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Analysis of Well ER-EC-4 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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Las Vegas, Nevada 89193

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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 ion
C	Carbon
°C	Degrees Celsius
CAU	Corrective Action Unit
CD	Compact disc
Cl	Chlorine
D	Deuterium
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 Pumps, Inc.
°F	Degrees Fahrenheit
FMP	Fluid Management Plan
ft	Foot (feet)
ft/d	Feet per day
ft^2/d	Square feet per day
fpm	Feet per minute
FS	Full scale
FY	Fiscal year
gals	Gallons
gpm	Gallons per minute
He	Helium
HSU	Hydrostratigraphic unit
Hz	Hertz
in.	Inch(es)

List of Acronyms and Abbreviations *(continued)*

ITLV	IT Corporation, Las Vegas Office
K	Hydraulic conductivity
LANL	Los Alamos National Laboratory
Li^+	Lithium ion
LiBr	Lithium bromide
LLNL	Lawrence Livermore National Laboratory
mbar	Millibars
mg/L	Milligram per liter
mL	Milliliter
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
pCi/L	Picocuries per liter
psi	Pounds per square inch
psig	Pounds per square inch gauge
PXD	Pressure transducer
R	Ratio
Ra	Natural atmospheric ratio
REOP	Real Estate/Operations Permit
rev/sec	Revolutions per second
SQP	Standard Quality Practice
SU	Standard Units
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
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-4 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-4 Data Report for Development and Hydraulic Testing*.

1.1 Well ER-EC-4

Well ER-EC-4 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 for Well ER-EC-4 has been documented in the *Completion Report for Well ER-EC-4, September 2000* (DOE/NV, 2000).

Hydraulic testing and groundwater sampling were conducted at Well ER-EC-4 to provide information on the hydraulic characteristics of hydrostratigraphic units (HSUs) and the chemistry of local groundwater. Well ER-EC-4 is constructed with three completion intervals which are isolated from each other by blank casing sections with annular seals. The completion intervals extend over substantial vertical distances and access different HSUs and/or lithologies. Figures illustrating the well construction and lithology are provided in Section 3.0. The testing and sampling activities were designed to assess the completion intervals individually.

1.2 WPM-OV Testing Program

The testing program included:

1. Discrete pressure measurements for each completion interval
2. Well development and step-drawdown tests
3. Flow logging at three pumping rates
4. Collection of discrete groundwater sample(s) with a downhole sampler
5. 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-4 for monitoring are discussed.

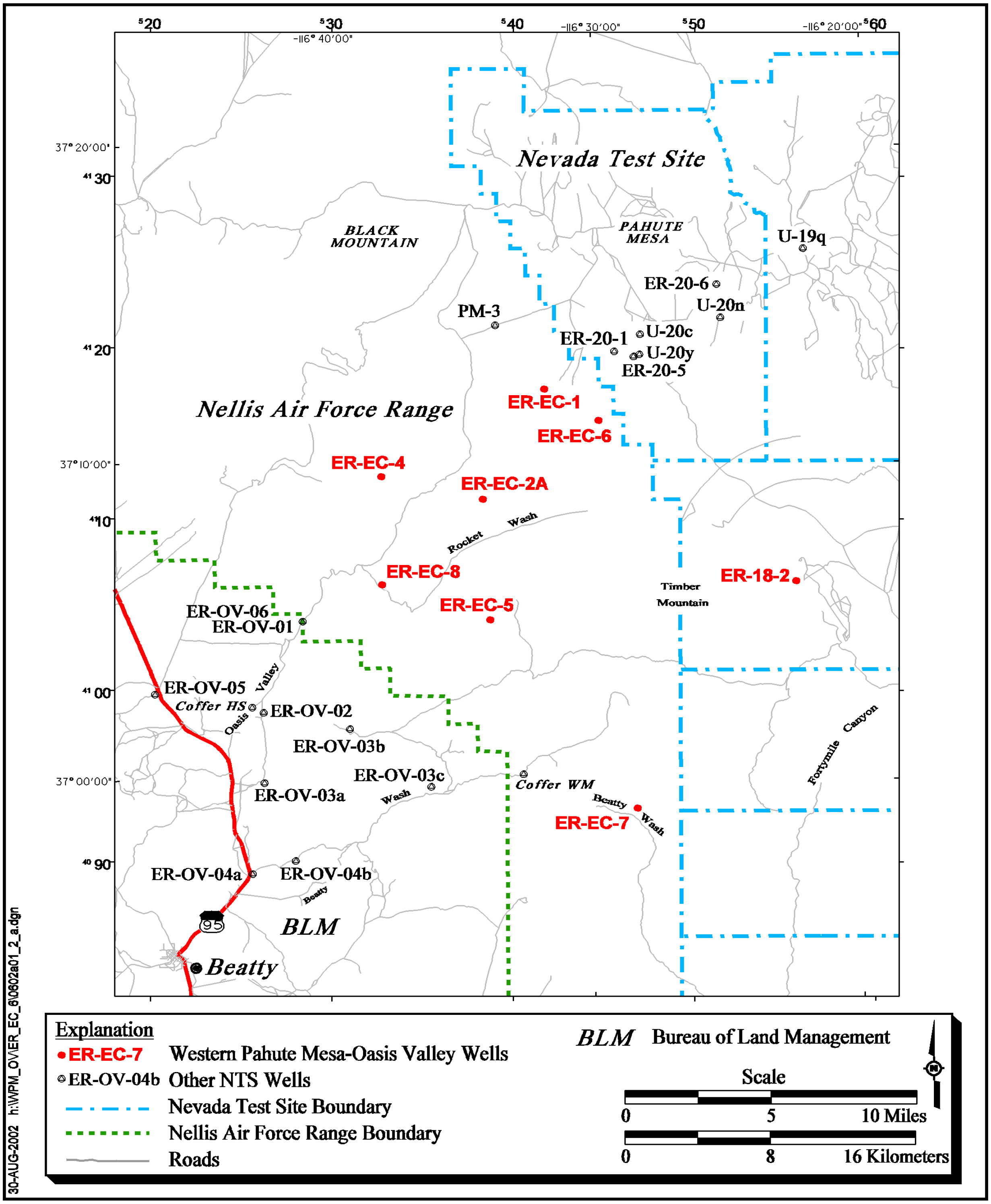


Figure 1-1
Location Map for WPM-OV ER Wells

2.0 Equilibrium Well Hydraulics

This section discusses many aspects of well hydraulics for Well ER-EC-4 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 in that report.

The well is constructed with three separate completion intervals. These intervals are accessed through slotted casing with blank casing interspersed to extend the slotted casing over the completion intervals. The slotted casing is installed as single joints or pairs; two adjacent joints of slotted casing are counted together as one screen. The completion intervals are isolated from each other outside the well casing by cement annular seals. Within each completion interval, the annulus is filled with continuous filter pack extending above and below the screens. Downhole flow features are often discussed with reference to individual screens. The convention for referencing screens is by the consecutive number (e.g., first, second, third) of the screen from the top downward.

2.1 Composite Equilibrium Water Level

Table A.2-2 in Appendix A presents all of the measurements of composite water level (depth-to-water) made during the testing program. The measurements reported in that table were very consistent, and there was no further information collected during the testing program which indicated 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 analysis and produce more accurate results. The importance of determining the correct value for barometric efficiency is somewhat dependent on the magnitude of the drawdown of the well during testing; the greater the drawdown, the less important the barometric correction. However, in circumstances 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 reported in the testing data report was the revised methodology. The analysis for the long-term monitoring yielded an efficiency of 93 percent, which was used to correct the constant-rate test data. Figure A.3-7 of the testing data report (Appendix A) shows this PXD record corrected for barometric variation. The corrected record exhibits an upward trend in the water level and diurnal earth-tide responses. The earth tides have a periodic variation in magnitude, with a cycle period of about 14 days, although this variation is not as clear as for other WPM-OV wells such as ER-EC-5 and ER-EC-7.

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. Note that the measurements were made sequentially as equipment was installed, not contemporaneously. Consequently, the reported head values may include some small changes resulting from trends in head, barometric changes, and earth tides during the installation process. 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 pounds per square inch (psi) as recorded by the instrumentation. The accuracy of these head values is then evaluated.

Table 2-1
Well ER-EC-4 Composite and Interval-Specific Head Measurements

Location in Well	**Initial Equilibration: Head as Depth Below Ground Surface**		**Change from Composite Head**	**End of Monitoring: Head as Depth Below Ground Surface**	
	Feet	Meters	Feet	Feet	Meters
Composite Static WL (e-tape)	748.89	228.26	▨	N/A	▨
Upper Interval (e-tape)	748.72	228.21	+0.17	748.94	228.28
Middle Interval (calculated)	751.83	229.16	-2.94	751.06	228.92
Lower Interval (calculated)	756.48	230.58	-7.59	757.11	230.77

The depth to water was measured in the well before installing the bridge plugs, and after each bridge plug was installed. The depth to water level decreased for each measurement, rising a total of 0.17 ft. This small rise indicates that there was some drawdown in the well associated with downward flow under the natural gradient. The pressure in the lower interval decreased to a stable value over about 20 minutes when the bridge plug between it and the middle interval was set. The pressure in the middle interval immediately decreased to a stable value when the bridge plug between it and the upper interval was set. At the end of the week of monitoring, the upper interval water level had risen about 0.09 ft, after correction for barometric changes.

Table 2-1 reports both the heads based on the initial adjustments and the final heads for each interval. These two sets of head values provide some sense of the variation in the head differences between the completion intervals that occurs over time. Each completion interval has a temporal trend that is somewhat different.

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. E-tape measurements are made to a precision of 0.01 ft, which is the accuracy to which the e-tapes are calibrated. For the reference head and upper interval head measurements, the measurements were made with the same e-tape. E-tape measurements are generally repeatable within 0.10 ft or less per 1,000 ft between independent measurements. 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.

The manufacturer's specification for accuracy of the PXD is 0.1 percent of the full-scale measurement. A 750 psi PXD (SN# 21014) was used in the middle interval, with a nominal accuracy of 0.75 psi (1.75 ft of head) and resolution of 0.06 psi (0.14 ft of head). A 2,500-psi PXD (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 absolute uncertainty (about 2.33 ft) based on this accuracy specification is similar to the head change derived from the measurement (3.2 ft). The calibration certificate supplied for this PXD indicates that the PXD had calibrated within about 0.06 psi at a pressure and temperature similar to those at which the measurements were made. The uncertainty associated with this apparent accuracy is an order of magnitude better, equivalent to about 0.14 ft. This is less than 4 percent of the head difference derived from the measurement. There is no independent measure of the accuracy of the PXD calibration at the time of the measurements at this level. However, the absolute pressure measurement is not used in the calculation to determine head, just the pressure change. The pressure record is very stable, suggesting that the measured change in pressure is probably accurate. The middle interval head is probably about 4.6 to 5.6 ft less than the middle interval.

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# 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# 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 4.65 to 6.05 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 measurements (0.15 ft) and the calibration stability of the PXD (0.40 ft), which is also less than the calculated head difference of 3.11 to 2.12 ft.

The head appears to decline progressively from the upper interval to the lower interval. Based on the potential error analysis, the calculated decline of the head in the lower middle and lower completion intervals exceed the uncertainty in the measurements.

2.4 Variable Density/Viscosity of Water in the Wellbore

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

Figure 2-1 shows the result of calculating the theoretical variation in density of water as a function of the temperature variation in the well. These calculations include the effect of compressibility. The temperature variation was derived from the posttesting ChemTool log, further discussed in Section 2.5.1. The pressures calculated from this exercise are within -0.34 to -0.47 percent of the measured pressure at the various depths of the bridge-plug measurements. For the middle completion interval, the discrepancy in pressure between the PXD measurement and the calculated pressure is from 1.55 to 1.67 psi. As discussed in Section 2.3, the PXD used for the middle interval had a nominal accuracy of 1.0 psi, and a calibration accuracy of 0.20 psi. For the lower completion interval, the discrepancy was 4.44 to 4.63 psi. That PXD had a nominal accuracy of 2.5 psi and a calibration accuracy of -0.27 psi. These numbers indicate that much of the discrepancy is probably not a matter of the accuracy of the PXD. Part of the discrepancy is the uncertainty in accounting for the reference pressure of the PXDs, which is not known and was not recorded in the measurement process. However, the fairly consistent percent discrepancy also suggests that the discrepancy is a consistent factor of the water density. The remainder of the difference is probably due to the other factors mentioned that affect water density. The calculated pressures are less than the adjusted measured pressure, indicating that the actual density is greater than the theoretical density, with the calculated specific gravity varying from 1.0034 to 1.0047. The discrepancy could be easily accounted for by suspended sediment or dissolved solids.

2.5 Flow in the Well Under Natural Gradient

Measurement of flow in the well under the natural gradient can be used in conjunction with other information collected to calculate transmissivity (T) values for the individual completion intervals. There are two types of analysis that can be developed, a steady-state analysis using the measurement of the head differences between the completion intervals, and a transient analysis using the pressure adjustment that occurred when the bridge plugs were set. Additionally, the flow measurements are used to calculate 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 Logs

The nonpumping temperature logs run by Desert Research Institute (DRI) (ChemTool log) six days after the constant-rate test pumping ceased are shown in Figure 2-2, along with the DRI postdevelopment thermal flow measurements discussed in the next section. Temperature logs give an indication of the entry, direction, and exit of flow from the borehole, but do not provide rate of flow information. The posttesting temperature log indicates downward flow from the upper interval to the middle interval, but not flow below the middle interval.

2.5.2 Flow Measurements (Thermal Flowmeter and Spinner Meter)

Thermal flowmeter measurements were made prior to completion and following the testing. The precompletion measurements indicated slight downward flow along the entire borehole of around 0.2 gpm. These measurements are very different from the measurements taken after testing, which showed considerably greater downward flow. Flow in the completed well under natural head gradient (e.g., nonpumping, equilibrium conditions) was measured after recovery following the constant-rate test (see Figure 2-2). The flow measurements are tabulated in Table A.2-10 of Appendix A. The measurements found downward flow of 2.2+ gpm from the upper completion interval downwards, which indicates that the flow exceeded the upper limit of the tool. A spinner tool was also used to log the downward flow, and this log is also shown on Figure 2-2. This log was run at high speed (trolling approximately 140 feet per minute [fpm]) due to lack of time, which probably accounts for the noisiness of the data. The log appears to show downward flow rates of up to 20 gallons per minute (gpm) from the upper completion interval, with rate decreasing with depth. However, some aspects of this log do not make sense. The increase in downward flow rate continued for some distance below the bottom of the upper completion interval, and the log appears to indicate downward flow of 5 gpm at the bottom of the lower interval, which should not be possible. These problems suggest that the high trolling speed caused effects in the well that distort the data. Consequently, these results are not considered to necessarily be quantitatively accurate but confirm that downward flow is occurring at apparently high rates.

2.5.3 Derived Hydraulic Properties

General estimates of the transmissivity of the completion intervals can be derived from information on the flow from and/or into the completion intervals and the hydraulic gradients associated with the flow. An estimate could be made using the empirical equation $T=2000Q/s_w$ (Driscoll, 1986), where Q is the flow rate in gpm and s_w is the drawdown in feet. The head change data and the flow data both have substantial relative uncertainty, but can be used to derive general estimates. The data available for this well provide the basis for lower bound estimates of the transmissivity of the completion intervals. The head differences associated with flow to or from each interval are the changes in head of the isolated completion interval from the composite head, as presented in Table 2-1. The flows attributed to each interval are based on the thermal flowlog measurements. The spinner log indicates higher flow rates, but the values reported appear unreliable. The upper interval appeared to produce a minimum of 2.2 gpm, and the lower interval appeared to receive a minimum of 2.2 gpm. The resultant T values are 3,460 and 78 square feet per day (ft^2/d) for the upper and lower intervals, respectively. The derived hydraulic conductivity (K) values, using the full thickness of the filter pack of the completion intervals, are 12.5 and 0.2 feet per day (ft/d). These are lower bound values based on the minimum flow rates and the lengths of the entire completion intervals. These values can be compared to the K values determined from the flow logging for screens in the upper and lower intervals presented in Table 3-8.

These are only general estimates since the flows are not well defined and the head measurements have substantial inherent uncertainty. While these estimates are less specific and accurate than pumping test information, they can provide estimates of T and K values where better or more specific information is not available.

2.6 Pressure Equilibration Following Setting of Bridge Plugs

The pressure equilibration records for each completion interval following setting the bridge plugs also have the potential for providing information on the transmissivity of the completion interval formation. For the upper completion interval, the recovery record could be analyzed if it could be captured with sufficient early-time data to accurately define the recovery curve. However, the upper interval adjustment was essentially instantaneous and no response curve was captured.

Analysis of the pressure equilibration data for the lower completion intervals can be conducted using a pressure fall-off model following cessation of injection (Earlougher, 1977). The assumptions for this analysis are a confined system, and the injection rate is constant until the injection is stopped. The records for the bridge-plug measurements are shown in Figure A.3-3 and Figure A.3-5 of Appendix A. The record for the middle interval shows rapid equilibration, which did not provide an interpretable curve; consequently, the pressure fall-off analysis cannot be done. The record for the lower interval shows a rapid adjustment over, with equilibration being recorded with 4 data points, which took about 20 minutes. These data points are plotted on Figure 2-3 against log-elapsed time after the bridge plug was set and show a straight-line response. This fits the theory for the pressure falloff analysis, yielding a value for T of 108 ft^2/d and for K of 0.27 ft/d using the flow rate of 2.2 gpm. This again is a lower bound value based on the minimum flow rate and the length of the entire completion interval. This is probably a more accurate value than that derived in Section 2.5.3.

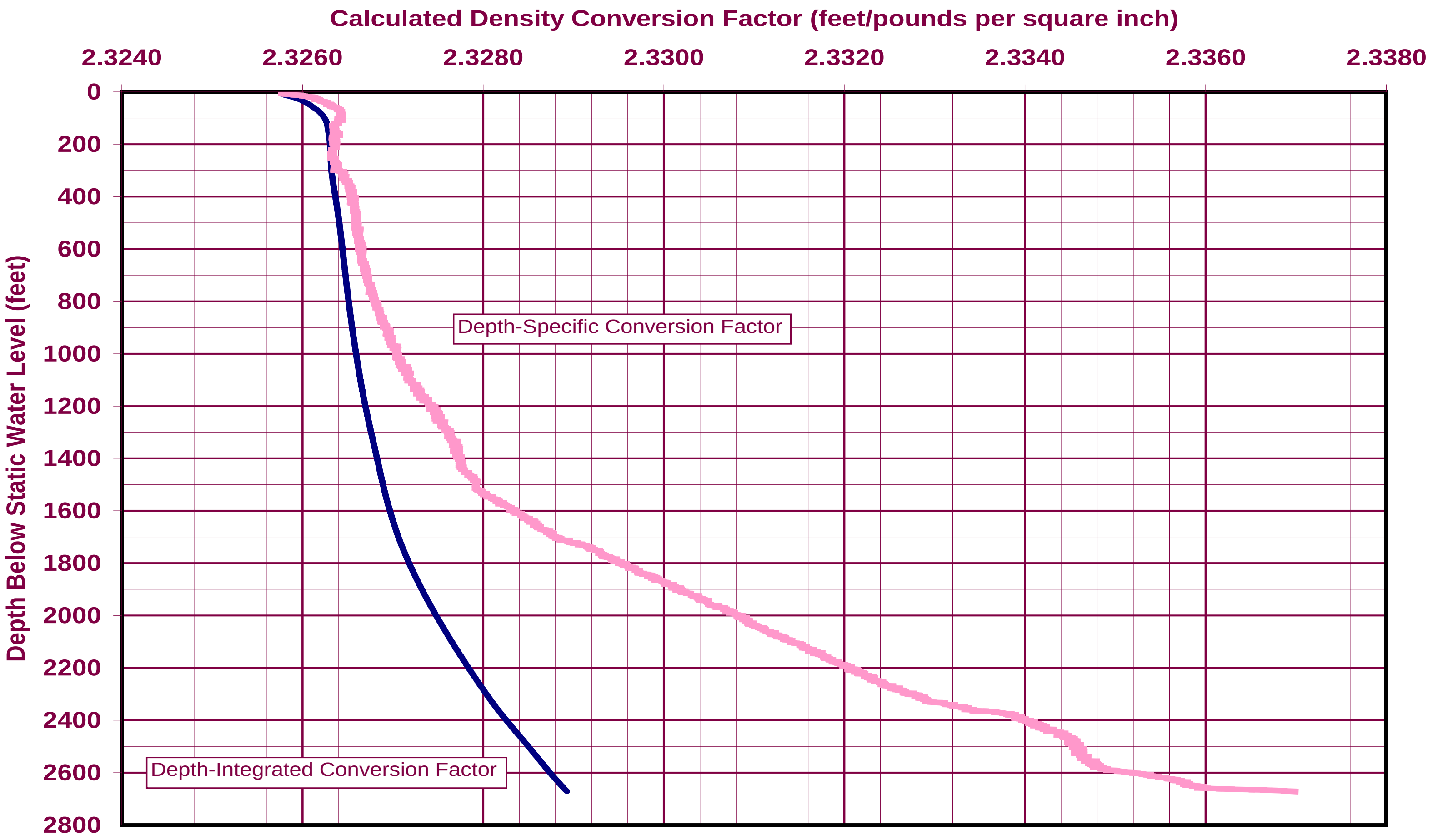


Figure 2-1
Temperature-Dependent Density Variation

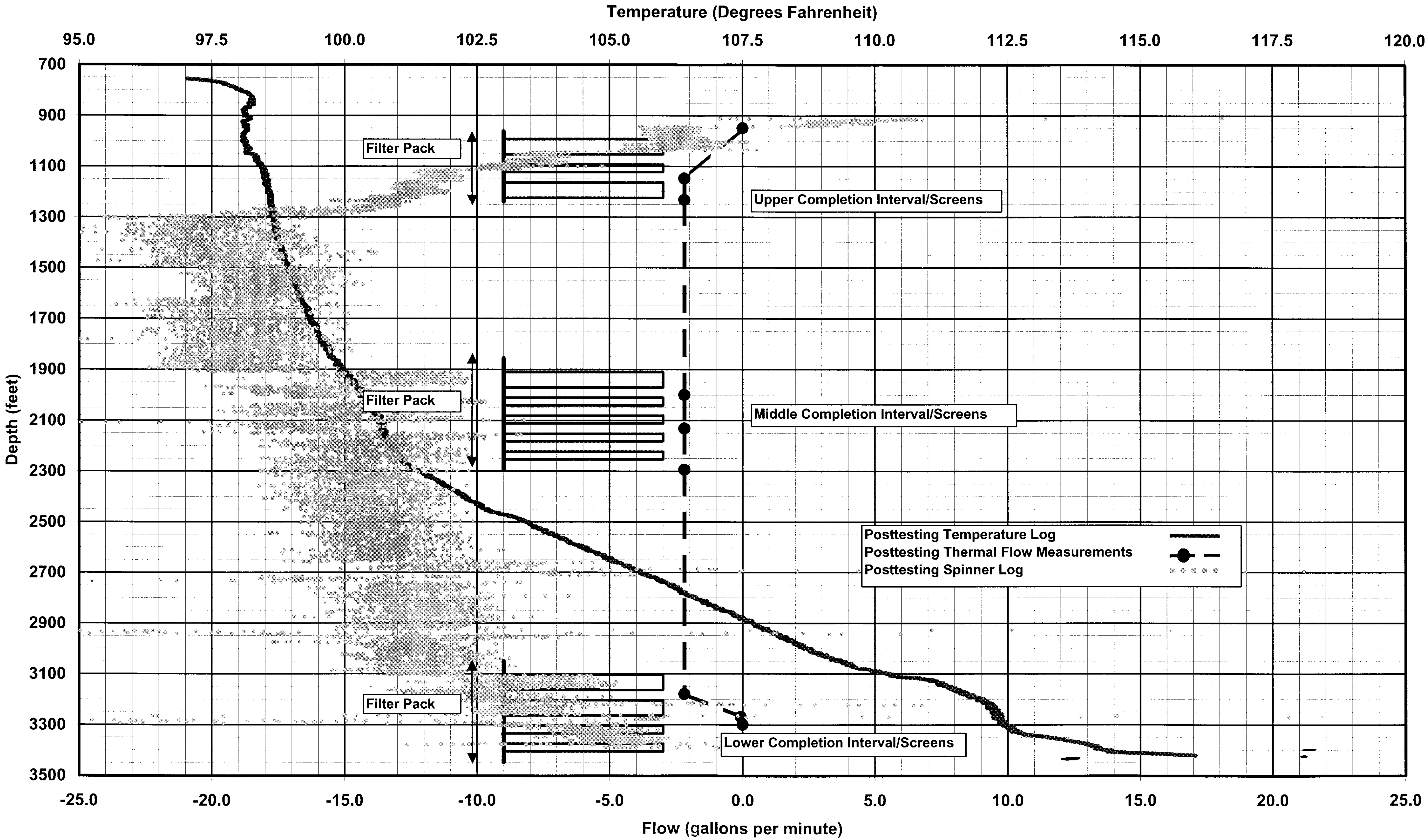


Figure 2-2
Nonpumping Temperature and Flow Logs

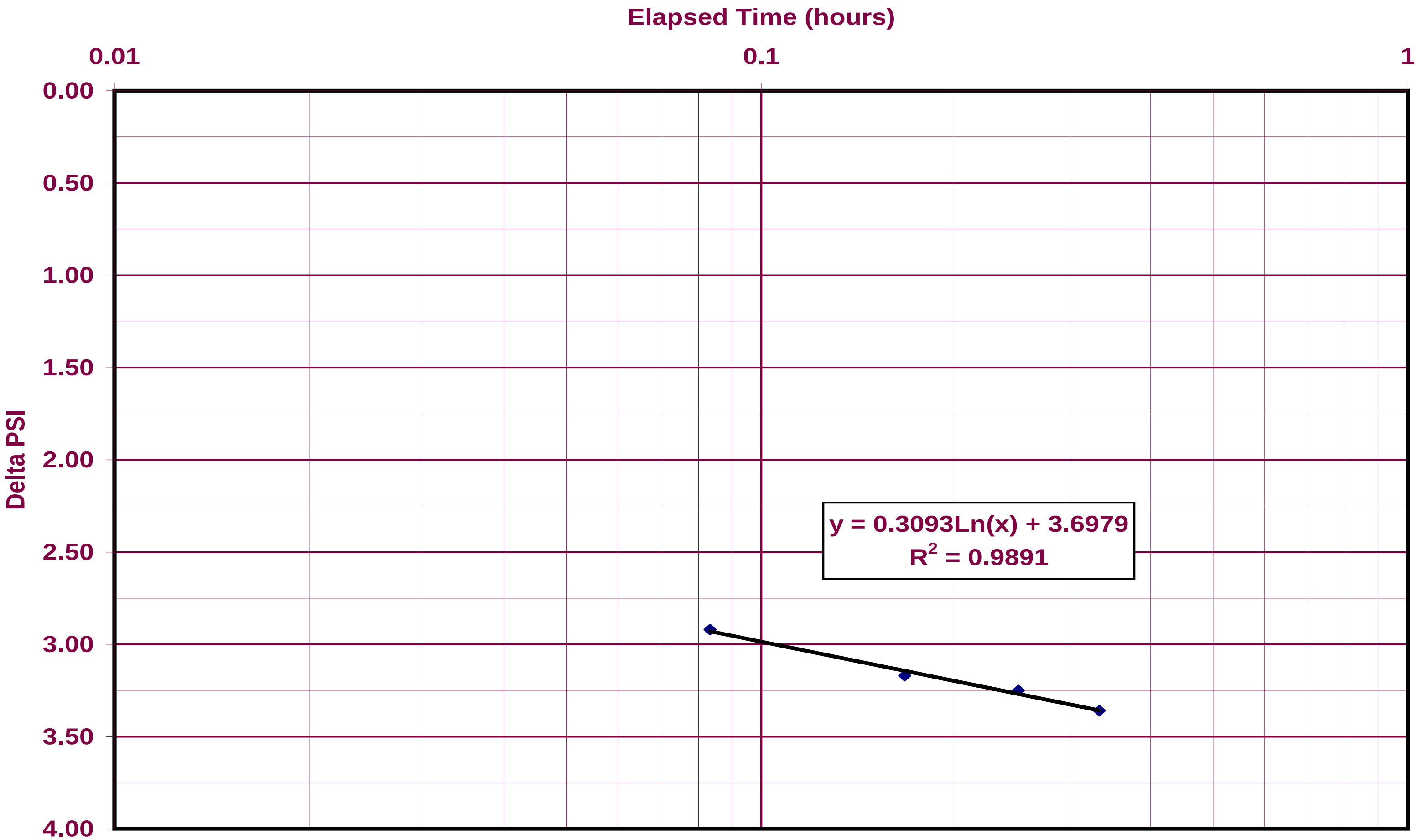


Figure 2-3
Lower Completion Interval Pressure Equilibration

3.0 Pumping Well Hydraulics

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

3.1 Measured Discrete Production

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

Flow logging in conjunction with the testing and sampling allows the interpretation to be made specific to the origin of the produced water and the specific response of each completion interval, or even part of a completion interval. For example, as discussed later in this section, the flowmeter results show that the production was very different between the completion intervals, even after accounting for the different lengths of the completion intervals. Consequently, the derived hydraulic conductivity is substantially greater for the upper interval; whereas, without the flow logging, all of the exposed formation would have been assigned one average value. The groundwater chemistry analyses can also be assigned more specifically to the depth and formation from which the samples actually came.

Figure 3-1 presents a composite picture of temperature and flow logs while pumping. The pumping case was characterized at the end of development and is presented with log ec4mov07 run at a nominal pumping rate of 182 gpm; but all of the logs show very similar results. Figure 3-2, Figure 3-3, and Figure 3-4 show the completion intervals and examples of the flow log for each of the three pumping rates that were used. These figures include depth, lithology, hole diameter, and well construction. Flow log ec4mov01 is presented for 61 gpm, ec4mov04 for 122 gpm, and ec4mov07 for 182 gpm.

All of the quantified production came from the upper completion interval, with the greatest amount from the upper screen of that interval. The flow increases progressively across the upper screen, but comes in as step increases in the second screen and at the top of the third screen. There is additional inflow from the middle interval that is discharged to the lower completion interval. The drawdown that occurred under pumping was less than the natural gradient downward to the lower completion interval, so that a downward gradient persisted in the lower part of the well even while pumping.

3.1.1 Temperature Logs

Figure 3-1 shows the temperature log from the ec4mov07 flowlog, run while the well was being pumped at 182 gpm, and the posttesting ChemTool temperature log. These logs are very similar from the lower part of the upper completion zone downward, indicating downward flow. The pumping temperature log is warmer, probably due to the reduced rate of downflow allowing greater heating from the borehole. The negative offset of the pumping log from the nonpumping log in the upper completion interval is probably due to a calibration difference between the two tools or a change in the near-borehole thermal regime due to the long-term pumping. The steeper gradient between the upper and middle completion intervals indicates higher rate flow between these intervals than between the middle and lower interval.

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 nine logging runs were made at different logging speeds and different pumping rates. In addition, a series of nine 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 listed pumping rates have been updated based on tabulation of the flowmeter records to more accurately reflect the actual average pumping rates.

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

The flowmeter impeller spins in response to water moving through the meter. The rate of revolution is related to water velocity and flow via an equation which accounts for pipe diameter and the trolling speed of the flowmeter. The coefficients of the equation relating the impeller response to the discharge are determined via calibration. In theory, the meter could be calibrated in the laboratory using the same pipe as the well, and no further calibration would be necessary. In reality, the flowmeter response is influenced by a large number of

Table 3-1
Summary of Impeller Flow Logs

Run Number	Direction of Run	Line Speed fpm	Pumping Rate gpm	Run Start/Finish ft bgs
ec4mov01	DOWN	20	61	917-3,388
ec4mov02	UP	40	61	3,392-915
ec4mov03	DOWN	60	61	921-3,388
ec4mov04	DOWN	60	122	924-3,388
ec4mov05	UP	40	122	3,392-926
ec4mov06	DOWN	20	122	925-3,388
ec4mov07	DOWN	20	182	924-3,388
ec4mov08	UP	40	182	3,392-925
ec4mov09	DOWN	60	182	924-3,398
ec4mov10	UP	140	0	3,392-905
ec4stat01	Stationary	0	66	2,700
ec4stat02	Stationary	0	66	1,550
ec4stat03	Stationary	0	66	950
ec4stat04	Stationary	0	177	2,700
ec4stat05	Stationary	0	177	1,550
ec4stat06	Stationary	0	177	950
ec4stat07	Stationary	0	127	2,700
ec4stat08	Stationary	0	127	1,550
ec4stat09	Stationary	0	127	950

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

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-4, the calibration of the flowmeter response is determined using flowmeter data collected above the uppermost screen but below the crossover to the nominal 5.5-inch (in.) pipe. In this section of the well, the amount of water flowing upward to the pump should equal the discharge at the land surface. The flowmeter response is calibrated against the measured surface discharge to provide the necessary coefficients to calculate the discharge at any depth in the well as a function of impeller response and logging speed.

3.1.3 Calibration of the Borehole Flowmeter in the Well

The borehole flowmeter measures the velocity of water movement via an impeller that spins in response to water moving past it. Typically, the flowmeter is calibrated in the laboratory, under controlled conditions, to establish a calibration between the impeller response and discharge. The calibration is specific to a certain size pipe and may be different if flow is moving upward or downward through the meter. Hufschmeid (1983) observed significant differences between the meter response to upward and downward flow and established separate calibration equations for those two conditions. Rehfeldt et al. (1989) also observed different flowmeter responses to upward and downward flow, but the differences were not significant enough to warrant separate calibration equations.

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.

Well ER-EC-4 is constructed with 40 feet (ft) of blank pipe above the uppermost screen. The pump is located above the blank section; therefore, the flow rate in the upper blank section should be the same as the discharge from the well. For each of the pumping rate and line speed combinations, the flowmeter response is recorded at 0.2-foot intervals along the length of the well including the blank section above the uppermost screen. To avoid end effects, the data observed from a 30-ft interval centered between the ends of the blank section are used to determine the calibration.

Data Preparation

Preparation of the flowmeter calibration data includes the following steps:

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

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

Differences in depth reporting equipment leads to errors in reported depths for the logging runs. 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, unless flow clearly occurred within a screened section far away from the ends of the screens. Considering the analysis method used, the impact of this assumption on the results would be negligible.

The flowmeter depths recorded for Well ER-EC-4 were adjusted to ensure that the flowmeter response corresponded to the well construction log. The top and bottom of blank and screened intervals were identified in the flowmeter logs by plotting the rate of change of flow rate versus depth, and recording the locations where flow rate was changing. These depths were compared with the top and bottom of pipe sections in the construction log. Then, the depth of the center of each section was calculated and compared between the two logs. The depth correction to match the flowmeter and construction logs was determined from the average difference in the center depth of blank and screened sections.

Figure 3-5 shows the differential flow log of the well corresponding to flow log ec4mov01 from depths 917.8 to 3,388.6 feet below ground surface (bgs). This depth interval contains the blank casing above the first screen but below the crossover. 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-in. casing is clearly visible at a depth of 948.2 ft bgs. The transition from the upper blank casing to the upper screen is also apparent at depths of 991.6 ft bgs. Likewise, the transition from the upper screen to the second blank casing section is apparent at a depth of 1,049.2 ft bgs. This process was performed for the top three blank sections and three top screened intervals, which could be clearly identified on each logging run. The depth of the midpoint for each of these intervals 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 the two intervals. The calculated depth correction was -2.07 ft. This process ensures that the appropriate depth intervals of the flow logs are analyzed.

Following depth correction, a 30-ft long section of the borehole flow log data (e.g., impeller revolutions per second [rev/sec], line speed, and surface discharge) in the blank section above the uppermost screen were extracted from each of the ten moving flow logging runs and from the three logging runs where the flowmeter was held stationary in the blank section while the well was pumped (stationary runs 3, 6, and 9).

Calibration Equation and Uncertainty

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

1. Determination of a calibration equation that relates the borehole flow rate to the flowmeter response and the line speed
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 (rev/sec) as the dependent variable and the line speed (fpm) and flow rate (gpm) as the independent variables. The second step consisted of expressing the flow rate as a function of the flowmeter response and the line speed by rearranging the equation used to regress the calibration data. The multiple linear regression approach in this work was chosen to provide a method by which the accuracy of the calibration could be quantified.

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

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

where:

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

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

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

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

where:

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

The primary advantage of the multiple regression approach is the ability to estimate the prediction error at any point in the response surface. For a given multiple regression on n data points where y is a variable that is dependent on k independent variables noted x_i, for i=1 to k, the confidence interval for a specific predicted value of y given specific values of the x_i may be calculated using the following equation (Hayter, 1996):

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

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

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

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 2,800 data points. One hundred and fifty-one data points corresponding to ec4mov10 were deleted from the calibration dataset because their inclusion increased the standard error by nearly one order of magnitude. The final calibration dataset includes 2,649 data points. Each data point consists of discrete measurements of line speed (fpm) and flow rates (gpm) (as discharge measurement recorded at the land surface), and a corresponding measurement of flowmeter response (rev/sec).

Table 3-2 contains the values of the coefficients in equations (3-1) and (3-2), the regression model correlation coefficients, and the standard error, which is the root mean square of the predicted minus the observed discharge. In addition to the correlation coefficients and the equation coefficients, Table 3-2 contains the 95 percent confidence intervals for flow rates calculated using specific pairs of flowmeter response and line speed. The 95 percent confidence interval was calculated for the measured range of flow to provide an estimate of the measure of accuracy for the flow rates calculated using the calibration equation. As shown in Table 3-2, the confidence interval is less than 2.88 gpm. Measured flow rates less than 2.88 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 and the surface discharge. The averaged-data approach is conceptually appealing because it eliminates the assumption of a direct link between a downhole response and surface discharge at the same instant in time. However, this approach has a major drawback, it greatly reduces the number of data points.

The averaged-data approach could not be used for Well ER-EC-4 because of the limited number of moving logging runs (10). After averaging along the section of blank casing used for flowmeter calibration, only 10 data points corresponding to

Table 3-2
Flowmeter Calibration Results Using all Data Collected Above the Top Screen at Well ER-EC-4

Equations 3-1 and 3-2 Solutions

	Equation 3-1	**Equation 3-2**
Constant (a and c)	0.0028	-0.1293
First dependent variable (b1 and d1)	0.0215	46.4288
Second dependent variable (b2 and d2)	-0.0215	0.9997
Multiple R	0.9997	-
Sum of Squared Errors	2.6316	5672.8651
Standard Error	0.0315	1.4642
Number of Observations	2,649	2,649

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)**
ec4mov01	0.4919	-22.3865	2.87
ec4mov02	-0.926	42.193	2.88
ec4mov03	1.375	-63.653	2.88
ec4mov04	1.387	-63.446	2.88
ec4mov04	-0.961	44.925	2.88
ec4mov06	0.474	-21.197	2.87
ec4mov07	0.467	-21.06	2.87
ec4mov08	-0.869	41.116	2.88
ec4mov09	1.373	-63.542	2.88

Notes: Impeller rate and line speed values were taken from depths ranging between 1,160.8 and 1,166.2 ft bgs, corresponding to low flow rates measured for this well.

[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.

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-4 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 provided in Table 3-2, 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 Well Construction

The physical construction of the screens and the limited screen length within the completion interval defined by the filter pack results in several limitations for resolving the origin of inflow from the aquifer. The slotting (3-in. slots, 18 per row) for each screen starts 2.5 ft on-center from the end of the casing joint, leaving 5 ft of unslotted casing between 25 ft lengths of closely spaced rows of slots (6-in. on-center). Also, the filter pack extends a substantial distance beyond the ends of the screen. The drawdown imposed by pumping is distributed in some manner throughout the filter pack and stresses the aquifer behind the blank casing. However, there is no way of accurately determining the distribution of inflow behind the blank casing. Some qualitative interpretation may be attempted by evaluating the increase in production at the edges of each screen on the flow logs and attributing some of that production to vertical flow from behind the blank casing, but this is very speculative. The hydraulics of vertical flow in the filter pack and end effects for the screens are undefined. 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 the well is comprised of aquifer drawdown and well losses resulting from the flow of water into the well and up to the pump. Aquifer drawdown can be observed directly in observation wells near a pumping well, but such wells were not available near Well ER-EC-4. The step-drawdown test analysis was used to determine the laminar and turbulent losses, and the laminar losses were attributed to aquifer drawdown. Flow losses inside the well were calculated independently, and subtracted from the turbulent losses to evaluate flow losses into the well. This breakdown of the total drawdown into its components provides better understanding of the hydraulics of water production and better estimates of aquifer properties. While there are some uncertainties in the accurate determination of the components of the drawdown, the calculated component values are better estimates of the actual values than the gross drawdown. This analysis provides more accurate results and reveals details of the hydraulics of production.

3.2.1 Step-Drawdown Test

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

The left side of Table 3-3 shows the basic data derived from the step-drawdown test, and Figure 3-6 shows the resultant graph of that data with the equation for the trendline. The coefficients of the trendline are substituted in the equation for losses, in the form of $s_w = BQ_n + CQ_n^2$ where s_w is the total drawdown in the well, Q_n is the net production rate, B is the linear loss coefficient, and C is the nonlinear loss coefficient. Evaluating this equation at the average production rate for the flow logging of 182 gpm gives a nonlinear component of about 2.79 ft, which is generally equated to turbulent losses in the well. The turbulent losses include flow losses from the aquifer into the wellbore (skin losses), entrance losses into the well casing through the screen slots, and flow losses up the casing to the pump. The linear component of the losses are generally considered to be the laminar losses of the flow in the aquifer. The predicted losses for all three flow logging pumping rates are tabulated in Table 3-3. It is recognized that this approach to determining total well losses for a single well test is not perfectly accurate, but it is believed to provide a reasonable estimate of the well losses. The results are used to estimate the aquifer drawdown, and this drawdown value is used to calculate hydraulic conductivity for each of the screens. This was particularly significant for this well because the calculated well losses are a large fraction (over 60 percent) of the total drawdown.

3.2.2 Flow Losses

Flow losses inside the well casing were computed based on standard theory of flow in a pipe using the Darcy-Weisbach equation. Losses through the slotted sections were assigned friction factors double those of blank pipe (Roscoe Moss Company, 1990). Table 3-4 presents a tabulated profile of calculated friction losses showing the cumulative loss at various locations down the well from the pump intake. The flow rates attributed to each screen section of the well were the

Table 3-3
Step-Drawdown Results and Application

Duration (Days)	Ave Pumping Rate - Q (gallons per minute)	Drawdown s_w (feet)	s_w/Q	Flow Logging Pumping Rate (gallons per minute)	Predicted s_w (feet)	Laminar Losses (feet)	Turbulent Losses (feet)
0.020	64.5	0.95	0.015	61.0	0.90	0.59	031
0.020	121.0	2.52	0.021	122.8	2.56	1.19	1.27
0.021	181.3	4.45	0.025	182.2	4.47	1.77	2.79

Table 3-4
Calculated Flow Losses

Location in Well	Flow at Location (gpm)			Cumulative Friction Loss Inside Casing (ft)			Incremental Flow Losses Into Casing Per Screen (ft)			Total Flow Losses at Center of Screen (ft)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Pump Intake	61.0	122.8	182.2									
Bottom of Pump Motor	61.0	122.8	182.2	0.031	0.106	0.213						
Btm of 7 5/8-in. Casing - Top of Crossover	61.0	122.8	182.2	0.039	0.136	0.273						
Crossover	61.0	122.8	182.2	0.074	0.257	0.517						
Top of Screen 1	61.0	122.8	182.2	0.078	0.270	0.546	0.07	0.20	0.42	0.18	0.59	1.20
Bottom of Screen 1	22.5	50.9	78.0	0.144	0.501	1.012						
Top of Screen 2	22.5	50.9	78.0	0.149	0.524	1.060	0.10	0.25	0.45	0.25	0.78	1.53
Bottom of Screen 2	0.0	11.1	24.2	0.155	0.548	1.111						
Top of Screen 3	0.0	11.1	24.2	0.155	0.549	1.117	0.00	0.32	0.91	0.15	0.87	2.03
Bottom of Screen 3	0	0	0									

Blank = Not applicable

average of the inflows from the flow logs that were conducted at pumping rates of about 182.2 gpm. These losses are associated with the flow of water up the well, and are only affected by the flow rate at each point where the loss is tabulated. The flow rates at each point of tabulation for the well screens should have been fairly stable since the well had been pumping for some time and the drawdown did not increase substantially during the period of logging. For the best applicability of flow logging data, flow logging should take place only after sufficient continuous pumping at each rate to achieve relatively stable drawdown.

For all three flow logging pumping rates, the component of turbulent losses for flow into the well casing were calculated by subtracting the flow losses inside the casing from the total turbulent losses tabulated in Table 3-3. The turbulent losses for flow into the well casing were then apportioned according to the flow through each screen by the square of the velocity.

This analysis was done using the flow logging pumping rates for use in the flow logging analysis. However, the constant-rate test pumping rate, 180.8 gpm, was very close to the 182.2 gpm flow logging rate, and the calculated flow losses would be very similar for the constant-rate test.

3.3 Head Distribution Under Pumping

The column in Table 3-4 labeled "Cumulative Friction Loss Inside Casing" tabulates the loss of head down the well casing due to flow up the casing. These values can be subtracted from the total measured drawdown to calculate the head at each tabulation point down the casing. For example, during the flow log runs at 182.8 gpm, the drawdown in the well would have been approximately 4.47 ft. This estimate is based on the equation derived from the step-drawdown test. During flow logging, the PXD was removed to allow access downhole, and drawdown could not be measured directly. At this time, the drawdown in the casing at the top of the first screen would have been about 3.92 ft (4.47-0.55), and the drawdown at the top of the second screen would have been about 3.46 ft. The column labeled "Total Flow Losses at Center of Screen" provides the total calculated flow loss from the aquifer into the casing and up to the pump intake. Subtracting this value from the total drawdown gives the aquifer drawdown at the center of each screen. The average drawdown for the flow inside the casing across the first screen would have been about 2.35 ft (4.47-1.20). The calculated total friction loss inside the casing is 1.12 ft, a substantial part of the turbulent losses of 2.79 ft calculated from the equation derived from the step-drawdown data. The losses from flow through the slots (calculated as approximately 0.9 ft, assuming they are 100 percent open) accounts for over half of the remaining turbulent losses. The remaining part of the turbulent losses is attributed to borehole losses, either due to a damaged borehole wall or clogged filter pack/screen slots. These small losses are reflected in the fairly low well skin factor determined in the constant-rate test analysis discussed in Section 3.4.

The purpose of these computations is to estimate the actual aquifer drawdown at each pumping rate for each screen. The flow loss values will be used in the flow logging analysis to calculate the hydraulic conductivity attributed to the production from each screen. This analysis shows that 60 percent of the measured drawdown results from flow losses in the well, and that the actual formation drawdown is only about 40 percent of the measured drawdown.

3.4 Constant-Rate Test Analysis

The constant-rate test provides data for determining the overall transmissivity of the well. The features of the record are explained in Section A.3.4.2 of Appendix A. The average pumping rate for the test was 180.8 gpm. 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) non-linear 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 (209.4 ft) for the producing section of the upper completion interval for aquifer thickness. This solution yields a K of 59.88 ft/day with an associated T of 12,539 ft^2/d. Figure 3-8 shows a solution using the combined length of the producing screens (85.5 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 155.1 ft/day, yielding a T of 13,261 ft^2/d.

The difference in these two values for aquifer thickness represents the overall uncertainty in the length of formation producing water. Examination of the flow logs generally finds progressive increases in flow near the bottom and top of the slotted portion of the screens rather than sudden increases which might be expected as an indication of substantial production behind the blank casing. However, the flow distribution that would be observed across the screen if there was significant production coming vertically through the filter pack has not been characterized in any calibrated fashion. Flow losses in the filter pack have an effect on the applied distribution of drawdown to the formation. Very high localized production related to a fracture would result in a different situation from well-distributed production from porous media. 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.

The analysis in Section 2.5.3 for the upper completion interval hydraulic conductivity produced a lower bound value of about 12.5 ft/d. The composite K for the well from the constant-rate test analysis is about 60 ft/d. However, as was mentioned in Section 2.5.2, the production from the upper zone may have been up to six times the value from the thermal flow logging that was used, which would yield a similar K value.

3.5 Interval Transmissivities/Conductivities

The flowmeter data provide a detailed assessment of the sections of the completion intervals producing water for determining the average hydraulic conductivity. In addition, the flowmeter data provide measurements to attribute varying production to the different 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.

3.5.1 The Borehole Flowmeter Method - Concept and Governing Equations

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

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

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

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

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

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 equation (3-8) (a special case of equation [3-7]) and equation (3-10).

3.5.2 Calculation Process to Determine Interval Hydraulic Conductivity Values

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

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

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

3.5.3 Selection of Depth Intervals to Calculate Hydraulic Conductivity

To determine the hydraulic conductivity of an interval, the interval must be defined by top and bottom depths so inflow to the well can be determined. Previous applications of the flowmeter method (Rehfeldt et al., 1989; Hufschmeid, 1983; and Molz et al., 1989) calculated hydraulic conductivity at small intervals within fully-screened wells in unconfined aquifers. One criterion to determine the size of the interval is to assess the minimum interval necessary to ensure that a statistically significant amount of flow enters the well between one flowmeter measurement and the next. The confidence intervals determined from equation (3-2) suggest that the difference in discharge should be greater than about 2.88 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 feet or more.

In partially-penetrating wells, or irregularly screened wells such as ER-EC-4, the horizontal flow assumption may not hold. Cassiani and Kabala (1998) examined flow to a partially-penetrating well in an anisotropic confined aquifer where wellbore storage and infinitesimal skin may be present. They showed that, in their example, the flux near the end of the well screen could be exaggerated more than several times compared with elsewhere along the screen. Previous work by Ruud and Kabala (1996, 1997b) also showed that the flux to partially penetrating wells in heterogeneous aquifers can be significantly nonuniform and is a function of the hydraulic conductivity contrast of the adjacent layers. Ruud and Kabala (1997a) also examined the flow to a well in a layered aquifer with a finite skin zone. For their examples, they showed that the horizontal flow assumption inherent in the flowmeter analysis was violated and led to incorrect estimates of interval hydraulic conductivity values. The errors associated with violation of the horizontal flow assumption increase as the layer size decreases (i.e., the smaller the measurement interval). Another factor that may lead to errors is the head loss associated with flow through the borehole flowmeter itself. Ruud et al. (1999) show that head loss caused by the flowmeter can force water to flow in the filter pack outside the well and can lead to errors in measured flow.

For the WPM-OV wells where alternating screen and blank sections are present, the errors in estimated K values may be substantial if the analysis interval is too small. To avoid the need to quantify the potential errors for the WPM-OV wells, the decision was made to interpret the flowmeter response for each screened interval that produced statistically measurable flow. As stated before, Well ER-EC-4 has 12 screened intervals. Each screened interval is composed of one or two slotted sections of pipe. The length of a single slotted section is approximately 30 ft with slots beginning about 2.5 feet from both ends. Hydraulic conductivity values averaged over intervals corresponding to continuous strings of producing screened intervals are expected to provide adequate vertical resolution for the CAU-scale and sub CAU-scale models.

3.5.4 Calculation of Hydraulic Conductivity of Each Interval

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

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

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

Interval Flow Rates (Q_i)

The quantities of inflow from each interval may be calculated from the flow in the well measured in the blank casing sections above and below each screen. The average discharges through the blank sections were determined for the portions of pipe centered between the ends of the blank section. This corresponds to lengths of 30 ft for all blank sections except Blank 4 and Blank 9 which have lengths of 200 ft. The average discharge values are tabulated in Table 3-5 for the blank sections. The point at which the flow changes directions within the well is also shown in Table 3-5. This point occurs in the upper part of Screen 3 resulting in the creation of two sub-intervals (screens 3-1 and 3-2). The inclusion of this point (referred to as a pseudo-blank) will allow calculation of the portion of flow that is discharged from the well, and the flow portion that moves down the well. Flow rates calculated for the screened intervals are presented in Table 3-6, beginning with the uppermost intervals. Flow rates were not recorded for the deepest blank section. However, flow rates recorded for the upper part of the lowermost screen of Well ER-EC-4 are statistically equal to zero. Therefore, flow at the bottom of the well is assumed to equal zero for all flow logs.

As seen in Table 3-5 and Table 3-6, several flow rates observed in Well ER-EC-4 are statistically equal to zero (less than 2.88 gpm), or significantly negative (less than -2.88 gpm). Hydraulic conductivities were calculated only for screens for which flow rates exceed +2.88 gpm. The top two screened intervals of Well ER-EC-4 (1 and 2) produced measurable flow for all moving flow logs at all three pumping rates. Screen 3-1 produced measurable flow only for moving flow logs recorded at the pumping rates of 123 and 182 gpm. Even though Screen 3-2 and the middle screened interval produce measurable positive flow for certain flow logging runs, this flow moves down the borehole and reenters the formation through either the middle screened interval, the bottom screened interval, or both. Hydraulic conductivities were not calculated for Screen 3-2, the Middle Screen, and the Lower Screen.

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:

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

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.

Formation and Interval Drawdowns (s and s_i*)*

The formation drawdown is the drawdown observed at a given time t since pumping began at a given pumping rate Q, adjusted for well flow losses. Well flow losses were calculated using an average of the “Total Flow Losses at Center of Screen” presented in Table 3-4 weighted by the intervals’ flow rates

Table 3-5
Average Flow Rates Through the Blank-Casing Sections in gpm During the Flow Logging Runs of Well ER-EC-4[a]

Pumping Rate = 61 gpm				
Blank Number	**ec4mov01**	**ec4mov02**	**ec4mov03**	**Average**
1	60.91	60.88	61.08	60.95
2	23.04	22.04	22.58	22.55
3	0.72	-1.47	0.88	0.04
Pseudo-Blank[b]	0.00	0.00	0.00	0.00
4	-9.75	-11.28	-8.94	-9.99
9	-6.10	-7.82	-5.99	-6.64
Pumping Rate = 123 gpm				
Blank Number	**ec4mov04**	**ec4mov05**	**ec4mov06**	**Average**
1	122.31	122.84	123.33	122.83
2	51.24	50.66	50.95	50.95
3	11.83	10.02	11.56	11.13
Pseudo-Blank	0.00	0.00	0.00	0.00
4	-5.46	-8.36	-6.52	-6.78
9	-4.03	-6.62	-5.26	-5.31
Pumping Rate = 182 gpm				
Blank Number	**ec4mov07**	**ec4mov08**	**ec4mov09**	**Average**
1	182.40	181.81	182.51	182.24
2	77.16	78.17	78.76	78.03
3	23.26	24.49	24.75	24.17
Pseudo-Blank	0.00	0.00	0.00	0.00
4	-1.02	-2.28	0.63	-0.89
9	-3.26	-4.58	-2.12	-3.32

[a] Flow at the bottom of the well is assumed to be zero.

[b] Pseudo-blank is defined as point in well were flow in the well changes direction. This point is located in the uppermost portion of Screen 3.

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

Pumping Rate = 61 gpm				
Screen Number	**ec4mov01**	**ec4mov02**	**ec4mov03**	**Average**
1	37.87	38.84	38.50	38.41
2	22.32	23.51	21.70	22.51
3-1	0.72	-1.47	0.88	0.04
3-2	10.47	9.80	9.81	10.03
Middle Screens	-3.65	-3.45	-2.94	-3.35
Lower Screens	-6.10	-7.82	-5.99	-6.64
Pumping Rate = 123 gpm				
Screen Number	**ec4mov04**	**ec4mov05**	**ec4mov06**	**Average**
1	71.07	72.18	72.39	71.88
2	39.41	40.65	39.38	39.81
3-1	11.83	10.02	11.56	11.13
3-2	5.46	8.36	6.52	6.78
Middle Screens	-1.42	-1.73	-1.25	-1.47
Lower Screens	-4.03	-6.62	-5.26	-5.31
Pumping Rate = 182 gpm				
Screen Number	**ec4mov07**	**ec4mov08**	**ec4mov09**	**Average**
1	105.24	103.65	103.75	104.21
2	53.90	53.68	54.01	53.86
3-1	23.26	24.49	24.75	24.17
3-2	1.02	2.28	-0.63	0.89
Middle Screens	2.25	2.30	2.75	2.43
Lower Screens	-3.26	-4.58	-2.12	-3.32

[a] Flow from bottom of well is assumed to be zero.

(Table 3-7). These weighted average well flow losses were substracted from the total drawdown to obtain an estimate of the formation drawdown for each pumping rate.

To capture the range of uncertainty associated with drawdowns during the flow logging, two sets of time-drawdown pairs were used. The drawdowns in the well corresponding to a pumping rate of 182 gpm were obtained from the time-drawdown data recorded during the constant-rate test. Drawdowns in the well for the other two pumping rates were estimated using the Cooper-Jacob (1946) equation applied to the whole well. The well transmissivity value derived from the constant-rate test was used in these calculations. The drawdowns were calculated for the time period between 0.0417 and 0.71875 day, after pumping began. This period approximately corresponds to the time period during which the flow logs were conducted. The formation drawdown was calculated by substrating the weighted average flow loss in the well (shown in Table 3-7) from the well drawdown values described above.

Table 3-7
Calculation of Average Well Losses For Each Pumping Rate

Q= 61 gpm			
Screen	**(1) Flow Rate into Well (gpm)**	**(2) Total Flow Losses at Center of Screen (ft)**	**(1) X (2)**
Screen 1	38.41	0.18	6.91
Screen 2	22.51	0.25	5.63
Screen 3-1	0.04	0.32	0.01
Total Flow	60.95		
Weighted Average Flow Loss in the Well = 0.21 ft			
Q= 123 gpm			
Screen 1	71.88	0.59	42.41
Screen 2	39.81	0.78	31.06
Screen 3-1	11.13	0.87	9.69
Total Flow	122.83		
Weighted Average Flow Loss in the Well = 0.68 ft			
Q= 182 gpm			
Screen 1	104.21	1.2	125.06
Screen 2	53.86	1.53	82.41
Screen 3-1	24.17	2.03	49.06
Total Flow	182.24		
Weighted Average Flow Loss in the Well = 1.41 ft			

The individual screen's formation drawdown (s_i) at the effective radius of the well are calculated as the drawdown in the well corrected for friction, entrance, and skin losses. These losses have been estimated previously and were presented in Table 3-4 and Table 3-7 as "Total Flow Losses at Center of Screen."

Transmissivity of the Formation

The transmissivity of the formation is the well transmissivity as calculated from the constant-rate test adjusted for well flow losses. An estimate of the formation transmissivity was derived by multiplying the transmissivity derived from the constant-rate pumping test (Q=182 gpm) by the ratio of the formation drawdown to the well drawdown at t=0.71875 day. The well drawdown @ 0.71875 day is 4.55 ft. As shown in Table 3-7, the average well flow losses at 182 gpm are equal to 1.41 ft. The estimated formation losses are, therefore, equal to 3.14 ft. As a result, the ratio of the formation drawdown to the observed well drawdown is equal to 0.69. As reported earlier, the transmissivity derived from the constant-rate pumping test is equal to 12,539 ft^2/d (for b=209.4 ft). The derived estimate of formation transmissivity is 18,155.66 ft^2/d.

Individual Interval's Transmissive Thickness (b_i)

The interval thickness is not precisely known because flow to the screen may be derived, in part, from behind the blank section of pipe above or below the screen. For Screens 1 and 2, the minimum contributing thickness is assumed to be the length of screen (between approximately 25 ft and 58 ft depending on the screen), and the maximum is assumed to be equal to the lengths of the filter packs (between approximately 70 and 111 ft). The thickness of Screen 3-2 was estimated to be 1.6 ft long and corresponds to the upper part of the slotted portion of Screen 3. The maximum thickness of Screen 3-2 was estimated to be 28 ft. The minimum thicknesses do not include the nonslotted portions of continuous strings of slotted sections of pipe.

3.5.4.1 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 interval hydraulic conductivities from equations (3-8) and (3-10) are given in Table 3-8 for each of the logging runs. The hydraulic conductivity of each interval is the interval transmissivity from equations (3-8) and (3-10) divided by the interval thickness. For all logging runs, the sum of the individual interval transmissivities represent the transmissivity of the formation within a reasonable margin of error.

Table 3-8
Interval Hydraulic Conductivities Calculated From Flow Logging Data for Well ER-EC-4

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)
			$s_{t=0.0417\ d}$[a]	$s_{t=0.71875\ d}$[b]	-		$s_{t=0.0417\ d}$	$s_{t=0.71875\ d}$	-
ec4mov01	Screen 1	58.41	193.11	197.80	204.17	110.54	102.04	104.52	102.01
ec4mov02	Screen 1	58.41	198.19	202.83	209.14	110.54	104.73	107.18	104.49
ec4mov03	Screen 1	58.41	195.66	200.33	206.67	110.54	103.39	105.86	103.26
ec4mov04	Screen 1	58.41	175.15	181.48	190.38	110.54	92.55	95.89	95.12
ec4mov05	Screen 1	58.41	178.24	184.57	193.48	110.54	94.18	97.53	96.67
ec4mov06	Screen 1	58.41	178.74	185.07	193.98	110.54	94.45	97.79	96.92
ec4mov07	Screen 1	58.41	175.72	175.99	189.90	110.54	92.85	92.99	94.88
ec4mov08	Screen 1	58.41	172.03	172.30	186.12	110.54	90.90	91.04	92.99
ec4mov09	Screen 1	58.41	172.96	173.23	187.06	110.54	91.39	91.54	93.46
ec4mov01	Screen 2	25.43	300.45	289.60	276.32	70.75	108.00	104.10	93.92
ec4mov02	Screen 2	25.43	317.44	305.45	290.78	70.75	114.11	109.80	98.83
ec4mov03	Screen 2	25.43	290.19	280.00	267.53	70.75	104.31	100.65	90.93
ec4mov04	Screen 2	25.43	265.24	255.02	242.51	70.75	95.34	91.67	82.42
ec4mov05	Screen 2	25.43	274.38	263.53	250.25	70.75	98.63	94.73	85.06
ec4mov06	Screen 2	25.43	265.13	254.92	242.42	70.75	95.31	91.63	82.39
ec4mov07	Screen 2	25.43	232.86	232.66	223.41	70.75	83.70	83.63	75.93
ec4mov08	Screen 2	25.43	230.66	230.47	221.39	70.75	82.91	82.84	75.25
ec4mov09	Screen 2	25.43	233.15	232.96	223.67	70.75	83.81	83.74	76.02
ec4mov04	Screen 3-1	1.63	1511.58	1337.35	1138.66	28.12	87.37	77.30	65.81
ec4mov05	Screen 3-1	1.63	1266.47	1125.59	965.04	28.12	73.20	65.06	55.78
ec4mov06	Screen 3-1	1.63	1475.96	1306.65	1113.58	28.12	85.31	75.52	64.36
ec4mov07	Screen 3-1	1.63	2087.30	2072.95	1508.46	28.12	120.64	119.81	87.19
ec4mov08	Screen 3-1	1.63	2192.81	2177.63	1580.63	28.12	126.74	125.86	91.36
ec4mov09	Screen 3-1	1.63	2225.84	2210.43	1604.06	28.12	128.65	127.76	92.71

[a] Drawdown in the well 0.0417 day after pumping started

[b] Drawdown in the well 0.71875 day after pumping started

3.5.5 Sources of Uncertainty

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

The model uncertainty is principally the result of violations of key model assumptions such as the applicability of the Cooper-Jacob equation describing horizontal flow to the well. As Ruud and Kabala (1997a and b), Cassiani and Kabala (1998), and Ruud et al. (1999) note, vertical flow may occur in the vicinity of the well due to heterogeneity, head losses, well skin effects, and partially penetrating screens. Each of these can lead to errors in the calculated interval hydraulic conductivity when using the horizontal flow assumption. Many of the errors due to small-scale vertical flow have been minimized in this work by integrating flowmeter responses over the length of each screened section. Other sources of model uncertainty include the assumed form of the interval storage coefficient. The impact of the latter assumptions are presented in Table 3-8.

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 2.88 gpm. This means that flow uncertainty is a small factor for the intervals which produced the most water, but could be a significant factor, almost 100 percent of the value for the middle screens. The drawdown in the aquifer is uncertain because it relies on corrections for well losses, both inside and outside the well. The well loss corrections are similar down the well, but the impact of the uncertainty will be larger for the lower screen which has a lower flow rate.

The parameters within the logarithmic term of equation (3-10) 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 3-8 summarized the hydraulic conductivity for each interval for each logging run using a range of interval thickness and a range of drawdowns. As can be seen, for a given screen, the differences between logging runs is quite small, considering that the logging runs were made at different times after pumping began. Therefore, the time of measurement was not a significant source of error in the interpretation. This is consistent with the expectation that the effect of these parameters is not too large because the logarithm has the effect of moderating the impact.

Perhaps the single biggest source of uncertainty is the selection of the length of the contributing interval for each screen. As was noted earlier, the thickness could vary between 25 and 111 ft for Screens 1 and 2, and between 1.6 and 28 ft for Screens 3-1. This uncertainty in the contributing thickness produces an uncertainty in interval hydraulic conductivity that is about a factor of three for Screens 1 and 2, and more than 17 for Screen 3-1.

In summary, the interval hydraulic conductivity values are uncertain, with greater uncertainty associated with the small hydraulic conductivity interval (lower screened interval). The interval hydraulic conductivity values are probably no more accurate than about a factor of 5 for screens 1 and 2, and a factor of 50 for Screen 3-2. This range is quite good when compared with the range of hydraulic conductivity values presented in the regional groundwater model report

(DOE/NV, 1997), where values of hydraulic conductivity for volcanic units ranged over more than seven orders of magnitude.

3.6 Comments on the Testing Program and the Well Design

The pumping test in this multiple-completion only yielded results for the upper completion interval. This is similar to result from Wells ER-EC-1 and ER-EC-6, for which results were also limited to the upper completion intervals. A combination of factors resulted in hydraulics of the well operation to limit production of water from the lower completion intervals. These factors include the high hydraulic conductivity of the upper completion interval relative to the hydraulic conductivities of the lower completion intervals, and the substantial vertical gradient relative to the drawdown. This well also experienced severe problems with noise in the drawdown data, and the low drawdown resulted in difficulty observing the response above the noise level.

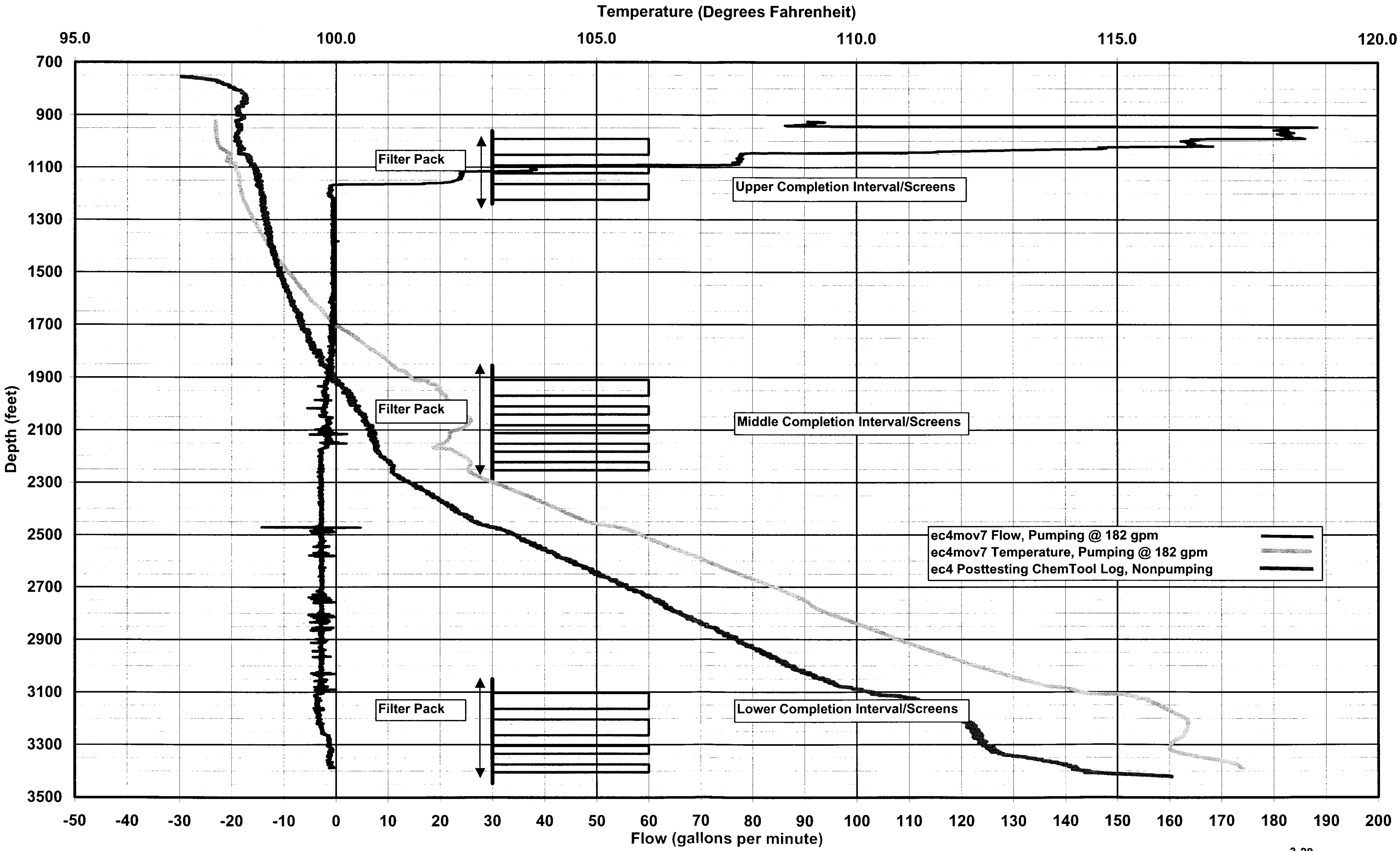


Figure 3-1
Pumping Temperature and Flow Logs

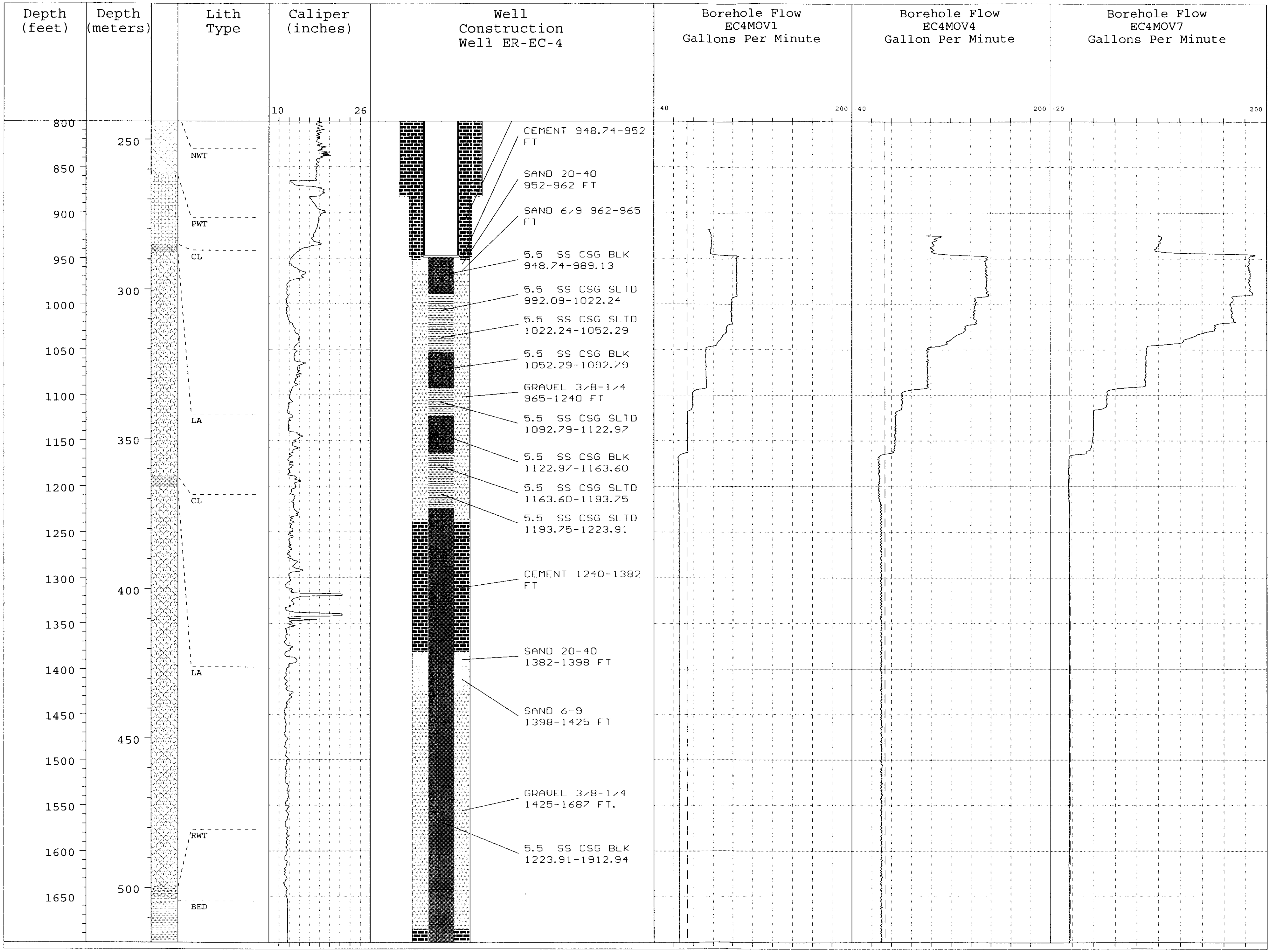


Figure 3-2
Geology and Well Construction for the Upper Completion Interval

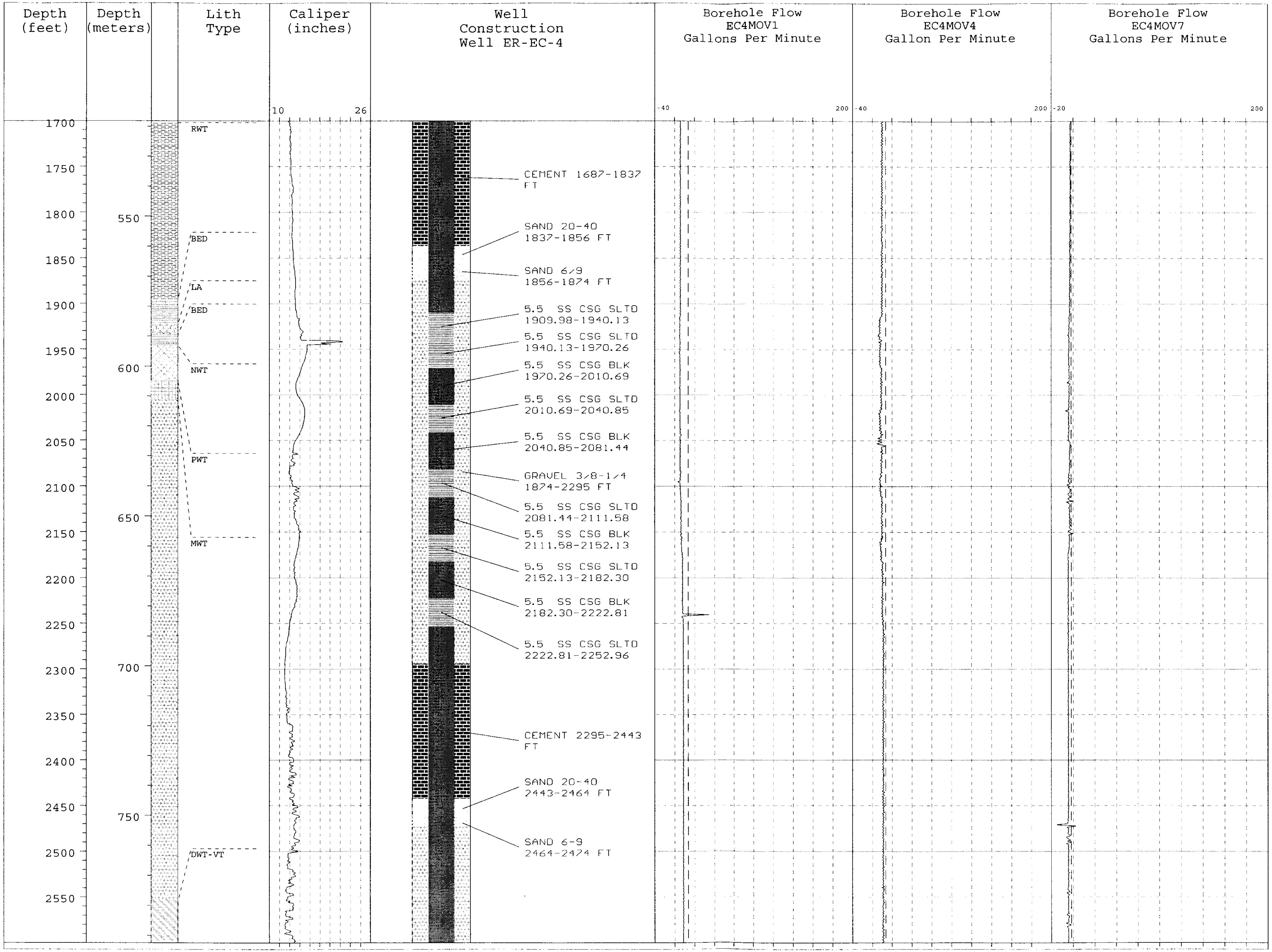


Figure 3-3
Geology and Well Construction for the Middle Completion Interval

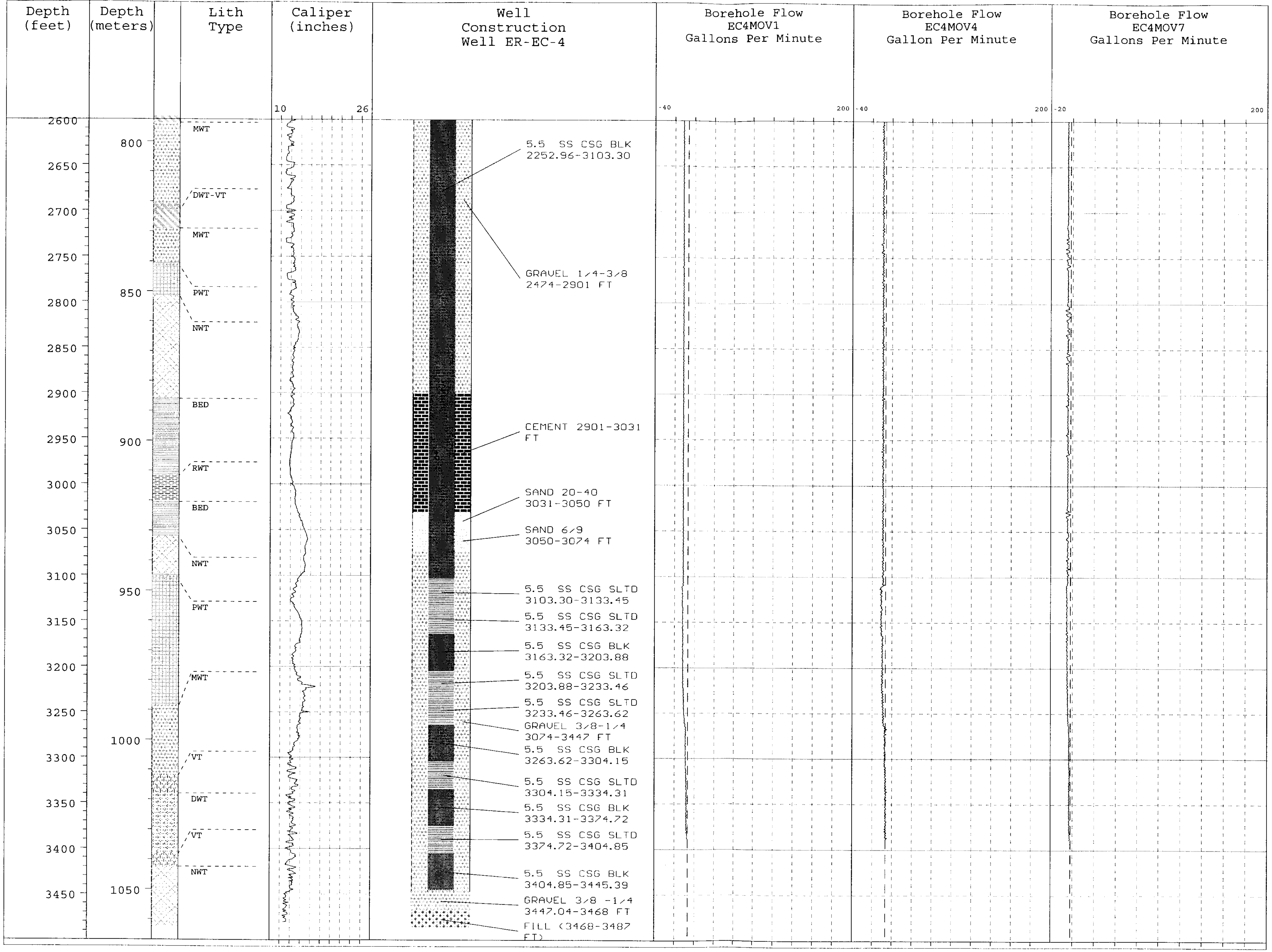


Figure 3-4
Geology and Well Construction for the Lower Completion Interval

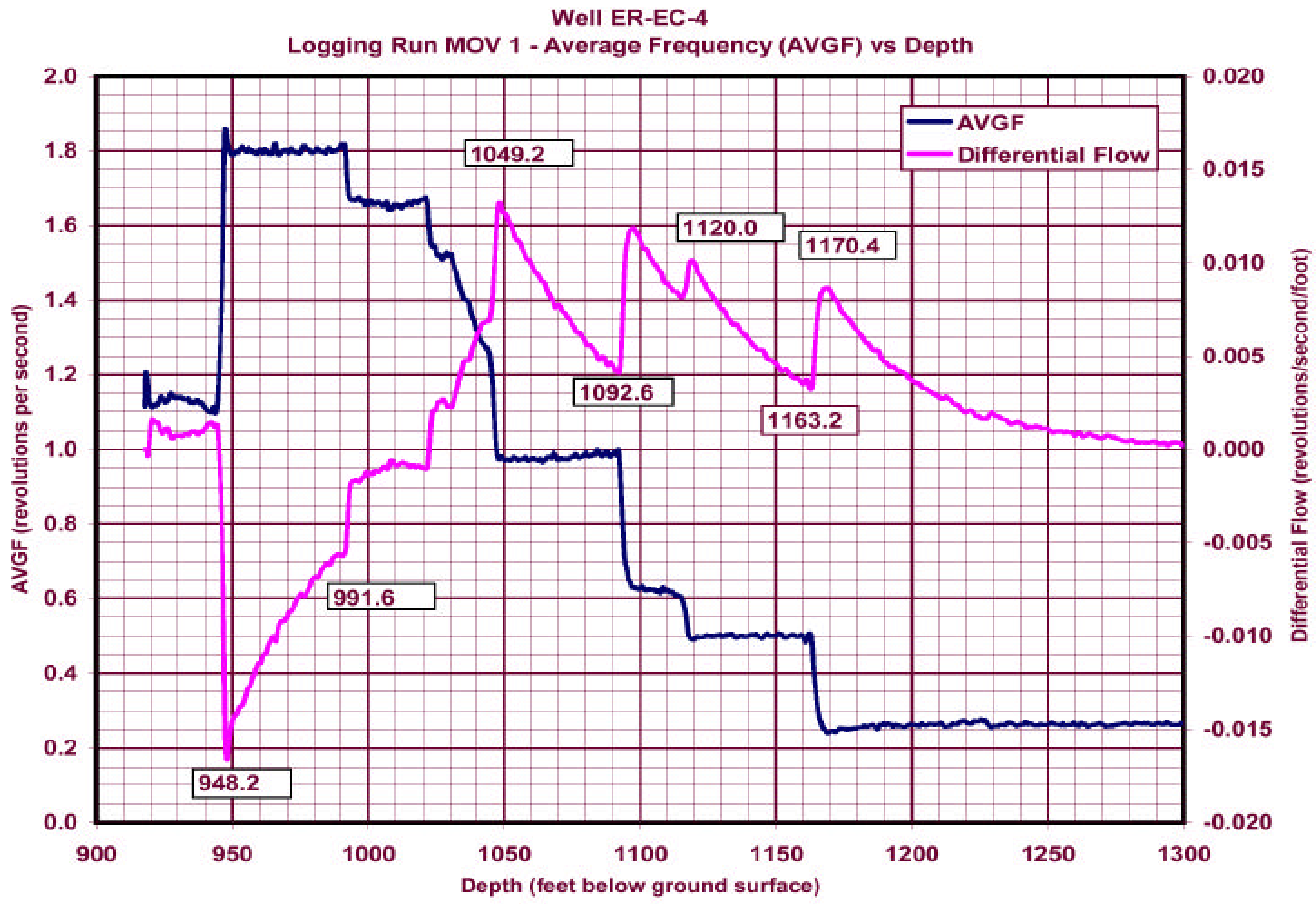


Figure 3-5
Example of Differential Flow Log Superposed on Flow Log (Flow Log ec4mov01)

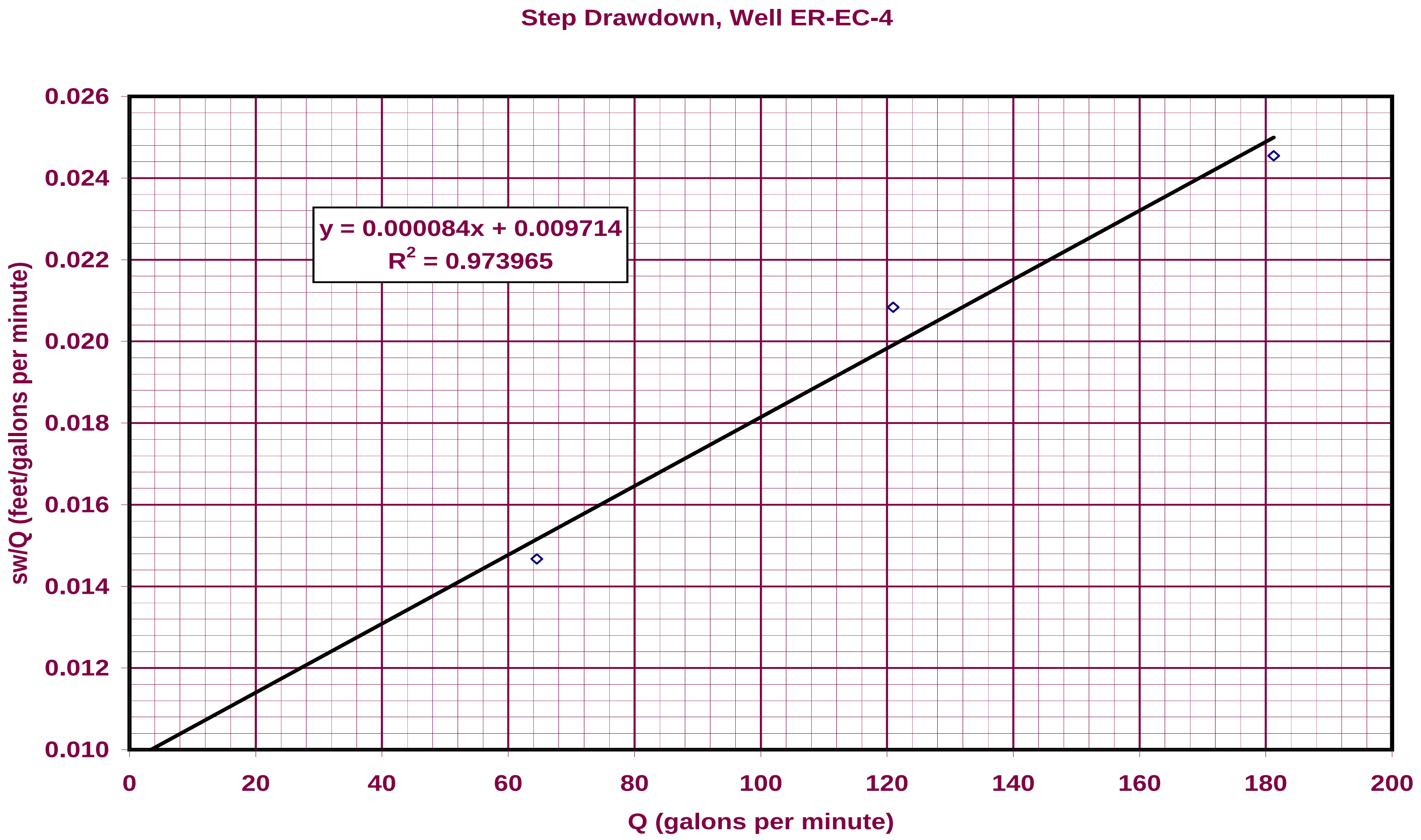
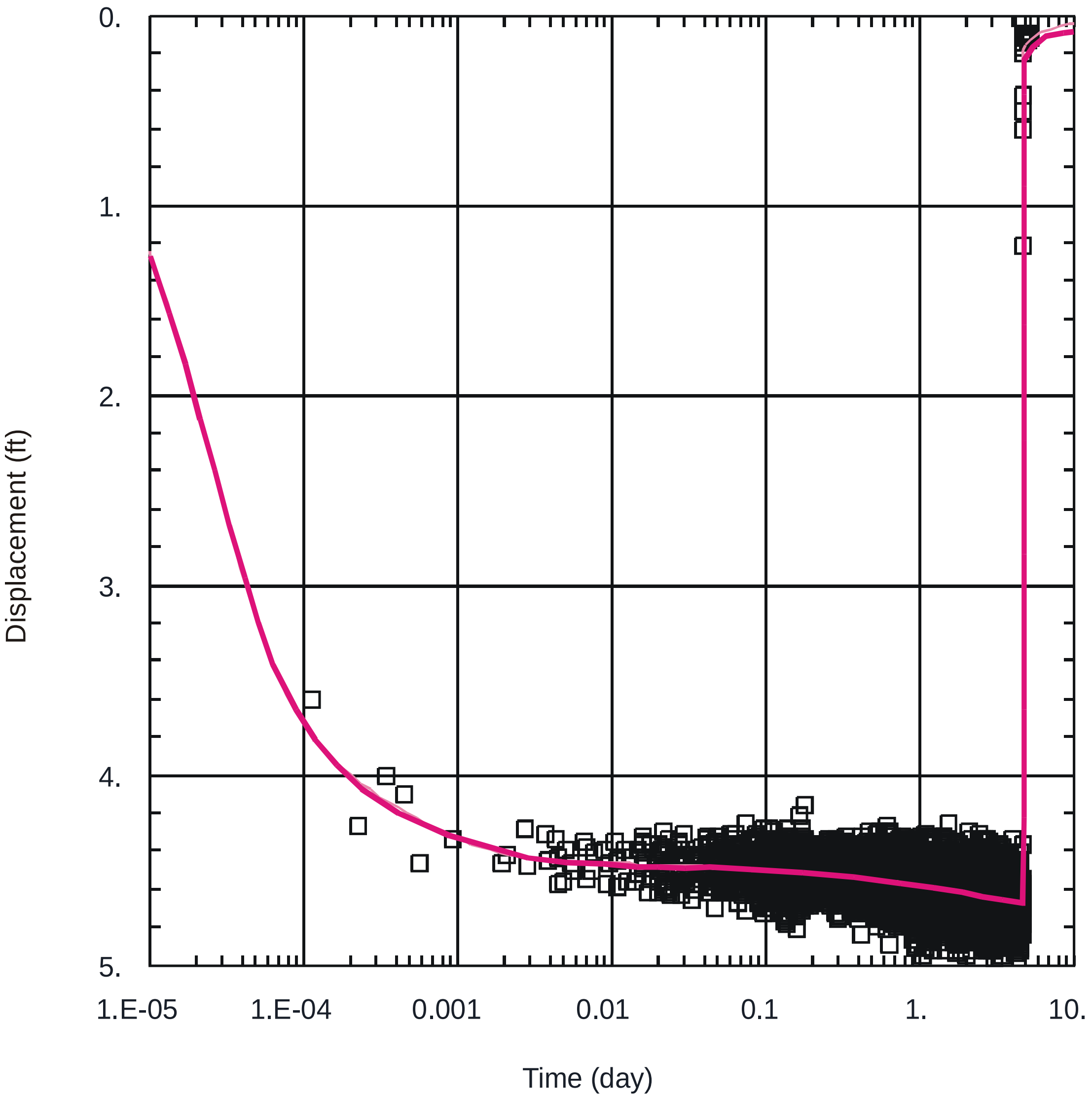


Figure 3-6
Step-Drawdown Analysis



Well ER-EC-4

Constant-Rate Test
Production Rate 180.8 GPM
Aquifer Thickness 209.4 ft

Aquifer Model

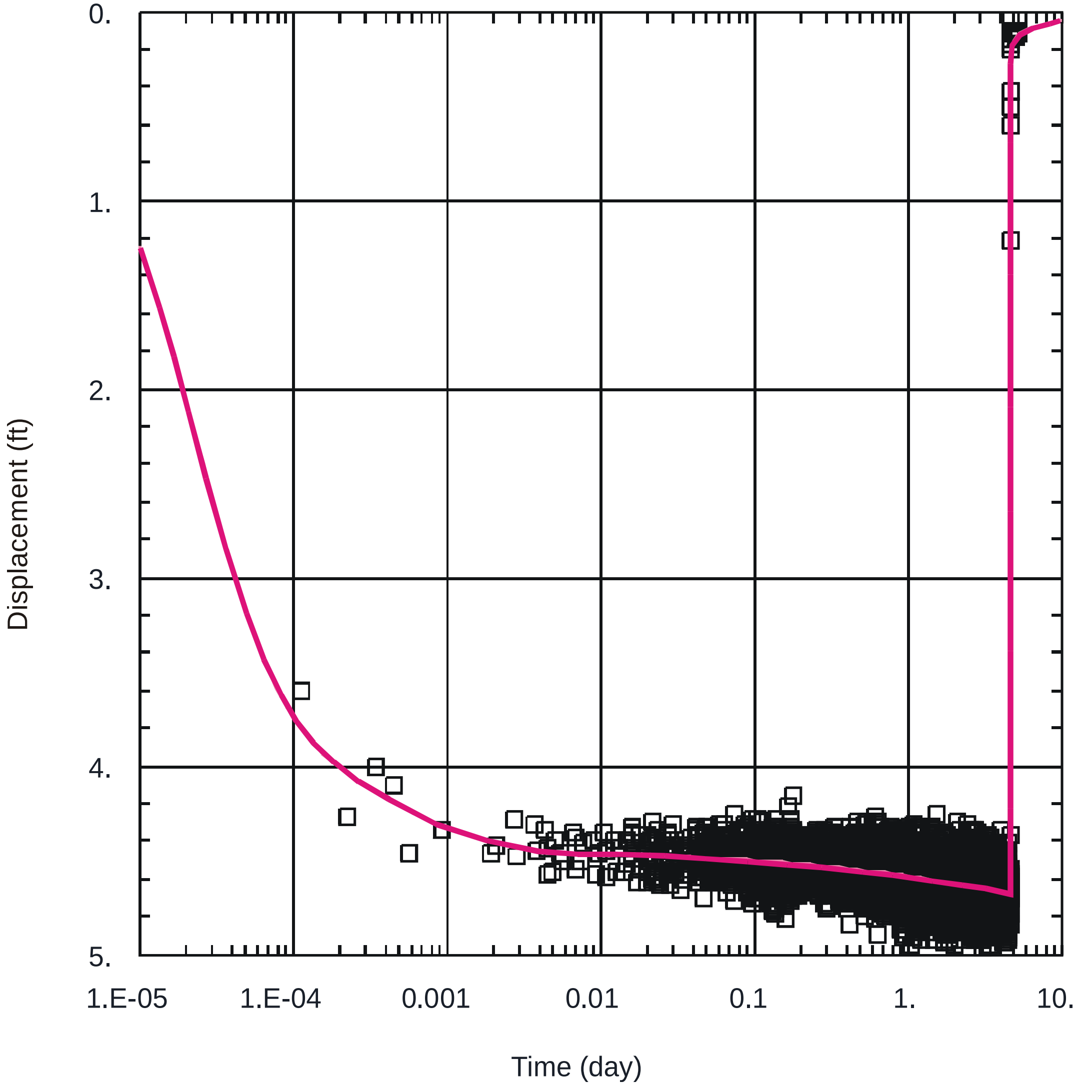
Dual-Porosity
Moench w/slab blocks

Parameters

K = 59.88 ft/day
Ss = 3.171E-08 ft^{-1}
K' = 1.001E-05 ft/day
Ss' = 0.0001768 ft^{-1}
Sw = 1.754
Sf = 0.2185

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 Analysis of the Constant-Rate Test



Well ER-EC-4

Constant-Rate Test
Production Rate 180.8 GPM
Aquifer Thickness 85.5 ft

Aquifer Model

Dual-Porosity
Moench w/slab blocks

Parameters

K = 155.1 ft /day
Ss = 9.147E-08 ft^{-1}
K’ = 2.088E-05 ft /day
Ss’ = 0.0004943 ft^{-1}
Sw = 2.344
Sf = 0.1718

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 Analysis of the Constant-Rate Test - Alternate Aquifer 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-4. One discrete bailer characterization sample and one composite characterization sample were collected at this site. The purpose of a discrete bailer sample is to collect a sample at a particular depth, sometimes under nonpumping conditions, that represents the water quality at that specific depth or in the corresponding completion zone, or to collect a sample that represents the composite water quality of all the production below the depth of collection. The purpose of a composite sample, on the other hand, is to obtain a sample that is as representative of as much of the open intervals as possible. The results from these groundwater characterization samples are used to examine the overall groundwater chemistry of the well and to compare this groundwater chemistry to that of other wells in the area. The groundwater chemistry results are also evaluated to establish whether Well ER-EC-4 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-4 will be discussed in this section, and then compared to the groundwater chemistry of other nearby sites.

4.1.1 ER-EC-4 Groundwater Characterization Sample Results

On August 4, 2000, a discrete bailer sample (#EC-4-080400-2) was obtained from a depth of 1,150 ft bgs at a pumping rate of approximately 180 gpm. The sample was obtained using a DRI logging truck, wireline, and discrete bailer (Section A.2.10.2, Appendix A). On August 17, 2000, a composite groundwater characterization sample (#EC-4-081700-1) was collected from the wellhead sampling port directly into sample bottles. A constant production rate of 182 gpm was maintained during the sampling event. This pumping rate was close to the same rate used during the constant-rate test. At the time of composite sampling, approximately 2.846×10^6 gallons of groundwater had been pumped from the well during development and testing activities (Section A.2.10.2). The results from these two samples have been tabulated and are presented in Appendix A, Attachment 3, Table ATT.3-1, Table ATT.3-2, and Table ATT.3-3.

Inspection of Appendix A, Attachment 3, Table ATT.3-1 reveals that both groundwater characterization samples have remarkably similar analytical results taking into account the uncertain nature of the qualified data. For example, it can be seen in the table that both groundwater characterization samples have sodium as the predominate cation with lesser amounts of calcium, potassium, and magnesium. The table reveals that the groundwater characterization samples had dissolved sodium concentrations of 120 milligrams per liter (mg/L), dissolved calcium concentrations that varied from 26 to 27 mg/L, dissolved potassium concentrations of 11 mg/L, and dissolved magnesium concentrations that ranged from 3.9 to 4.1 mg/L. Further inspection of the table reveals that both groundwater characterization samples also have bicarbonate as the predominate anion with lesser amounts of sulfate and chloride. The table reveals that the samples had bicarbonate concentrations that ranged from 120 to 150 mg/L as $CaCO_3$, sulfate concentrations that ranged from 110 to 120 mg/L, and chloride concentrations that ranged from 84 to 86 mg/L. It can also be seen from the table that both groundwater characterization samples have identical silicon concentrations of 33 mg/L, and estimated pH values that varied from 7.5 to 7.6.

Inspection of the "Age and Migration Parameters" section in Appendix A, Attachment 3, Table ATT.3-1 for the composite groundwater characterization sample reveals several interesting observations. For example, it can be seen in the table that the helium-3/helium-4 ($^3He/^4He$) ratio (R) in Well ER-EC-4 groundwater is 1.41×10^{-6}. Lawrence Livermore National Laboratory (LLNL) (2001) maintains that this value is very close to the natural atmospheric ratio (R_a) of 1.38×10^{-6}, giving a R/R_a value of 1.02. According to LLNL (2001), this value suggests a small contribution of helium from the mantle. LLNL (2001) states, however, that the isotope abundance data shows high concentrations of both mantle-derived ^3He and crustal-derived ^4He in the groundwater. LLNL (2001) states that crustal ^4He originates from natural uranium and thorium α-decay in the aquifer host rocks, and can be used to develop a model-dependent age estimate for the groundwater. LLNL (2001) states that a ^4He model age of approximately 8,000 years is obtained from the data after applying corrections for recharge solubility and excess air, and after assuming a ^4He in-growth rate of 1.2×10^9 atoms/year. Further inspection of Appendix A, Attachment 3, Table ATT.3-1 reveals that the carbon-14 (^{14}C) value of dissolved inorganic carbon (DIC) in Well ER-EC-4 groundwater is 5.0 percent modern, yielding an uncorrected ^{14}C age of 24,700 years. This value is substantially greater than the ^4He apparent groundwater age. LLNL (2001) states that the $\delta^{13}C$ value of the DIC suggests that the groundwater has equilibrated with fracture-lining carbonate minerals in the volcanic aquifers. LLNL (2001) explains that equilibration with ^{14}C-absent minerals results in measured radiocarbon ages that are much greater than the actual mean age of the groundwater. It can also be seen from the table that the chlorine-36/chlorine ($^{36}Cl/Cl$) ratio for Well ER-EC-4 groundwater is 5.61×10^{-13}. LLNL (2001) states that this value is similar to reported values for other environmental monitoring wells in this region.

Appendix A, Attachment 3, Table ATT.3-2 presents the results of the colloid analyses for Well ER-EC-4. It can be seen from the table that the discrete bailer sample had a total colloid concentration of 3.23×10^7 particles per milliliter (mL) for colloids in the size range of 50 to 1,000 nanometers (nm). The composite groundwater characterization sample, on the other hand, had a total colloid concentration of 1.41×10^6 particles/mL for colloids in the same size range. The total colloid concentration for the discrete bailer groundwater characterization sample is more than an order of magnitude greater than the total colloid concentration for the composite groundwater characterization sample. It can also be seen from the table that for each particle size range the discrete bailer sample has a greater colloid concentration than the composite groundwater characterization sample. Further inspection of the table reveals that for both groundwater characterization samples the colloid concentrations for each particle size range decrease, in general, as the particle size range increases. 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.

In general, the geochemical compositions of the two groundwater characterization samples are typical for wells that penetrate volcanic rocks. These types of rocks tend to impart high concentrations of sodium and bicarbonate to groundwaters. Preliminary stratigraphic logs for the well indicated that the completion intervals for this well were within trachyte of Ribbon Cliff, Ammonia Tanks Tuff, and Rainier Mesa Tuff (DOE/NV, 2000).

4.1.2 Radionuclide Contaminants

Radiological indicator parameters were not detected in the two groundwater characterization samples from Well ER-EC-4.

4.1.3 Comparison of ER-EC-4 Groundwater Chemistry to Surrounding Sites

Table 4-1 presents a summary of the groundwater chemistry data for Well ER-EC-4 and for recently collected samples from wells and springs in close proximity to Well ER-EC-4. 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 the major ions in a groundwater sample. 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, or hydrochemical facies, and the relationships that may exist between the types. Examination of the cation triangle in Figure 4-1 reveals that for Well ER-EC-4 and the surrounding sites the relative concentrations of the major cations fall within the sodium (or potassium) groundwater type. This can be ascertained from the figure because the relative concentrations of the major cations plot in the lower right corner of the cation triangle. Further inspection of the anion triangle in Figure 4-1 reveals that most of the wells and springs can be classified as also having bicarbonate type water. This can be deduced from the figure because, for the most part, the relative concentrations of the major anions plot within the lower left corner of the anion triangle. It can be seen in the anion

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

Analyte	ER-EC-4				Coffer's Ranch, Windmill Well	Coffer Ranch Spring	ER-20-5 #1	ER-20-5 #3	ER-OV-01	ER-OV-02	ER-OV-03a	ER-OV-03a2	ER-OV-03a3	ER-OV-03c
	Bailer at 1150' bgs		Wellhead Composite											
	Total	Dissolved	Total	Dissolved										
Metals (mg/L)														
Aluminum	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2	0.0009	<0.00004	3.1	11	0.0512	0.003	0.0182	0.5011	0.0198	0.0113
Arsenic	U 0.01	B 0.0039	B 0.0055	B 0.0048	0.00836	0.0064	0.042	B 0.0085	0.003	0.003	0.0031	0.0224	0.004	0.0149
Barium	UJ 0.0028	UJ 0.0016	UJ 0.00056	UJ 0.00051	0.00161	0.0098	< 0.01	B 0.0076	0.0026	0.0039	0.0113	0.0254	0.0079	0.0019
Cadmium	UJ 0.005	UJ 0.005	U 0.005	U 0.005	0.000019	< 0.000016		< 0.005	0.001	0.001	0.001	0.001	0.001	0.001
Calcium	26	26	27	27	19.3	21.8	7.18	3.14	5.7	13.6	13.8	5.7	12.7	14.4
Chromium	B 0.0036	UJ 0.0011	UJ 0.00093	UJ 0.0013	0.00013	0.0008		0.0792	0.0015	0.0015	0.0044	0.0138	0.0013	0.001
Iron	U 0.2	U 0.067	U 0.13	U 0.12	0.1933		0.39	8.48	0.0036	0.0034	0.0026	0.0599	0.0045	0.0023
Lead	UJ 0.003	UJ 0.003	U 0.003	U 0.003	0.000274	0.000013	0.001	0.0206	0.002	0.002	0.002	0.0046	0.002	0.002
Lithium	0.11	0.11	0.12	0.11	0.12	0.166	0.09	0.0696	0.175	0.192	0.146		0.143	0.123
Magnesium	3.9	3.9	4.1	4.1	0.21	1.52	0.27	0.09	0.05	0.59	1.01	1.03	1.06	0.38
Manganese	B 0.0096	B 0.0039	B 0.0042	B 0.0043	0.0082	0.00034	0.02	0.305	0.0005	0.001	0.0008		0.0007	0.0005
Potassium	11	11	11	11	0.91	9.54	5.65	3	6.56	5.41	5.04	84.7	5.37	1.19
Selenium	U 0.005	U 0.005	U 0.005	U 0.005	0.00053	0.00057	< 0.01	< 0.005	0.00082	0.00079	0.00084	0.004	0.00082	0.00041
Silicon	33	33	34	33			38.4	41.7						
Silver	U 0.01	U 0.01	UJ 0.01	U 0.01	0.00002	< 0.00002		< 0.01	0.001	0.001	0.001	0.001	0.001	0.001
Sodium	120	120	120	120	72.2	176	105	73	142	146	121	331	124	81.9
Strontium	0.14	0.14	0.14	0.14	0.181	0.163	0.02	B 0.027	0.0047	0.0474	0.0752	0.167	0.0755	0.102
Uranium	U 0.2	U 0.2	U 0.2	U 0.2	0.00586	0.0154	0.014	< 0.5	0.0085	0.018319	0.009114	0.0098	0.00795	0.004187
Mercury	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002			< 0.0002	0.00029	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Inorganics (mg/L)														
Chloride	86		84		7.6	65.8	21.7	17.8	44.4	49.2	41.6	262	43.3	17.5
Fluoride	3.1		3.1		3.29	3.32	10.1	3.16	2.04	2.34	2.29		2.14	4.55
Bromide	0.43		0.39		0.035	0.31	0.103	< 0.25	0.22	0.263	0.202		0.228	0.066
Sulfate	110		120		31	110	39	35.1	82	86	76	295	79	44
pH	J 7.5		J 7.6		8.43	7.13	8.6	8.8	8.54	8.29	8.48	9.08	8.5	8.38
Total dissolved solids	510		500		194	445	436	489	338	366	308	1100	320	218
Carbonate as CaCO3	U 10		U 50						1.7			41.6		
Bicarbonate as CaCO3	120		150		189	281.82	186	109	197	232	186	154	186	164
Age and Migration Parameters (pCi/L) - unless otherwise noted														
Carbon-13/12 (per mil)	N/A		-2.7 +/- 0.2		-3.4		-2.82	-5.75	-1.43	-2.17	-2.48	-4.7	-2.35	-2.9
Carbon-14, Inorganic (pmc)	N/A		5.0 +/- 0.1		9.6		81657	1346	5	16.2	16.3	21	16.5	6.8
Carbon-14, Inorganic age (years)*	N/A		24,700		19,350				24,830	15,050	14,990	12,900	14,875	22,280
Chlorine-36	N/A		1.77E-03					0.01102						
Helium-3/4, measured value (ratio)	N/A		1.41E-06				0.157	0.001						
Helium-3/4, relative to air (ratio)	N/A		1.02		0.85		114000	723	1.13	1.51	1.1			0.88
Oxygen-18/16 (per mil)	N/A		-14.7 +/- 0.2		-14.2 +/- 0.2		-14.9	-15.1	-14.7 +/- 0.2	-14.6 +/- 0.2	-14.7 +/- 0.2	-14.5 +/- 0.2	-14.6 +/- 0.2	-14.7 +/- 0.2
Strontium-87/86 (ratio)	N/A		0.709984 +/- 0.000038		0.70922		0.71104 +/- 6E-5	0.70868 +/- 3E-5	0.71058	0.71006	0.71029	0.70809	0.71003	0.70924
Uranium-234/238 (ratio)	N/A		0.000159				0.000165	0.000158						
Hydrogen-2/1 (per mil)	N/A		-112 +/- 1.0		-104 +/- 1		-115	-113	-112 +/- 1	-112 +/- 1	-111 +/- 1	-109 +/- 1	-110 +/- 1	-109 +/- 1
Radiological Indicator Parameters-Level I (pCi/L)														
Tritium	U -30 +/- 160		U 90 +/- 160		0.47 +/- 0.86		60400000	142000	3.33 +/- 0.90					
Gross Alpha	U 5.2 +/- 2.6		U 3.1 +/- 1.9				C 23.7	37.3	14.7	27.5	14.5	19.8	17.9	10.7
Gross Beta	9.6 +/- 2.8		9.5 +/- 2.5				C 29.6	24.8	11.8	10.1	9.89	58.9	8.8	3.45
Radiological Indicator Parameters-Level II (pCi/L)														
Carbon-14	U 110 +/- 180		UJ 210 +/- 190				260	-3.8						
Strontium-90	N/A		U -0.16 +/- 0.37				0.5	0.43						
Plutonium-238	U -0.001 +/- 0.013		U 0.004 +/- 0.017				< 0.062	< 0.31						
Plutonium-239	U 0 +/- 0.013		U 0.002 +/- 0.017											
Iodine-129	N/A		U 0.18 +/- 0.92				<570	-0.6						
Technetium-99	N/A		U 0.0 +/- 1.2				< 1.88	< 5.17						

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

Analyte	ER-OV-06a	Goss Springs North, 11S/47E-10bad	PM-3	PM-3, 3019 feet	Rita Mullen Spring, 11S/47E-03cdb	Springdale Upper Well, 10S/47E-32adc	U-20al (Egmont)	U-20ao (Goldstone)	U-20c	UE-20d	UE-20j Water Well	Unnamed Spring, 10S/47E-14bab	Unnamed Spring, 10S/47E-33aab	Unnamed Spring, 11S/47E-03cdb	Unnamed Well, 10S/47E-27a1	Unnamed Well, 10S/47E-30c1
Metals (mg/L)																
Aluminum	0.688	0.0033	0.03	< 0.01	0.0084	0.0017			< 0.1	0.09	0.01		0.012	0.0124		
Arsenic	0.0085	0.00752		0.004	0.00725	0.0137										
Barium	0.0021	0.00497	0.004	0.002	0.00438	0.0211							0.025	0.0082		
Cadmium	0.001	< 0.0000163		< 0.001	< 0.000016	< 0.000016										
Calcium	2.32	16.2	30.1	36	6.1	21.5	13.1	8.82	2.8	8.5	46		30	16	24	29
Chromium	0.0016	0.00132	0.01	0.002	0.00118	0.00141										
Iron	0.0082	0.0073	0.24	0.06	0.003	0.0036			0.03		4.8		0.018	0.0201		
Lead	0.002	0.000007		< 0.005	0.000012	0.000023										
Lithium	0.167	0.146	0.278		0.147	0.097			0.01	0.075				0.15		
Magnesium	0.72	1.14	0.79	1.5	1.05	4.08	2.05	1.24	< 0.1	0.1	1.2		4.6	1.1	2	4.9
Manganese	0.0024	0.0001	0.014	0.014	0.0004	0.0001			< 0.01	0.39						
Potassium	7.7	4.79	10.9	10	4.95	8.15	11.1	1.9	1.4	2.6	6.4		9	4.8		
Selenium	0.004	0.0005		< 0.001	0.00049	0.00089				0.01						
Silicon				63					42	45	44			47		
Silver	0.001	< 0.00001		< 0.001	< 0.00001	< 0.00001										
Sodium	141	104	140	130	103	130	122	38	95	107	138		169	122		
Strontium	0.0105	0.0916		0.081	0.0861	0.277			0.04	< 0.01			0.19	1		
Uranium	0.005237	0.00923			0.00949	0.00266					0.0085					
Mercury	0.0002			< 0.1												
Inorganics (mg/L)																
Chloride	47.5	42.4	93.5	98	42.5	36	32.8	3.2	8.1	24	115		68	45	66	49
Fluoride	3.07	2.45	2.5	2.4	2.45	2.07			6.4	3	2.2		4.4	2.9	3.7	1.5
Bromide	0.224	0.16			0.183	0.092										
Sulfate	80.9	76	129	130	76	66	77.6	8.1	18	40	135		103	90	34	34
pH	8.4	8.35	8.73	7.9	8.2	7.84	8.3	8.14		8.5	7		7.8	8.2	8	7.9
Total dissolved solids	426	306	441	555.6241	311	358			264	327	583			430	712	412
Carbonate as CaCO3	3															
Bicarbonate as CaCO3	196	186	159	150	186	297	250	114	130	192	150		296	188	288	266
Age and Migration Parameters (pCi/L) - unless otherwise noted																
Carbon-13/12 (per mil)	-1.8	-2.4			-2.39	-1.46						-5.5	-4.91		-5.33	
Carbon-14, Inorganic (pmc)	6	21.8			18.2	10.8						14.5			38.9	
Carbon-14, Inorganic age (years)*	23,330	12,600			14,090	18,440										
Chlorine-36																
Helium-3/4, measured value (ratio)																
Helium-3/4, relative to air (ratio)	1.16	1.12				1.1										
Oxygen-18/16 (per mil)	-14.7 +/- 0.2	-14.7 +/- 0.2			-14.7 +/- 0.2	-13.9 +/- 0.2						-14.52	-14.02			
Strontium-87/86 (ratio)	0.70932	0.71039			0.71027	0.71026										
Uranium-234/238 (ratio)																
Hydrogen-2/1 (per mil)	-113 +/- 1	-110 +/- 1			-111 +/- 1	-104 +/- 1						-112.5	-108			
Radiological Indicator Parameters-Level I (pCi/L)																
Tritium	1.94 +/- 0.87		16		1											
Gross Alpha	9.74															
Gross Beta	7.46									3.2	13	8.7				
Radiological Indicator Parameters-Level II (pCi/L)																
Carbon-14																
Strontium-90																
Plutonium-238																
Plutonium-239																
Iodine-129																
Technetium-99																

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.

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

N/A = Not Applicable for that sample

pmc = Percent modern carbon

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, however, that there are a number of sites whose relative anion concentrations do not fall within the bicarbonate type zone including both groundwater characterization samples from Well ER-EC-4 and UE-20j Water Well. These sites tend to plot within the center of the anion triangle. For these sites, there is no dominant anion type. It can also been seen in Figure 4-1 that the relative cation concentrations for all of the wells and springs tend to plot fairly close to each other along a straight line. The relative anion concentrations also tend to plot along a straight line in the anion triangle, but there is a greater amount of spread among the anion concentrations. Regardless of the discrepancies between the cation and anion triangles, Figure 4-1 shows that the groundwater chemistry for Well ER-EC-4 is relatively similar to the surrounding wells and springs at least in terms of the major ionic constituents.

The groundwater 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-4 and for selected sites within 12.5 miles of Well ER-EC-4. 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, however, that there is some variability associated with the stable oxygen and hydrogen isotope compositions for Well ER-EC-4 and its nearby neighbors. For example, it can be seen that the δ^{18}O values vary from approximately -14 per mil to greater than approximately -15 per mil, while the delta deuterium (δD) values vary from approximately -105 per mil to greater than approximately -115 per mil. It can be seen from Figure 4-2; however, that the water from the wells and springs plots isotopically lighter than the precipitation averages suggesting little to no influence of modern atmospheric recharge. One possible explanation for the isotopically lighter groundwater of these wells and springs is that the recharge areas for the groundwater at those sites are located north of Pahute Mesa. 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. Further inspection of the figure reveals that the isotopic signatures of some wells and springs plot well below the global and meteoric water lines. In general, data that fall below the meteoric water lines indicate that some form of secondary fractionation has occurred. This 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). Since the recent precipitation data plot along the meteoric water lines, it appears that fractionation during recent precipitation can be ruled out as causing the isotopic shift observed in most of the groundwater data. This tends to suggest that the isotopic shift in wells and springs surrounding Well ER-EC-4 can likely be attributed to sublimation of snowpack or fractionation during infiltration.

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. Various aspects of the restoration of the natural groundwater quality will be discussed in this section.

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 (Section A.3.5, Appendix A), but these groundwater characterization samples can also help to address the effectiveness of well development. For example, during drilling operations for Well ER-EC-4, the makeup water was tagged with a lithium bromide (LiBr) tracer to help determine such things as the water production during drilling through reference to the dilution of the tracer. The makeup water was tagged with a LiBr concentration of approximately 15 mg/L to approximately 90 mg/L (Section A.2.6.1, Appendix A). The concentration of the tracer was increased as water production increased to keep the concentration in the produced water at measurable levels. The relatively high concentrations of lithium (Li^+) and bromide ions (Br^-) injected into the well bore (15 to 90 mg/L) also provide a means to further ascertain the effectiveness of the well development. For example, if the groundwater characterization samples contained bromide concentrations 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 4-1 that both groundwater characterization samples have relatively low bromide concentrations. For example, the table shows that the discrete bailer sample had a bromide concentration of 0.43 mg/L, while the composite groundwater sample had a bromide concentration of 0.39 mg/L. In addition, it can be seen from the table that the highest concentration of bromide in the surrounding wells and springs is 0.31 mg/L for Coffer Ranch Spring. This value tends to indicate a fairly low background concentration of bromide in the surrounding wells and springs. The bromide concentrations for both groundwater characterization samples are at least an order of magnitude lower than the concentration of bromide used during drilling, but slightly higher than the surrounding wells and springs bromide concentrations. Even so, these values likely indicate that the well was sufficiently developed to restore groundwater quality back to its natural condition. This conclusion only pertains to the formations producing water during pumping.

4.2.2 Evaluation of Flow Between Completion Intervals

Well ER-EC-4 was drilled and completed in May and June of 1999 with three discrete completion intervals. In order to determine flow in the well under ambient, static conditions, thermal flow logging was conducted. The results from the thermal flow logging were addressed in a previous report (Section A.2.11.2, Appendix A), and, in general, indicated flow from the upper completion zone downwards to the lower completion zones at a rate of 2.2 gpm or greater. Specifically, the thermal flow logging found downward flow from the middle of the upper completion zone to the upper-middle of the lower completion zone. Information on flow into the middle completion interval is qualitative, suggesting that it also receives substantial flow from the upper completion interval.

4.2.3 Source Formation(s) of Groundwater Samples

As has been discussed in Section 3.1, flow logging during pumping indicated that 100 percent of the water production came from the upper completion zone. It was also shown that approximately 60 percent of production in the upper completion zone originated from the upper slotted interval of the upper completion zone regardless of the pumping rate (Section A.2.7.2, Appendix A). The flow logs also indicated downward flow during pumping. This implies that the pumping rate was not sufficient enough to overcome the natural downward groundwater gradient. As a result, it can be concluded that the discrete bailer sample also only represents the upper completion zone. Preliminary lithologic and stratigraphic logs indicated that the upper completion zone was completed within the trachyte of Ribbon Cliff. This formation must be assumed the source for the discrete bailer groundwater characterization sample. In fact, since the pumping rate was not sufficient enough to overcome the natural downward groundwater gradient the composite groundwater characterization sample is also only drawn only from the upper completion zone. Therefore, it can also be concluded that the trachyte of Ribbon Cliff is the source formation for the composite groundwater characterization sample.

4.3 Representativeness of Water Chemistry Results

The analytical results from the groundwater characterization samples tend to support the conclusions about the origin of the groundwater. There are no major geochemical differences between the discrete bailer sample and the composite groundwater characterization sample. This information along with the flow logging during pumping can be interpreted to mean that the composite groundwater characterization sample was indeed drawn from the same groundwater source as the discrete bailer characterization sample. In addition, since there was no direct evidence of residual contamination from drilling, it can likely be assumed that both characterization samples are representative of the groundwater in the formation opposite the upper completion zone. The lower completion zones, however, are not considered developed, and the chemistry of the water opposite these zones may not be representative of the groundwater within the adjacent formations. In fact, the groundwater chemistry of the lower zones is likely impacted by the flow of groundwater from the upper zone due to the natural downward groundwater gradient.

4.4 Use of ER-EC-4 for Future Monitoring

As discussed in this section, the flow logging indicates that 100 percent of the produced water originates from the upper completion interval at pumping rates of 182 gpm and below. The permanent sampling pump that was installed after testing has a maximum capacity of about 44 gpm, and sampling conducted with this pump should also produce water that primarily represents the water quality of the upper completion interval.

The direction of natural-gradient flow in the well is downwards, with measured flow rates of 2.2+ gpm from the upper completion interval downward. The lower completion interval receives 2.2+ gpm. There is no good quantitative data on the rate that the middle completion interval receives water, but from the natural-flow spinner log it appears to accept at a rate similar to the lower interval. Consequently, the upper completion interval should not become contaminated with any foreign water between pumping episodes. However, the lower intervals will be flooded with water from the upper interval during the periods when the well is not being pumped. However, a bridge plug was installed in this well to prevent crossflow to the lower interval. In any case the middle and lower intervals were not developed during the development and testing program, and any water obtained from those intervals in the future would be suspect as significantly affected by the crossflow that has occurred. Extended purging will be required to produce water from the lower intervals that actually represents water quality of the lower intervals if and when a method is employed that will produce substantial amounts from the lower intervals.

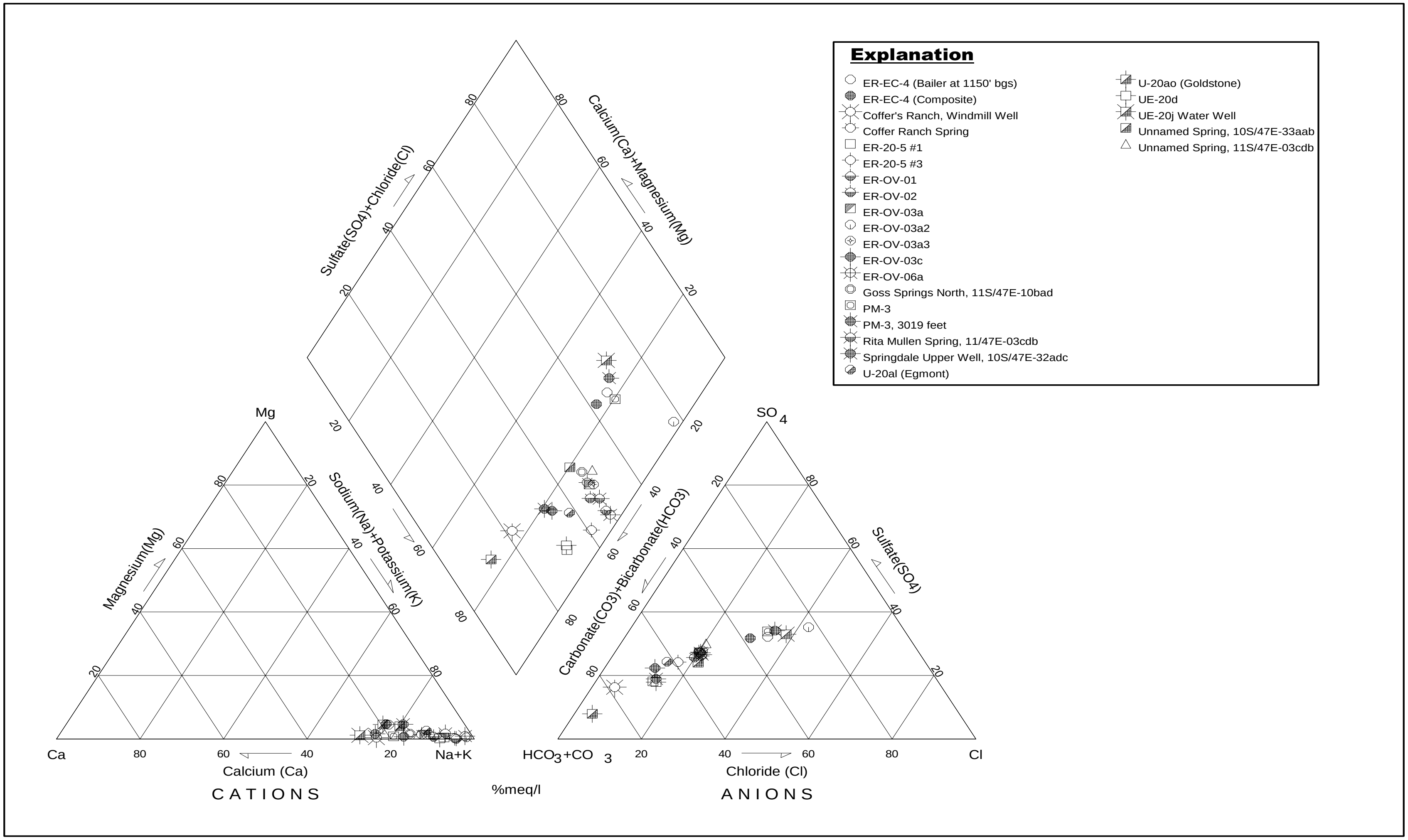


Figure 4-1
Piper Diagram Showing Relative Major Ion Percentages

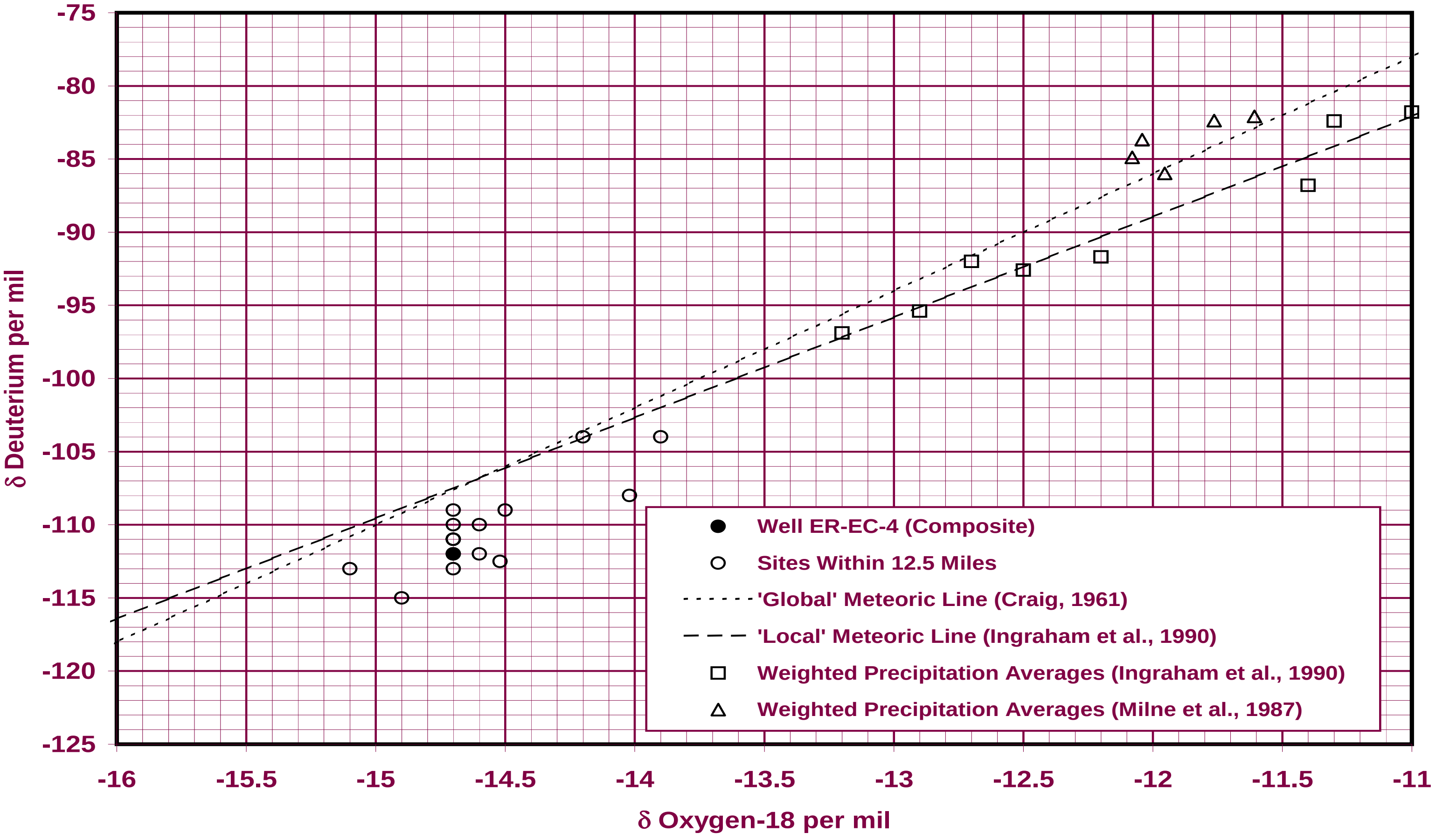


Figure 4-2
Stable Isotope Composition of Groundwater for Well ER-EC-4 and Nearby Sites

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Appendix A

Western Pahute Mesa-Oasis Valley Well ER-EC-4 Data Report for Development and Hydraulic Testing

A.1.0 Introduction

Well ER-EC-4 is one of seven groundwater wells that were completed as part of FY 1999 activities for the UGTA Project of the NNSA/NV. Figure A.1-1 shows the location of the WPM-OV wells. Hydraulic testing and groundwater sampling were conducted at Well ER-EC-4 to provide information on the hydraulic characteristics of HSUs and the chemistry of local groundwater. Well ER-EC-4 is constructed with three completion intervals, intervals of slotted casing with filter-pack, separated by blank casing sections with cement seals in the annular space. The three completion intervals are separated by distances of about 597 ft (upper to middle completion interval) and 736 ft (middle to lower completion interval). The upper interval is completed within the lava-flow aquifer of the Thirsty Canyon Group and the middle interval is completed across the tuff-confining unit of the Beatty Wash Formation and the welded-tuff aquifer of the Timber Mountain Group. The lower interval is completed across the tuff-confining unit and welded-tuff aquifer of the Timber Mountain Group.

This document presents the data collected during well development and hydraulic testing for Well ER-EC-4 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 natural groundwater quality.
3. Determine the hydraulic parameters of the formations penetrated.
4. Collect groundwater 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-4 was the eighth of the WPM-OV wells to be developed and tested. Activities began February 16, 2000 (with installation of bridge plug/PXDs), and were completed by September 5, 2000 (end of demobilization), with a total of 35 operational days. A variety of testing activities were conducted including discrete head measurements for each completion interval, flow logging under ambient conditions and during pumping, chemistry logging under ambient conditions, a constant-rate pumping test, water quality parameter monitoring, and groundwater sampling of individual producing intervals and the composite discharge.

A.1.1 Well ER-EC-4 Specifications

The drilling and completion specifications for Well ER-EC-4 can be found in the *Completion Report for Well ER-EC-4*, September 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) and associated technical change records.

The testing activities included: (1) discrete head measurements for each completion interval using bridge plugs equipped with pressure transducers and data loggers 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 completion intervals actually producing water; (3) flow and chemistry logging under ambient head conditions to determine circulation in the well under the natural gradient and assess development; (4) a constant-rate pumping test to determine hydraulic parameters for the formation(s); (5) discrete downhole sampling during pumping to capture samples that 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-4 testing program was as follows:

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, flow and chemistry logging, and discrete sampling (estimated 7 days).
4. Water level recovery (estimated 5 days).
5. Constant-rate pumping test 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 (estimated 2 days).
9. Installation of dedicated sampling pump and possible groundwater characterization sampling (estimated 4 days).

A brief summary of the actual testing program at Well ER-EC-4 is shown in Table A.1-1. In general, the work proceeded according to the planned schedule, but the work was spread over a greater time period than the generic schedule due to unplanned repair work conducted on the testing pump by the manufacturer prior to its installation.

A.1.4 Governing Documents

Several documents govern the field activities implemented during this project. 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,* (IT, 1999b), as modified by Technical Change No. 1, dated December 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) and three Technical Change Notices. The work for completing field activities is authorized under the NNSA/NV Real Estate/Operations Permit (REOP) #IT-0010-00 of which IT Corporation, Las Vegas Office (ITLV) is the primary holder. 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
Brief Summary of Work Performed at Well ER-EC-4

Activity	Start Date	Finish Date	Duration (days)
Predevelopment water level monitoring	7/18/1999	8/19/1999	31
Interval-specific head measurements (bridge plugs)	2/16/2000	2/22/2000	7
Site mobilization	7/20/2000	7/20/2000	1
Repair and install testing pump, and check pump functionality	7/24/2000	7/29/2000	6
Develop well and conduct step-drawdown testing	7/29/2000	8/2/2000	5
Conduct flow logging while pumping and collect discrete samples; install check valve and shutdown pump	8/3/2000	8/5/2000	3
Monitor recovery and pretest conditions	8/5/2000	8/10/2000	6
Constant-rate test	8/10/2000	8/19/2000	10
Composite wellhead sampling	8/17/2000	8/17/2000	1
Monitor recovery	8/19/2000	8/24/2000	6
Remove access line and testing pump	8/24/2000	8/25/2000	2
Thermal flow and chemistry tool logging under ambient conditions	8/25/2000	8/25/2000	1
Install sampling pump and test for functionality	8/29/2000	8/30/2000	2
Demobilize from site	8/30/2000	9/5/2000	3*

*Excludes three non-work days

A.1.5 Document Organization

This data report is organized in the following manner:

- Section A.1.0: Introduction

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

- Section A.3.0: Data Reduction and Review. This chapter further refines and reduces the data to present specific results that are derived from the program objectives. Information is presented on vertical gradients and borehole circulation, intervals of inflow into the well, the state of well development, reducing the data from the constant-rate test, changes in water quality parameters, and representativeness of groundwater samples.

- Section A.4.0: Environmental Compliance. This chapter records the results of the tritium and lead monitoring, fluid disposition and waste management.

- Section A.5.0: References.

- Attachment 1: Manufacturer Pump Specifications.

- 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).

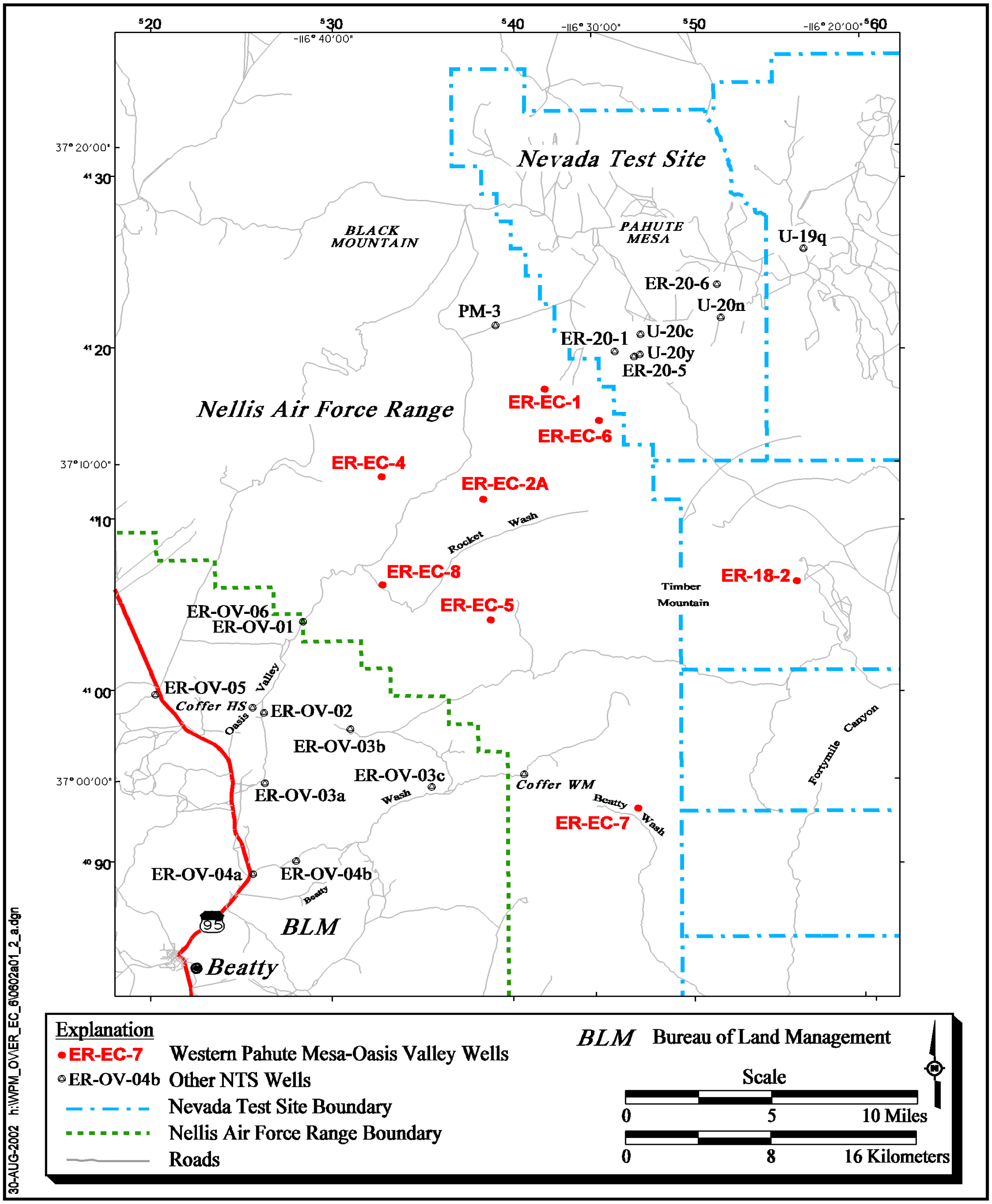


Figure A.1-1
Area Location Map

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-4 development and testing is shown in Table A.2-1.

A.2.1 Measurement Equipment

Following is a general description of the equipment used by ITLV personnel 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 a conductivity sensor. The PXDs were Design Analysis Associates 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 is crossed over to a wireline above the water surface. The PXDs employ a silicon strain gauge element, and include downhole electronics to process the voltage and temperature measurements. Data is transmitted digitally to a Campbell Scientific CR10Xe datalogger located on the surface using SDI-12 protocol. The rated accuracy of the PXDs are 0.02 percent full scale (FS). Barometric pressure is measured with a Vaisala Model PTA 427A barometer housed within the datalogger enclosure. 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 presenting the data. Following are explanations of these conventions to aid in understanding the data presentations:

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

- The PXD data are presented as the pressure recorded by the datalogger so that it corresponds to the raw data in the data files. These data can be

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

Date	Activity
7/18/1999	ITLV measured the water level at 748.99 ft bgs and installed a 0-15 psig PXD to monitor the predevelopment water level.
8/19/1999	ITLV removed the 0-15 psig PXD and measured the water level at 748.89 ft bgs.
10/21/1999	GyroData Inc. ran earth-rate gyro tool to a depth of 3,415 ft bgs.
2/16/2000	ITLV measured the water level at 748.89 ft bgs. Baker Hughes ran a gauge basket to 3,105 ft bgs. Baker Hughes set lower bridge plug/PXD at 3,000 ft bgs. ITLV measured the water level at 748.79 ft bgs. Baker Hughes set upper bridge plug/PXD at 1,800 ft bgs. ITLV measured the water level at 748.72 ft bgs and installed a 0-15 psig PXD.
2/22/2000	ITLV removed the 0-15 psig PXD and measured the water level at 748.93 ft bgs. Baker Hughes removed both bridge plugs.
7/20/2000	BN mobilized work-over rig and installed the access line to a depth of 918.10 ft bgs.
7/24/2000	BN and Centrilift assembled pump but surface checks of the pump indicated bad bushings. Pump was disassembled and secured for transport back to the factory.
7/28/2000	Pump returned from the factory. BN and Centrilift assembled, checked and installed the pump on 27 joints of tubing to a pump bottom depth of 915.03 ft bgs. ITLV measured the water level at 749.00 ft bgs and installed a 0-50 psig PXD.
7/29/2000	BN wired pump to VSD and generator. BN and ITLV conducted a functionality test of the pump at various rates. ITLV initiated water-quality sampling and monitoring activities. The pump was turned off/on four separate occasions to surge the well. Pumping continued overnight at a rate of 175 gpm.
7/30/2000	ITLV conducted a step-drawdown test at 60, 120, and 180 gpm with drawdown ranging from 0.83 ft to 4.5 ft. The pump was turned off/on four separate occasions throughout the day for surging. Pumped overnight at a rate of 175 gpm.
7/31/2000	Pump was turned off/on four separate occasions for surging. Pumping continued overnight at a rate of 175 gpm.
8/1/2000	ITLV conducted a step-drawdown test at 60, 120, and 180 gpm with drawdown ranging from 0.66 ft to 4.5 ft. The pump was turned off/on four separate occasions throughout the day for surging. Pumped overnight at a rate of 175 gpm.
8/2/2000	Pump was turned off and ITLV removed PXD. ITLV measured the water level at 748.91 ft bgs. DRI rigged up and tagged fill at 3,420 ft bgs. With pump on, DRI attempted to flow log, but due to tool problems logging was suspended and the pump was turned off.
8/3/2000	Pump was turned on and DRI conducted flow logging at 60 and 120 gpm. Pumped overnight at a rate of 120 gpm.
8/4/2000	DRI completed flow logging at 120 and 180 gpm. ITLV collected discrete bailer sample from a depth of 1,150 ft bgs. Pumped overnight at a rate of 120 gpm.
8/5/2000	DRI installed check valve. ITLV measured the water level at 749.05 ft bgs and installed a 0-15 psig PXD to monitor water level recovery.
8/6-9/2000	Monitored water level recovery and prepared for the constant-rate test.
8/10/2000	BN replaced worn seals on the back pressure valve. The constant-rate test began at a rate of 181 gpm with a drawdown of 4.5 ft. ITLV resumed water-quality sampling and monitoring activities.
8/11-15/2000	Continued with constant-rate test at 181 gpm until mechanical failure of the generator shut off the pump. BN repaired the generator and the test resumed at 181 gpm with 4.8 ft of drawdown. Datalogger program modified to collect data more rapidly.
8/16/2000	Continued with constant-rate test at 182 gpm. Datalogger program was modified to collect data at five-minute intervals.
8/17/2000	Continued with constant-rate test at 182 gpm. ITLV, LLNL, DRI, and UNLV-HRC collected groundwater characterization samples from the wellhead.
8/18/2000	Continued with constant-rate test at 182 gpm. ITLV temporarily removed PXD and measured the water level at 753.33 ft bgs. Additional testing on the data logger programs was performed.
8/19/2000	Pump was turned off to complete constant-rate test. Monitoring of water level recovery began. ITLV collected Fluid Management Plan sample from the active sump.
8/20-23/2000	Continued monitoring of water level recovery.
8/24/2000	ITLV removed PXD from the well and measured the water level at 749.14 ft bgs. DRI removed the check valve from the pump string. BN mobilized work-over rig and pulled the pump.
8/25/2000	BN and Centrilift removed testing pump. DRI ran chemistry and thermal flow logs. Baker Hughes ran junk basket to 2,600 ft bgs and installed permanent bridge plug at 2,365 ft bgs. BN demobilized the work-over rig.
8/29/2000	BN and ESP assembled and installed dedicated sampling pump, intake at 960.5 ft bgs.
8/30/2000	BN/ESP wired pump to VSD and completed a functionality test of the pump at production rates from 21 to 46 gpm. BN, ITLV, and ESP began demobilizing equipment.
8/31-9/5/2000	BN and ITLV continued and completed demobilization.

ESP - Electrical Submersible Pumps, Inc.
BN - Bechtel Nevada
DRI - Desert Research Institute
ITLV - IT Corporation, Las Vegas Office
UNLV-HRC - University of Nevada at Las Vegas - Harry Reid Center
LLNL - Lawrence Livermore National Laboratory

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

processed to various forms of head, with or without barometric correction. Additional data, which may be required for further processing, is included in this report. Note that the data files contain a column in which raw pressure measurements have been processed to head measurements in terms of feet-of-water column above the PXD. This information was meant for field use in monitoring downhole water level relationships. The conversion was initially based on a standard density for water and was later updated when a well-specific density was determined. In Section A.3.1, well-specific value(s) for water density are discussed, and an appropriate value for density was subsequently used for the processing of the drawdown response into elevation head.

- Groundwater pressure measurements are reported as pounds per square inch gauge (psig) since the PXDs used for groundwater pressure monitoring were vented, not absolute. Pressure differences are reported as psi. Barometric pressure is reported as millibars (mbar); 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 equal to 68.94757 mbar. For presentation convenience, the scales are proportioned with 70 mbar equal to 1 psi, which is close enough so that the relative magnitude of pressure changes is represented. 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 derived conversion factor for pressure in psi converted to vertical height of water column in feet. This is actually the inverse of weight density expressed in mixed units (feet-square inches/pound or feet/pounds per square inch). 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 <u>derived</u> 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-4, the water level was monitored with a PXD and datalogger for a period of about four and one-half weeks to establish the equilibrium composite head for this well. Figure A.2-1 shows the results of this monitoring. The record, corrected for barometric variation, is presented in Figure A.3-7. An electronic copy of this data record can be found on the CD as file EC4_Predev_Monitoring.xls.

A.2.3 Depth-to-Water Measurements

Table A.2-2 presents the composite depth-to-water measurements made for Well ER-EC-4 following well completion. The consistency of these measurements indicate that these water levels represent composite equilibrium conditions. Measurements representing nonequilibrium or noncomposite water levels are presented in the appropriate section for the testing activity involved.

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

Date	Time	Depth-to-Water bgs		Barometric Pressure (mbar)
		Feet	Meters	
07/18/1999	12:45	748.99	228.29	--
08/19/1999	16:25	748.89	228.26	854.92
02/16/2000	09:24	748.89	228.26	851.56
07/28/2000	17:59	749.00	228.30	855.42
08/02/2000	12:35	748.91	228.27	857.32
08/05/2000	11:50	749.05	228.31	857.69
08/24/2000	11:00	749.14	228.34	860.68

bgs - Below ground surface
mbar - Millibars

A.2.4 Interval-Specific Head Measurements

The equilibrium hydraulic heads of the individual completion intervals were measured to provide information on vertical hydraulic gradients. This was accomplished by isolating the completion intervals from each other with bridge plugs and measuring the equilibrium pressure or head in each interval. The bridge plugs contained pressure transducers and dataloggers to measure and record the pressure in the interval below each 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 the equilibration of the intervals.

A.2.4.1 Bridge Plug Installation and Removal

The procedure for installing the bridge plugs included:

1. Run gauge and basket to below lower bridge plug set depth 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 collect four or more pressure readings (bridge plug <u>not</u> set).
4. Lower bridge plug to set-depth plus 50 ft and collect four or more pressure readings (bridge plug <u>not</u> set).
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 (bridge plug <u>not</u> set).
8. Lower bridge plug to set-depth plus 50 ft and collect four or more pressure readings (bridge plug <u>not</u> set).
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. Remove PXD after five days and measure water level in upper interval with an e-tape. Remove bridge plugs 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 about five days, a length of time expected to be sufficient for equilibration to occur.

Table A.2-3 shows the interval-specific pressure and head measurements, including the calibration data. Graphs of the interval equilibration monitoring are included in Section A.3.0. Note that corrected depths for the bridge plug are given in Table A.2-3 that are slightly different from the PXD set depths that had been specified and listed in the Morning Reports. The set depths were located by keying off of casing collars, and a calibration of the wireline was used to correct the depths. The difference between the specified set depths and actual depths of the measurements does not present any problem for the analysis. The depth location corrections are discussed in Section A.3.1.1. The datalogger files for the equilibration of the pressure transducers can be found on the enclosed CD, labeled as follows: EC4_Bridge Plug_ITPXD.xls (upper interval), EC4_Bridge Plug_Upper.xls (middle interval), and EC4_Bridge Plug_Lower.xls (lower interval).

Table A.2-3
Interval-Specific Head Measurements

Interval	Comment	Depth (ft bgs)	Depth (m bgs)	Barometric Pressure (mbar)	PXD Measurement (psig)
Upper	Final Head	748.94 (e-tape)	228.28	857.55	--
Middle	Reference Head - composite of upper two intervals	748.79 (e-tape)	228.23	850.08	450.38
	Bridge Plug set depth minus 50 feet	1,748.70	533.01	NA	428.92
	Bridge Plug set depth - post set	1,798.71	548.25	NA	449.35
	Bridge Plug set depth plus 50 feet	1,848.70	563.48	NA	471.99
Lower	Reference Head - composite of all three intervals	748.89 (e-tape)	228.26	851.56	968.46
	Bridge Plug set depth minus 50 feet	2,948.98	898.85	NA	947.19
	Bridge Plug set depth - post set	2,998.67	913.99	NA	965.09
	Bridge Plug set depth plus 50 feet	3,048.35	929.14	NA	989.96

ft bgs - Feet below ground surface
m bgs - Meters below ground surface
mbar - Millibars
PXD - Pressure transducer
psig - Pounds per square inch gauge
NA - Not applicable

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 (#01F83184 and #01F83185) with 43 stages each, seal section (#31D53113), and a 130 horsepower motor assembly (375 Series, 2 sections - #21D47849 and #21D47843). 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 unit, which is located at the bottom of the assembly. The pump was installed on 2 7/8-inch (in.) Hydril® tubing. A model "R" seating nipple was placed just above the pump in the production tubing to allow future installation of a wireline-set check valve. The pump was operated without a check valve during development to allow the water in the production tubing to backflow into the well when the pump was shut down. This was intended to "surge" the well and aid in development. A check valve was installed prior to the constant-rate pumping test to prevent such backflow. The pump was landed with the bottom of the motor at 894.56 ft bgs, which placed the pump intake at 854.22 ft bgs.

An Electro Speed 2250-VT variable speed drive (VSD) was used to regulate the production of the pump. The VSD can vary the pumping rate by supplying alternating current (AC) power of adjustable frequency to the pump. In Mode 1 operation, the frequency of the power is fixed to a selected value. In Mode 2 operation, the frequency is varied by the VSD in response to a control signal. To maintain a constant production rate for testing, the transmitter of a 1.5-in. magnetic 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 to maintain the selected production rate. The flowmeter record shows that this worked very well and a constant production rate could be maintained as drawdown progressed.

A.2.5.2 Pump Performance

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. The pump was operated with an additional backpressure of 390 psig (nominal) imposed at the surface to meet the operational requirements of the pump. Note that the drawdown data provided in this table for the various pumping rates is only an instantaneous value without reference to the recent pumping history. For the drawdown data to be used quantitatively, it would need to be related to the amount of time of pumping at that rate and the water level from which the pumping started. Since this well exhibited very quick equilibration of drawdown, these values provide a close approximation of relative drawdowns. This information indicates the range of drawdowns experienced during development and testing.

Table A.2-4
Performance of Testing Pump

Date	Time	VSD Setting (Hz)	Production Rate (gpm)	Approximate Drawdown[a] (ft)
7/29/2000	09:40	53.5	61.77	0.92
7/29/2000	11:24	68.5	182.00	5.01
7/29/2000	12:03	62.1	151.42	3.76
7/30/2000	09:55	54.3	60.39	0.83
7/30/2000	13:50	67.8	181.81	4.60
7/31/2000	07:45	67.1	176.21	4.35
7/31/2000	13:40	67.9	181.94	4.56
8/1/2000	12:30	68.3	181.94	4.57
8/1/2000	14:40	54.1	60.68	0.66
8/2/2000	07:20	67.5	176.22	4.26
8/4/2000	20:32	58.1	120.87	NA

Note: Significant figures reported as recorded from field documents.

[a] Drawdown derived from PXD pressure data using a density of 2.3774 ft/psi.

Hz - Hertz (cycles per second); gpm - Gallons per minute; ft - Feet; NA - PXD removed for logging

The data in Table A.2-4 indicates that there was an apparent reduction in the well drawdown at the same production rates during the course of development. Three flow rates were selected for the steps to be used in development activities: 60, 120, and 180 gpm. In practice, there may be variations in actual pumping rates that were used resulting from variables in pumping conditions at the time. The emphasis was placed on maintaining consistent pumping rates for any particular period.

A.2.6 Development

There were two objectives for well development, the physical improvement of the condition of the well completion and restoration of 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 remaining from drilling and well construction to maximize the hydraulic efficiency of the well screen, filter pack, and the borehole walls. These improvements promote efficient and effective operation of the well and accurate measurement of hydrologic properties. The development phase was primarily intended to accomplish hydraulic development in preparation for hydraulic testing.

Restoration of 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 may 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 completed. 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-4 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 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. Barometric pressure was also recorded in conjunction with PXD records. During flow logging and discrete sampling, the PXD had to be removed to allow access for the flow logging tool and the discrete bailer.

Monitoring during development included hydraulic performance data and a variety of 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 Br^- concentration) to evaluate restoration of natural water quality. With regard to the Br^- concentration, the fluid used during drilling was "tagged" with lithium bromide to have an initial concentration from about 15 mg/L to approximately 90 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. Initially a 0 to 50 psig PXD was installed for development, but this was replaced with a 0 to 15 psig PXD for the constant-rate test for greater accuracy. Information on the 0 to 50 psig PXD installation and calibration is presented in Table A.2-5. Information on the installation of the 0 to 15 psig PXD will be provided in Section A.2.8.1 on the constant-rate test methodology.

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

Design Analysis H-310 PXD SN 2268, 0-50 psig					
Installation Date: 7/28/2000					
Calibration Date: 7/28/2000					
Static water level depth: 749.00 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
WRL/TOC[a]	530	570	595	620	645
PXD psig	-0.00540	11.225	21.790	32.300	42.812
Delta depth (ft): Cal5 - Cal2					75
Delta psi: Cal5 - Cal2					31.587
Density ft of water column/psi: delta depth / delta psi (in ft/psi)					2.374
Equivalent ft water: PXD psig (at Cal 5) x density of water (ft/psi)					101.65
Calculated PXD installation depth: static water level + equiv. ft water					850.65

[a] Length of wireline (WRL) below top of casing (TOC); does not include the length of the PXD integral cable.

ft - Feet bgs - Below ground surface
PXD - Pressure transducer
psi(g) - Pounds per square inch (gauge)

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. Note that the Cal 1 PXD psig value was a measurement in air above the water surface, and is not used for the water density calculation.

The well was pumped for about five days prior to flow logging. During that time, development consisted mostly of pumping at high rates, periodically stopping the pump to surge the well with the backflow from the production tubing. Step-drawdown protocol was run to assess well and pump performance. Water quality was monitored using an in-line system and through the field analysis of grab samples.

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 barometric pressure variation during development. An electronic file of these data can be found on the attached CD (file name EC4_AQTEST_WD.xls). The first day shows the initial testing of the pump/VSD to determine the operating range of the pump and resultant drawdown (see Table A.2-4). Four and one-half days were spent surging and pumping the well for development, step-drawdown protocol was run three times. The pump was generally operated at rates of about 60, 120, and 180 gpm during the development phase. The 180-gpm production rate was near the maximum pumping rate possible. Maximum drawdown during pumping was on the order of 5 ft. The barometric pressure was proportionately constant relative to the PXD pressure.

Several factors should be kept in mind when evaluating 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. Whenever the pump was started, sufficient water had to be pumped to fill the production tubing and surface plumbing before production would register at the flowmeter. This produces a lag time between the start of a drawdown response and the start of the flowmeter readings. This was not significant for this well because the depth-to-water is less than the other WPM-OV wells. There is also a delay due to the startup procedure, which bypasses the initial production around the instrumentation to avoid effects of sediment on the instruments. The typical total delay for flowmeter readings to begin is several minutes, as can be seen on Figure A.2-4.

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 effect can be seen in the early-time drawdown (Figure A.2-4). Dividing the volume of the discharge system by the time lag for production to reach the surface gives a production rate greater than the VSD setting would produce under stable pumping conditions. As a result of this situation, the rate of drawdown was initially greater until a stable pumping rate was reached. The installation of a check valve for the constant-rate test avoids these irregularities by maintaining the water column above the pump so that the stable TDH is developed very quickly as the system is pressurized.

For development, the pump was normally started with the VSD operating in Mode 1. In this mode, the VSD is set to operate at a specific power frequency (Hertz [Hz]). The calibration of Hz versus gpm through the pumping range is determined during the functionality test. After the system is pressurized and a stable pumping rate is established, the VSD is switched to Mode 2. In this mode, the VSD varies the Hz to maintain a specified gpm based on feedback from the flowmeter. Since the testing is run according to desired pumping rates, the objective is for consistency in the pumping rate between the two modes.

As mentioned earlier, to avoid problems from the initial production of sediment each time the pump is started during development, the initial production is bypassed around the flowmeter. Consequently, there is a delay before flow rate is registered and recorded. If the pump were to be turned on directly in Mode 2, the VSD would accelerate the pump until the flowmeter reading equals the pumping rate setting. However, since the feedback from the flowmeter is zero until production reaches the flowmeter, the VSD would initially accelerate to the upper clamp setting, usually set at the maximum pumping rate. This would result in correspondingly high pumping rates and drawdown until the flowmeter returned accurate pumping rate information. The VSD would then decelerate the pump and seek the gpm setting. This method of starting the pump was used previously, but was changed to the present approach because of the irregularity it introduced in the startup. For the constant-rate test, the check valve that is installed to maintain the water column precludes most of this problem since the flowmeter starts to measure the pumping rate very quickly.

An additional irregularity in the starting pumping rate is introduced by the backpressure system which is required to achieve the minimum required TDH for proper pump operation. Bechtel Nevada (BN) protocol for starting the pump requires that the backpressure valve be initially open, it is then closed to produce the required backpressure after full-flow is established. The additional backpressure causes a reduction in pumping rate, which is then compensated by the VSD in Mode 2 (Figure A.2-4). This procedure applies both to development and the constant-rate test. For Well ER-EC-4 the applied backpressure is proportionally larger relative to the head buildup above the pump as the production tubing is filled than for the other WPM-OV wells. This is due to the shallow water table, resulting in a small lift to the surface and consequently requiring large applied backpressure.

2.6.2.2 Surging and Step-Drawdown Protocol

Figure A.2-2 shows each instance when the pump was stopped, and also the step-drawdown protocol that was conducted several times. Stopping the pump was intended to produce a surging effect in the well. 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 that 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 would simply speed the apparent recovery of the well, with the surge rapidly dissipating and merging into the recovery curve. This effect may occur in the response from Well ER-EC-4, although there also appears to be an oscillatory phenomenon that may be a component of the apparent surge. Figure A.2-5 shows a representative instance of the surge/oscillations expanded to illustrate the detail. The shutdown response during development will be contrasted with the shutdown response at the end of the constant-rate test in Section A.2.8.2 to further evaluate these phenomena, and further discussions will be presented in Section A.3.4.2.

The starting and stopping effects are much subdued for 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, the specific amount depending on the extent the backpressure valve was opened from its operating position.

For the step-drawdown protocol, the pump was run for a certain period of time at each of three progressively higher rates, approximately 65, 121, and 181 gpm, producing drawdowns of the order of 0.9, 2.6, and 4.5 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. Figure A.2-6 shows a representative instance of the step-drawdown protocol. The water level closely approached equilibrium before the protocol was initiated and approached an equilibrium drawdown during the period of each step. Data from the step-drawdown protocol will be useful in evaluating changes in well performance and well losses.

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 produced water was typically turbid for a few seconds after which the water cleared.

A.2.7 Flow Logging During Pumping

Downhole flow logging (spinner tool) was performed while pumping was conducted after the development phase. The data on the proportional inflow of water from different completion intervals was used for tuning the production rate used for the 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-4 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 target rates were used as for the step-drawdown protocol during development (60, 120, and 180 gpm) so that results could be directly compared with previous observations.

Logging with the spinner tool was conducted by the DRI on August 3 and 4, 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 were conducted at three different line speeds and in both directions to evaluate flow under all test conditions. As in previous logging runs at other WPM-OV wells, the best results appear to have been obtained at a line speed of 20 fpm in a downward direction.

2.7.1.1 Equipment and Calibration

The DRI flow-logging system consists of, from top to bottom (all Flexstak equipment): a telemetry cartridge, an upper centralizer, a temperature tool, a lower 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 has a minimum measurement of 5 fpm for a static tool, and a resolution of 0.1 percent.

The 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.

2.7.1.2 Logging Methodology

Nine successful trolling flow logs were recorded at three different line speeds from just above the top of the upper completion interval to the bottom of the lower completion interval. The runs were typically from about 920 to 3,400 ft bgs. The bottom of the well (soft sediment fill) was tagged by DRI at 3,420 ft bgs. The logging runs were generally made in the following order: (1) a down run at 20 fpm, (2) an up run at 40 fpm, (3) a down run at 60 fpm, and (4) stationary flow measurements conducted while tripping up. This four-step sequence was repeated for each of three discharge rates, 60, 120, and 180 gpm. Stationary flow measurements (tool held motionless in the well) were taken at the following locations: above the upper completion interval (950 ft bgs), between the upper and the middle completion intervals (1,550 ft bgs), and between the middle and the lower completion intervals (2,700 ft bgs). Table A.2-6 lists the trolling flow logs that were run. Stationary measurements are listed in Table A.2-7.

Table A.2-6
Listing of Trolling Flow Logs

Run Number	Date	Direction of Run	Line Speed (fpm)	Surface Discharge (gpm)	Start - Finish (ft bgs)
ec4mov01	8/03/2000	Down	20	60	917 - 3,388
ec4mov02	8/03/2000	Up	40		3,392 - 915
ec4mov03	8/03/2000	Down	60		921 - 3,388
ec4mov04	8/03/2000	Down	60	120	924 - 3,388
ec4mov05	8/03/2000	Up	40		3,392 - 926
ec4mov06	8/04/2000	Down	20		925 - 3,388
ec4mov07	8/04/2000	Down	20	180	924 - 3,388
ec4mov08	8/04/2000	Up	40		3,392 - 925
ec4mov09	8/04/2000	Down	60		924 - 3,398
ec4mov10[a]	8/25/2000	Up	140	0	3,392 - 905

[a] This run was conducted three weeks after the rest of the flow logs as an adjunct to the thermal flow logging to provide additional data on flow under ambient conditions.

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	Average Temperature (°F)	Pumping Rate (gpm)	Depth (ft bgs)	Average Flow[a] (gpm)
ec4sta01	Between middle and lower CZ	105.9	60	2,700	-4.726
ec4sta02	Between upper and middle CZ	98.4		1,550	-9.307
ec4sta03	Above upper CZ	97.7		950	60.780
ec4sta04	Between middle and lower CZ	106.5	120	2,700	0.00
ec4sta05	Between upper and middle CZ	98.7		1,550	0.00
ec4sta06	Above upper CZ	97.7		950	122.730
ec4sta07	Between middle and lower CZ	107.6	180	2,700	0.00
ec4sta08	Between upper and middle CZ	99.2		1,551	0.00
ec4sta09	Above upper CZ	97.7		950	183.063

[a] Negative flow values indicate downward flow

°F - Degrees Fahrenheit
gpm - Gallons per minute
ft bgs - Feet below ground surface
CZ - Completion interval

A.2.7.2 Flow Logging Results

The results of the trolling flow logs are presented in Figures A.2-7 through A.2-15. Figure A.2-7, Figure A.2-8, and Figure A.2-9 depict the flow logs for the three trolling speeds [20 fpm (down), 40 fpm (up), and 60 fpm (down), respectively] at a well production rate of 60 gpm. Figure A.2-10, Figure A.2-11, and Figure A.2-12 show the flow logs for the three trolling speeds at a production rate of 120 gpm. Figure A.2-13, Figure A.2-14 and Figure A.2-15 present the flow logs for the three trolling speeds at a production rate of 180 gpm. The optimal logging direction/speed was downwards at 20 fpm, producing the least amount of noise and fluctuations. This configuration seemed to provide the most sensitivity with the least induced disturbance. All nine trolling logs are shown in this report so that a complete evaluation of the merits of the different trolling speeds can be made.

The trolling flow logs indicate that 100 percent of the total production from pumping in the well originated from the upper completion interval (989 to 1,224 ft bgs). The logs also indicate downward flow (as indicated by negative flow values) from the upper interval to the middle and lower completion intervals during pumping, with rates of downward flow decreasing with increased production. The distribution of production throughout the completion intervals has been tabulated and is discussed in more depth in Section A.3.3.2.

The results from the stationary flow measurements also indicate that 100 percent of the total production from the well originated from the upper completion interval. The stationary logs also show that downward flow was occurring between the upper and middle completion intervals (-9.307 gpm) at a production rate of 60 gpm. A downward flow (-4.726 gpm) was indicated between the middle and the lower completion intervals at the same production rate. Downward flow was not measured at the higher production rates of 120 and 180 gpm.

A.2.7.3 Recovery After Flow Logging

After flow logging and discrete sampling were completed, the check valve was installed, and a PXD was installed to monitor water level recovery. Figure A.2-2 shows the recovery monitoring.

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. However, due to the slow rate of recovery for the last several feet of head, the constant-rate test was begun before equilibration was achieved. Pumping for this test commenced on August 10, 2000, and continued for almost five days when the generator powering the VSD/pump shutdown at 03:00 on August 15, 2000. The generator was repaired later that day, and the pump was restarted to extend the constant-rate test on the evening of August 15. Based on the performance of the well from August 10 to 15, it was thought that there was no benefit to be gained by allowing a long recovery monitoring period before any restart. Pumping continued for an additional four days until August 19, 2000. In addition to providing data for determining hydraulic parameters, the pumping during the constant-rate test served to continue and complete the development process to restore natural water quality for sampling purposes. The additional pumping was pursued to improve the quality of the groundwater characterization samples. Following the pumping period, head recovery was monitored for five days until August 24, 2000.

A.2.8.1 Methodology

A continuous datalogger record was captured for PXD pressure and barometric pressure for the constant-rate test and 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 during increasing drawdown. In addition, water quality was monitored during the constant-rate test with field analyses of grab samples taken at regular intervals (usually every 2 hours during the day).

A pumping rate of 180 gpm was chosen for the test. This rate was near the maximum sustainable rate the pump could achieve. A PXD with a range of 0 to 15 psig, the minimum available, was installed after flow logging for the pretest monitoring and the constant-rate test. The PXD was installed on August 5, 2000, at a calculated depth of 780.35 ft bgs based on the calibration. Table A.2-8 shows the calibration and PXD installation data for the constant-rate test.

Table A.2-8
PXD Installation Prior to Constant-Rate Test

Design Analysis H-310 PXD SN 2263, 0-15 psig					
Installation Date: 8/5/2000					
Calibration Date: 8/5/2000					
Static water level depth: 749.05 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
WRL/TOC[a]	650	659	668	677	686
PXD psig	-0.00080	1.8387	5.6972	9.5446	13.389
Delta depth (ft): Cal5 - Cal2					27
Delta psi: Cal5 - Cal2					11.550
Density ft of water column/psi: delta depth / delta psi (in ft/psi)					2.338
Equivalent ft water: PXD psig (at Cal 5) x density of water (ft/psi)					31.30
Calculated PXD installation depth: static water level + equiv. ft water					780.35

[a] Length of wireline (WRL) below top of casing (TOC); does not include the length of the PXD integral cable.

ft - Feet
bgs - Below ground surface
PXD - Pressure transducer
psi(g) - Pounds per square inch (gauge)

A.2.8.2 Hydraulic Data Collection

Figure A.2-16 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.2-17 shows the head record for both the pumping and recovery periods, as well as the barometric pressure record. Note that the barometric record in Figure A.2-17 has been scaled proportionate to the PXD record so that fluctuations are of proportional magnitude. The barometric record shows that the barometric pressure was proportionately constant relative to the PXD pressure changes. The data file is EC4_AQTEST_HT.xls on the accompanying CD.

These graphs illustrate the datalogger record and major features of the testing. The average pumping rate was 180.7 gpm during the first five days of pumping and 180.8 gpm during the additional four days. The data record was somewhat noisy during the first five days. The term noise in this context refers to the apparent rapid random variation in PXD pressure about the long-term trend of the PXD pressure curve. This interpretation is based on the expectation that the consistent pumping rate should produce a smooth progressive change in drawdown. The thickness of the band of PXD pressure measurements on the graph reflects the amount of this noise. Examination of the record for the first five days found that the early-time records for drawdown and recovery were inadequate due to the apparent very rapid rates of water level change. In this context, early-time refers to the high rate-of-change in the PXD pressure that the initially occurs when the pumping rate changes. The data collection was modified before restarting the pump to improve the recording of the early-time response.

The data collection rate was increased for the restart of the constant-rate test to better capture drawdown and recovery data. However, this resulted in much increased noise, on the order of over 1-psi variation (equivalent to about 2.3 ft). In an attempt to deal with the noise, the PXD operation and the datalogger program were modified several times. This is further discussed in Section A.2.8.3. The cause of the noise is not positively known, but it is not believed to be an instrumentation problem and is likely noise from the pump. The noise disappears instantly when the pump is stopped (see Figure A.2-17). The flow rate record does not show variations in the flow rate of a proportional magnitude to the noise in the PXD pressure record, although there is also some noise in the flow rate record. The reason for the apparent pumping-rate fluctuations is not known, but may be a result of the rapid data acquisition rate. This will also be discussed in the next section. Further, an attempt was made to determine if the water surface in the well was possibly fluctuating similar to the PXD pressure variation. However, incremental measurements to the water surface with an e-tape only detected a small amount of fluctuation of the water surface, <0.1 ft. Therefore, it is thought that the PXD may have been affected by sound waves transmitted through the water from the pump during pumping.

Figure A.2-18 shows an expanded view of the PXD pressure and pumping rate record at shutdown of the constant-rate test, which clearly shows the oscillatory phenomenon referred to earlier. Note the differences between this graph and Figure A.2-5, which showed the shutdown response during development before the check valve was installed. Figure A.2-18 shows just the oscillatory phenomenon, while Figure A.2-5 shows the oscillatory phenomenon superimposed on a surge decaying into the recovery curve.

A.2.8.3 Noise in the Datalogger Record

Prior to restarting the constant-rate test, the data-collection configuration (data logger data collection parameters and PXD mode) was modified to try to improve data capture during drawdown and recovery when water levels rapidly changed. The rate of water level response at these times was very quick, achieving near equilibrium in less than 16 seconds after the starting or stopping of the pump. The existing data-collection configuration was too slow and coarse to adequately capture these rapid responses, and the shape of the response curves were poorly defined. The changes to the data logger program included a faster execution interval and decreases of the “head-change criteria.” The head-change criterion refers to a “trigger” value of head change measured as the difference between the last recorded PXD value and the latest reading. The datalogger saves data when the change in head exceeds the specified “trigger” value. This programming feature causes the rate of data collection to vary in response to the rate-of-change of PXD pressure, responding automatically to changes in pumping conditions and head response rates. The value can be changed to increase or reduce the rate of data collection. The existing programs, as used at the other WPM-OV wells, used head-change criteria that were too large to sufficiently define the drawdown and recovery curves for Well ER-EC-4, which had limited drawdown and rapid water level changes.

Additional modifications to the data-collection configuration included changing the PXD mode from slow to fast. The PXDs used during the program can operate in two modes: in fast mode the PXDs average eight readings over one second, and in slow mode the PXDs average sixty-four readings over eight seconds. Finally, to speed up data logger processing, program instructions pertaining to the mechanical flowmeter were removed and programmed references to the Hydrolab® were discontinued.

A series of "flags," which contain different sets of data collection parameters, were included in the revised in the program to implement the different configurations. The use of flags provides a convenient means to alter the rate of data collection. These flags were used to reduce the rate after drawdown data were adequately captured at a very fast rate. The ability to reduce the data-collection rate is necessary because continued data collection at a rapid rate, required for the capture of drawdown and recovery data, would have resulted in a massive data file for the entire testing period. The data logger programs also included a secondary data collection schedule that runs on a fixed time period (in this case, every five minutes).

A.2.8.4 Data Collection Configurations

During the first five days of pumping for the constant-rate test, data were being acquired based on a head-change criteria of 0.10 and 0.25 ft; the datalogger execution interval was 10 seconds, and the PXD was operating in slow mode. Upon restarting the constant-rate test on August 15 at 18:45, data were being collected based on a head-change criterion of 0.001 ft, the datalogger execution interval was 2 seconds, and the PXD was operating at fast mode. Upon processing and evaluation of the data record after the restart, the PXD pressure data was found to have excessive noise, much greater than in the record from the first five days of pumping. In an attempt to correct this, a variety of other data collection configurations were tried; data collection proceeded under Flag-2 (head-change criterion of 0.25 ft), Flag-3 (head-change criterion of 0.50 ft), and Flag-4 (head-change criterion of 1.0 ft), while the datalogger execution rate remained at 2 seconds and the PXD remained in fast mode. None of these configurations seemed to reduce the noise.

While data were being acquired under Flag-4 (from 20:00 on August 15 to 10:20 on August 16), the data record had a unique configuration. The data recorded during this period showed continued noise, but the PXD pressure data record displayed a majority of the noise occurring below some sort of a baseline. After these data were evaluated, it was determined that an incorrect instruction was included in the Flag-4 section of the program, causing the data logger to collect data based on head changes from a reference value that was not being reset. Since the reference value was on one side of the data mean, the recorded values were all below a baseline determined by the reference value less the "trigger" value.

The data logger program was modified further on August 16: the conversion for ft water/psi was changed from the standard density of 2.307 to 2.3376; a head-change criterion of 3.0 ft was set for Flag-2; and an instruction was added to collect rapidly if the flow rate decreased below 150 gpm (as a means to automatically capture recovery data at high-speed should pumping stop). At 10:20, the data-collection configuration was changed to collect data based on a head-change of 3.0 ft or every 5 minutes, data collection decreased to approximately one data point every five minutes. Data collection using this configuration was maintained until August 18. During this period, the PXD was still operated in fast mode.

On August 18, ITLV conducted testing of the data-collection system (i.e., data logger and downhole PXD) to determine how the data record was affected by different data-collection configurations. The testing consisted of systematically recording data with different configurations; this was accomplished by successively downloading three different programs into the data logger. Each of the data logger programs utilized four different flags having different head-change criteria and data logger sampling rates. The PXD mode was also toggled between fast and slow during the testing. A constant pumping rate was maintained throughout the testing period. The results of the testing are illustrated in Figure A.2-19, Figure A.2-20, and Figure A.2-21. These figures present an expanded view of the data record from the constant-rate testing, previously shown in Figure A.2-16 and Figure A.2-17, with the data collection configurations labeled.

During the initial phases of the testing, it was recognized that the PXD could not be set to the 8-sec slow mode while the data logger was operating at a 2-sec execution interval. This situation forced the data logger to wait for data from the PXD, and other parameters (e.g., flow rate and barometric pressure) could not be updated while the data logger was retrieving data from the PXD. There are two periods in the record in which no data were recorded (12:50-13:04 and 15:30-15:50) because it was necessary to set all flags “low” (no data collection) within the active program while a new program was downloaded. It can be seen in the PXD pressure record that there is much greater noise when the PXD is operated in fast mode. In general, the flow rate record is also noisier when the data logger was operated at the 2-second execution interval. The testing results will be evaluated and data collection will be optimized for future data collection operations. After the testing was completed, the data-collection system was returned to the configuration in use on August 17 (data logger execution interval of 2 seconds, head-change criterion of 3.0 ft, PXD in fast mode, and secondary data collection schedule of every 5 minutes).

At 09:30 on August 19, the VSD/pump was shut down to end the pumping phase of the extended constant-rate test. At 09:26, prior to the shut down, the data logger program was changed to provide a fast rate of data capture so the rapid water level recovery could be captured (Figure A.2-16). At 10:00, an attempt was made to decrease the rate of data acquisition, a rapid rate was no longer required after

30 minutes of recovery. However, rapid data collection continued because the data logger program was modified so data would be collected rapidly if the flow rate decreased below 150 gpm. The continued rapid rate of data collection was recognized, and at 10:35 a new configuration was used to reduce the rate of data collection; the head-change criterion was increased to 1.0 ft, the data logger execution interval was set to 10 seconds, and the PXD was set to slow mode.

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. Monitoring was accomplished using two different field measurement methods, grab samples taken from a wellhead spigot and an in-line continuously monitoring Hydrolab® H20 Multiprobe. Certain parameters such as Br^- 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 were 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-4 included the following: pH, EC, temperature, turbidity, DO and Br^-. 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 during development for all of the standard parameters except bromide. Grab samples were obtained every two hours, when possible, and analyzed for all the water quality parameters.

Pumping for well development was initiated on July 29, 2000, and in-line monitoring was also begun with the installation of a Hydrolab® H20 Multiprobe. The datalogger began receiving data from the Hydrolab® at 10:10. Grab sample monitoring was conducted as usual, with the first sample obtained at 10:00 on July 29, 2000.

A.2.9.1 Grab Sample Monitoring

Grab samples were obtained from a sample port located on the wellhead assembly. For the development phase, beginning July 29, grab samples were collected and analyzed every two hours, primarily during daylight hours, until 19:22 on August 4, 2000. For the constant-rate pumping test, samples were collected and analyzed about every two hours, beginning on August 10 and ending on August 19, 2000.

Grab samples were analyzed using equipment and methodology described in 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 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 complete results of grab sample monitoring have been compiled and are presented in Attachment 2. The results have been related to the pumping rate, the total discharge, and the phase of development or testing. Additionally, two graphs have been derived showing water quality parameters versus total discharge in gallons (gals). Figure A.2-22 shows EC, pH, and DO, while Figure A.2-23 shows turbidity and Br^- ion concentration.

As shown in Figure A.2-22, fluctuations in EC, pH and DO values were more pronounced during the development phase, probably as a direct result of pump shutdowns and starts and variable pumping rates. The pH remained fairly constant throughout the constant-rate test, while EC and DO showed slightly more variations, but within the range of normal field laboratory error. At the end of the constant-rate test, EC leveled off around 790 micromhos per centimeter (µmhos/cm) and pH stabilized around 7.8, DO continued to fluctuate showing a slight increasing trend.

Turbidity remained mostly below 0.5 nephelometric turbidity units (NTU) with all spikes in the data occurring during development, the high was 39 NTU (Figure A.2-23). The Br^- concentration fluctuated mostly between 0.3 and 1.8 mg/L, averaging a little higher than the other WPM-OV wells near a value of 1.0 mg/L. There were no long-term trends in turbidity or Br^- concentration which indicated any continued progress in development. These parameters remained fairly stable during the constant-rate test.

The temperature of the grab samples remained fairly constant, averaging 38.3°C, with a range of 37.3 to 39.6°C. Temperature results from grab samples are not depicted graphically. Temperature values can often fluctuate depending on ambient air temperatures and the efficiency with which the temperature of the wellhead sample is measured. Therefore, a temperature graph from the in-line monitoring is presented in Section A.2.9.2 and downhole temperatures are discussed in Section A.2.11, where ChemTool logging results are presented. The results of lead and tritium monitoring are presented in Section A.4.0, Environmental Compliance.

A.2.9.2 In-Line Monitoring

In-line monitoring was conducted using a Hydrolab® H20 Multiprobe. The data logger recorded in-line water quality data at a 10-minute interval. Temperature, EC, pH, turbidity, and DO were recorded continuously from July 29 (10:10) to August 2, 2000 (08:20), while pumping during well development. During the constant-rate test, the Hydrolab® was not used, so no discharge was diverted away from the flowmeters and, because any changes in water quality were expected to be gradual, could be obtained via grab samples. During development, the Hydrolab® was taken off-line during pump shutdowns/startups to prevent damage to delicate components and to eliminate the collection of data from stagnant water in the probe cell (displayed as anomalous spikes in data from previous well reports). Just before shutdown, collection of Hydrolab® data by the data logger was suspended and the valve to the Hydrolab® flow system was closed to eliminate the exposure of the system to elevated vacuum pressures when the water column fell. During pump startup, the valve remained closed to allow turbid water to discharge and to allow the pressure to stabilize. After about 5 minutes, the valve to the Hydrolab® was opened, flow through the system was adjusted to approximately 1.5 gpm, and collection of Hydrolab® data by the data logger was reinitiated. Additionally, the plumbing of the Hydrolab® system was also modified so the flow-through cell was in a vertical position. This was done to help drive entrained air through the cell, minimizing the accumulation of air pockets within the cell.

The Hydrolab® was calibrated and maintenance was performed prior to development and also on August 1, 2000, in accordance with DOP ITLV-UGTA-312. The DO was calibrated for percent saturation according to the DOP, but data output was not switched to the concentration mode (mg/L) as specified in the DOP. A conversion formula has been obtained from the Hydrolab® manufacturer; the converted data is presented in Figure A.2-25. The conversion is temperature corrected, but not salinity corrected. The formula and conversion is included within the file Hydrolabcalc.xls contained in the accompanying CD. A refinement was initiated for calibration of turbidity to eliminate potential interference from ambient light. The flow-through cell was calibrated in the dark (wrapped in an absorbent pad), and the cell was also kept covered at the wellhead to prevent light interferences during daytime operations.

Three figures have been produced from the in-line monitoring data. Figure A.2-24 presents EC and pH related to total discharge in gallons, Figure A.2-25 depicts turbidity and DO (in mg/L) over the same time period, and Figure A.2-26 shows temperature and pumping rate versus total discharge. The EC record shows three distinct plateaus: an early plateau around 500 µmhos/cm, a middle plateau around 650 µmhos/cm, and a late plateau around 550 µmhos/cm. The last plateau developed after the probe was recalibrated on August 1. The configuration of the pH record was similar with fairly stable values from 7.6 to 7.65. The pH record also displays a shift in values (to around 7.8) after the recalibration. The pH results from in-line monitoring compare well with the grab sample results. However, the two EC records do not compare well as the grab sample results fluctuated between 750 and 800 µmhos/cm during this same period.

The in-line turbidity record shows a great deal of fluctuation of NTU values much greater than the values obtained from grab samples (Figure A.2-25). The in-line turbidity record does show a decreasing trend as pumping progressed, with turbidity values fluctuating less than the values noted from the other WPM-OV wells. The DO record also shows several stable plateaus of values, ranging from 5.2 to 6.3 mg/L. Again, the recalibration on August 1 shifted DO values higher to around 8.1 mg/L. The values in the post-calibration record are extremely high compared to previous WPM-OV data and are suspect. The precalibration DO data compare well with the DO results from the grab samples. In-line temperatures were fairly steady from 39 to 40°C, with elevated values correlating with increases in pumping rates (Figure A.2-26). The in-line temperature record agrees well with the grab sample average of 38.3°C.

A.2.10 Groundwater Sample Collection

Two types of well samples were collected for characterization of the groundwater in Well ER-EC-4: discrete downhole samples collected via wireline bailer, and composite samples collected at the wellhead.

A.2.10.1 Discrete Downhole Sampling

There are two purposes for the collection of discrete downhole samples. The first is to collect samples at a particular depth, sometimes under nonpumping conditions, to obtain samples that represent the water quality at that specific depth or in the corresponding completion interval. The second purpose is to collect samples that represent the composite water quality of all production below the depth of collection, and is taken while pumping. 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 are to be collected, and (2) a pumping rate can be maintained that will ensure a representative sample of the interval of interest. The discrete sampling interval was determined after initial well development and downhole flow and temperature logging.

On August 4, 2000, discrete samples were obtained from a depth of 1,150 ft bgs, while pumping at a rate of approximately 180 gpm. The sample was obtained using a DRI logging truck, wireline, and discrete bailer. The bailer was decontaminated by ITLV personnel using the methodology in DOP ITLV-UGTA-500, “Small Sampling Equipment Decontamination,” and SQP ITLV-0405, “Sampling Equipment Decontamination.” Equipment rinsate samples were collected from the decontaminated bailer prior to collection of the discrete samples. The samples were processed according to 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 processed and stored in coolers with ice, and were transported to secure refrigerated storage that day. Samples were obtained for the following laboratories: Paragon; Los Alamos National Laboratory (LANL); and University of Nevada, Las Vegas - Harry Reid Center (UNLV-HRC).

The final, validated results of the August 4, 2000, discrete bailer samples have been tabulated and are presented in Attachment 3. These results can be compared to the results of the discrete groundwater characterization samples taken during drilling before well completion. Those samples were obtained by bailer on June 15, 1999, from depths of 1,690 and 3,460 ft bgs (DOE/NV, 2000).

A.2.10.2 Composite Wellhead Sampling

The purpose of this sampling is to obtain a composite groundwater sample that is comprised of water produced from multiple completion intervals within the well. The composite groundwater characterization samples were collected at the end of the constant-rate pumping test from the sampling port at the wellhead. Since these samples are meant to represent a composite of the whole well, there are two criteria for the samples to be the most representative: (1) the samples 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. From the results of the flow logging, the proportional composition of the composite samples was also determined. As discussed in Section A.2.7.2, the flow logging showed that 100 percent of the flow into the well originated in the upper completion interval at a production rate of 180 gpm.

On August 17, 2000, composite characterization samples were collected from the wellhead sampling port directly into sample bottles. A field duplicate quality control sample was obtained concurrently. A constant production rate of 182 gpm was maintained during the sampling event, close to the same rate used during the constant-rate test. At the time of sampling, approximately 2,846,000 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 bailer sampling. Samples were immediately put on ice in coolers and were transported to secure refrigerated storage that day. Samples were collected for the following laboratories: Paragon, UNLV-HRC, LLNL, LANL, and DRI. The final, validated results of the composite samples are presented in Attachment 3.

A.2.11 Thermal Flow, Spinner, and ChemTool Logs

Thermal Flow, Spinner, and ChemTool logging was conducted by DRI on August 25, 2000, at the end of the development and testing program to characterize flow and natural circulation in the well under ambient conditions. The ChemTool provides a depth log of temperature, pH, and EC. The spinner log was run to quantify flows that exceeded the upper limit of the thermal flow logging tool. Flow information from the thermal flow and spinner tools run in the well completion may differ from that of the thermal flow logging conducted in the open borehole before well completion. This results from the limited access of the completion intervals to the formation. The new flow information also reflects remediation of borehole conditions resulting from drilling by the well development activities.

A.2.11.1 Methodology

The ChemTool consists of three sensors that record temperature, pH, and EC. The tool is trolled along the well completion to give parameter variation with depth. The thermal flowmeter utilizes a heat-source with sensing grids and can measure vertical flow rates at low velocities (less then 2.2 gpm). The flow profile from the thermal log along the well completion is constructed from multiple stationary flow measurements. The spinner log is a trolling log that utilizes an impeller and can record higher rates of vertical flow than the thermal flow tool.

A.2.11.2 Results

The results of the ChemTool logging are presented in Figure A.2-27. The ChemTool log shows relatively constant EC values from above the upper completion interval down to the bottom of the lower completion interval, around 3,400 ft bgs. The EC log is fairly clean, with the values gradually increasing from 775 to 825 μmhos/cm over a 2,600-ft interval. The pH is extremely high, around 12.5 to 13.0 standard units (SU), and is to be considered corrupt data. DRI attempted to correct problems with the pH sensor on location but was unsuccessful. Post-calibration of the pH sensor revealed that output from the probe was about 3 to 5 SUs higher than the calibration standards. The temperature log shows gradual increases (from 36°C to 46°C) with depth, with the largest deflection occurring at the bottom of the middle completion interval.

The thermal flow log data, as collected at nine stations between 950 and 3,300 ft bgs, are presented in Table A.2-9. Six of the stations indicated downward flow of 2.2 gpm (2.2 gpm is the maximum flow rate that can be measured by the thermal flowmeter). The stations at 950 and 3,300 ft bgs indicated 0 gpm (no-flow), while the station at 3,270 ft bgs indicated a downward flow rate of 0.065 gpm. Results from the spinner log indicate downward flow in the range of 4 to 20 gpm, with downward flow rates decreasing with depth. The tool was trolled upward at a line speed of 140 fpm; trolling at such a rapid rate may have produced some interference with the well completion as well as noise in the data. Results from the spinner flow log are depicted in Figure A.2-28.

Table A.2-9
Thermal Flow Log Results

Station Depth (ft bgs)	Response (sec)	Flow Rate (gpm)	Velocity (fpm)
950.0	12.70+/-2.440*	0.000+/-0.000	0.000+/-0.000
1,148.0	-0.50+/-0.002	-2.200+/-0.009	-2.157+/-0.009
1,233.0	-0.50+/-0.002	-2.200+/-0.009	-2.157+/-0.009
2,000.0	-0.50+/-0.002	-2.200+/-0.009	-2.157+/-0.009
2,132.0	-0.54+/-0.108	-2.200+/-0.440	-2.157+/-0.431
2,295.0	-0.50+/-0.002	-2.200+/-0.009	-2.157+/-0.009
3,180.0	-0.50+/-0.002	-2.200+/-0.009	-2.157+/-0.009
3,270.0	-10.30+/-0.306	-0.065+/-0.002	-0.063+/-0.002
3,300.0	40.00+/-20.000*	0.000+/-0.000	0.000+/-0.000

ft bgs - Feet below ground surface
sec - Second(s)
gpm - Gallons per minute
fpm - Feet per minute

*Measurement below calibration limits

Notes: Internal diameter of production casing at all stations was 5.0 inches; positive values indicate upward flow; negative values indicate downward flow.

A.2.12 Sampling Pump and Bridge Plug Installation

A bridge plug was installed inside the 5.5-in. casing by Baker-Hughes on August 25, 2000, to isolate the lower completion interval from the upper completion intervals. The bridge plug was set at 2,365 ft bgs in a section of the well above the lower completion interval with cement in the annulus.

On August 30, 2000, a dedicated sampling pump was installed in Well ER-EC-4 by BN with the assistance of a Electrical Submersible Pumps, Inc. (ESP) representative. The pump assembly was installed using a 2 7/8-in. outside diameter (od), stainless-steel tubing. The bottom of the pump assembly is landed at 984.2 ft bgs; the pump intake is at 960.51 ft bgs; and the top of the pump assembly is at 951.64 ft bgs. The total length of the pump assembly, not including a crossover at the top, is 32.6 ft, and a 3.39-ft stickup makes the entire string (pump and tubing) a length of 987.59 ft. Table A.2-10 summarizes the details of the components of the pump assembly. The manufacturer’s specifications for the pump are provided in Attachment 1.

The pump string was landed on a 1-in. landing plate at the wellhead. Figure A.2-29 depicts the final wellhead configuration. A VSD was wired to the pump and on August 30, 2000, a functionality test of the sampling pump was conducted after appropriate wellhead plumbing was attached. The discharge was routed to Sump #1. At 11:00, the pump was started at 60 Hz (~40 gpm) and discharge occurred at the surface 4 minutes, 29 seconds later. The pump was run at seven different VSD frequencies for about 52 minutes. The results of the functionality testing are shown is Table A.2-11. Approximately 1,800 gallons were pumped during the functionality test. A few problems were encountered during initial startup, the electrical problems were corrected, and the functionality testing proceeded without further mishap.

Table A.2-10
Dedicated Sampling Pump Specifications for ER-EC-4

Pump Component	Type/Model	Serial Number	Other Information
ESP Pump	TD 800	2D8I15037	87 Stages
ESP Protector	TR3 STD	3B8I07991	Not Applicable
ESP Motor	MD TR3 UT (Frame 17 THD)	1B0D90983P	40 hp, 750 V, 40 A

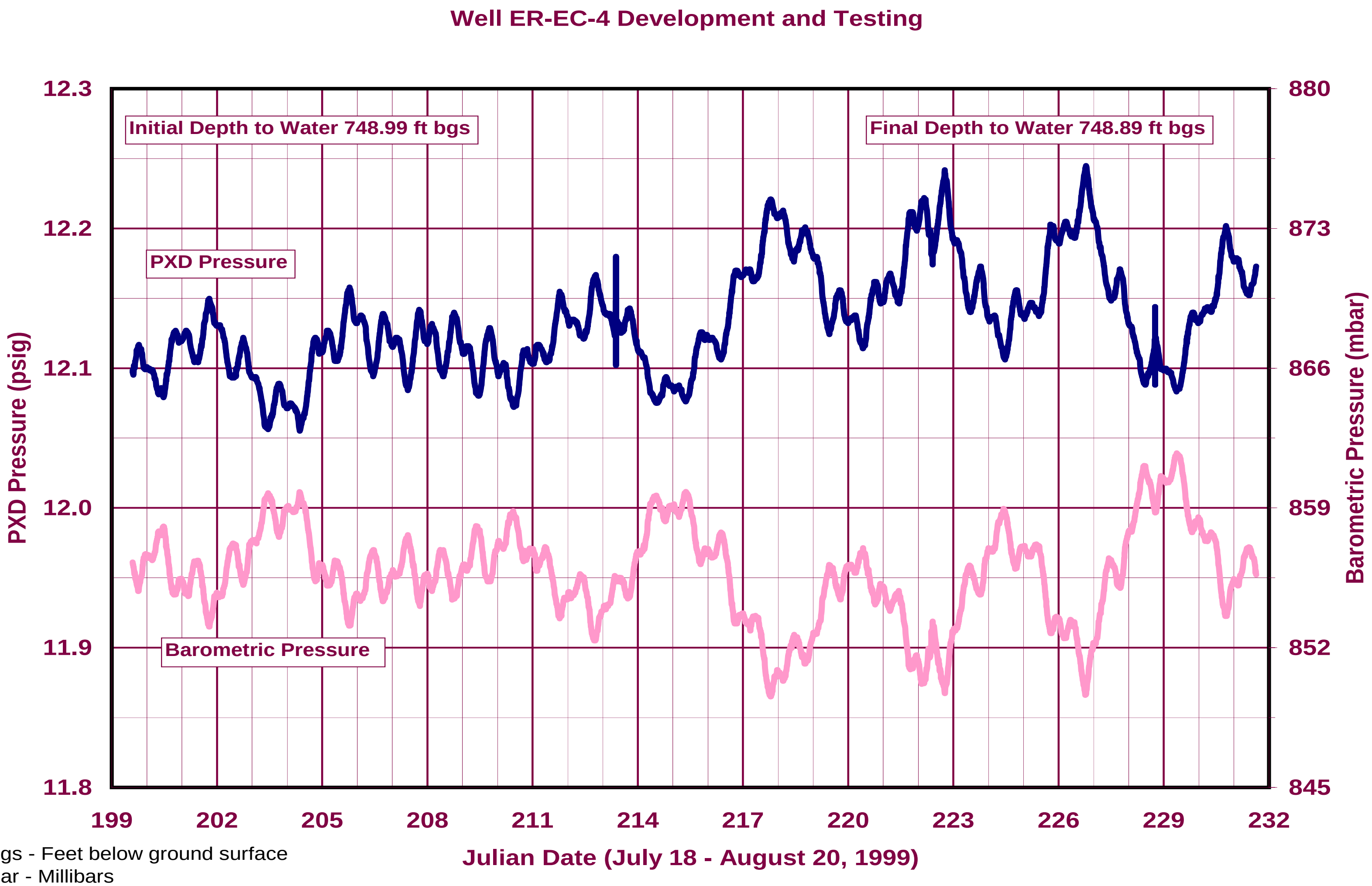
ESP - Electrical Submersible Pumps, Inc.
hp - Horsepower
V - Volts
A - Amps

Table A.2-11
Functionality Test Results for Dedicated Sampling Pump

Time	VSD Frequency (Hz)	Flow Rate Magnetic Flowmeter (gpm)	VSD Amps	VSD Volts	Downhole Amps	Downhole Volts
11:08	60.0	39.14	79	327	34	701
11:18	69.0	46.06	93	375	41	800
11:28	65.0	42.83	84	352	36	755
11:36	55.0	35.03	66	298	29	643
11:43	50.0	30.69	61	272	26	612
11:50	45.0	26.37	34	245	23	553
11:54	40.0	21.41	48	218	21	491

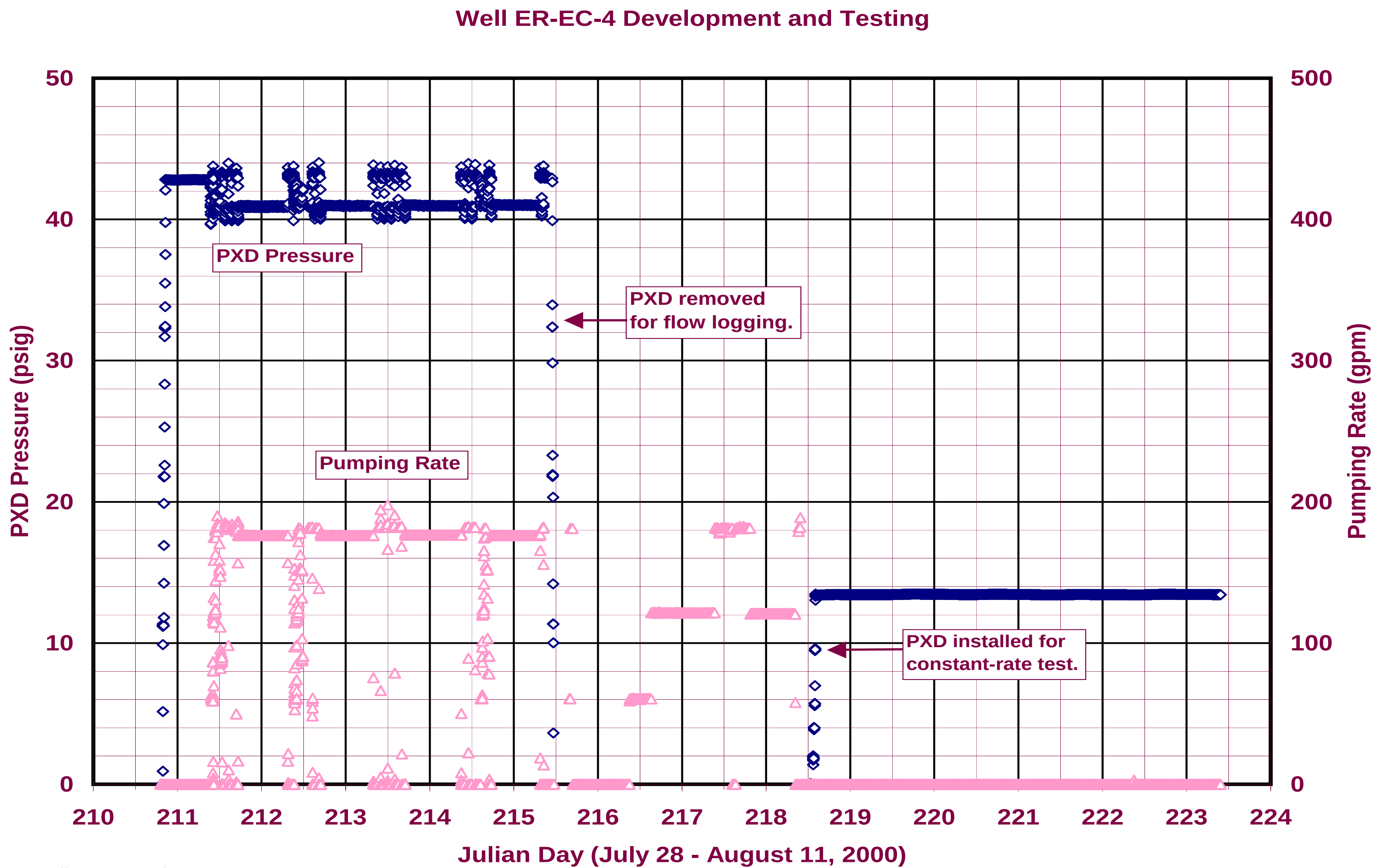
Notes: Test conducted on 8/30/2000. Values for amperage and voltage are nominal of three electrical phases.

Hz - Hertz (cycles per second)
gpm - Gallons per minute
VSD - Variable-Speed Drive



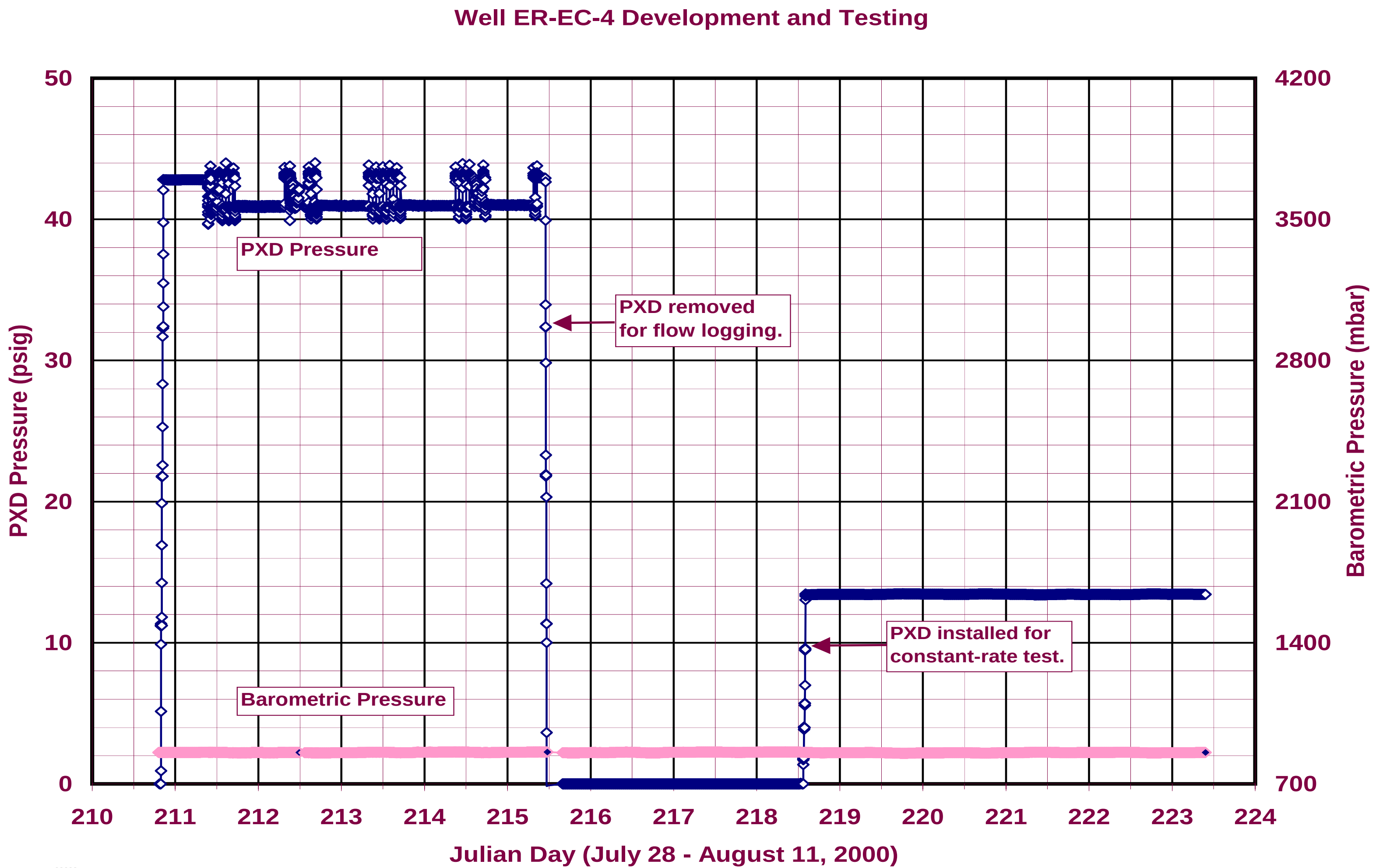
ft bgs - Feet below ground surface
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-1
Predevelopment Water Level Monitoring



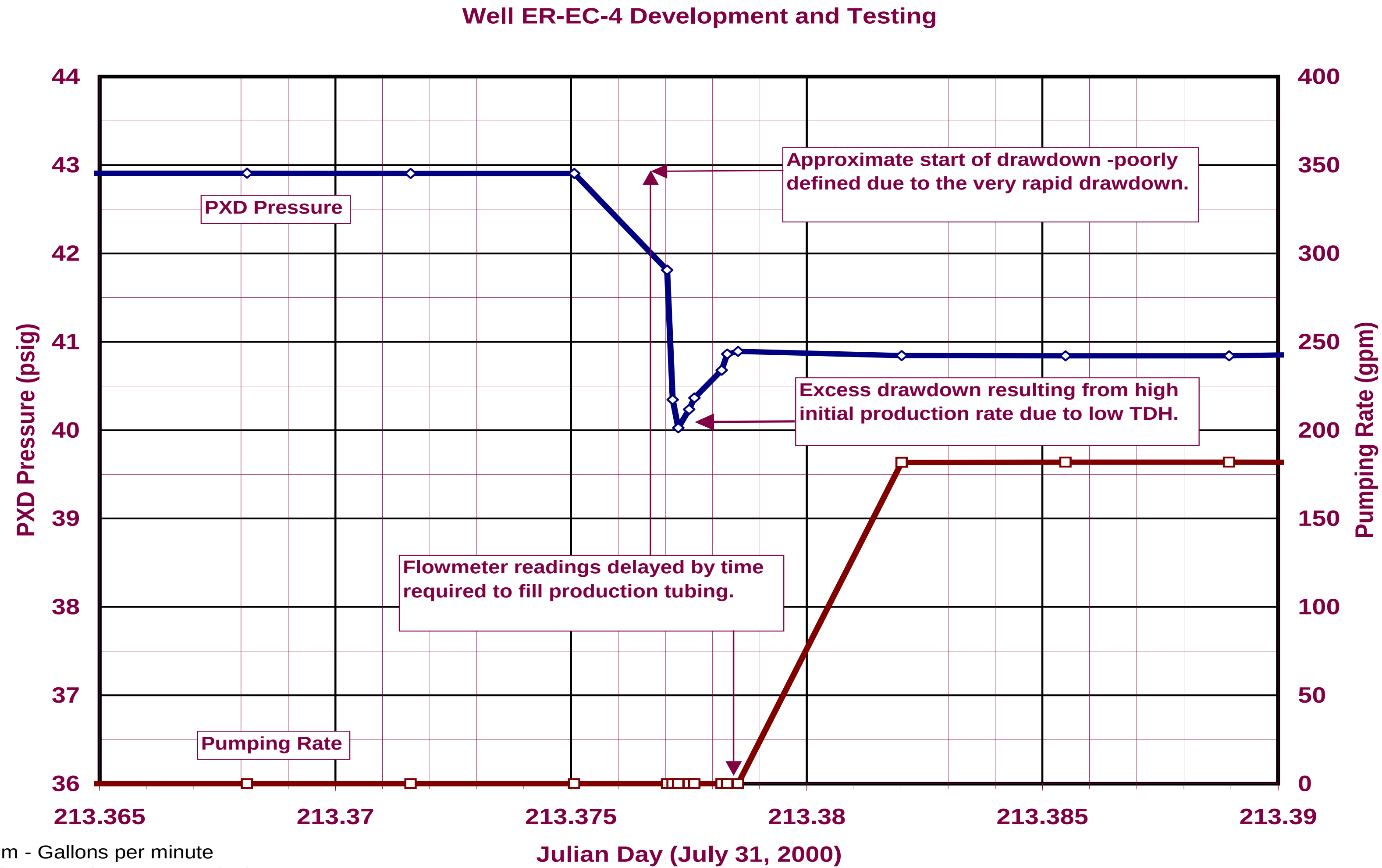
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



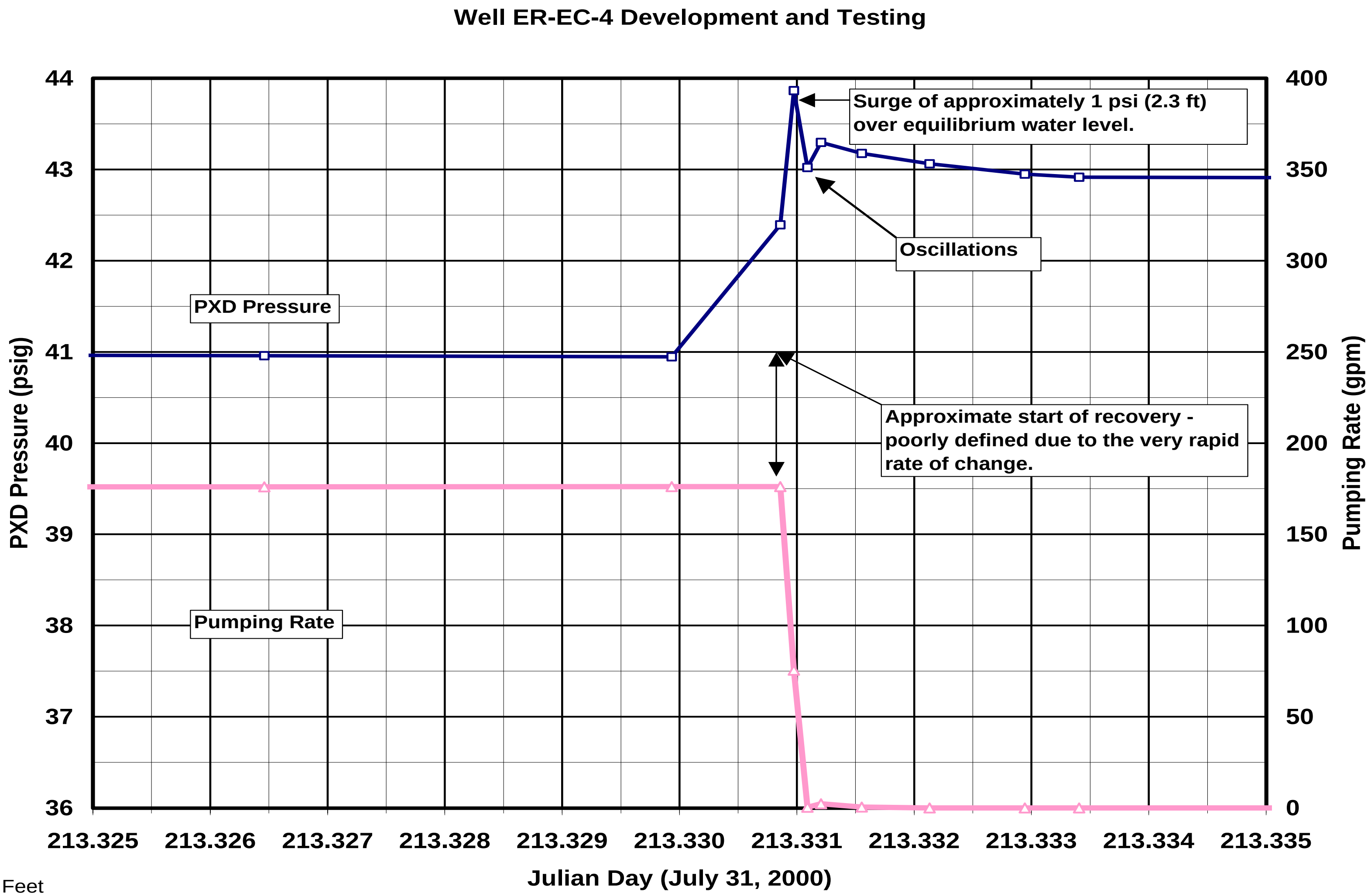
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



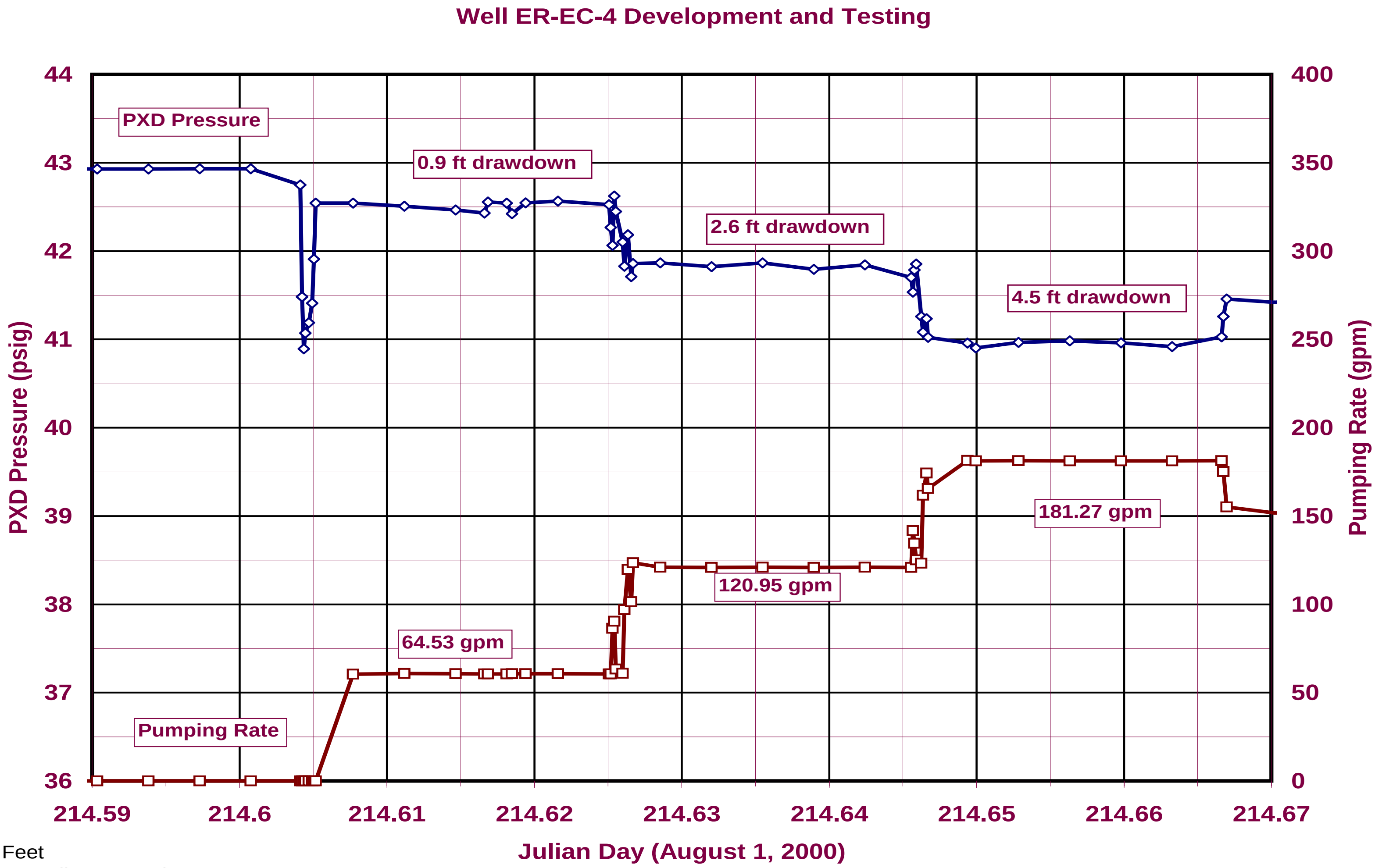
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer
TDH - Total dynamic head

Figure A.2-4
Detail of Startup Effects



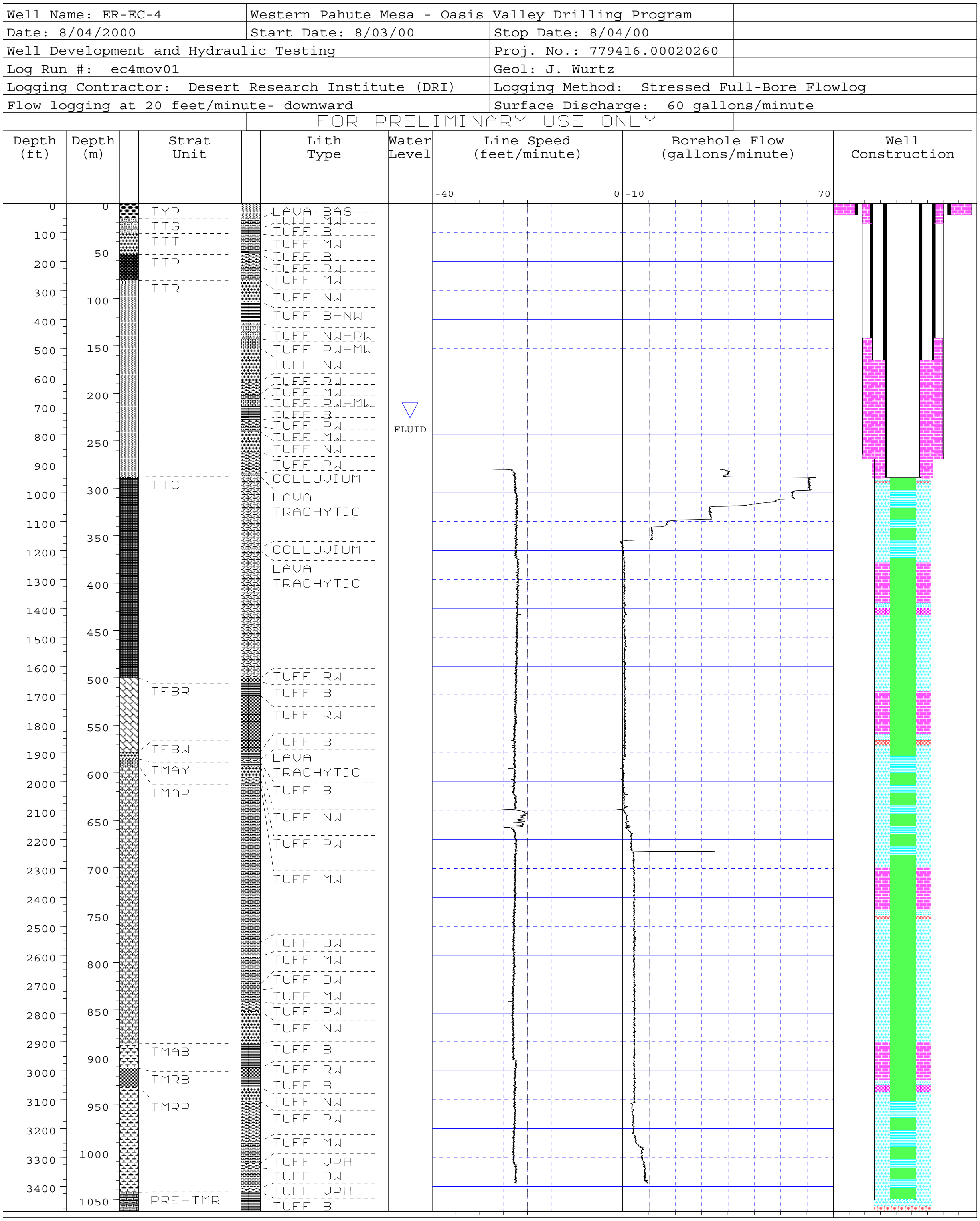
ft - Feet
gpm - Gallons per minute
psi - Pounds per square inch
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-5
Detail of Pump-Shutdown Response and Surging Action



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

Figure A.2-6
Detail of Step-Drawdown Protocol



Well Name: ER-EC-4
Western Pahute Mesa - Oasis Valley Drilling Program
Date: 8/04/2000
Start Date: 8/03/00
Stop Date: 8/04/00
Well Development and Hydraulic Testing
Proj. No.: 779416.00020260
Log Run #: ec4mov01
Geol: J. Wurtz
Logging Contractor: Desert Research Institute (DRI)
Logging Method: Stressed Full-Bore Flowlog
Flow logging at 20 feet/minute- downward
Surface Discharge: 60 gallons/minute
FOR PRELIMINARY USE ONLY

Figure A.2-7
Flow Log at 60 gpm Production Rate and 20 fpm Downward Trolling Rate

Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program		
Date: 8/04/2000	Start Date: 8/03/00	Stop Date: 8/04/00	
Well Development and Hydraulic Testing		Proj. No.: 779416.00020260	
Log Run #: ec4mov02		Geol: J. Wurtz	
Logging Contractor: Desert Research Institute (DRI)		Logging Method: Stressed Full-Bore Flowlog	
Flow logging at 40 feet/minute - upward		Surface Discharge: 60 gallons/minute	

FOR PRELIMINARY USE ONLY

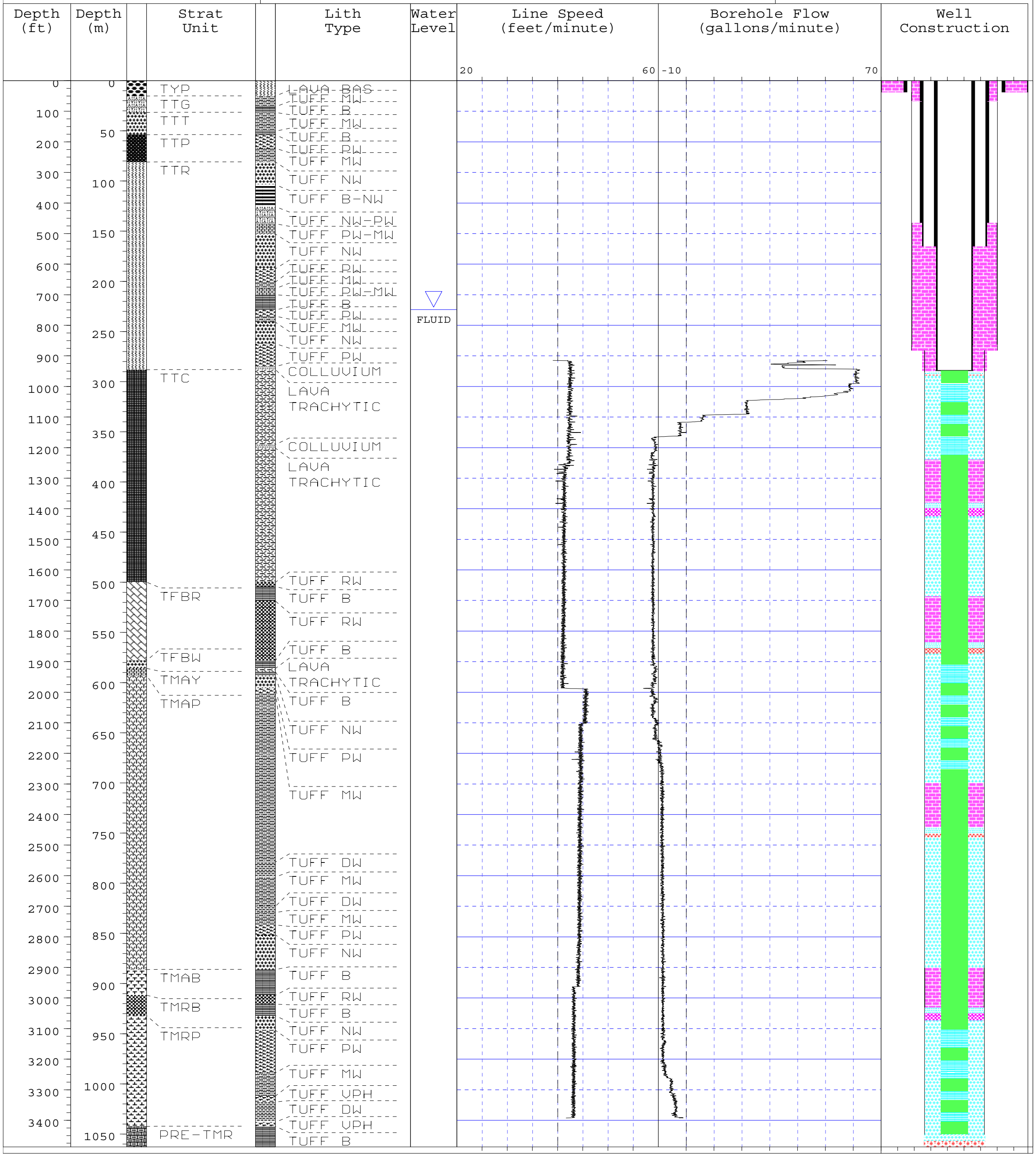
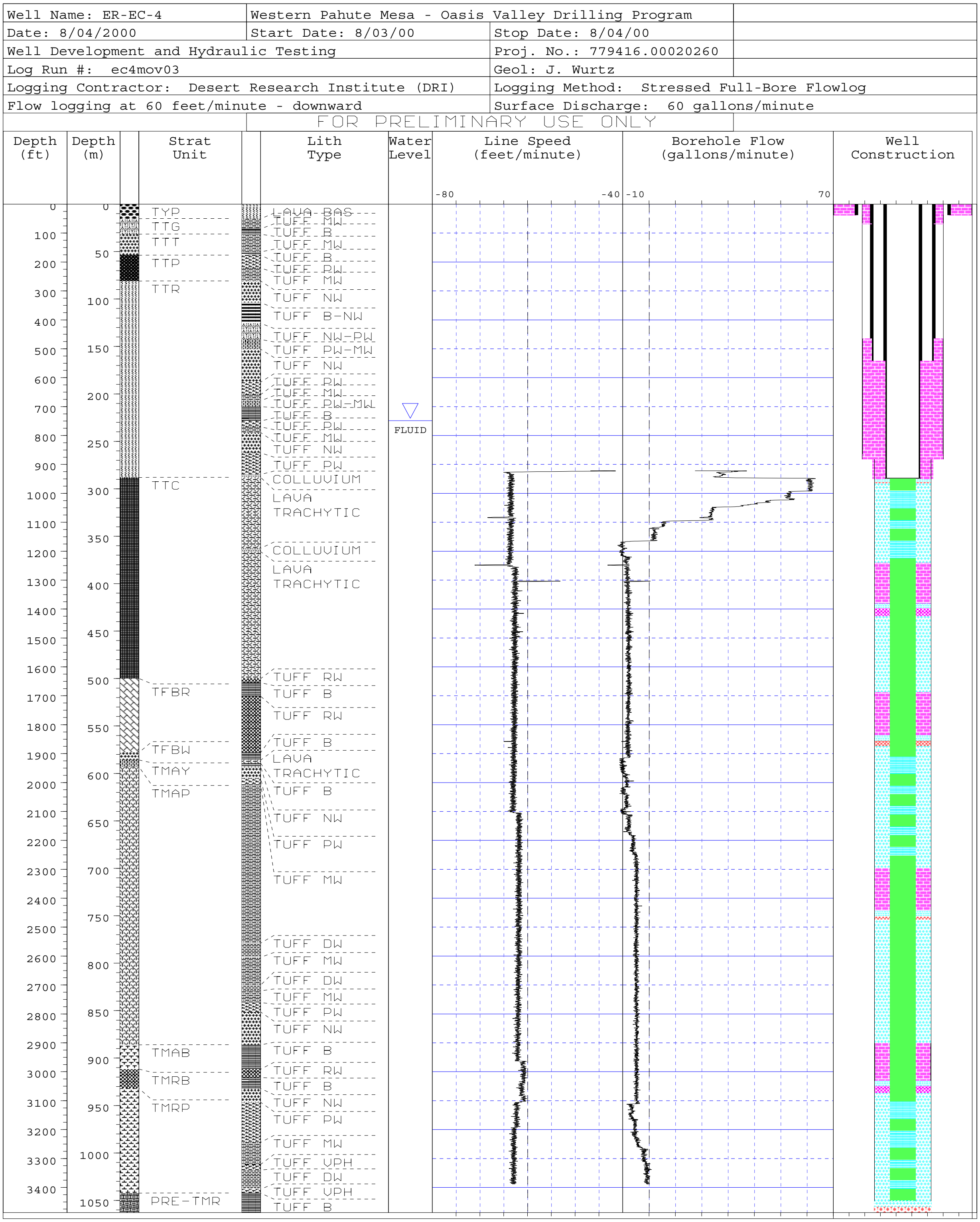
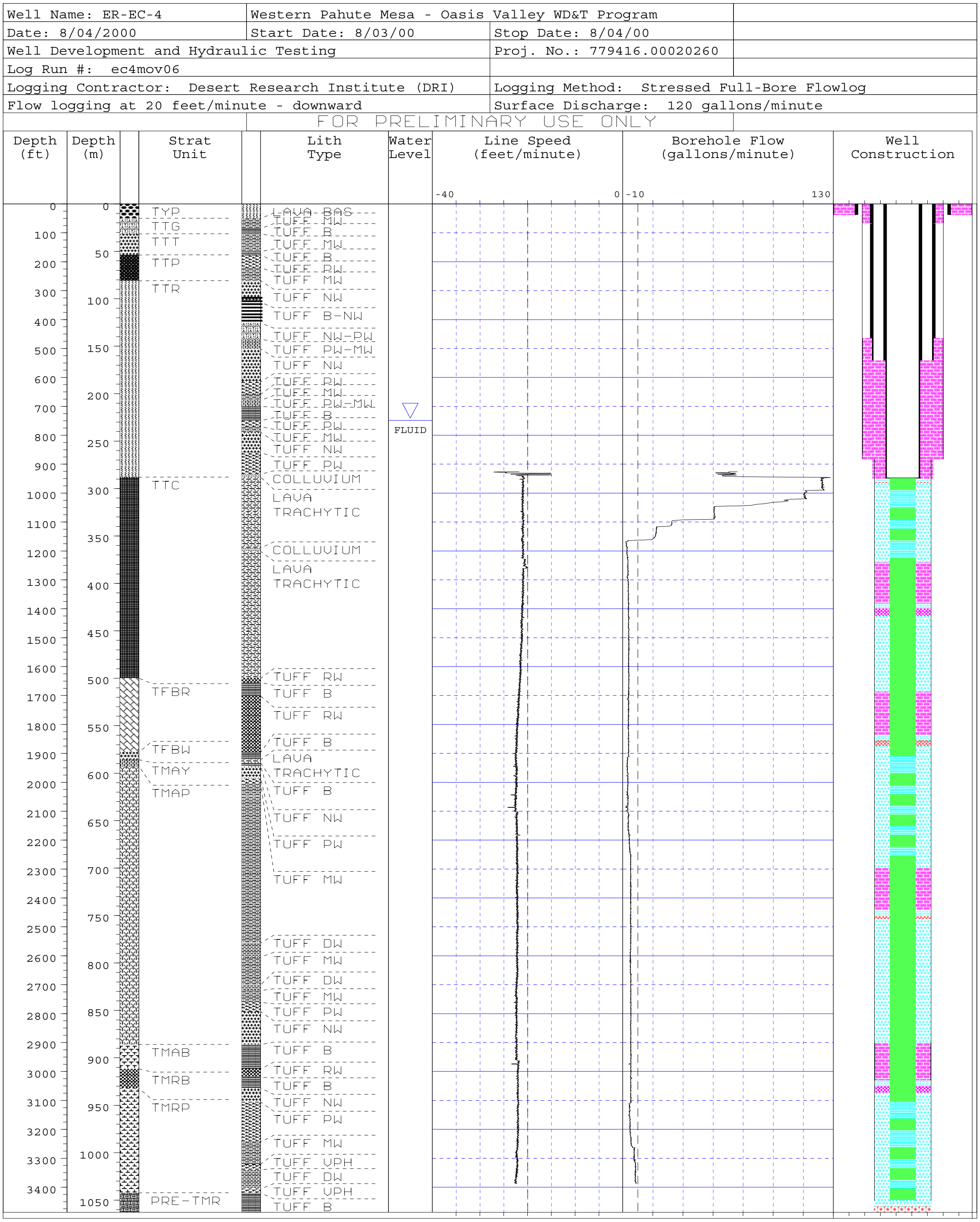


Figure A.2-8
Flow Log at 60 gpm Production Rate and 40 fpm Upward Trolling Rate



Well Name: ER-EC-4
Western Pahute Mesa - Oasis Valley Drilling Program
Date: 8/04/2000
Start Date: 8/03/00
Stop Date: 8/04/00
Well Development and Hydraulic Testing
Proj. No.: 779416.00020260
Log Run #: ec4mov03
Geol: J. Wurtz
Logging Contractor: Desert Research Institute (DRI)
Logging Method: Stressed Full-Bore Flowlog
Flow logging at 60 feet/minute - downward
Surface Discharge: 60 gallons/minute

Figure A.2-9
Flow Log at 60 gpm Production Rate and 60 fpm Downward Trolling Rate



Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley WD&T Program	
Date: 8/04/2000	Start Date: 8/03/00	Stop Date: 8/04/00
Well Development and Hydraulic Testing		Proj. No.: 779416.00020260
Log Run #: ec4mov06		
Logging Contractor: Desert Research Institute (DRI)		Logging Method: Stressed Full-Bore Flowlog
Flow logging at 20 feet/minute - downward		Surface Discharge: 120 gallons/minute

FOR PRELIMINARY USE ONLY

Figure A.2-10
Flow Log at 120 gpm Production Rate and 20 fpm Downward Trolling Rate

Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley WD&T Program		
Date: 8/04/2000	Start Date: 8/03/00	Stop Date: 8/04/00	
Well Development and Hydraulic Testing		Proj. No.: 779416.00020260	
Log Run #: ec4mov05			
Logging Contractor: Desert Research Institute (DRI)		Logging Method: Stressed Full-Bore Flowlog	
Flow logging at 40 feet/minute - upward		Surface Discharge: 120 gallons/minute	
	FOR PRELIMINARY USE ONLY		

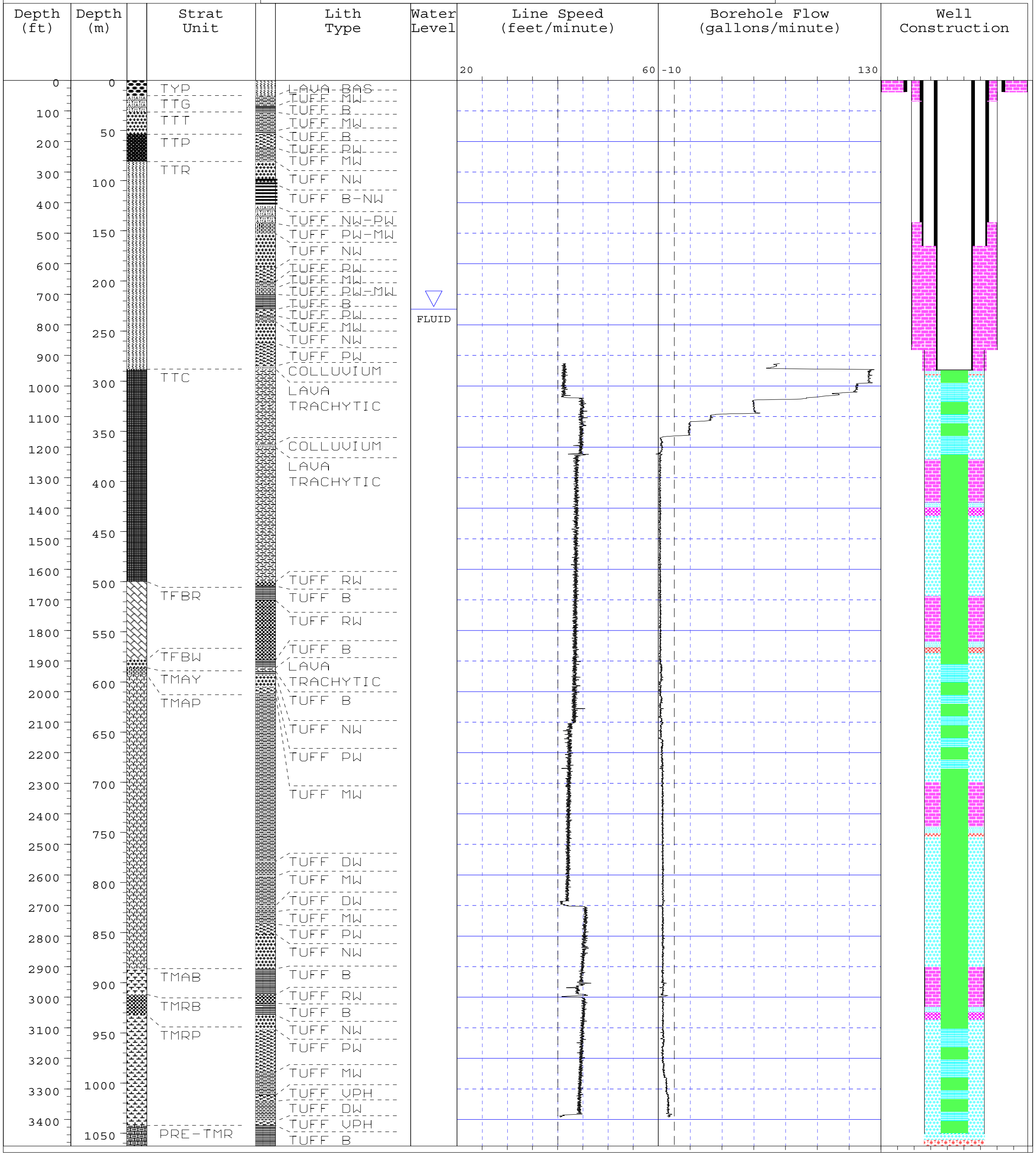


Figure A.2-11
Flow Log at 120 gpm Production Rate and 40 fpm Upward Trolling Rate

Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley WD&T Program		
Date: 8/04/2000	Start Date: 8/03/00	Stop Date: 8/04/00	
Well Development and Hydraulic Testing		Proj. No.: 779416.00020260	
Log Run #: ec4mov04			
Logging Contractor: Desert Research Institute (DRI)		Logging Method: Stressed Full-Bore Flowlog	
Flow logging at 60 feet/minute -downward		Surface Discharge: 120 gallons/minute	
	FOR PRELIMINARY USE ONLY		

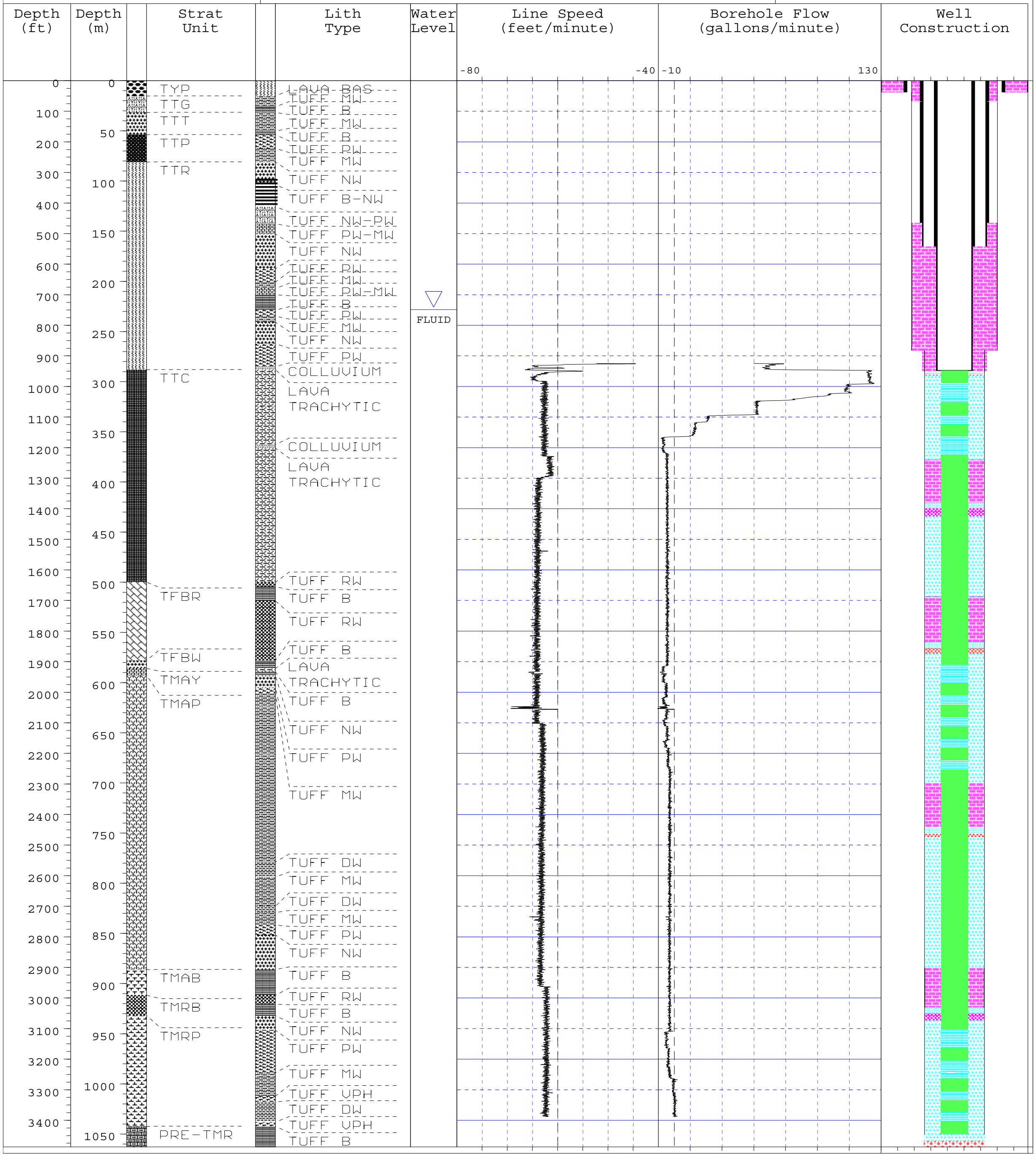


Figure A.2-12
Flow Log at 120 gpm Production Rate and 60 fpm Downward Trolling Rate

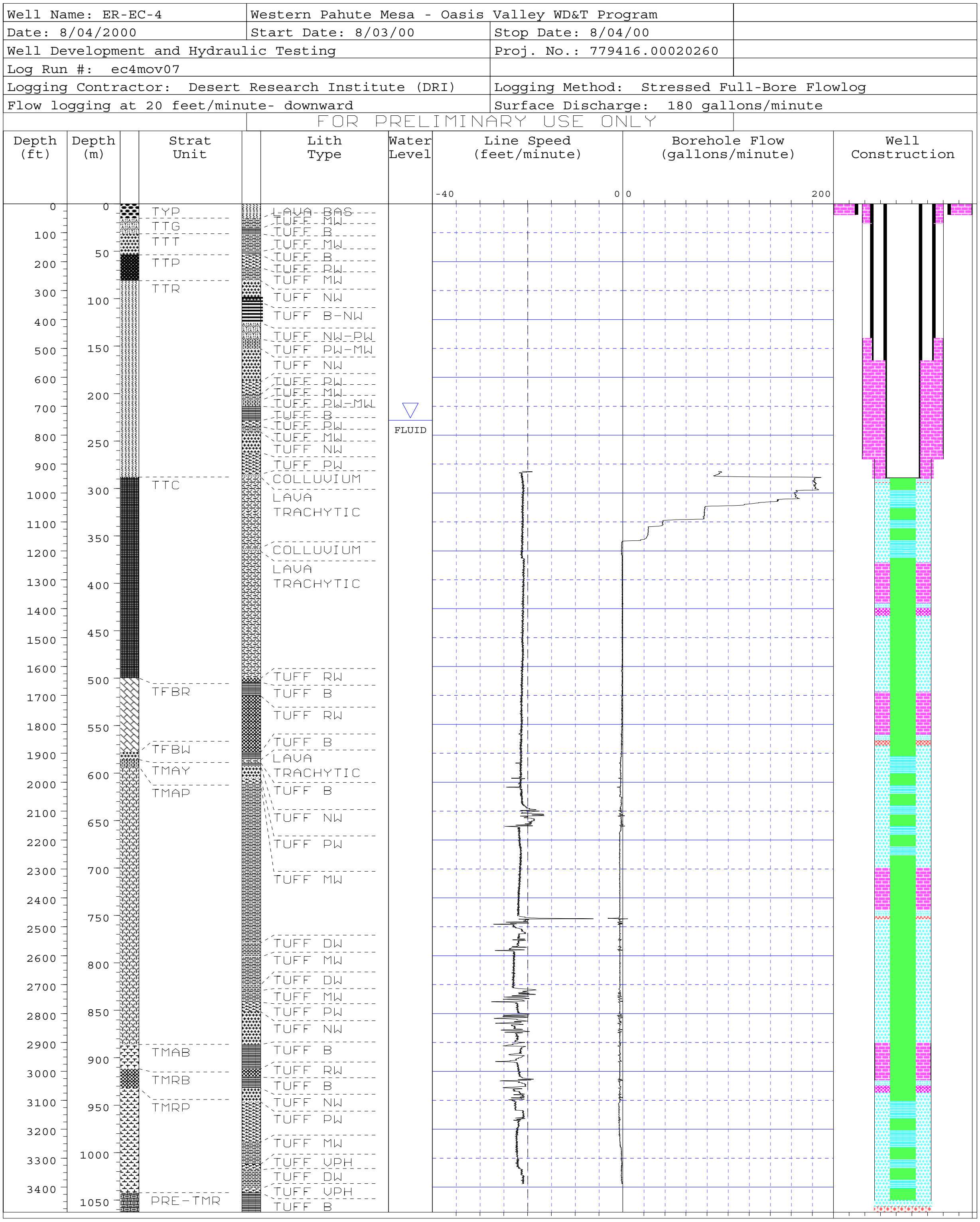
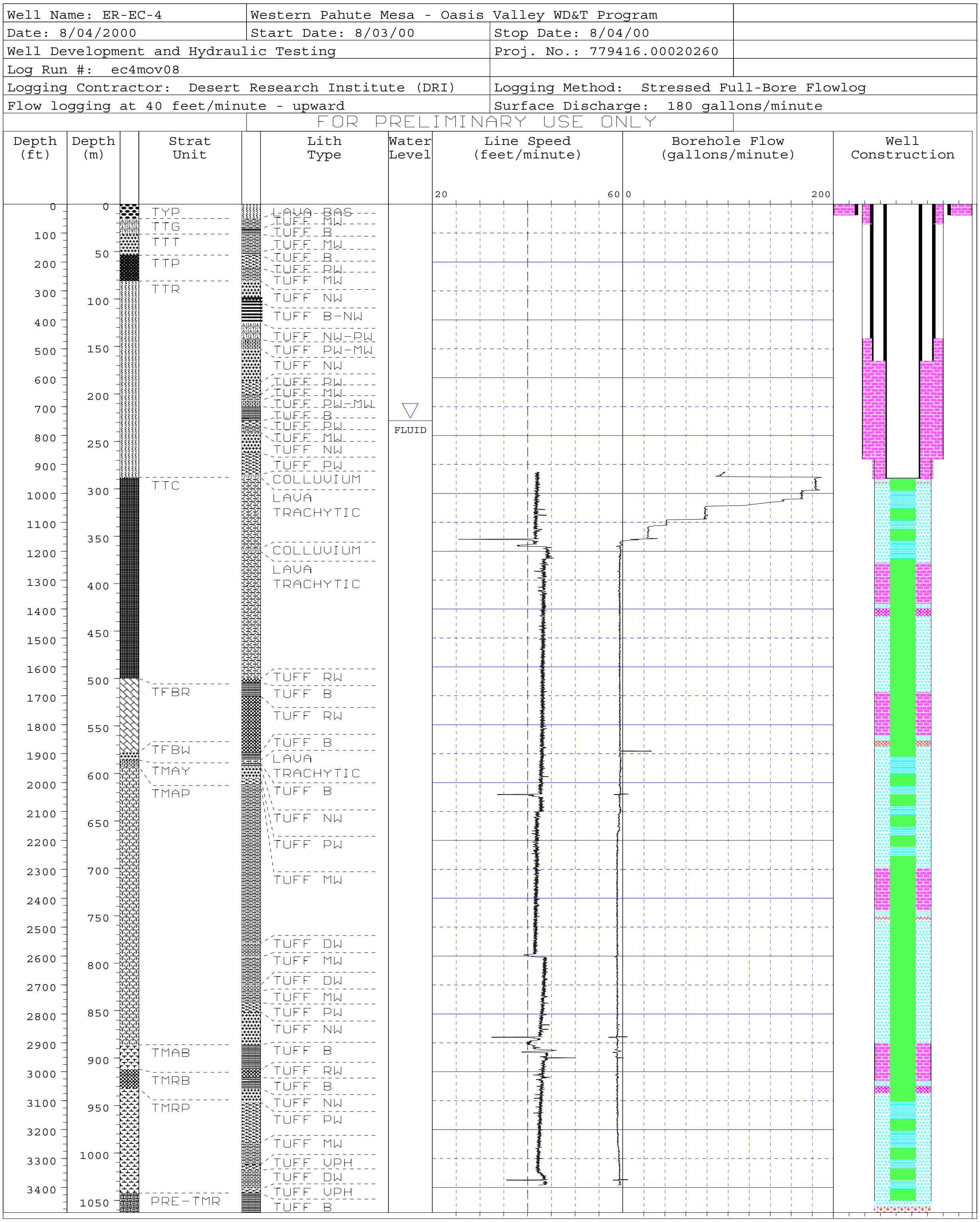
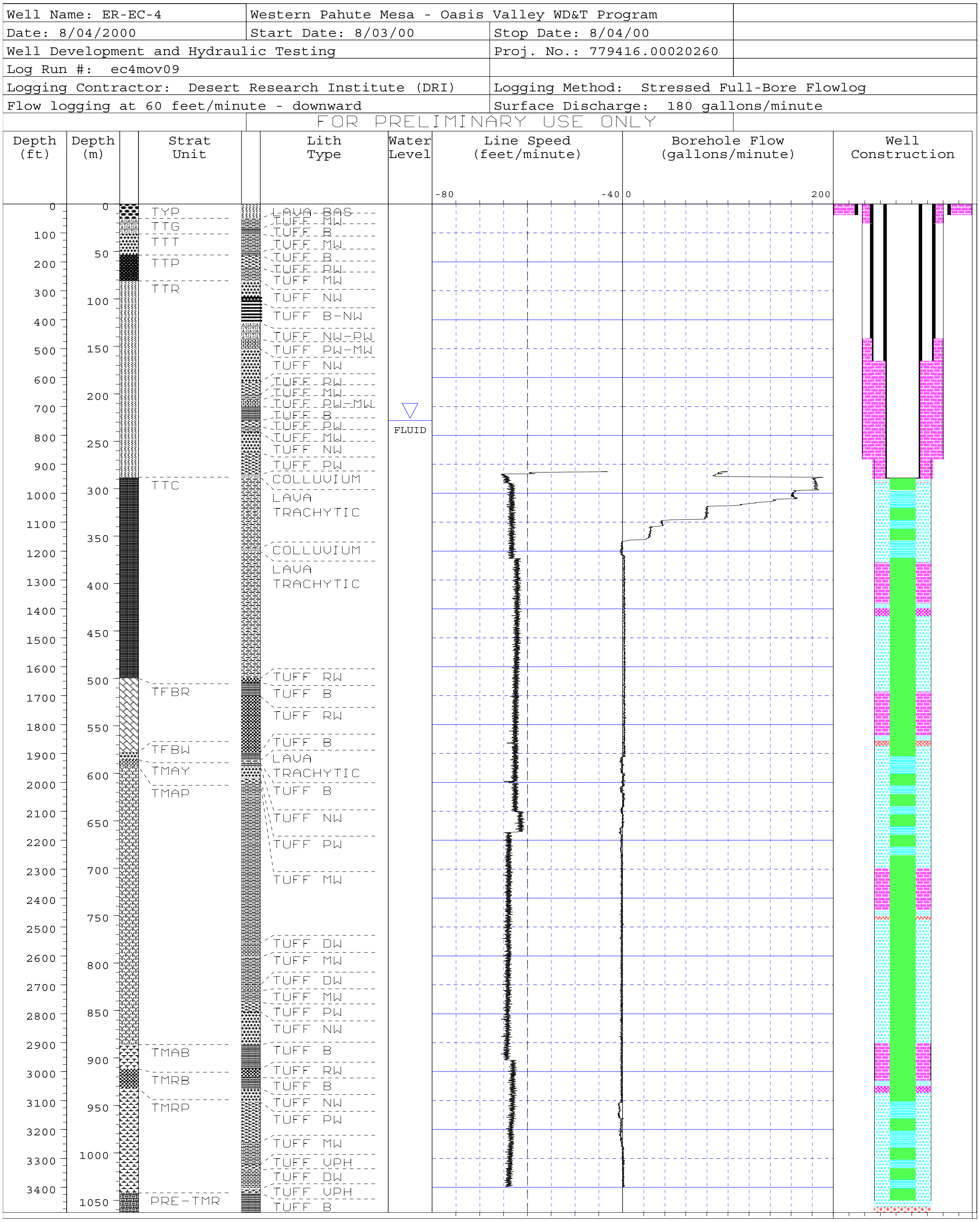


Figure A.2-13
Flow Log at 180 gpm Production Rate and 20 fpm Downward Trolling Rate



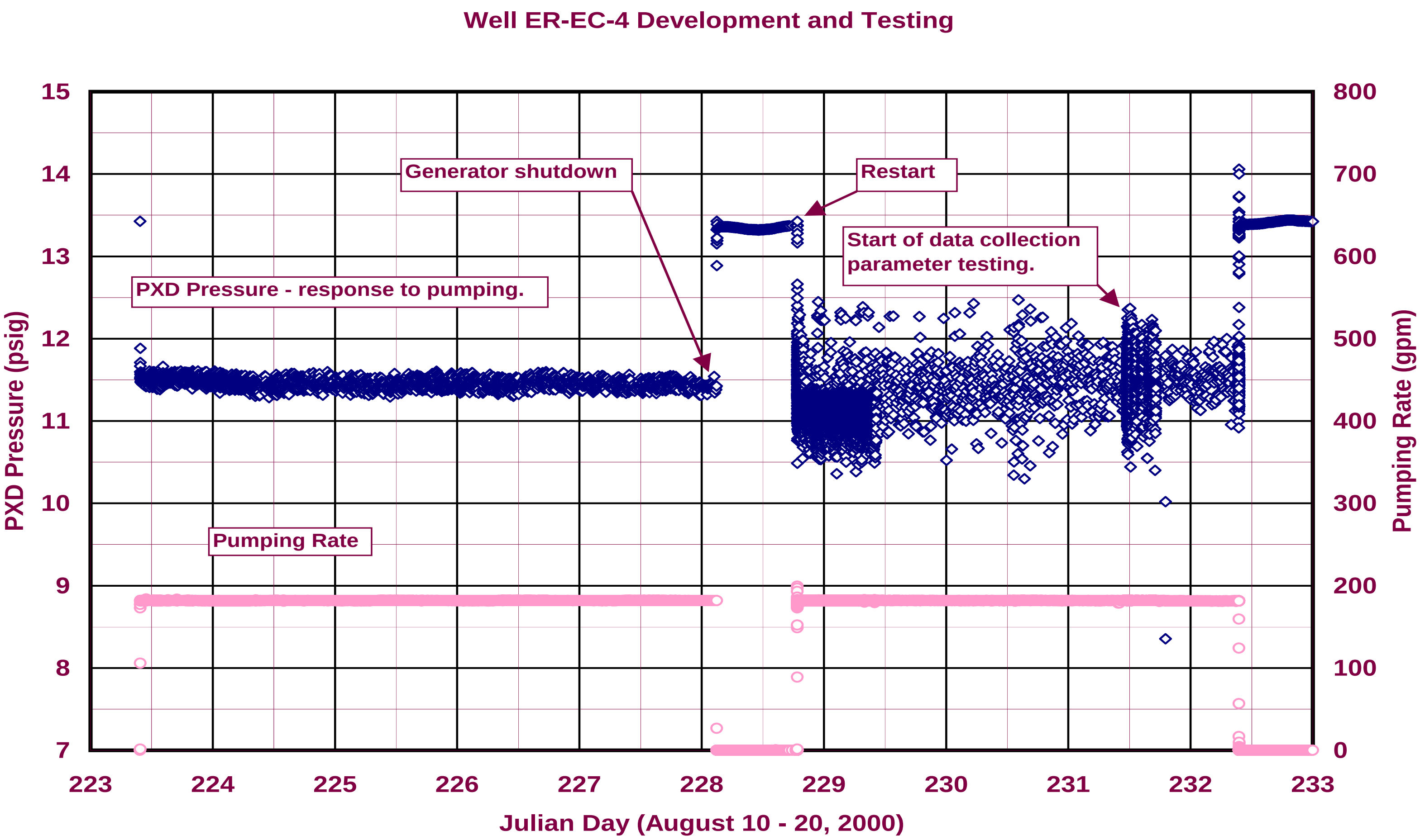
Well Name: ER-EC-4
Western Pahute Mesa - Oasis Valley WD&T Program
Date: 8/04/2000
Start Date: 8/03/00
Stop Date: 8/04/00
Well Development and Hydraulic Testing
Proj. No.: 779416.00020260
Log Run #: ec4mov08
Logging Contractor: Desert Research Institute (DRI)
Logging Method: Stressed Full-Bore Flowlog
Flow logging at 40 feet/minute - upward
Surface Discharge: 180 gallons/minute
FOR PRELIMINARY USE ONLY

Figure A.2-14
Flow Log at 180 gpm Production Rate and 40 fpm Upward Trolling Rate



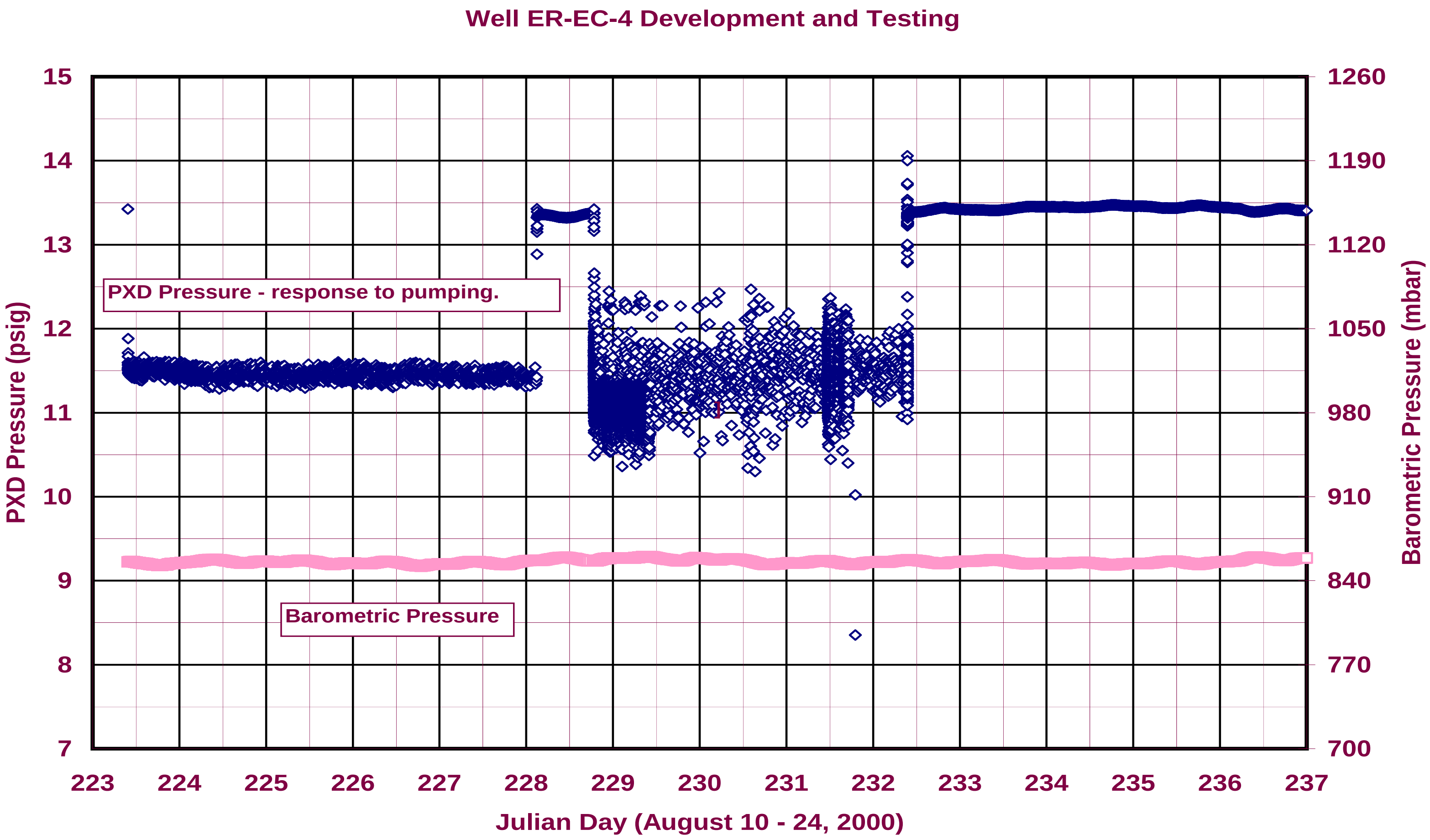
Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley WD&T Program	
Date: 8/04/2000	Start Date: 8/03/00	Stop Date: 8/04/00
Well Development and Hydraulic Testing		Proj. No.: 779416.00020260
Log Run #: ec4mov09		
Logging Contractor: Desert Research Institute (DRI)		Logging Method: Stressed Full-Bore Flowlog
Flow logging at 60 feet/minute - downward		Surface Discharge: 180 gallons/minute

Figure A.2-15
Flow Log at 180 gpm Production Rate and 60 fpm Downward Trolling Rate



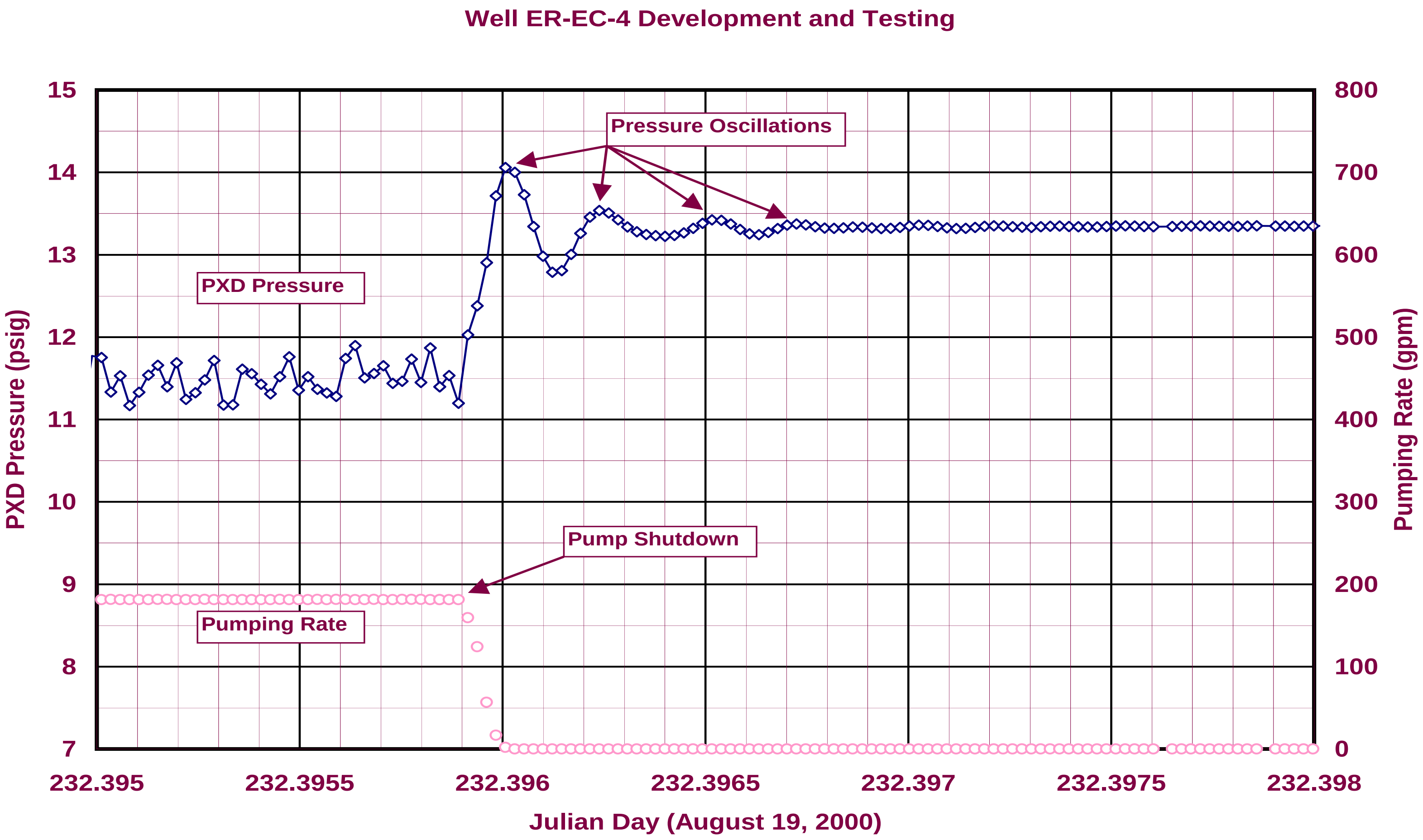
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-16
Pumping Rate and Hydraulic Response During the Constant-Rate Test



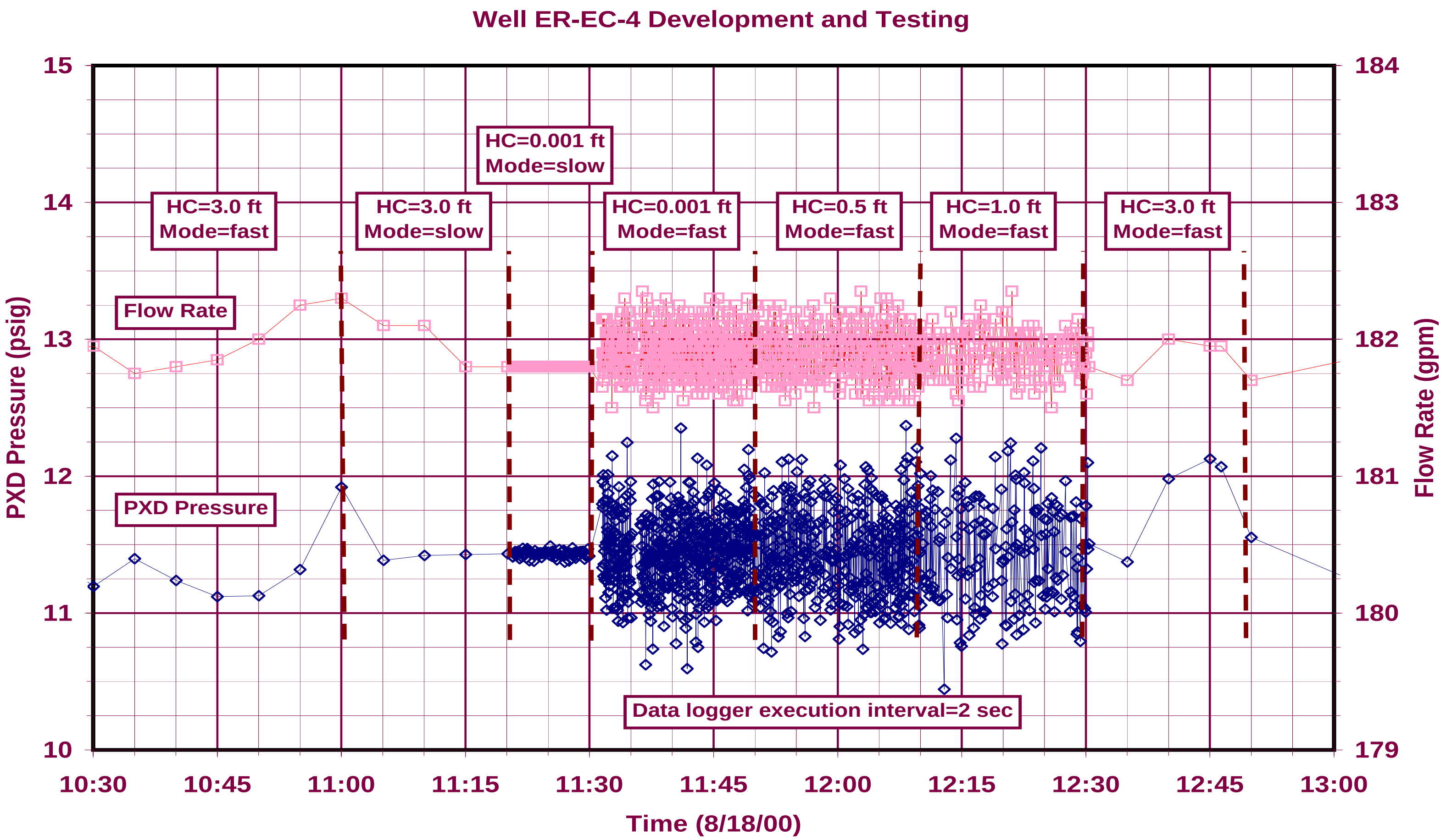
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-17
Hydraulic Response and Barometric Pressure During the Constant-Rate Test



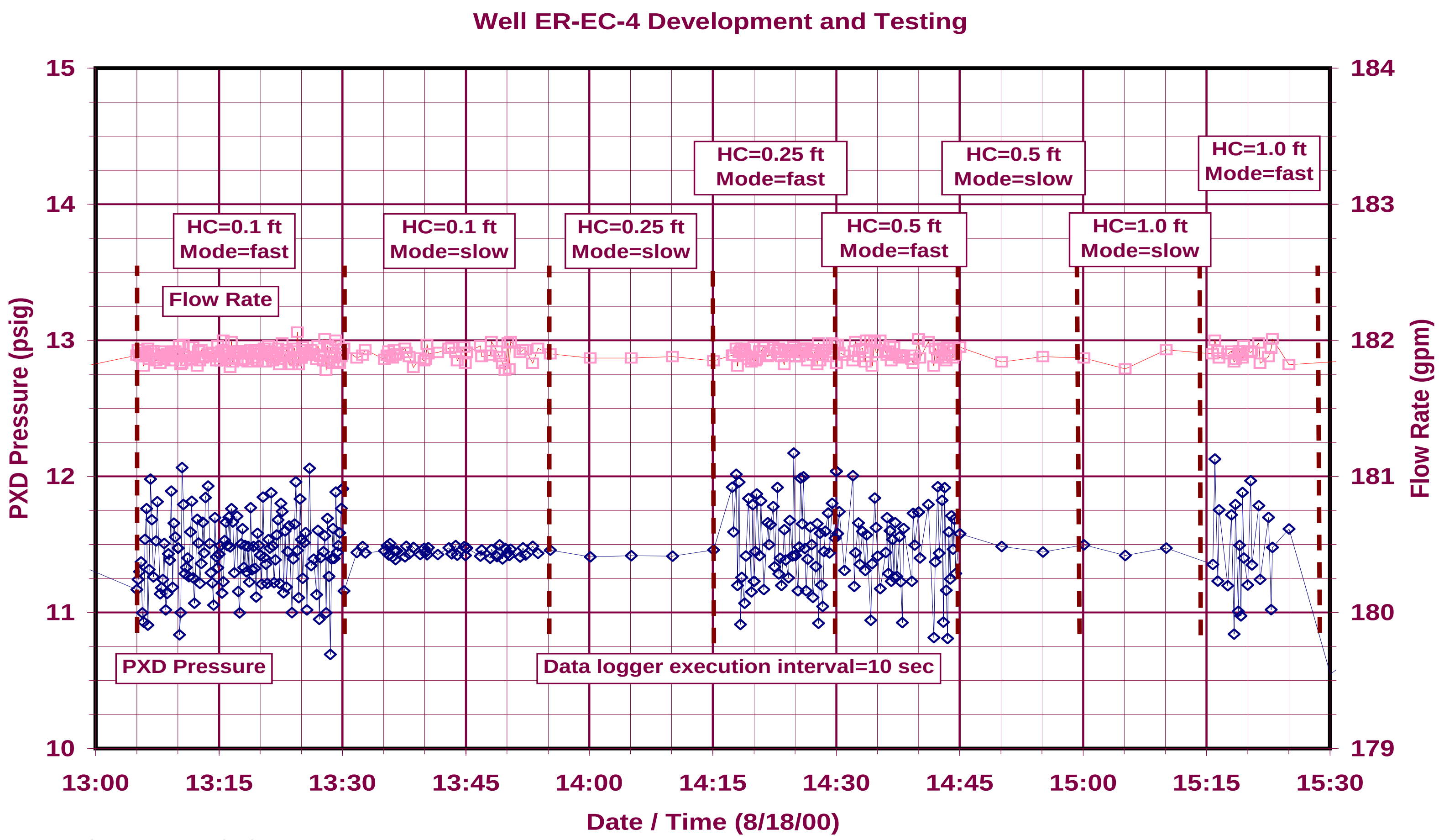
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-18
Hydraulic Response at Shutdown of the Constant-Rate Test



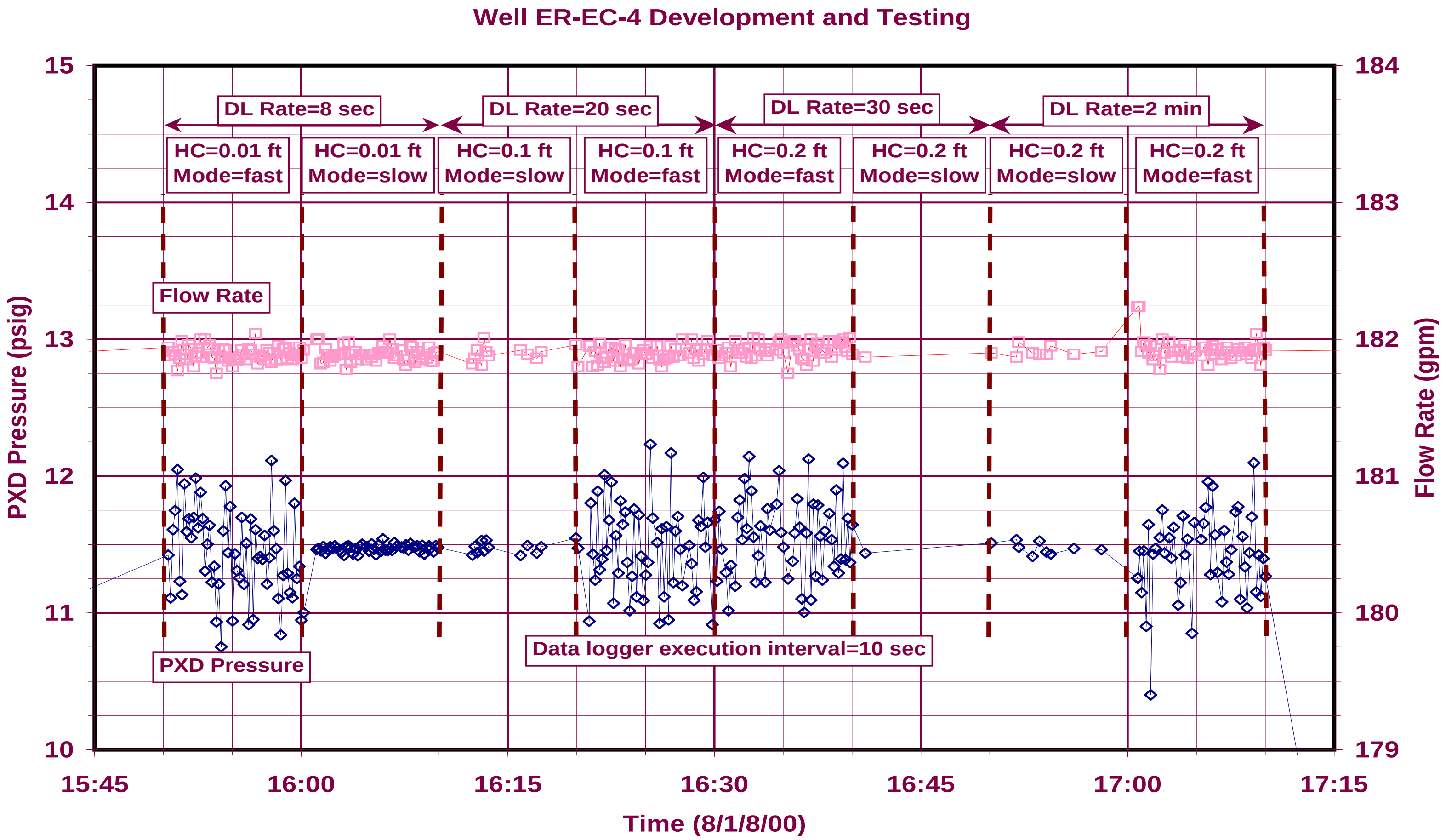
psig - Pounds per square inch gauge
PXD - Pressure transducer
Mode - PXD speed (fast = 1-sec average, slow = 8-sec average)
HC - Head-change criterion in data logger program (trigger to record data)
ft - Feet
sec - Second(s)

Figure A.2-19
Data Collection Testing During the Constant-Rate Test (1)



psig - Pounds per square inch gauge
PXD - Pressure transducer
Mode - PXD speed (fast = 1-sec average, slow = 8-sec average)
HC - Head-change criterion in data logger program (trigger to record data)
ft - Feet
sec - Second(s)

Figure A.2-20
Data Collection Testing During the Constant-Rate Test (2)



psig - Pounds per square inch gauge
PXD - Pressure transducer
Mode - PXD speed (fast = 1-sec average, slow = 8-sec average)
HC - Head-change criterion in data logger program

DL Rate - Data collection rate of data logger (if head-change remained less than HC criterion, data was aquired based on DL Rate)

Figure A.2-21
Data Collection Testing During the Constant-Rate Test (3)

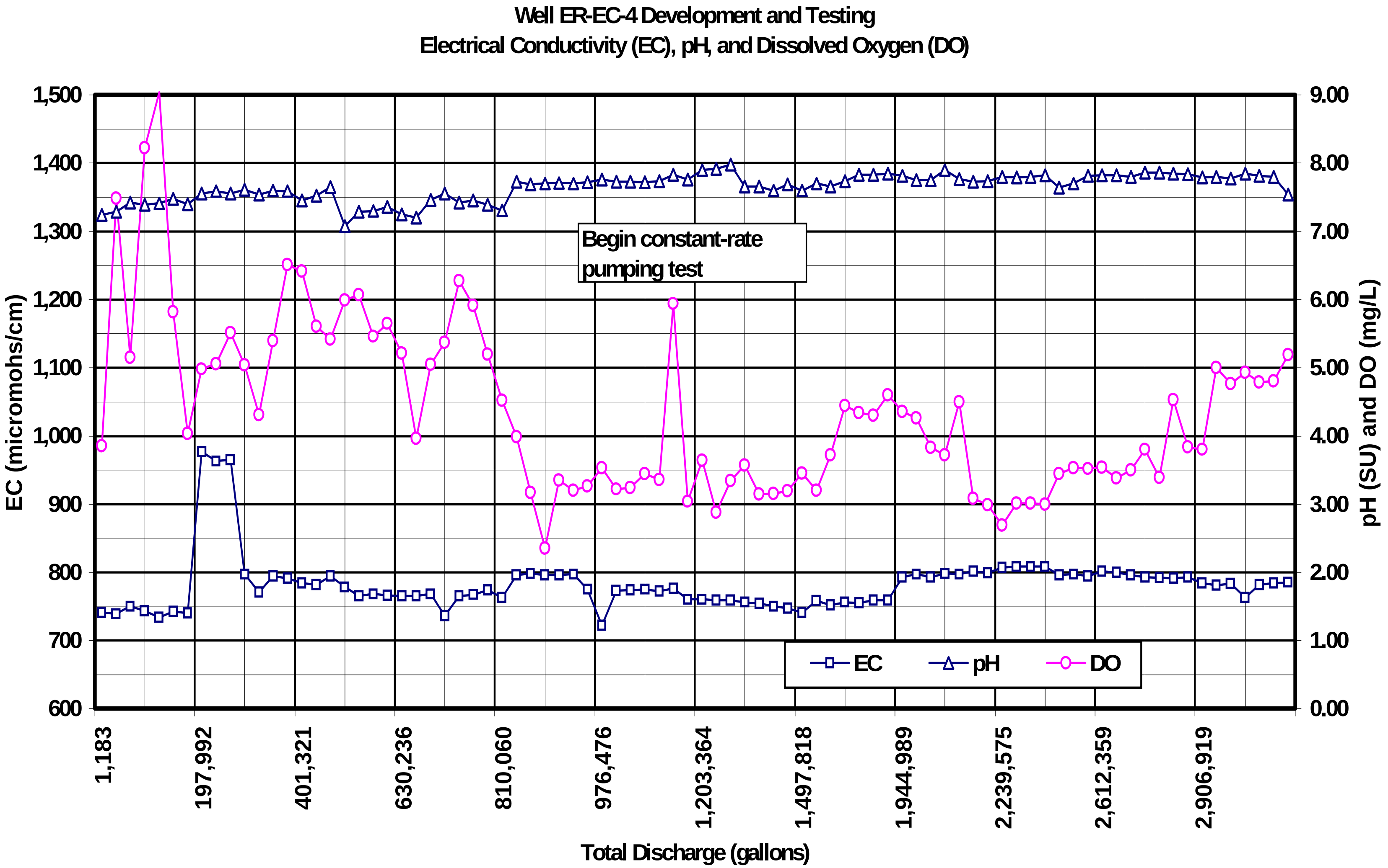
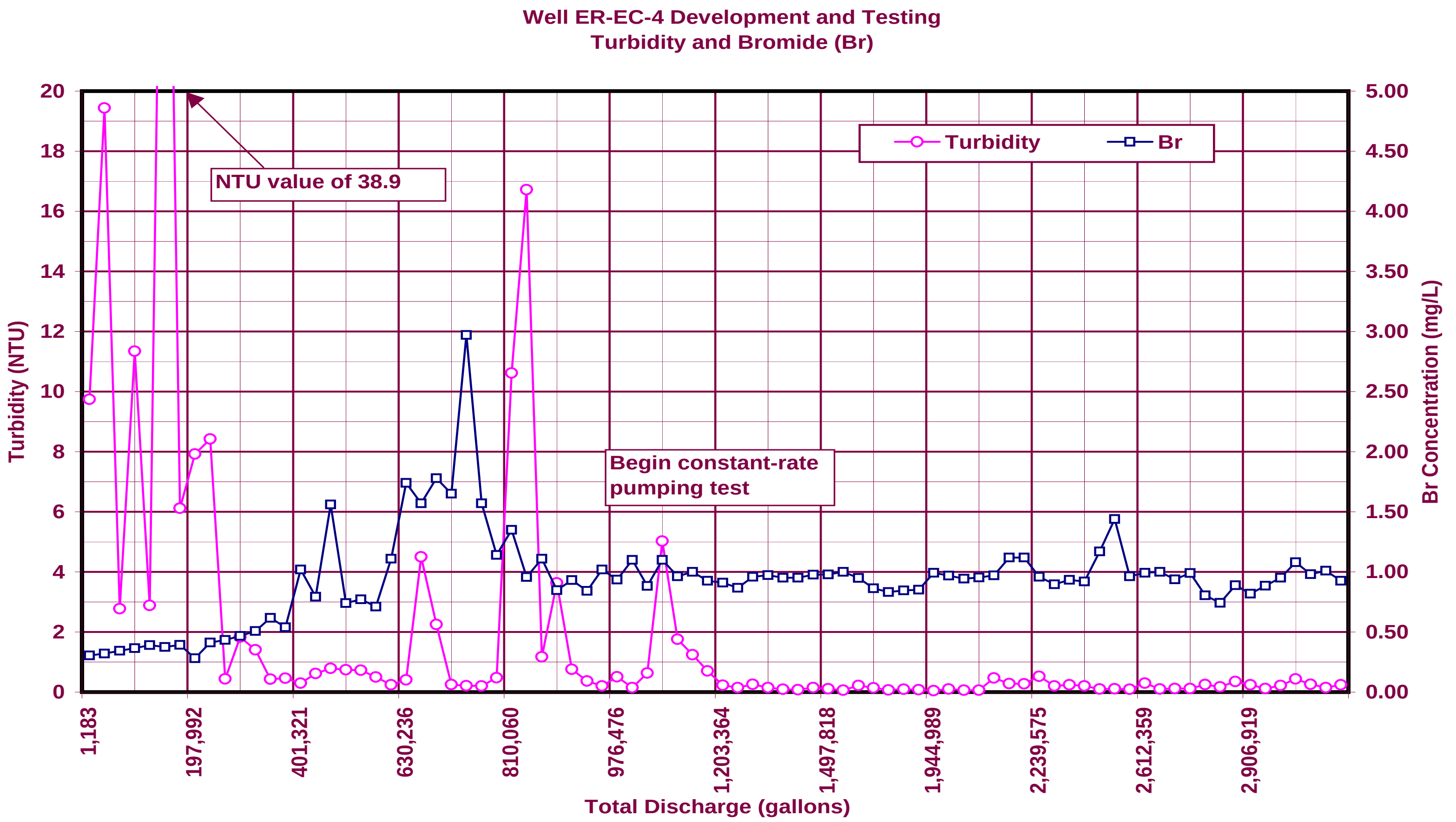
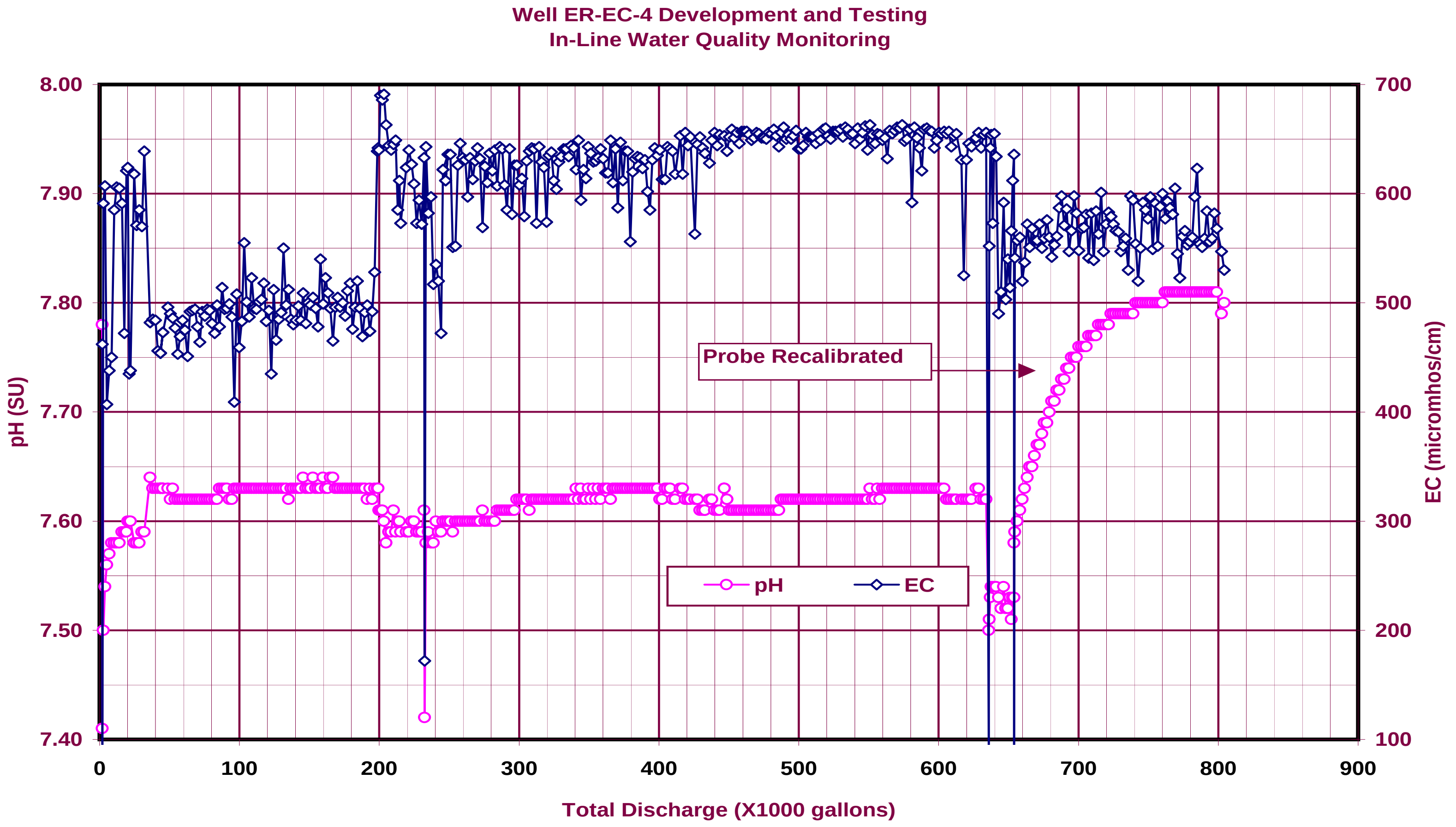


Figure A.2-22
Grab Sample Monitoring for EC, pH, and DO



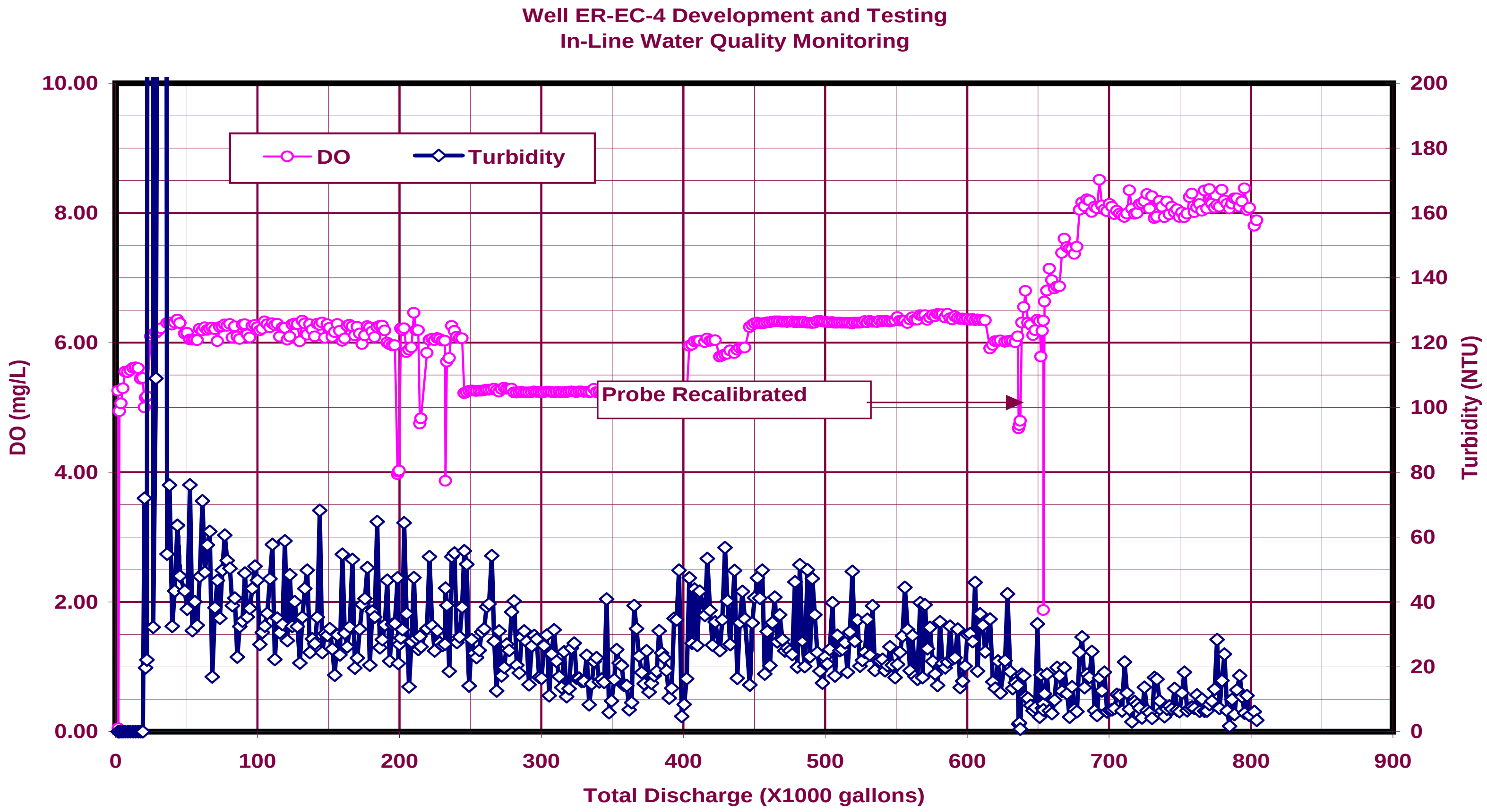
NTU - Nephelometric turbidity unit
mg/L - Milligrams per liter

Figure A.2-23
Grab Sample Monitoring for Bromide and Turbidity



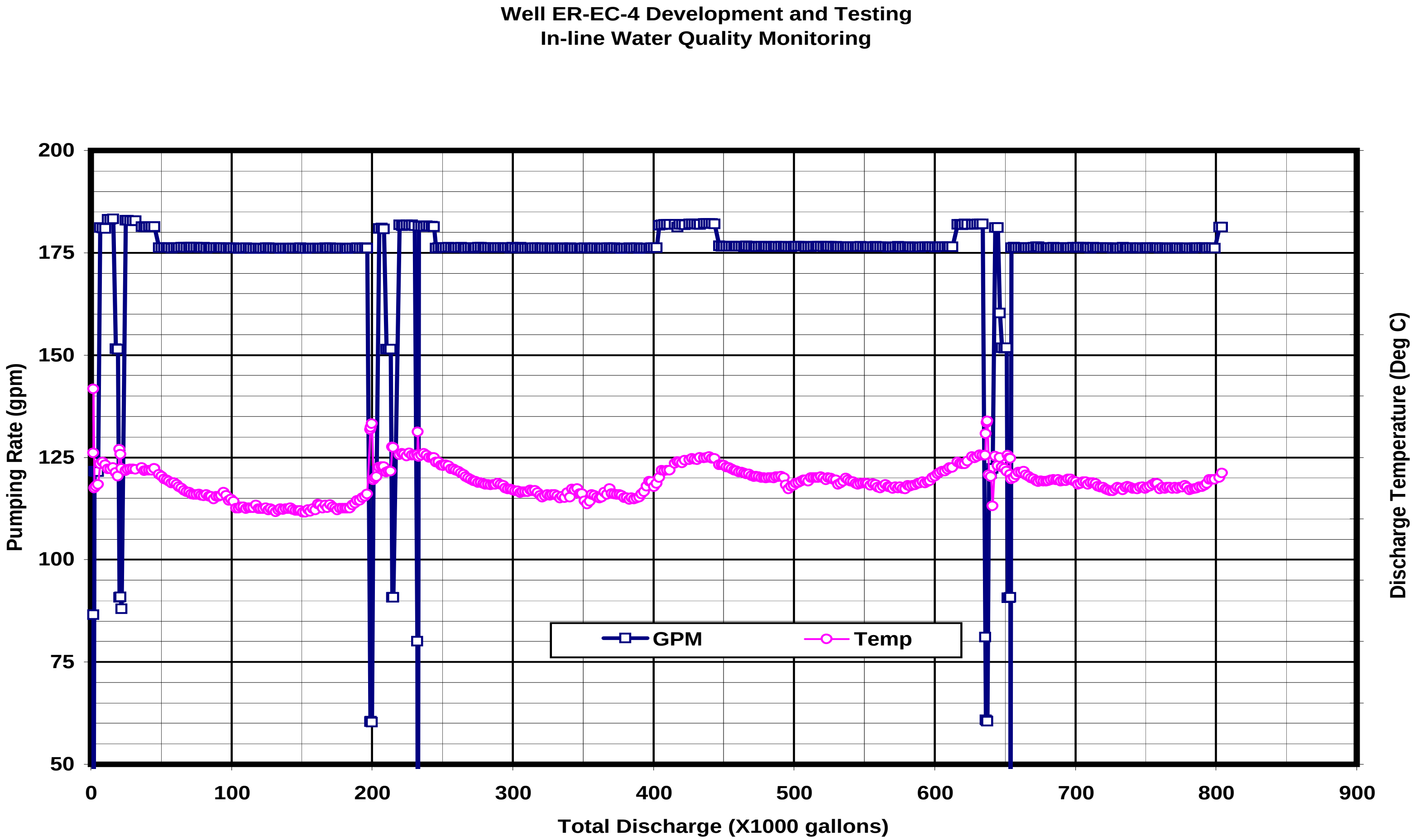
EC - Electrical conductivity
cm - Centimeters
SU - Standard units

Figure A.2-24
In-Line Monitoring for EC and pH



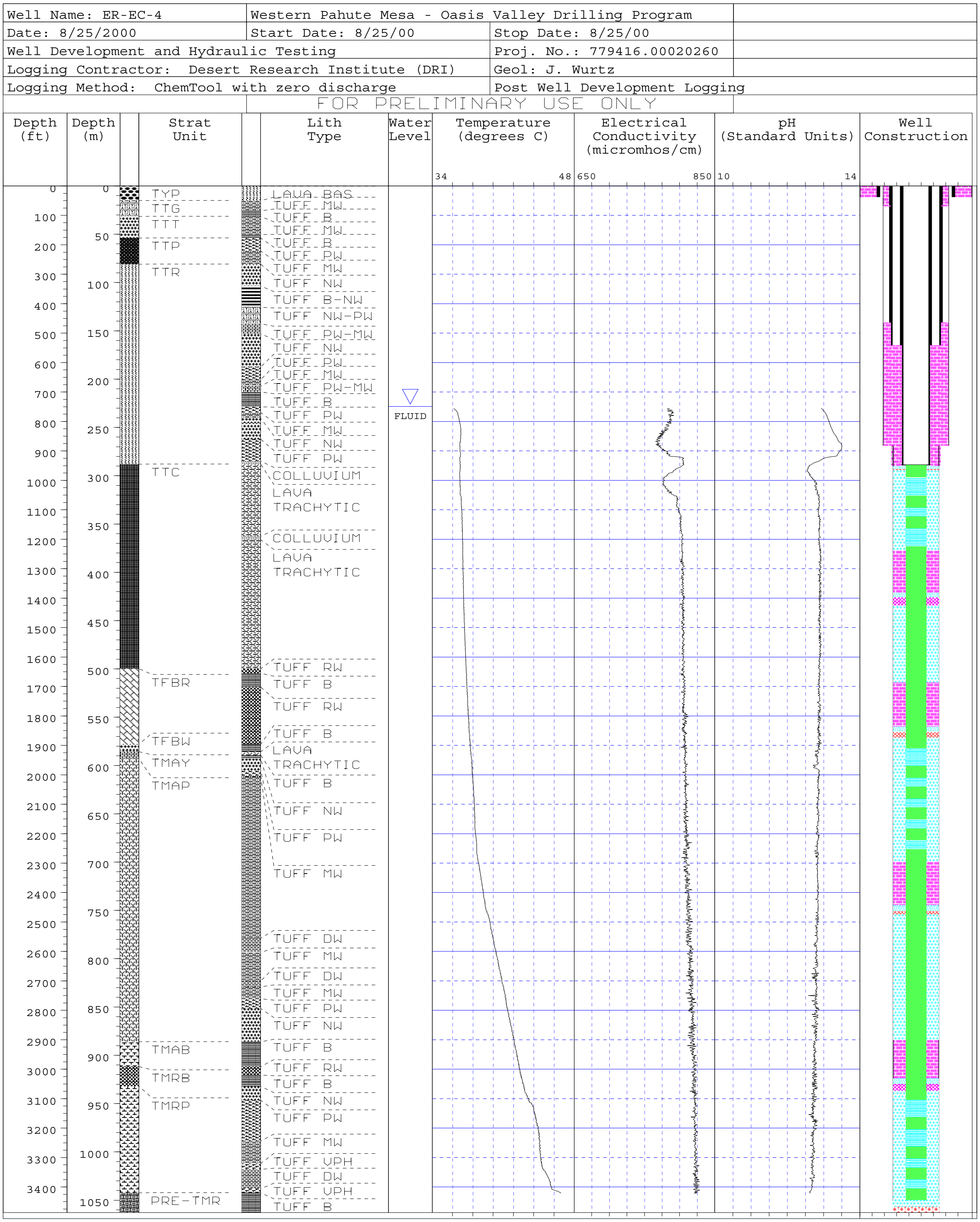
NTU - Nephelometric turbidity units
DO - Dissolved oxygen
mg/L - Milligrams per liter

Figure A.2-25
In-Line Monitoring for DO and Turbidity



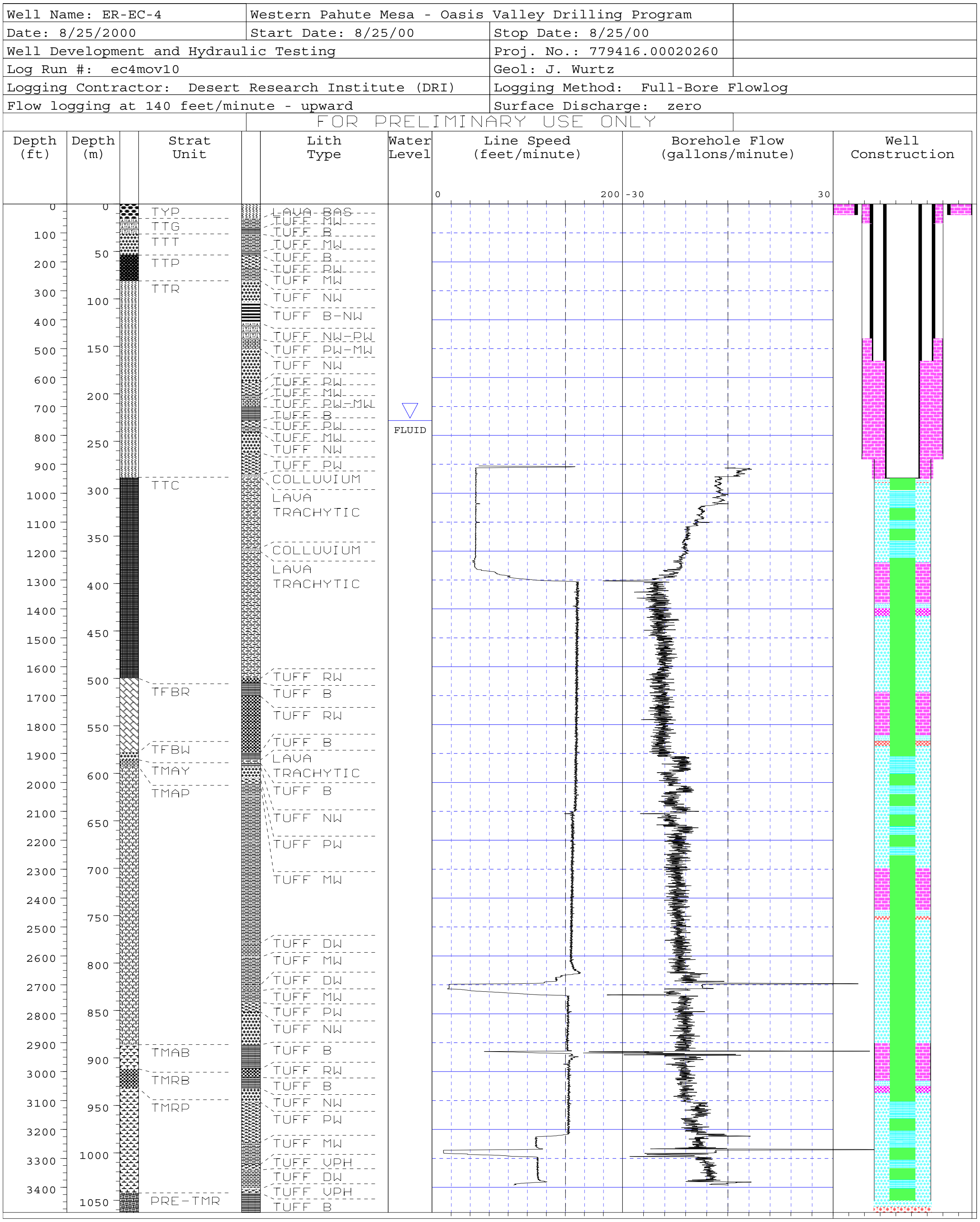
gpm - Gallons per minute (from magnetic flowmeter)
Deg C - Degrees centigrade
Temp - Temperature

Figure A.2-26
In-Line Monitoring for Temperature Versus Pumping Rate



Well Name: ER-EC-4
Western Pahute Mesa - Oasis Valley Drilling Program
Date: 8/25/2000
Start Date: 8/25/00
Stop Date: 8/25/00
Well Development and Hydraulic Testing
Proj. No.: 779416.00020260
Logging Contractor: Desert Research Institute (DRI)
Geol: J. Wurtz
Logging Method: ChemTool with zero discharge
Post Well Development Logging
FOR PRELIMINARY USE ONLY

Figure A.2-27
ChemTool Log Under Ambient Conditions



Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program	
Date: 8/25/2000	Start Date: 8/25/00	Stop Date: 8/25/00
Well Development and Hydraulic Testing		Proj. No.: 779416.00020260
Log Run #: ec4mov10		Geol: J. Wurtz
Logging Contractor: Desert Research Institute (DRI)		Logging Method: Full-Bore Flowlog
Flow logging at 140 feet/minute - upward		Surface Discharge: zero

FOR PRELIMINARY USE ONLY

Figure A.2-28
Spinner Flow Log Under Ambient Conditions

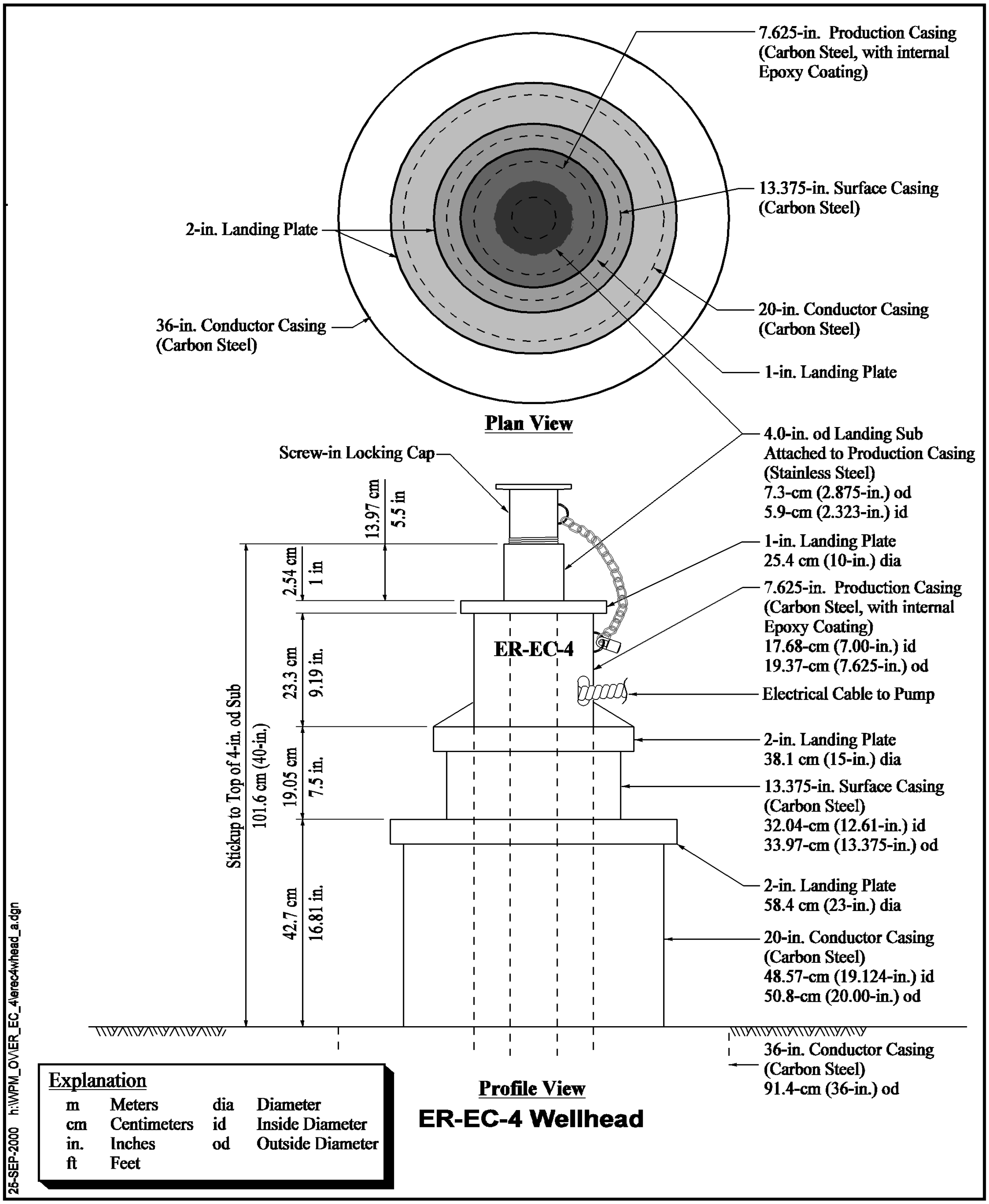


Figure A.2-29
Final Wellhead Completion Diagram

A.3.0 Data Reduction and Review

This section presents basic reduction and processing of the data collected during the development and testing operations at Well ER-EC-4. 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 in the well 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 when the interval was isolated with a bridge plug. The head was computed by multiplying the pressure change by the composite density of the water in the well above the PXD, and adding that head to the elevation of the PXD. The composite density of the water in the well was computed by dividing the height of the water column above the PXD by the PXD pressure at the set depth measured before setting the bridge plug. Determining the composite density from the actual pressure of the water column was required to calibrate the head calculation to the water density. Due to 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 also renders the calculation insensitive to wireline measurement errors.

The height of the water column was determined from water level measurements (denoted as reference heads) taken after each bridge plug was set. This measurement accounted for any head adjustment that occurred due to the isolation of the lower intervals. While there is a chance that this water level may not have completely stabilized, it provides a better estimate of the height of the water column than the total well composite water level. The intervals were left to equilibrate for about five days 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 an e-tape measurement. The upper interval was monitored with a PXD set on a wireline.

A.3.1.2 Data Reduction

Figure A.3-1 shows the PXD monitoring record for the upper interval. Since the upper interval was open to atmospheric pressure in the well, the head was affected by barometric pressure changes during the equilibration period. This figure shows the PXD pressure record and the barometric record for that period, and also a PXD pressure record corrected for barometric change. A barometric efficiency of 0.93, calculated from the monitoring record, was used to make the correction. The method for calculating the barometric efficiency is discussed in Section A.3.4.1.

The head in the upper interval appears to have been rising during the monitoring period, and did not stabilize. The rate of water-level rise is slow and not clear without barometric correction. Given the high productivity of the upper interval, the upper interval probably equilibrated to the installation of the upper bridge plug rapidly, and the upper-interval head measured during the bridge plug installation is probably representative of the equilibrated upper interval. During the monitoring period the upper interval was on a rising trend. After the completion of development and testing activities, a bridge plug was installed between the middle and lower completion intervals. Water levels measured subsequent to this later bridge plug installation only represent the composite of the upper two intervals. However, the upper interval appeared to be the primary control on the composite water level, so water levels measured after the bridge plug installation will probably be similar to composite water levels for all three intervals. Note that earth tides can be seen in the corrected record for the upper interval.

The calibration and monitoring records for the middle interval are illustrated in Figure A.3-2 and Figure A.3-3, respectively, and for the lower interval in Figure A.3-4 and Figure A.3-5. The calibration records indicate that the PXD pressure values were stable before the bridge plug was set. The monitoring records show rapid equilibration to the isolation of the intervals. The pressure in the middle interval slowly increased during the remainder of the monitoring period, similar to the upper interval. The monitoring record for the lower interval shows small-scale cyclic variations with a slight downward trend. The cyclic variations in the data may be earth tides. The heads derived for these intervals may be considered representative.

Figure A.3-3 and Figure A.3-5 also show the uncertainty in the PXD readings. These data records show a band of noise in the form of random readings of a certain amount, both above and below a central value representing the resolution of the instrumentation. There are two levels of offset; the larger value is due to the pressure resolution and the smaller value due to the temperature compensation resolution. For this analysis, the central value of the latter part of the record was used as the equilibrium value for both intervals.

Table A.3-1 shows interval-specific head information for Well ER-EC-4 at the end of monitoring. The methodology for calculating the head for the middle and lower

Table A.3-1
ER-EC-4 Interval-Specific Heads

Measurement	Well Composite	Upper Interval	Middle Interval	Lower Interval
Head - Depth ft bgs	748.89	748.94	751.06	757.11
Determination Method	Direct Measurement Using E-Tape	Direct Measurement Using E-Tape[a]	Calculated from Bridge Plug Data	Calculated from Bridge Plug Data
Change in Head ft			-2.27	-8.22
Composite Water Density Conversion Factor ft/psi	---	---	2.320	2.321
Representative Pressure psig	---	---	449.40	964.92
Preset Pressure psig	---	---	450.38	968.46
Reference Head ft	---	---	748.79	748.89
PXD Set Depth ft	---	---	1,798.71	2,998.67
PXD Serial Number	---	---	21014	01157
PXD Range psig	---	---	0-750	0-2,500

[a] Value has been corrected for barometric change since start of monitoring.

ft - Feet
bgs - Below ground surface
psi(g) - Pounds per square inch (gauge)
PXD - Pressure transducer

intervals is insensitive to uncertainty in wireline measurements for the PXD set depth. The methodology depends upon the e-tape reference head measurement and the change in PXD pressure from before to after setting of the bridge plug. There has been no correction for friction losses due to gradient-driven circulation in the well.

The data indicate a downward hydraulic gradient: the head of the middle interval was 2.12 ft less than the head of the upper interval, and the head of the lower interval was 6.05 ft less than the head of the middle interval. The head adjustments for the two lower intervals were both downward. Successive water level measurements indicate that the water level rose as bridge plugs were set. The PXD pressure record for the upper interval further indicates that the head in the interval rose during the five days of monitoring. The final water level, when corrected for the barometric change that occurred from the initial water level, indicates a rise of about 0.1 ft overall compared to the 0.05 ft rise in the PXD record.

The following discussion on the absolute potential error of these measurements indicates that the calculated head differences are in the range of the uncertainty in the individual measurements. However, the methodology used to analyze the data uses changes in pressure rather than the absolute measurement. This will be discussed further in the analysis report. Quoted accuracy for the PXDs is

0.1 percent of FS. The potential uncertainty for the middle interval pressure (750 psi PXD, SN 21014) measurement is +/- 0.75 psi, and for the lower interval (2500 psi PXD, SN 01157) is +/- 2.5 psi. These uncertainties result in potential uncertainty in the head differences of +/-0.75 psi (approximately 1.8 ft) between the upper and middle intervals and 3.25 psi (approximately 8 ft) between the middle and lower intervals. In addition, the uncertainty in the e-tape measurements is about 0.075 ft. The composite static water level measurement was used as the reference head for the lower interval, while the upper interval head was determined by a separate e-tape measurement. Since two different e-tape measurements are used to determine the lower interval head and the upper interval head, the uncertainty of e-tape measurements affects the calculated head difference between the upper and lower intervals. This uncertainty is probably in the range of 0.15 ft.

A.3.1.3 Correction of Bridge Plug Set Depths

As mentioned in Section A.2.4, the actual set depths of the bridge plugs have been corrected from the originally specified set depths. Table A.3-2 shows the specified and the corrected depths. These corrections were supplied by BN Geophysics, who oversaw these measurements. The bridge plugs were located by placing them a specified distance from a reference casing collar that was located downhole based on the casing tallies from well construction. Corrections were required for the calibration error of the wireline measurement. The method employed to determine the calibration error correction was based on the error in the measured depth to the reference casing collar.

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)
Lower Interval Calibration at +50 ft	3,050.00	929.64	3,048.35	929.14
Lower Interval Calibration at -50 ft	2,950.00	899.16	2,948.98	898.85
Lower Interval Set Depth	3,000.00	914.40	2,998.67	913.99
Middle Interval Calibration at +50 ft	1,850.00	563.88	1,848.70	563.48
Middle Interval Calibration at -50 ft	1,750.00	533.40	1,748.72	533.01
Middle Interval Set Depth	1,800.00	548.64	1,798.71	548.25

ft - Feet
bgs - Below ground surface
m - Meters

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 and 2.323 ft of water column/psi (0.991 and 0.994 in terms of specific gravity corrected for temperature) for the middle and lower intervals, respectively. The specific gravity values are based on calculations relative to values for standard temperature-corrected weight density of water (Roberson and Crowe, 1975). These values seem reasonable considering they must accommodate effects of dissolved and entrained gases, and dissolved and suspended solids. The values also compare well with the conversion factor value of 2.322 ft of water column/psi (specific gravity 0.995) that was calculated from the PXD installation for predevelopment water level monitoring. The specific gravity values for the upper part of the well are slightly less. This is reasonable because they apply to the upper part of the water column, which should have less suspended sediment and a greater proportion of entrained gas. A conversion factor value of 2.338 ft of water column/psi (specific gravity 0.988) was calculated from the PXD installation for monitoring drawdown for the constant-rate test, which was installed after development. The data appear to show a slight progression of decreased density over time with continued pumping.

A.3.1.5 Thermal Flow Logging

The thermal flow logging found downward flow of 2.2 gpm (the upper limit of the thermal tool) from the middle of the upper completion interval (1,148 ft bgs) to the upper-middle of the lower completion interval (3,180 ft bgs). No flow was measured at the uppermost station (950 ft bgs) above the upper completion interval, and at the lowest station (3,300 ft bgs) in the lower part of the lower completion interval. These results indicate flow from the upper completion interval downwards to the lower completion intervals at a rate of 2.2 gpm or greater. The spinner log that was run under ambient conditions (Figure A.2-28) indicated that downward flow between the upper and middle completion intervals reached a maximum of 20 to 25 gpm. This log is somewhat suspect due to the elevated noise in the data and the fact that the log was run at a rather fast line speed of 140 fpm. However, the log does support the thermal flow log results, which indicated downward flow throughout the entire length of the well. Also, this log correlates to the downward flow observed while pumping (Section A.3.3), which also showed flow exceeding 2.2 gpm.

A.3.2 Well Development

Well development efforts appear to have had a limited, but progressive effect on improving the hydraulic efficiency of the well (see Table A.2-4). The drawdown decreased slightly each day, based on overnight pumping at the consistent rate of 180 gpm. The amount of sediment produced was negligible.

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 collected.

A.3.3.1 Optimal Flow Logging Run

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

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

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

Where:

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

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

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, provide for relatively short logging runs (one to two hours), yet minimize the contribution of R_{ls} and maximize 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 and in different directions under identical conditions shifts the depths within the borehole where this is occurring so that any flow occurring in the borehole can be logged.

A.3.3.2 Intervals of Inflow

Figures A.2-7 through A.2-15 show the flow logs run during pumping at Well ER-EC-4. The trolling flow logs conducted during pumping indicate that 100 percent of the water production came from the upper completion interval. This result is consistent between the three line speeds (20, 40, and 60 fpm) at all three pumping rates (60, 120, and 180 gpm). Based on evaluations of the logging runs conducted downward at 20 fpm, about 60 percent of the production originated from the upper slotted interval of the upper completion interval regardless of the pumping rate. With increasing pumping rates, proportional production from the middle slotted interval (of the upper completion interval) decreases, with corresponding increases in production from the lower slotted interval (Table A.3-3).

Table A.3-3
Water Production From Upper Completion Interval During Pumping
(From Trolling Spinner Flow Logs[a])

Slotted Interval of Upper Completion Interval	Interval Top - Bottom (ft bgs)	Percentage of Total Production		
		60 gpm	120 gpm	180 gpm
Upper	989-1,050	60	60	60
Middle	1,091-1,122	40	30	27
Lower	1,163-1,224	0	10	13

[a] All data from downward runs with line speed of 20 feet per minute (fpm)

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

These flow logs also show downward flow to the lower completion intervals during pumping. Based on the 20-fpm trolling logs at pumping rates of 60 and 120 gpm, downward flow (negative flow values) begins at a depth of approximately 1,165 ft, at the top of the lower slotted interval of the upper completion interval. The magnitude of downward flow is inversely related to the pumping rate. This is apparent in the differences in downward flow at each production rate: downward flow of 10 gpm at a production rate of 60 gpm and downward flow of 7 gpm at a production rate of 120 gpm. The downward flow decreased below the middle completion interval to about 6 and 4 gpm, respectively. The start of downward flow (at a rate of 3 gpm) shifted to the middle completion interval while pumping at 180 gpm.

The stationary flow measurements during pumping (Table A.2-7) indicate upward flow only above the upper completion interval, in agreement with measurements from the trolling runs. In addition, at the 60 gpm production rate, about 9 gpm downward (negative) flow was measured between the upper and middle completion intervals and about 5 gpm downward flow measured between the middle and lower completion intervals.

The bridge plug measurements determined downward vertical head gradients, and the overall downward gradient exceeds the drawdown produced by pumping. The situation may be clarified somewhat when the downhole hydraulics of the well are analyzed, incorporating the vertical gradient, entrance losses, and friction losses for flow from the lower intervals.

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 a well to a change in barometric pressure; when barometric pressure rises, the head will be depressed by some fractional amount. The barometric efficiency for the entire well (all three completion intervals) was first determined from the predevelopment water level monitoring record (Figure A.3-6). The derived efficiency of 0.93 was used to correct the predevelopment monitoring record so that any trend in the water level would be evident (Figure A.3-7). There is an obvious trend in the corrected record, but initially it was not clear whether the trend represented continuing equilibration. However, water level measurements collected later in the program (Table A.2-1) do not show a long-term increase, but rather fluctuations in the same range. It appears that a short-term trend is observed in the corrected record rather than any long-term equilibration. The long-term water level record indicates that the well had recovered from the effects of drilling and completion.

A barometric efficiency for the upper completion interval was determined from the monitoring record for the interval during the bridge plug (vertical gradient) activities (Figure A.3-8). As discussed in Section A.3.1.2, this derived efficiency of 0.93 was used to correct the upper-interval equilibration record. A barometric efficiency was derived again for the entire well from the recovery record following the constant-rate test (Figure A.3-9). The derived efficiency of 0.90 was used for correction of the constant-rate test. The differences between the three different determinations of barometric efficiency are probably within the uncertainty of the analyses.

The method used for determining barometric efficiency was to overlay the barometric record onto the PXD pressure record and adjust it with a scaling factor and a trend rate until a best-fit was obtained. In order to overlay the barometric record onto the PXD record, the barometric record had to be converted into psi, offset onto the PXD record, and reversed to match the sense of the response. The resultant factors are the barometric efficiency and a linear trend characterizing the PXD pressure record. Note that this is a different method than that used in the first several reports of this series. This is a more rigorous approach and the barometric efficiencies calculated for the previous wells will be updated using this new approach.

A.3.4.2 Drawdown Record

Figure A.3-10 shows the record for both pumping periods of the constant-rate test, along with the recovery period. The drawdown record was converted to equivalent changes in groundwater head using a conversion value for pressure-to-head derived from the calibration data collected when the PXD was removed after the constant-rate test (Table A.2-8). There are several features to note on this figure. The shaded trace consists of the full dataset (high rate of data collection) for the first five days and a synthetic data record for the four-day extension. As discussed in Section A.2.8.2, the record for the extension period was extremely noisy and includes a section where the noise appears to be unbalanced. This was effect due to the recording scheme, and the effect was removed by extracting the five-minute data record (mentioned in Section A.2.8.3), which is presented. This data was not affected by the problem in the datalogger program. However, to provide better definition of the drawdown and recovery periods, approximately 16 seconds of the full record has been included at the beginning and end of the pumping period. This additional data is not affected by the recording problem.

As can be seen in Figure A.3-10, the five-minute data of the extension period is still substantially noisier than the full record of the initial five days. As was presented in Section A.2.8.3, the noise appears to correlate with the PXD mode of operation. The record during the first five days was collected with the PXD in slow mode (averaging 64 readings over 8 seconds), while the record for the four-day extension period was almost totally collected with the PXD in fast mode (averaging 8 readings over 1 second). The noise level in the second pumping period can be reduced to that of the initial pumping period by processing the record to reproduce the averaging that is done by the PXD when it is run in slow mode.

The dark trace shows an initial attempt to reduce the width of the noise band by running a moving average through the data record. The moving average was only applied to the record after the rate of head-change when the pump was started, and when it stopped had declined to a low value in order not to significantly change the shape of the curve. The dark trace shows a greater density of data points at the start and end of the four-day extension period, better defining the drawdown and recovery responses. The difference in detail is particularly noticeable in the truncation of the oscillations when the pump stopped, ending the initial five-day pumping period.

The drawdown response of Well ER-EC-4 was characterized by extremely rapid initial drawdown and very gradual long-term drawdown. Figure A.3-11 shows an expanded view of the drawdown data for the four-day extension period, for which the early drawdown curve is better defined. Note the apparent oscillation at the beginning of the drawdown, similar to the oscillations seen in the recovery curve Figure A.2-18. The oscillatory phenomena is also indicative of high transmissivity. Most of the early time drawdown record is obscured by the oscillation, and the data for this part of the record will be difficult to use. The gradual long-term drawdown trend evident in the five-day record, shown in expanded form in Figure A.3-12, does not provide much curvature for curve matching.

A.3.5 Water Quality

A variety of water-quality information was collected, including grab samples taken during pumping, data collected using a Hydrolab® in-line monitoring system and DRI ChemTool logs, which were run before well completion and after well development and testing. Comparisons can be made between the water-quality parameters obtained by DRI before well completion and after well development and testing.

A.3.5.1 Grab Sample and Hydrolab® Results

Water quality parameter values measured from grab samples taken from water produced during development and testing have been compiled and are presented in Attachment 2. During the course of pumping, pH was generally stable between 7.6-7.8 SU (Figure A.2-22 and Figure A.2-24). The Hydrolab® is generally more sensitive to small, short-term fluctuations because readings were recorded every 10 minutes, whereas grab samples were typically collected every two hours during daytime operations. Figure A.3-13 presents the total gallons pumped during development, along with associated pumping rates, and the in-line pH values and DO concentrations. Changes in pH values were minimal because all of the water produced while pumping was originating from the upper completion interval, and the pumping rates did not change markedly. A rebound effect, where parameter values decline after each successive pumping cycle, was not observed at Well ER-EC-4. The DO concentrations did fluctuate more than pH, indicating a greater effect of pumping changes on DO. The DO results have been converted from percent saturation to mg/L for direct comparison with DO results from the grab samples.

In comparing grab sample results to Hydrolab® results, it should be noted that all of the Hydrolab® data were collected during development, when water quality parameter values are typically more erratic (than during constant-rate testing). This is likely due to incomplete development and changing pumping conditions. The Hydrolab® pH values are similar to the grab sample values, while the Hydrolab® EC values are much lower. The EC values from grab samples (see Figure A.2-22) were consistently between 740 and 810 µmhos/cm, while the in-line values were generally between 480 and 660 µmhos/cm. The reason for this discrepancy is not known. When the Hydrolab® was recalibrated, after several days online, EC values declined about 100 µmhos/cm. The in-line DO values are also similar to grab sample results, although slightly higher. Turbidity measurements were much higher and more erratic in the in-line data. There appears to be a continued problem with turbulence and entrained air in the flow-through cell of the Hydrolab®. In general, the Hydrolab® data may be judged as agreeing with the grab sample data, and show the recurrent equilibration of parameter values to changes in pumping conditions.

A.3.5.2 Precompletion Versus Postdevelopment Water Quality

The ChemTool logs of downhole water quality were obtained under ambient flow at the end of the development and testing program. These logs provide additional information on the effectiveness of the development and testing activities on water-quality restoration. Figure A.3-14, Figure A.3-15, and Figure A.3-16 show the ChemTool logs that were obtained following drilling, prior to well completion, along with the logs that were obtained following well development and testing. Figure A.3-14 presents the two temperature logs, Figure A.3-15 shows the pH logs, and Figure A.3-16 presents the EC logs.

The precompletion and postdevelopment temperature logs show a marked difference. The postdevelopment log is about 3°C cooler at the top of the upper completion interval and approximately 20°C cooler at the bottom of the logging run (3,400 ft bgs). There is also less of an increase in temperature with depth in the postdevelopment log trace.

The EC and pH values generally give an indication of the representativeness of the water within the well relative to formation water. Unfortunately, the postdevelopment pH log was erroneous (values approached 13.0 SU), the probe was found to be faulty and out-of-calibration after retrieval of the tool. Therefore, the measurements of postdevelopment pH cannot be used or compared to the precompletion pH values. The EC logs indicate significantly higher EC values from the postdevelopment run, ranging from 775 to 825 µmhos/cm, compared to values ranging from 650 to 690 µmhos/cm range from the precompletion run. An increase in EC after development and testing has also been observed in other WPM-OV wells. The large decline in EC values that is observed in the lower part of the trace of the precompletion log is not seen in the postdevelopment log. The EC logs show general consistency throughout the depth of the well with gradual increases in values with depth. The general, straight-line consistency of the water-quality parameters suggests that there is considerable natural circulation in the well. Such consistency could be expected to persist lower in the well since pumping during development and testing appears to have had minimal impact below the upper completion interval.

A.3.5.3 Grab Sample Results Versus ChemTool Results

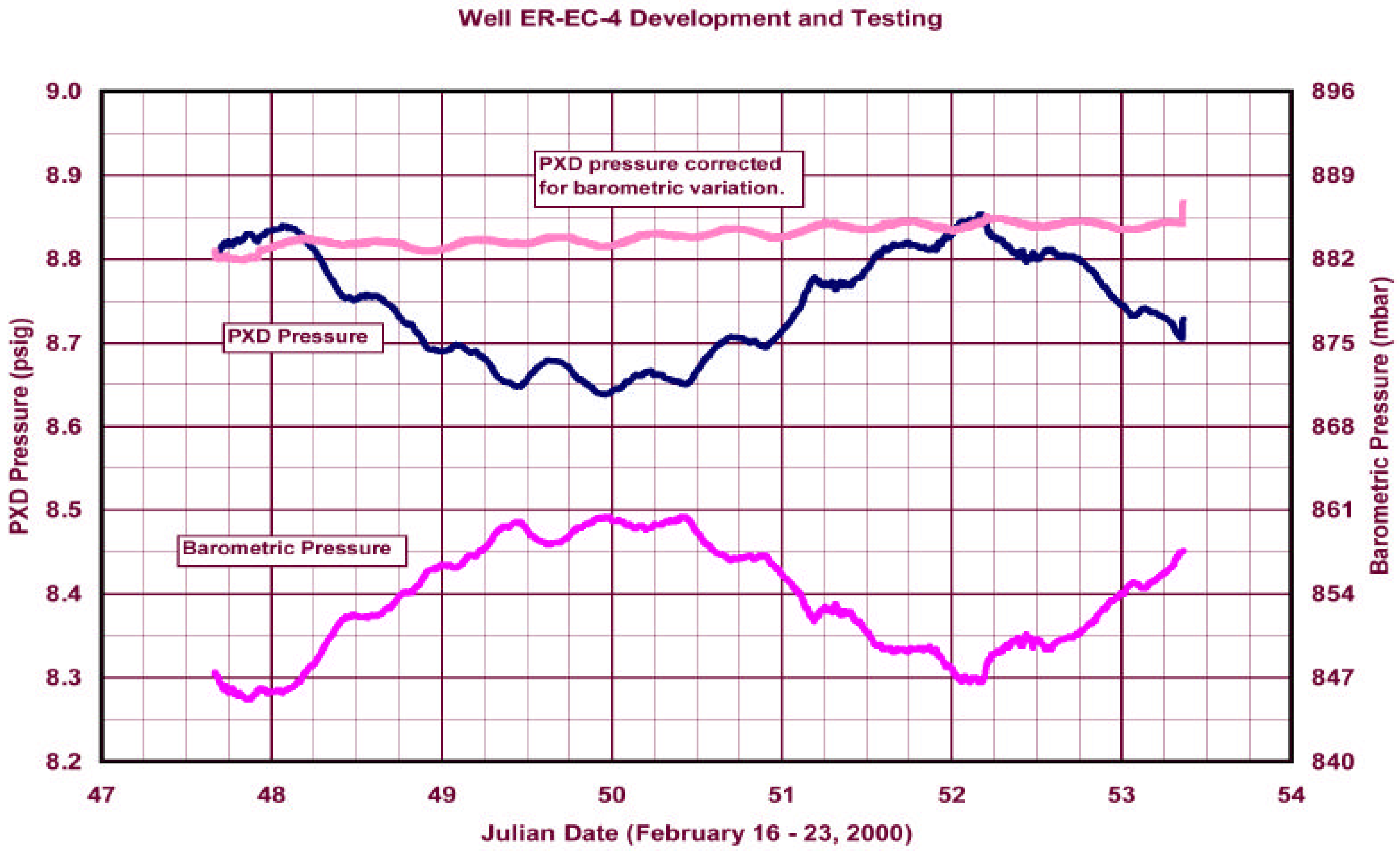
The postdevelopment pH values from the ChemTool are erroneously high and, therefore, would not be expected to agree with the grab sample results which averaged approximately 7.7 SU. The ChemTool EC values (775 to 825 µmhos/cm), on the other hand, do agree with the grab samples which were generally between 760 and 810 µmhos/cm at the end of the constant-rate test. The

ChemTool temperature log indicates a measurement of about 37°C in the area adjacent to the upper interval, 1.3°C cooler than the grab sample average.

A.3.6 Representativeness of Hydraulic Data and Water Samples

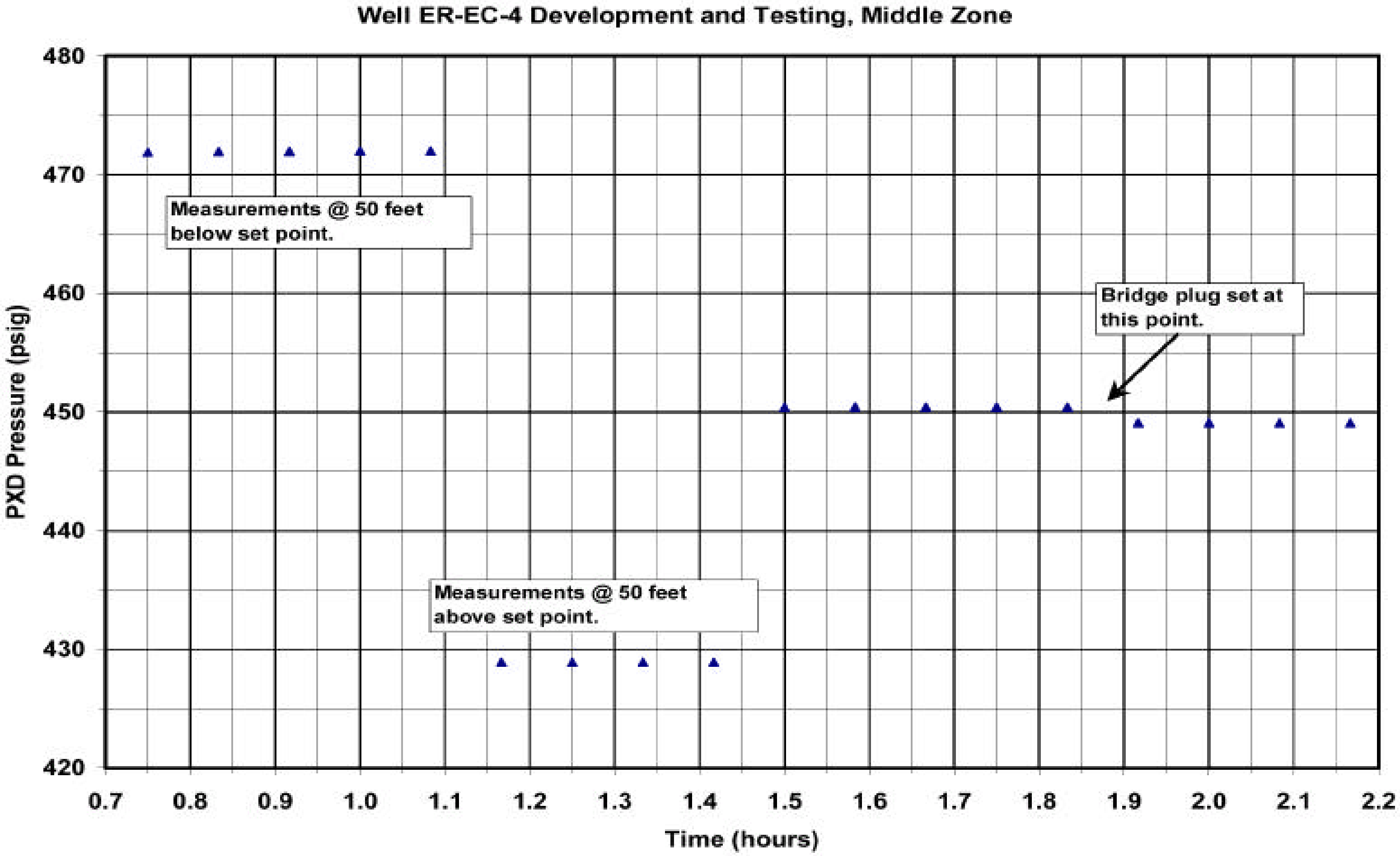
The results of water-quality monitoring, development, hydraulic testing, and composite sampling can be considered to only represent the upper completion interval of this well. Since the upper completion interval appears to have the highest head, and any natural flow in the well appears to be downward, the upper completion interval does not naturally receive water from any lower sources. Therefore, the upper interval will probably maintain its individual chemical character during any future sampling. Due to the nature of flow in the well, the discrete and composite samples collected probably only represent the chemistry of the upper completion interval.

The lower completion intervals are not considered developed, and the chemistry of the water in these intervals may not be representative of the groundwater chemistry within the adjacent formation. In light of the rates of natural downward flow from the upper interval, the water chemistry of the lower intervals is likely impacted by the flow of water above. Samples that may be collected below the upper completion interval may only reflect the chemistry of the upper interval. The lower intervals may still be impacted by drilling-induced fluids, since it is believed that such fluids were not removed.



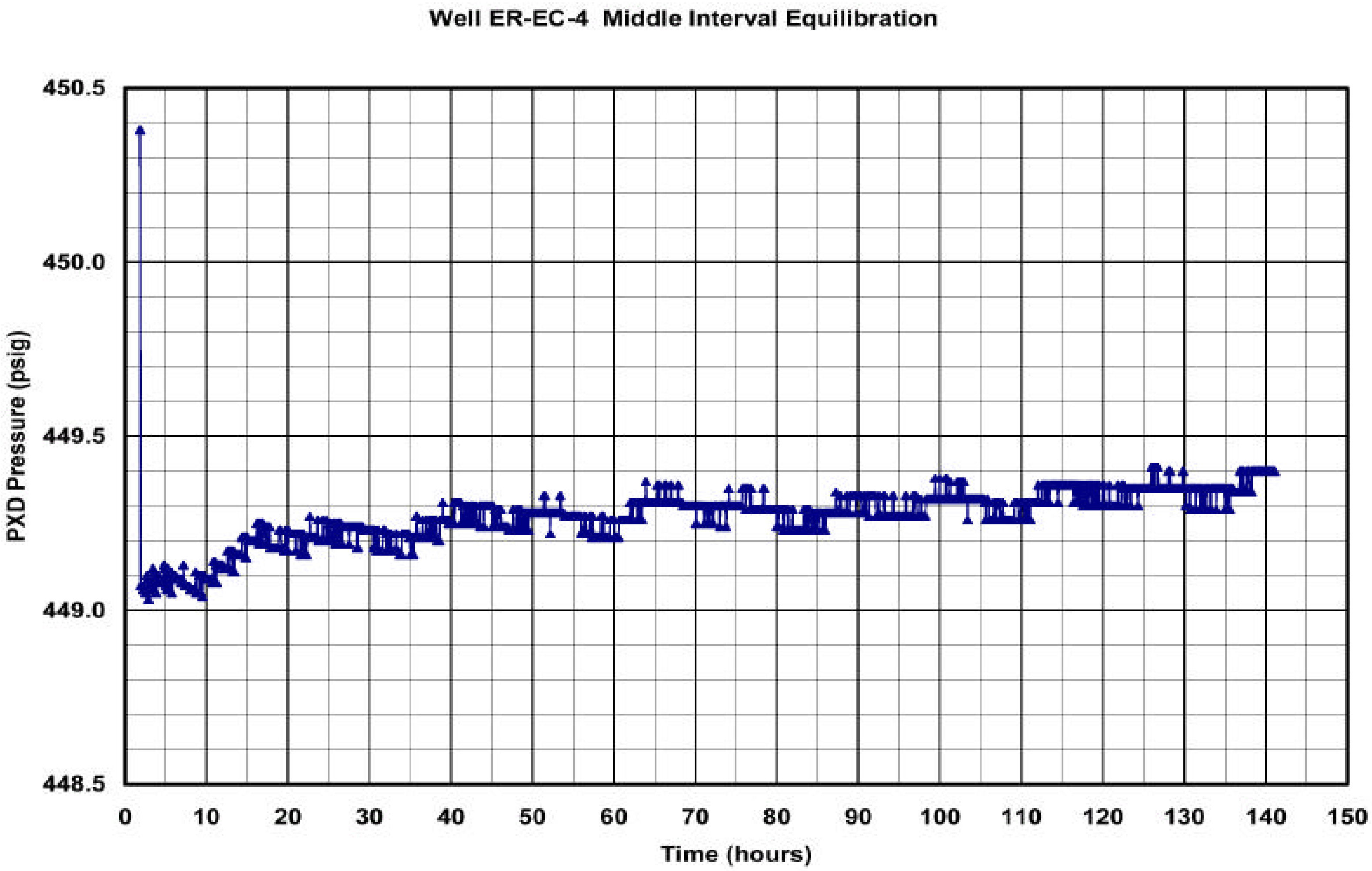
psig - Pounds per square inch gauge
mbar - Millibars
PXD - Pressure transducer

Figure A.3-1
PXD Equilibration Record for the Upper Interval



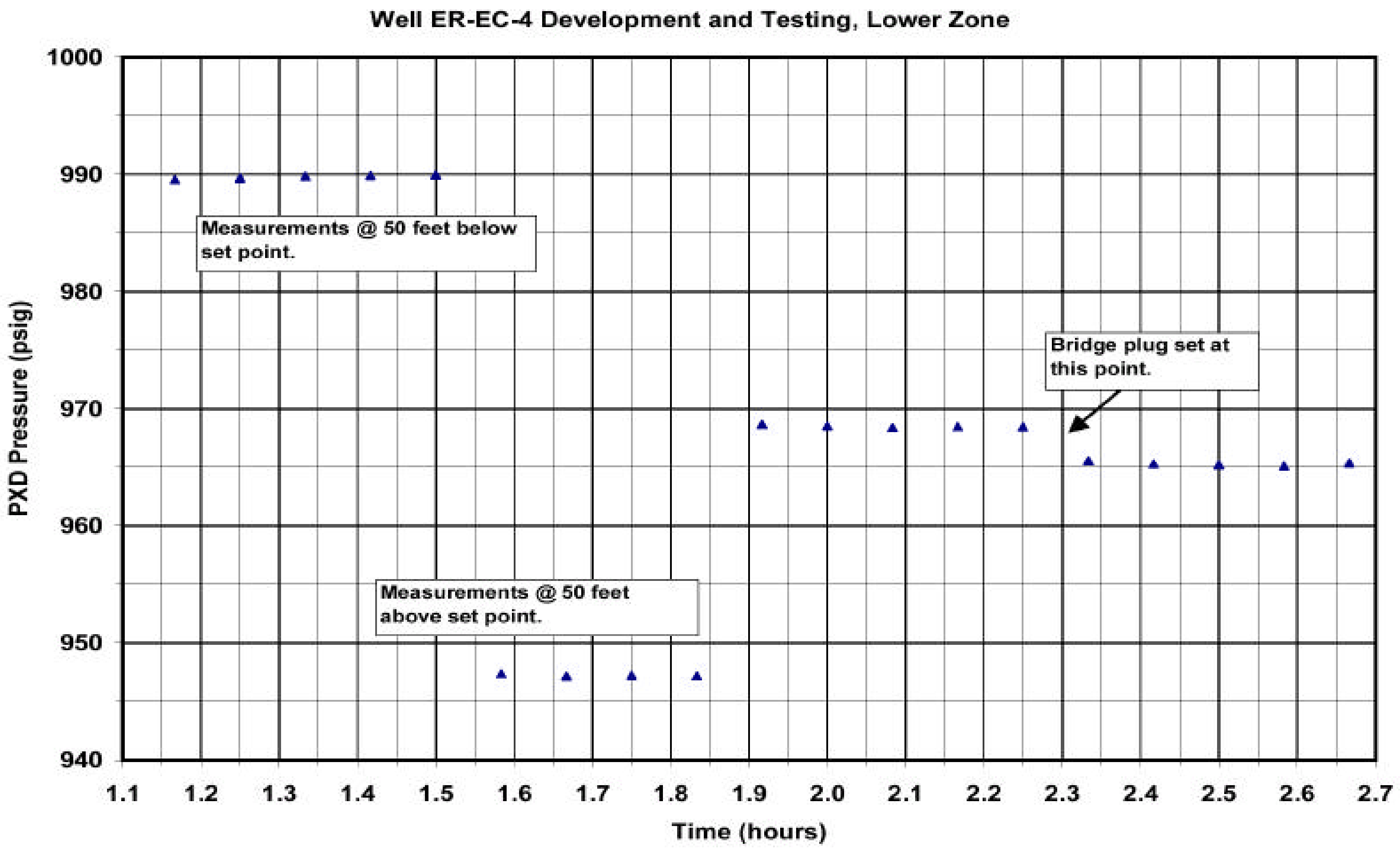
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-2
Middle Interval Calibration and Bridge Plug Set



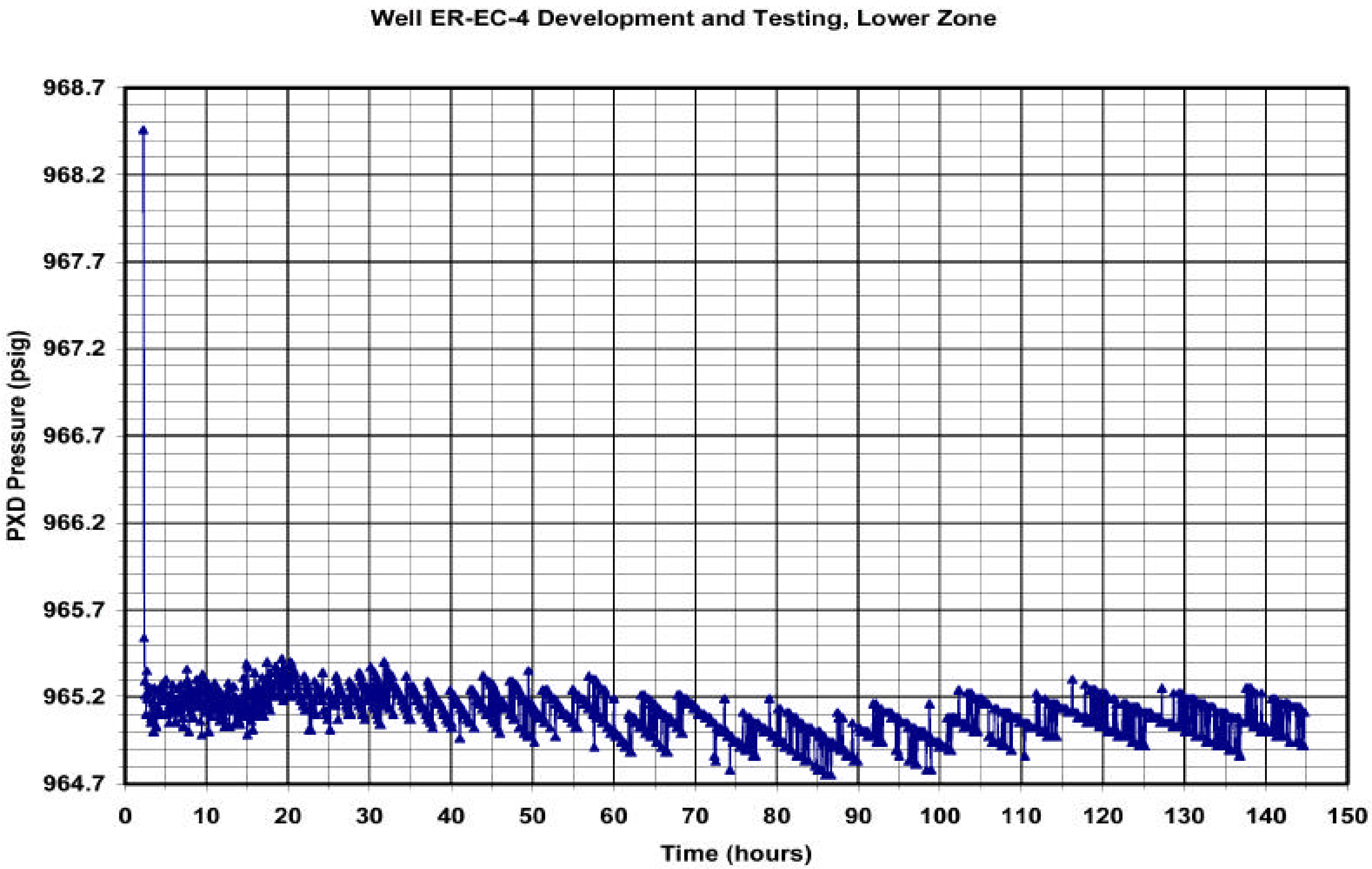
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



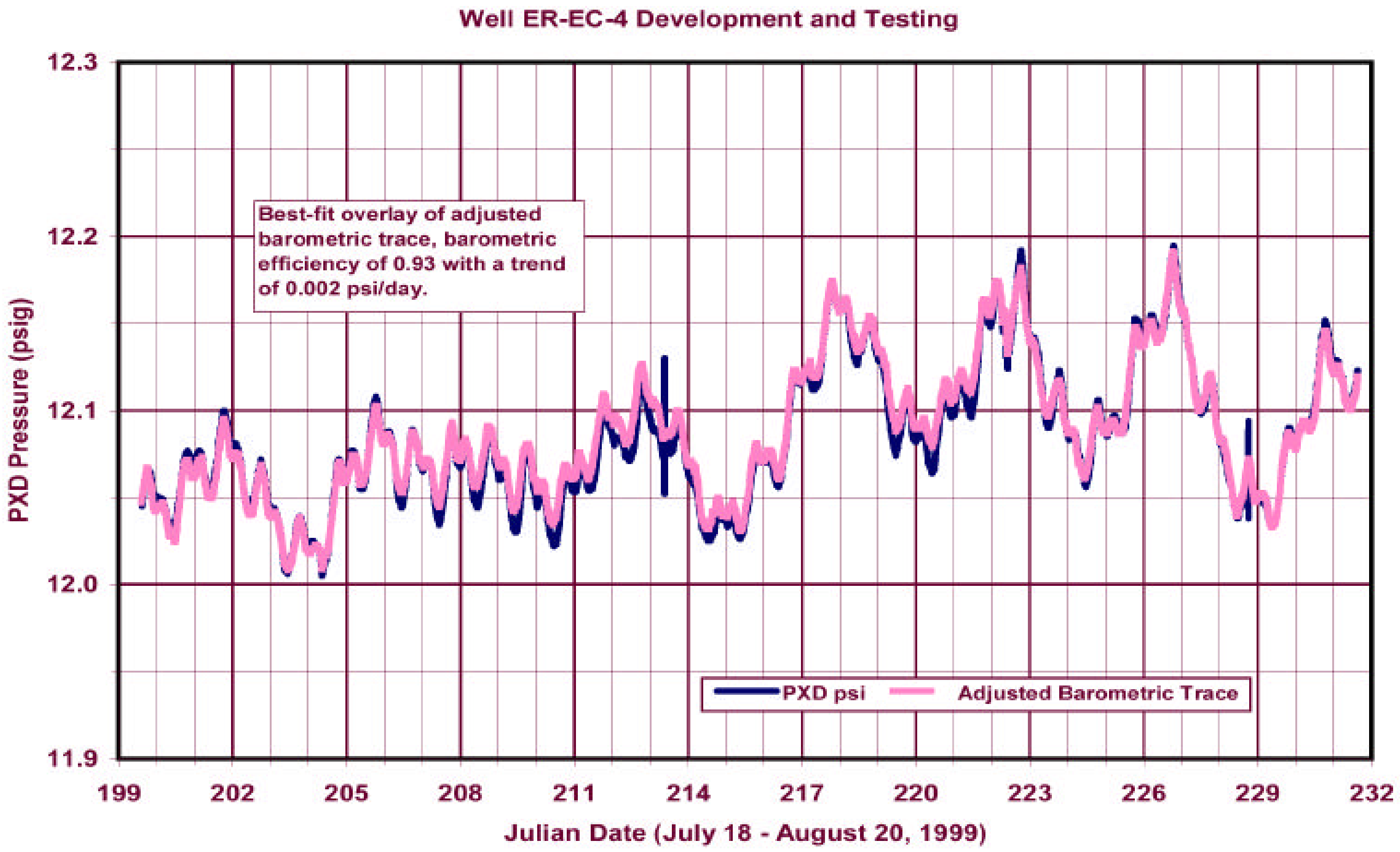
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-4
Lower Interval Calibration and Bridge Plug Set



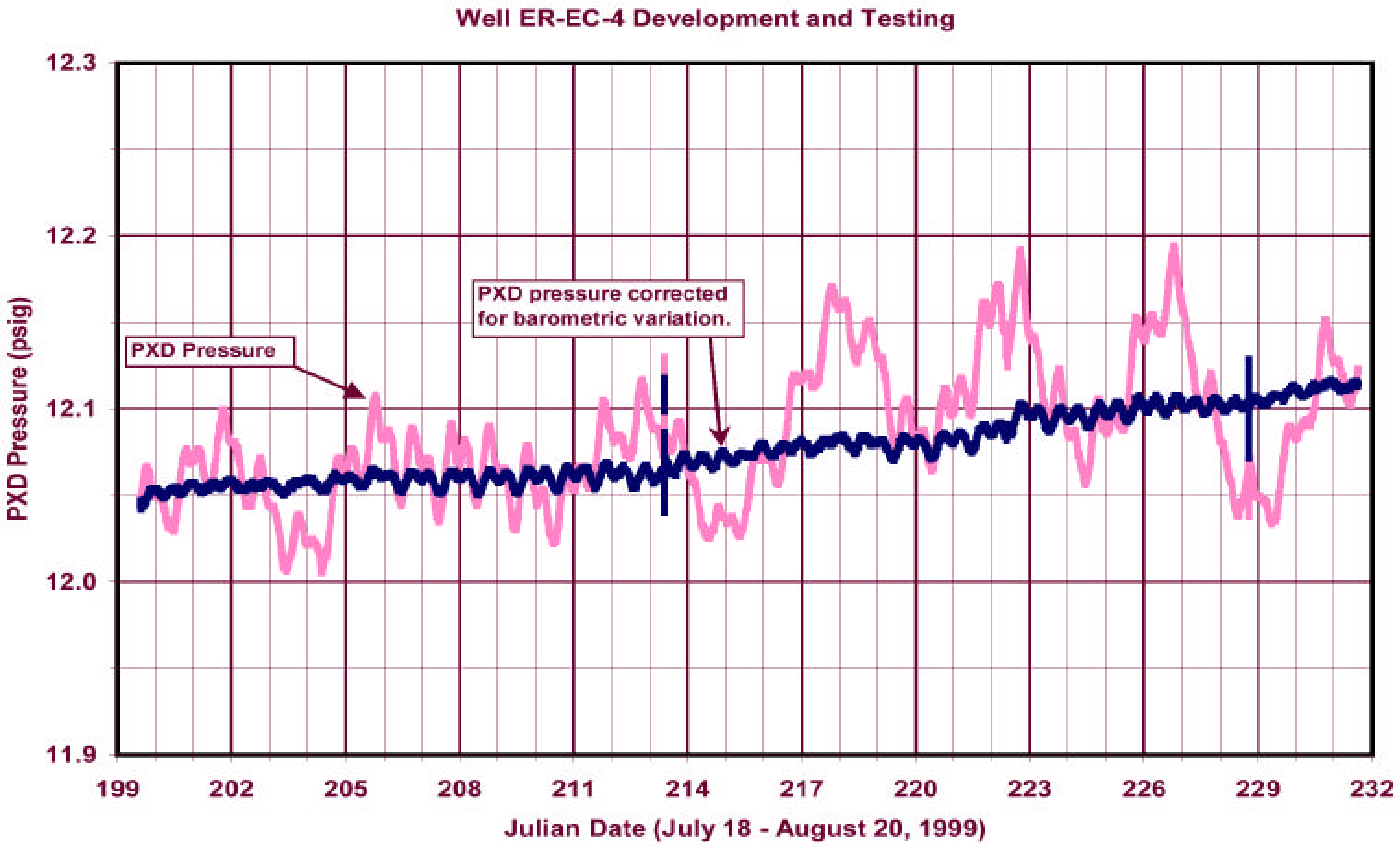
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-5
Bridge Plug PXD Response for the Lower Interval



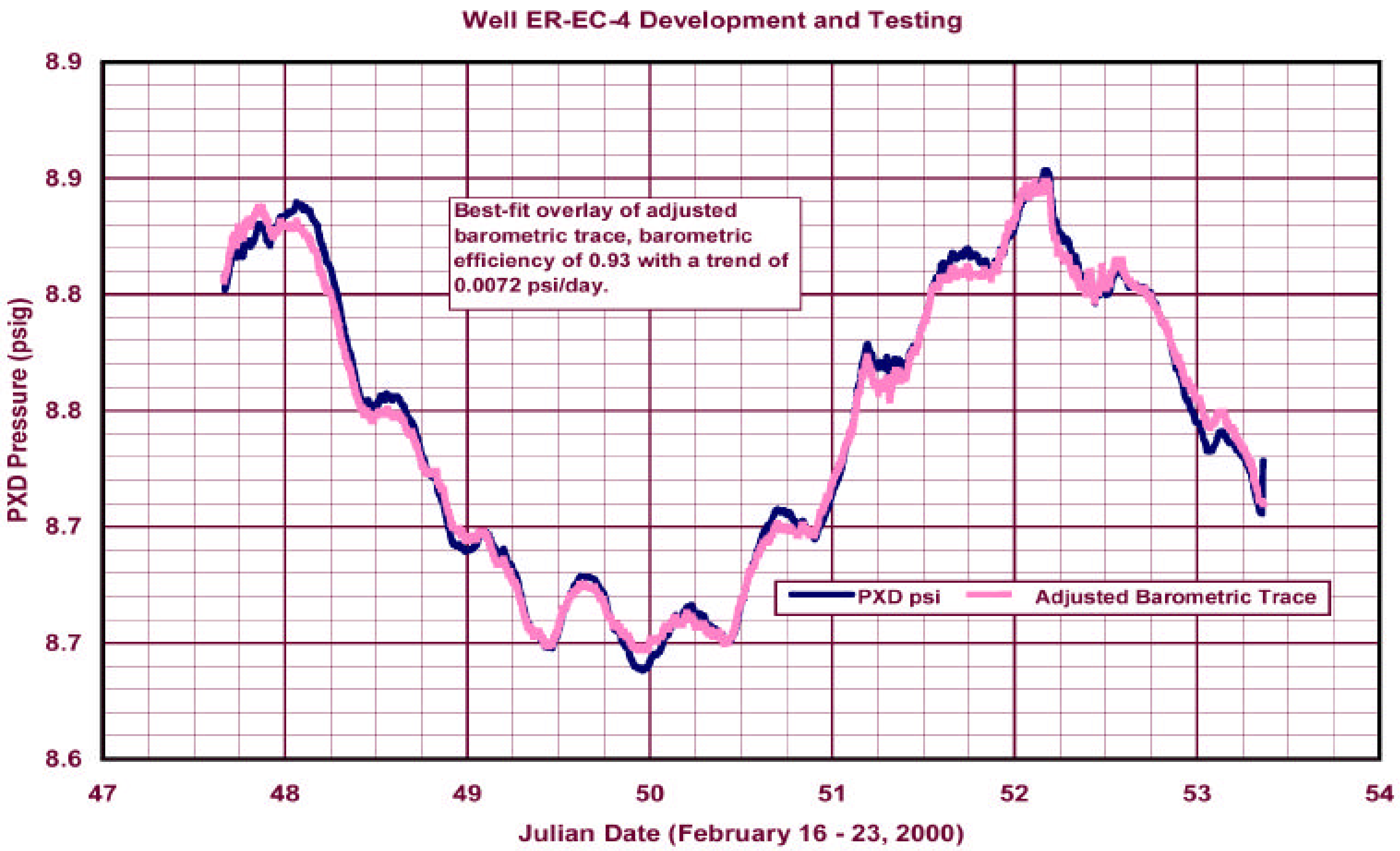
psi(g) - Pounds per square inch (gauge)
PXD - Pressure transducer

Figure A.3-6
Barometric Efficiency Overlay for Predevelopment Water Level Monitoring



psig - Pounds per square inch gauge
PXD - Pressure transducer

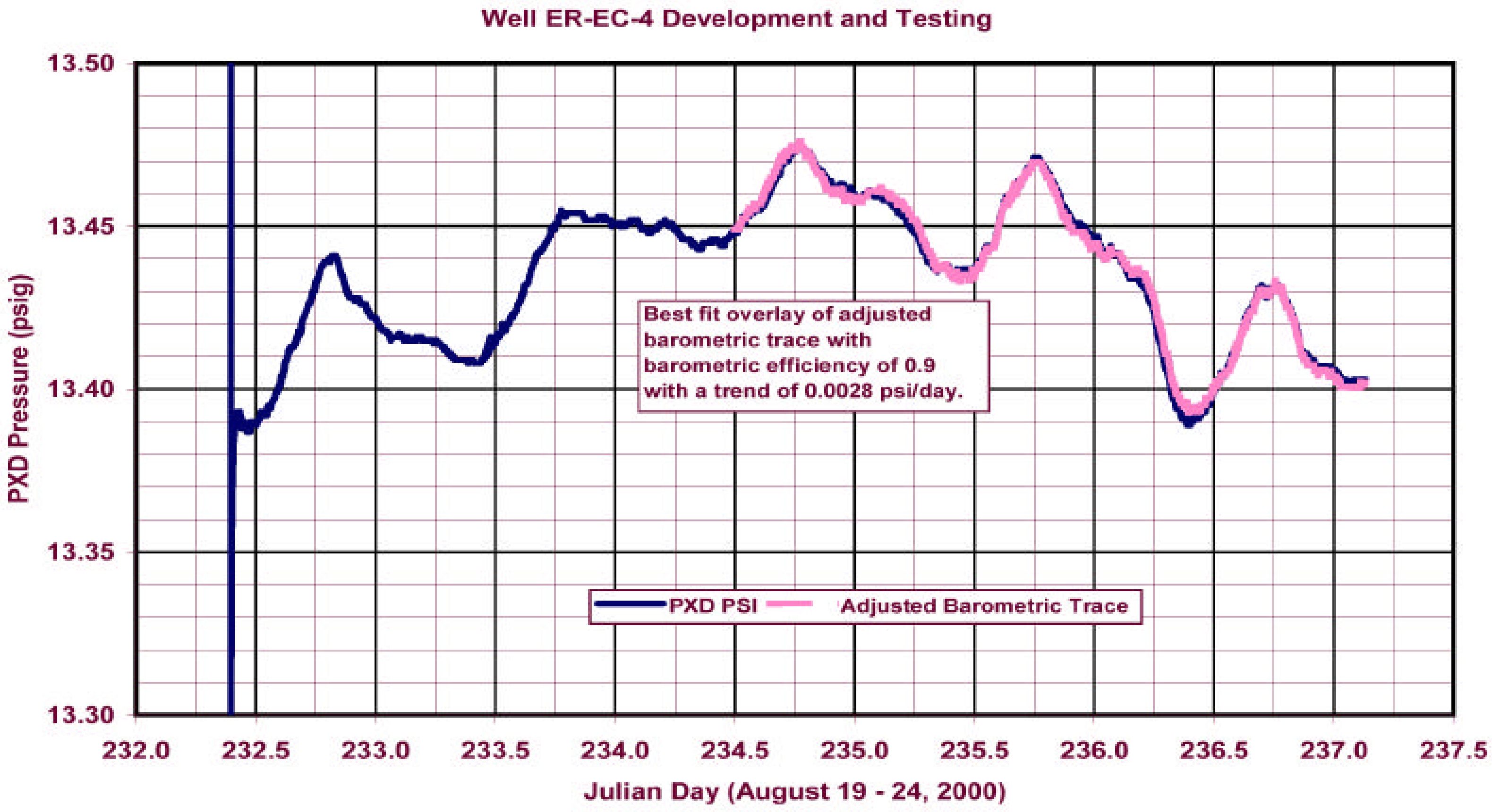
Figure A.3-7
Predevelopment Water Level Monitoring with Barometric Correction



Best-fit overlay of adjusted barometric trace, barometric efficiency of 0.93 with a trend of 0.0072 psi/day.

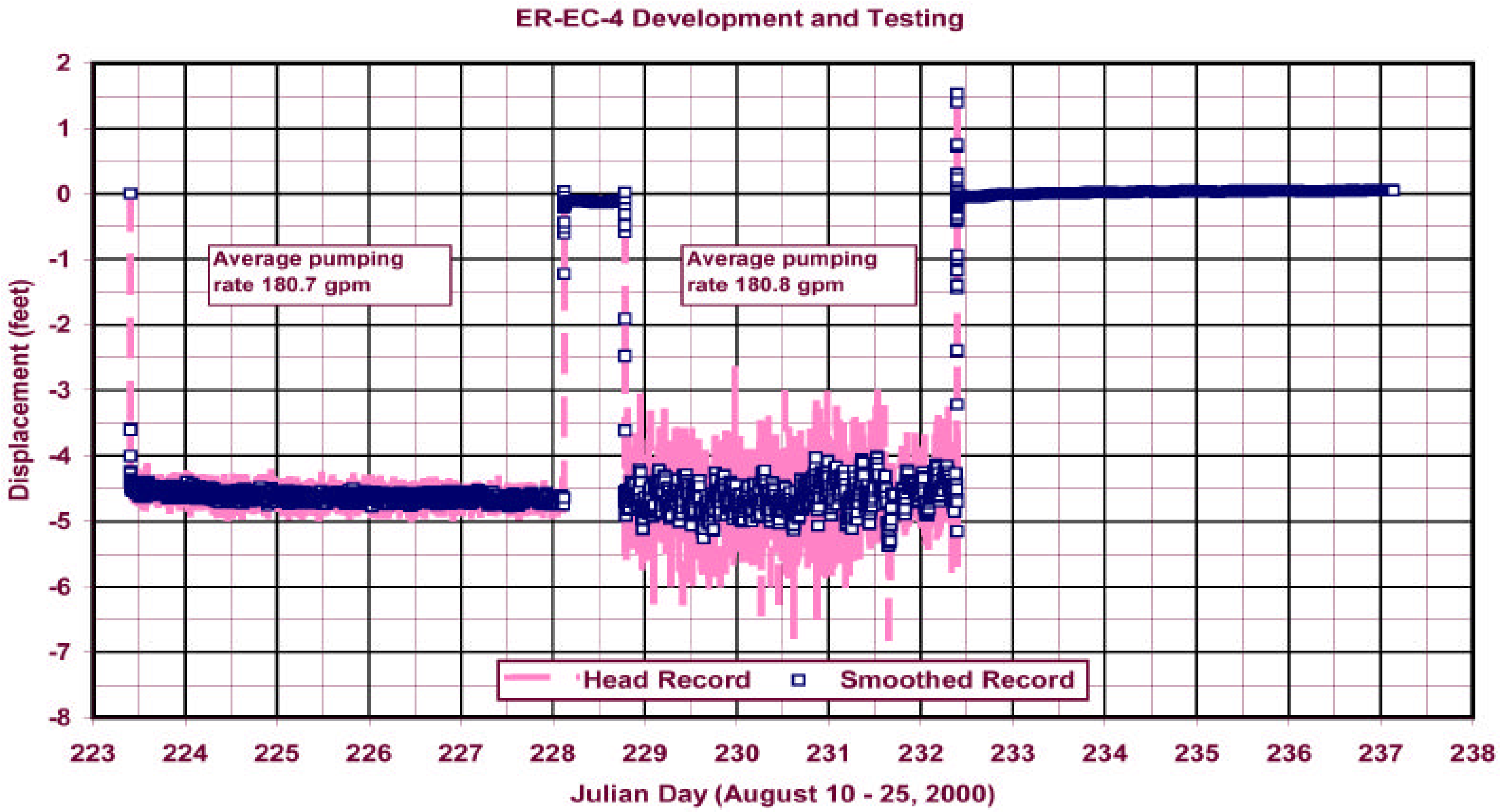
psi - Pounds per square inch
psig - Pounds per square inch (gauge)
PXD - Pressure transducer
psi - Pounds per square inch

Figure A.3-8
Barometric Efficiency Overlay for Upper Interval Water Level Monitoring



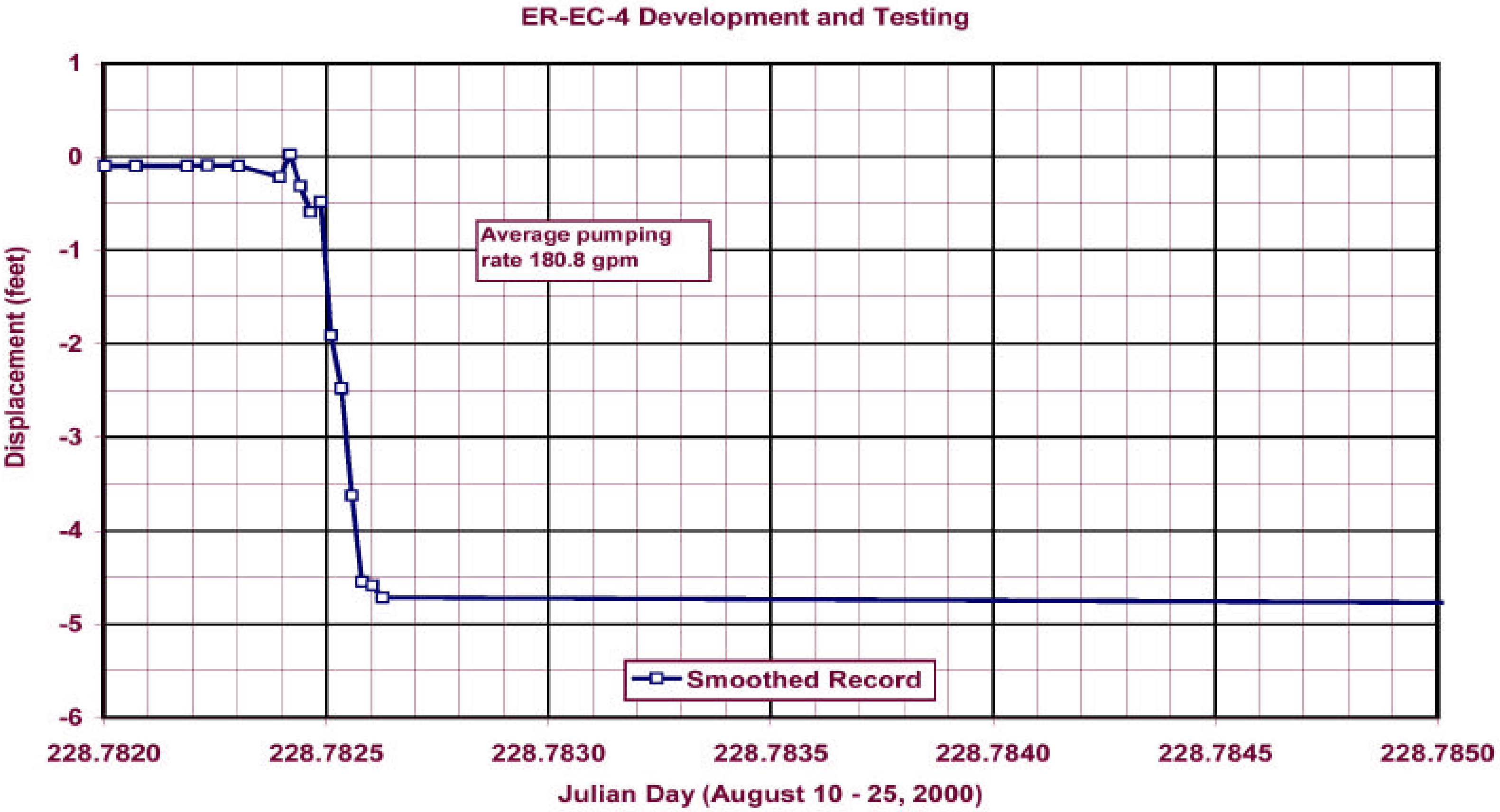
psi - Pounds per square inch
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-9
Barometric Efficiency Overlay for Constant-Rate Test



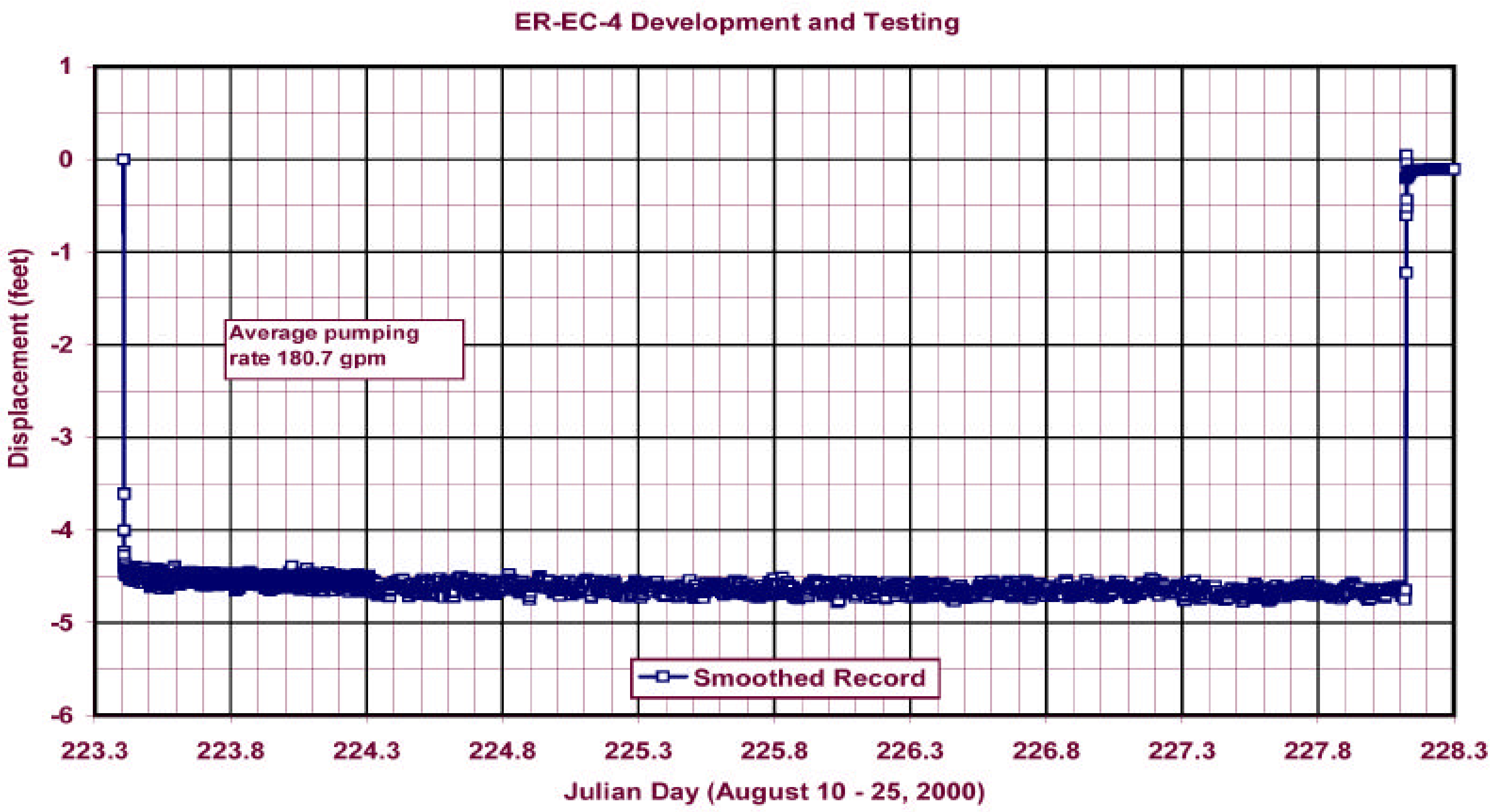
ft msld - Feet above mean sea level datum
gpm - Gallons per minute

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



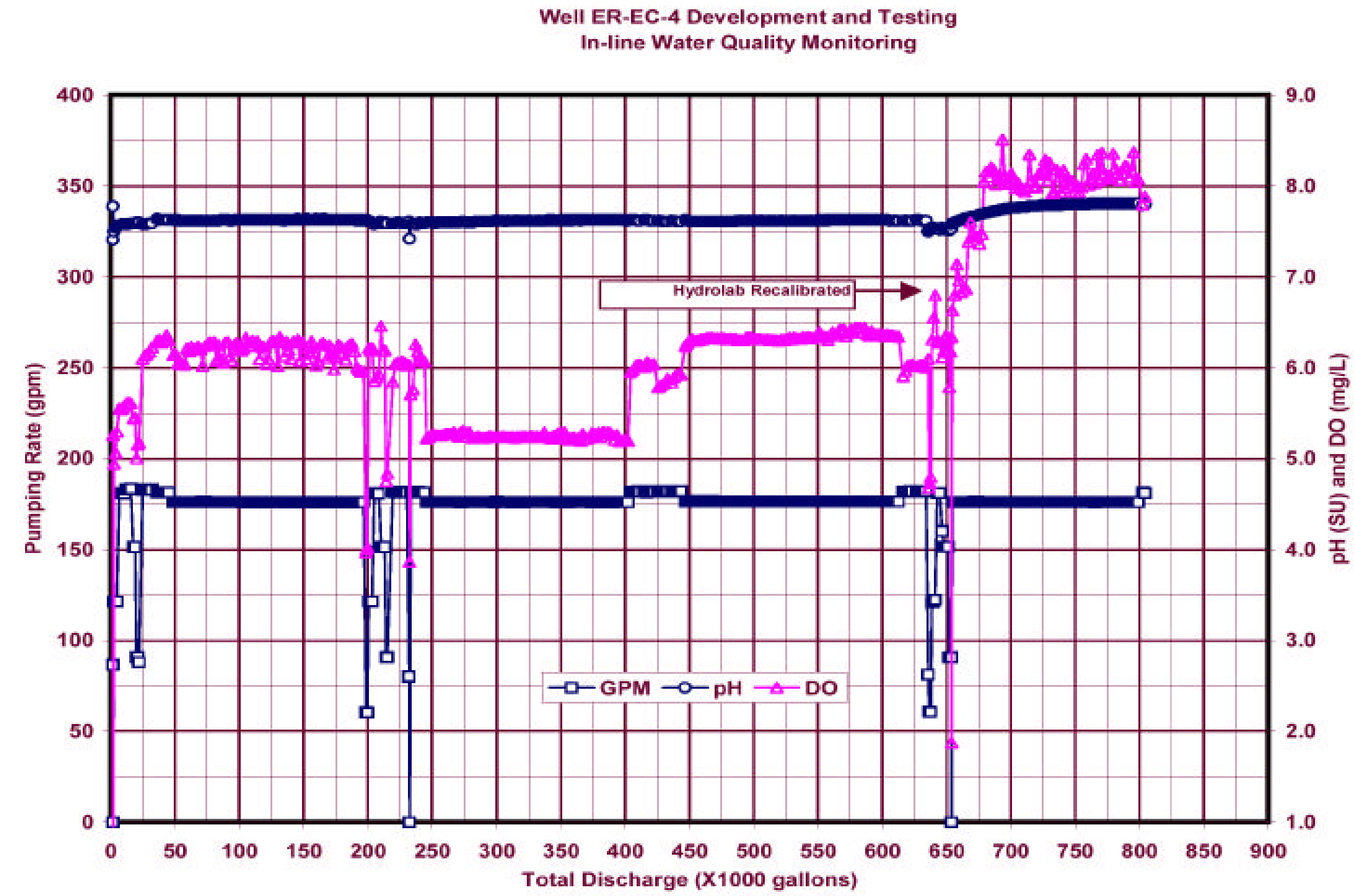
ft msld - Feet above mean sea level datum
gpm - Gallons per minute

Figure A.3-11
Expanded View of Drawdown (Synthetic Record)



ft msld - Feet above mean sea level datum
gpm - Gallons per minute

Figure A.3-12
Expanded View of the First Five Days of the Constant-Rate Test



gpm - Gallons per minute
SU - Standard units
mg/L - Milligrams per liter
DO - Dissolved oxygen

Figure A.3-13
In-Line pH and DO, and Pumping Rate Versus Total Gallons Pumped

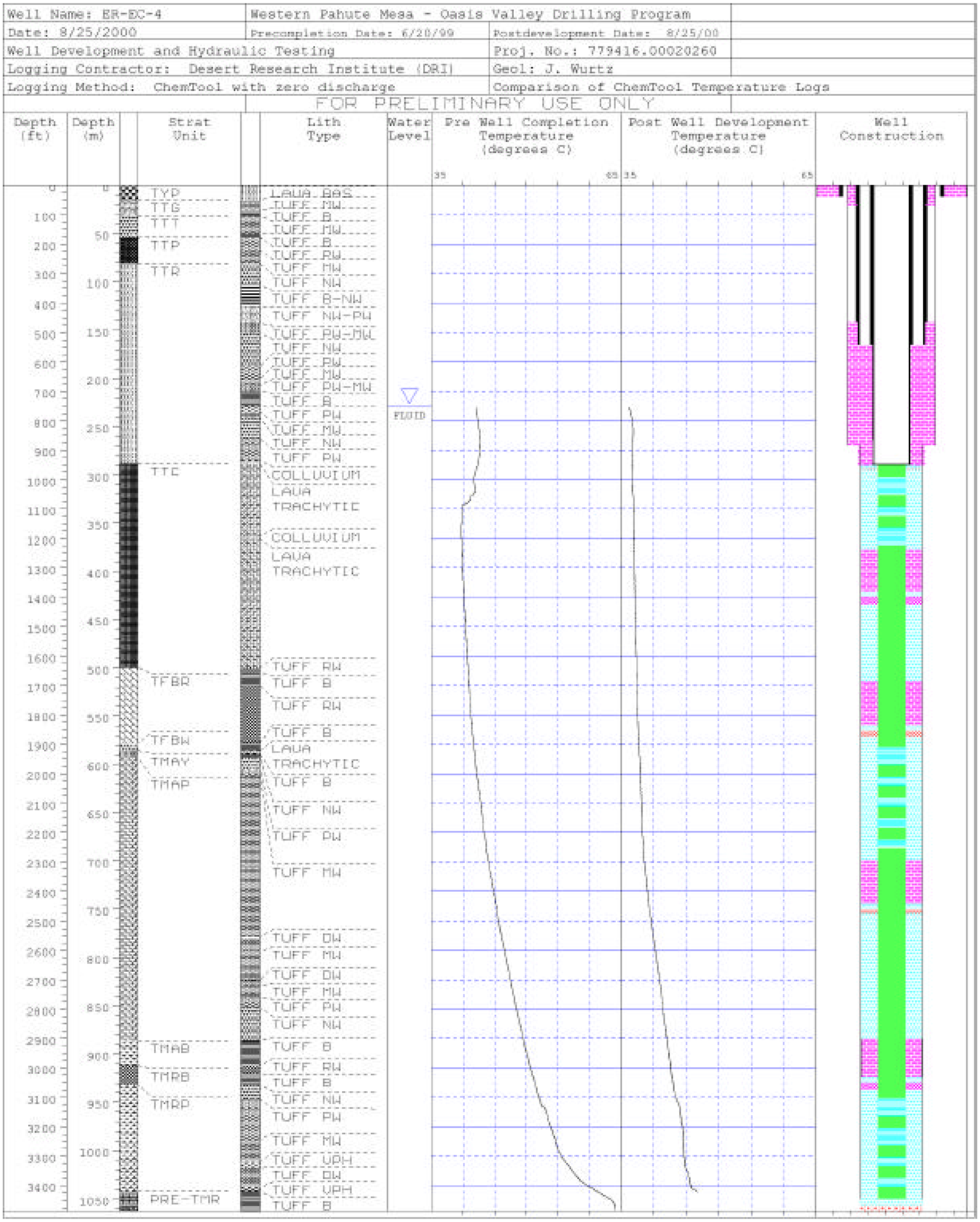
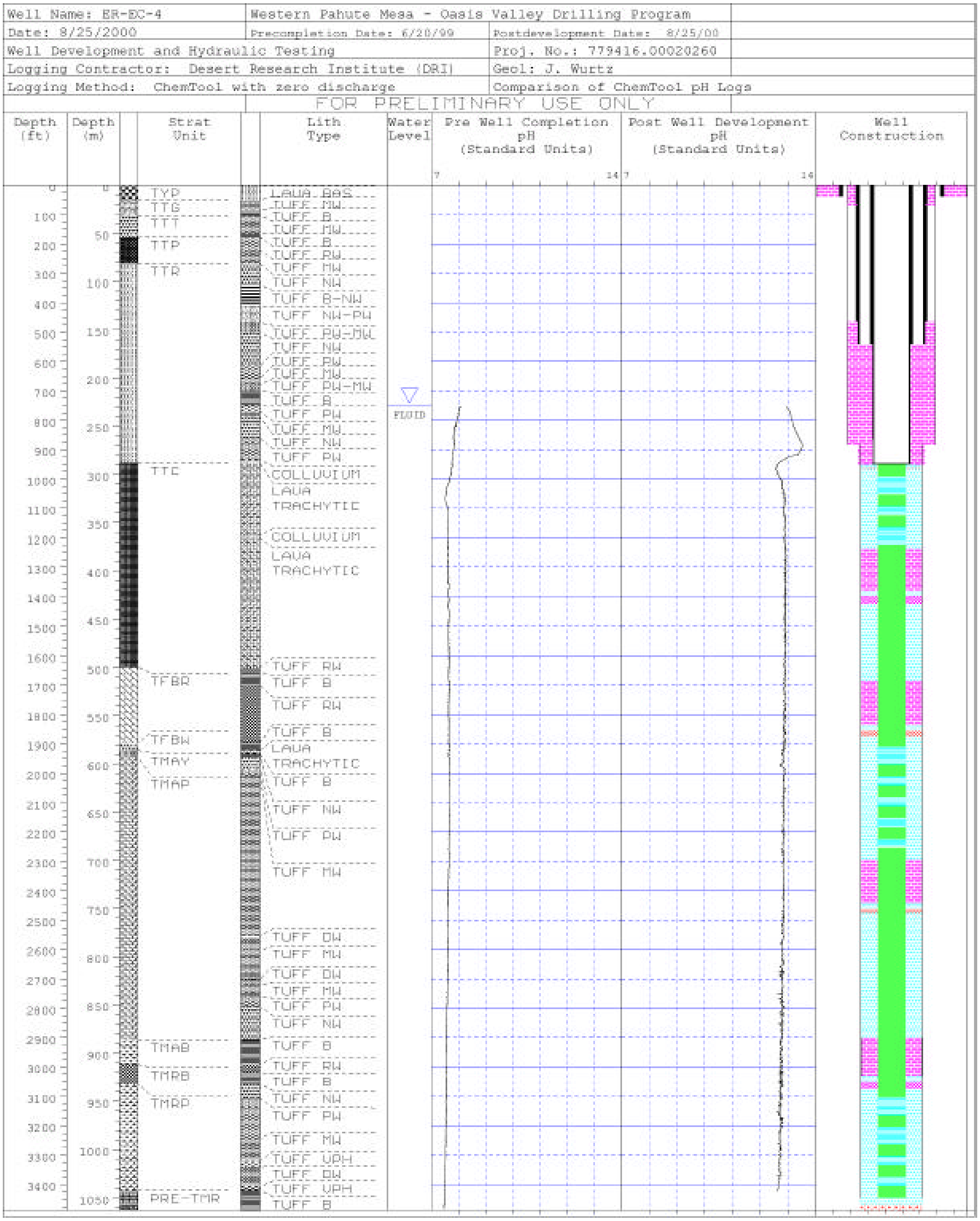


Figure A.3-14
Temperature Log, Precompletion Versus Postdevelopment



Well Name: ER-EC-4
Western Pahute Mesa - Oasis Valley Drilling Program
Date: 8/25/2000
Precompletion Date: 6/20/99
Postdevelopment Date: 8/25/00
Well Development and Hydraulic Testing
Proj. No.: 779416.00020260
Logging Contractor: Desert Research Institute (DRI)
Geol: J. Wurtz
Logging Method: ChemTool with zero discharge
Comparison of ChemTool pH Logs
FOR PRELIMINARY USE ONLY

Figure A.3-15
pH Log, Precompletion Versus Postdevelopment

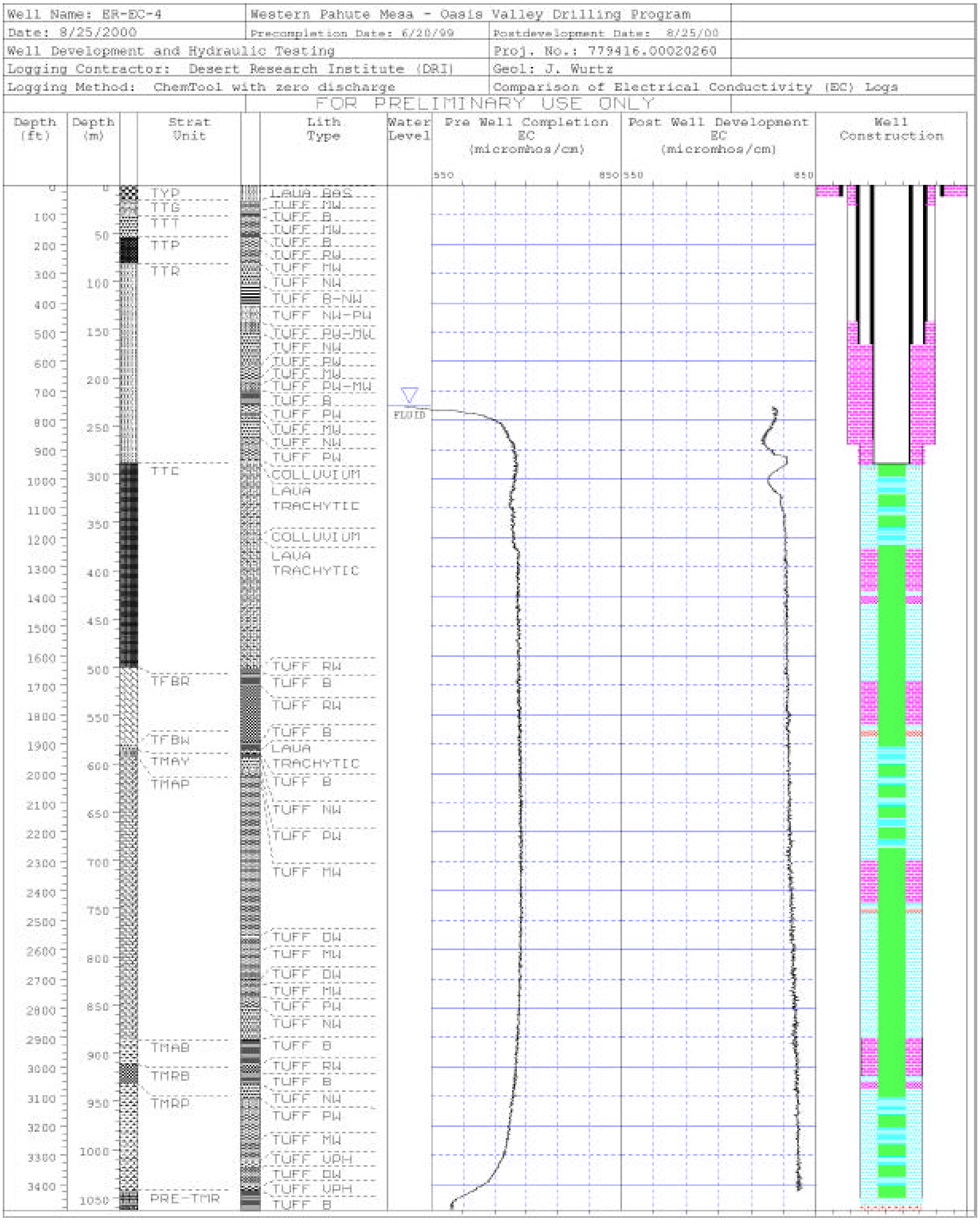


Figure A.3-16
EC Log, Precompletion Versus Postdevelopment

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 active sump and analyzed at a certified laboratory for total and dissolved metals, gross alpha/beta, and tritium. Based on process knowledge, Nevada Operations Office requested a waiver for the disposal of fluids produced during well development/hydraulic testing for Wells ER-EC-1, ER-EC-2a, ER-EC-4, ER-EC-5, ER-EC-6, ER-EC-7, ER-EC-8, and ER-18-2. The Nevada Operations Office'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 Nevada Operations Office a waiver to discharge fluids directly to the ground surface during well development, testing, and sampling at the above wells (NDEP, 1999). The waiver (provided in Attachment 4) was granted under the mandate that the following conditions were satisfied:

- The only fluid allowed to be discharged to the surface is water 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 unlined, noncontaminated basins to allow the sediments to settle out before being discharged to the ground 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 non-detect 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 concentrations less then 75 µg/L (5 times the *Nevada Drinking Water Standards* [NDWS]), then sampling must occur every 12 hours until two consecutive nondetect results 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-4, all fluids from well development and testing were discharged into unlined Sump #1. Sump #2 was also unlined, but was not used during development and testing activities. Sump #1 serves as an infiltration basin and has an overflow pipe approximately 7.5 ft from the sump floor. Fluids reached the overflow pipe and began discharging to the ground surface at the southern perimeter of Sump #1 on August 4, 2000. Discharge to the ground surface occurred after approximately 900,000 gallons of fluid had been pumped into Sump #1.

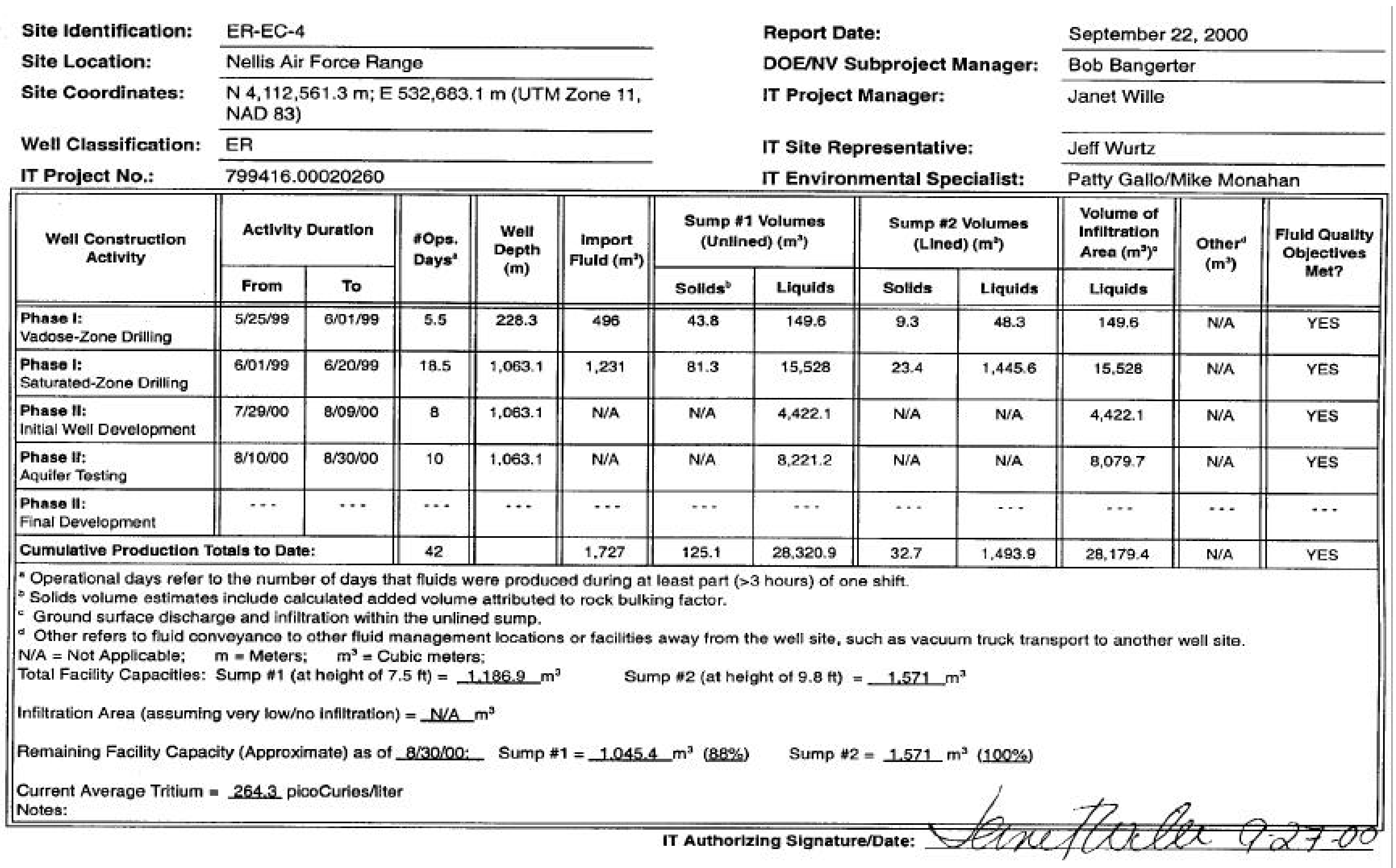
A total of approximately 3,340,000 gals of groundwater were pumped from Well ER-EC-4 during well development, hydraulic testing, and sampling activities. The total consists of 1,168,322 gallons produced during well development and 2,172,053 gallons during the constant-rate pumping. Table A.4-1 contains the Fluid Disposition Reporting 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 the NDEP waivers. Lead analyses were conducted on site in a 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 from the wellhead sampling port. All tritium samples were kept in a locked storage until transport to the BN Site Monitoring Services at the Control Point in Area 6 of the Nevada Test Site. The tritium samples were analyzed using a liquid scintillation counter.

The NDWS were not exceeded at any time. The highest lead result was 1.75 μg/L and highest tritium activity was 646 picocuries per liter (pCi/L). Both of these maximum results were well below NDWS values. The complete results of lead and tritium monitoring are presented in Table A.4-2.

Table A.4-1
Fluid Disposition Reporting Form



Site Identification: ER-EC-4
Site Location: Nellis Air Force Range
Site Coordinates: N 4,112,561.3 m; E 532,683.1 m (UTM Zone 11, NAD 83)
Well Classification: ER
IT Project No.: 799416.00020260

Report Date: September 22, 2000
DOE/NV Subproject Manager: Bob Bangerter
IT Project Manager: Janet Wille
IT Site Representative: Jeff Wurtz
IT Environmental Specialist: Patty Gallo/Mike Monahan

Well Construction Activity	Activity Duration		#Ops. Days[a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (Unlined) (m^3)		Sump #2 Volumes (Lined) (m^3)		Volume of Infiltration Area (m^3)[c]	Other[d] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids[b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	5/25/99	6/01/99	5.5	228.3	496	43.8	149.6	9.3	48.3	149.6	N/A	YES
Phase I: Saturated-Zone Drilling	6/01/99	6/20/99	18.5	1,063.1	1,231	81.3	15,528	23.4	1,445.6	15,528	N/A	YES
Phase II: Initial Well Development	7/29/00	8/09/00	8	1,063.1	N/A	N/A	4,422.1	N/A	N/A	4,422.1	N/A	YES
Phase II: Aquifer Testing	8/10/00	8/30/00	10	1,063.1	N/A	N/A	8,221.2	N/A	N/A	8,079.7	N/A	YES
Phase II: Final Development	---	---	---	---	---	---	---	---	---	---	---	---
Cumulative Production Totals to Date:			42		1,727	125.1	28,320.9	32.7	1,493.9	28,179.4	N/A	YES

[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] Ground surface discharge and infiltration within the unlined sump.
[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.

N/A = Not Applicable; m = Meters; m^3 = Cubic meters;

Total Facility Capacities: Sump #1 (at height of 7.5 ft) = 1,186.9 m^3 Sump #2 (at height of 9.8 ft) = 1,571 m^3

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

Remaining Facility Capacity (Approximate) as of 8/30/00: Sump #1 = 1,045.4 m^3 (88%) Sump #2 = 1,571 m^3 (100%)

Current Average Tritium = 264.3 picoCuries/liter

Notes:

IT Authorizing Signature/Date: Janet Wille 9-27-00

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

Sampling Date	Sample Number	Lead Results[1]	Tritium Results[2a]
		μg/L	pCi/L
7/29/2000	EC-4-072900-1	0.9	337.4
7/29/2000	EC-4-072900-2	0.5	N/A
7/30/2000	EC-4-073000-1	1.5	309.8
7/31/2000	EC-4-073100-1	0.9	145.8
8/1/2000	EC-4-080100-1	0.9	389.7
8/2/2000	EC-4-080200-1	1.0	420.5
8/3/2000	EC-4-080300-1	1.75	350.7
8/4/2000	EC-4-080400-1	1.0	646.0
8/5/2000	EC-4-080500-1	1.0	229.2
8/10/2000	EC-4-081000-01	0.5	666.5
8/11/2000	EC-4-081100-01	1.0	59.6
8/12/2000	EC-4-081200-01	1.0	259.5
8/13/2000	EC-4-081300-01	1.5	0.0
8/14/2000	EC-4-081400-01	0.5	0.0
8/15/2000	EC-4-081500-1	1.0	372.9
8/16/2000	EC-4-081600-1	1.0	0.0
8/17/2000	EC-4-081700-1	1.0	131.6
8/18/2000	EC-4-081800-1	<2.0	162.7
8/19/2000	EC-4-081900-1	0.5	275.7
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 BN Site Monitoring Services

μg/L - Micrograms per liter
pCi/L - Picocuries per liter

A.4.1.3 Fluid Management Plan Sampling

Fluid management samples were collected from the active unlined sump (Sump #1) at the end of well development and testing activities to confirm on-site monitoring of well effluent. The samples were collected, along with an equipment rinsate sample, on August 19, 2000, and sent to Paragon Analytical for analyses. The FMP parameters of total and dissolved metals, gross alpha/beta, and tritium were requested for analysis. The laboratory results are presented in Table A.4-3, along with comparisons to the NDWS.

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

Analyte	CRDL	Laboratory	NDWS	Results of Sump Composite Sample # EC-4-081900-4 (F)	
Metals (mg/L)					
				Total	**Dissolved**
Arsenic	0.01	Paragon	0.05	B 0.0051	B 0.0041
Barium	0.2	Paragon	2.0	B 0.00095	B 0.00068
Cadmium	0.005	Paragon	0.005	U 0.005	U 0.005
Chromium	0.01	Paragon	0.1	B 0.0013	B 0.0027
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	B 0.0006	B 0.00054
Mercury	0.0002	Paragon	0.002	U 0.0002	U 0.0002
Analyte	**MDC**	**Laboratory**	**NDWS**	**Result**	**Error**
Radiological Indicator Parameters-Level I (pCi/L)					
Tritium	270	Paragon	20,000	U -20	+/- 160
Gross Alpha	3.8	Paragon	15	5.7	+/- 2.8
Gross Beta	2.8	Paragon	50	7.1	+/- 2.1

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, 2000)
MDC - Minimum Detectable Concentration, sample-specific
NDWS - *Nevada Drinking Water Standards*
mg/L - Milligrams per liter
pCi/L - Picocuries per liter

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 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, including absorbent pads (containing pump oil, hydraulic fluid and diesel fuel), soil, and debris, were produced.
- Hazardous Waste: Approximately 2 gallons of solid hazardous waste were generated from the installation of the bridge plugs. This material consists of combustion by-products. Similar waste from other WPM-OV well sites has been sampled and has been determined to be hazardous because of the presence of benzene and other volatiles. The waste is currently being stored in a Satellite Accumulation Area at the ER-EC-4 well site. Monthly inspections shall be conducted of this area until the waste is transported off site for disposal.

Hydrocarbon and sanitary waste were disposed of by BN Waste Management after well development operations at the Nellis Air Force Range were completed. The hazardous waste from each well site was removed and disposed of by Safety-Kleen Corporation before the end of the fiscal year.

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*. Las Vegas, NV.

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

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

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

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

IT Corporation. 2000. *ITLV Standard Quality Practices Manual*, Vol. 1 and 2. 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. Las Vegas, NV.

U. S. Department of Energy, Nevada Operations Office. 1998. *Underground Test Area Quality Assurance Project Plan*, DOE/NV--341, Rev. 2. 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. Las Vegas, NV.

U.S. Department of Energy, Nevada Operations Office. 2000. *Completion Report for Well ER-EC-4*, DOE/NV/11718--397, September. Las Vegas, NV.

Attachment 1

Manufacturer's Pump Specifications

High-Capacity Testing Pump

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

CENTRILIFT

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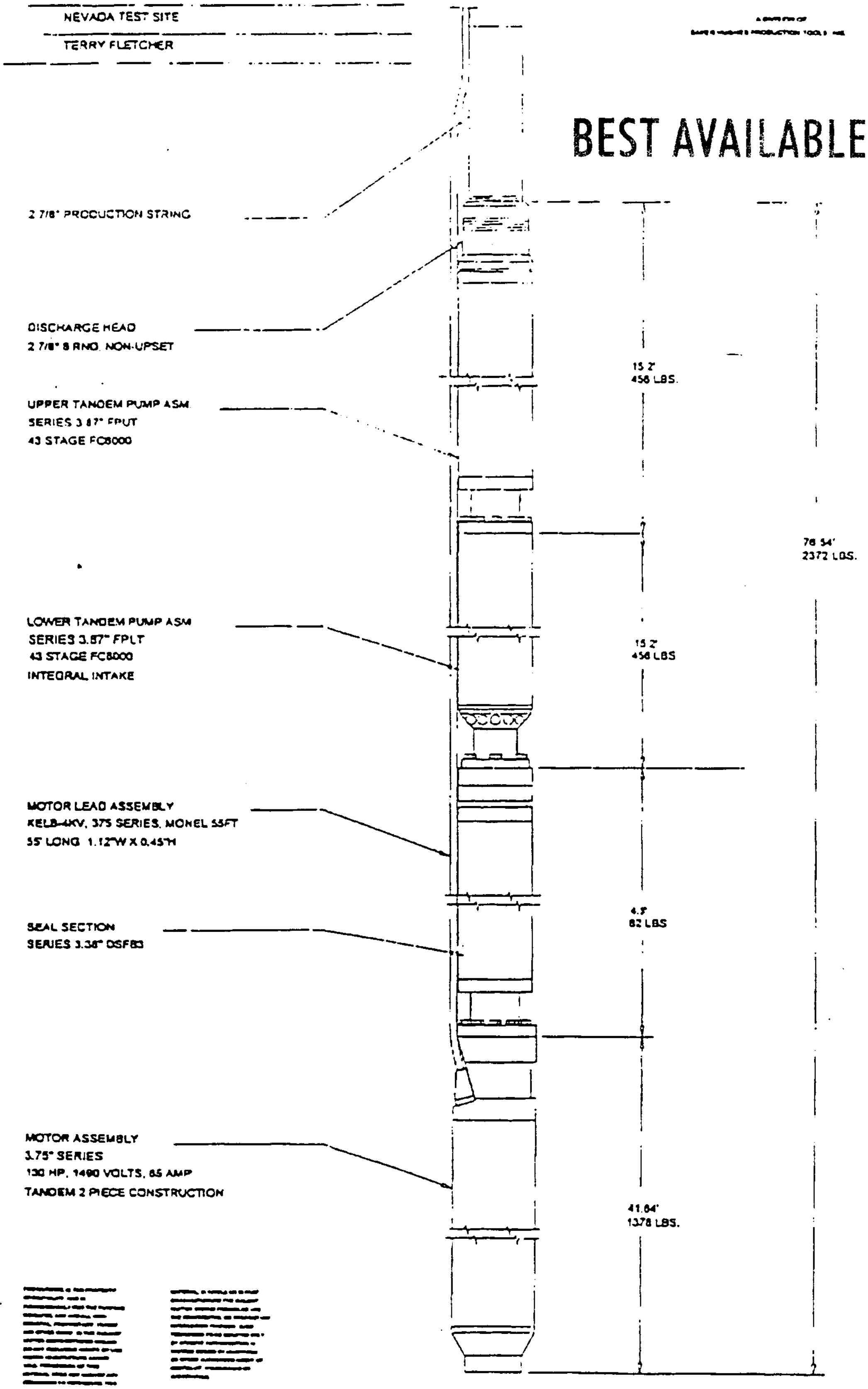
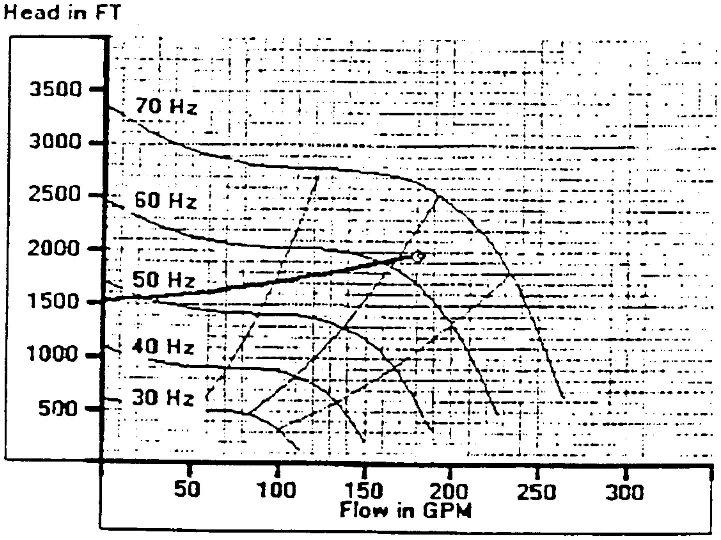
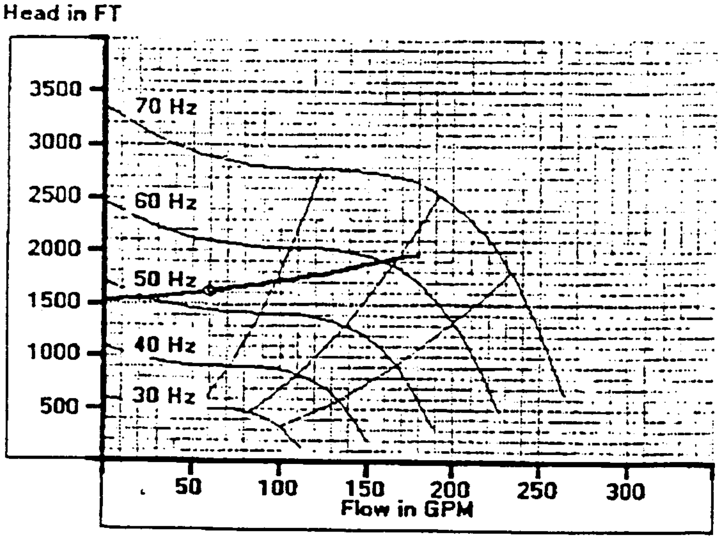


60-180 G P.M. OPERATION
AT 500 FT PUMP SETTING DEPTH (600 PSI tubing pressure)





Frequency	Hz	50	55	60	65
Flow at Stock Tank	GPM	23.67	93	150	181
Pump Intake Pressure	psi	365	327	295	279
Total Dynamic Head	FT	1555	1702	1873	1980
Fluid speed by motor	ft/sec	0.284	1.115	1.804	2.166
Motor Load	%	34.19	56.27	78.79	93
Motor Amps	A	40.6	43.52	54.28	61.07
Pump RPM	rpm	2940	3224	3469	3719
Surface KVA	kVA	73.76	89.54	134	171

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 ,980ft
Controller: VSD 2250-VT 260kVA/ 480V/ 313A

60-180 GPM @ 500' pump setting depth, 53.1-65 Hz. operation (600 PSI tubing)
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 64.9 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 = 500ft
Perfs V. Depth = 2500ft
Datum Static P = 154psi
Test Flow = 6171BPD
Test Pressure = 64.94psi
PI = 63.05BPD/psi
IPR Method = Composite IPR

Target:
Pump Setting Depth (vertical) = 1000ft
Desired Flow = 6171BPD
Gas Sep Eff = 90%
Tbg Surf Press = 600psi
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: Hagedom & Brown
Casing Flow: Hagedom & Brown

AutographPC V3.5 File:Bechtel180GPM500ft.apc

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

October 10,1999

Operating Parameters / Selection:

Design Point:

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

Frequency = 64.9 Hz
GOR into pump= 1.0 scf/STB
TDH = 1978 FT

Pump Selection:

	Intake	Discharge
Pressure	= 279 psi	1125 psi
Flowrate	= 6252 BPD	6237 BPD
Specific Gravity	= 0.987 rel-H2O	0.989 rel-H2O
Viscosity	= 0.516Cp	0.534Cp

60-180 GPM @ 500' pump setting depth, 53.1-65 Hz. operation (600 PSI tubing)

Pump Selected:
86 stages Type: FC6000 [400 Series]
Shaft HP at 64.9 Hz = 125 (33 %)
Required motor shaft HP at 60.0 Hz = 120

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 = 194°F
Chamber Cap Used (Top to Bot)=
19% 21%
Thrust bearing load =52 %
Shaft load = 70 %

Motor Selection:

Terminal Voltage =1574.8 V
Cable Current =60.9 A
Load acc to N.P. =92.3 %
Shaft Load =48.6 %

Fluid Speed =2.158ft/s
Internal Temp =161°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 = 980ft
MLE length = 20.0ft
Surface Temp = 75°F

Wellhead Voltage = 1609.4V
Wellhead kVA = 169.9kVA
Voltage Drop = 34.5V
Cond Temp (main) = 169°F
Temp Rating = 205°F

Surface Cable	Main Cable	MLE Cable
#2 CTTF 3kV 50.0ft	#4 CPNR 3kV 980ft	#6 MLE-KLHTLP 5kV 20.0ft
No comments		

Controller Selection:

Input kVA = 134.7kVA
System kW = 129.0kW
Max Ctrl Current = 204.9A
Power Cost/kWH = 0.05$/kW
Total Power Cost = $4644/month

Voltage Input = 480V
Max Well Head Volts = 1609V
Max Frequency = 64.9Hz (7.40V/Hz)
Start Frequency = 10.0Hz
Step-up Trafo = 3.361 ratio
Selected: VSD 2250-V 260kVA/ 480V/ 313A

NEMA 3 design (outdoor use)

— End of Report —

AutographPC V3.5 File:Bechtel180GPM500ft.apc

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

October 10,1999

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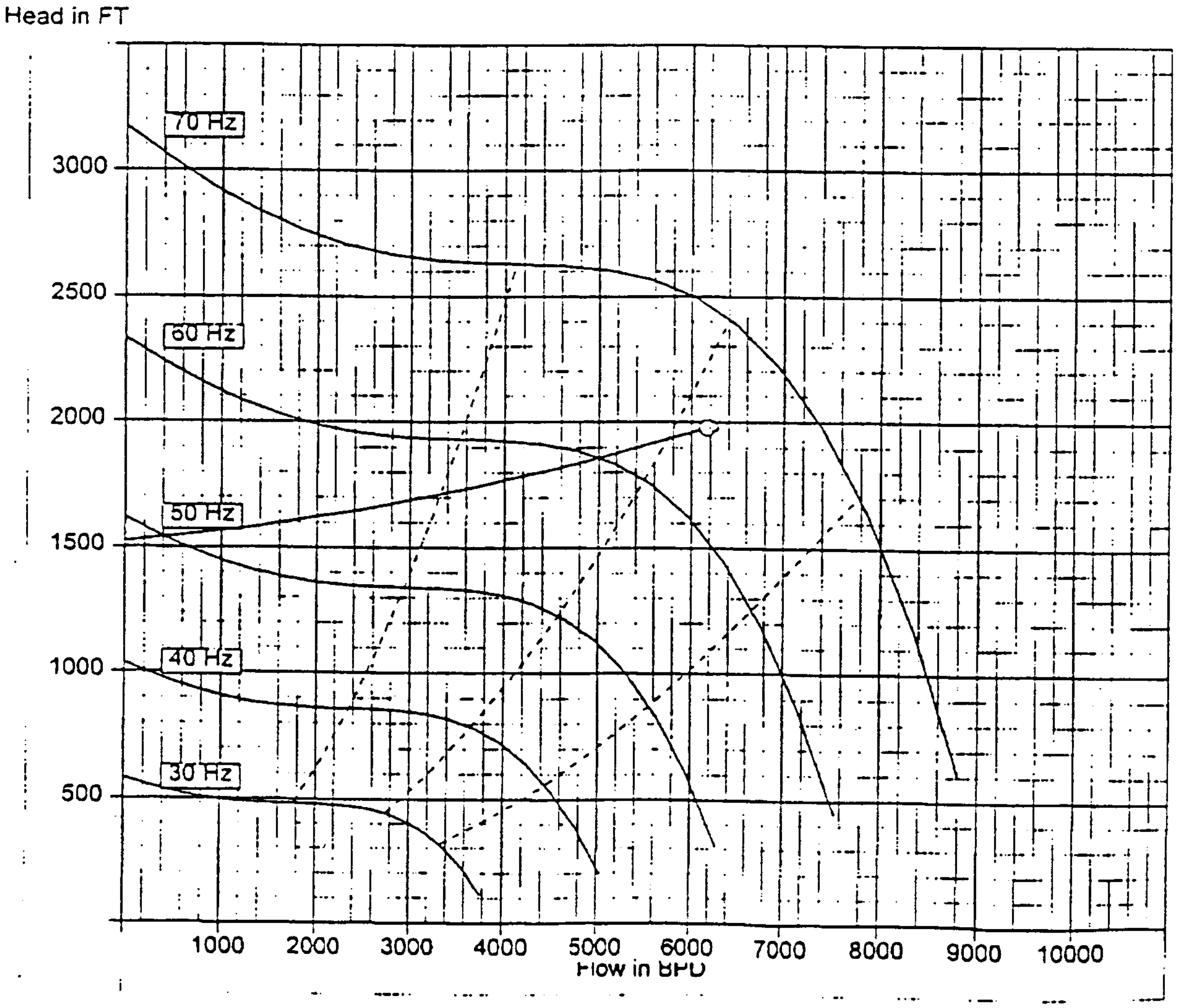
Motor: DMF 130 HP 1490V 65 A [375Series]
Cable: #4 CPNR 3kV ,980ft
Controller: VSD 2250-VT 260kVA/ 480V/ 313A

60-180 GPM @ 500' pump setting depth, 53.1-65 Hz. operation (600 PSI tubing)
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 64.9 Hz

86-FC6000 Series: 400



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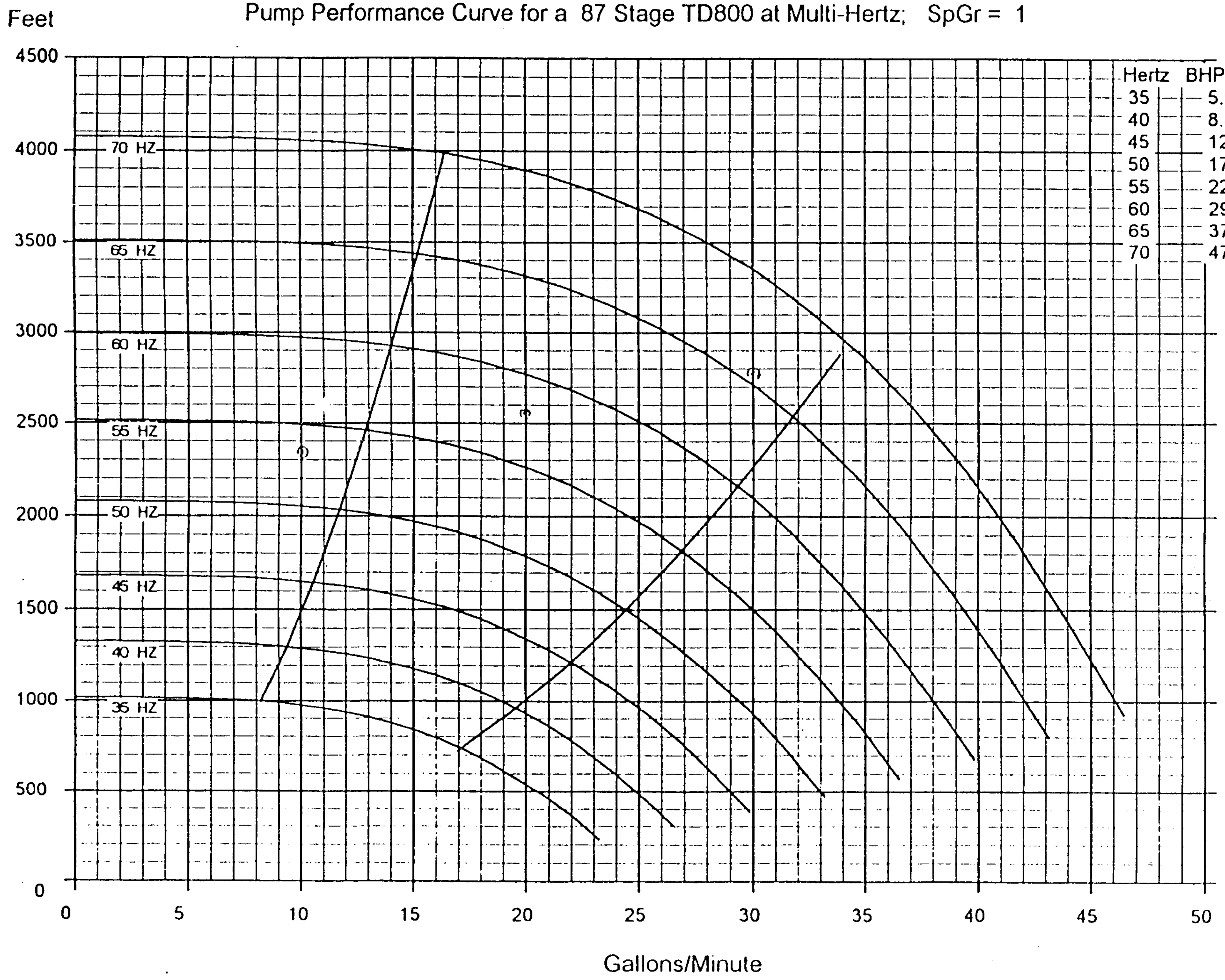
Dedicated Sampling Pump

Plot Program by Electric Submersible Pumps,Inc

4.00 ESP Pumps

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



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

Att-9

Post-it® Fax Note 7671

Date [illegible]/16/00	# of pages ▶ 16		
To D. SCHWICHTENBERG		From K. ORTEGO	
Co./Dept.		Co.	
Phone #		Phone #	
Fax #		Fax #	

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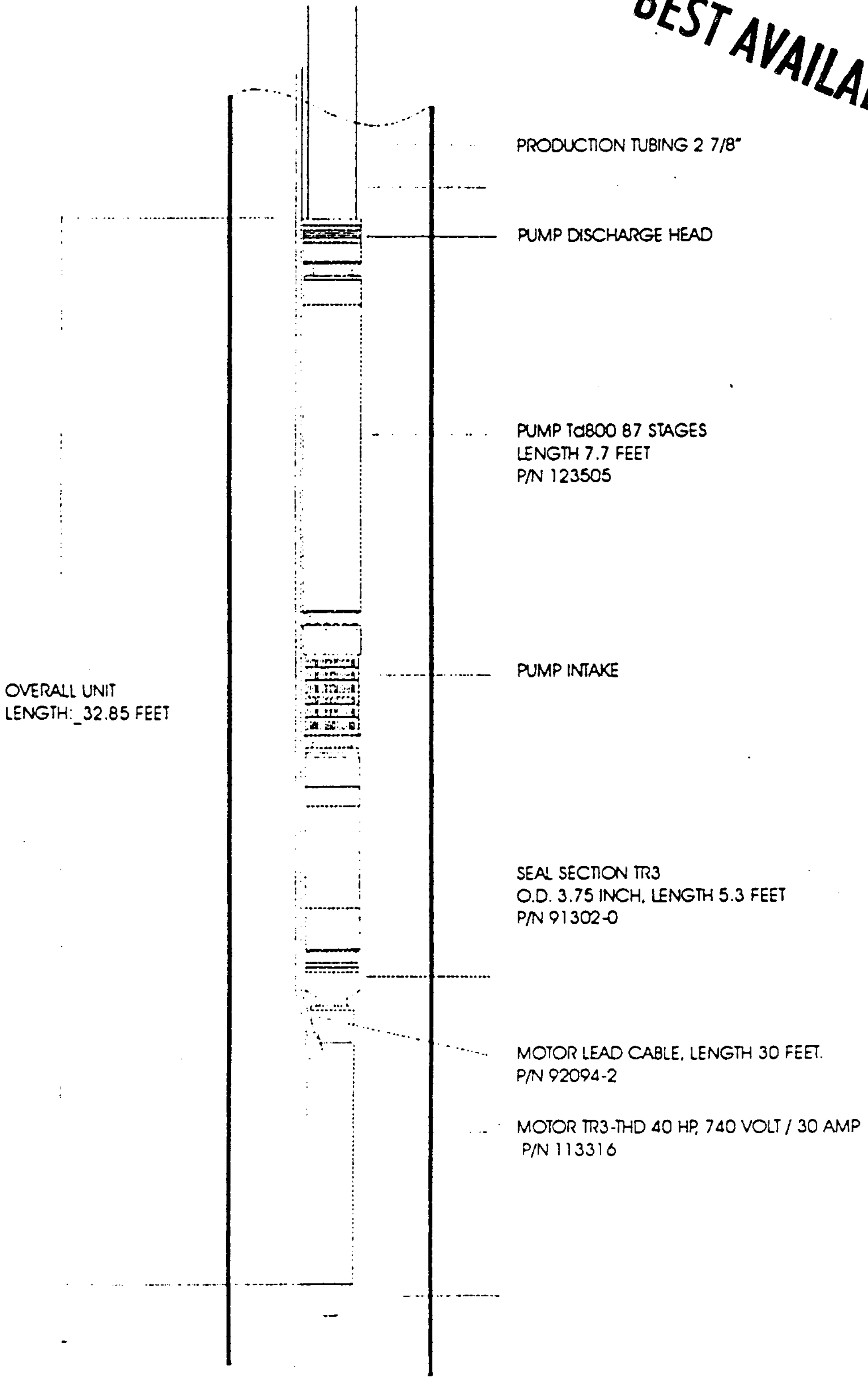
ESP

Bechtel Nevada
Las Vegas Nevada
Item Number 0001

WOOD GROUP

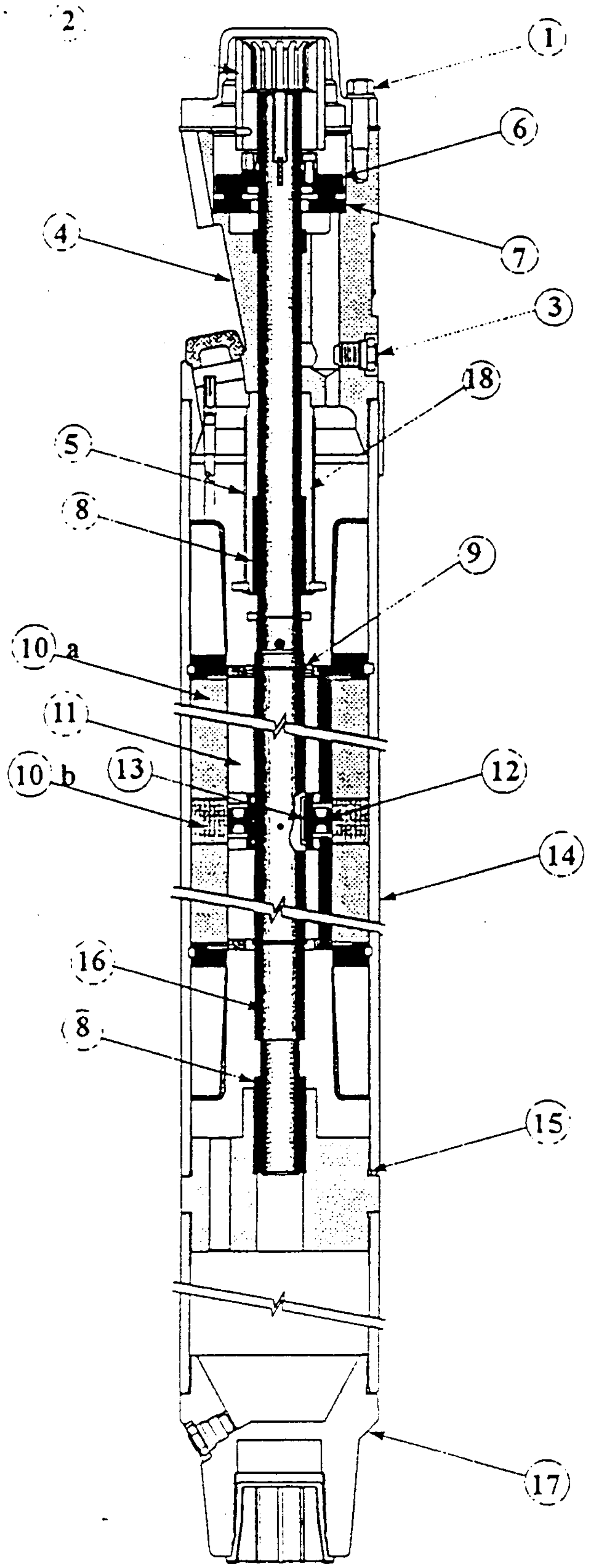


NOT TO SCALE

ESP

WG WOOD GROUP

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

QUALITY RUNS DEEP AT ESP

materials\mtr,tr-sgl.cdr

New Release
15 May 1997

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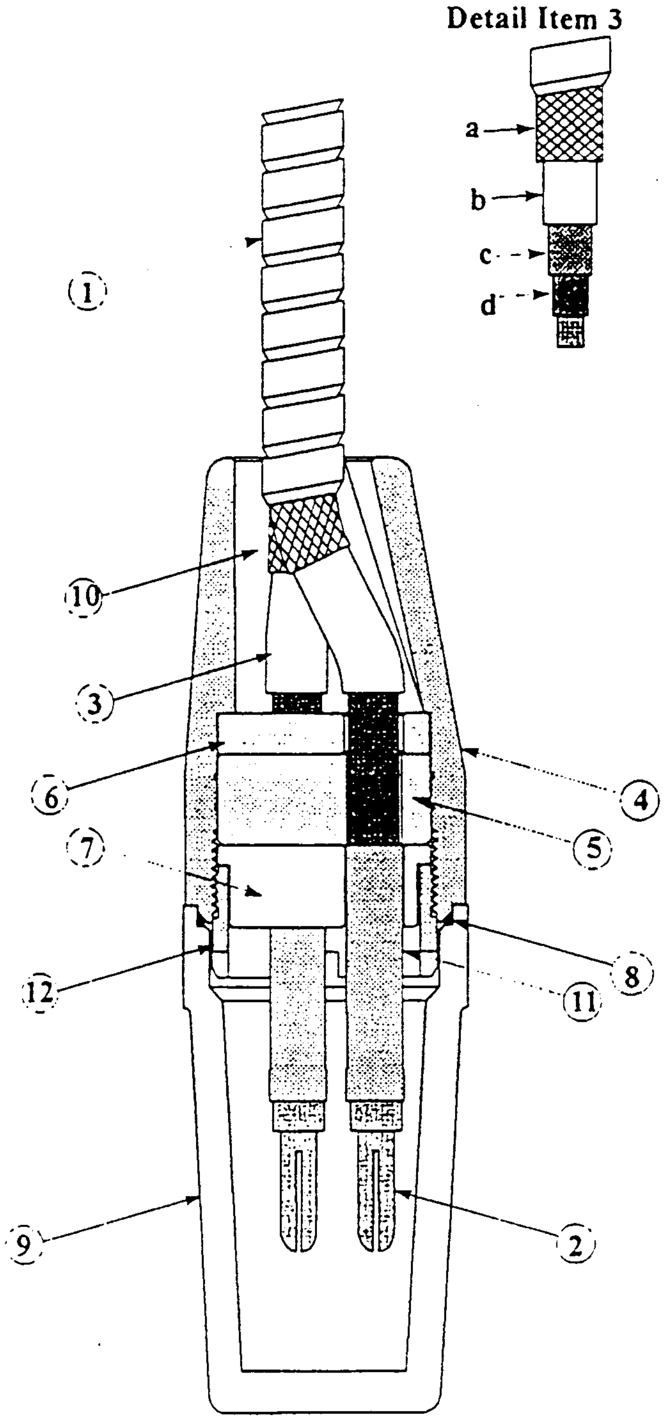
MLC, Tr3 KEOTB GALV.



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

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QUALITY RUNS DEEP AT ESP

New Release
27 May 1997

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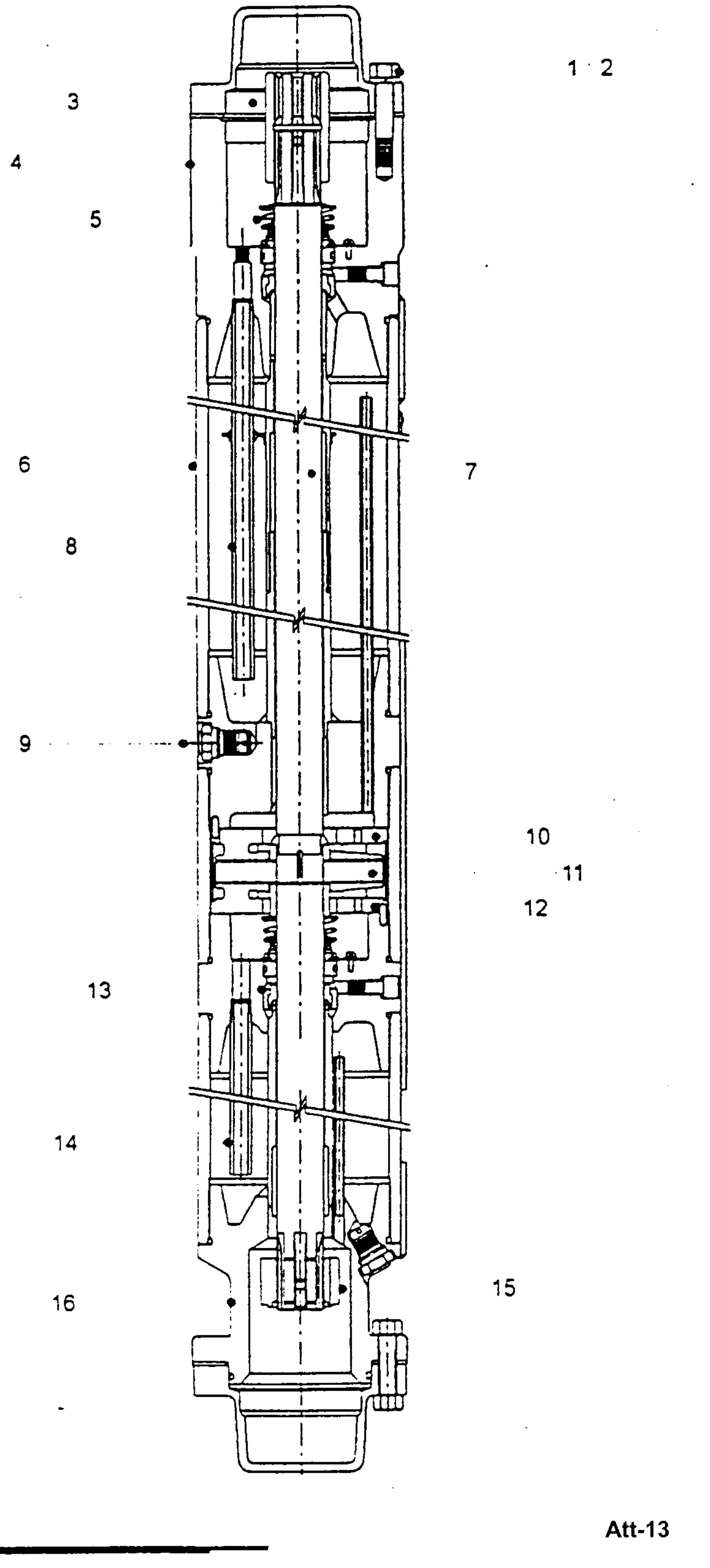
ESP

Standard Seal

WOOD GROUP



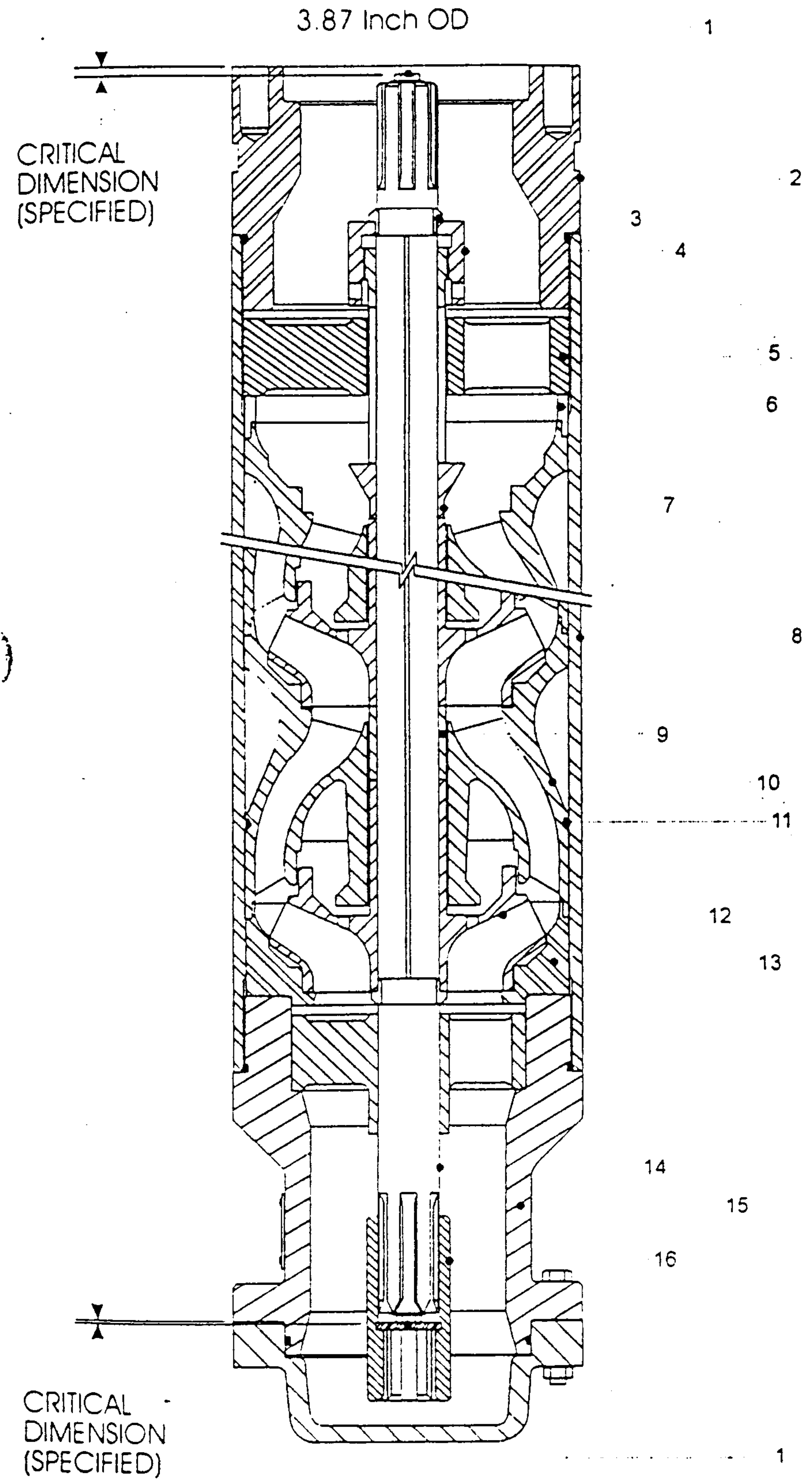
PARTS LIST

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

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

tr-std.cdr

Standard Pump (Floater Stage Design)



PARTS LIST

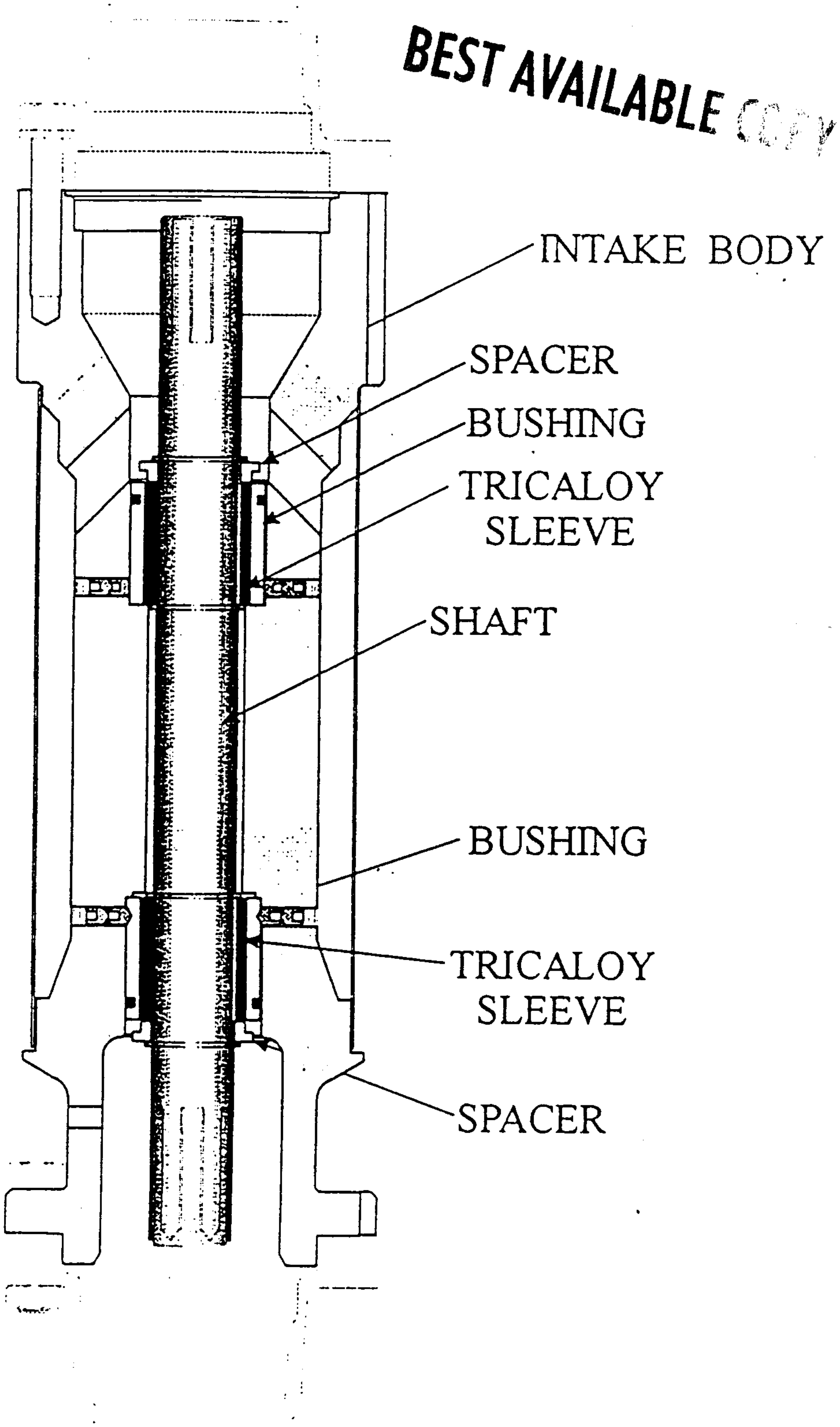
ITEM	DESCRIPTION
1	Adj. Nuts & Shims
2	Head, TDM
3	Two Piece Ring
4	Compression Nut, Sleeve & Set Screw
5	Compression Bearing
6	Compression Tube
7	Fluid Director
8	Housing
9	Spacer - Impeller
10	Diffuser
11	O'Ring, Diffuser
12	Impeller
13	Lower Diffuser
14	Shaft
15	Base, TDM S/A
16	Coupling

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

cmp-mix.cdr

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-4
(Page 1 of 5)

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTU	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
07/29/2000	10:00	38.4	741	7.24	3.85	9.74	0.305	60	1,183	Conduct a functionality test of the pump at various rates. The pump was turned off/on four separate occasions to surge the well. Pumping continued overnight at a rate of 175 gpm.
07/29/2000	11:10	38.3	739	7.29	7.49	19.44	0.320	180	8,584	
07/29/2000	12:00	38.4	750	7.42	5.15	2.77	0.343	180	17,618	
07/29/2000	13:40	38.2	743	7.39	8.22	11.34	0.365	150	22,806	
07/29/2000	14:20	38.4	734	7.41	9.04	2.88	0.391	180	30,120	
07/29/2000	15:30	38.6	742	7.48	5.82	38.90	0.375	180	32,910	
07/29/2000	16:30	38.3	740	7.40	4.03	6.12	0.393	180	43,423	
07/30/2000	9:30	38.5	977	7.56	4.98	7.92	0.281	60	197,992	Conduct a step-drawdown test at 60, 120, and 180 gpm. The pump was turned off/on four separate occasions throughout the day for surging. Pumped overnight at a rate of 175 gpm.
07/30/2000	10:30	38.1	963	7.59	5.06	8.42	0.413	120	203,318	
07/30/2000	11:30	38.1	965	7.56	5.51	0.44	0.434	150	213,174	
07/30/2000	13:30	38.4	797	7.61	5.04	1.83	0.466	180	221,088	
07/30/2000	14:35	37.6	771	7.54	4.31	1.41	0.508	60	232,344	
07/30/2000	15:30	37.9	794	7.60	5.39	0.43	0.617	180	234,988	
07/30/2000	17:10	38.5	791	7.59	6.51	0.46	0.539	175	247,221	
7/31/2000	7:45	38.3	784	7.45	6.42	0.30	1.020	175	401,321	Pump was turned off/on four separate occasions for surging. Pumping continued overnight at a rate of 175 gpm.
7/31/2000	9:20	37.6	782	7.52	5.61	0.62	0.792	180	406,036	
7/31/2000	11:15	37.9	794	7.65	5.42	0.79	1.560	180	415,977	
7/31/2000	13:15	38.3	778	7.08	5.99	0.74	0.741	180	426,469	
7/31/2000	15:15	38.3	765	7.29	6.07	0.73	0.771	180	436,895	
7/31/2000	17:20	38.3	768	7.30	5.46	0.50	0.710	175	448,473	

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

Date	Time hr:min.	Temperature °C	EC μmhos/cm	pH SU	DO mg/L	Turbidity NTU	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
08/01/2000	8:00	37.9	766	7.36	5.65	0.24	1.110	175	603,735	Conducted step-drawdown test at 60, 120, and 180 gpm. The pump was turned off/on four separate occasions throughout the day for surging. Pumped overnight at a rate of 175 gpm.
08/01/2000	12:30	38.1	765	7.25	5.21	0.41	1.740	180	630,236	
08/01/2000	14:45	38.8	765	7.20	3.96	4.50	1.570	60	636,607	
08/01/2000	15:15	38.1	768	7.46	5.05	2.25	1.780	120	639,249	
08/01/2000	15:45	38.4	736	7.56	5.37	0.25	1.650	180	643,748	
08/01/2000	16:15	38.1	765	7.42	6.27	0.21	2.970	150	648,742	
08/01/2000	16:45	38.4	767	7.45	5.91	0.20	1.570	90	652,444	
08/02/2000	7:35	37.3	774	7.39	5.20	0.48	1.140	175	800,733	Pump was turned off for logging.
08/02/2000	16:20	38.3	763	7.31	4.52	10.62	1.350	180	810,060	
08/03/2000	10:00	39.1	796	7.73	3.99	16.72	0.958	60	818,386	Pump was turned on for flow logging at 60 and 120 gpm. Pumped overnight at a rate of 120 gpm.
08/03/2000	12:00	39.0	798	7.69	3.17	1.17	1.110	60	825,639	
08/03/2000	14:00	39.6	796	7.70	2.35	3.63	0.847	60	832,906	
08/03/2000	16:00	38.5	796	7.71	3.35	0.76	0.932	120	843,191	
08/03/2000	17:30	38.7	797	7.70	3.20	0.37	0.841	120	854,120	
08/04/2000	8:20	38.7	775	7.72	3.26	0.20	1.020	120	962,102	Completed flow logging at 120 and 180 gpm. Pumped overnight at a rate of 120 gpm.
08/04/2000	10:00	38.7	722	7.76	3.53	0.51	0.935	180	976,476	
08/04/2000	12:00	38.9	773	7.73	3.22	0.15	1.100	180	998,141	
08/04/2000	14:00	39.1	774	7.73	3.24	0.63	0.883	180	1,019,873	
08/04/2000	16:00	38.6	775	7.72	3.44	5.02	1.100	180	1,032,050	
08/04/2000	18:00	38.3	772	7.74	3.36	1.76	0.962	180	1,053,642	
08/04/2000	19:22	34.6	776	7.83	5.94	1.24	1.000	180	1,069,054	

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-4
(Page 3 of 5)

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTU	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
08/10/2000	11:00	38.9	760	7.76	3.04	0.70	0.926	180	1,181,549	The constant-rate test began at a rate of 181 gpm.
08/10/2000	13:00	38.9	760	7.90	3.64	0.23	0.910	180	1,203,364	
08/10/2000	15:10	38.6	759	7.92	2.88	0.15	0.867	180	1,226,998	
08/10/2000	17:00	38.7	759	7.98	3.34	0.26	0.959	180	1,246,996	
08/11/2000	8:30	38.1	756	7.66	3.57	0.15	0.972	181	1,415,995	Continued with constant-rate test at 181 gpm.
08/11/2000	10:00	38.2	754	7.66	3.14	0.09	0.952	181	1,432,353	
08/11/2000	12:00	38.3	750	7.60	3.15	0.08	0.952	181	1,454,171	
08/11/2000	14:00	38.1	747	7.69	3.19	0.15	0.976	181	1,475,996	
08/11/2000	16:00	38.4	741	7.60	3.45	0.11	0.979	181	1,497,818	
08/11/2000	18:00	38.2	758	7.70	3.20	0.06	1.000	181	1,519,636	
08/12/2000	9:00	37.6	752	7.66	3.72	0.22	0.949	181	1,683,204	Continued with constant-rate test at 181 gpm.
08/12/2000	11:00	38.0	756	7.74	4.44	0.14	0.864	181	1,705,034	
08/12/2000	13:00	38.0	755	7.83	4.34	0.07	0.832	181	1,726,866	
08/12/2000	15:00	38.2	759	7.83	4.30	0.09	0.845	181	1,748,695	
08/12/2000	17:00	38.3	759	7.85	4.60	0.08	0.851	181	1,770,524	
08/13/2000	9:00	37.7	793	7.81	4.36	0.05	0.993	181	1,944,989	Continued with constant-rate test at 181 gpm.
08/13/2000	11:00	37.9	797	7.75	4.26	0.10	0.968	181	1,966,823	
08/13/2000	13:00	37.7	793	7.75	3.83	0.06	0.943	181	1,988,659	
08/13/2000	15:00	38.2	798	7.90	3.72	0.06	0.953	181	2,010,494	
08/13/2000	17:00	37.9	797	7.77	4.50	0.47	0.971	181	2,032,328	

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

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTU	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
08/14/2000	8:00	38.6	801	7.73	3.08	0.28	1.120	182	2,195,933	Continued with constant-rate test at 181 gpm.
08/14/2000	10:00	38.6	799	7.74	2.99	0.27	1.120	182	2,217,740	
08/14/2000	12:00	38.4	807	7.80	2.69	0.52	0.959	182	2,239,575	
08/14/2000	14:00	38.5	808	7.79	3.01	0.20	0.897	182	2,261,410	
08/14/2000	16:00	38.5	808	7.80	3.01	0.24	0.933	182	2,283,245	
08/14/2000	17:30	38.5	808	7.82	3.00	0.20	0.919	182	2,299,619	
08/16/2000	8:00	38.4	796	7.64	3.44	0.10	1.170	182	2,547,255	Continued with constant-rate test at 181 gpm until mechanical failure on the generator shut off the pump on 8/15/00. Test resumed at 181 gpm after repairs.
08/16/2000	10:00	38.4	797	7.70	3.53	0.11	1.440	182	2,569,062	
08/16/2000	12:00	38.7	794	7.81	3.52	0.09	0.962	182	2,589,624	
08/16/2000	14:00	38.7	801	7.82	3.54	0.30	0.992	182	2,612,359	
08/16/2000	16:00	38.7	800	7.82	3.38	0.10	1.000	182	2,633,283	
08/16/2000	17:30	38.4	796	7.80	3.50	0.12	0.937	182	2,649,653	
08/17/2000	9:00	38.5	793	7.86	3.80	0.12	0.991	182	2,818,715	Continued with constant-rate test at 182 gpm. ITLV, LLNL, DRI and UNLV-HRC collected groundwater characterization samples.
08/17/2000	11:00	38.6	792	7.86	3.39	0.25	0.804	182	2,841,444	
08/17/2000	13:30	38.6	791	7.85	4.53	0.17	0.742	182	2,867,815	
08/17/2000	15:00	38.8	793	7.84	3.84	0.35	0.888	182	2,884,181	
08/17/2000	17:00	38.5	784	7.79	3.80	0.24	0.818	182	2,906,919	
08/18/2000	8:50	37.9	781	7.80	5.00	0.12	0.884	182	3,078,701	Continued with constant-rate test at 182 gpm.
08/18/2000	11:00	38.7	783	7.78	4.77	0.22	0.952	182	3,102,061	
08/18/2000	13:00	38.5	763	7.85	4.93	0.44	1.080	182	3,120,546	
08/18/2000	15:00	38.5	782	7.81	4.79	0.26	0.981	182	3,140,645	
08/18/2000	17:00	38.6	784	7.80	4.80	0.15	1.010	182	3,161,084	

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

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTU	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
08/19/2000	9:00	38.9	785	7.54	5.19	0.24	0.926	181	3,334,914	Pump was turned off, test complete.

EC - Electrical conductivity
SU - Standard units
hr:min - Hour: minute
mg/L - Milligrams per liter
DO - Dissolved oxygen
in. - Inch
NTU - Nephelometric turbidity units
gpm - Gallons per minute
µmhos/cm - Micro mhos per centimeter
LLNL - Lawrence Livermore National Laboratory
GW - Groundwater
ITLV - IT Corporation, Las Vegas Office
LANL - Los Alamos National Laboratory
DRI - Desert Research Institute
UNLV-HRC - University of Nevada at Las Vegas, Harry Reid Center

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-4
(Page 1 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-4-080400-2		Results of Wellhead Composite Sample #EC-4-081700-1	
Metals (mg/L)						
			Total	**Dissolved**	**Total**	**Dissolved**
Aluminum	0.2	Paragon	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2
Arsenic	0.01	Paragon	U 0.01	B 0.0039	B 0.0055	B 0.0048
Barium	0.1	Paragon	UJ 0.0028	UJ 0.0016	UJ 0.00056	UJ 0.00051
Cadmium	0.005	Paragon	UJ 0.005	UJ 0.005	U 0.005	U 0.005
Calcium	1	Paragon	26	26	27	27
Chromium	0.01	Paragon	B 0.0036	UJ 0.0011	UJ 0.00093	UJ 0.0013
Iron	0.1	Paragon	U 0.2	U 0.067	U 0.13	U 0.12
Lead	0.003	Paragon	UJ 0.003	UJ 0.003	U 0.003	U 0.003
Lithium	0.01	Paragon	0.11	0.11	0.12	0.11
Magnesium	1	Paragon	3.9	3.9	4.1	4.1
Manganese	0.01	Paragon	B 0.0096	B 0.0039	B 0.0042	B 0.0043
Potassium	1	Paragon	11	11	11	11
Selenium	0.005	Paragon	U 0.005	U 0.005	U 0.005	U 0.005
Silicon	0.05	Paragon	33	33	34	33
Silver	0.01	Paragon	U 0.01	U 0.01	UJ 0.01	U 0.01
Sodium	1	Paragon	120	120	120	120
Strontium	0.01	Paragon	0.14	0.14	0.14	0.14
Uranium	0.2	Paragon	U 0.2	U 0.2	U 0.2	U 0.2
Mercury	0.0002	Paragon	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002
Inorganics (mg/L) - unless otherwise noted						
Chloride	2	Paragon	86		84	

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-4
(Page 2 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-4-080400-2	Results of Wellhead Composite Sample #EC-4-081700-1
Inorganics (mg/L) - unless otherwise noted				
Fluoride	0.1	Paragon	3.1	3.1
Bromide	0.2	Paragon	0.43	0.39
Sulfate	10	Paragon	110	120
pH (pH units)	0.1	Paragon	J 7.5	J 7.6
Total Dissolved Solids	20	Paragon	510	500
Electrical Conductivity (micromhos/cm)	1	Paragon	635	790
Carbonate as CaCO3	10, 50	Paragon	U 10	U 50
Bicarbonate as CaCO3	10, 50	Paragon	120	150
Organics (mg/L)				
Total Organic Carbon	1	Paragon	3.1	U 1
Redox Parameters (mg/L)				
Total Sulfide	5	Paragon	UJ 5	U 5
Age and Migration Parameters (pCi/L) - unless otherwise noted				
Carbon-13/12 (per mil)	Not Provided	DRI	N/A	-2.7 +/- 0.2
Carbon-14, Inorganic (pmc)	Not Provided	LLNL	N/A	5.0 +/- 0.1
Carbon-14, Inorganic age (years)*	Not Provided	LLNL	N/A	24,700
Chlorine-36	Not Provided	LLNL	N/A	1.77E-03
Chlorine-36/Chlorine (ratio)	Not Provided	LLNL	N/A	5.61E-13
Helium-4 (atoms/mL)	Not Provided	LLNL	N/A	1.30E+13
Helium-3/4, measured value (ratio)	Not Provided	LLNL	N/A	1.41E-06
Helium-3/4, relative to air (ratio)	Not Provided	LLNL	N/A	1.02
Oxygen-18/16 (per mil)	Not Provided	DRI	N/A	-14.7 +/- 0.2
Strontium-87/86 (ratio)	Not Provided	LLNL	N/A	0.709984 +/- 0.000038
Uranium-234/238 (ratio)	Not Provided	LLNL	N/A	0.000159

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-4
(Page 3 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-4-080400-2	Results of Wellhead Composite Sample #EC-4-081700-1
Age and Migration Parameters (pCi/L) - unless otherwise noted				
Hydrogen-2/1 (per mil)	Not Provided	DRI	N/A	-112 +/- 1.0
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' or 'R'	All nuclides reported with a 'U'
Tritium	270	Paragon	U -30 +/- 160	U 90 +/- 160
Gross Alpha	3.5, 2.9	Paragon	U 5.2 +/- 2.6	U 3.1 +/- 1.9
Gross Beta	3.7, 3.4	Paragon	9.6 +/- 2.8	9.5 +/- 2.5
Radiological Indicator Parameters-Level II (pCi/L)				
Carbon-14	300, 310	Paragon	U 110 +/- 180	UJ 210 +/- 190
Strontium-90	0.67	Paragon	N/A	U -0.16 +/- 0.37
Plutonium-238	0.037, 0.033	Paragon	U -0.001 +/- 0.013	U 0.004 +/- 0.017
Plutonium-239	0.013, 0.039	Paragon	U 0 +/- 0.013	U 0.002 +/- 0.017
Iodine-129	1.6	Paragon	N/A	U 0.18 +/- 0.92
Technetium-99	2	Paragon	N/A	U 0.0 +/- 1.2

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
R = The data are unusable. The analyte may or may not be present.
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-4
(Page 1 of 2)

Analyte	Laboratory	Results of Discrete Bailer Sample #EC-4-080400-2	Results of Wellhead Composite Sample #EC-4-081700-1
Colloid Particle Size Range (in nanometer)		**Colloid Concentration (particles/mL)**	**Colloid Concentration (particles/mL)**
50 - 60	LANL	4.314E+06	3.129E+05
60 - 70	LANL	5.117E+06	2.980E+05
70 - 80	LANL	3.512E+06	2.111E+05
80 - 90	LANL	3.913E+06	1.341E+05
90 - 100	LANL	2.709E+06	1.043E+05
100 - 110	LANL	1.957E+06	8.692E+04
110 - 120	LANL	2.207E+06	4.719E+04
120 - 130	LANL	1.906E+06	4.470E+04
130 - 140	LANL	1.054E+06	2.980E+04
140 - 150	LANL	9.532E+05	2.483E+04
150 - 160	LANL	6.522E+05	2.483E+04
160 - 170	LANL	6.522E+05	9.930E+03
170 - 180	LANL	7.024E+05	1.987E+04
180 - 190	LANL	3.512E+05	1.738E+04
190 - 200	LANL	3.010E+05	1.490E+04
200 - 220	LANL	5.016E+05	1.242E+04
220 - 240	LANL	3.134E+05	6.460E+03
240 - 260	LANL	1.842E+05	3.050E+03
260 - 280	LANL	1.220E+05	1.440E+03
280 - 300	LANL	6.700E+04	9.000E+02
300 - 400	LANL	1.998E+05	2.450E+03
400 - 500	LANL	4.210E+04	3.600E+02
500 - 600	LANL	6.820E+04	7.200E+02
600 - 800	LANL	1.664E+05	1.020E+03

Table ATT.3-2
Colloid Analyses for Well ER-EC-4
(Page 2 of 2)

Analyte	Laboratory	Results of Discrete Bailer Sample #EC-4-080400-2	Results of Wellhead Composite Sample #EC-4-081700-1
Colloid Particle Size Range (in nanometer)		**Colloid Concentration (particles/mL)**	**Colloid Concentration (particles/mL)**
800 - 1,000	LANL	9.220E+04	3.600E+02
>1,000	LANL	2.812E+05	7.800E+02
Total Concentration, Particle Size Range, 50-1,000 nm	LANL	3.23E+07	1.41E+06

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-4-080400-2
Ag, Dissolved	0.16	UNLV-HRC	<	0.16
Al, Dissolved	0.17	UNLV-HRC		7.56
As, Dissolved	0.02	UNLV-HRC		4.68
Au, Dissolved	0.030	UNLV-HRC	<	0.030
Ba, Dissolved	0.006	UNLV-HRC		2.43
Be, Dissolved	0.018	UNLV-HRC		0.024
Bi, Dissolved	0.004	UNLV-HRC		0.017
Cd, Dissolved	0.008	UNLV-HRC		0.031
Co, Dissolved	0.006	UNLV-HRC		0.066
Cr, Dissolved	0.006	UNLV-HRC		1.53
Cs, Dissolved	0.003	UNLV-HRC		0.761
Cu, Dissolved	0.011	UNLV-HRC		0.323
Ga, Dissolved	6.3	UNLV-HRC		24
Ge, Dissolved	0.009	UNLV-HRC		1.21
Hf, Dissolved	0.015	UNLV-HRC	<	0.015
In, Dissolved	0.004	UNLV-HRC	<	0.004
Ir, Dissolved	4.5	UNLV-HRC	<	4.5
Li, Dissolved	0.015	UNLV-HRC		114
Mn, Dissolved	0.01	UNLV-HRC		3.82
Mo, Dissolved	0.01	UNLV-HRC		8.01
Nb, Dissolved	5.1	UNLV-HRC	<	5.1
Ni, Dissolved	0.006	UNLV-HRC		0.686
Pb, Dissolved	0.04	UNLV-HRC	<	0.04
Pd, Dissolved	0.021	UNLV-HRC	<	0.021
Pt, Dissolved	0.006	UNLV-HRC		0.032
Rb, Dissolved	0.003	UNLV-HRC		35.3
Re, Dissolved	0.004	UNLV-HRC	<	0.004
Rh, Dissolved	0.004	UNLV-HRC	<	0.004
Ru, Dissolved	0.005	UNLV-HRC	<	0.005
Sb, Dissolved	0.004	UNLV-HRC		0.211
Se, Dissolved	0.12	UNLV-HRC		1.14

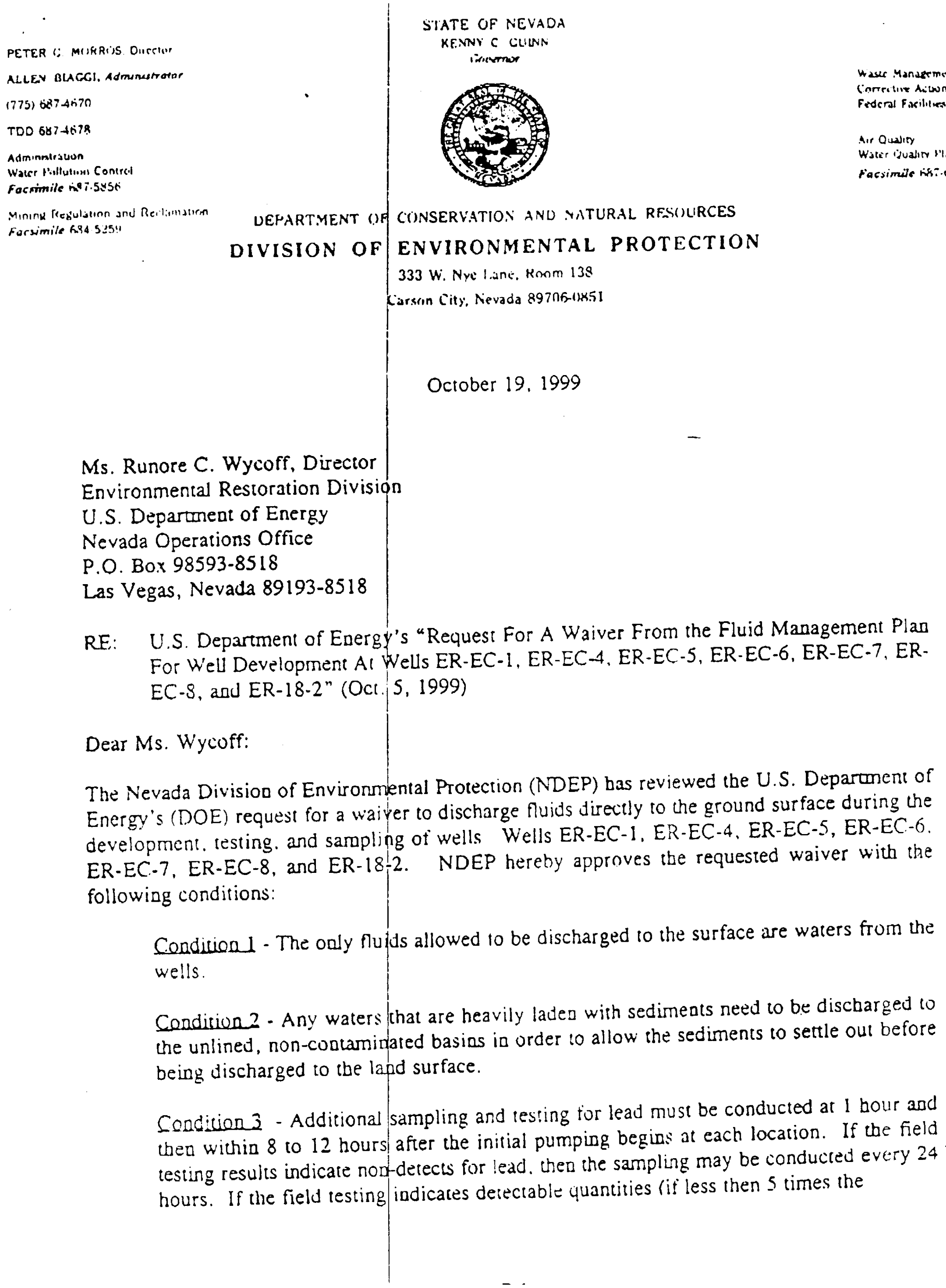
Table ATT.3-3
Trace Element Results for Groundwater Characterization Samples
(Page 2 of 2)

Analyte	**Detection Limit**	**Laboratory**	**Qualifier**	**Results of Discrete Bailer Sample #EC-4-080400-2**
Sn, Dissolved	0.004	UNLV-HRC		0.015
Sr, Dissolved	0.01	UNLV-HRC		145
Ta, Dissolved	0.009	UNLV-HRC	<	0.009
Te, Dissolved	0.008	UNLV-HRC		0.008
Ti, Dissolved	0.009	UNLV-HRC		0.810
Tl, Dissolved	0.009	UNLV-HRC		0.547
U, Dissolved	0.005	UNLV-HRC		3.22
V, Dissolved	0.009	UNLV-HRC		3.50
W, Dissolved	0.004	UNLV-HRC		1.18
Zn, Dissolved	0.2	UNLV-HRC		27.3
Zr, Dissolved	0.018	UNLV-HRC		0.083

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



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ALLEN BIAGGI, *Administrator*
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Facsimile 684-5259

STATE OF NEVADA
KENNY C. GUINN
Governor

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Corrective Actions
Federal Facilities

Air Quality
Water Quality Planning
Facsimile 687-6396

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

October 19, 1999

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

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

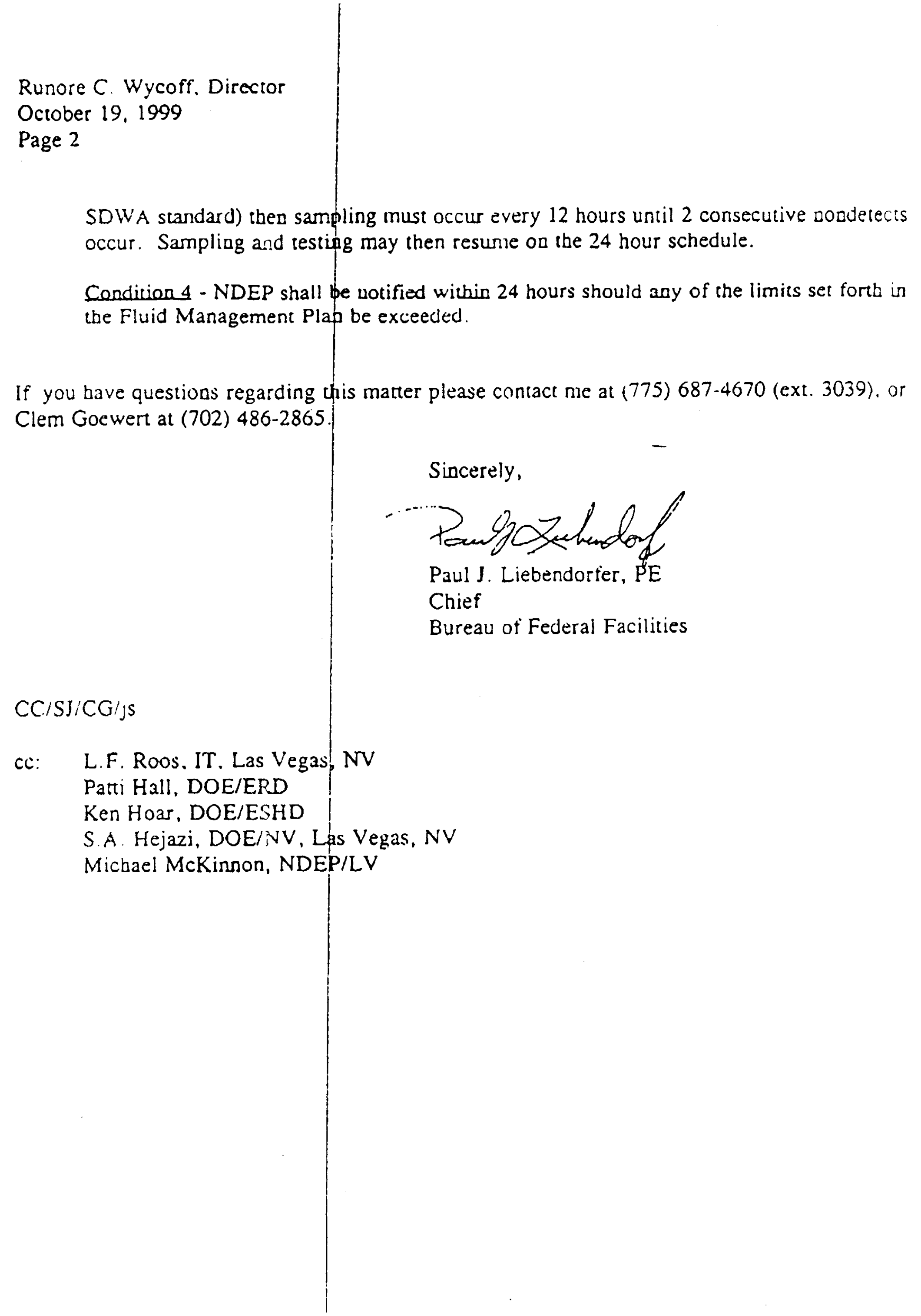
Dear Ms. Wycoff:

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

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

<u>Condition 2</u> - 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.

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



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

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

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

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

Sincerely,

Paul J. Liebendorfer, PE
Chief
Bureau of Federal Facilities

CC/SJ/CG/js

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

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-4 Development and Testing Data Report*:**

This README file identifies the included data files.

Included with this report are 27 files containing data that were collected electronically during the development and testing program for Well ER-EC-4. 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) EC4_Bridge Plug_Lower.xls
Bridge plug monitoring data for the lower interval.

2) EC4_Bridge Plug_Upper.xls
Bridge plug monitoring data for the upper middle interval.

3) EC4_Bridge Plug_ITPXD.xls
Monitoring data for the upper interval during the bridge plug measurements.

4) EC4_Aqtest_WD.xls
Complete monitoring record of development.

5) EC4_Aqtest_HT.xls
Complete monitoring record of testing.

6) EC4_Predev_Monitoring.xls
Pre-development monitoring record.

7) DRIFileInfoGeneric.txt
DRI log head information.

8) ec4mov01, ec4mov02, ec4mov03, ec4mov04, ec4mov05, ec4mov06, ec4mov07, ec4mov08, ec4mov09, and ec4mov10.txt - DRI flow logs.

9) ec4sta01, ec4sta02, ec4sta03, ec4sta04, ec4sta05, ec4sta06, ec4sta07, ec4sta08, and ec4sta09
DRI static impeller tool flow measurements.

10) Hydrolabcalc.xls
Hydrolab water quality data.

Distribution

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