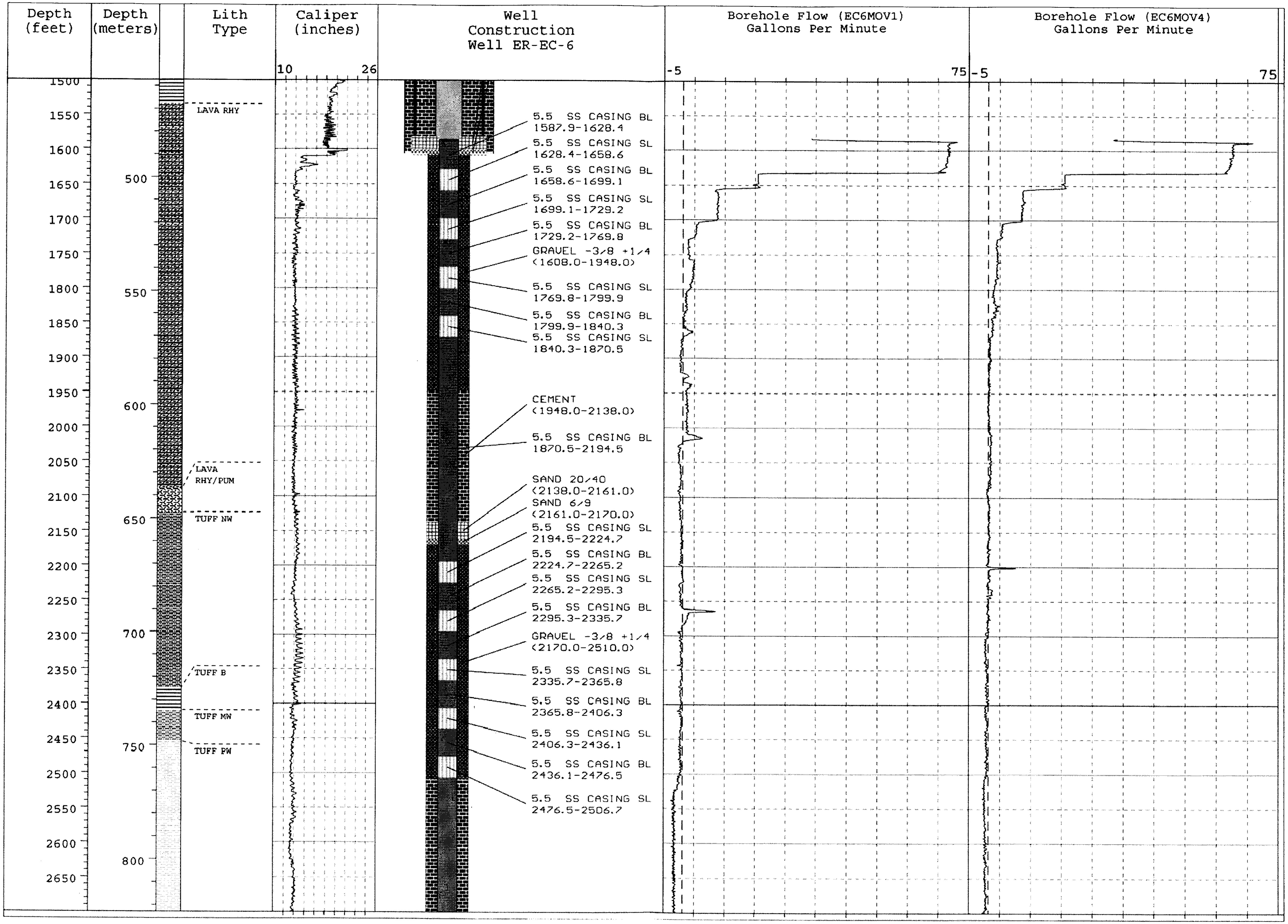


Figure 3-2
Upper and Upper Middle Completion Intervals

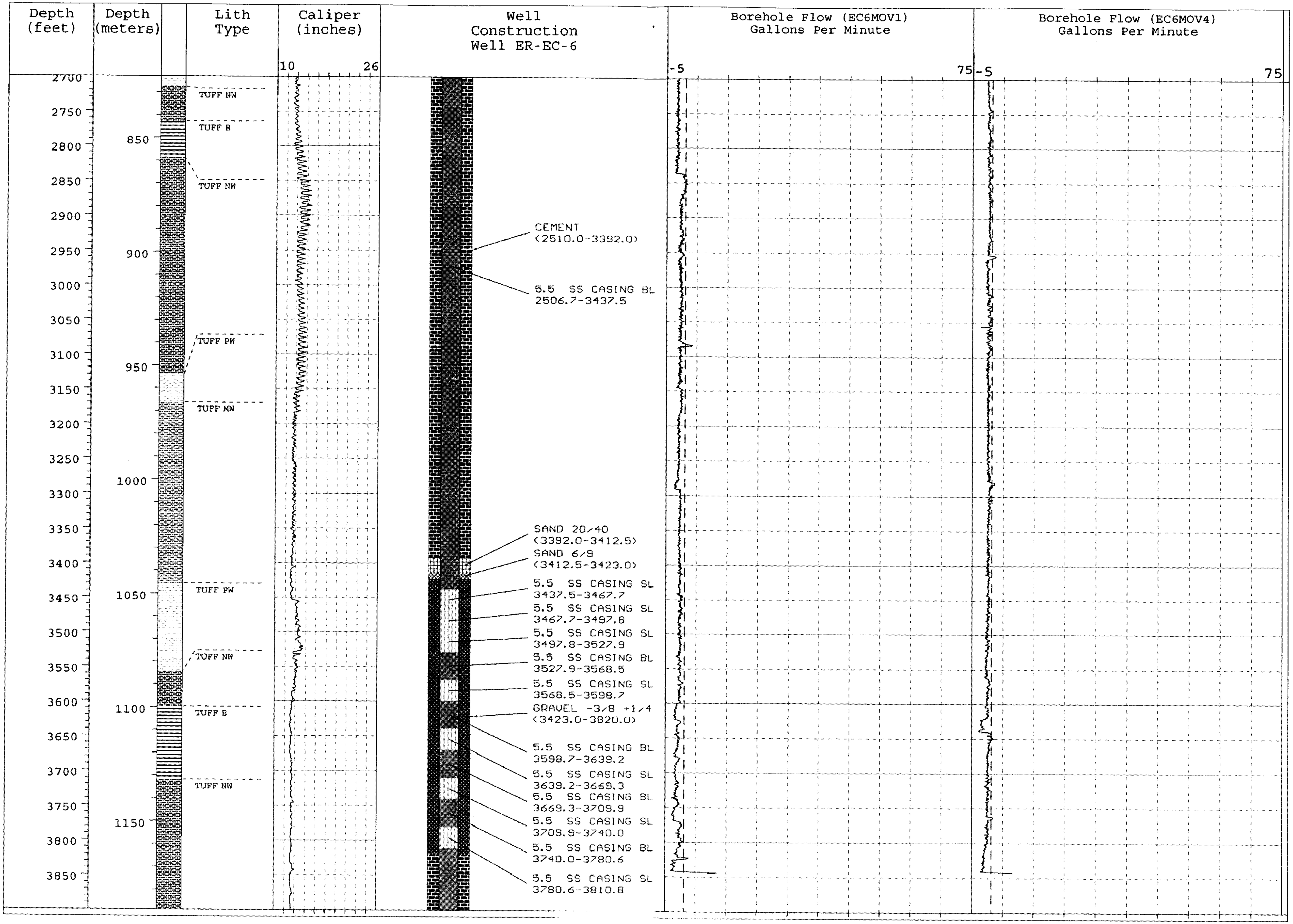


Figure 3-3
Lower-Middle Completion Interval

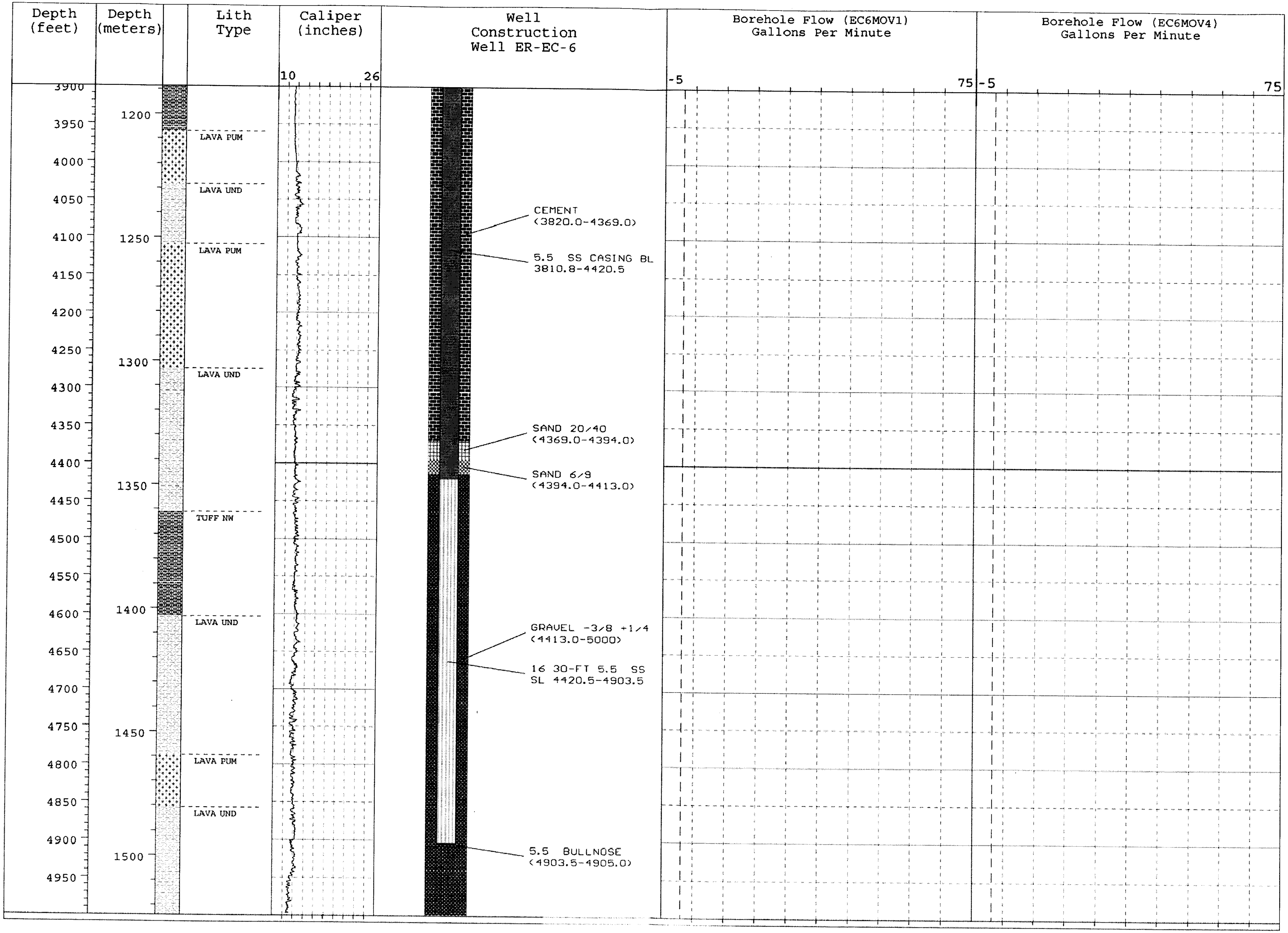


Figure 3-4
Lower Completion Interval

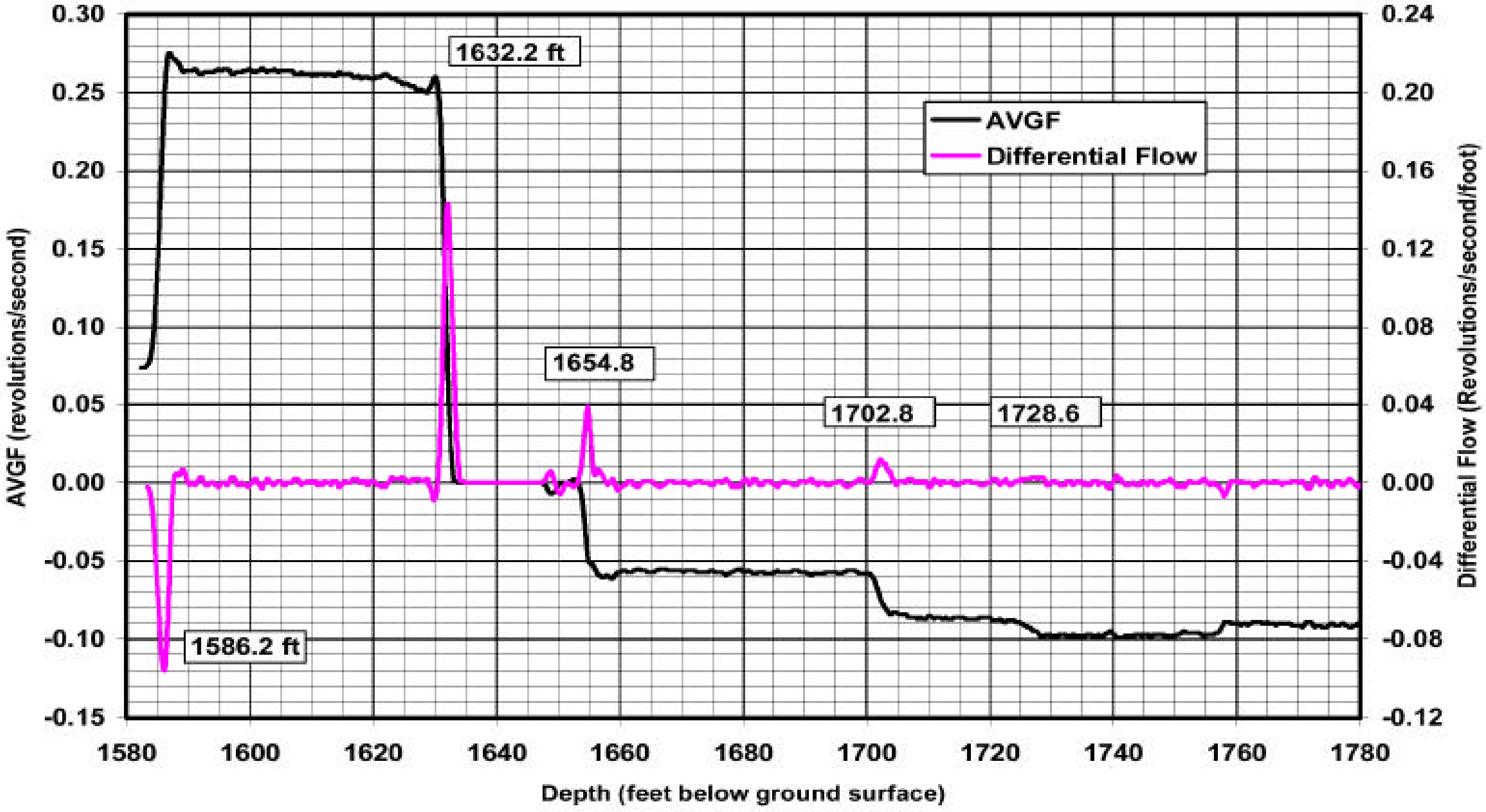


Figure 3-5
Example of Differential Flow Log Superposed on Flow Log (Flow Log ec6mov1)

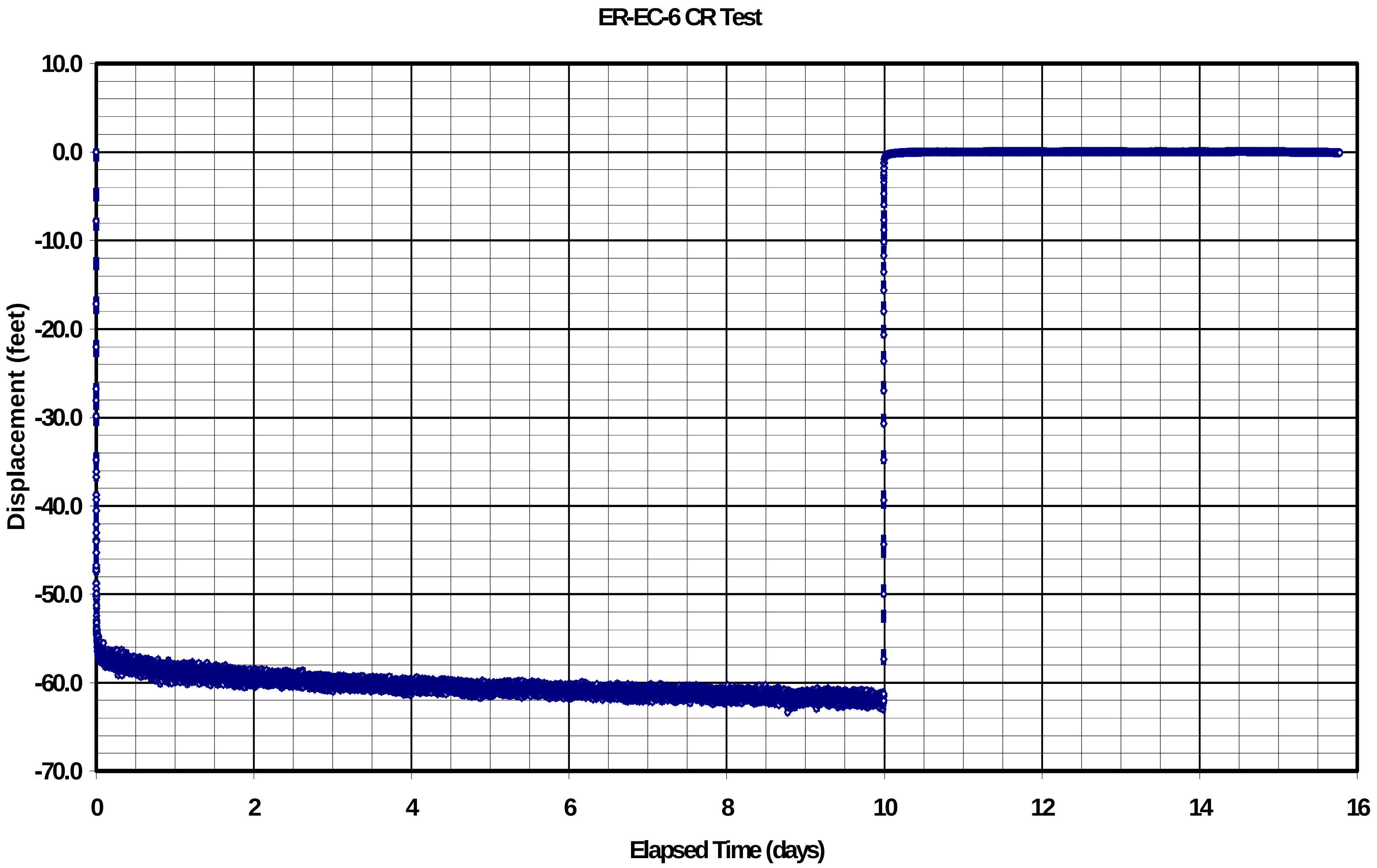
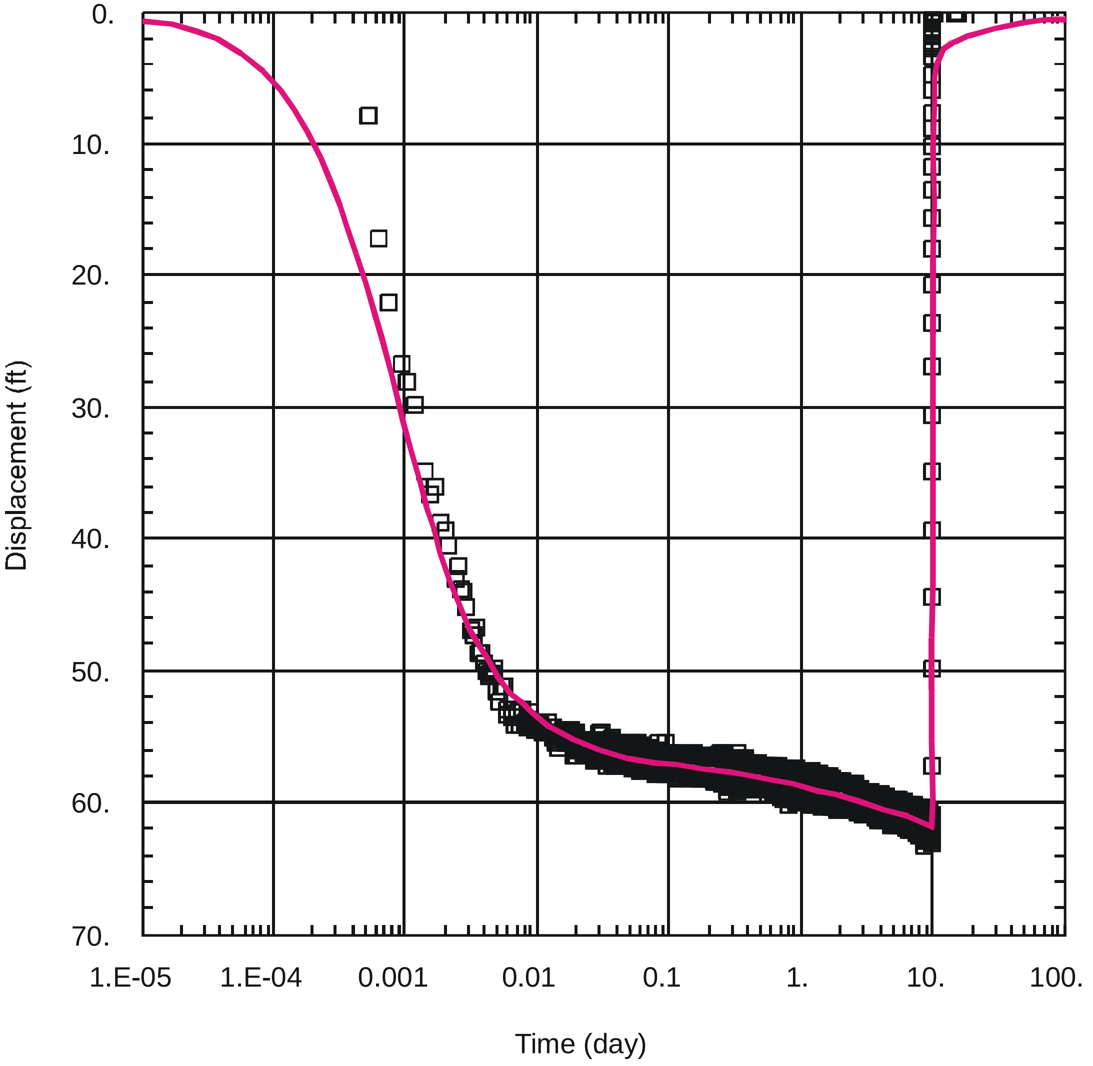


Figure 3-6
Constant-Rate Test Data



Well ER-EC-6

Constant-Rate Test
Production Rate 68.4 GPM
Aquifer Thickness 143 ft

Aquifer Model

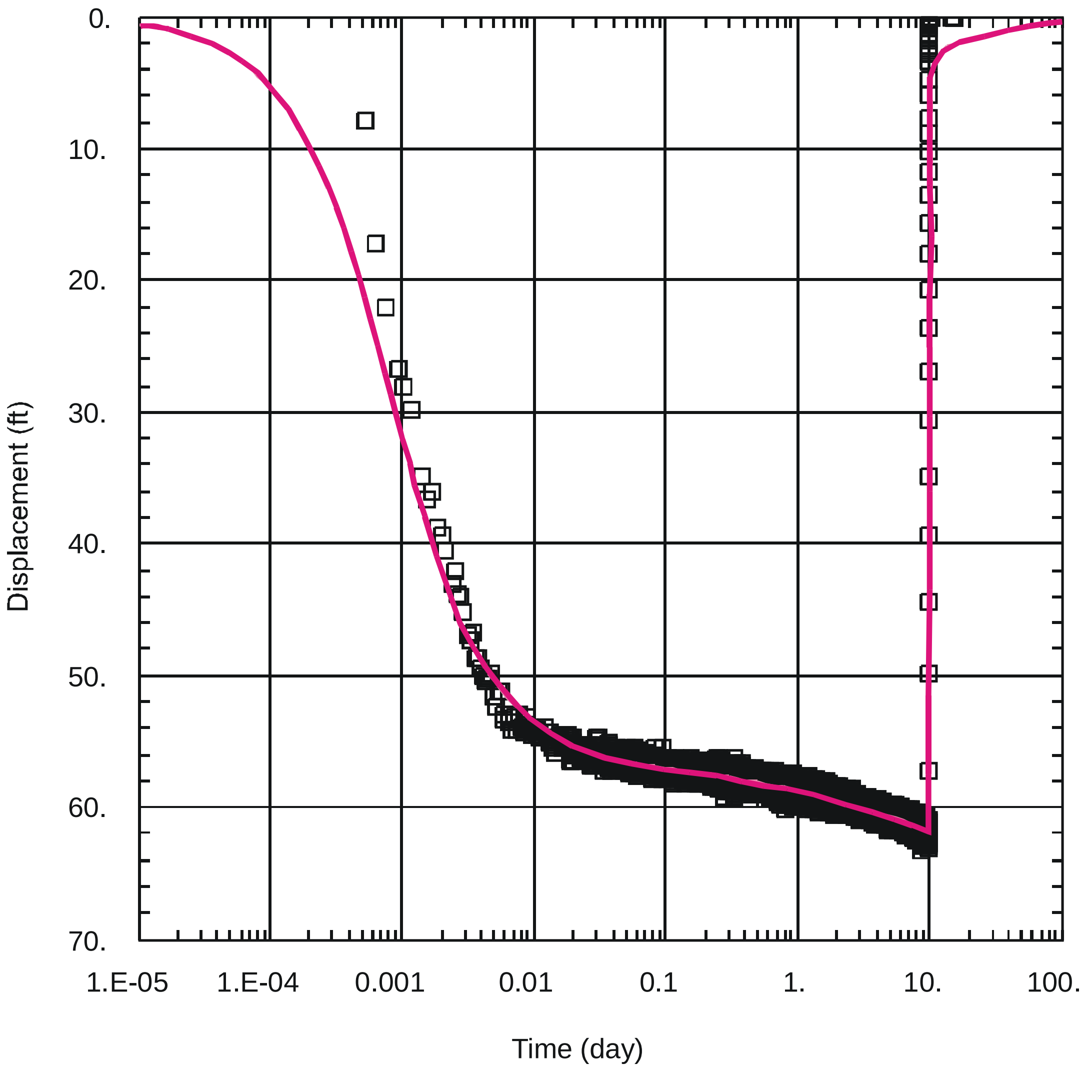
Dual-Porosity
Moench w/slab blocks

Parameters

K = 1.797 ft /day
Ss = 1.782E-07 ft^{-1}
K’ = 7.451E-06 ft /day
Ss’ = 5.946E-05 ft^{-1}
Sw = 0.004607
Sf = 0.3103

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

Figure 3-7
Moench Dual-Porosity Solution for Filter Pack Thickness



Well ER-EC-6

Constant-Rate Test
Production Rate 68.4 GPM
Aquifer Thickness 51 ft

Aquifer Model

Dual-Porosity
Moench w/slab blocks

Parameters

K = 5.209 ft/day
Ss = 3.327E-07 ft^{-1}
K' = 1.269E-05 ft/day
Ss' = 0.0001014 ft^{-1}
Sw = 0.0008256
Sf = 0.2886

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

Figure 3-8
Moench Dual-Porosity Solution for Screen Thickness

4.0 Groundwater Chemistry

This section presents an evaluation of the analytical results for the groundwater characterization samples collected during well development and hydraulic testing activities at Well ER-EC-6. Both a discrete bailer and a well composite sample were collected at this site. The purpose of the discrete bailer sample was to target a particular depth interval for sampling under either static or pumping conditions, while the purpose of the composite groundwater sample was to obtain a sample that was as representative of as much of the open intervals as possible. The results from these two groundwater characterization samples were used to examine the overall groundwater chemistry of the well and to compare this groundwater chemistry to that of other sites in the area. The groundwater chemistry results were also evaluated to establish whether Well ER-EC-6 was sufficiently developed to restore natural groundwater quality in the formation around the well.

4.1 Discussion of Groundwater Chemistry Sampling Results

The groundwater chemistry of Well ER-EC-6 will be discussed in this section and then compared to the groundwater chemistry of other nearby sites.

4.1.1 ER-EC-6 Groundwater Characterization Sample Results

On January 27, 2000, one discrete bailer sample (#EC-6-012700-1) was obtained from a depth of 1,648 ft below ground surface (bgs) at a pumping rate of approximately 68.5 gpm. The sample was obtained using a DRI logging truck and a discrete bailer. On February 10, 2000, a composite groundwater characterization sample (#EC-6-021000-1) was collected from the wellhead sampling port directly into sample bottles. A constant production rate of 68.4 gpm was maintained during the sampling event. At the time of composite sampling, approximately 1.65×10^6 gallons of groundwater had been pumped from the well during development and testing activities (see Section A.2.10.2, Appendix A). The results from these two samples have been tabulated and are presented in Table ATT.3-1, Table ATT.3-2, and Table ATT.3-3, Attachment 3, Appendix A.

Inspection of Table ATT.3-1, Attachment 3, Appendix A, reveals that both groundwater characterization samples have relatively similar analytical results. For example, it can be seen from the dissolved analyses column of the “Metals” section that both groundwater characterization samples had a silicon concentration of 23 milligrams per liter (mg/L). In addition, it can be seen from the “Metals” section of the table that sodium, potassium, and calcium are the predominate cations in both groundwater characterization samples, with sodium having the highest concentration. The table also reveals in the “Inorganics” section that bicarbonate, sulfate, and chloride are the predominate anions in both groundwater characterization samples, with bicarbonate having the highest concentration. Further examination of Table A.3-1, Attachment 3, Appendix A, reveals that both groundwater characterization samples have a slightly basic pH, with the discrete bailer sample having the highest pH of 8.1. Both groundwater characterization samples also have a similar total dissolved solids concentration and relatively similar electrical conductivities. It can also be seen from Table A.3-1, Attachment 3, Appendix A, that a significant number of the analytes were not detected at the given detection limits, as indicated by the 'U' qualifier.

Inspection of the “Age and Migration Parameters” section of the table for the composite groundwater sample reveals several interesting things. For example, LLNL (2000) states that the Helium-3 (^{3}He)/Helium-4 (^{4}He) ratio for Well ER-EC-6 ($R=9.11x10^{-7}$) is slightly lower than the atmospheric ratio ($R_a=1.38x10^{-6}$) giving a R/R_a value of 0.66. According to LLNL (2000), the sample contains high concentrations of non-atmospheric ^{4}He derived from the *in situ* α-decay of naturally occurring radioactive elements in the host rock. The ^{4}He apparent age for this groundwater is on the order of 11,500 years after correcting the ^{4}He data for the presence of non-equilibrium “excess-air” and assuming a ^{4}He in-growth rate of 1.2×10^9 atoms/year (LLNL, 2000). Inspection of the Table A.3-1, Attachment 3, Appendix A, also reveals that the carbon-14 (^{14}C) value of dissolved inorganic carbon (DIC) from Well ER-EC-6 is 5.4 percent modern, yielding an uncorrected ^{14}C apparent age of 24,200 years. LLNL (2000) states that the uncorrected ^{14}C apparent age is more than twice that of the ^{4}He apparent age, implying the DIC has reacted with the ^{14}C-absent carbonate minerals present in the aquifer. They also state that the delta carbon-13 (δ^{13}C) value of the DIC is consistent with partial equilibration with carbonate minerals. Further examination of the table shows that the chlorine-36 (^{36}Cl)/chlorine (Cl) ratio for Well ER-EC-6 (5.41×10^{-13}) is similar to previous measurements of environmental samples from Pahute Mesa and that the strontium-87 (^{87}Sr)/strontium-86 (^{86}Sr) ratio (0.70982) is consistent with natural abundance in the volcanic tuffs in and around the Nevada Test Site (LLNL, 2000).

Table A.3-2, Attachment 3, Appendix A, presents the results of the colloid analyses for Well ER-EC-6. The table reveals that both groundwater characterization samples have relatively similar total colloid concentrations. For example, it can be seen in the table that the discrete bailer characterization sample had a total colloid concentration of $3.37x10^7$ 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 $3.69x10^7$ particles/mL for particles in the size range of 50-1,000 nm. It can also be seen from the table; however, that even though the composite groundwater characterization sample had the greater total colloid concentration, the discrete bailer sample had greater colloid concentrations for each of the particle size ranges after 80-90 nm. Further inspection of the table reveals that the colloid concentrations for both groundwater characterization samples decrease, in general, as the particle size ranges increase. In addition, it can be seen from the table that the colloid concentrations for the composite groundwater characterization sample decrease at a slightly greater rate than the colloid concentrations for the discrete bailer sample, especially for the larger particle size ranges.

One potential difference between the two groundwater characterization samples, however, can be seen in the oxidation-reduction sensitive parameters: iron and manganese. For example, examination of the table reveals that for the composite groundwater characterization sample the concentrations of iron and manganese are essentially found in the dissolved phase and not the total phase. It can be seen in the table; however, in the discrete bailer sample there is essentially no dissolved iron or manganese. The concentrations of iron and manganese in the discrete sample are seen only in the total analyses. This potentially indicates some sort of sampling artifact such as an oxidation-reduction change in the groundwater sample between when the discrete bailer sample was collected and when it was filtered at the ground surface.

Overall, the geochemical compositions from the two groundwater characterization samples are typical for wells that penetrate volcanic rocks. In fact, lithologic logs indicated that the upper completion interval penetrates rhyolitic lava from the Paintbrush Group (DOE/NV, 2000).

4.1.2 Radionuclide Contaminants

Radiological indicator parameters were not detected in the groundwater characterization samples from Well ER-EC-6.

4.1.3 Comparison of ER-EC-6 Groundwater Chemistry to Surrounding Sites

Table 4-1 presents groundwater chemistry data for Well ER-EC-6 and for recently collected samples from sites in close proximity to ER-EC-6. 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 contain three different plots of major-ion chemistry and are used to show the relative concentrations of major ions in the groundwater. The triangular plots in Figure 4-1 show the relative concentrations of major cations and anions. The diamond-shaped plot in the center of the figure combines the information from the adjacent cation and anion triangles. The concentrations in all three plots 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. Examination of the figure reveals that the dominant cation type for Well ER-EC-6 and the surrounding sites is Na+K, with minor amounts of calcium and magnesium. It can also be seen from the figure that there is very little scatter associated with the cation concentrations. Inspection of the anion triangle reveals that the dominant anion type for most of the sites is bicarbonate; however, there are a number of sites that have no dominant anion type as a result of greater sulfate and chloride concentrations. It can also be seen from the anion triangle that there is a greater spread among the anionic constituents than was seen in the cation

Table 4-1
Groundwater Chemistry Data for Well ER-EC-6 and Surrounding Sites
(Page 1 of 2)

Analyte	ER-EC-6				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, 3019 feet	U-19az	U-19bh	U-20 WW	U-20a #2 WW	U-20ai
	(Bailer at 1648' bgs) Total	Dissolved	(Wellhead Composite) Total	Dissolved													
Metals (mg/L)																	
Aluminum (Al)	U 0.055	U 0.054	U 0.086	U 0.076	3.1			0.31	1.13	< 0.06	0.03	< 0.01			5.3	< 0.01	
Arsenic (As)	B 0.0078	B 0.0058	B 0.0045	B 0.0041	0.042	B 0.0085	< 0.01	0.039	0.051	0.016		0.004			5.89		
Barium (Ba)	B 0.0072	B 0.0065	B 0.0017	B 0.0016	< 0.01	B 0.0076	< 0.2	< 0.01		< 0.01	0.004	0.002			0.00008		
Cadmium (Cd)	UJ 0.005	UJ 0.005	U 0.005	U 0.005		0.005	< 0.005					< 0.001			< .000016		
Calcium (Ca)	J 4.7	J 4.7	4.2	4.1	7.18	3.14	6.95	7.1	8.3	10.1	30.1	36	19.9		6.8	6.34	4.29
Chromium (Cr)	U 0.0038	U 0.0021	U 0.00065	U 0.01		0.0792	0.0422				0.01	0.002			0.00025		
Iron (Fe)	0.57	U 0.045	0.44	0.36	0.39	8.48	0.845	0.12	0.48	0.17	0.24	0.06			0.0767	0.09	
Palladium (Pd)	U 0.003	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	0.14	0.13	0.14	0.09	0.0696	0.0572	0.06	0.06	0.05	0.278			0.405	0.063	0.065	
Magnesium (Mg)	U 0.11	U 0.1	U 0.061	U 0.058	0.27	0.09	0.891	0.57	0.71	0.8	0.79	1.5	1.8		0.27	0.24	1.05
Manganese (Mn)	0.01	U 0.002	0.026	0.025	0.02	0.305	< 0.015	0.01	0.03	0.04	0.014	0.014			0.0496	0.01	
Potassium (K)	3.3	3.4	3.2	3.1	5.65	3	< 1.95	2.2	3.1	3.6	10.9	10	5.78		1.37	2.27	7.17
Selenium (Se)	0.0066	0.0063	U 0.005	B 0.0048	< 0.01	< 0.005	< 0.005	< 0.01	< 0.01	< 0.01		< 0.001			0.00051		
Silicon (Si)	22	23	23	23	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)	100	100	130	140	105	73	59	60.6	61.1	56	140	130	102		59.5	62.6	115
Strontium (Sr)	0.011	0.012	B 0.0049	B 0.006	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)	52		52		21.7	17.8	12.2	12.3	11.6	13.6	93.5	98	94.4		11.1	11.2	63.5
Fluoride (F)	3.3		3.1		10.1	3.16	2.64	2.93	3.84	2.45	2.5	2.4			2.23	2.7	2.9
Bromide (Br)	0.48		0.32		0.103	< 0.25	< 0.25								0.064		
Sulfate (SO4)	79		77		39	35.1	32.2	32.3	31.5	31.8	129	130	18.7		31	38.4	26
pH	J 8.1		J 7.4		8.6	8.8	8.46	8.12	8.16	8.42	8.73	7.9	7.97		8.56	7.7	8.43
Total Dissolved Solids (TDS)	370		380		436	489	227				441	555.6241			166	201	
Carbonate as CaCO3	5.9		U 5														
Bicarbonate as CaCO3	120		120		186	109	96	103	112	109	159	150	145		101	112	175
Age and Migration Parameters (pCi/L) - unless otherwise noted																	
Carbon-13/12 (per mil)	N/A		-4.4		-2.82	-5.75	-7.9 +/- 0.2	-6.67	-7.28	-7.24					-6.2	-13.47	
Carbon-14, Inorganic (pmc)	N/A		5.4		81657	1346		344.23	1068.53	16.31					8.6	15.3	
Carbon-14, Inorganic age (years)*	N/A		24200												20260		
Chlorine-36	N/A		7.85E-04			0.01102											
Helium-3/4, measured value (ratio)	N/A		9.11E-07		0.157	0.001		< 0.001	< 0.001	9.27E-07					4.74E-07		
Helium-3/4, relative to air (ratio)	N/A		0.66		114000	723		< 720	<720	0.67					0.34		
Oxygen-18/16 (per mil)	N/A		-14.9		-14.9	-15.1	-15 +/- 0.2	-14.98	-15	-14.97					-14.7 +/- 0.2	-14.75	
Strontium-87/86 (ratio)	N/A		0.709822 +/- 0.00001		0.71104 +/- 6E-5	0.70868 +/- 3E-5		0.71016	0.71029	0.70974					0.71126		
Uranium-234/238 (ratio)	N/A		0.000223454		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 -190 +/- 160		U -120 +/- 160		60400000	142000	2310	1700000	944000		16		50.016		3.8 +/- 0.93		16
Gross Alpha	7.7 +/- 1.7		7.6 +/- 1.8		C 23.7	37.3	C 7.7									0.0053	
Gross Beta	4.4 +/- 1.5		U 3.6 +/- 1.5		C 29.6	24.8	2.1									5.6	
Radiological Indicator Parameters-Level II (pCi/L)																	
Carbon-14	UJ -10 +/- 180		UJ -150 +/- 180		260	-3.8	25										
Strontium-90	N/A		U 0.21 +/- 0.15		0.5	0.43									0.13		
Plutonium-238	U 0.017 +/- 0.021		U 0.003 +/- 0.013		< 0.062	< 0.31	0.001								0.43		
Plutonium-239	U -0.005 +/- 0.012		U -0.005 +/- 0.012														
Iodine-129	N/A		UJ -0.20 +/- 0.81		<570	-0.6	0.04										
Technetium-99	N/A		UJ 0.56 +/- 0.98		< 1.88	< 5.17	0.5								3.22		

Table 4-1
Groundwater Chemistry Data for Well ER-EC-6 and Surrounding Sites
(Page 2 of 2)

Analyte	U-20al	U-20ao	U-20c	U-20e	U-20f	U-20n	U-20n PS#1 DDH (Cheshire)	UE-18r	UE-19fs	UE-20bh #1	UE-20d	UE-20e #1	UE-20f (13686 feet)	UE-20f (4543 feet)	UE-20h WW	UE-20j WW
Metals (mg/L)																
Aluminum (Al)			< 0.1	< 0.1	0.26		0.97	< 0.06	0.02	0.01	0.09	0.01	0.07	0.07	0.02	0.01
Arsenic (As)							J 0.0089	< 0.1		0.0056						
Barium (Ba)							< 0.02	20		0.0005						
Cadmium (Cd)							< 0.002									
Calcium (Ca)	13.1	8.82	2.8	3.6	14		3	21.5	11	3.14	8.5	0.2	4.8	4.8	0.6	46
Chromium (Cr)							< 0.01									
Iron (Fe)			0.03	0.07	0.04		0.58	< 0.02		0.06		0.02	0.56	0.56		4.8
Palladium (Pd)							< 0.003	< 0.01		0.0006						
Lithium (Li)			0.01	0.06	0.04		0.11	0.08	0.02	< 0.1	0.075	0.07			0.08	
Magnesium (Mg)	2.05	1.24	< 0.1	0.2	0.1		0.45	0.92	1.6	0.59	0.1			0.1		1.2
Manganese (Mn)			< 0.01	0.14	0.02		0.15	< 0.03	0.03	0.004	0.39	< 0.01	0.14	0.14	0.03	
Potassium (K)	11.1	1.9	1.4	2.9	3		B 2	3.49	3	8.72	2.6	2	2	2	1.8	6.4
Selenium (Se)				0.03	0.02		< 0.005	< 0.01		< 0.004	0.01					
Silicon (Si)			42	40	39		25.6	21.6	56	21.8	45	36	47	47	49	44
Silver (Ag)							< 0.01									
Sodium (Na)	122	38	95	73	82		61	73.1	29	87.7	107	83	113	113	64	138
Strontium (Sr)			0.04	0.01	0.07		B 0.015	0.08	0.02	0.0009	< 0.01	0.03			< 0.02	
Uranium (U)							< 0.3	0.0035	0.0021	0.001					0.0018	0.0085
Mercury (Hg)							< 0.0001									
Inorganics (mg/L)																
Chloride (Cl)	32.8	3.2	8.1	21	15		13.8	6.9	6.3	4.7	24	20	40	40	15	115
Fluoride (F)			6.4	2.7	3.7		4.8	3	3.6	< 1	3	4.5	5	5	2.7	2.2
Bromide (Br)							0.4									
Sulfate (SO4)	77.6	8.1	18	35	65		34	23	9	14	40	42	48	48	30	135
pH	8.3	8.14		7.3	8.4		8.8	8.05	8.1	8.26	8.5	8.5		7.2	8.1	7
Total Dissolved Solids (TDS)			264	200	268		251	208	186		327	245	368	368	231	583
Carbonate as CaCO3																
Bicarbonate as CaCO3	250	114	130	120	140		88	227	86	214	192	119	164	164	107	150
Age and Migration Parameters (pCi/L) - unless otherwise noted																
Carbon-13/12 (per mil)								-1.4		-9.2						
Carbon-14, Inorganic (pmc)							160450	6.7 +/- 0.06		20.95						
Carbon-14, Inorganic age (years)*																
Chlorine-36							0.4966	0.0001342								
Helium-3/4, measured value (ratio)							0.2168									
Helium-3/4, relative to air (ratio)							160000	1.128 +/- 2		0.923 +/- 2						
Oxygen-18/16 (per mil)							-15	-14.7		-14.7						
Strontium-87/86 (ratio)							0.71009 +/- 2E-5	0.70909								
Uranium-234/238 (ratio)							0.000223									
Hydrogen-2/1 (per mil)							-124	-110		-109						
Radiological Indicator Parameters-Level I (pCi/L)																
Tritium						61830000	J 69409830	8 +/- 1.9		3.2 +/- 1.7						
Gross Alpha							< 22.3509			< 3						
Gross Beta					2.1		J 1246.545		3.2	3	3.2	9.8			8.8	13
Radiological Indicator Parameters-Level II (pCi/L)																
Carbon-14							< 304									
Strontium-90							J 202.2122									
Plutonium-238																
Plutonium-239																
Iodine-129							< 0.714									
Technetium-99								< 5								

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

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.

J = The result is an estimated value.

N/A = Not Applicable for that sample

pmc = Percent modern carbon

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

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

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

triangle. Regardless, Figure 4-1 clearly shows that the groundwater chemistry for Well ER-EC-6 is similar to surrounding sites, at least in terms of the major ionic constituents.

The chemistry data in Table 4-1 were also used to construct Figure 4-2. The figure shows the stable oxygen and hydrogen isotope compositions of groundwater for Well ER-EC-6 and for selected sites within ten miles of ER-EC-6. 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 from the figure, the precipitation data, as expected, lie along the local and global meteoric water lines of Ingraham et al. (1990) and Craig (1961), respectively. It can be seen from the figure that the stable oxygen and hydrogen isotopes for Well ER-EC-6 plot extremely close to the stable oxygen and hydrogen isotopes of the surrounding sites. This again illustrates that the groundwater chemistry for Well ER-EC-6 is similar to the surrounding sites. As can be seen from the figure, the groundwater data for most of these sites lie below the global meteoric water line. In general, 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). However, because the recent precipitation data plot along the meteoric water line, it appears that fractionation during evaporation of precipitation can be ruled out as causing the isotopic shift observed in groundwater data. It can also be seen from the figure that the groundwater data are isotopically lighter than precipitation data. One possible explanation for the isotopically lighter groundwater is that the recharge areas for the groundwater are located north of Pahute Mesa. For example, 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 water in Central Nevada. An alternate explanation for the lighter isotopic signature is that the groundwater was recharged during cooler climatic conditions. It can be clearly seen from the figure, however, that based on the data available the stable isotopic composition of Well ER-EC-6 appears to be typical for the area.

4.2 Restoration of Natural Groundwater Quality

A primary purpose for well development was to restore the natural groundwater quality of the completion intervals so that any future groundwater samples taken from the well would accurately represent the water quality of the producing formations. The formations 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

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. The values of certain geochemical parameters (e.g., pH, turbidity, dissolved oxygen) were expected to decline and stabilize as development progressed, indicating restoration of natural groundwater quality as opposed to water affected by drilling and completion activities. The results from the water quality monitoring were examined in a previous report (IT, 2000), but the composite groundwater characterization sample can also help to address the effectiveness of well development. For example, during drilling operations for Well ER-EC-6, 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 10-50+ mg/L. This relatively high concentration of lithium (Li^+) and bromide ions (Br^-) injected into the well bore also provides another means to further ascertain the effectiveness of the well development. For example, if the groundwater characterization sample contained a bromide concentration of 20 mg/L after well development, it would tend to suggest that the well might still not be completely developed. It can be seen in Table A.3-1, Attachment 3, Appendix A, however, that the dissolved concentration of Br^- ions in the groundwater characterization sample was 0.32 mg/L. This value is more than two orders of magnitude lower than the concentration of LiBr injected into the well during well development and testing activities. In addition, inspection of Table 4-1 reveals that the concentration Br^- ions in the surrounding sites is on the same order as found in Well ER-EC-6. For example, the table shows that the highest concentration of Br^- ions in the surrounding sites was 0.4 mg/L for U-20n PS#1 DDH. The relatively low background concentration of Br^- ions in the surrounding sites and the low Br^- ion concentration in Well ER-EC-6 likely indicates that the well was sufficiently developed to restore groundwater quality close to its natural condition. This conclusion only pertains to the formation producing water during pumping.

4.2.2 Evaluation of Flow Between Completion Intervals

The thermal flow measurements indicated flow under static conditions from the upper and/or upper-middle completion interval to the lower-middle completion interval of about 0.2 gpm, Table 2-2. This suggests that the completion interval would be flooded with water from a different formation. However, no water samples were taken below the upper completion interval that would provide any data to assess differences in water quality between the completion intervals. The one discrete bailer sample was taken within the upper screen of the upper completion interval and represents a similar mix of production to the composite sample. The proportion of water in the composite sample from below the upper completion interval is not accurately determined from the data, but is a small fraction of the water produced during pumping. As a result, there is no information on water quality differences between the completion intervals. The long-term impact of this crossflow on the lower-middle completion interval cannot be predicted. However, any sample taken from this interval without substantial, confirmed remediation would be suspect. Crossflow to the other lower completion intervals was not determined by the thermal flow measurements although it is suspected, but at lower rates. The impact of this potential crossflow also cannot be predicted.

4.2.3 Source Formation(s) of Groundwater Samples

As discussed in Section 3.1, flow logging indicated that about 95 percent or more of the flow into the well during well development and testing activities came from the upper screened interval between 1,630 and 1,870 ft bgs. Any production that might have come from the lower completion intervals is on the order of the uncertainty of the measurements, which is about 2 gpm (Table 3-2). Accordingly, the source of both the discrete and the composite groundwater characterization samples is apparently only the uppermost completion interval. Preliminary lithologic logs indicate that the upper completion interval penetrates rhyolitic lava from the Paintbrush Group (DOE/NV, 2000), and the review of the groundwater chemistry done in Section 4.1.1 supports this observation. Consequently, the source formation of groundwater for both the discrete and composite groundwater characterization samples is attributed to the rhyolitic lava of the Paintbrush Group.

4.3 Representativeness of Water Chemistry Results

Due to the fact that the flow logs indicate that all of the water production in the well was derived from the upper completion interval and there was marginal indication of residual contamination from drilling, it is assumed that any discrete or composite groundwater characterization sample is fairly representative of the formation water for the uppermost completion interval. The concentrations of all chemical parameters are within the range expected for the groundwater environment at the NTS.

4.4 Use of ER-EC-6 for Future Monitoring

As discussed in this section, almost all of the water produced at the highest pumping rate (68 gpm) at which flow logs were run originated from the upper part of the upper completion interval. 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 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 this is generally not possible due to a lack of necessary depth for the drawdown that would occur. 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 much greater than the rates that have been employed, and flow logging would be required to confirm 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.

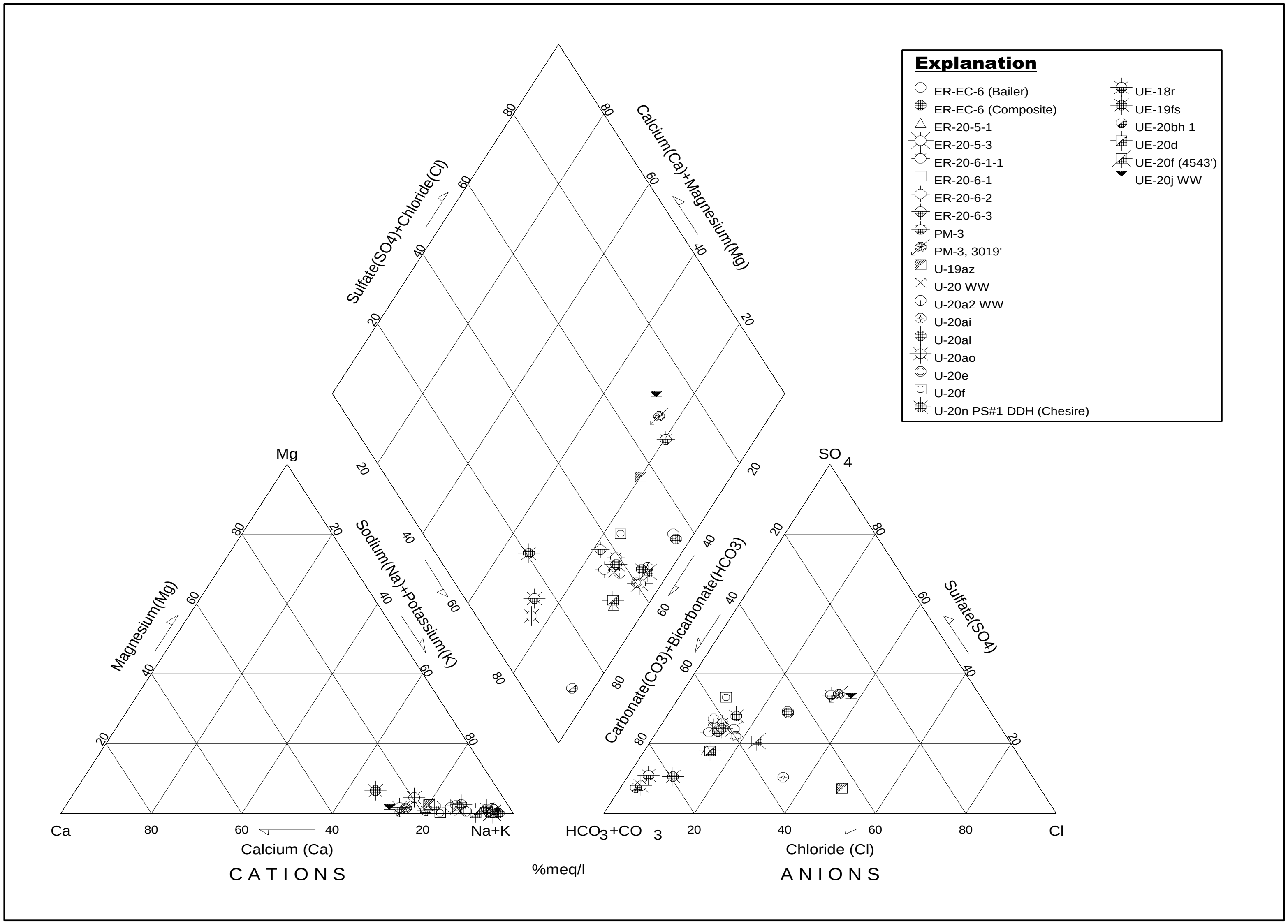


Figure 4-1
Piper Diagram Showing Relative Major Ion Percentages for Groundwater from Well ER-EC-6 and Surrounding Sites

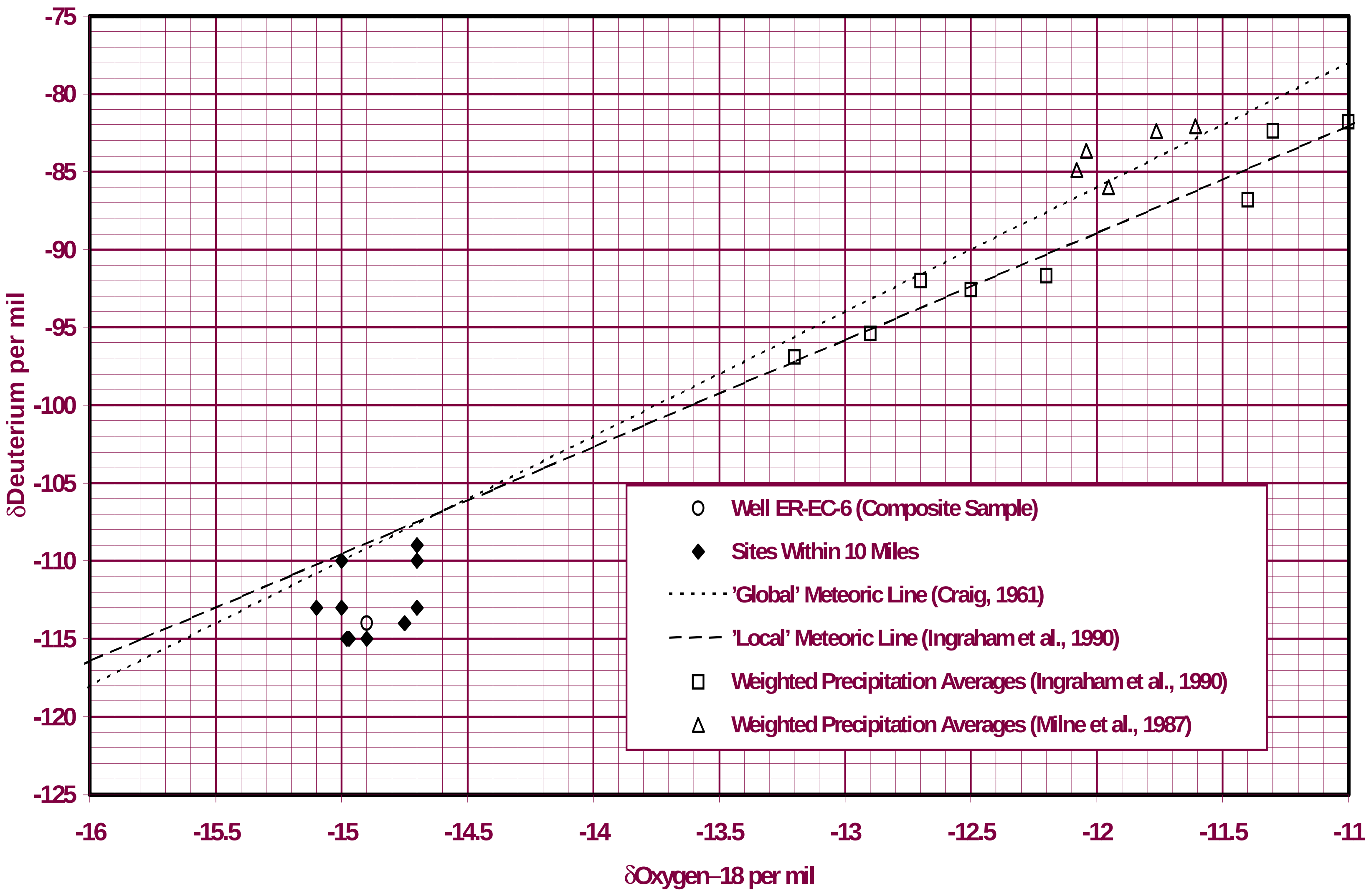


Figure 4-2
Stable Isotope Composition of Groundwater for Well ER-EC-6 and Nearby Sites

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Appendix A

Western Pahute Mesa-Oasis Valley Well ER-EC-6 Data Report for Development and Hydraulic Testing

A.1.0 Introduction

Well ER-EC-6 is one of seven groundwater wells that were completed as part of FY 1999 activities for the DOE 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-6 to provide information on the hydraulic characteristics of HSUs and the chemistry of local groundwater. Well ER-EC-6 is constructed with multiple completion intervals, intervals of slotted casing with gravel pack, which are isolated from each other by blank casing sections 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-6 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 discrete locations and/or specific completion intervals to characterize spatial variability in downhole chemistry.
5. Collect groundwater characterization samples to evaluate composite chemistry.

Well ER-EC-6 was the first of the WPM-OV wells to be developed and tested. Activities began January 2, 2000, and were completed by the end of March 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 of individual producing intervals and of the composite discharge.

A.1.1 Well ER-EC-6 Specifications and Geologic Interpretation

The drilling and completion specifications for Well ER-EC-6 can be found in the *Completion Report for Well ER-EC-6*, May 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 accessed by the well completion. The elements of the testing can be found in *Well Development and Hydraulic Testing Plan for Western Pahute Mesa - Oasis Valley Wells,* Rev. 0, November 1999 (WDHTP) (IT, 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-6 testing program was:

1. Measurements of interval-specific hydraulic heads, including monitoring of equilibration 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-6 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 in place when the testing program was initiated. These measurements were subsequently made after development and the constant-rate test were completed. 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 (IT, 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) (IT, 1999b), as modified by *Technical Change No. 1, 12/22/1999*. This document calls out a variety of Detailed Operating Procedures (DOPs) (IT, 1999a) and Standard Quality Practices (SQPs) (IT, 2000), 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, 1999* (IT, 1999c). Specifications for the handling and analyses of groundwater samples are listed in the Underground Test Area Quality Assurance Project Plan, Rev. 2 (DOE/NV, 1998).

Table A.1-1
Schedule of Work Performed at ER-EC-6

Activity	Start	Finish
Site mobilization	1/5/2000	1/12/2000
Install access line and testing pump	1/6/2000	1/12/2000
Check pump functionality	1/13/2000	1/14/2000
Lower pump and check pump functionality	1/18/2000	1/18/2000
Develop well and conduct step-drawdown testing	1/19/2000	1/25/2000
Pumping-condition flow logging (impeller flowmeter)	1/25/2000	1/26/2000
Discrete downhole sampling	1/27/2000	1/27/2000
Shut down pump and monitor for recovery and pretest	1/27/2000	2/1/2000
Constant-rate test	2/1/2000	2/11/2000
Groundwater characterization sampling	2/11/2000	2/11/2000
Pump shutdown/monitor recovery	2/11/2000	2/17/2000
Remove test equipment, testing pump, and access line	2/18/2000	3/1/2000
Interval-specific head measurements (bridge plugs)	3/1/2000	3/7/2000
Ambient-condition flow logging (thermal flowmeter)	3/8/2000	3/8/2000
Install long-term bridge plug above lowest interval	3/22/2000	3/22/2000
Install sampling pump	3/23/2000	3/28/2000
Test sampling pump for function	3/28/2000	3/28/2000
Demobilize from site	3/29/2000	3/29/2000

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 are 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's Pump Specifications.
- Attachment 2: Water Quality Monitoring - Grab Sample Results. This appendix 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: Water Quality Analyses - Composite Characterization Sample and Discrete Samples.
- Attachment 4: Fluid Management Plan Waiver for 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).

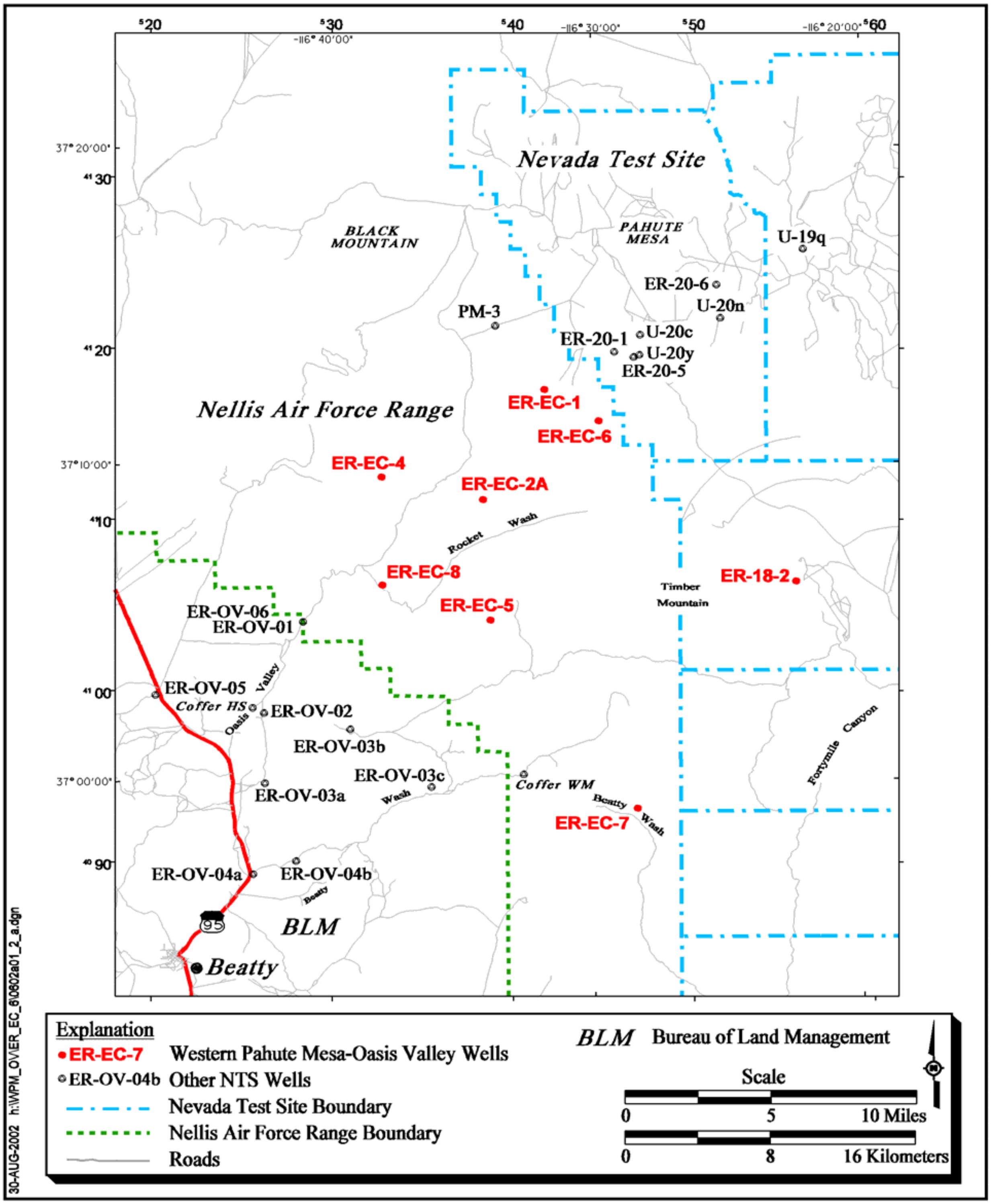


Figure A.1-1
Area Location Map

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-6 development and testing is shown in Table A.2-1.

A.2.1 Water Level Measurement Equipment

Following is a general description of the equipment used by 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, which are vented. The vent line is housed in an integral cable of sufficient length to allow installation of the PXD to its maximum working depth below the water surface. The cable was crossed over to a wireline above the water surface. The PXDs employ a silicon strain gauge element and downhole electronics to process the voltage and temperature measurements. Data is output to a Campbell Scientific CR10X datalogger located on the surface using SDI 12 protocol. The rated accuracy of the PXDs are 0.02 percent full scale (FS). Barometric pressure was measured with a Vaisala Model PTA 427A barometer housed with the datalogger. All equipment was in calibration.

A.2.1.1 Data Presentation

Most of the data were loaded into Excel® spreadsheets for processing and are presented with graphs directly from the spreadsheets. Due to the nature of the data and how the data were recorded in the datalogger program, certain conventions were used in formatting the data. Following are explanations of these conventions to aid in understanding 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.

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

Date	Activities
4/26/1999	ITLV installs 0-15 psig PXD for water level monitoring.
6/15/1999	ITLV removes PXD, completing water level monitoring.
1/5/2000	BN and ITLV mobilize to site. Move Franks 300 on site, begin rigging up. Set up generators.
1/6/2000	Finish setting up rig. Install 2 3/8-in. access line to 1,532 ft bgs. Assemble pump and splice power cable.
1/11/2000	Finish splicing power cable and start pump installation.
1/12/2000	Land pump at 1,521.6 ft bgs; intake at 1,475.4 ft bgs. Rig moved off site. Install 0-15 psig PXD.
1/13/2000	Wire pump power system. Operate pump at 50.8 hz producing 45 gpm, and resulting in approximately 50 ft. of drawdown. Stop and restart pumping to surge well two times, with decreases in drawdown to approximately 45 feet. Drawdown water level is near the pump intake, and drawdown exceeds PXD range.
1/14/2000	Replace PXD with 0-75 psig PXD. Pump well at 50.8 hz and stop repeatedly to surge well.
1/17/2000	Remove PXD and wellhead plumbing in preparation for lowering pump.
1/18/2000	Lower pump and access line 1 joint each; pump intake at 1,506.2 ft bgs. Test pump and pump overnight at 53 hz, 60 gpm.
1/19/2000	Pump at 53 hz, 60 gpm. Shut down for 7.5 hrs. to replace PXD, but problems persist. Measure water levels with e-tape.
1/20/2000	Shut down pump. Install 0-50 psig PXD. Restart pump and test pump performance up to 55.2 hz. Drawdown within limits.
1/20 - 1/25/2000	Pump for development. Surge well by stopping pump. Use step-drawdown protocol to assess well response.
1/25/2000	Remove PXD. DRI begins flow logging during pumping.
1/26/2000	DRI completes flow logging and installs check valve.
1/27/2000	DRI and ITLV collect discrete downhole sample at 1,648 ft bgs, pumping rate 68 gpm. ITLV installs 0-50 psig PXD. Pump shut down for recovery; 771,000 gallons pumped during development.
1/27 - 2/1/2000	Monitor recovery/pretest baseline for constant-rate test.
2/1/2000	Start constant-rate test at 15:45 at 68 gpm.
2/2 - 2/11/2000	Continuous pumping at 68 gpm. Continue monitoring drawdown and water quality.
2/10/2000	Collect groundwater characterization sample at the wellhead.
2/11/2000	Shut down pump at 15:30, ending test.
2/11 - 2/17/2000	Monitor recovery.
2/17/2000	Remove PXD.
2/18/2000	DRI removes check valve.
2/24/2000	BN mobilizes Franks 300 to site; prepare to remove pump string and access line.
2/29/2000	Remove access line and start to remove pump from well.
3/1/2000	Pump removed from well. Basket/gauge run to 4,400 ft bgs. Baker Hughes sets bridge plug/PXD (2,500 psig) at 4,325 ft bgs for discrete-interval measurement.
3/2/2000	Baker Hughes sets bridge plug/PXDs at 3,370 ft bgs and 2,120 ft bgs. ITLV sets 0-15 psig PXD at 1,450 ft bgs.
3/7/2000	ITLV removes PXD. Baker Hughes removes bridge plugs.
3/8/2000	DRI runs ChemTool log and thermal flow logging tool to 4,400 ft bgs.
3/13/2000	BN mobilizes Franks 300 to site.
3/22/2000	Basket/gauge run to 4,400 ft bgs. Baker Hughes sets long-term bridge plug at 4,302.2 ft bgs.
3/23/2000	Assemble and check dedicated sampling pump. Replace faulty motor.
3/27/2000	Begin running in dedicated sampling pump string.
3/28/2000	Land pump and wire pump to power. Conduct functionality test on pump at 13 to 31.5 gpm.
3/29/2000	Demobilization.

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

- 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 data included. However, various interpretations must be made in using these data, which are subject to revision and reinterpretation. Therefore, the raw data are presented in the 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 (pounds per square inch). Atmospheric pressure (i.e., barometric pressure) is reported as mbar (millibars); this is an absolute measurement.

- On graphs showing both PXD data and barometric data, the pressure scales for psi and mbar have been matched to show the changes in pressure proportionately. One psi is approximately equal to 69 mbar. For presentation convenience, the scales are not matched exactly, but are close enough so that the relative magnitude of the pressure changes is apparent. Complete electronic data files are included on an accompanying CD, which allows the user to evaluate details of barometric changes and aquifer response, as desired.

- The data on water density in this report are presented in terms of the conversion factor between the vertical height of water column in feet 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.

- Note that various derived values for parameters presented in this report may differ from values previously reported in Morning Reports. These differences are the result of improved calculations. Changes in measured parameter values are the result of corrections based on checking and confirming values from multiple sources.

- 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-6, the water level in this well was monitored with a PXD and datalogger for a period of approximately two months to establish the equilibrium composite head for this well. Figure A.2-1 shows the results of this monitoring. An electronic copy of this data record can be found on the CD as file ER-EC-6 Water-Level Monitoring.xls.

A.2.3 Depth-to-Water Measurements

A series of depth-to-water measurements were made in Well ER-EC-6 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 nonequilibrium or noncomposite water levels are presented in the appropriate section for the testing activity involved. All of these water level measurements are equilibrium, composite measurements.

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

Date	Time	Depth-to-Water bgs		Barometric Pressure (mbar)
		Feet	Meters	
4/26/1999	11:00	1,425.75	434.57	828
6/15/1999	17:20	1,425.76	434.57	828
1/12/2000	17:25	1,425.89	434.61	831.10
1/18/2000	15:10	1,425.73	434.56	831.28
1/19/2000	14:40	1,425.76	434.57	831.6
1/20/2000	9:20	1,425.79	434.58	--
2/17/2000	12:48	1,425.90	434.61	825.47
3/1/2000	16:48	1,425.95	434.63	829.54

bgs - Below ground surface
mbar - Millibars

A.2.4 Interval-Specific Head Measurements

The representative hydraulic head of the individual completion intervals were measured to provide information on the vertical hydraulic gradients. The equilibrium hydraulic head of the individual completion intervals were 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 in 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 in the uppermost interval was monitored using a PXD installed on a wireline. After removal of the PXD, corresponding water levels were measured with an e-tape. The bridge plugs remained in their downhole stations for five days to monitor pressure changes in the intervals. This activity was conducted after development and the constant-rate 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 4,400 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 interpreting the equilibrated 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 time interval of 5 minutes following an initial 20-minute delay from the start of the datalogger. The datalogger time is in decimal hours. Since there was no data connection to the surface once the bridge plug was set, data could not be read or evaluated until the bridge plug was retrieved. The bridge plug/PXDs were left downhole for five days, a length of time 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.3.0. Note that the corrected depths for the bridge plug are slightly 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 measurements 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), EREC6U.xls (upper-middle interval), EREC6M.xls (lower-middle interval), and EREC6L.xls (lower interval). Attachment 5 contains a description of the data files.

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. The following sections discuss the details of pump installation and performance.

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 (#01F83215 and #01F83216) with 43 stages each, and a 130-horsepower (hp) motor (375 Series) (#21048009 and #21048010). Manufacturer's specifications for this pump are included in Attachment 1. Note that the pump units total 30.0 ft in length with the intake at the bottom of the lower pump unit. A seal section separates the pump units from the motor, which is located at the bottom of the assembly. The pump was installed on 2 7/8-in. Hydril® tubing. A model "R"

Table A.2-3
Interval-Specific Head Measurements

Interval	Comment	Depth (ft bgs)	Depth (m bgs)	PXD Measurement (psig)
Upper	Final Head	1,425.83 (e-tape)	434.59	--
Upper-Middle	Reference Head - composite of upper two intervals	1,425.81 (e-tape)	434.59	295.32
	Bridge Plug set depth minus 50 ft	2,169.10	661.14	273.84
	Bridge Plug set depth - post-set	2,119.13	645.91	295.07
	Bridge Plug set depth plus 50 ft	2,069.06	630.65	316.69
Lower-Middle	Reference Head - composite of upper three intervals	1,425.88 (e-tape)	434.61	834.83
	Bridge Plug set depth minus 50 ft	3,418.89	1,042.08	813.37
	Bridge Plug set depth - post-set	3,368.97	1,026.86	834.09
	Bridge Plug set depth plus 50 ft	3,318.95	1,011.62	856.56
Lower	Reference Head - composite of all three intervals	1,425.95 (e-tape)	434.63	1,238.37
	Bridge Plug set depth minus 50 ft	4,374.00	1,333.20	1,217.20
	Bridge Plug set depth - post-set	4,323.97	1,317.95	1,236.04
	Bridge Plug set depth plus 50 ft	4,274.03	1,302.72	1,259.56

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

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 prior to the constant-rate pumping test to prevent such backflow. 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 transmitter of the Foxboro flowmeter was connected to the VSD 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.

The pump was initially landed with the bottom of the motor at 1,521.55 ft bgs, which placed the pump intake at 1,475.40 ft bgs. The pump was subsequently lowered to 1,552.35, with the intake at 1,506.20 to accommodate the greater than expected drawdown.

A.2.5.2 Pump Performance

Pump performance is indicated by the records as shown in Table A.2-4. These production rates are in line with performance projections supplied by the manufacturer for this pump with similar pumping parameters. However, the pump could not be run at a higher rate than the low end of its operating range because the resultant drawdown would have brought the pumping water level down to the pump intake. After the excessive drawdown was discovered, the pump was lowered as much as possible. However, the well configuration does not allow the pump to be lowered enough, while still providing access past the pump, to accommodate higher production rates.

Table A.2-4
Pump Performance

Date	VSD Setting (hz)	Production Rate (gpm)	Approximate Drawdown (ft)
1/13/2000	50.8	45[a] - 46.2	45[a] - 50[a]
1/14/2000	50.8	45[a]	36[a] - 37[a]
1/18/2000	50.8	45[a]	36[a]
1/18/2000	54.0	72[a]	76[a]
1/18/2000	53.0	60[a] - 64[a]	60[a] - 61.5
1/19/2000	53[a] - 53.1	57.5 - 58.9	55.5 - 55.7
1/20/2000	54.3	66.6 - 67.3	63.8 - 64.4
1/21/2000	54.7	68.7 - 69.3	62.8 - 63.4
1/22/2000	54.7	67.7 - 68.1	62.5 - 63.1
1/24/2000	53.4	60.8	48.0
1/24/2000	54.1	65.0	54.3
1/24/2000	54.6	67.0 - 67.9	58.2 - 58.4
2/1/2000	54.7	68.2 - 68.3	53.4 - 56.1
2/2/2000	55.0 - 55.1	68.4 - 68.6	57.6 - 57.9
2/4/2000	55.4	67.7	58.2 - 58.8

[a] Significant figures reported as recorded

hz - Hertz, cycles per second
gpm - Gallons per minute
ft - Feet

The data in Table A.2-4 shows that there was a reduction in the well drawdown between January 13 and 14, 2000, while the production rate remained constant. No further significant reductions were observed. The data shows that the production rate was very sensitive to the VSD setting. Please note that the performance data in Table A.2-4 (production rate and resultant drawdown for a given VSD setting) are somewhat noisy and inexact. This is probably the result of operating near the lower limits of the operating range for the pump.

A.2.6 Development

There were two objectives for well development, the physical improvement of the condition of the well completion and restoration of the natural water quality. The early development activities were primarily designed to improve the physical condition of the well completion. 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. The development phase of these operations were primarily intended to accomplish hydraulic development in preparation for hydraulic testing.

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 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 issue would be important for the representativeness of 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. Discrete sampling for groundwater characterization was scheduled at the end of the development stage, which provided the maximum development possible before downhole sampling without interfering with the constant rate test. An evaluation of the status of development at the time of sampling is presented in Section A.3.6.

The history of the development phase for Well ER-EC-6 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 hydraulic performance data and 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 drawdown associated with different production rates to evaluate improvement in well efficiency, visual observation of sediment production and turbidity to evaluate removal of sediment, and water quality parameters (temperature, pH, EC, turbidity, DO), and the Br concentration to evaluate restoration of natural water quality. With regard to the Br concentration, the drilling fluid used during drilling was “tagged” with lithium bromide to have an initial concentration from 10 mg/L to over 50 mg/L. 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 of the well to monitor the hydraulic response of the well during pumping. The PXD range must be sufficient to accommodate the change in pressure corresponding to the amount of drawdown produced by pumping at the maximum rate. It is also advantageous to use a PXD with the minimum range necessary to maximize accuracy. As discussed in Section A.2.5.2, the amount of drawdown in Well ER-EC-6 was unexpectedly large and restricted the maximum pumping rate. The 0 to 15 pounds per square inch gauge (psig) PXD initially installed was found to have inadequate range and was replaced with a 0 to 75 psig PXD until the amount of drawdown and pressure surge was determined. A 0 to 50 psig PXD was then installed for the balance of development. Information on the PDX installations prior to January 17, 2000, is available but has not been included. The data records up to this point are not particularly useful for analysis because of the various problems with excessive drawdown relative to the pump depth. Information on the 0 to 50 psig PXD installation and calibration is presented in Table A.2-5. This PXD was used to collect all the data used in analyses.

The method of installing these PXDs does not provide a direct measurement of the total depth of the PXD. The uncertainty in the total measured depth is due to uncertainty in the hanging length of the PXD vent cable, which is difficult to measure accurately. Therefore, the installation depth is calculated from the depth-to-water and calibration measurements made during installation. The pressure reading of the PXD at the installation depth is multiplied by the water density conversion factor to give the depth below the static water level, which is then added to the measured depth-to-water level. The water density conversion factor is determined from the calibration measurements.

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

Design Analysis H-310 PXD SN 2268, 0-50 psig					
Install Date: 1/20/2000					
Installation Calibration Data: 1/20/2000					
Static water level depth 1,425.79 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
PXD depth ft below TOC[a]	1,220	1,245	1,270	1,295	1,320
PXD psig	0.1168	10.797	21.437	32.038	42.67
Delta depth (ft): Cal5 - Cal2					100
Delta psi: Cal5 - Cal2					42.553
Density ft of water column/psi: delta depth / delta psi (in ft/psi)					2.350
Equivalent ft water: PXD psig (at Cal 5) x density of water (ft/psi)					100.27
Calculated PXD installation depth: static water level + equiv. ft water					1,526.06

[a] PXD depth shown does not include the length of the rubber vent hose.

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

The well was pumped for a total time of about six and one-half days prior to flow logging. This period was longer than planned 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 generally not used because the range of pumping rates that could be used was too restrictive to effectively assess well and pump performance. Water quality was monitored using both field laboratory grab sample testing and with an in-line Hydrolab® 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 barometric pressure. An electronic file of these data can be found on the attached CD with the file name EC-6_Aqtest_WD.xls. The first eight days of the data record show the initial testing of the pump to determine the operating range of the pump (see Table A.2-4) and resultant drawdown. Note that the varying equilibrium pressures shown during this time are the result of changing PXD and changing set depths. The pump was lowered during this period. After being lowered, the pump was generally operated at a rate of about 68 gpm for the remainder of the development phase. This production rate was close to the maximum rate that could be used without producing excessive drawdown. Drawdown during pumping was approximately 60 ft. The barometric record shows that the barometric pressure was proportionately constant relative to the PXD pressure. The stress that could be applied to the completions for development was limited by the depth the pump could be lowered, which was restricted by the well configuration. Pumping was periodically stopped to surge the well.

Several factors should be kept in mind when scrutinizing the pumping and drawdown record from the development phase. First, the well was operated without a check valve. Consequently, a water column above the pump was not maintained after the pump was stopped. When the pump was restarted, sufficient water had to be pumped to fill the tubing and surface hose before production would register at the flowmeter. This produces a lag time of approximately 4 minutes between the start of a drawdown response and the start of the flowmeter readings. Also note the brief surge that registered with the flowmeter just after the pump was started. This is probably residual water in a low spot of the surface hose, pushed through the flowmeter by air compressed ahead of the rising water column.

Second, because there was little head on top of the pump at startup, the initial pumping rate was much higher than the rate when the final, stable, total dynamic head (TDH) was reached. The pumping rate decreased as the TDH increased until the discharge system was filled and TDH stabilized. This phenomenon is illustrated in Figure A.2-4. Dividing the volume of the discharge system by the time lag for flowmeter readings to start gives a production rate much greater than the VSD setting would produce under stable pumping conditions. As a result of this situation, the initial drawdown (both the rate of drawdown and the magnitude) was much greater until the stable pumping rate was reached. Since the large amount of drawdown resulted in low head on the pump intake, there may have been some cavitation at the pump intake affecting performance and creating turbulence, which is reflected in noisy data.

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 several times. Since the range of possible pumping rates was severely restricted, the step-drawdown protocol was not used often with this well.

Stopping the pump produced a surging effect in the well which can be seen very clearly in Figure A.2-4. This figure shows a representative instance of surging expanded to illustrate the detail. When the pump is stopped, the water in the production casing backflows through the pump into the well, raising the water level in the well. This is referred to as the “U-tube” effect. The water level in the well casing temporarily rises above the instantaneous head in the formation around the completion because the rate of backflow down the casing is faster than the rate the water is injected into the formation under the instantaneous head differential. This action produces a reverse head differential which “surges” the well. The reverse flow may simply speed the apparent recovery of the well or result in a rise above the equilibrium water level, followed by a decline to the equilibrium head. The surge rapidly dissipates, merging into the recovery curve. This effect was substantial in this well. The "u-tube" effect resulted in a rise in the water level in the well of approximately 40 feet above the equilibrium water level.

With the step-drawdown protocol, the pump was run for a certain period of time at each of three progressively higher rates, 60.8, 65.3 and 67.9 gpm (53.4, 54.3 and 54.7 hz), producing drawdowns from 48 to 58 feet. Drawdowns at the end of each pumping period could then be compared to evaluate the well performance and any improvement in hydraulic efficiency since the last time the protocol was run. However, the pumping rate range was restricted by the maximum drawdown that could be tolerated and the minimum pumping rate for proper motor cooling. Figure A.2-5 shows a representative closeup of the step-drawdown protocol. The lowest and highest steps were also used for flow logging. The performance of this well did not change much during the development phase after the initial improvement the first day.

These starting and stopping effects do not occur during the constant-rate test because a check valve is installed to prevent backflow into the well and maintain the water column in the production tubing. The initial condition upon startup is then a high proportion of the operating TDH.

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. Logbook entries indicated that there was initial reddish-brown turbidity in the water for two minutes or less each time the pump was started, after which the water cleared.

A.2.7 Flow Logging During Pumping

Downhole flow logging was conducted after the development phase. Data on the proportional in-flow of water from different completion intervals would be used for tuning the production rate used for constant-rate test, and later in understanding 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-6 that are completed across a great vertical range 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 (62 and 68 gpm), so that results could be directly compared with previous observations. Only the highest and lowest pumping rates were used because of the limited range between steps.

Flow logging was conducted by the DRI from January 25 to 26, 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. Logging runs at three different speeds and in different directions were run to evaluate methodology.

A.2.7.1.1 Equipment and Calibration

The DRI flow-logging system consists of, from top to bottom (all Flexstak equipment): telemetry cartridge, a centralizer, a temperature tool, another centralizer, and a fullbore flowmeter. All logging tools and the data acquisition system are manufactured by Computalog. 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 needs a minimum of 5 to 15 feet per minute (fpm) to activate the impeller. This minimum flow past the impeller, known as the stall speed, can vary depending upon the condition of the impeller/flowmeter.

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. Centralizers are run in conjunction with the sensor tools to center the tool string in the wellbore. The temperature tool is 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.

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.2.7.1.2 Logging Methodology

Six trolling flow logs were run at three different line speeds from just above the top of the upper screened interval to just below the bottom of the second to lowest screened interval. The runs were typically from 1,580 to 3,850 ft bgs. Logging was not conducted on the lower screened interval because an interior screen prevented logging tools from entering this area. The logging runs were made in the following order: (1) stationary measurements made going down, (2) an up run at 20 fpm, (3) a down run at 40 fpm, and (4) an up run at 60 fpm. This four-step set of logs was run at two different discharge rates, 62 and 68 gpm. In addition to the moving logs, stationary flow measurements (tool held motionless in the well) were taken above the upper screened interval (1,609 ft bgs) and between screened intervals (2,032 and 2,972 ft bgs). Table A.2-6 lists the trolling flow logs that were run. Stationary measurements are listed in Table A.2-7. The data files for these flow logs are included with the electronic data files on the attached CD.

Table A.2-6
Listing of Trolling Flow Logs

Run Number	Date of Run	Direction of Run	Run Speed	Surface Discharge	Run Start/Finish
			fpm	gpm	ft bgs
ec6mov1	1/25/2000	Up	20	68	3,852 - 1,582
ec6mov2	1/25/2000	Down	40	68	1,575 - 3,851
ec6mov3	1/25/2000	Up	60	68	3,902 - 1,579
ec6mov4	1/26/2000	Up	20	62	3,851 - 1,581
ec6mov5	1/26/2000	Down	40	62	1,580 - 3,850
ec6mov6	1/26/2000	Up	60	62	1,580 - 3,856

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

Table A.2-7
Listing of Stationary Flow Measurements

Log Run	Location	Pumping Rate (gpm)	Depth (ft bgs)	Average (gpm)
erec6stat1	above upper completion interval	68	1,607	68.4
erec6stat2	above upper-middle completion interval		2,032	.00
erec6stat3	above lower-middle completion interval		2,972	0.0
erec6stat4	above upper completion interval	62	1,607	62.9
erec6stat5	above upper-middle completion interval		2,032	0.0
erec6stat6	above lower-middle completion interval		2,972	0.0

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

A.2.7.2 Flow Logging Results

The results of the trolling flow logs are presented in Figures A.2-6 through A.2-9. 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 62 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 68 gpm. The optimal logging speed/direction was upwards at 20 fpm, producing the least amount of noise. This configuration seemed to provide the most sensitivity with the least induced disturbance. The logs run at a production rate of 62 gpm are significantly less noisy than at 68 gpm. The two logs that were run at the trolling rate of 60 fpm are not shown, being considerably noisier due to linespeed variability and not revealing any new information.

The flow logs indicate that all of the production in the well was derived from the upper completion interval (1,630 to 1,870 ft bgs). The temperature log shows steps that mirror the steps in the flow log results in the upper completion interval. Beyond the upper completion interval, the temperature gradually increases with depth. The details in the flow and temperature logs in the area of the upper completion interval can be found in Section A.3.0 in Figure A.3-1 and Figure A.3-2.

There were no results from the stationary flow measurements, that is, the flow was measured as zero between the completion intervals. The low-end sensitivity of the impeller flow logging tool is 5 fpm; consequently, flow rates below that rate (approximately equivalent to 5 gpm) would not be measured by this tool. The trolling flow logs indicate that flow from the lower completion intervals uphole did not exceed that threshold.

A.2.8 Constant-Rate Test

A constant-rate pumping test was conducted following well development to collect hydraulic response data for determination of aquifer parameters. 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 February 1, 2000, and continued for 10 days until February 11, 2000. The test was terminated to coordinate with BN work schedules. 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 six days until February 17, 2000.

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 68 gpm was chosen for the test. This rate was estimated to be near the maximum rate the well was able to sustain without excessive drawdown. Based on experience during the early part of development, a PXD with a range of 0 to 50 psig was installed after flow logging for the pretest monitoring and constant-rate test. The 0 to 50 psig range provided an appropriate range of measurement for the maximum anticipated drawdown. Use of the lowest possible range maximizes the accuracy of the pressure measurements, which are proportional to the overall measurement range of the PXD.

The PXD was installed on January 27, 2000, at a calculated depth of 1,529.29 ft bgs based on the calibration performed when the PXD was removed on February 17, 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.2-8 shows the calibration and PXD installation data for the constant-rate test.

Table A.2-8
PXD Installation for Constant-Rate Test

Design Analysis H-310 PXD SN 2268, 0-50 psig					
Install Date: 1/27/2000					
Removal Calibration Data: 2/17/2000					
Static Water level depth 1,425.90 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
PXD depth ft below TOC[a]	1,220	1,245	1,270	1,295	1,320
PXD psig	1.4448	12.01	22.494	32.965	44.002
Delta depth (ft): Cal5 - Cal2					100
Delta psi: Cal5 - Cal2					42.557
Density ft of water column/psi: delta depth / delta psi (in ft/psi)					2.350
Equivalent ft water: PXD psig (at Cal5) x density of water (ft/psi)					103.39
Calculated PXD installation depth: static water level + equiv. ft water					1,529.29

[a] PXD depth shown does not include the length of the rubber vent hose.

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

A.2.8.2 Hydraulic Data Collection

Figure A.2-10 shows the datalogger record for the constant-rate test pumping period in terms of the pumping rate and the hydraulic response to pumping. Figure A.2-11 shows the head record for both the pumping period and the recovery period as well as the barometric pressure record. These graphs illustrate the datasets and major features of the respective activities. Note that these graphs were made with only half the data (every other data point) due to limitations for data handling in the graphing program. Pumping started on February 1, 2000 (32.65626 Julian days), and was terminated on February 11, 2000 (42.64602 Julian days). The average pumping rate was 68.4 gpm. The data file is EC-6_Aqtest_HT.xls on the accompanying CD. The data records are very clean with only a small amount of noise in the drawdown PXD record. Note that the barometric record has been scaled proportionate to the PXD record so that fluctuations are consistent. The barometric record shows that the barometric pressure was proportionately constant relative to the PXD pressure changes.

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 Br^- ion concentration, pH, EC, turbidity and DO were expected to decline as development progressed indicating natural groundwater quality as opposed to water affected by drilling and completion activities. Also, parameter values should stabilize after prolonged pumping and development as natural groundwater permeates the well environment. Rebound of parameter values at the beginning of each cycle of pumping was expected to decline toward the values observed toward the end of the previous cycle as development progressed.

The standard parameters that were monitored during development and testing of Well ER-EC-6 include the following: pH, EC, temperature, turbidity, DO and Br^- 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 19, 2000, at 19:03 for well development. In-line monitoring began at 19:40 with 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 initiated on January 14, 2000, at 10:45, as the field laboratory was fully operational during functionality testing of the pump.

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 19 and ending on January 27, 2000, at 20:15 after the discrete bailer sample was collected. For the constant-rate pumping test, one grab sample was obtained daily beginning on February 2 and ending on February 11, 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 and Section A.4.0. The results have been related to the pumping rate, the total discharge, and the phase of development or testing. Additionally, two graphs have been made showing water quality parameters versus total discharge in gallons. Figure A.2-12 shows EC, pH, and DO. Figure A.2-13 shows turbidity and Br concentration. The temperature remained fairly constant varying only a few degrees between 36.4 and 38.3°C, and the results are not depicted. Temperature differences can often fluctuate depending on ambient air temperature and how soon the temperature of the wellhead sample is measured after sample collection. Figure A.2-12 shows that pH and EC remained fairly constant throughout the monitoring, with EC between 600 and 640 and pH between 8.0 and 8.6. The EC/DO peaks coincided with the resurgence of pumping after a period when the pump was shut down.

In Figure A.2-13, turbidity mostly stayed below 0.5 nephelometric turbidity units (NTUs) with occasional peaks up to 10.0 NTUs. The bromide concentration generally fluctuated between 0.6 and 1.1 mg/L with occasional peaks as high as 1.34 mg/L. The Br peaks appeared to coincide with the EC/DO peaks. There were no long-term trends in any of the parameters which indicate any continuing progress in development. The bromide concentrations in the produced water suggest persistence of drilling fluids in the formation at a low level. 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. The parameters temperature, EC, pH, turbidity, and DO were recorded continuously when the pump was running between January 19 at 19:40, and January 25, 2000, at 08:52. 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 1 to 3 gpm away from the flowmeter which could cause unsteadiness in the flow rate.

The Hydrolab® in-line data correlated with the grab sample data reasonably well on temperature, pH and EC. Temperature was about 1°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. The EC was consistently 40 to 60 micromhos per centimeter (μmhos/cm) lower on the Hydrolab® data, while pH data correlated very closely. Turbidity and dissolved oxygen data from the Hydrolab® were recorded incorrectly. This was discovered on January 23 while trying to resolve the differences between the grab sample data and the Hydrolab® data. The datalogger was misrecording the data from the Hydrolab® through an error in programing, resulting in loss of DO and turbidity data. The in-line data have been saved and are contained in the Excel® file EC-6_AQTEST.XLS on the accompanying 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 water samples were collected for characterization of the groundwater in Well ER-EC-6: 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 27, 2000, one discrete sample was obtained from a depth of 1,648 ft bgs at a pumping rate of approximately 68.5 gpm. The sample was obtained using a DRI 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 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 27, 2000, discrete sample have been tabulated and are presented in Attachment 3. These results are very similar for most of the parameters compared to the results of the discrete groundwater characterization sample taken during drilling (before the well was completed). That sample was obtained from 1,750 ft bgs.

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 this sample is meant to represent a composite of the whole well, there are two criteria for the sample to be the most representative: (1) the sample should be obtained after pumping for the longest possible time, and (2) the pumping rate should be as great as possible in order for the component water production to include as many completion intervals as possible. The results of the flow logging indicate the proportional composition of the composite sample. As discussed in Section A.2.7.2, the flow logging showed that 100 percent of the inflow to the well apparently occurred in the upper screened interval between 1,628.4 and 1,870.5 ft bgs at the highest production rate.

On February 10, 2000, beginning at 09:00, a composite characterization sample was collected from the wellhead sampling port directly into sample bottles. A field duplicate sample was obtained concurrently. A constant production rate of 68.4 gpm was maintained during the sampling event, the same rate used during the constant-rate test. At the time of sampling, approximately 1,650,000 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. Samples were immediately put on ice and transported to secure, refrigerated storage. Sample bottles were collected for the following laboratories: Paragon, LANL, LLNL, and DRI.

The final, validated results of the February 10, 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 27, 2000, discrete sample.

A.2.11 Thermal Flow Log and ChemTool Log

Thermal flow logging was conducted at the very end of the development and testing program to determine flow in the well under ambient, static conditions. The resulting flow information may differ from that of the thermal flow logging conducted in the open borehole before well completion because it is specific to the completion intervals, and reflects remediation of conditions imposed by drilling. The ChemTool provides a depth log of temperature, pH, and EC. The thermal flow and ChemTool logging was 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

The results of the ChemTool logging are presented in Figure A.2-14. The ChemTool log shows relatively constant EC from above the upper completion down to about 3,000 ft bgs above the lower-middle completion interval. The pH readings were erratic through the upper completion interval, and also high relative to measurements of produced water. Both EC and pH decline with depth below the upper-middle completion interval. The temperature log is relatively clean, and shows a slightly increasing gradient with no particular deflections. The thermal flow logging results are shown in Table A.2-9. Flow of less than 1 gpm downwards was measured at all stations (1,661; 1,900; 2,011; 2,551; and 3,820 ft bgs).

Table A.2-9
Thermal Flow Log Results

Depth (ft)	Flowmeter (gpm)	+/- gpm
1,661	-0.580	0.067
1,900	-0.162	0.061
2,011	-0.197	0.001
2,551	-0.211	0.071
3,820	0.000	0.000

gpm - Gallons per minute

A.2.12 Sampling Pump and Bridge Plug Installation

A bridge plug was installed inside the 5.5-in. casing by Baker-Hughes on March 22, 2000, to isolate the lower completion interval from the upper completion intervals. The bridge plug was set at 4,302.2 ft bgs in a section of the well above the lower completion interval with cement in the annulus.

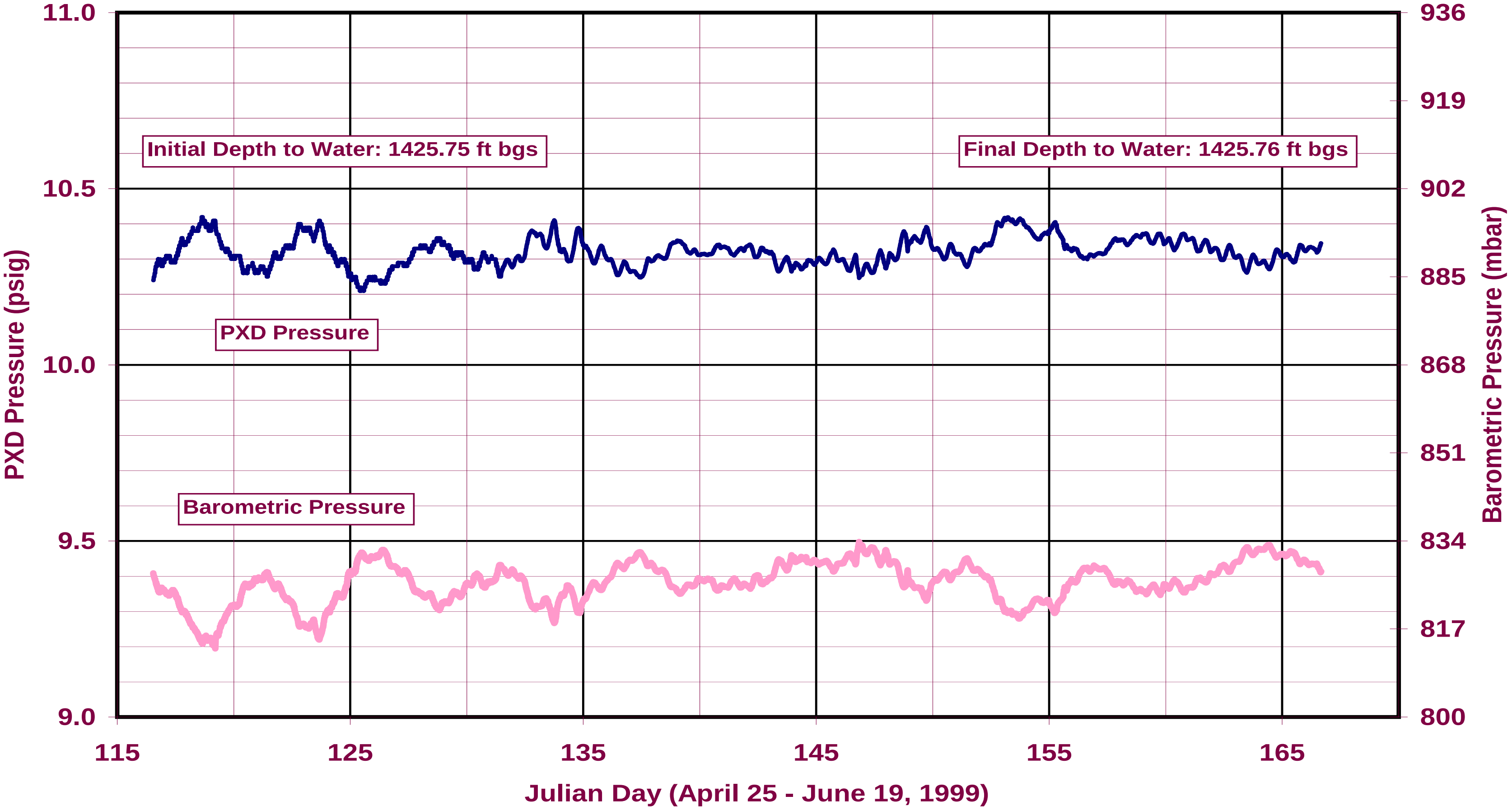
On March 28, 2000, a sampling pump was installed in Well ER-EC-6 by Bechtel Nevada (BN) with the assistance of the electrical submersible pump (ESP)

Systems representative. Specifications for this pump can be found 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 1,619.3 ft bgs. A 2.58-ft stickup makes the entire string a length of 1,622.2 ft. The pump intake is located at 1,595.6 ft bgs and the top of the pump assembly is at 1,586.7 ft bgs. The total length of the pump assembly is 32.58 ft. Table A.2-10 summarizes the details of the pump assembly components. Figure A.2-15 shows details of the final wellhead configuration.

Table A.2-10
Dedicated Sampling Pump

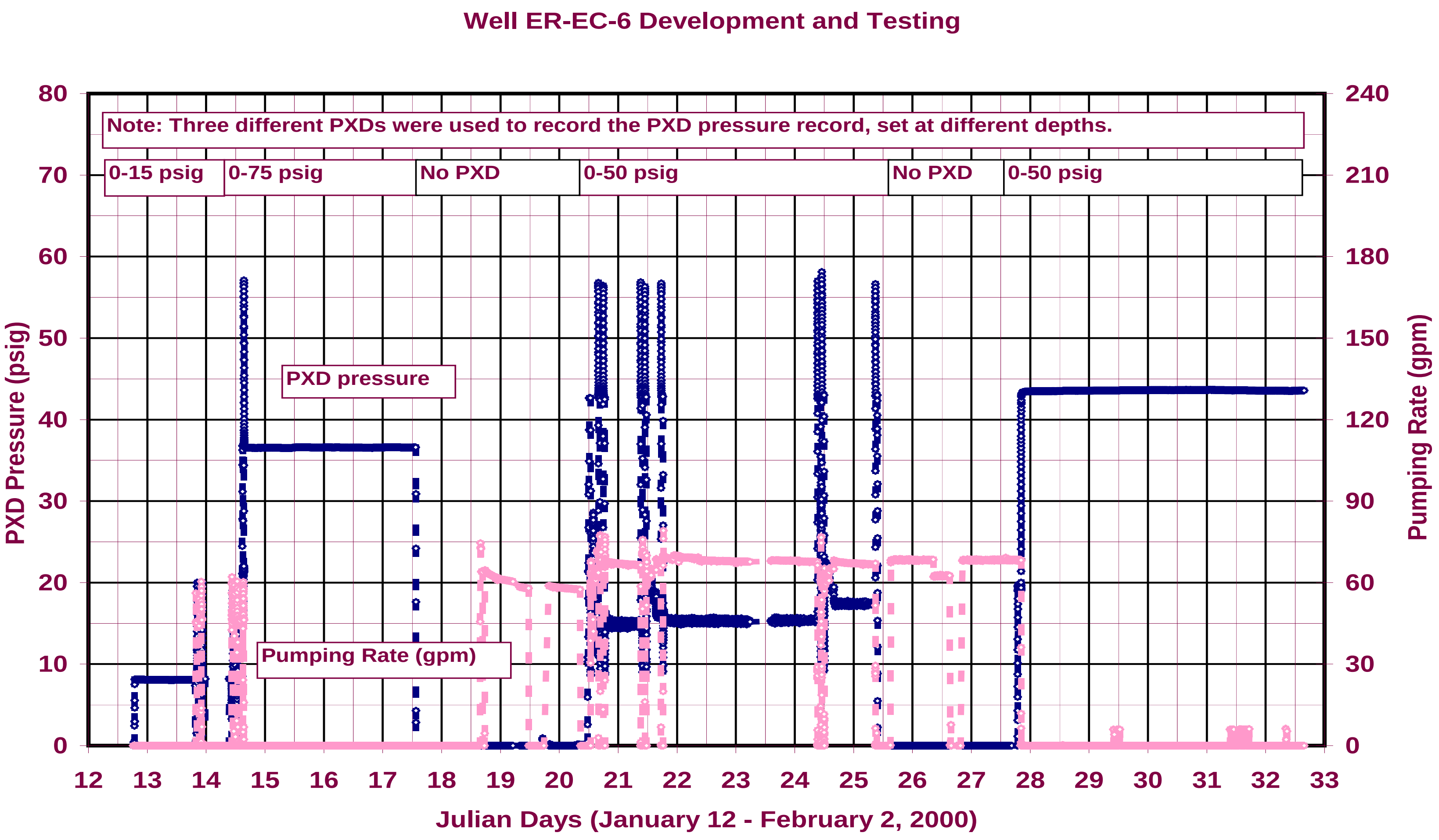
Pump Component	Type/Model	Serial Number	Other Information
ESP Pump	TD 800	2D8I15038	Stage 87
ESP Protector	TR3-STD	3B8I07989	- - -
ESP Motor	TR3-UT/17 THD	3B8I06463	40 hp, 740 V, 40 A

The pump string was landed to a 1-in. landing plate at the wellhead. Figure A.2-15 shows the final wellhead diagram. A VSD was wired to the pump. On March 28, 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 14:56, the pump was started and discharge occurred at the surface approximately 7 minutes later. The pump was run for about 35 minutes at discharge rates of between 13 gpm (46 hertz [hz] and 22 amps) and 31.5 gpm (64 hz and 41 amps). Approximately 1,000 gals were pumped during the functionality test. No problems were encountered.



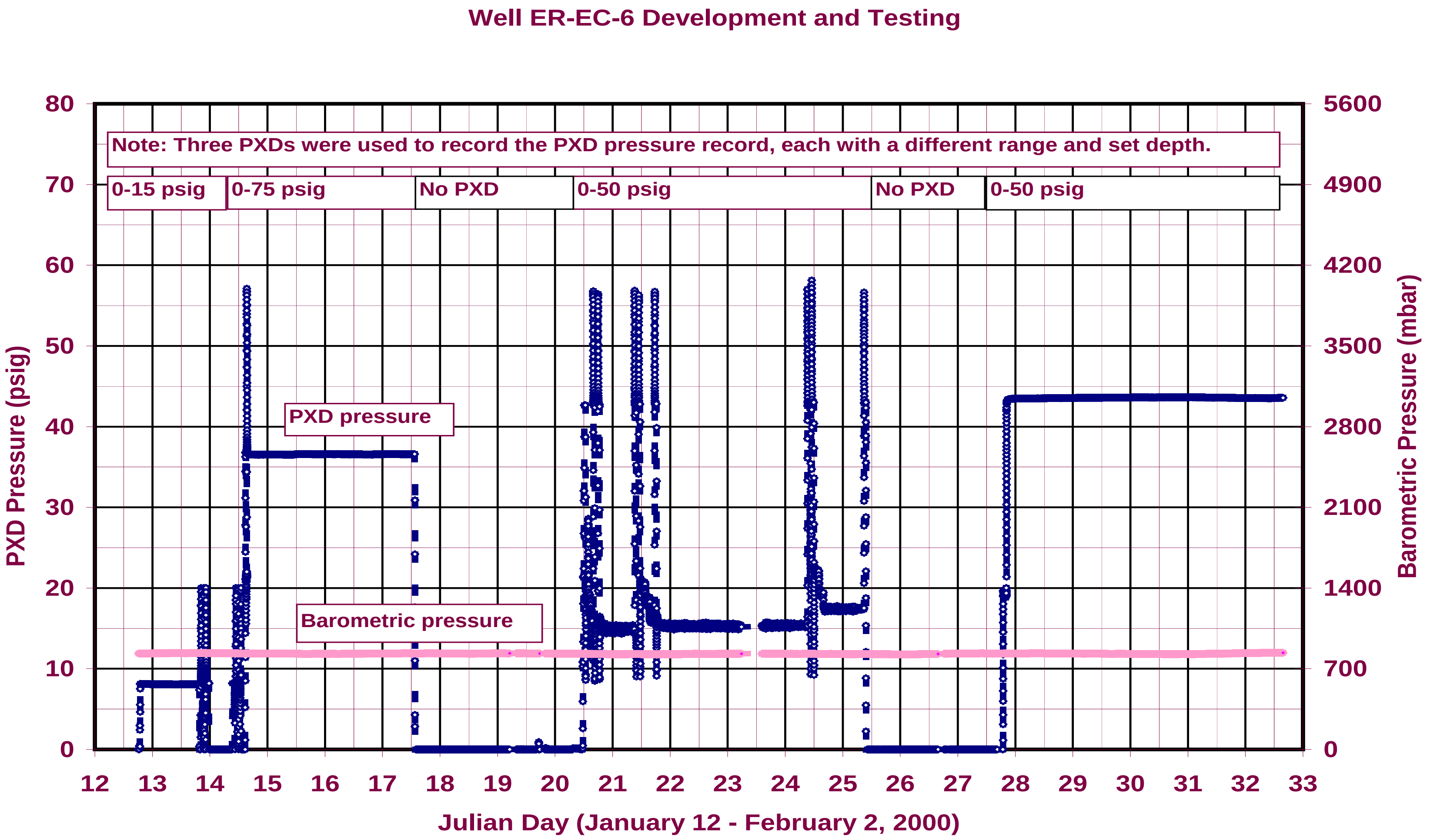
psig - Pounds per square inch gauge
mbar - Millibars
PXD - Pressure transducer
ft bgs - Feet below ground surface

Figure A.2-1
Predevelopment Water Level Monitoring



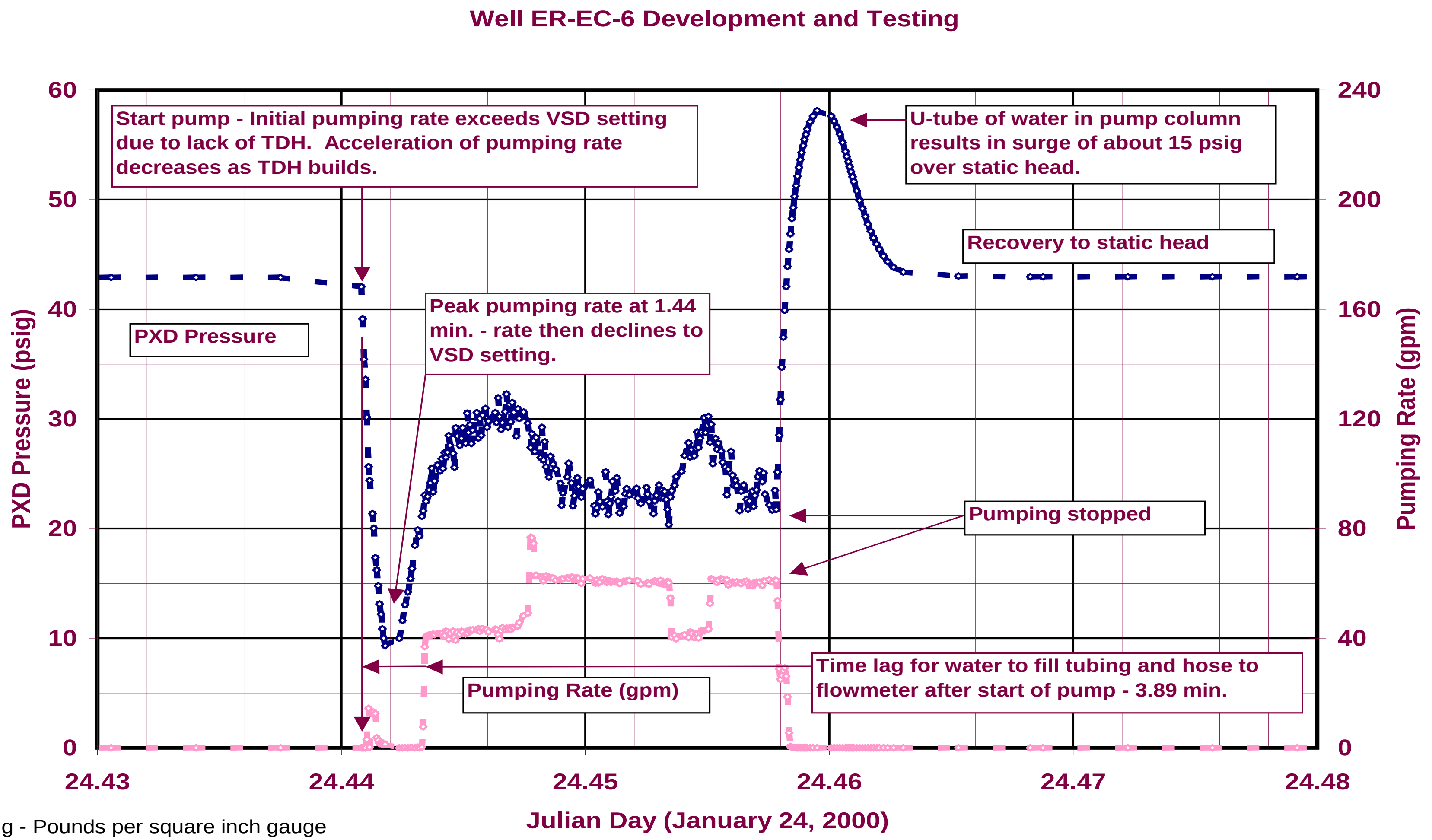
psi - Pounds per square inch
psig - Pounds per square inch gauge
PXD - Pressure transducer
gpm - Gallons per minute

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



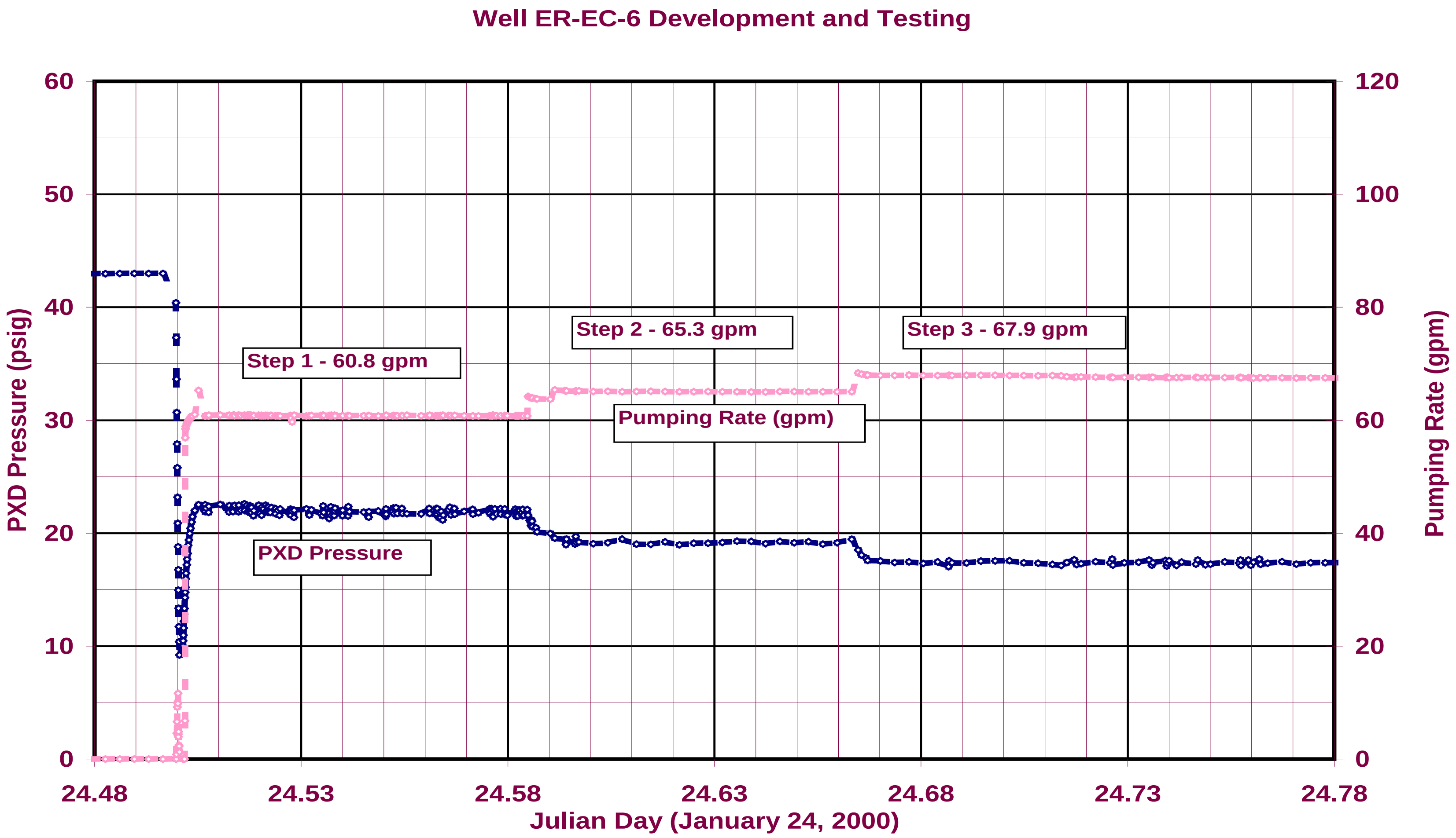
psi - Pounds per square inch
psig - Pounds per square inch gauge
PXD - Pressure Transducer
mbar - Millibars

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



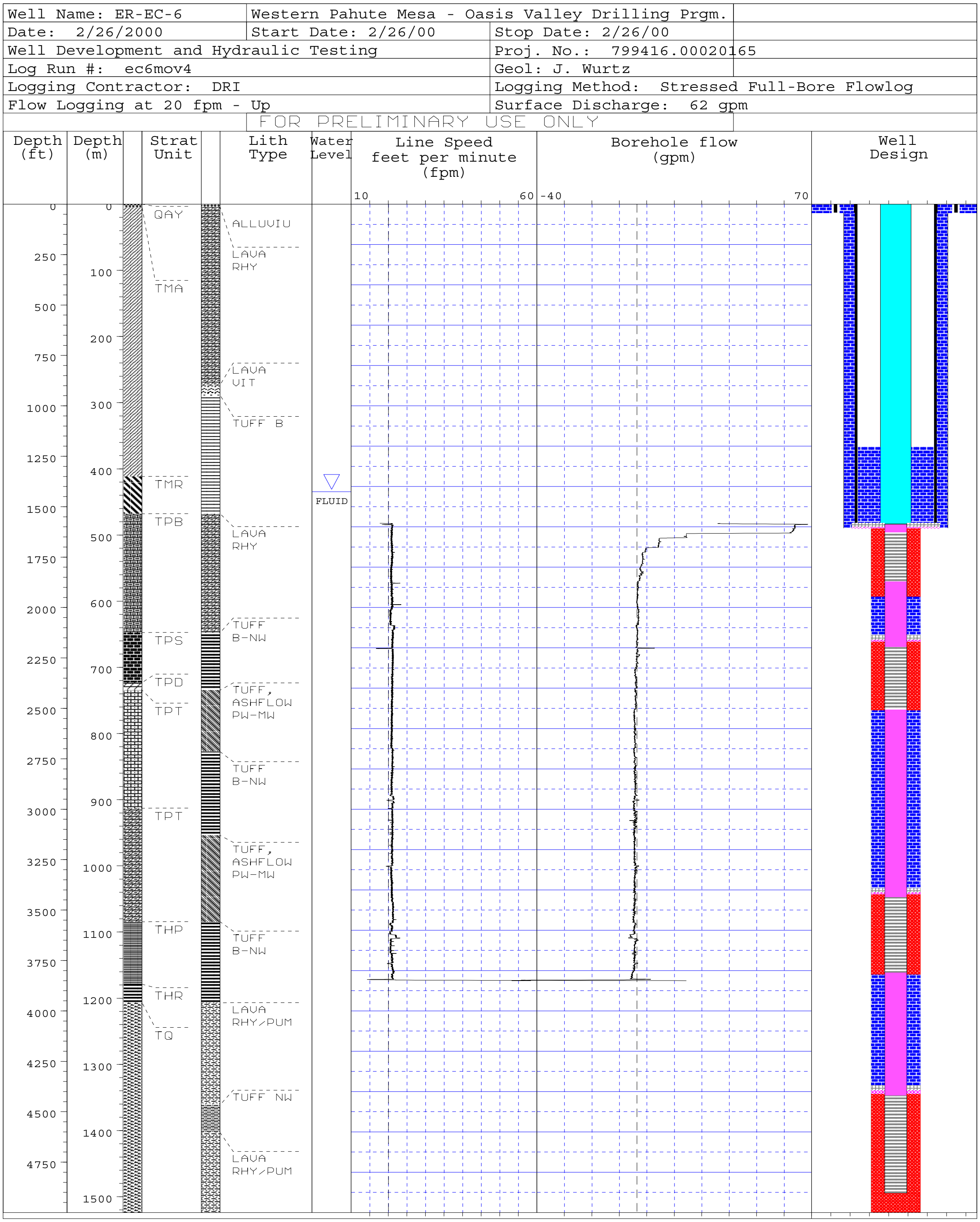
psig - Pounds per square inch gauge
PXD - Pressure transducer
gpm - Gallons per minute
VSD - Variable speed drive
TDH - Total dynamic head

Figure A.2-4
Detail of Startup Effects and Surging Action



psig - Pounds per square inch gauge
PXD - Pressure transducer
gpm - Gallons per minute

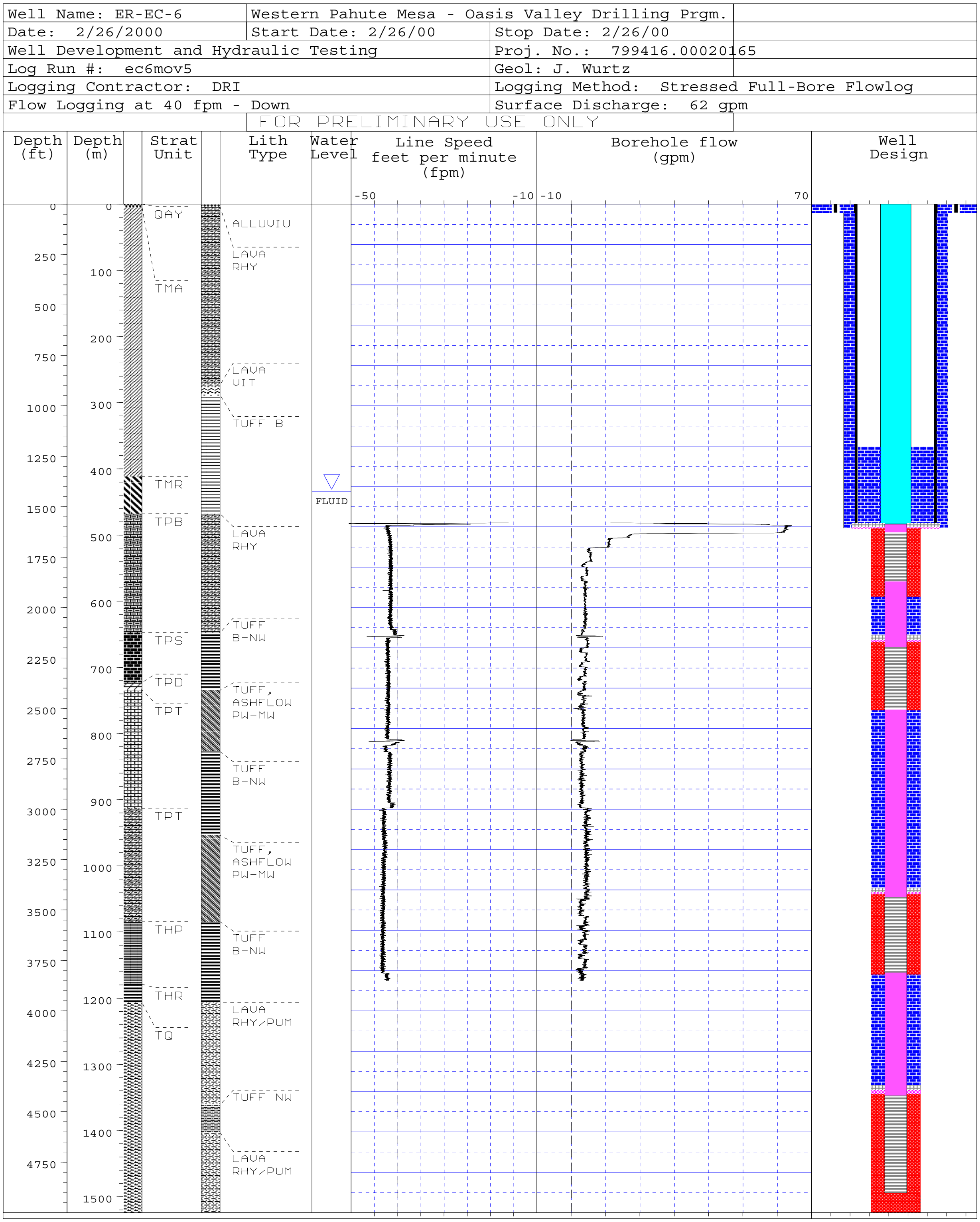
Figure A.2-5
Detail of Step-Drawdown Development



Well Name: ER-EC-6	Western Pahute Mesa - Oasis Valley Drilling Prgm.	
Date: 2/26/2000	Start Date: 2/26/00	Stop Date: 2/26/00
Well Development and Hydraulic Testing		Proj. No.: 799416.00020165
Log Run #: ec6mov4		Geol: J. Wurtz
Logging Contractor: DRI		Logging Method: Stressed Full-Bore Flowlog
Flow Logging at 20 fpm - Up		Surface Discharge: 62 gpm

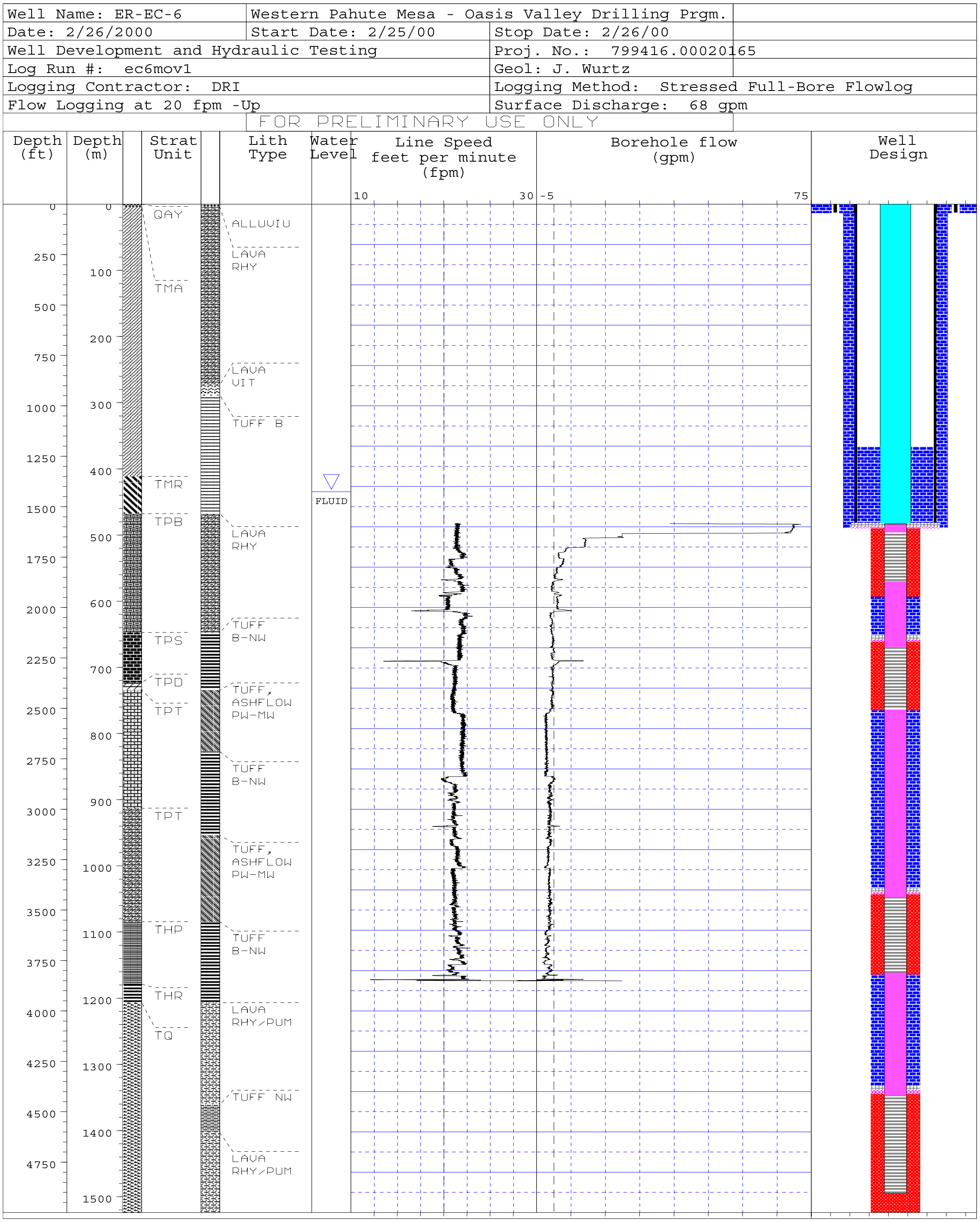
FOR PRELIMINARY USE ONLY

Figure A.2-6
Flow Log at 62 gpm Production Rate and 20 fpm Upward Trolling Rate



Well Name: ER-EC-6
Western Pahute Mesa - Oasis Valley Drilling Prgm.
Date: 2/26/2000
Start Date: 2/26/00
Stop Date: 2/26/00
Well Development and Hydraulic Testing
Proj. No.: 799416.00020165
Log Run #: ec6mov5
Geol: J. Wurtz
Logging Contractor: DRI
Logging Method: Stressed Full-Bore Flowlog
Flow Logging at 40 fpm - Down
Surface Discharge: 62 gpm
FOR PRELIMINARY USE ONLY

Figure A.2-7
Flow Log at 62 gpm Production Rate and 40 fpm Downward Trolling Rate



Well Name: ER-EC-6
Western Pahute Mesa - Oasis Valley Drilling Prgm.
Date: 2/26/2000
Start Date: 2/25/00
Stop Date: 2/26/00
Well Development and Hydraulic Testing
Proj. No.: 799416.00020165
Log Run #: ec6mov1
Geol: J. Wurtz
Logging Contractor: DRI
Logging Method: Stressed Full-Bore Flowlog
Flow Logging at 20 fpm -Up
Surface Discharge: 68 gpm
FOR PRELIMINARY USE ONLY

Figure A.2-8
Flow Log at 68 gpm Production Rate and 20 fpm Upward Trolling Rate

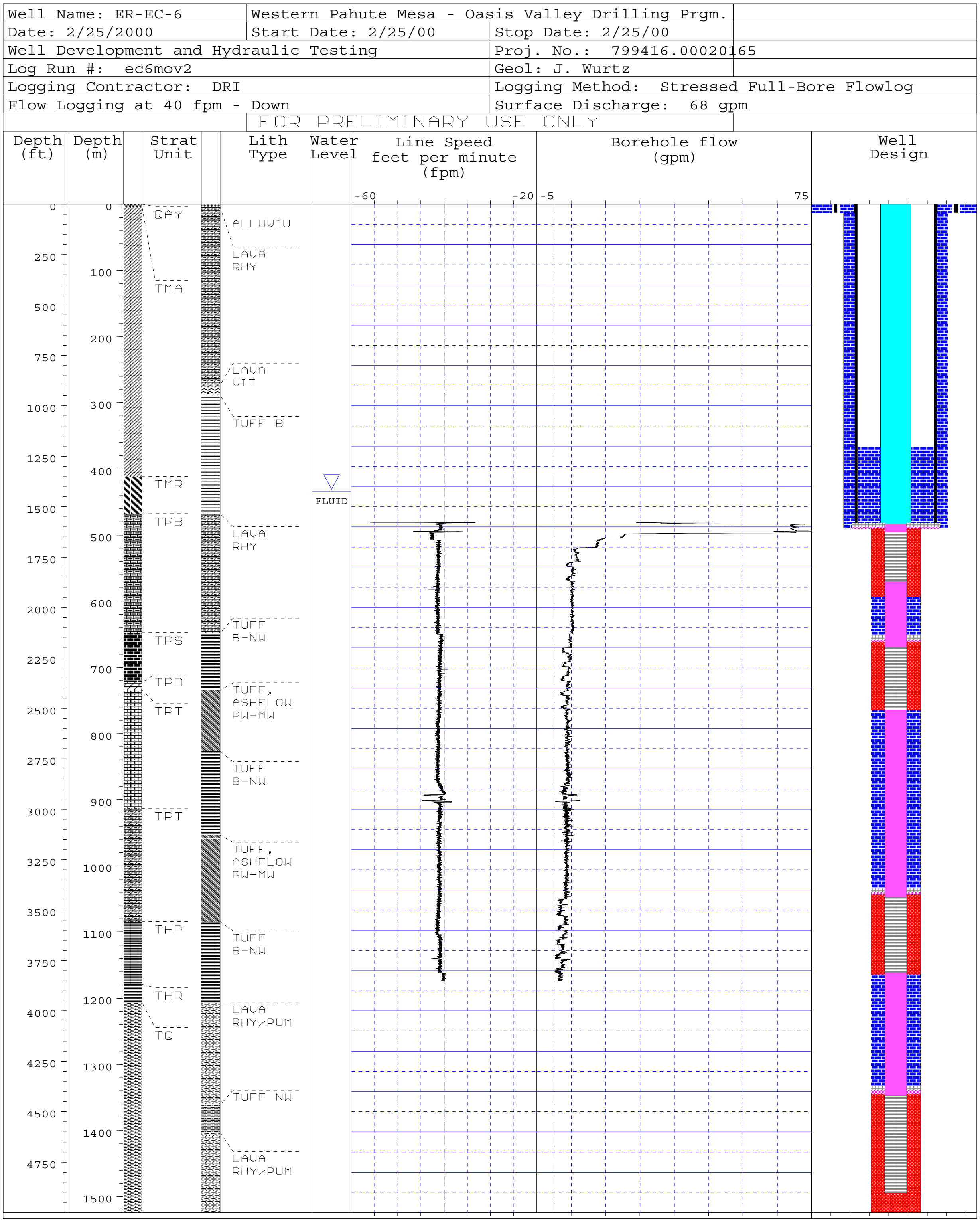
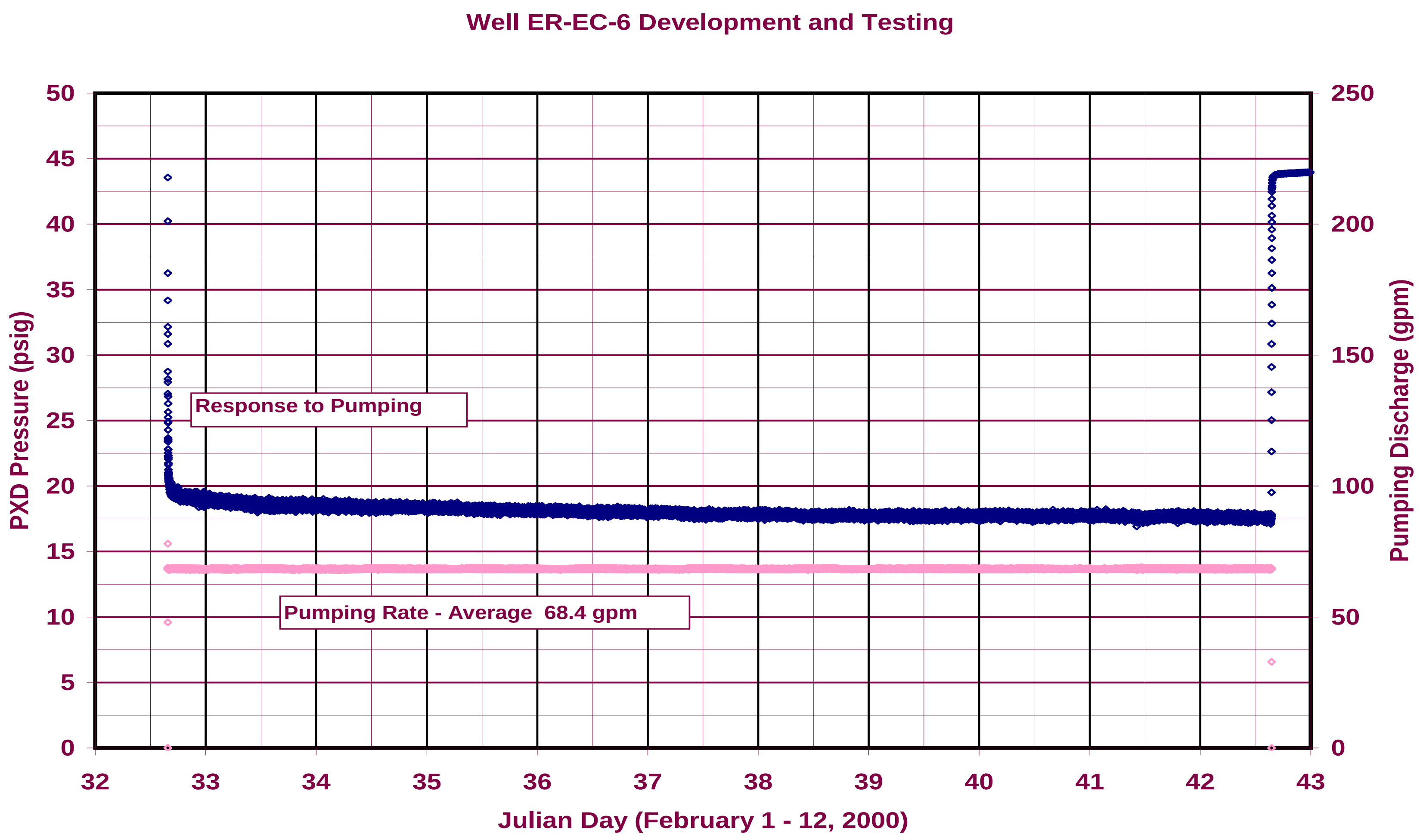
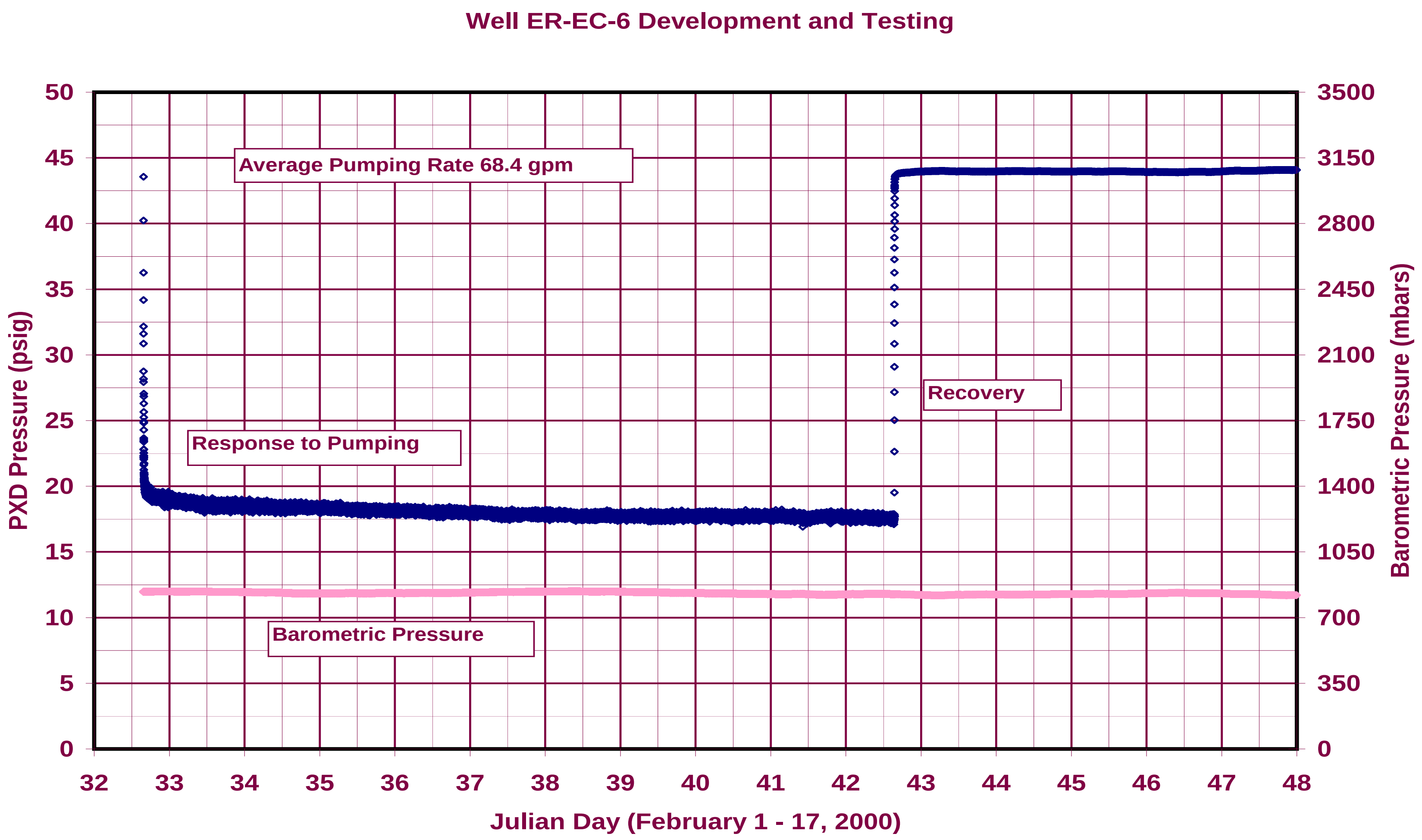


Figure A.2-9
Flow Log at 68 gpm Production Rate and 40 fpm Downward Trolling Rate



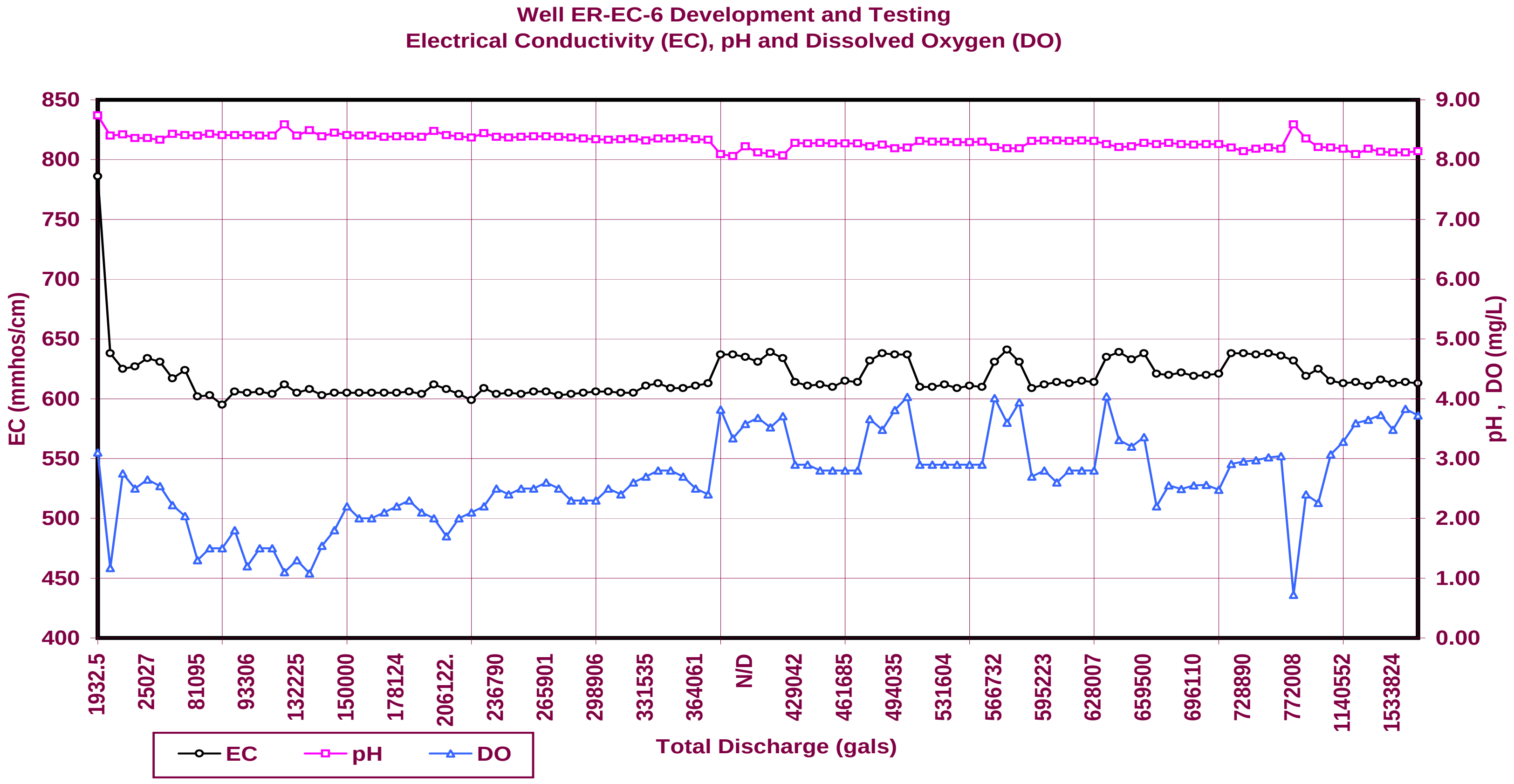
psig - Pounds per square inch gauge
PXD - Pressure transducer
gpm - Gallons per minute

Figure A.2-10
Pumping Rate and Hydraulic Response During Constant-Rate Test



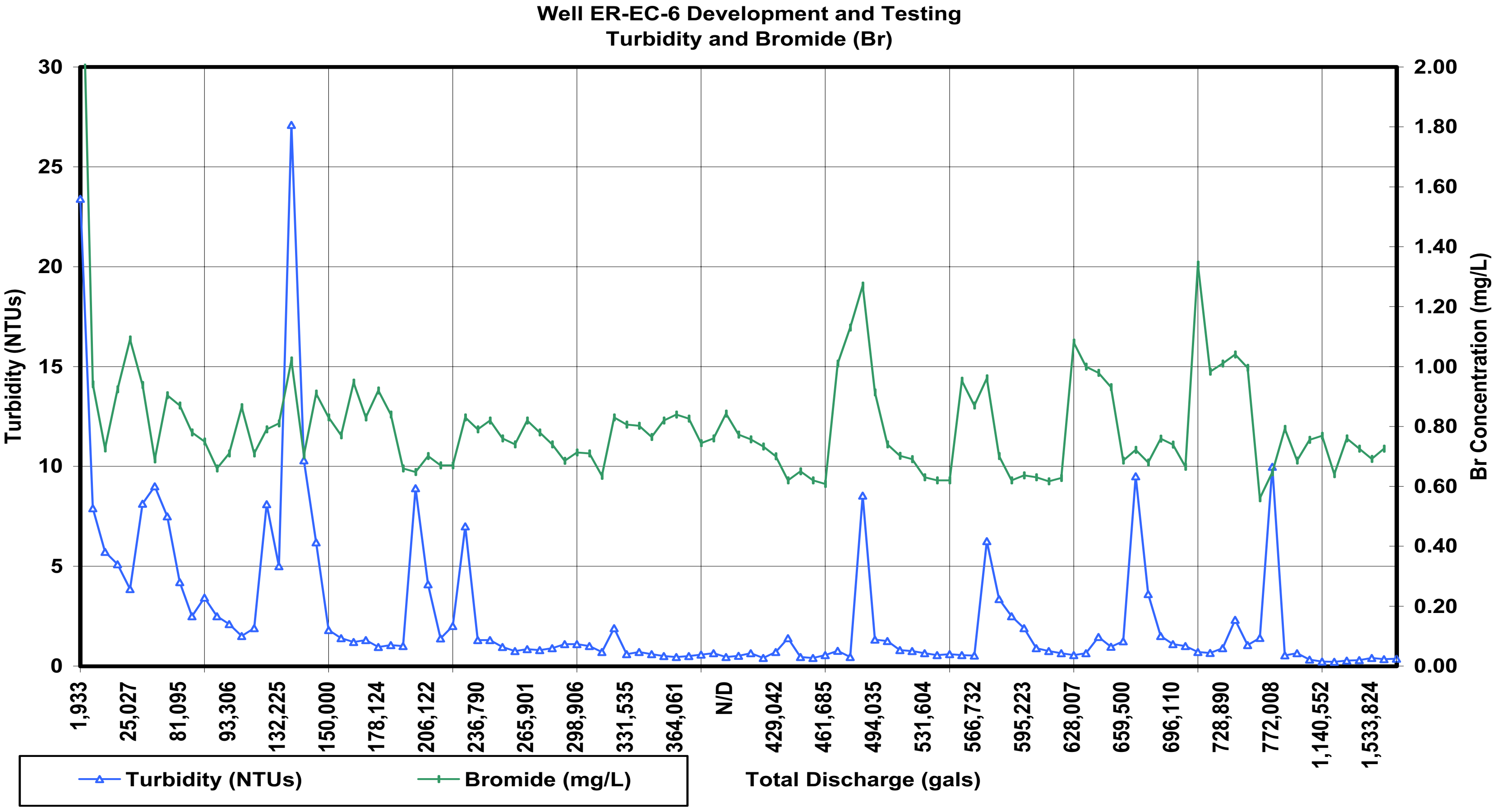
psig - Pounds per square inch gauge
mbars - millibars
PXD - Pressure Transducer
gpm - Gallons per minute

Figure A.2-11
Hydraulic Response and Barometric Pressure During Constant-Rate Test



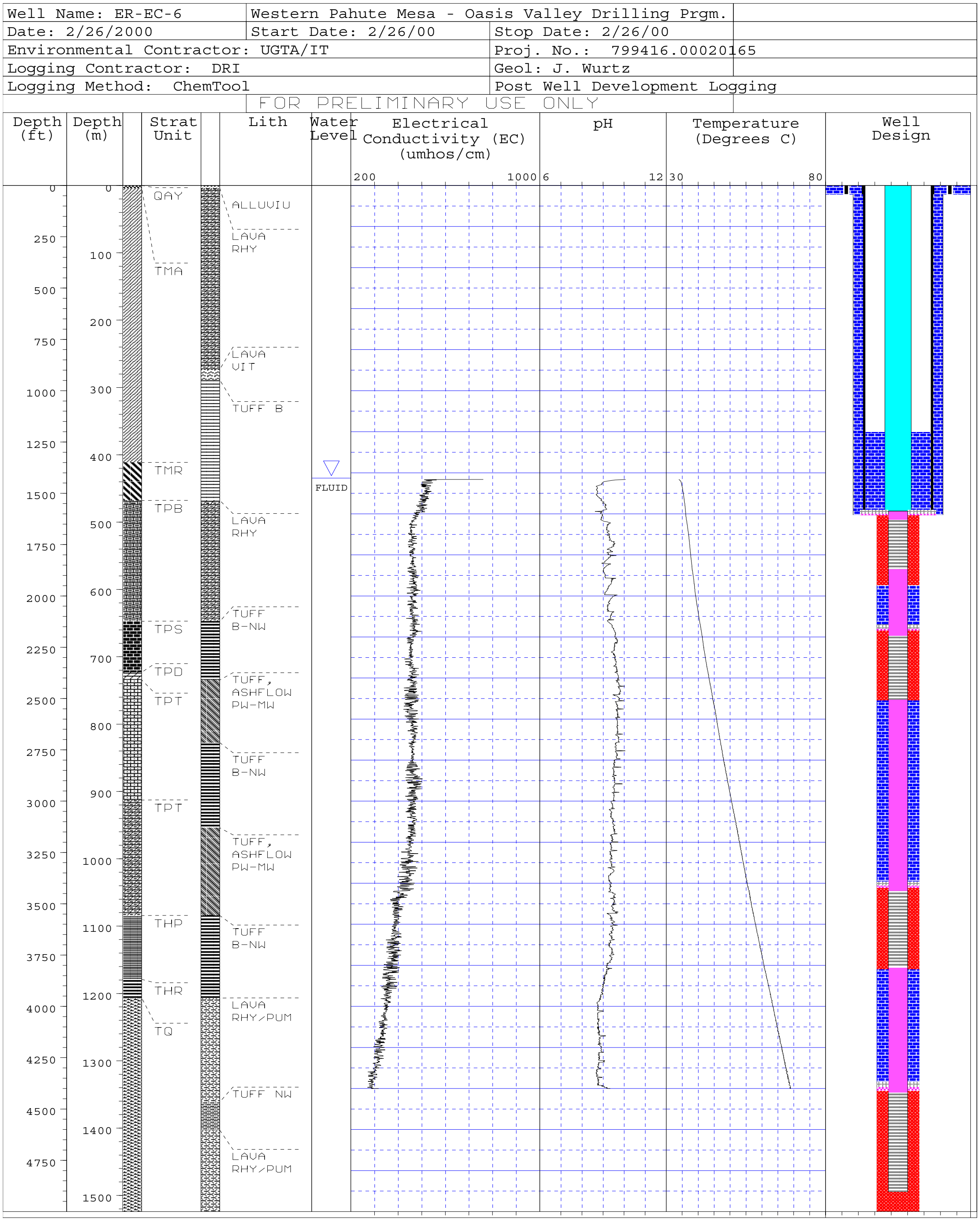
µmhos/cm - Micromhos per centimeter
mg/L - Milligrams per Liter
gals - Gallons
N/D - No Data

Figure A.2-12
Grab Sample Monitoring for EC, pH, and DO



NTUs - Nephelometric Turbidity Units
mg/L - Milligrams per Liter
gals - Gallons
N/D - No data

Figure A.2-13
Grab Sample Monitoring for Bromide and Turbidity



Well Name: ER-EC-6	Western Pahute Mesa - Oasis Valley Drilling Prgm.	
Date: 2/26/2000	Start Date: 2/26/00	Stop Date: 2/26/00
Environmental Contractor: UGTA/IT		Proj. No.: 799416.00020165
Logging Contractor: DRI		Geol: J. Wurtz
Logging Method: ChemTool		Post Well Development Logging

FOR PRELIMINARY USE ONLY

Figure A.2-14
ChemTool Log

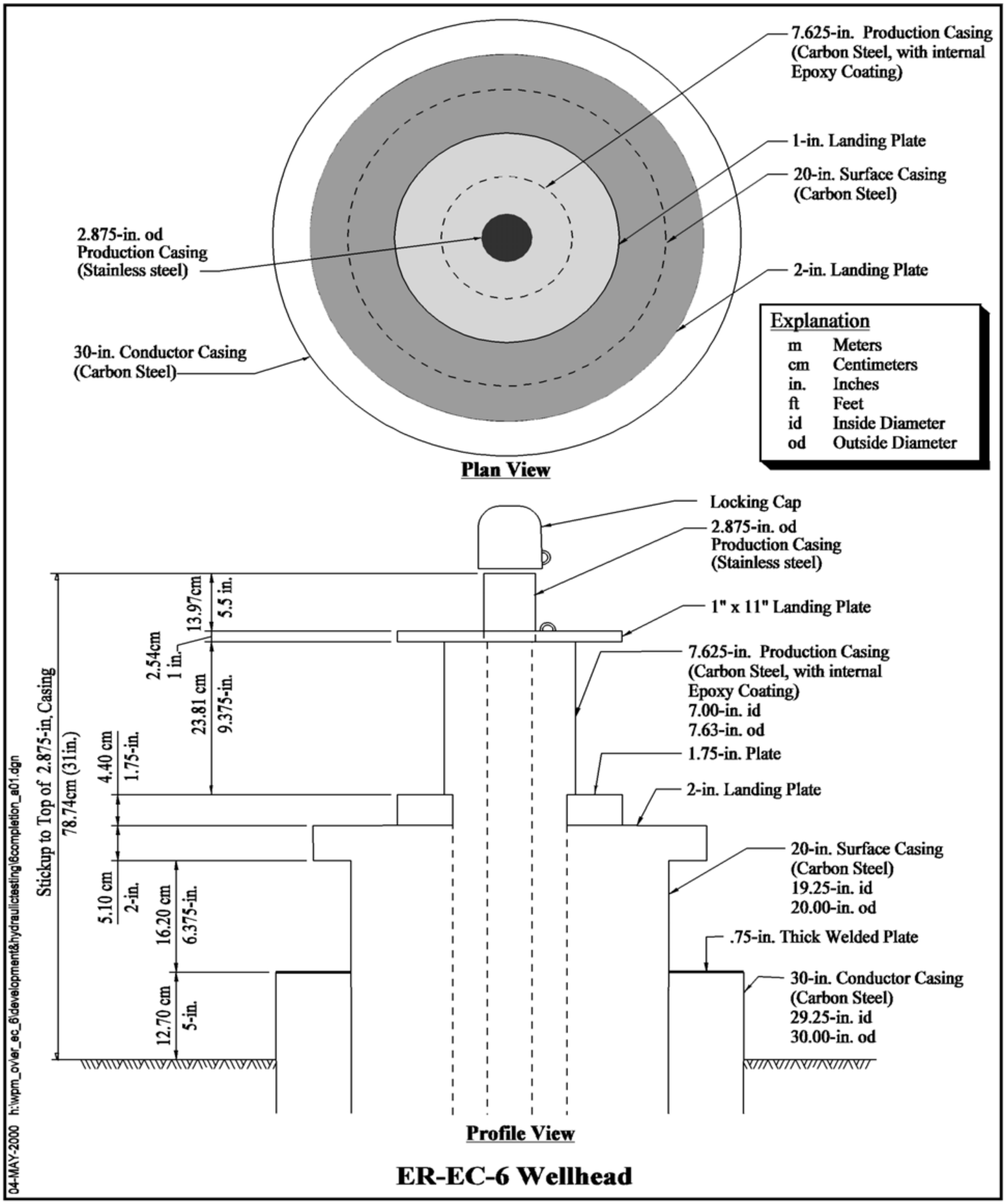


Figure A.2-15
Wellhead Completion Diagram After Sampling Pump Installation
ER-EC-6

A.3.0 Data Reduction and Review

This section presents basic processing and reduction of data collected during the Well ER-EC-6 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. Bridge plug head measurements provide independent measurements of the head in each of the completion intervals, and the thermal flow logging provides a direct measure of the resultant flow. The equilibrium composite water level for the well is a 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 measured after 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 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 due to isolating the 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 height 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 five-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 monitoring records for the lower interval are illustrated in Figure A.3-1 and Figure A.3-2, respectively; for the lower-middle interval in Figure A.3-3 and Figure A.3-4; and for the upper-middle interval in Figure A.3-5 and Figure A.3-6. Figure A.3-7 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 show that the pressure in the completion intervals equilibrated during the period of measurement and further show any trends in the interval head. Note the steadiness in the pressure readings for the calibration data points indicating the PXD temperatures were stable by the beginning of the record segments. Figure A.3-1, Figure A.3-3, and Figure A.3-5 show slight adjustments in pressure immediately following setting the bridge plugs. Figure A.3-2, Figure A.3-4, and Figure A.3-6 show that the interval pressures equilibrated over periods from 30 to 60 hours after the bridge plugs were set. These figures also 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-6 based on the final pressure values in each interval. 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. Data are presented as recorded.

The data indicate a downward hydraulic gradient: the head of the upper-middle interval was 0.56 ft less than the head of the upper interval, the head of the lower-middle interval was 1.35 ft less than the head of the upper-middle interval, and the head of the lower interval was 3.66 ft less than the head of the lower-middle interval. These differences in calculated head between intervals are similar in magnitude to the absolute potential measurement errors. Quoted accuracy for the PXDs is 0.1 percent of Full Scale. Treating the nominal accuracy as measurement uncertainty, the potential uncertainty for the upper-middle interval pressure measurement is +/- 0.75 psi, for the lower-middle interval pressure measurement is +/- 1 psi, and for the lower interval is +/- 2.5 psi. These uncertainties result in potential uncertainty in the head difference of +/- 0.75 psi (approximately 1.8 ft) between the upper and upper-middle interval, 1.75 psi (approximately 4 ft) between the upper-middle and lower-middle interval, and 3.5 psi (approximately 8 ft) between the lower-middle and lower interval. However, the data reduction method uses relative changes for which the uncertainty is less. The uncertainty will be analyzed in more detail in the analysis report.

Table A.3-1
ER-EC-6 Interval-Specific Heads

Measurement	Well Composite	Upper Interval	Upper-Middle Interval	Lower-Middle Interval	Lower Interval
Head - Depth (ft bgs)	1,425.95	1,425.83	1,426.39	1,427.74	1,431.40
Determination Method	Direct Measurement Using e-tape	Direct Measurement Using e-tape	Calculated from Bridge Plug Data	Calculated from Bridge Plug Data	Calculated from Bridge Plug Data
Change in Head (ft)	---	---	-0.58	-1.86	-5.45
Composite Water Density Conversion Factor (ft/psi)	---	---	2.331	2.323	2.338
Representative Pressure (psig)	---	---	295.07	834.03	1,236.04
Pre-Set Pressure (psig)	---	---	295.32	834.83	1,238.37
Reference Head (ft)	---	---	1,425.81	1,425.88	1,425.95
PXD Set Depth (ft)	---	---	2,119.13	3,368.97	4,323.97
PXD Serial Number	---	---	21014	21003	01157
PXD Range (psig)	---	---	0-750	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 Bechtel Nevada (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 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 Table 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.

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 Calibration @ +50 ft	4,375.00	1,333.50	4,374.00	1,333.20	-3.46
Lower Interval Calibration @ -50 ft	4,275.00	1,303.02	4,274.03	1,302.72	-3.38
Lower Interval Set Depth	4,325.00	1,318.26	4,323.97	1,317.94	-3.42
Lower-Middle Interval Calibration @ +50 ft	3,420.00	1,042.42	3,418.89	1,042.08	5.16
Lower-Middle Interval Calibration @ -50 ft	3,320.00	1,011.94	3,318.95	1,011.62	5.00
Lower-Middle Interval Set Depth	3,370.00	1,027.18	3,368.97	1,026.86	5.08
Upper-Middle Interval Calibration @ +50 ft	2,170.00	661.42	2,169.10	661.14	-2.96
Upper-Middle Interval Calibration @ -50 ft	2,070.00	630.94	2,069.06	630.65	-2.82
Upper-Middle Interval Set Depth	2,120.00	646.18	2,119.13	645.91	-2.89

ft bgs - Feet below ground surface
m - Meter

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 casing, between the casing joints. The actual set depths of the bridge plugs, although somewhat different from the specified depths, fulfilled those requirements.

A.3.1.4 Composite Water Density

The calculated composite density conversion factors were 2.331, 2.323, and 2.340 ft of water column/psi (0.998, 1.008, and 1.007 in terms of specific gravity corrected for temperature), respectively, for the upper-middle interval, lower-middle interval, and the lower interval. The specific gravity values are based on calculated standard temperature corrected weight density of water using data from Roberson and Crowe, 1975. These values reflect the effects of entrained gases, suspended solids, and dissolved solids and indicate increasing density with depth. The upper interval value compares with the conversion factor value of 2.350 ft of water column/psi (specific gravities of 0.983) calculated from the PXD installations for monitoring drawdown. This situation may reasonably be expected because the upper part of the water column would 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 of less than 1 gpm at all stations, including a station located in casing above the uppermost completion interval.

This measured flow rates do not correspond well with the calculated head differences.

A.3.2 Well Development

Well development actions did not appear to have a substantial effect on improving the hydraulic efficiency of the well after a small initial improvement. 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.

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 line speed

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 line speed, depth offset, and other related factors. 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 uppermost completion interval. There was no substantial difference in the measured production distribution between the flow log run at a production rate of 62 gpm and at 68 gpm. Figure A.3-8 shows the flow log at 20 fpm up-line speed for just the upper completion interval at a production rate of 62 gpm, and Figure A.3-9 shows the log at a production rate of 68 gpm. These logs show the distribution of water production, which was limited to the upper completion interval. The production was almost all from the upper half of the completion interval, with approximately 70 percent indicated at the very top of the completion interval. This may indicate that a considerable portion of the production was actually coming from above the screen by way of the gravel pack.

The reason for the lack of production from lower completion intervals is not clear. The amount of drawdown (approximately 60 ft) during pumping greatly exceeded the measured vertical gradient, and should also have exceeded the friction loss required to move water at these rates up the completion casing to the pump. The latter losses are poorly estimated due to lack of information on the equivalent surface roughness of the slotted pipe in the completion intervals, but would probably be in the range of an order of magnitude less than the drawdown. The other unknown is the head loss required to bring water into the well. The step-drawdown data is probably inadequate for a good analysis of well losses due to the very restricted range of production for which data is available. The most obvious conclusion would be that the lower completion intervals are not very productive. This may be due to low hydraulic conductivity of the formations or it may be that the borehole wall, gravel pack, and/or screen in these completion intervals are poorly conductive. The development efforts did not remediate such a condition. This conclusion is consistent with the lack of substantial downward flow measured with the thermal flow logging.

Table A.3-3 is a tabulation of the approximate cumulative water production at various depths in the upper completion interval based on an interpretation of the graphical log. The flow logs show that production increased in specific steps and values are given for each step. The accompanying temperature logs in Figure A.3-8 and Figure A.3-9 show the same steps. Results were similar for the two different production rates. The amount of production coming from the lower half of the interval is not well defined, but very low.

Table A.3-3
Cumulative Water Production Versus Depth

Depth (ft bgs)	Percentage of Total Production	
	62 gpm	68 gpm
1,635	100	100
1,660	31	28
1,705	13	12
1,805	5	5
1,870	0	0

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.

A.3.4.1 Barometric Efficiency

Barometric efficiency is a measure of the proportional 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. The response of the well to barometric changes was determined from the monitoring record for the upper interval during the bridge plug measurement. This was the best record where there was a substantial barometric excursion with a clean response. While this response was limited to the upper completion interval, this may be appropriate since only that interval was found to produce water. Figure A.3-7 shows the segment of that monitoring which was used to calculate the barometric efficiency. Table A.3-4 shows the calculation using measurement values extracted from the data file (file EC6gradient.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 - 0.01303 psi/mbar (-89.8 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.3-10 shows the resultant record for the pumping period. The pressure drawdown record was converted to 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 PXD was removed after testing. This information is presented in Table A.2-8. 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. The correction for barometric variation did not

Table A.3-4
Calculation of Barometric Efficiency

Time Julian Days	PXD Pressure (psi)	Barometric Pressure (mbar)
64.00011	9.8516	825.91
65.50011	9.9998	812.55
66.50011	9.8901	818.99
Barometric Excursion mbar		9.9
PXD Excursion psi		- 0.12895
Barometric Efficiency psi/mbar		- 0.01303
Barometric Efficiency %		- 89.806

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

have a great effect because the drawdown was proportionally very great, but did remove some minor inflections in the drawdown curve, resulting in a very consistent response. The PXD data record during pumping has noise of approximately 1.5 ft, which is attributed to the pump. It is not known if the pump was running unevenly or if the pump had some mechanical problem. However, this level of noise is small compared to the drawdown, and does not present a problem for analysis.

A.3.4.3 Recovery Record

Figure A.3-11 shows the recovery period after correction for barometric variation. The same comments on processing and presentation for the drawdown record (Section A.3.4.2) apply to the recovery record.

A.3.5 Water Quality

ChemTool logs were run at various stages of Well ER-EC-6 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 Precompletion 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.3-12 shows temperature logs, Figure A.3-13 shows the pH logs, and Figure A.3-14 shows EC logs. Included on these figures are lithologic information and well completion details.

The temperature log pre and postdevelopment show some differences. They both show the same temperature at the top of the upper completion, but the postdevelopment log shows a gradual increase in temperature with depth relative to the predevelopment log. The temperature increase is about 4EC at a depth of 4,300 ft bgs. Much of the difference is in the temperature gradient down to the bottom of the upper-middle completion interval.

The parameters pH and EC generally give an indication of the representativeness of the water within the well relative to formation water. The postdevelopment pH log indicates that the water has high pH (between 9 and 10) down to the bottom of the lower-middle completion interval, and decreases a little below that. The pH log appears noisy and somewhat erratic, especially in comparison to the precompletion log. The postdevelopment pH log seems anomalous, and shows no obvious correlation with development. The EC log, in contrast, indicates significantly lower EC values postdevelopment. This log also appears noisy. The lower values extend down the well to the lower-middle completion interval and decline further below that. Neither log shows any significant correlation with the interpretation of development based on flow logging.

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 declined gradually during the course of pumping from values in the mid 800s to values in the low 800s. The EC values adjusted rapidly into the low 600s (µmhos/cm). These values can be compared to the results of the downhole ChemTool logs shown in Figure A.3-13 and Figure A.3-14. The grab sample results for pH are very similar to the precompletion ChemTool logs, but are somewhat different from the postdevelopment ChemTool log to which they should correlate. The postdevelopment ChemTool pH log in the interval of production shows erratic and anomalously high pH (9-9.5). The ChemTool EC values in this interval (around 450 µmhos/cm) are considerably lower than the grab sample EC values (600-650 µmhos/cm). Until the ChemTool log values in the interval of production for these parameters can be correlated with the grab samples, reliance on these logs for interpretation is suspect. Perhaps this is primarily a calibration problem, but the noisy and erratic nature of these two logs suggest that there was also some other problem.

The pH and EC logs both generally show one feature of interest; a marked decline in values at and below the depth of the lower-middle completion interval. This was evident in the predevelopment EC log and shows in both the pH and EC postdevelopment logs. This may be indicative of downward flow from the lower-middle to the lower completion interval; the isolated-interval head measurements indicated a substantial gradient between these two intervals. The high pH below the upper completion interval in the postdevelopment log may reflect effects of well completion activities and materials. In general, the data does not appear to fully support any conclusion that water quality in the lower part of the well reflects water quality in the formation around the well. Natural flow down the well under ambient conditions may have accomplished some remediation of drilling and completion effects. However, the lower part of the well is not clearly fully remediated.

A.3.6 Representativeness of Hydraulic Data and Water Samples

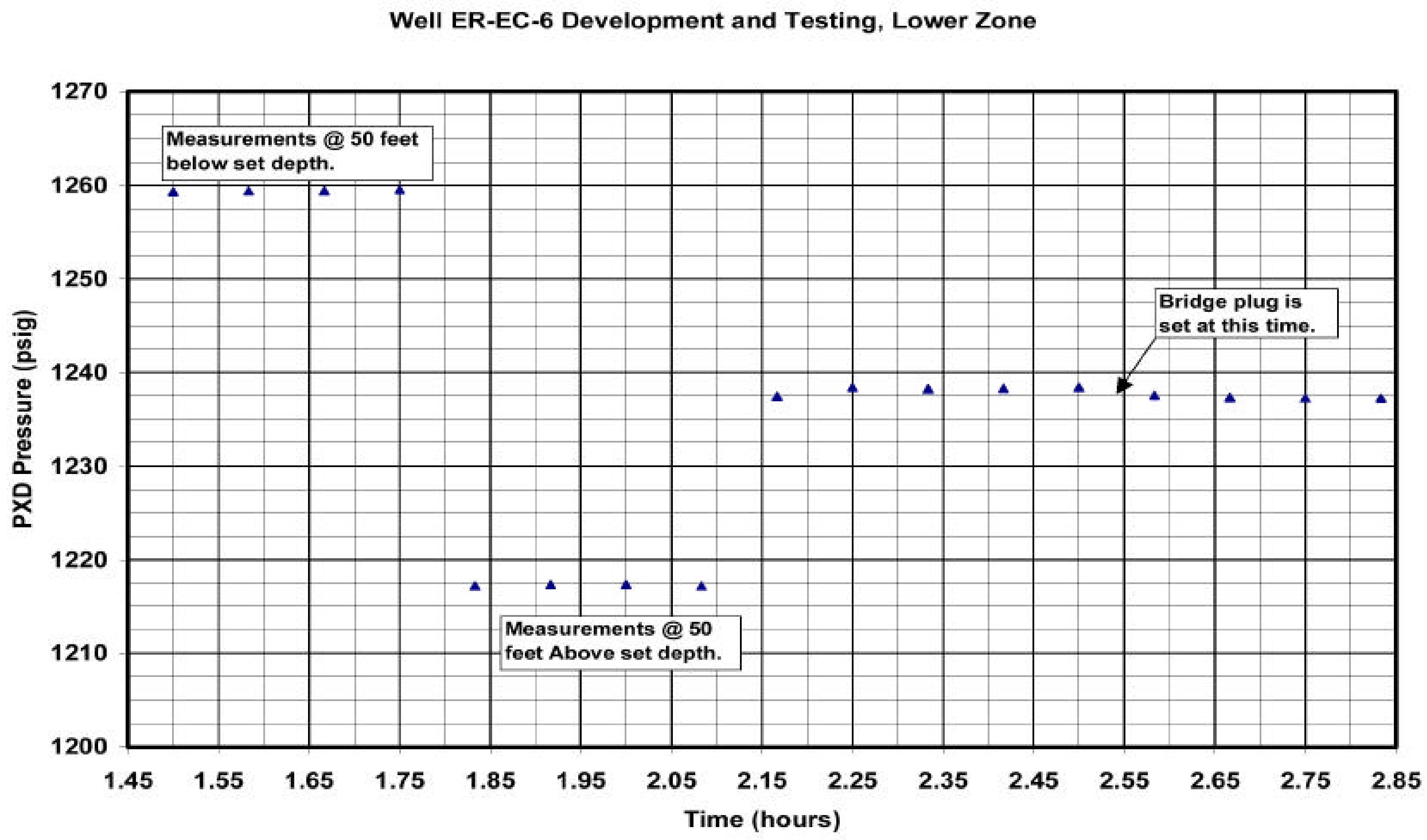
A conclusion that can be drawn from the testing of Well ER-EC-6 is that all of the water quality, development, hydraulic testing, and composite sampling must be considered to be applicable only to the uppermost completion interval. The analysis of the constant-rate test for hydraulic parameters would be applicable only to the interval of the formation that produced water.

Likewise, the water quality information obtained, both general parameters from grab samples and results of laboratory analyses of samples, must be considered representative only of the formation in the upper completion interval. The upper completion interval can probably be considered well developed. Since all natural flow in the well appears to be downward, the upper completion interval has not been affected by receiving water from any source. Presumably that interval was only affected by residual impacts of drilling and completion. This suggests that the final water quality in that interval is natural.

Since no development appears to have occurred below this level, any samples that could be taken below this should not be considered representative of formation water quality at lower depths. There was some evidence to suggest that the lower-middle interval was producing water under the natural gradient, and that flow could be restoring the natural water quality for that interval. However, a long-term bridge plug was placed below this interval (i.e., 4,300 ft bgs), which should have stopped this flow and the remediation process. Future sampling using the low dedicated pump can probably be considered representative of the production interval observed during this testing.

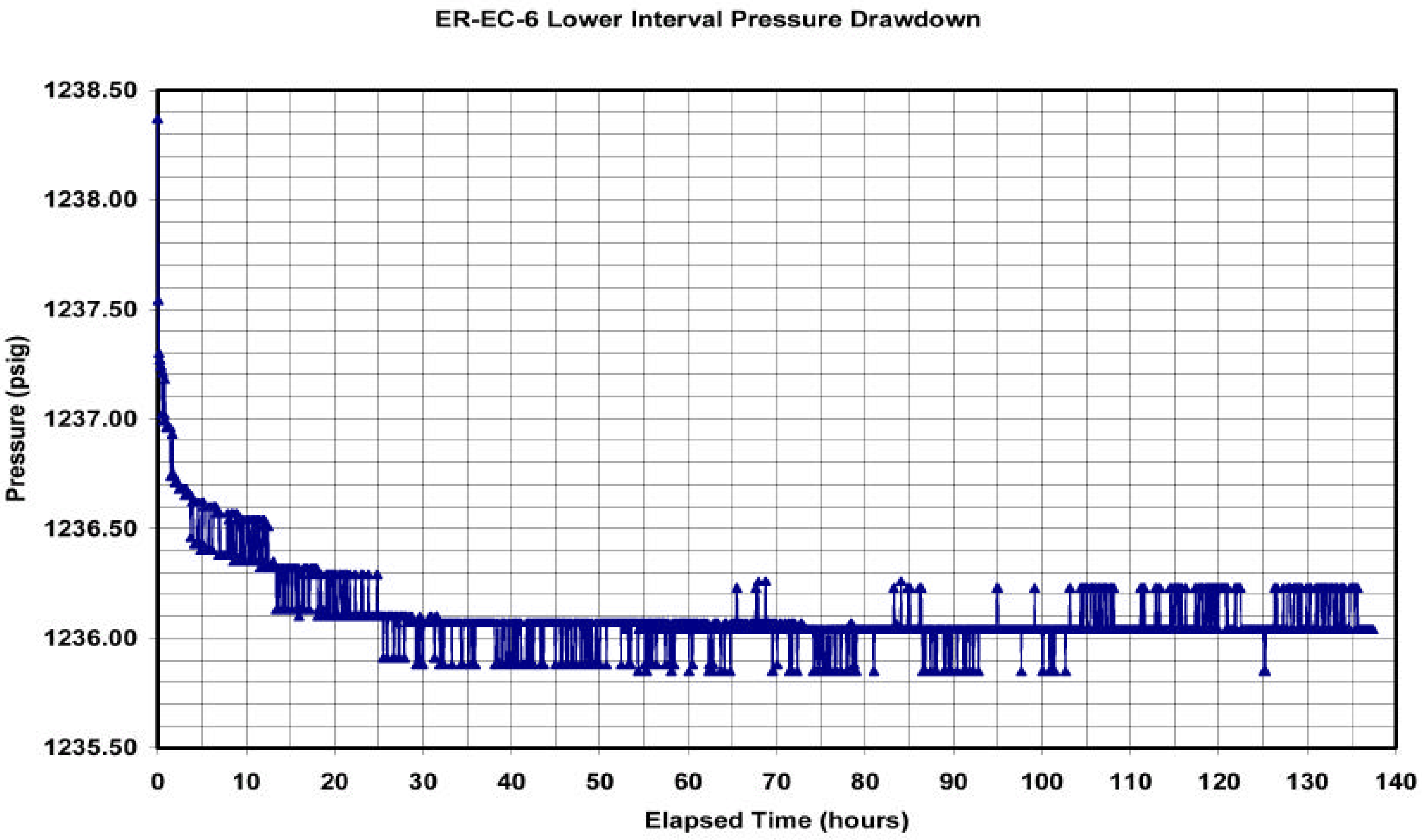
A.3.7 Development of the Lower Completion Intervals

To affect development in the lower completion intervals, some method of isolating production to the lower completion intervals would probably be required to stress and sample them separately. The simpler approach of increasing the production rate to increase the stress further downhole would probably not be effective, and pumping at higher rates would be difficult due to limitations in installing a larger pump, and may not be effective in any case.



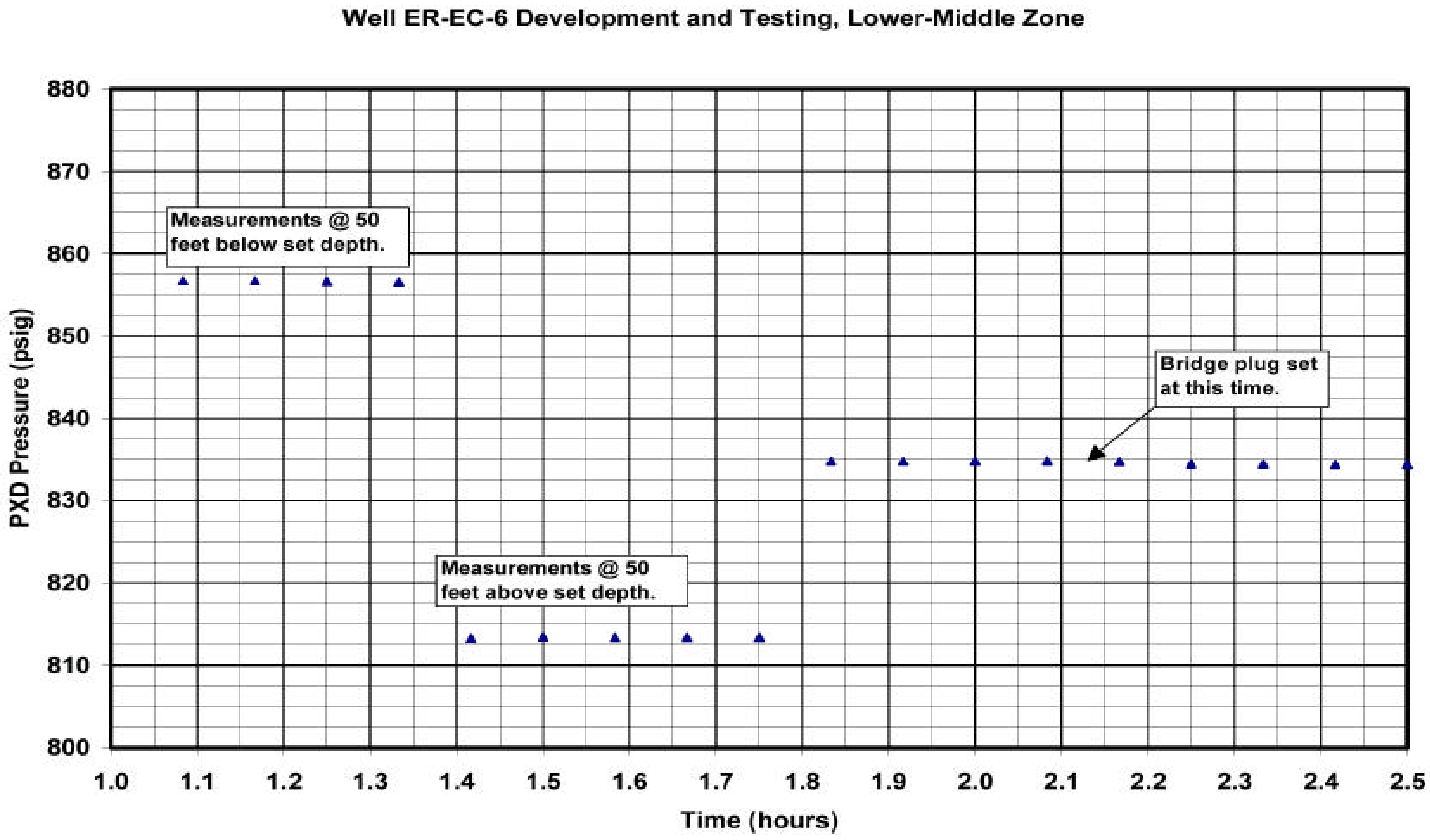
PXD - Pressure transducer
psig - Pounds per square inch gauge

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



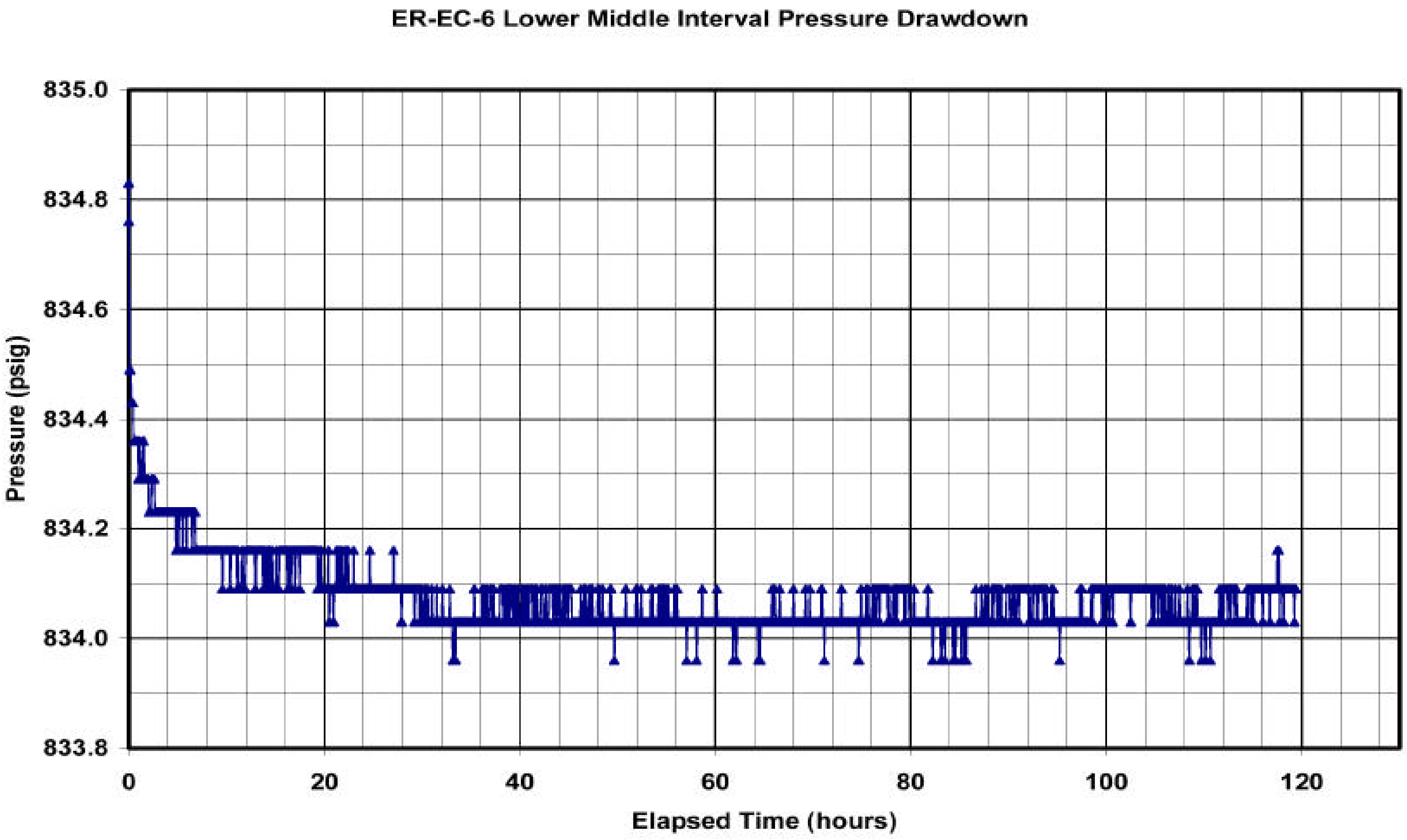
PXD - Pressure transducer
psig - Pounds per square inch gauge

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



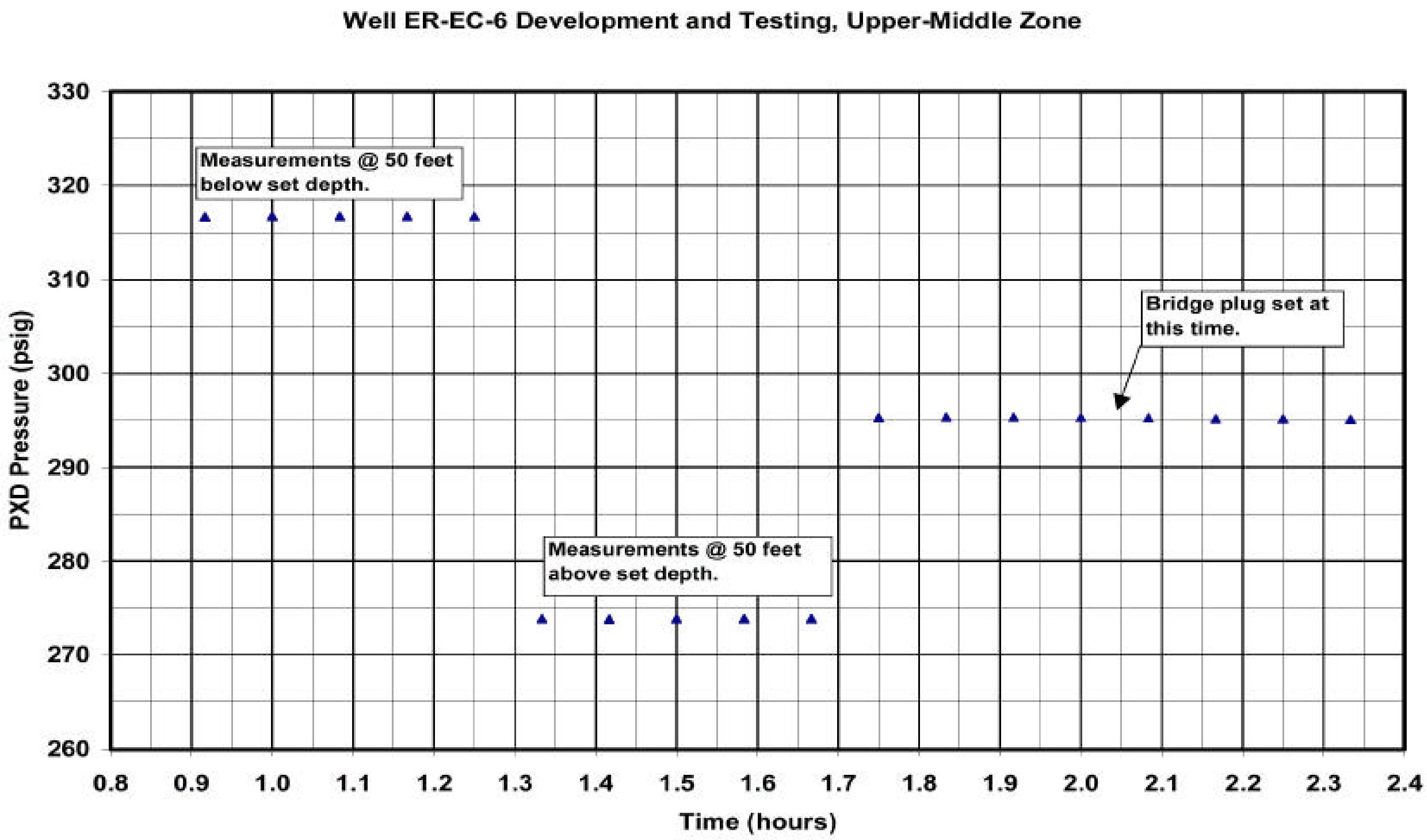
PXD - Pressure transducer
psig - Pounds per square inch gauge

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



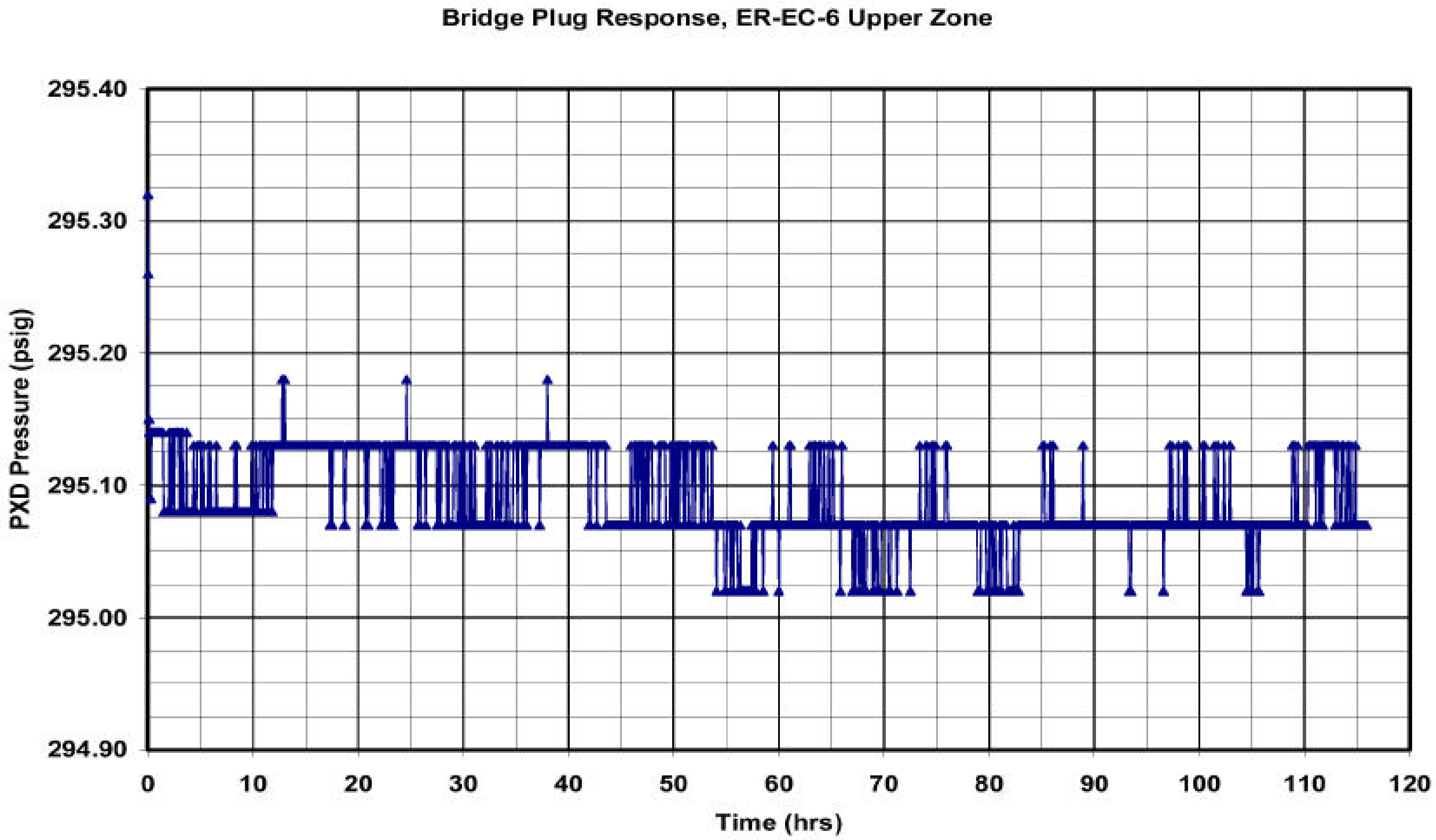
PXD - Pressure transducer
psig - Pounds per square inch gauge

Figure A.3-4
Bridge Plug PXD Response for Lower-Middle Interval



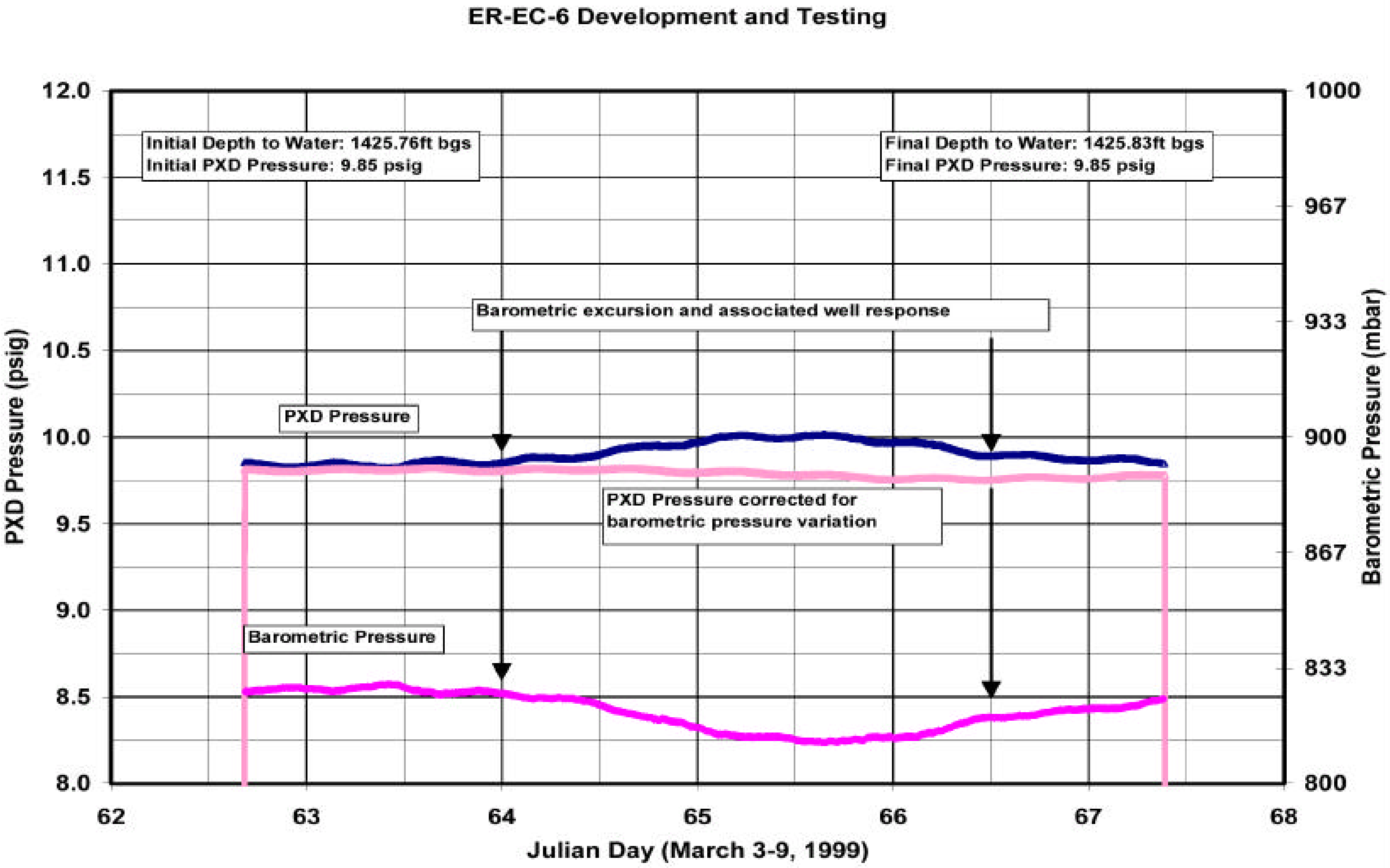
PXD - Pressure tranducer
psig - Pounds per square inch gauge

Figure A.3-5
Upper-Middle Interval Calibration and Bridge Plug Set



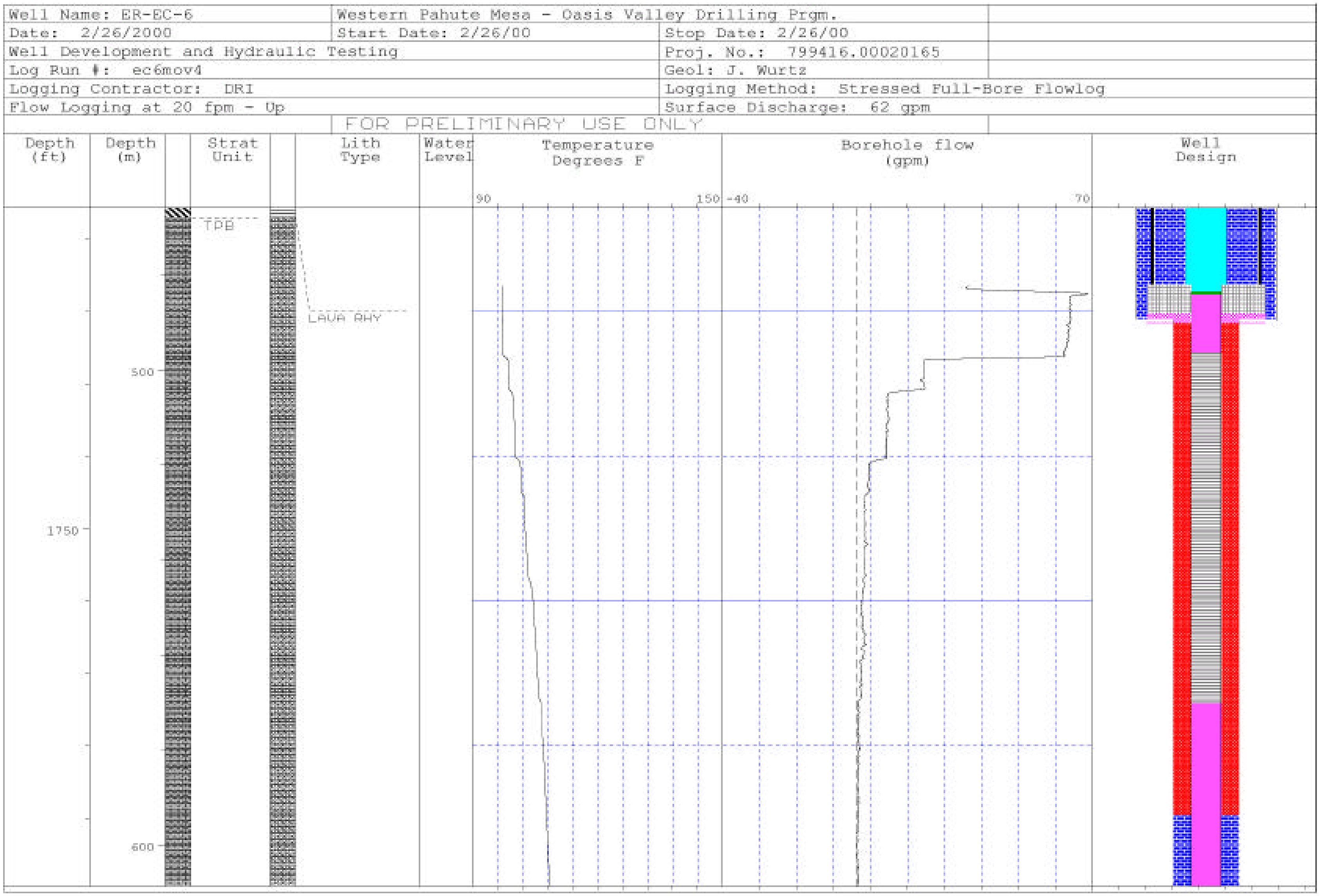
PXD - Pressure transducer
psig - Pounds per square inch gauge

Figure A.3-6
Bridge Plug PXD Response for Upper-Middle Interval



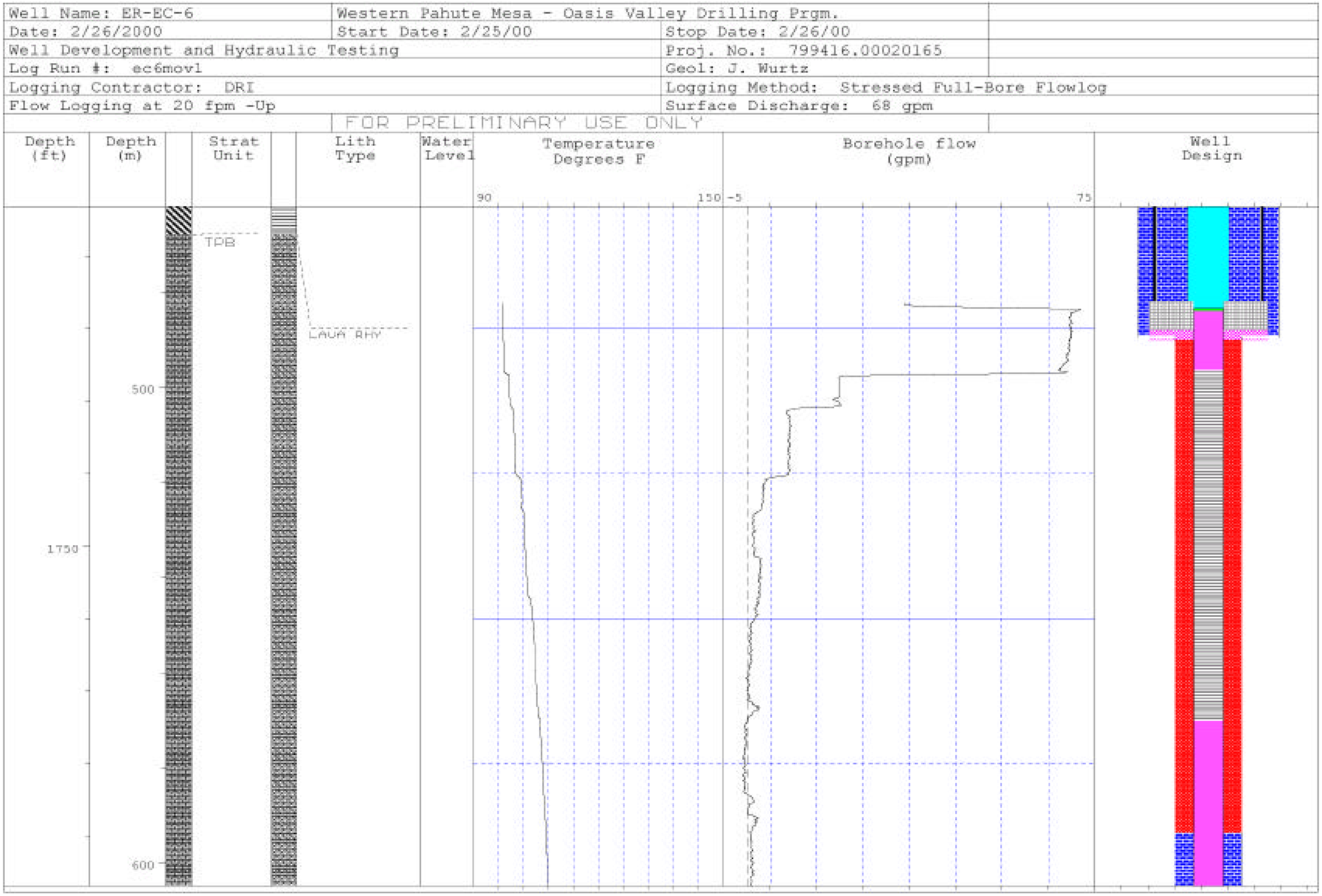
psig - Pounds per square inch gauge
PXD - Pressure transducer
mbar - Millibars

Figure A.3-7
PXD Record for Upper Interval



Well Name: ER-EC-6
Western Pahute Mesa - Oasis Valley Drilling Prgm.
Date: 2/26/2000
Start Date: 2/26/00
Stop Date: 2/26/00
Well Development and Hydraulic Testing
Proj. No.: 799416.00020165
Log Run #: ec6mov4
Geol: J. Wurtz
Logging Contractor: DRI
Logging Method: Stressed Full-Bore Flowlog
Flow Logging at 20 fpm - Up
Surface Discharge: 62 gpm
FOR PRELIMINARY USE ONLY

Figure A.3-8
Flow and Temperature Log for the Upper Interval at 62 gpm



Well Name: ER-EC-6
Western Pahute Mesa - Oasis Valley Drilling Prgm.
Date: 2/26/2000
Start Date: 2/25/00
Stop Date: 2/26/00
Well Development and Hydraulic Testing
Proj. No.: 799416.00020165
Log Run #: ec6mov1
Geol: J. Wurtz
Logging Contractor: DRI
Logging Method: Stressed Full-Bore Flowlog
Flow Logging at 20 fpm -Up
Surface Discharge: 68 gpm
FOR PRELIMINARY USE ONLY

Figure A.3-9
Flow and Temperature Log for the Upper Interval at 68 gpm

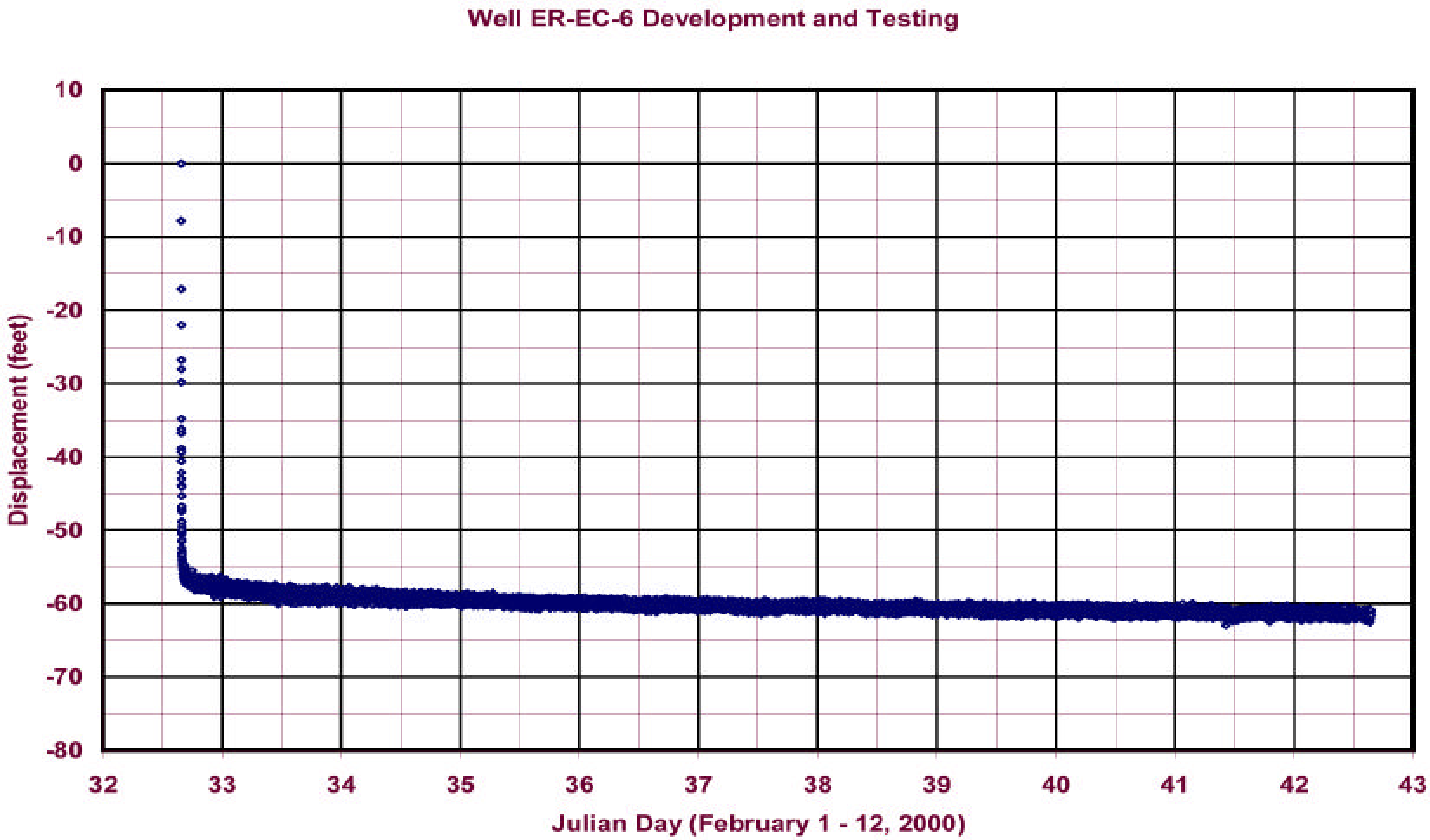


Figure A.3-10
Constant-Rate Pumping Test with Barometric Correction

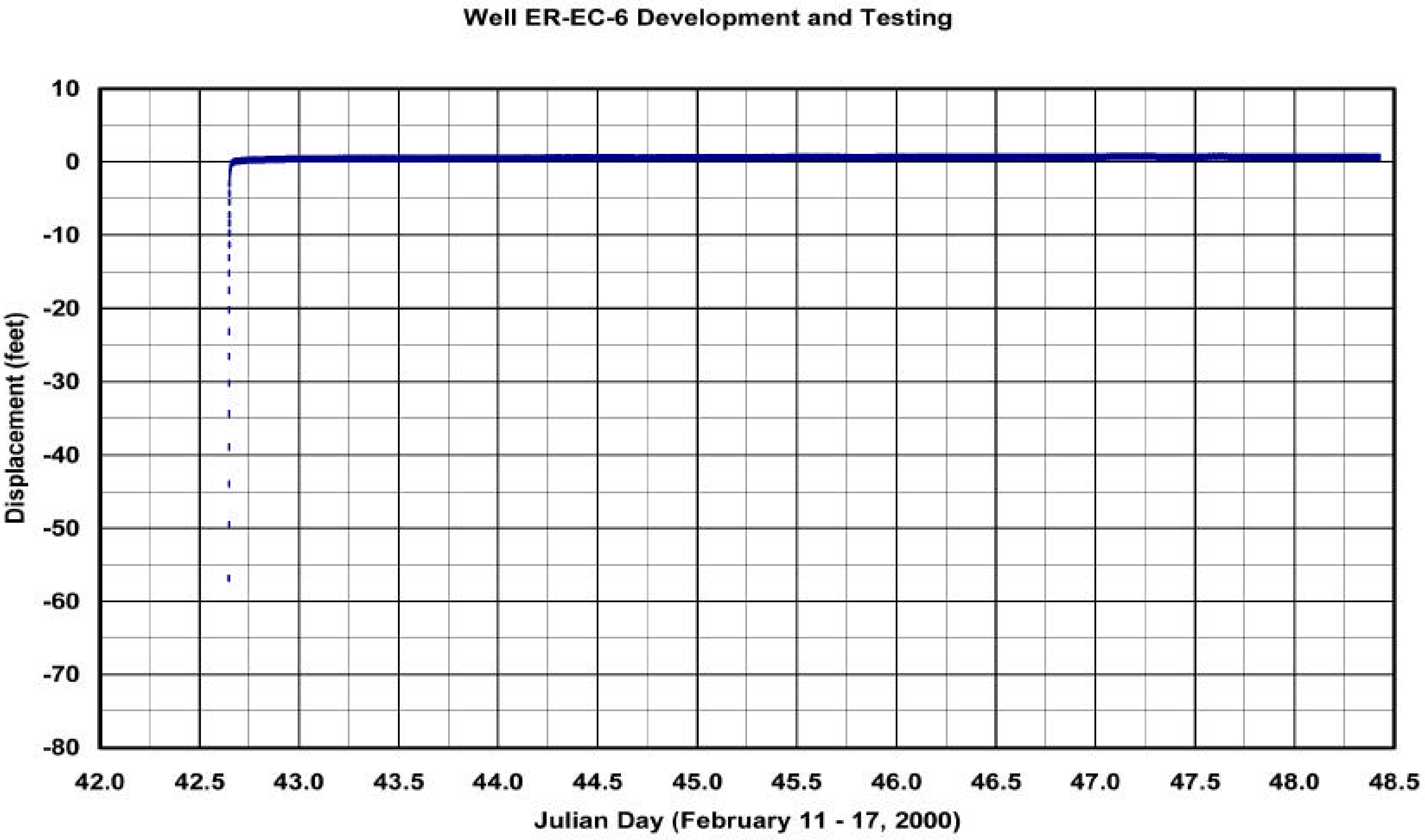


Figure A.3-11
Recovery Period with Barometric Correction

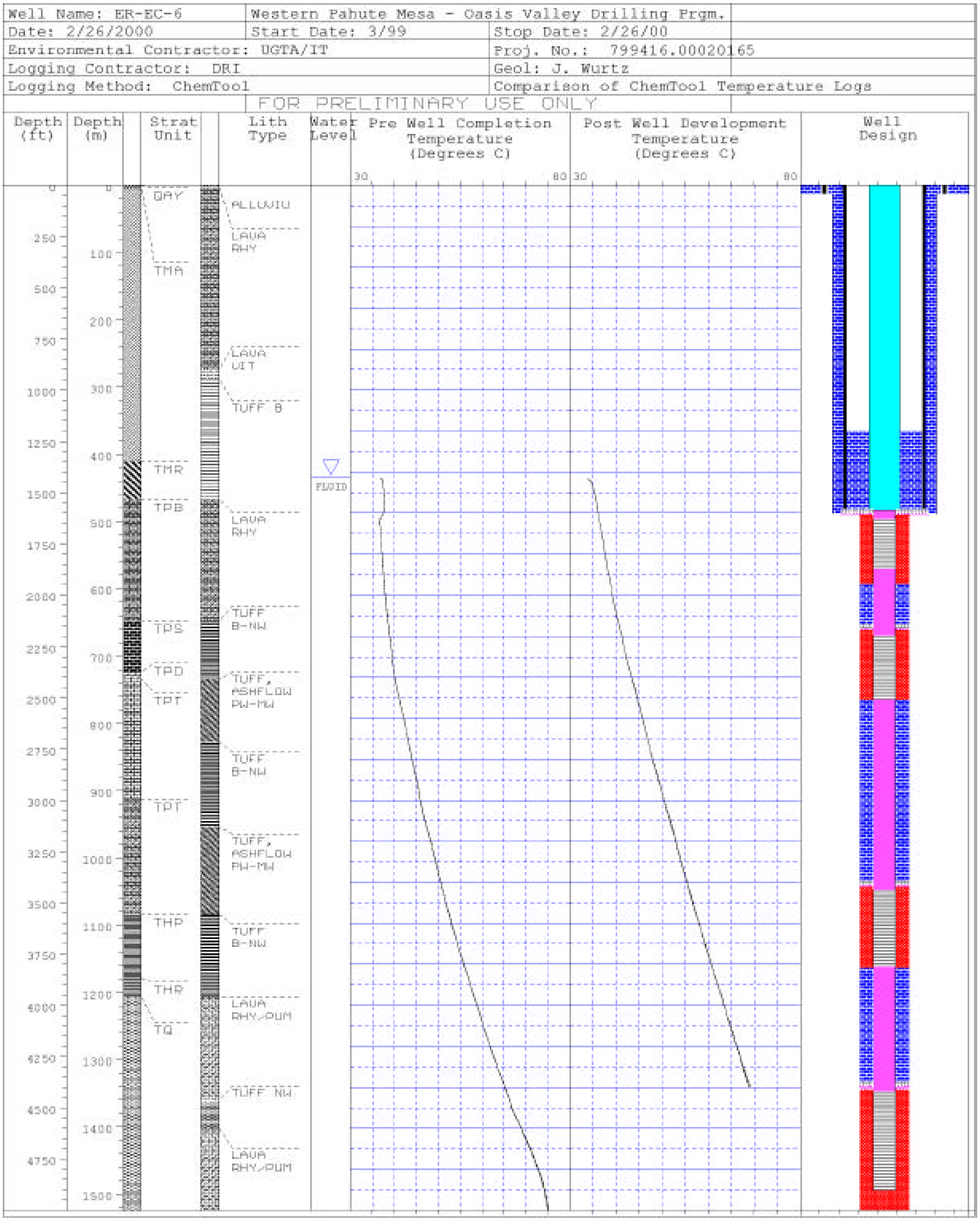


Figure A.3-12
Temperature Log Prior to Completion Versus Postdevelopment

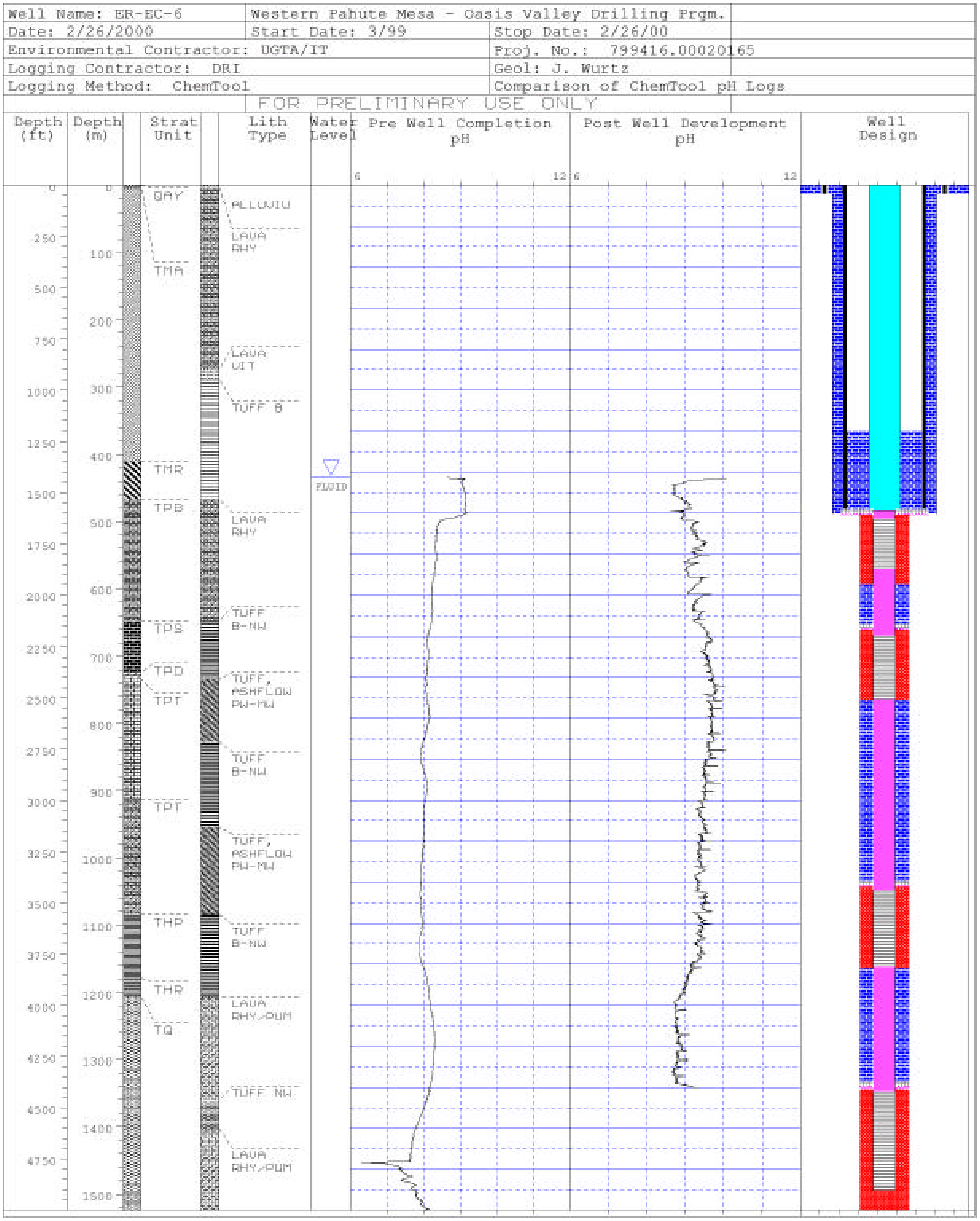


Figure A.3-13
pH Log Prior to Completion Versus Postdevelopment

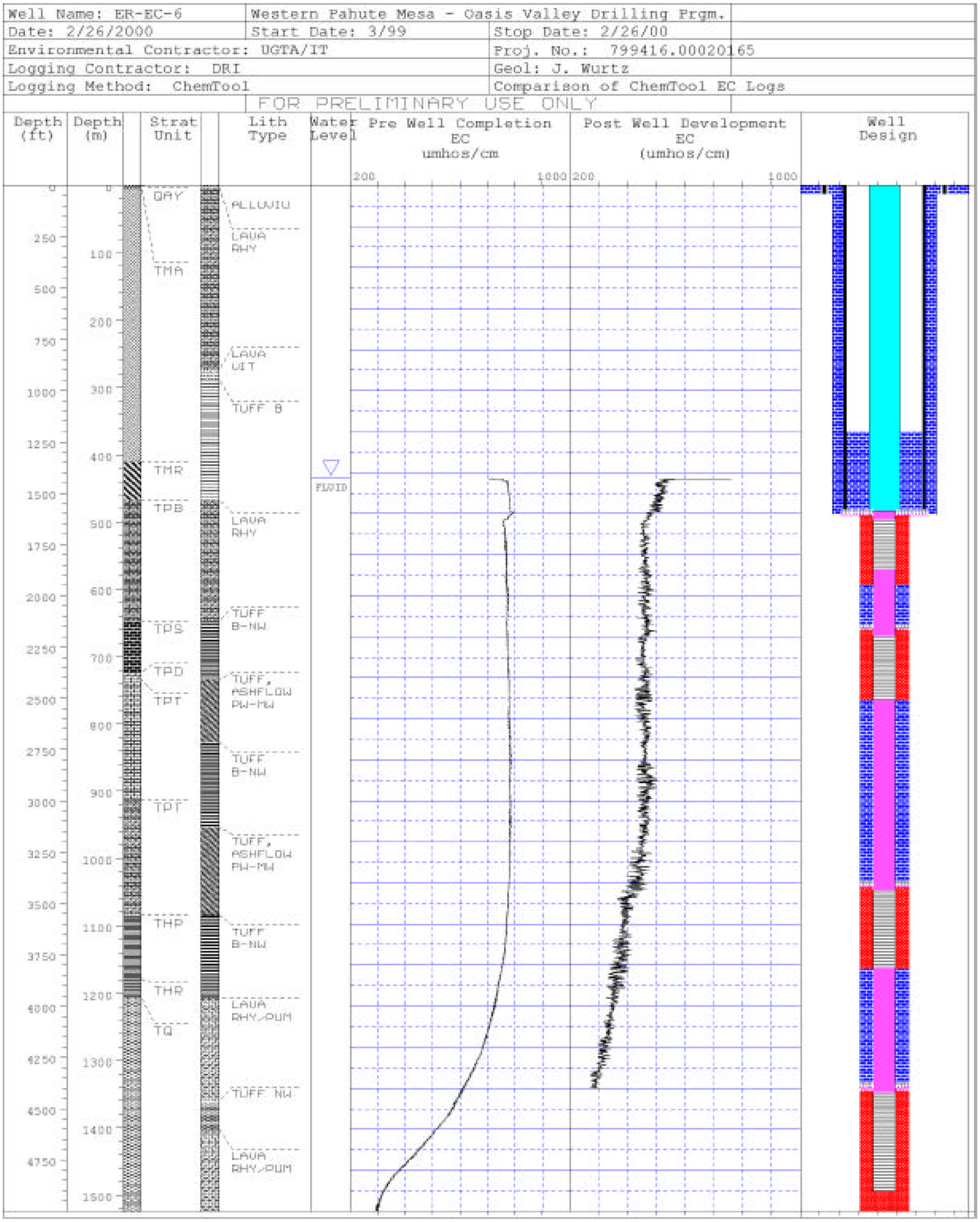


Figure A.3-14
EC Log Prior to Completion Versus Postdevelopment

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 NNSA/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 (NDEP, 1999a), testing, and sampling at the above wells. The waiver (provided in Attachment 4) 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-6, 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 7.7 ft from the bottom. On January 22, 2000, the fluid level reached the overflow pipe and began discharging to the ground surface via a drainage ditch at the southwest corner of Sump #1.

A total of approximately 1,759,387 gallons of groundwater were pumped from Well ER-EC-6 during well development, hydraulic testing, and sampling activities. Table A.4-1 shows the 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 highest tritium activity was 343 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 11, 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* (IT, 1997); SQP ITLV-0501, “Control of Hazardous Materials”; and SQP ITLV-0513, “Spill Management.” The following

Table A.4-1
Fluid Disposition Report Form

Site Identification: ER-EC-6
Site Location: Nellis Air Force Range
Site Coordinates: N 4,115,745m E 544,710m
Well Classification: ER Hydrogeologic Investigation Well
IT Project No: 776706.02080302; 799416.00020165

Report Date: 6/12/2000
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 [c] (m^3)		Infiltration Area (m^3) [e]	Other [d] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids [b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	2/16/99	3/8/99	20	435	1,188	385	540	- - -	- - -	540	N/A	Y
Phase I: Saturated-Zone Drilling	2/26/99	3/19/99	21	1,524	746	197	343	182	408	343	N/A	Y
Phase II: Initial Well Development	1/13/00	1/27/00	15	1,524	- - -	- - -	2,918.2	- - -	- - -	2,918.2	N/A	Y
Phase II: Aquifer Testing	2/01/00	2/11/00	11	1,524	- - -	- - -	3,741.1	- - -	- - -	3,144.7	N/A	Y
Phase II: Final Development	N/A	N/A	-	-	-	-	-	-	-	-	-	-
Cumulative Production Totals to Date:			67	1,524	1,934	582	7,542.3	182	408	6,945.9	-	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] Optional fluid management devices not installed for this well site.
[d] 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.
[e] Ground surface discharge and infiltration to a natural surface

NA = Not Applicable; m = meters; m^3 = cubic meters; AIP = Analysis In Process
Total Facility Capacities: Sump #1 (Unlined) = 1,086 m^3 Sump #2 (Lined) = 7,483 m^3

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

Remaining Facility Capacity (Approximate) as of 3/29/00: Sump #1 = 489.6 m^3 (45.1 %) Sump #2 = 7,422.6 m^3 (99.2 %)

Current Average Tritium = (Natural Background) pCi/L
Notes: Activity Duration for Phase I and Phase II included drilling and subsequent reaming

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

LV\6-12-0\forms\form_158

Table A.4-2
Results of Tritium and Lead Monitoring at ER-EC-6

Sampling Date	Sample Number	Lead Results[1]	Tritium Results[2]	
		µg/L	dpm[a]	pCi/L*
01/13/2000	ER-EC-6-011300-1	1.0	3.81	343.24
01/14/2000	ER-EC-6-011400-1	2.0	0.00	0.00
01/18/2000	EC-6-011800-1	7.0	0.00	0.00
01/19/2000	EC-6-011900-1	2.0, 1.0	0.16	14.41
01/20/2000	EC-6-012000-1	1.0	1.29	116.22
01/21/2000	EC-6-012100-1	< 1.0	0.00	0.00
01/22/2000	EC-6-012200-1	1.0	2.94	264.86
01/23/2000	ER-EC-6-012300-1	1.0	0.00	0.00
01/24/2000	EC-6-012400-1	0.5	0.00	0.00
01/25/2000	ER-EC-6-012500-1	1.0	0.00	0.00
01/26/2000	ER-EC-6-012600-1	1.0	3.17	288.2[a]
01/27/2000	ER-EC-6-012700-1	1.0	0.00	0.00
02/01/2000	ER-EC-6-020100-1	1.0	- - -	0.00[a]
02/02/2000	ER-EC-6-020200-1	1.0	- - -	0.00[a]
02/03/2000	ER-EC-6-020300-1	< 1.0	- - -	0.00[a]
02/04/2000	ER-EC-6-020400-1	< 1.0	- - -	0.00[a]
02/05/2000	ER-EC-6-020500-1	< 1.0	- - -	0.00[a]
02/06/2000	ER-EC-6-020600-1	1.0	- - -	0.00[a]
02/07/2000	ER-EC-6-020700-1	1.0	- - -	417.0[a]
02/08/2000	ER-EC-6-020800-1	< 1.0	- - -	0.00[a]
02/09/2000	ER-EC-6-020900-1	< 1.0	- - -	53.0[a]
02/10/2000	ER-EC-6-021000-1	1.0	- - -	30.4[a]
02/11/2000	ER-EC-6-021100-1	< 1.0	- - -	0.00[a]
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.

[a] Analysis provided by Bechtel Nevada Site Monitoring Service at the CP in Area 6

*pCi/L derived from the following conversion equation:
dpm/5mL * 1,000 mL/L * 0.45045 pCi/dpm = pCi/L

Table A.4-3
Preliminary Analytical Results of Sump Fluid Management Plan Sample at Well ER-EC-6

Analyte	CRDL	Laboratory	NDWS	Results of Sump Composite Sample #EC-6-021100-2
Metals (mg/L)				
				Total | Dissolved
Arsenic	0.01	Paragon	0.05	B 0.0046 | B 0.0042
Barium	0.2	Paragon	2.0	B 0.0025 | B 0.0011
Cadmium	0.005	Paragon	0.005	U 0.005 | U 0.005
Chromium	0.01	Paragon	0.1	B 0.0012 | B 0.00066
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 -10 | +/- 170
Gross Alpha	2.0	Paragon	15	9.4 | +/- 2.3
Gross Beta	2.4	Paragon	50	3.1 | +/- 1.6

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, UGTA QAPP (DOE/NV, 1998)
MDC = Minimum Detectable Concentration, sample-specific
NDWS = Nevada Drinking Water Standards
mg/L = Milligrams per liter
pCi/L = Picocuries per liter

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:

- 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: Two drums of hydrocarbon waste were produced containing oily/diesel-stained absorbant pads/debris and used pump oil.
- Hazardous Waste: Approximately one gallon of solid hazardous waste was generated from the installation of bridge plugs/packers. 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 the ER-EC-6 well site. Monthly inspections were conducted of this area until the waste was transported off site for disposal.

All waste, hydrocarbon and hazardous, was disposed of by BN Waste Management when well development operations at the NTS were 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.

IT Corporation. 2000. *ITLV Standard Quality Practices Manual*, Volumes 1 and 2, March. 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-6*, Rev. 0, DOE/NV/11718-360, May. Las Vegas, NV.

Attachment 1

Manufacturer's Pump Specifications

High-Capacity Testing Pump

RFQ # 623 HIGH VOLUME ELECTRIC SUBMERSIBLE PUMP SYSTEMS

BECHTEL NEVADA CORPORATION

YUCCA MOUNTAIN PROJECT

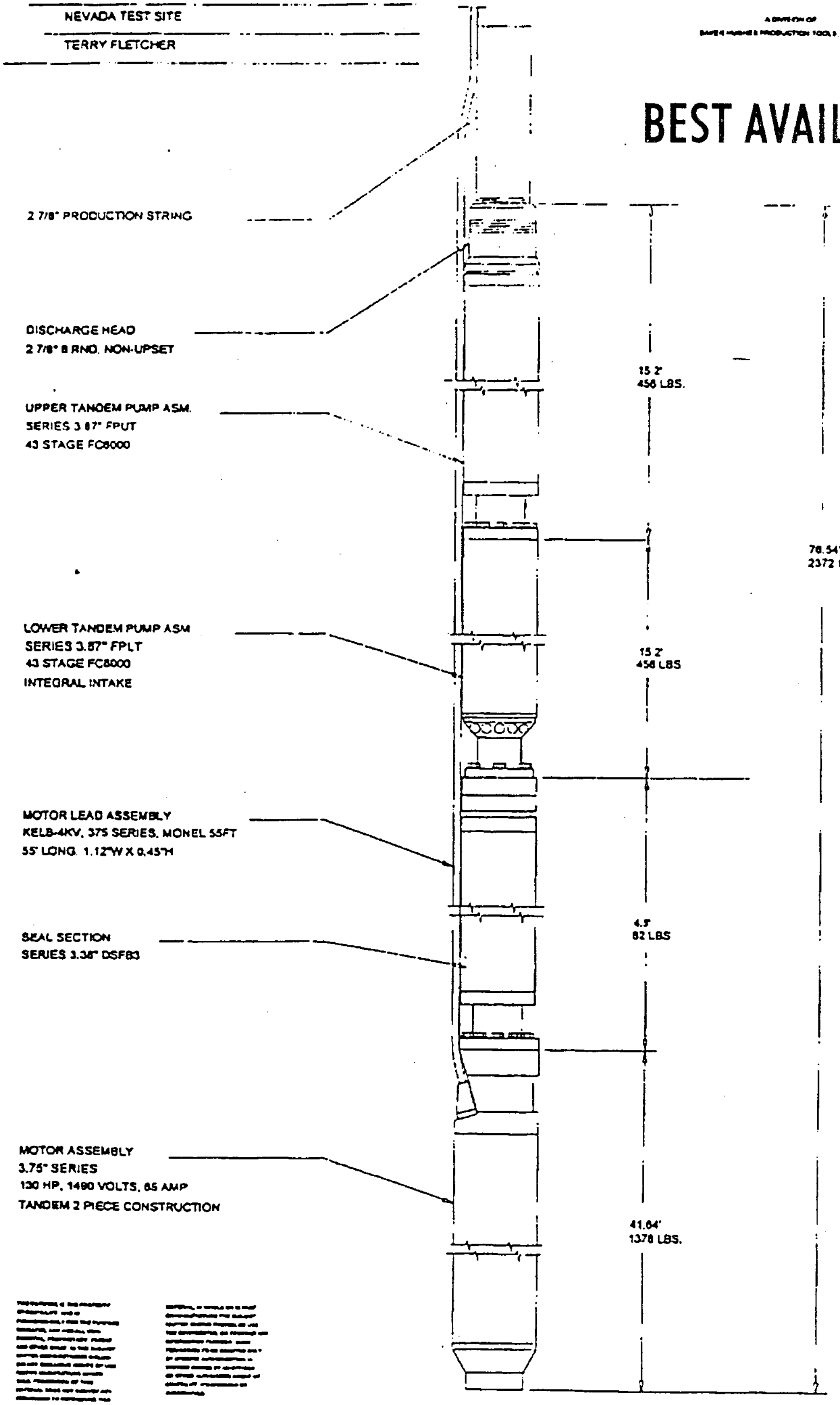
NEVADA TEST SITE

TERRY FLETCHER

CENTRILIFT

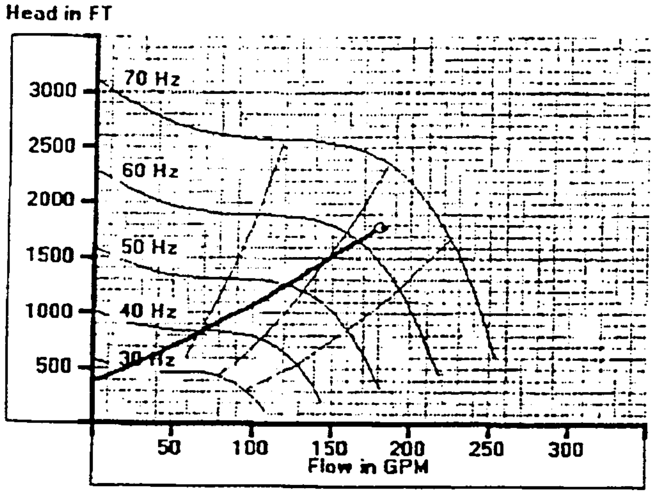
A DIVISION OF BAKER HUGHES PRODUCTION TOOLS, INC.

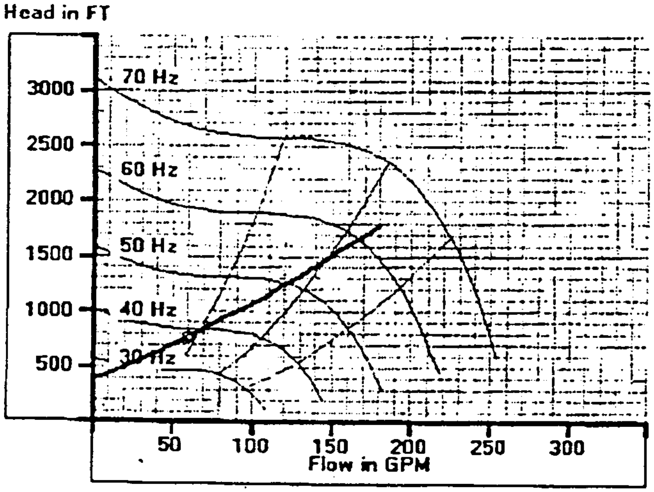
BEST AVAILABLE COPY



Attachment 1

60-180 G.P.M. OPERATION
1500 FT. PUMP SETTING DEPTH





Frequency	Hz	35	40	45	50	55	60	65
Flow at Stock Tank	GPM	50.1	78.3	106	129	151	170	189
Pump Intake Pressure	psi	377	304	234	173	119	68.99	21.69
Total Dynamic Head	FT	694	902	1120	1321	1510	1692	1871
Fluid speed by motor	ft/sec	0.601	0.939	1.268	1.553	1.808	2.041	2.263
Motor Load	%	21.24	32.4	44.99	57.24	69.16	81.07	93
Motor Amps	A	40.6	40.6	40.6	43.98	49.63	55.39	61.27
Pump RPM	rpm	2058	2352	2646	2930	3201	3463	3717
Surface KVA	kVA	52.81	60.03	67.26	83.65	109	139	173

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 10,1999

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 ,1480ft
Controller: VSD 2250-VT 260kVA/ 480V/ 313A

60-180 GPM @ 1500' pump setting depth, 38.2-63.5 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 62.6 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 = 1500ft
Perfs V. Depth = 2500ft
Datum Static P = 500psi
Test Flow = 6171BPD
Test Pressure = 43.29psi
PI = 13.37BPD/psi
IPR Method = Composite IPR

Target:
Pump Setting Depth (vertical) = 1500ft
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: Beggs & Robinson
Saturated Visc: Beggs & Robinson
UnderSaturated: Vasquez & Beggs
Gas Visc: Lee

Oil Compress: Vasquez & Beggs
Formation Vol: Standings
Z factor: Hall & Yarborough
Bubble Point P: Standings

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

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 10,1999

Operating Parameters / Selection:

Design Point:
Desired flow (total) = 6171 BPD
% water = 100.0 %
% Gas into pump = 0.0 %bs /0.0 %

Frequency = 62.6 Hz
GOR into pump= 1.0 scf/STB
TDH = 1787 FT

Pump Selection:

	Intake	Discharge
Pressure	= 43.62 psi	807 psi
Flowrate	= 6256 BPD	6243 BPD
Specific Gravity	= 0.986 rel-H2O	0.988 rel-H2O
Viscosity	= 0.511Cp	0.527Cp

60-180 GPM @ 1500' pump setting depth, 38.2-63.5 Hz. operation

Pump Selected:
86 stages Type: FC6000 [400 Series]
Shaft HP at 62.6 Hz = 114 (32 %)
Required motor shaft HP at 60.0 Hz = 113

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 = 193°F
Chamber Cap Used (Top to Bot)=
17% 20%
Thrust bearing load =49 %
Shaft load = 66 %

Motor Selection:
Terminal Voltage =1494.8 V
Cable Current =58.4 A
Load acc to N.P. =87.3 %
Shaft Load =45.9 %

Fluid Speed =2.16ft/s
Internal Temp =157°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 = 1480ft
MLE length = 20.0ft
Surface Temp = 75°F

Wellhead Voltage = 1543.0V
Wellhead kVA = 156.2kVA
Voltage Drop = 48.2V
Cond Temp (main) = 165°F
Temp Rating = 205°F

Surface Cable	Main Cable	MLE Cable
#2 CTTF 3kV 50.0ft	#4 CPNR 3kV 1480ft	#6 MLE-KLHTLP 5kV 20.0ft

No comments

Controller Selection:
Input kVA = 148.5kVA
System kW = 119.3kW
Max Ctrl Current = 224.6A
Power Cost/kWH = 0.05$/kW
Total Power Cost = $4294/month

Voltage Input = 480V
Max Well Head Volts = 1543V
Max Frequency = 62.6Hz (7.67V/Hz)
Start Frequency = 10.0Hz
Step-up Trafo = 3.843 ratio
Selected: VSD 2250-V 260kVA/ 480V/ 313A

NEMA 3 design (outdoor use)

--- End of Report ---

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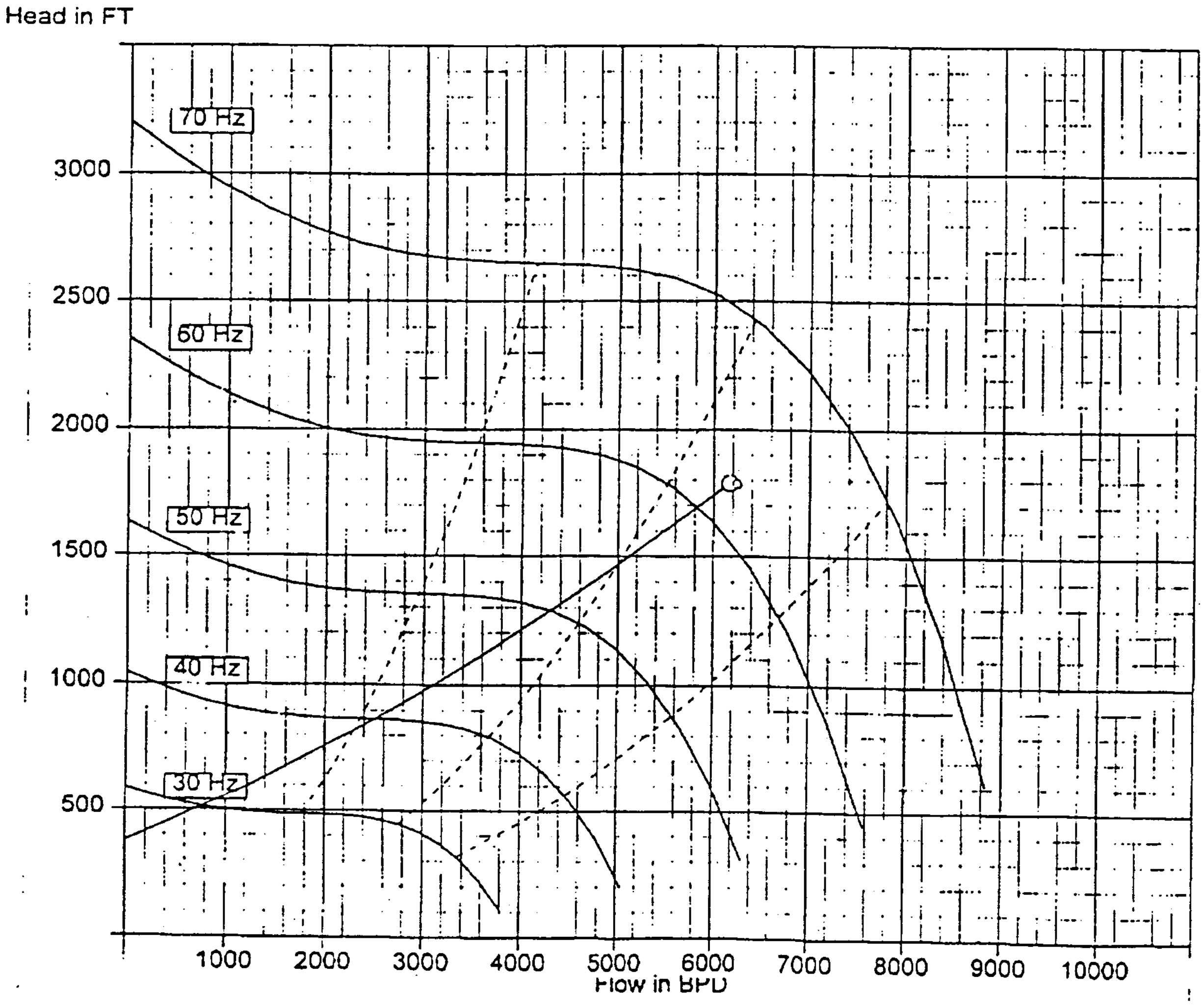
5421 Argosy Drive Huntington Beach, CA. 92649
Terry Fletcher- Sales Engineer E- Mail: Terry.Fletcher@Centrilift.com

October 10,1999

Project:	Nevada Test Site	**Pump:**	86-FC6000 [400Series]
Customer:	Bechtel Nevada	**Seal:**	DSFB3 [338Series]
Well:	Various	**Motor:**	DMF 130 HP 1490V 65 A [375Series]
Engineer:	Mr. Ken Ortego	**Cable:**	#4 CPNR 3kV ,1480ft
		Controller:	VSD 2250-VT 260kVA/ 480V/ 313A

60-180 GPM @ 1500' pump setting depth. 38.2-63.5 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 62.6 Hz

86-FC6000 Series: 400

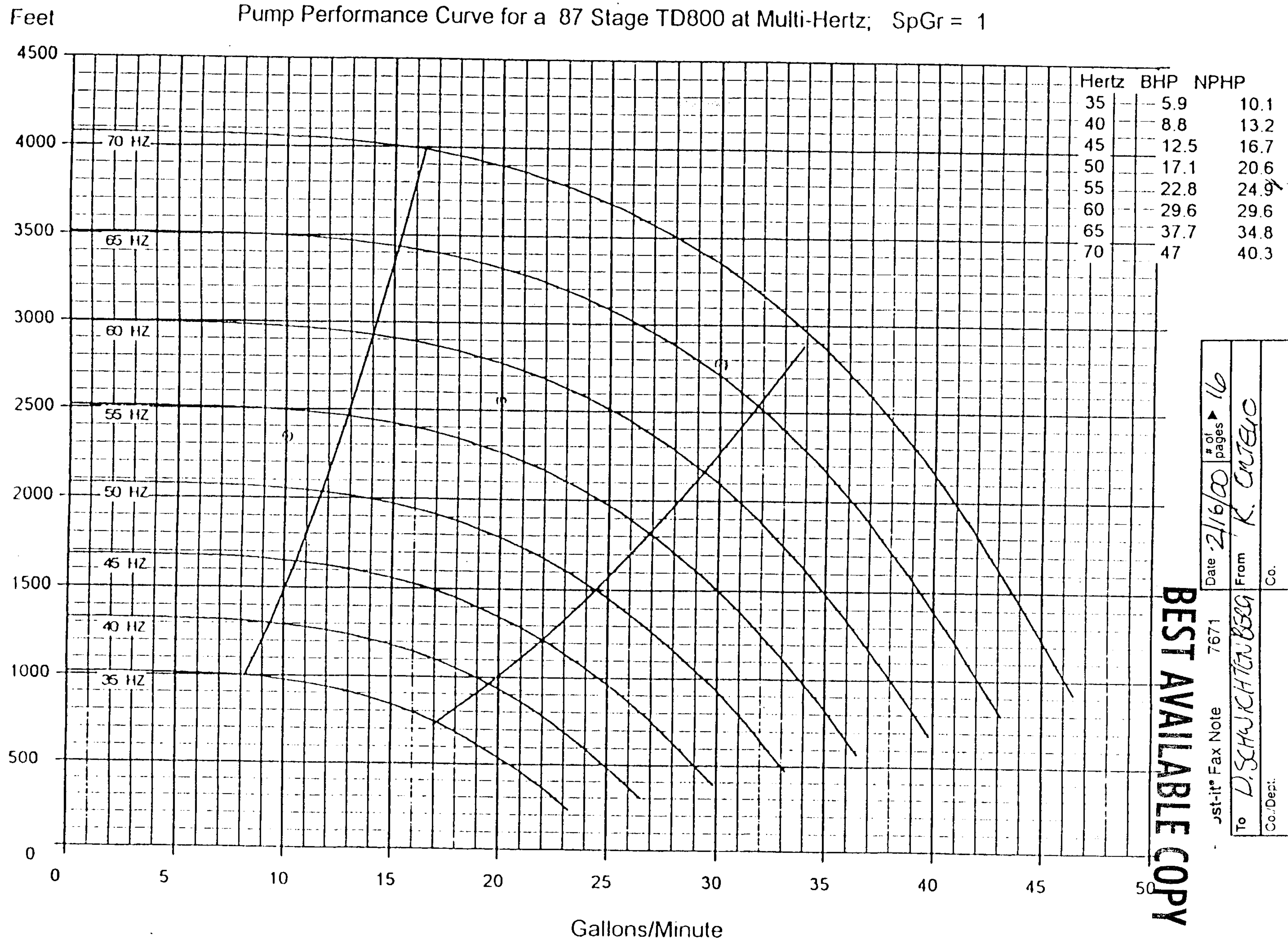


Dedicated Sampling Pump

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

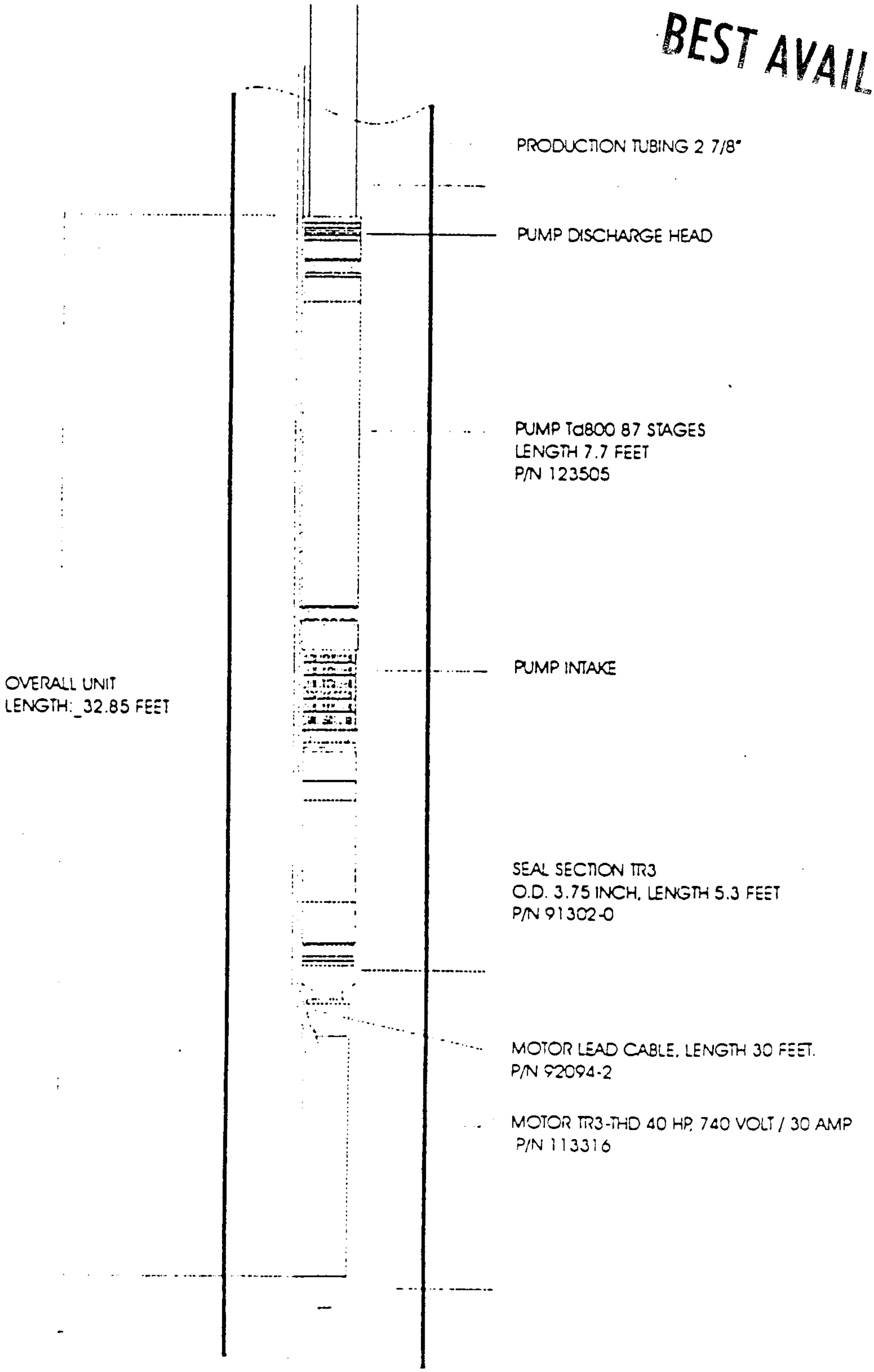
Attachment 1

BEST AVAILABLE COPY

ost-it® Fax Note 7671

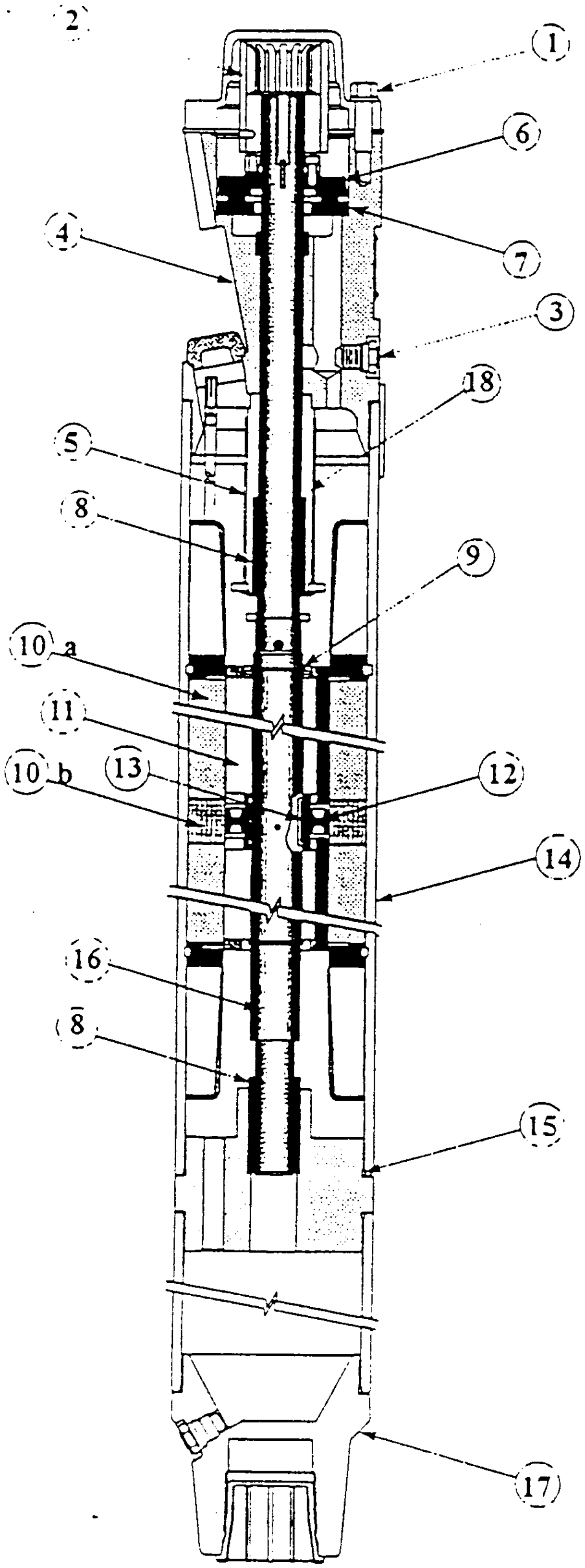
Date 2/16/00	# of pages ▸ 16
To D. SCHWICHTENBERG	From K. CATEYO
Co./Dept.	Co.
Phone #	Phone #
Fax #	Fax #

Bechtel Nevada
Las Vegas Nevada
Item Number 0001



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

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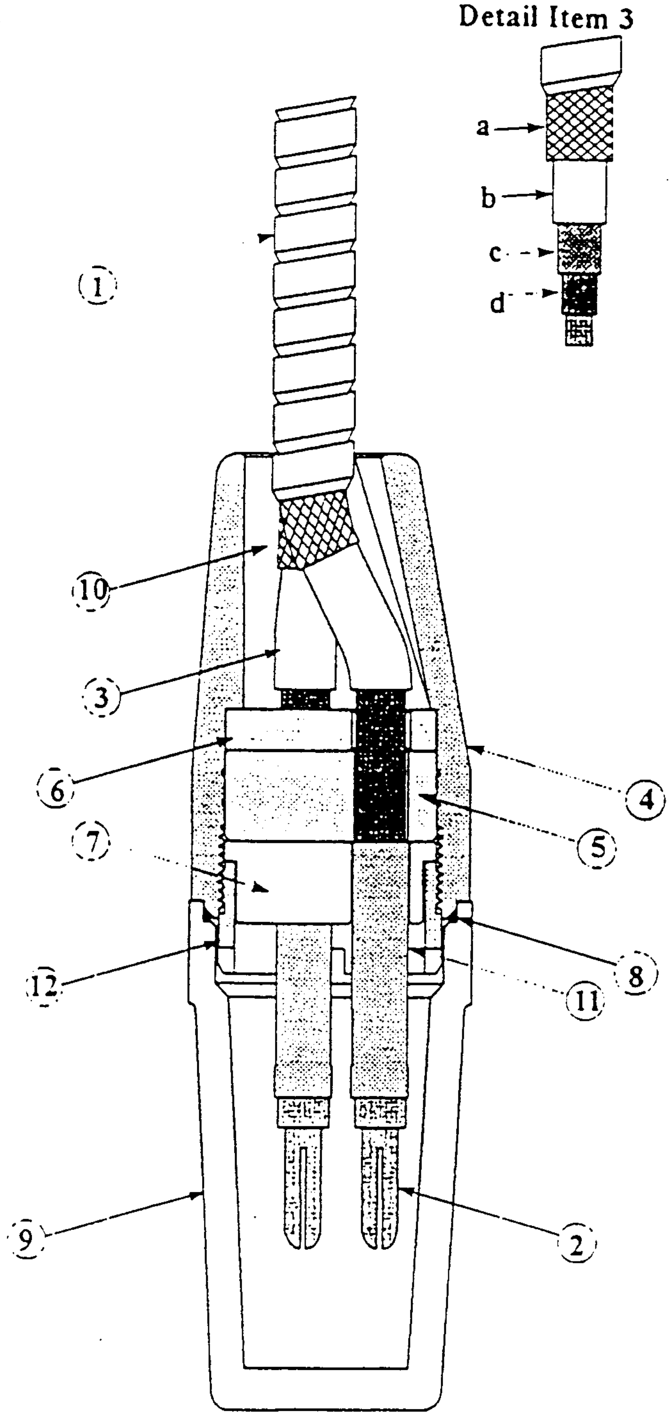
MLC, Tr3 KEOTB GALV.



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,tr5-kelb-4kv.cdr

New Release
27 May 1997

Standard Seal

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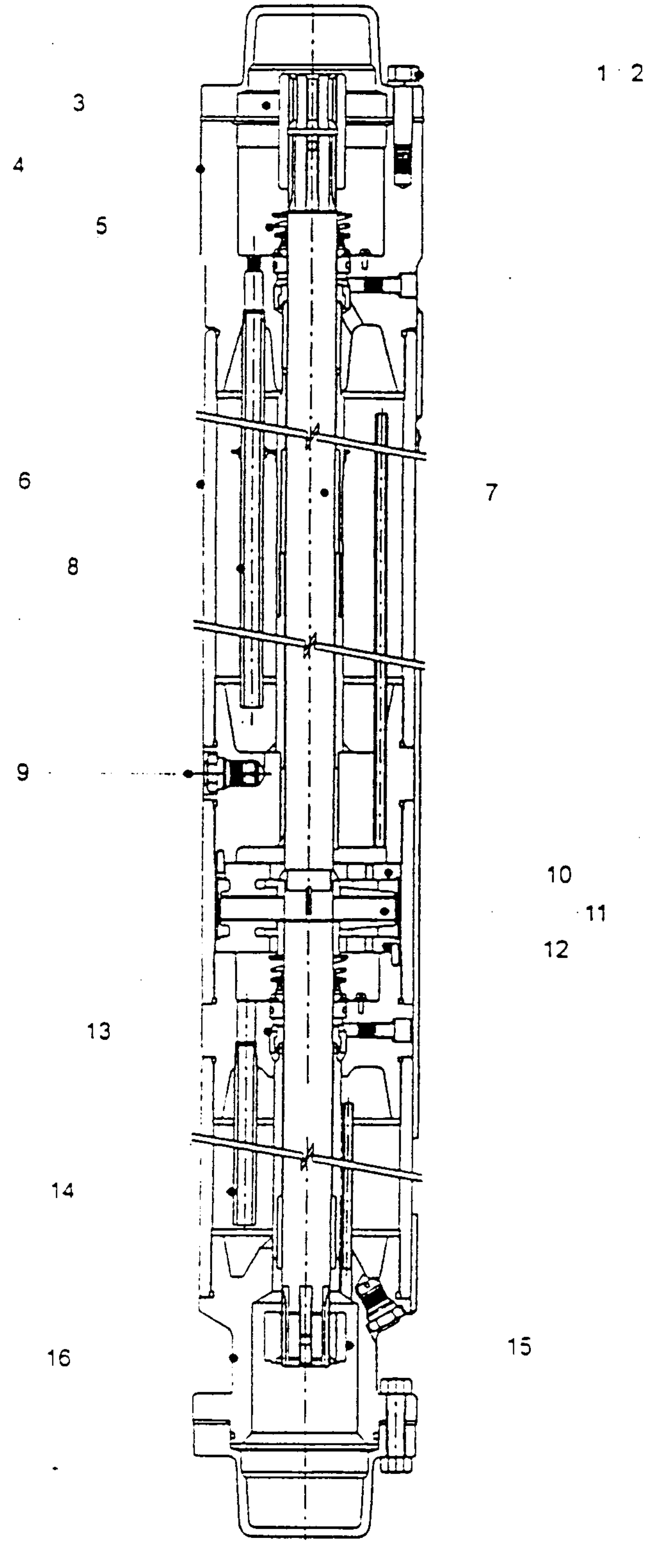


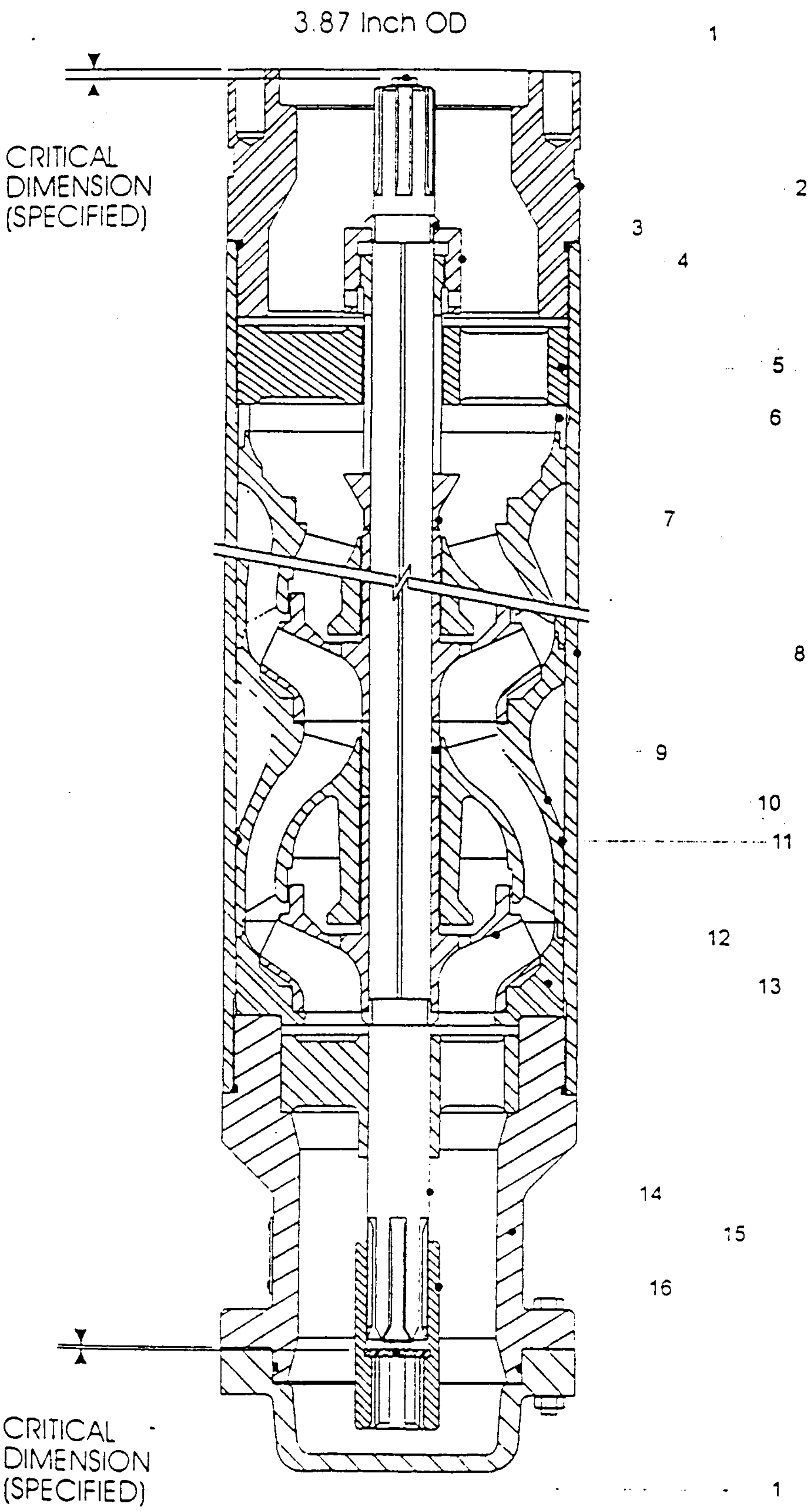
PARTS LIST

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.

ESP

Standard Pump (Floater Stage Design)



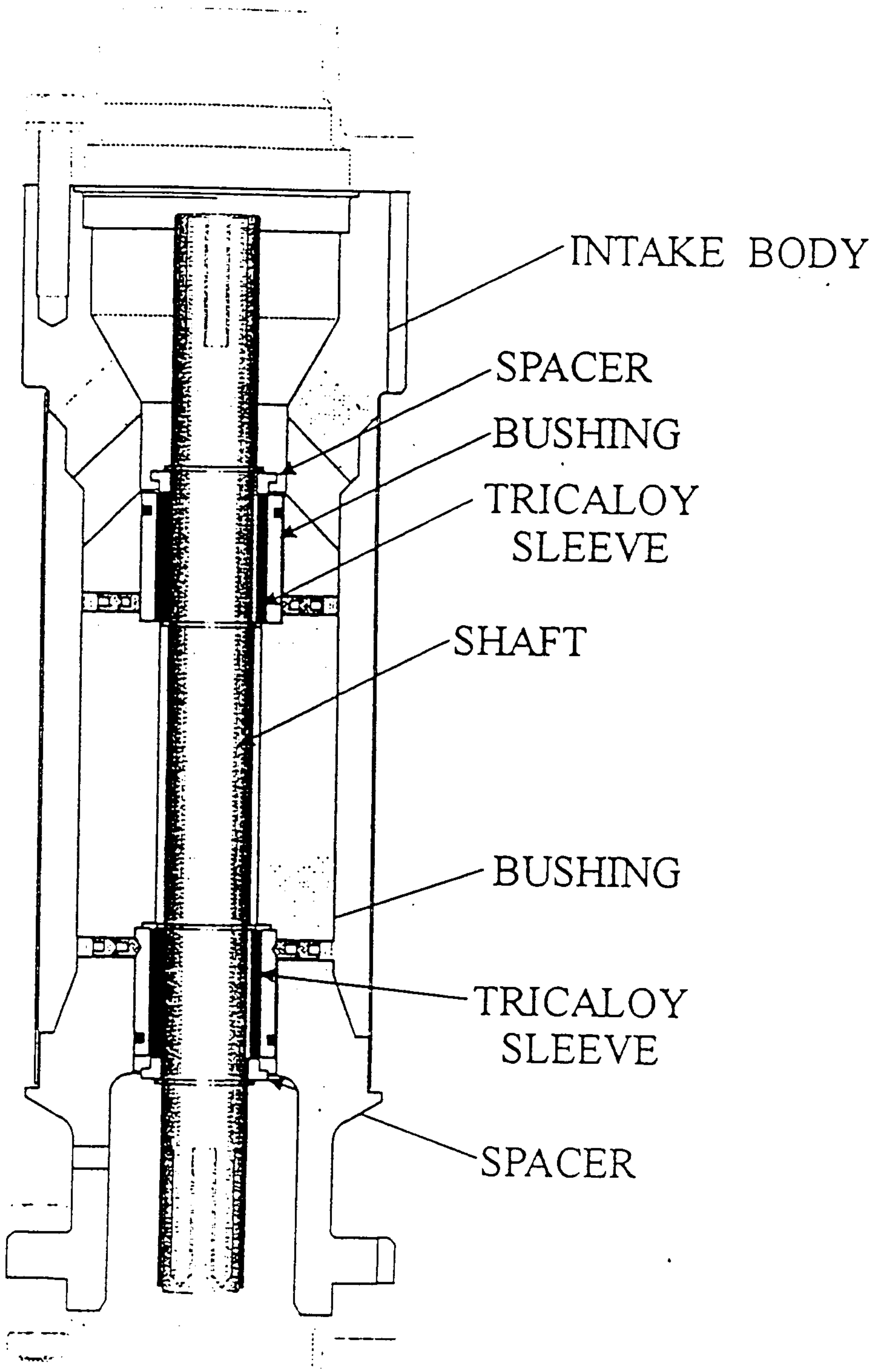
PARTS LIST

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

3.87 INTAKE

BEST AVAILABLE COPY



Attachment 2

Water Quality Monitoring - Grab Sample Results

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-6

(Page 1 of 5)

Date	Time hr:min.	Temperature °C	EC μmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development or Testing
1/14/2000	10:45	36.9	786	8.74	3.10	23.4	N/A	46.2	1,933	Pump functionality testing
1/18/2000	21:00	36.5	638	8.40	1.17	7.9	2.66	62.4	12,323	Pump testing continued
1/18/2000	23:10	36.6	625	8.42	2.75	5.7	0.94	61.2	16,340	
1/19/2000	1:05	37.0	627	8.36	2.50	5.1	0.73	61.1	19,856	
1/19/2000	3:55	37.1	634	8.36	2.65	3.9	0.92	60.6	25,027	
1/19/2000	6:09	37.1	631	8.33	2.54	8.1	1.09	60.4	27,144	
1/19/2000	8:30	37.6	617	8.43	2.22	9.0	0.94	58.3	38,046	
1/19/2000	10:15	37.2	624	8.41	2.04	7.5	0.69	58.0	41,098	
1/19/2000	21:00	37.5	602	8.40	1.30	4.2	0.90	58.5	81,095	Began development & SDDT at 1903
1/19/2000	23:00	37.4	603	8.43	1.50	2.5	0.87	58.3	84,600	
1/20/2000	1:00	37.7	595	8.41	1.50	3.4	0.78	58.1	88,091	
1/20/2000	2:00	37.5	606	8.41	1.80	2.5	0.75	58.0	89,832	
1/20/2000	4:00	37.3	605	8.41	1.20	2.1	0.66	57.9	93,306	
1/20/2000	6:00	37.5	606	8.40	1.50	1.5	0.71	57.6	97,596	
1/20/2000	8:00	37.7	604	8.40	1.50	1.9	0.86	57.5	104,496	
1/20/2000	13:00	37.7	612	8.59	1.10	8.1	0.71	59.3	124,241	Pump off between 0830-1230
1/20/2000	15:13	37.7	605	8.40	1.30	5.0	0.79	63.8	132,225	Incr. Pumping rate to 65 gpm at 1345
1/20/2000	16:45	38.1	608	8.49	1.08	27.1	0.81	68.2	135,337	Pump off between 1552-1635
1/20/2000	17:50	37.3	603	8.39	1.54	10.3	1.02	73.2	140,023	
1/20/2000	19:00	37.4	605	8.45	1.80	6.2	0.70	67.8	141,894	Pump off between 1751-1831
1/20/2000	21:00	37.5	605	8.41	2.20	1.8	0.91	67.5	150,000	
1/20/2000	22:00	37.4	605	8.40	2.00	1.4	0.83	67.3	154,038	
1/21/2000	0:00	37.3	605	8.40	2.00	1.2	0.77	67.0	162,088	

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-6

(Page 2 of 5)

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development or Testing
1/21/2000	2:00	37.5	605	8.38	2.10	1.3	0.95	66.9	170,115	
1/21/2000	4:00	37.7	605	8.39	2.20	1.0	0.83	66.7	178,124	
1/21/2000	6:00	37.5	606	8.39	2.30	1.1	0.92	66.6	186,118	
1/21/2000	8:00	38.2	604	8.38	2.10	1.0	0.84	66.5	194,099	
1/21/2000	10:06	38.1	612	8.48	2.00	8.9	0.66	71.3	199,444	Pump off between 0910-0951
1/21/2000	12:30	37.9	608	8.41	1.70	4.1	0.65	62.2	206,122	Pump off between 1050-1130
1/21/2000	14:30	36.0	604	8.39	2.00	1.4	0.70	64.8	213,731	
1/21/2000	16:30	37.8	599	8.37	2.10	2.0	0.67	68.2	221,710	Pumping at approx. 67 gpm
1/21/2000	19:00	37.4	609	8.44	2.20	7.0	0.67	69.4	228,502	Pump off between 1730-1814
1/21/2000	21:00	37.6	604	8.38	2.50	1.3	0.83	68.9	236,790	
1/21/2000	22:00	37.5	605	8.37	2.40	1.3	0.79	68.7	240,917	Pumping at approx. 70 gpm
1/22/2000	0:00	37.4	604	8.38	2.50	1.0	0.82	70.0	249,268	
1/22/2000	2:00	37.4	606	8.39	2.50	0.8	0.76	69.3	257,597	
1/22/2000	4:00	37.4	606	8.39	2.60	0.9	0.74	69.2	265,901	
1/22/2000	6:00	37.3	603	8.38	2.50	0.8	0.82	69.2	274,203	
1/22/2000	8:00	37.4	604	8.37	2.30	0.9	0.78	69.0	282,491	
1/22/2000	10:00	37.7	605	8.35	2.30	1.1	0.74	68.2	290,724	Pumping at approx. 68 gpm
1/22/2000	12:00	37.8	606	8.34	2.30	1.1	0.69	68.1	298,906	
1/22/2000	14:00	37.8	606	8.33	2.50	1.0	0.71	68.1	307,068	
1/22/2000	16:00	37.4	605	8.34	2.40	0.7	0.71	67.9	315,230	
1/22/2000	18:00	37.4	605	8.35	2.60	1.9	0.64	68.0	323,383	
1/22/2000	20:00	37.5	611	8.32	2.70	0.6	0.83	67.9	331,535	
1/22/2000	22:00	37.6	613	8.35	2.80	0.7	0.81	67.9	339,677	
1/23/2000	0:00	37.5	609	8.35	2.80	0.6	0.80	67.8	347,811	
1/23/2000	2:00	37.5	609	8.36	2.70	0.5	0.77	67.7	355,937	

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-6

(Page 3 of 5)

Date	Time hr:min.	Temperature °C	EC μmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development or Testing
1/23/2000	4:00	37.6	611	8.34	2.50	0.5	0.82	67.8	364,061	
1/23/2000	6:00	37.8	613	8.33	2.40	0.5	0.84	67.7	371,161	
1/23/2000	8:30	36.3	637	8.09	3.82	0.6	0.83	N/D	N/D	No data from flow log recorded
1/23/2000	9:51	37.4	637	8.06	3.34	0.7	0.74	N/D	N/D	
1/23/2000	12:20	36.8	635	8.22	3.58	0.5	0.76	N/D	N/D	
1/23/2000	13:01	37.3	602	8.50	N/A	N/A	N/A	N/D	N/D	grab sample from Hydrolab® data
1/23/2000	14:33	37.1	631	8.12	3.68	0.5	0.84	68.3	406,888	
1/23/2000	16:29	37.1	639	8.10	3.52	0.7	0.77	68.2	414,732	
1/23/2000	18:16	36.4	634	8.07	3.71	0.4	0.76	68.1	422,008	
1/23/2000	20:00	37.4	614	8.28	2.90	0.7	0.73	68.1	429,042	
1/23/2000	22:00	37.6	611	8.27	2.90	1.4	0.70	68.0	437,214	
1/24/2000	0:00	37.5	612	8.28	2.80	0.5	0.62	68.1	445,381	
1/24/2000	2:00	37.6	610	8.27	2.80	0.4	0.65	68.1	453,550	
1/24/2000	4:00	37.8	615	8.27	2.80	0.6	0.62	67.7	461,685	
1/24/2000	6:00	37.3	614	8.27	2.80	0.8	0.61	67.7	469,810	
1/24/2000	8:57	37.4	632	8.22	3.66	0.5	1.01	67.6	481,651	Pump off 0915-1033 & 1055-1157
1/24/2000	12:41	37.2	638	8.25	3.48	8.5	1.13	60.9	486,630	1st step in SDDT at 60.8 gpm
1/24/2000	14:42	36.9	637	8.19	3.81	1.3	1.27	65.1	494,035	2nd step in SDDT at 65.3 gpm
1/24/2000	16:57	36.3	637	8.20	4.03	1.3	0.91	67.9	502,984	3rd step in SDDT at 68.0 gpm
1/24/2000	20:00	37.5	610	8.31	2.90	0.8	0.74	67.4	515,479	
1/24/2000	22:00	37.9	610	8.30	2.90	0.8	0.70	67.2	523,547	
1/25/2000	0:00	37.6	612	8.30	2.90	0.7	0.69	67.1	531,604	
1/25/2000	2:00	37.7	609	8.29	2.90	0.6	0.63	67.0	539,654	
1/25/2000	4:00	37.3	611	8.29	2.90	0.6	0.62	66.9	547,692	
1/25/2000	6:00	37.7	610	8.30	2.90	0.6	0.62	66.8	555,719	

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-6
(Page 4 of 5)

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development or Testing
1/25/2000	8:46	37.0	631	8.21	4.01	0.5	0.95	66.6	566,732	
1/25/2000	15:52	36.4	641	8.19	3.60	6.3	0.87	68.2	570,274	Pump off between 0850-1455
1/25/2000	18:02	36.1	631	8.19	3.94	3.4	0.96	68.3	578,816	Began flow logging at 1640
1/25/2000	20:00	37.5	609	8.31	2.70	2.5	0.70	68.5	587,019	
1/25/2000	22:00	37.3	612	8.32	2.80	1.9	0.62	68.2	595,223	End flow logging at 2230
1/26/2000	0:00	37.1	614	8.32	2.60	0.9	0.64	68.4	603,421	
1/26/2000	2:00	37.2	613	8.31	2.80	0.8	0.63	68.4	611,616	
1/26/2000	4:00	37.3	615	8.32	2.80	0.7	0.62	68.3	619,812	
1/26/2000	6:00	37.1	614	8.31	2.80	0.6	0.63	68.2	628,007	
1/26/2000	8:05	37.0	635	8.26	4.04	0.6	1.08	68.0	636,542	
1/26/2000	10:02	36.1	639	8.21	3.31	1.5	1.00	62.3	643,877	Lower discharge to 61.4 at 0830
1/26/2000	12:05	35.7	633	8.22	3.20	1.0	0.98	62.8	651,689	DRI continues flow logging
1/26/2000	14:10	35.8	638	8.28	3.36	1.2	0.93	62.4	659,500	
1/26/2000	20:00	37.6	621	8.26	2.20	9.5	0.69	68.0	672,893	Pump off between 1430-1815
1/26/2000	22:00	37.2	620	8.28	2.55	3.6	0.72	68.3	679,721	
1/27/2000	0:00	37.3	622	8.26	2.49	1.5	0.68	68.0	687,915	
1/27/2000	2:00	37.3	619	8.25	2.55	1.1	0.76	68.6	696,110	
1/27/2000	4:00	37.4	620	8.26	2.56	1.0	0.74	68.5	704,302	
1/27/2000	6:00	37.6	621	8.26	2.48	0.7	0.67	68.3	712,496	
1/27/2000	8:00	37.0	638	8.20	2.91	0.7	1.34	68.4	720,691	
1/27/2000	10:00	37.1	638	8.14	2.95	0.9	0.98	68.1	728,890	Coll. GW discrt. sample, 0830-1430
1/27/2000	12:00	35.9	637	8.18	2.97	2.3	1.01	68.6	737,093	
1/27/2000	14:00	37.3	638	8.20	3.02	1.1	1.04	69.3	745,295	
1/27/2000	19:17	37.5	636	8.18	3.04	1.4	1.00	68.3	766,998	Shutdown pump for recovery at 2015

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-6
(Page 5 of 5)

Date	Time hr:min.	Temperature °C	EC μmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gal	Comments/Phase of Development or Testing
2/1/2000	16:00	36.2	632	8.59	0.72	10.0	0.56	68.6	772,008	
2/2/2000	16:48	37.7	619	8.35	2.40	0.5	0.65	68.4	873,774	Began constant-rate test at 68.5 gpm
2/3/2000	8:30	37.4	625	8.21	2.26	0.7	0.79	68.4	938,143	
2/4/2000	8:30	37.7	615	8.20	3.07	0.3	0.69	68.3	1,036,683	
2/5/2000	9:50	37.9	613	8.18	3.28	0.2	0.76	68.5	1,140,552	
2/6/2000	9:00	38.1	614	8.09	3.59	0.2	0.77	68.6	1,235,596	
2/7/2000	10:45	37.9	611	8.18	3.65	0.3	0.64	68.5	1,341,264	
2/8/2000	13:20	38.3	616	8.13	3.73	0.3	0.76	68.6	1,450,380	
2/9/2000	9:40	37.9	613	8.12	3.48	0.4	0.73	68.6	1,533,824	
2/10/2000	15:39	37.7	614	8.12	3.83	0.4	0.69	68.3	1,656,900	
2/11/2000	13:42	37.7	613	8.14	3.72	0.4	0.73	68.2	1,747,380	Collect GW composite sample

SDDT - Step-drawdown testing
N/A - Not analyzed
N/D - No data available
GW - Groundwater

Attachment 3

Water Quality Analyses, Composite Characterization Sample and Discrete Samples

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-6
(Page 1 of 3)

Analyte	**Laboratory Detection Limit**[a]	**Laboratory**	**Results of Discrete Bailer Sample #EC-6-012700-1**		**Results of Wellhead Composite Sample #EC-6-021000-1**	
Metals (mg/L)						
			Total	Dissolved	Total	Dissolved
Aluminum	0.2	Paragon	U 0.055	U 0.054	U 0.086	U 0.076
Arsenic	0.01	Paragon	B 0.0078	B 0.0058	B 0.0045	B 0.0041
Barium	0.1	Paragon	B 0.0072	B 0.0065	B 0.0017	B 0.0016
Cadmium	0.005	Paragon	UJ 0.005	UJ 0.005	U 0.005	U 0.005
Calcium	1	Paragon	J 4.7	J 4.7	4.2	4.1
Chromium	0.01	Paragon	U 0.0038	U 0.0021	U 0.00065	U 0.01
Iron	0.1	Paragon	0.57	U 0.045	0.44	0.36
Lead	0.003	Paragon	U 0.003	U 0.003	U 0.003	U 0.003
Lithium	0.01	Paragon	0.13	0.14	0.13	0.14
Magnesium	1	Paragon	U 0.11	U 0.1	U 0.061	U 0.058
Manganese	0.01	Paragon	0.01	U 0.002	0.026	0.025
Potassium	1	Paragon	3.3	3.4	3.2	3.1
Selenium	0.005	Paragon	0.0066	0.0063	U 0.005	B 0.0048
Silicon	0.05	Paragon	22	23	23	23
Silver	0.01	Paragon	U 0.01	U 0.01	U 0.01	U 0.01
Sodium	10, 10, 1, 1	Paragon	100	100	130	140
Strontium	0.01	Paragon	0.011	0.012	B 0.0049	B 0.006
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

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-6
(Page 2 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-6-012700-1	Results of Wellhead Composite Sample #EC-6-021000-1
Inorganics (mg/L) - unless otherwise noted				
Chloride	1, 2	Paragon	52	52
Fluoride	0.1	Paragon	3.3	3.1
Bromide	0.2	Paragon	0.48	0.32
Sulfate	1	Paragon	79	77
pH (pH units)	0.1	Paragon	J 8.1	J 7.4
Total Dissolved Solids	20	Paragon	370	380
Electrical Conductivity (micromhos/cm)	1	Paragon	560	630
Carbonate as CaCO3	5	Paragon	5.9	U 5
Bicarbonate as CaCO3	5	Paragon	120	120
Organics (mg/L)				
Total Organic Carbon	1	Paragon	U 1	U 1
Redox Parameters (mg/L)				
Total Sulfide	5	Paragon	UJ 5	UJ 5
Age and Migration Parameters (pCi/L) - unless otherwise noted				
Carbon-13/12 (per mil)	Not Provided	DRI	N/A	-4.4 +/- 0.2
C-14, Inorganic (pmc)	Not Provided	LLNL	N/A	5.4
C-14, Inorganic age (years)*	Not Provided	LLNL	N/A	24,200
Chlorine-36	Not Provided	LLNL	N/A	7.85E-04
Cl-36/Cl (ratio)	Not Provided	LLNL	N/A	5.41E-13
He-4 (atoms/mL)	Not Provided	LLNL	N/A	1.68E+13
He-3/4, measured value (ratio)	Not Provided	LLNL	N/A	9.11E-07
He-3/4, relative to air (ratio)	Not Provided	LLNL	N/A	6.60E-01
Oxygen-18/16 (per mil)	Not Provided	DRI	N/A	-14.9 +/- 0.2
Strontium-87/86 (ratio)	Not Provided	LLNL	N/A	0.709822 +/- 0.00001
Uranium-234/238 (ratio)	Not Provided	LLNL	N/A	0.000223454

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-6
(Page 3 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-6-012700-1	Results of Wellhead Composite Sample #EC-6-021000-1
H-2/1 (per mil)	N/A	DRI	N/A	-114 +/- 1
Colloids	Not Provided	LANL	See Table ATT.3-2	
Radiological Indicator Parameters-Level I (pCi/L)				
Gamma Spectroscopy	Sample Specific	Paragon	All nuclides reported with a ’U’	All nuclides reported with a ’U’
Tritium	270	Paragon	U -190 +/- 160	U -120 +/- 160
Gross Alpha	1.6, 1.8	Paragon	7.7 +/- 1.7	7.6 +/- 1.8
Gross Beta	2.2, 2.3	Paragon	4.4 +/- 1.5	U 3.6 +/- 1.5
Radiological Indicator Parameters-Level II (pCi/L)				
Carbon-14	300	Paragon	UJ -10 +/- 180	UJ -150 +/- 180
Strontium-90	0.23	Paragon	N/A	U 0.21 +/- 0.15
Plutonium-238	0.035, 0.033	Paragon	U 0.017 +/- 0.021	U 0.003 +/- 0.013
Plutonium-239	0.035, 0.033	Paragon	U -0.005 +/- 0.012	U -0.005 +/- 0.012
Iodine-129	1.4	Paragon	N/A	UJ -0.20 +/- 0.81
Technetium-99	1.7	Paragon	N/A	UJ 0.56 +/- 0.98

U = Result not detected at the given minimum detectable limit or activity.
J = The result is an estimated value.
B = The result is less than the contract-required detection limit, but greater than the instrument detection limit.
N/A = Not applicable for that sample.
mg/L = Milligrams per liter µg/L = Micrograms per liter pCi/L = Picocuries per liter
micromhos/cm = Micromhos per centimeter
pmc = Percent modern carbon
* = The carbon-14 age presented is not corrected for reactions along the flow path.
[a] = If there is only one value present, that value is the detection limit for each analysis (or there was only one analysis).

Table ATT.3-2
Colloid Analyses for Well ER-EC-6
(Page 1 of 2)

Analyte	**Laboratory**	**Results of Discrete Bailer Sample #EC-6-012700-1**	**Results of Wellhead Composite Sample #EC-6-021000-1**
Colloid Particle Size Range (in nanometer)		Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)
50 - 60	LANL	6.844E+06	9.967E+06
60 - 70	LANL	6.145E+06	8.715E+06
70 - 80	LANL	4.946E+06	6.636E+06
80 - 90	LANL	3.347E+06	3.756E+06
90 - 100	LANL	2.973E+06	2.654E+06
100 - 110	LANL	1.499E+06	1.227E+06
110 - 120	LANL	1.474E+06	9.516E+05
120 - 130	LANL	1.149E+06	7.262E+05
130 - 140	LANL	9.242E+05	5.760E+05
140 - 150	LANL	7.994E+05	4.508E+05
150 - 160	LANL	5.996E+05	3.006E+05
160 - 170	LANL	3.498E+05	3.006E+05
170 - 180	LANL	2.498E+05	1.002E+05
180 - 190	LANL	5.246E+05	1.002E+05
190 - 200	LANL	3.498E+05	1.252E+05
200 - 220	LANL	4.746E+05	1.252E+05
220 - 240	LANL	2.750E+05	6.240E+04
240 - 260	LANL	1.464E+05	3.120E+04
260 - 280	LANL	1.016E+05	2.400E+04
280 - 300	LANL	5.380E+04	7.800E+03
300 - 400	LANL	1.536E+05	2.640E+04
400 - 500	LANL	4.300E+04	4.800E+03
500 - 600	LANL	5.020E+04	1.200E+04
600 - 800	LANL	1.040E+05	1.380E+04

Table ATT.3-2
Colloid Analyses for Well ER-EC-6
(Page 2 of 2)

Analyte	**Laboratory**	**Results of Discrete Bailer Sample #EC-6-012700-1**	**Results of Wellhead Composite Sample #EC-6-021000-1**
Colloid Particle Size Range (in nanometer)		Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)
800 - 1000	LANL	3.340E+04	4.200E+03
>1000	LANL	9.440E+04	1.380E+04
Total Concentration, Particle Size Range, 50-1000 nm	LANL	3.37E+07	3.69E+07

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

Analyte	Detection Limit	Laboratory	Qualifier	Results of Discrete Bailer Sample #EC-6-012700-1	Unit
Ag, Dissolved	0.05	UNLV-HRC	<	0.05	µg/L
Al, Dissolved	0.10	UNLV-HRC		23.3	µg/L
As, Dissolved	0.03	UNLV-HRC		5.89	µg/L
Au, Dissolved	0.057	UNLV-HRC	<	0.057	µg/L
Ba, Dissolved	0.010	UNLV-HRC		6.46	µg/L
Be, Dissolved	0.014	UNLV-HRC		0.018	µg/L
Bi, Dissolved	0.004	UNLV-HRC		0.006	µg/L
Cd, Dissolved	0.004	UNLV-HRC		0.020	µg/L
Ce, Dissolved	2.7	UNLV-HRC		7.5	ng/L
Co, Dissolved	0.004	UNLV-HRC		0.021	µg/L
Cr, Dissolved	0.010	UNLV-HRC		1.35	µg/L
Cs, Dissolved	0.004	UNLV-HRC		1.61	µg/L
Cu, Dissolved	0.010	UNLV-HRC		2.87	µg/L
Ga, Dissolved	5.0	UNLV-HRC		288	ng/L
Ge, Dissolved	0.010	UNLV-HRC		0.900	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		20	ng/L
La, Dissolved	3.5	UNLV-HRC		6.1	ng/L
Li, Dissolved	0.009	UNLV-HRC		129	µg/L
Mn, Dissolved	0.01	UNLV-HRC		1.24	µg/L
Mo, Dissolved	0.01	UNLV-HRC		20.5	µg/L
Nb, Dissolved	3.7	UNLV-HRC	<	3.7	ng/L
Ni, Dissolved	0.020	UNLV-HRC		0.250	µg/L
Pb, Dissolved	0.14	UNLV-HRC	<	0.14	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		8.42	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		0.006	µg/L

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

Analyte	Detection Limit	Laboratory	Qualifier	Results of Discrete Bailer Sample #EC-6-012700-1	Unit
Sb, Dissolved	0.005	UNLV-HRC		0.325	µg/L
Se, Dissolved	0.32	UNLV-HRC		5.69	µg/L
Sn, Dissolved	0.006	UNLV-HRC		0.033	µg/L
Sr, Dissolved	0.02	UNLV-HRC		9.15	µg/LL
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		0.660	µg/L
Tl, Dissolved	0.016	UNLV-HRC		0.39	µg/LL
U, Dissolved	0.004	UNLV-HRC		4.18	µg/LL
V, Dissolved	0.010	UNLV-HRC		3.15	µg/LL
W, Dissolved	0.010	UNLV-HRC		2.42	µg/L
Y, Dissolved	0.003	UNLV-HRC		0.008	µg/L
Zn, Dissolved	0.2	UNLV-HRC		6.90	µg/L
Zr, Dissolved	0.026	UNLV-HRC		0.087	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

STATE OF NEVADA
KENNY C. GUINN
Governor

PETER G. MORROS, Director
ALLEN BIAGGI, *Administrator*
(775) 687-4670
TDD 687-4678

Administration
Water Pollution Control
Facsimile 687-5856

Mining Regulation and Reclamation
Facsimile 684-5259

Waste Management
Corrective Actions
Federal Facilities

Air Quality
Water Quality Planning
Facsimile 687-[illegible]

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

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

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

ERD (R)
ERD (RF)
EM (RF)
MGR (RF)

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.

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-6 Development and Testing Data Report*:**

This README file identifies the included data files.

Included with this report are 20 files containing data that were collected electronically during the development and testing program for Well ER-EC-6. 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 4, 5, and 6 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) EREC6L.xls
Bridge plug monitoring data for the lower interval.

2) EREC6M.xls
Bridge plug monitoring data for the lower middle interval.

3) EREC6U.xls
Bridge plug monitoring data for the upper middle interval.

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

5) EC-6_Aqtest_WD.xls
Complete monitoring record of development.

6) EC-6_Aqtest_HT.xls
Complete monitoring record of testing.

7) ER-EC-6 Water Level Monitoring.xls
Pre-development monitoring record.

8) DRIFileInfoGeneric.txt
DRI log head information.

9) ec6mov1, ec6mov2, ec6mov3, ec6mov4, ec6mov5, and ec6mov6.txt
DRI flow logs.

10) erec6stat1, erec6stat2, erec6stat3, erec6stat4, erec6stat5, and erec6stat6.txt
DRI static impeller tool flow measurements.

Distribution

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