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Analysis of Well ER-EC-2a Testing, Western Pahute Mesa-Oasis Valley FY 2000 Testing Program

Revision No.: 0

September 2002

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IT CORPORATION
P.O. Box 93838
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 Pump Systems
°F	Degrees Fahrenheit
FI	Field Instruction
FMP	Fluid Management Plan
ft	Foot (feet)
fpm	Feet per minute
FS	Full scale
FY	Fiscal year
gals	Gallons
gpm	Gallons per minute
He	Helium
HSU	Hydrostratigraphic unit
H_z	Hertz
in.	Inch(es)
ITLV	IT Corporation, Las Vegas Office

List of Acronyms and Abbreviations (continued)

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
O	Oxygen
od	Outside diameter
pCi/L	Picocuries per liter
pmc	Percent modern carbon
psi	Pounds per square inch
psig	Pounds per square inch gauge
PXD	Pressure transducer
R	Ratio
R_a	Natural atmospheric ratio
REOP	Real Estate/Operations Permit
RCRA	*Resource Conservation and Recovery Act*
rev/sec	Revolutions per second
SQP	Standard Quality Practice
SVOC	Semivolatile organic compounds
T	Transmissivity
TDH	Total dynamic head
UGTA	Underground Test Area

List of Acronyms and Abbreviations (continued)

UNLV-HRC	University of Nevada, Las Vegas - Harry Reid Center
V	Volt
VOC	Volatile organic compounds
VSD	Variable speed drive
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-2a 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-2a Data Report for Development and Hydraulic Testing*.

1.1 Well ER-EC-2a

Well ER-EC-2a is one of eight groundwater wells that were tested during FY 2000 investigations for the Western Pahute Mesa Corrective Action Unit (CAU). This work was done under the auspices of the U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Operations Office (NNSA/NV), Underground Test Area (UGTA) Project. Figure 1-1 shows the location of the WPM-OV wells. Drilling and well construction information has been documented in the *Completion Report for Well ER-EC-2a* (NNSA/NV, 2002).

Hydraulic testing and groundwater sampling were conducted at Well ER-EC-2a to provide information on the hydraulic characteristics of hydrostratigraphic units (HSUs) and the chemistry of local groundwater. Well ER-EC-2a 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 accesses 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 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 radionuclides. The primary objective for this analysis was to evaluate all of the data collected and 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 evaluate this well for use in future monitoring.

General goals for the analysis were to 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-2a for monitoring are discussed.

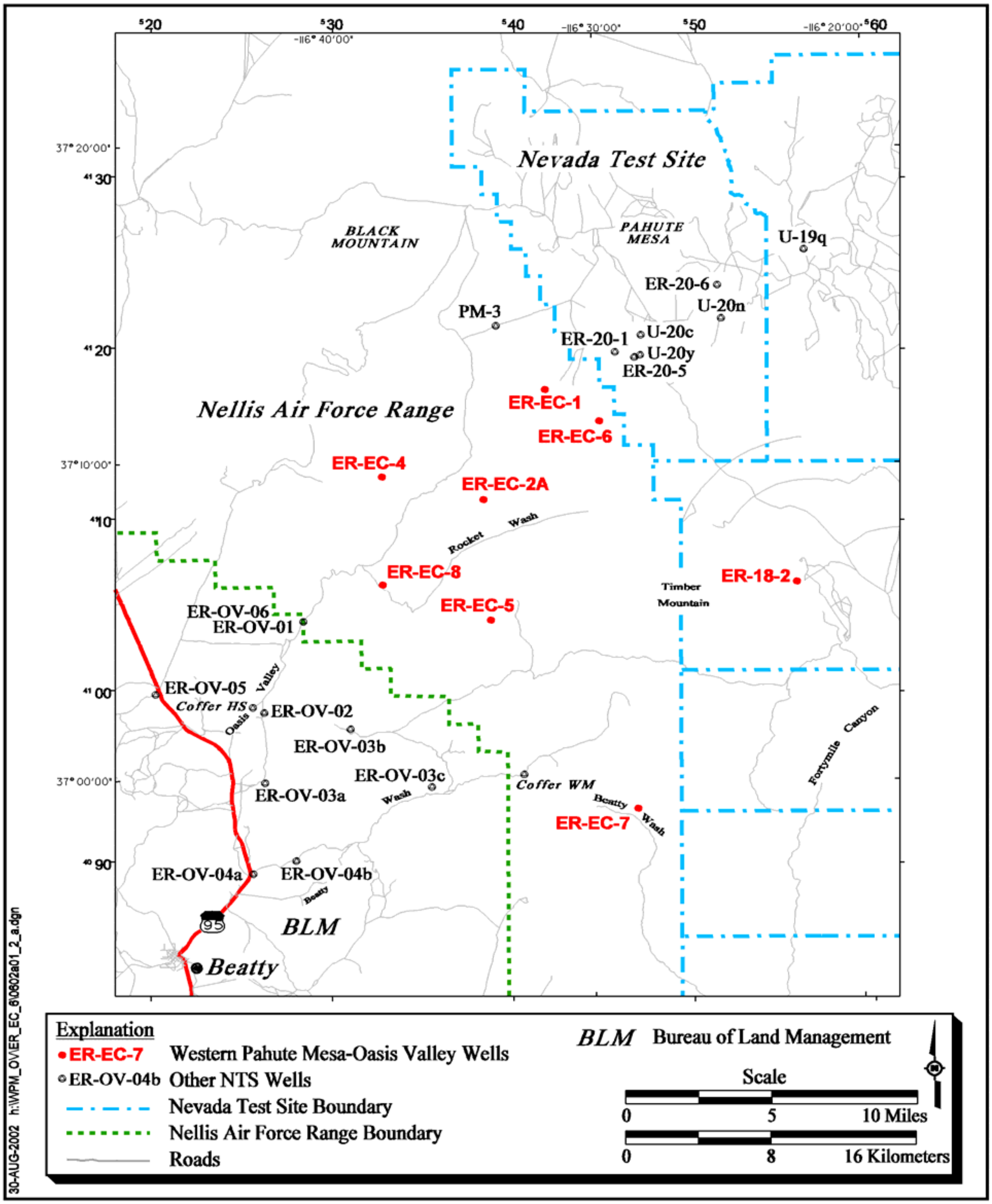

Figure 1-1
Location Map for WPM-OV ER Wells

2.0 Equilibrium Well Hydraulics

This section discusses many aspects of well hydraulics for Well ER-EC-2a 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 presented in that report.

The well is constructed with three separate completion intervals. The intervals are each composed of continuous joints of slotted casing. 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 of the completion interval. Following testing, bridge plugs were installed between the completion intervals to prevent crossflow due to the natural head gradient.

2.1 Composite Equilibrium Water Level

Table A.2-2 in Appendix A presents the water level measurements that were collected during the testing program. Table 2-1 repeats those measurements and presents several additional measurements made after the testing program. The pattern of the measurements indicates the well was still equilibrating for a long time after drilling. As presented in Section A.3.1 of Appendix A, the earlier water level measurements indicated the head in the formation had been drawn down a substantial distance by production that occurred during drilling. It is not clear whether the well was even in equilibrium on June 28, 2000, when development was started, although it was probably very close to equilibrium. Based on these water level measurements, it appears that the best estimate of the equilibrium composite depth-to-water for this well is between 747 and 748 feet (ft) below ground surface (bgs). The variation in the composite water level measurements can be attributed to residual drawdown from recent pumping. This well appears to take a fairly long time to recover from drawdown. There is also some indication that the water level may vary somewhat during the course of a year.

After testing, additional water level monitoring was conducted following the installation of bridge plugs and the permanent sampling pump since the well had not recovered completely at the time they were installed. Water level measurements were made at the installation and removal of the pressure transducer (PXD) used for monitoring the remaining recovery. However, these water levels represent only the upper completion interval since a bridge plug isolated the upper interval from the lower part of the well.

Table 2-1
Water Level Measurements

Date	Relationship to Testing Program	Applicability	Depth-to-Water feet	Barometric Pressure (mbar)
2/18/2000	Prior to setting bridge plugs	Composite of completion intervals	760.93	855.51
2/18/2000	After lower bridge plug set	Upper two completion intervals	761.24	854.32
2/18/2000	After upper bridge plug set	Upper completion interval	758.11	854.07
2/23/2000	End of bridge-plug monitoring period	Upper completion interval	754.59	846.36
3/14/2000	PXD install for long-term monitoring	Composite of completion intervals	750.11	853.57
4/14/2000	PXD removal after long-term monitoring	Composite of completion intervals	747.92	843.13
6/28/2000	PXD install prior to development	Composite of completion intervals	747.65	849.68
7/20/2000	PXD install prior to constant-rate test	Composite of completion intervals	749.42	852.47
8/7/2000	End of recovery monitoring	Composite of completion intervals	750.90	850.82
8/16/2000	PXD install for posttest monitoring	Upper completion interval	757.77	855.56
11/10/2000	PXD removal after posttest monitoring	Upper completion interval	757.76	--

mbar = Millibar

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 yielded an efficiency of 80 percent. Figure A.3-9 in Appendix A shows the predevelopment PXD record corrected for barometric variation. This corrected record exhibits semi-diurnal earth tide responses, but does not appear to show the periodic variation in magnitude (14-day cycle) that was evident in other well records.

2.3 Completion Interval Heads

The interpretation of the bridge plug head measurements presented in the testing data report (Section A.3.2.2) has been reconsidered. As mentioned in Section 2.2, at the time of the bridge plug head measurements all three completion intervals appear to have been equilibrating from the drawdown induced by water production during drilling. For the lower two intervals, the head initially declined before starting to rise. This behavior is interpreted as the adjustment of the isolated interval pressures from the composite head to the interval-specific recovery curves, which were apparently at lower heads than the upper interval. The rise in pressure in the later time of monitoring is now attributed to the head recovery for the lower intervals rather than leakage from an upper interval. For the lower two completion intervals, the low point in the pressure decline before pressure started to rise is not thought to be representative of head for the interval. It is considered to represent the transition from the composite head to the recovery head of the interval at that time. The pattern of pressure changes in the lower two intervals can be seen in Figure A.3-5 and Figure A.3-7 of Appendix A.

Table 2-1 contains the available measurements for the composite and individual completion intervals. These measurements were made during the course of nine months, and are often associated with other testing activities for the well. Figure 2-1 shows these water levels graphed against the date of measurement and labeled with the completion interval that they represent and the activity during which they were measured. The reported heads may include some variation resulting from trends in head, barometric changes, and earth tides. The e-tape measurements are generally repeatable within about 0.10 ft per 1,000 ft. The most representative composite head appears to be the measurement made on June 28, 2000, following the greatest undisturbed length of time for equilibration. Representative heads for the middle and lower intervals cannot be derived from the bridge plug data because both intervals were still in recovery from drawdown during drilling. The bridge plug monitoring records are too short to support good projections of the recovery curves. A representative head for the upper interval was obtained after testing when long-term bridge plugs were installed and the upper interval could be monitored independently.

The apparent relationship of the upper interval water level to the composite head changed during the course of the monitoring. At the time of the bridge plug measurements, the upper interval head was higher than the composite head and both heads appeared to be rising at a similar rate. The relationship was reversed between the last composite water level measurement made during recovery after the constant-rate test and the upper interval water level after the permanent bridge plugs were set. At this time the upper interval was at least 7 ft lower than the composite water level. The upper interval water level was stable at this lower level for three months of monitoring following setting of bridge plugs isolating the intervals. That head is almost 10 ft lower than the highest composite head measured. This head relationship appears to be best supported by the water level data. The apparent long recovery times of the completion intervals from drawdown makes it difficult to establish equilibrium heads for the individual completion intervals. The earlier data was collected during recovery from drawdown that occurred from drilling, and each completion interval appears to have recovered at a different, slow rate. The middle interval was most productive during the pumping test, and is thought to be the primary control on the composite head.

Substantial downward flow (+ 2.2 gallons per minute [gpm]) was measured in the well from the upper interval to the middle interval at the end of testing, which would indicate that the lower intervals are at lower head than the upper interval. Since the composite water level was higher than the upper interval water level, the lower intervals must have been at higher head than the upper interval. The explanation for this contradiction is not known.

No flow was measured to the lower interval. There is little information on the lower completion interval other than the inconclusive bridge plug measurements, but the lower interval head is probably higher than the composite. There are indications that the heads in all three intervals vary seasonally.

2.4 Variable Density/Viscosity of Water in the Wellbore

The measurements of pressure at various depths in the well indicate a variation in density of the water with depth that results in a nonlinear pressure-depth relationship. The variation in density is significant, and it is important to use the appropriate composite density when interpreting the bridge-plug pressure measurements to determine the head in a completion interval. The variation of temperature with depth 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 2-2 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, and is further discussed in Section 2.5.1. The pressures calculated from this exercise are within +0.09 to -0.24 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 +0.71 to +0.84 pounds per square inch (psi). The PXD used for the middle interval (SN 21016) had a nominal accuracy of 1.00 psi, and had calibrated to -0.20 psi or less across its operational range. For the lower completion interval, the discrepancy was -3.38 to -3.71 psi. That PXD (SN 01227) had a nominal accuracy of 2.50 psi and had calibrated to 0.34 psi or less across its operational range. 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 difference for the middle interval is negative, indicating that the actual density is less than the theoretical density, with a calculated specific gravity of 0.999. The discrepancy is within the measurement error and can be easily accounted for by dissolved gases. The difference for the lower interval is positive, with a calculated specific gravity of 1.002. This may be due to measurement errors or suspended sediment low in the well, where development was very poor.

2.5 Flow in the Well Under Natural Gradient

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

Nonpumping temperature logs were run by Desert Research Institute (DRI) (ChemTool) prior to completion of the well, and then 11 days after pumping for the constant-rate test ceased. These logs are shown in Figure 2-3. Temperature logs give an indication of the entry, direction, and exit of flow from the borehole, but do not provide any rate information. Both the precompletion and the postdevelopment temperature profiles show temperatures and gradient probably representative of the geothermal gradient without flow from below the middle completion interval to total depth. The gradient in this interval is about 1.0 degree Fahrenheit (°F) per 100 ft. This is consistent with the flow logging during pumping and the thermal flow logging after testing which both indicated the lack of flow in this interval. The precompletion temperature log also indicates downward flow from the upper part of the borehole to the area of the middle completion interval. This is consistent with the downward gradient that was observed in the bridge plug measurements. This may explain why the precompletion temperatures are several degrees cooler than posttesting.

2.5.2 Flow Measurements (Thermal Flowmeter)

Thermal flowmeter measurements (Figure 2-3) were made during precompletion logging and following the testing. The precompletion measurements indicated downward flow in the upper part of the borehole. These measurements probably do not indicate natural gradient flow because the gradient at that time was the result of the differing recovery rates of different sections of the borehole. Flow in the completed well under natural head gradient (nonpumping, equilibrium conditions) was measured after recovery following the constant-rate test. Those measurements indicated downward flow from the upper completion interval to the middle interval. However, these measurements conflict with the apparent gradient between the two intervals, as discussed in Section 2.3.

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 can be made using the empirical equation $T=2000Q/s_w$ (Driscoll, 1986), where Q is the flow rate in gallons per minute (gpm) and s_w is the drawdown in feet. The head change data and the flow data generally have substantial relative uncertainty, but can be used to derive general estimates. While these estimates are less specific and accurate than pumping test information, they can provide estimates of T values where better information is not available. However, the flow and head data for this well are contradictory and do not provide the required information to estimate the transmissivity of either the middle or the lower intervals.

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. 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 records for the lower completion interval are shown in Figure A.3-3 and Figure A.3-6 of Appendix A. As mentioned in Section 2.3, the records do not show interpretable equilibration curves. Consequently, the pressure fall-off analyses cannot be performed.

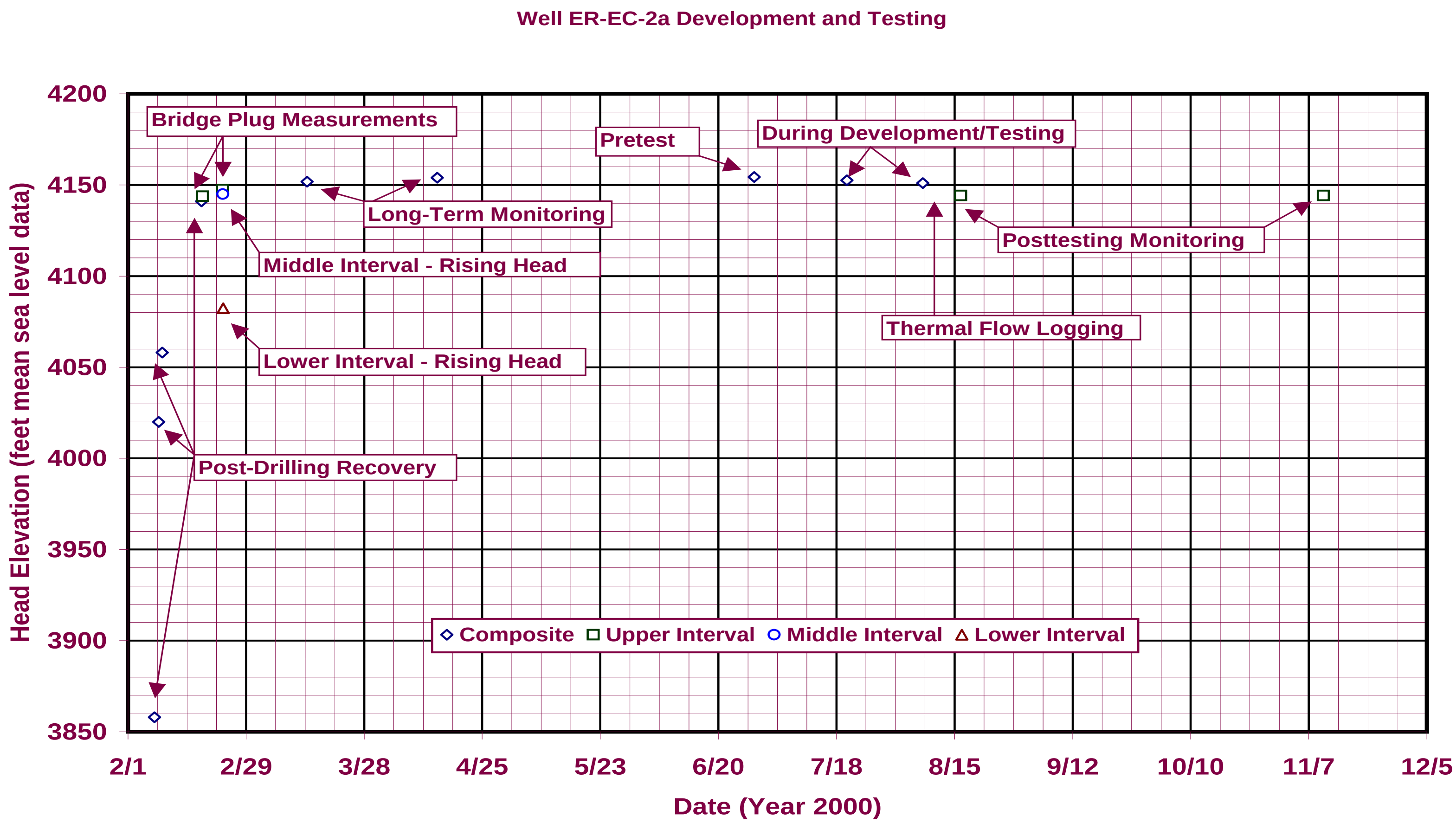

Figure 2-1
Post-Drilling Water Levels

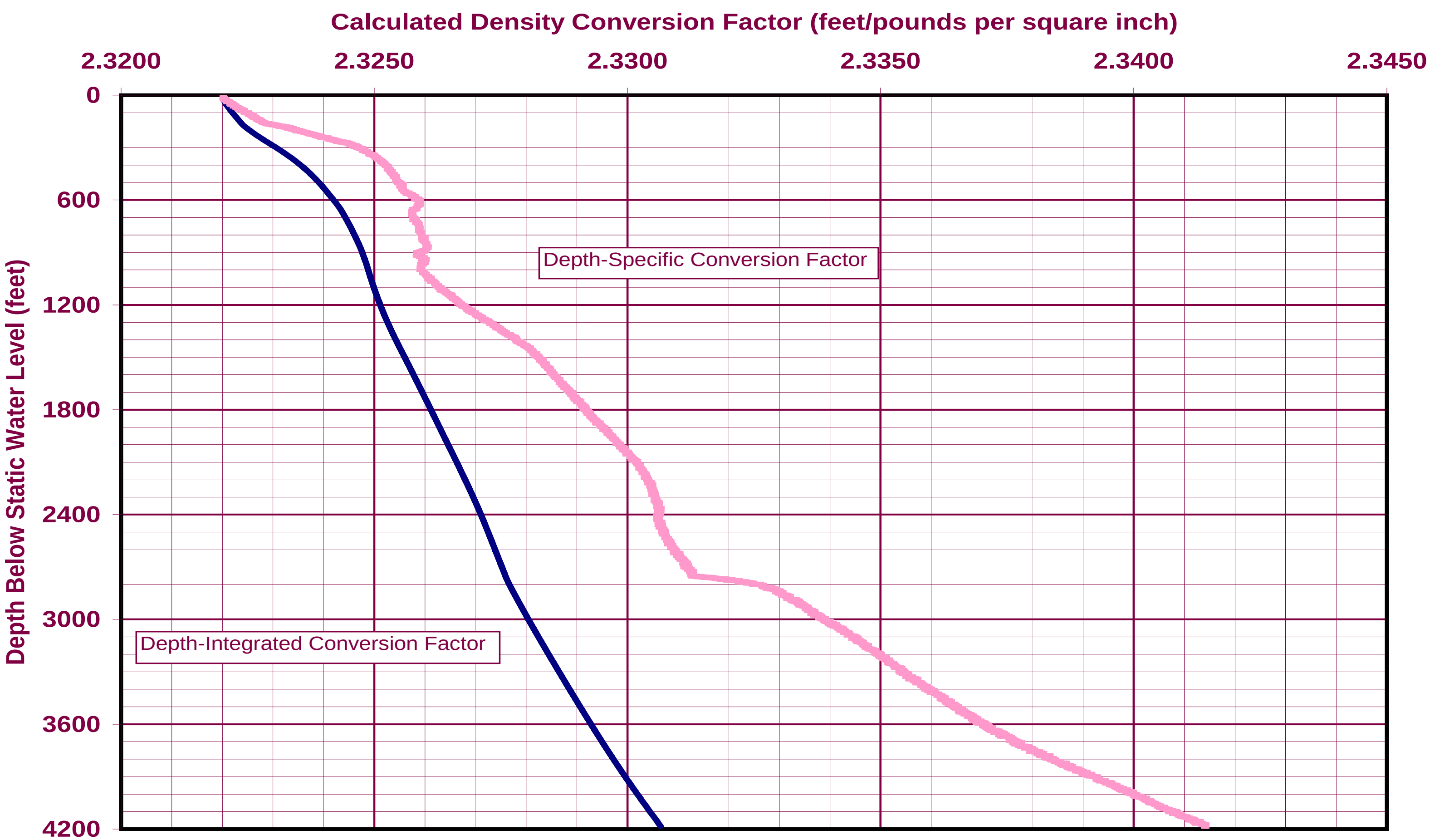

Figure 2-2
Temperature-Dependent Density Variation

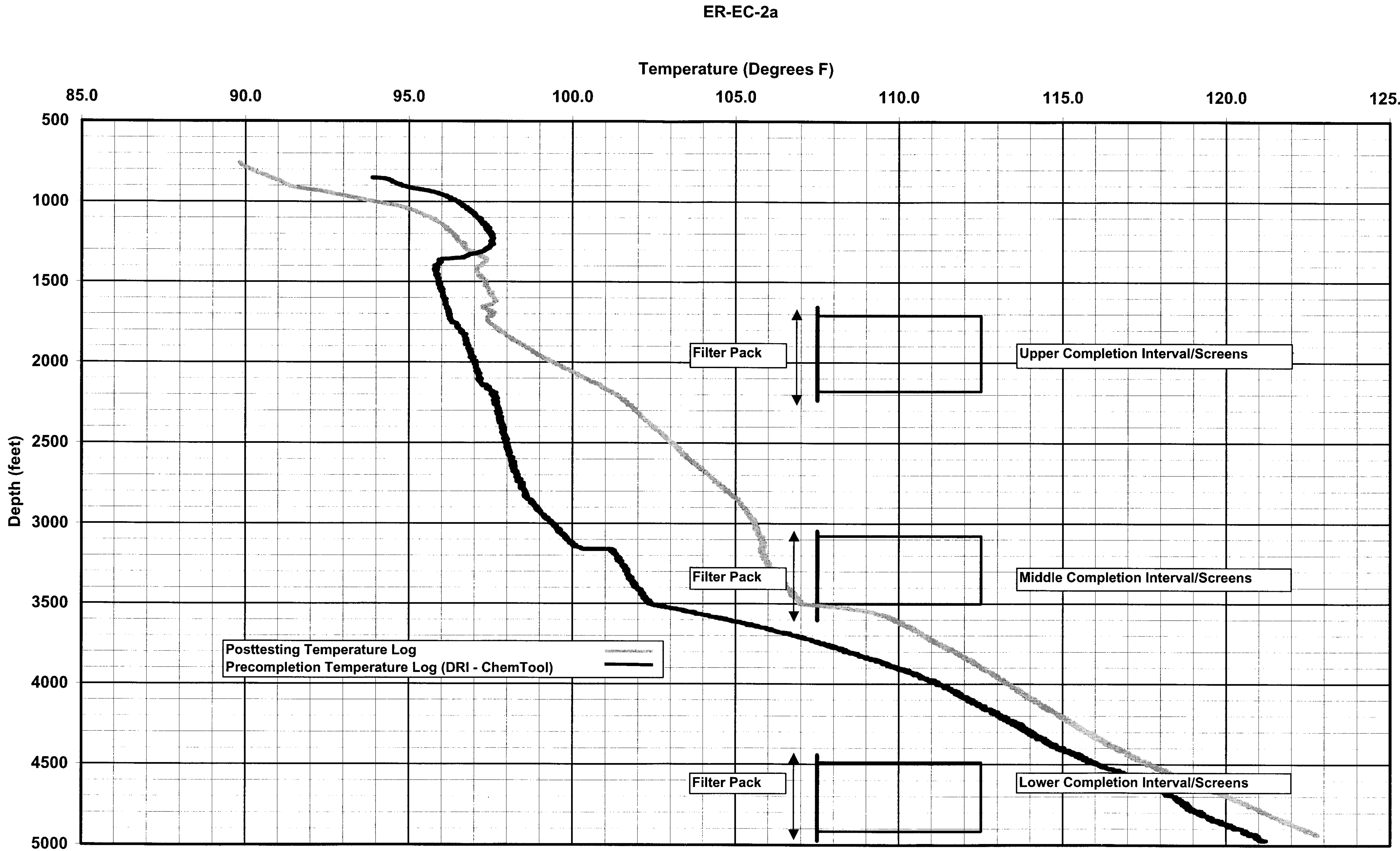

Figure 2-3
Nonpumping Temperature and Flow Logs

3.0 Pumping Well Hydraulics

The hydraulic testing of the well has been analyzed to provide both the transmissivity of the well and hydraulic conductivity of sections of the formation in the completion intervals. The hydraulic conductivity analysis is based on the flow logging 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 the production was very different between the two completion intervals, even after accounting for the different lengths of the completion intervals. Consequently, the derived hydraulic conductivity is substantially greater for the one interval than the other; 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 ec2amov06 run at a nominal pumping rate of 171 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 ec2amov01 is presented for 71 gpm, ec8mov04 for 121 gpm, and ec2amov04 for 171 gpm.

The flowmeter logs typically show a small amount of inflow to the well from the lower completion interval, about one percent of the total production, which is below the quantitation limit. The middle completion interval appears to have two distinct production zones. The lower zone of the middle interval produces about 9 percent of the total production, and the upper zone about 55 percent. The upper completion interval produces about 35 percent of the total which comes in progressively across the entire screen with somewhat more water entering near the top of the screen than near the bottom.

3.1.1 Temperature Logs

Figure 3-1 shows the temperature log from the ec2amov06 flow log. This log is typical of the temperature logs from all of the flowmeter runs. The lower part of the log below the middle completion interval is almost identical to the nonpumping log, but about 1.5°F warmer. This may be the result of the very low production from the lower interval. The temperature log shows the distinct stepwise production from the middle interval, and generally mirrors the flow log, indicating the pattern of production.

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 seven 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 (K) in Section 3.5.4.

The flowmeter impeller spins in response to water moving through the meter. The rate of revolution is related to water velocity and flow via an equation which accounts for pipe diameter and the trolling speed of the flowmeter. The coefficients of the equation relating the impeller response to the discharge are determined via calibration. In theory, the meter could be calibrated in the laboratory using the same pipe as the well and no further calibration would be necessary. In reality, the flowmeter response is influenced by a large number of factors specific to an individual well including temperature, pumping rate variation, hole condition, and sediment load. Therefore, it is advantageous to perform a calibration in the well to use for interpretation. For Well ER-EC-2a, 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.

Table 3-1
Summary of Impeller Flow Logs

Run Number	Direction of Run	Line Speed (fpm)	Pumping Rate (gpm)	Run Start/Finish (ft bgs)
ec2amov01	DOWN	20	71	1,318-4,926
ec2amov02	UP	40	71	4,892-1,341
ec2amov03	DOWN	60	71	1,342-4,892
ec2amov04	DOWN	20	121	1,342-4,891
ec2amov05	DOWN	60	121	1,338-4,888
ec2amov06	DOWN	20	171	1,340-4,888
ec2amov07	DOWN	60	171	1,339-4,894
ec2asta01	Stationary	0	71	3,800
ec2asta02	Stationary	0	71	2,600
ec2asta03	Stationary	0	71	1,500
ec2asta04	Stationary	0	121	3,800
ec2asta05	Stationary	0	121	2,600
ec2asta06	Stationary	0	121	1,500
ec2asta07	Stationary	0	171	3,800
ec2asta08	Stationary	0	171	2,600
ec2asta09	Stationary	0	171	1,500

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

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.

The well is constructed with 340.7 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-ft intervals along the length of the well including the blank section above the uppermost screen. To avoid end effects, the data observed from a 60-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, which may not be correct in every case. However, considering the analysis method used, the impact of this assumption on the results would be negligible.

The flowmeter depths recorded for Well ER-EC-2a were adjusted to ensure that the flowmeter response corresponded to the well construction log. The top and bottom of blank and screened intervals were identified in the flowmeter logs by plotting the rate of change of flow rate versus depth, and recording the locations where flow rate was changing. These depths were compared with the top and bottom of pipe sections in the construction log. Then, the depth of the center of each section was calculated and compared between the two logs. The depth correction to match the flowmeter and construction logs was determined from the average difference in the center depth of blank and screened sections.

Figure 3-5 shows the flow log for ec2amov07 and the corresponding differential flow log from depths of 1,339.8 to 4,894.4 ft bgs. This depth interval contains the blank casing above the first screen but below the crossover. Each peak on the differential flow 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 1,366.8 ft. Likewise, the transition from the upper blank casing to the upper screen is also apparent at a depth of 1,711.6 ft. The transition points between screens and blank sections, which were clearly depicted on all differential flow logs, were identified. The transitions from the upper screen to the second blank casing, and from the third blank casing section to the lower screen could not be identified on the flow logs and were not used to calculate the depth correction. In addition, data from ec2amov02 were not used for this purpose because the flowmeter recorded a zero response for a good portion of the logged depths (1,857 to 2,725.4 ft bgs). The depth of the midpoint for each of the intervals identified from each moving 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 intervals. The calculated depth correction was +5.98 ft. This process ensures that the appropriate depth intervals of the flow log are analyzed.

Following depth correction, a 60-ft long section of the borehole flow log data (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 six borehole flowmeter logging runs and from the three logging runs where the flowmeter was held stationary in the blank section while the well was pumped (stationary runs 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 (feet/minute [fpm]) and flow rate (gpm) as the independent variables. The second step consisted of expressing the flow rate as a function of the flowmeter response and the line speed by rearranging the equation used to regress the calibration data. The multiple linear regression approach in this work was chosen to provide a method by which the accuracy of the calibration could be quantified.

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

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

where:

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

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

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

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

where:

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

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

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

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

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

and

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 2,959 data points. Sixty-two data points from flow logging run ec2amov03, between depths of 1,529.4 to 1,541.4 ft bgs, were eliminated from the original dataset because they were anomalous. The final calibration dataset consisted of 2,898 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 a measure of accuracy for the flow rates calculated using the calibration equation. As shown in Table 3-2, the confidence interval is less than 2.6 gpm. Measured flow rates less than 2.6 gpm are considered statistically indistinguishable from zero.

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

The averaged-data approach could not be used for Well ER-EC-2a because of the limited number of logging runs (10). After averaging along the section of blank casing used for flowmeter calibration, only 10 data points corresponding to each of the logging runs would remain for use in the multiple regression. This number is too small to yield reliable results. This method was, however, used for Well ER-EC-1, the dataset was reduced to 14 sets of measurements which were used to derive a second calibration equation. The regression coefficients derived from the detailed and reduced datasets were nearly identical. The calculated flow rates using the coefficients from the two methods differed by less than 0.2 gpm over the entire range of values. The primary difference was that the confidence interval near the zero discharge prediction was narrower for the full dataset than when average values were used. Based on the case of Well ER-EC-1, it will be assumed that the time lag between the discharge measured at the land surface and the flow recorded by the flowmeter for Well ER-EC-2a has a negligible impact on the flowmeter calibration.

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

Equations 3-1 and 3-2 Solutions		
	Equation 3-1	**Equation 3-2**
Constant (a and c)	-0.0098	0.4501
First dependent variable (b1 and d1)	0.0219	45.7461
Second dependent variable (b2 and d2)	-0.02138	0.9782
Multiple R	0.9998	-
Sum of Squared Errors	2.3474	4,912.3648
Standard Error	0.0285	1.3026
Number of Observations	2,898	2,898

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)**
ec2amov01	0.294	-22.637	2.56
ec2amov02	-0.935	42.449	2.56
ec2amov03	1.383	-64.5	2.56
ec2amov04	0.47	-21.619	2.56
ec2amov04	1.335	-62.303	2.56
ec2amov06	0.47	-21.615	2.56
ec2amov07	1.329	-62.146	2.56

Notes: Impeller rate and line speed values were taken from depths below 3,500 ft bgs corresponding to near-zero flow rates measured in this well.

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

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 lengths of closely spaced rows of slots (6-in. on-center). Also, the filter pack often 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-2a. Due to the slow recovery of this well, the step-drawdown testing did not supply good enough quality data for analysis. Consequently, there is no data to determine the laminar and turbulent losses. However, it is likely that well losses in total at these pumping rates are a small fraction of the large drawdown that was observed. Flow losses inside the well were calculated independently, and subtracted from the total observed drawdown to provide a better estimate of the actual formation hydraulic conductivity, but these losses constituted only a small fraction (less than 3 percent) of the drawdown. 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

As mentioned, the step-drawdown testing did not provide data suitable for analysis.

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 [p.225]). Table 3-3 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 average of the inflows from the flow logs that were conducted at pumping rates of about 170.5 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.

Table 3-3
Calculated Flow Losses

Location in Well	Flow at Location (gpm)			Cumulative Friction Loss Inside Casing (ft)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Pump Intake	71.1	121.8	170.5			
Bottom of Pump Motor	71.1	121.8	170.5	0.047	0.121	0.220
Btm of 7 5/8-in. Casing - Top of Crossover	71.1	121.8	170.5	0.063	0.163	0.297
Crossover	71.1	121.8	170.5	0.417	1.081	1.964
Top of Screen 1	71.1	121.8	170.5	0.421	1.095	1.990
Bottom of Screen 1	46.2	82.1	110.3	1.167	3.055	5.502
Top of Screen 2-1	46.2	82.1	110.3	1.598	4.249	7.515
Bottom of Screen 2-1	3.5	12.9	17.2	1.657	4.410	7.787
Top of Screen 2-2	3.5	12.9	17.2	1.657	4.410	7.787
Bottom of Screen 2-2	0.05	1.7	1.7	1.659	4.438	7.833
Top of Screen 3	0.05	1.7	1.7	1.659	4.438	7.833
Bottom of Screen 3	0	0	0			

Blank = Not applicable

The middle completion interval was subdivided to deal better with the large step increase in production in that interval. The subdivision is designated on Table 3-3 as Screen 2-1 and Screen 2-2, denoting the upper and lower portions of the screen, respectively.

This analysis was done for the flow logging pumping rates for use in the flow logging analysis. However, the constant-rate test pumping rate (120.75 gpm) was very close to the flow logging rate (121.8 gpm), and the calculated flow losses would be very similar for the constant-rate test.

3.3 Head Distribution Under Pumping

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

3.4 Constant-Rate Test Analysis

The constant-rate test provides data for determining the overall transmissivity of the well. The features of the test record are explained in Section A.3.4.2 of Appendix A. The average pumping rate for the test was 120.75 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 3-6 shows the type curve for a dual-porosity solution and the resultant parameter values using the extent of the filter pack (1,033 ft) for the producing section of the upper completion interval for aquifer thickness. This solution yields a K of 0.06 ft/day with an associated T of 58 ft^2/d. Figure 3-7 shows a solution using the combined length of the producing screens (880.8 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 0.06 ft/day, yielding a T of 55 ft^2/d.

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

3.5 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:

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

where:

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

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

$$S_i = S\frac{K_i b_i}{Kb}$$

(3-6)

where:

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

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

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

(3-7)

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

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

(3-8)

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

and Molz and Young (1993) 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 2.6 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 feet or as large as 10 feet or more.

In partially penetrating wells, or irregularly screened wells such as ER-EC-2a, 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 interval. For their examples, they showed that the horizontal flow assumption inherent in the flowmeter analysis was violated and led to incorrect estimates of interval hydraulic conductivity values. The errors associated with violation of the horizontal flow assumption increase as the layer size decreases (i.e., the smaller the measurement interval). Another factor that may lead to errors is the head loss associated with flow through the borehole flowmeter itself. Ruud et al. (1999) show that head loss caused by the flowmeter can force water to flow in the filter pack outside the well and can lead to errors in measured flow.

For the WPM-OV wells where alternating screen and blank sections are present, the errors in estimated 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-2a has three screened intervals. Each screened interval is composed of several 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

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

3.5.4.1 Data Requirements

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

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

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

Interval Flow Rates (Q_i)

The 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.

Two problems were encountered during this process for Well ER-EC-2a. First, the well construction record indicates that the bottom of the second filter pack is at a depth of 3,450 ft bgs and that the bottom of the second screen is at a depth of 3,548.61 ft bgs. However, geophysical logs indicate the bottom of the second filter pack actually occurs at a depth of 3,500 ft bgs. Therefore, the effective portion of Screen 2 stops at a depth of 3,500 ft bgs. Second, it was apparent from all moving flow logs that production within Screen 2 occurred only at the top and bottom of the screened interval, with a nonproducing portion in between. The top producing portion of the screened interval clearly matches a distinct lithologic unit. To facilitate the estimation of distinct hydraulic conductivities for the geologic units contributing to Screen 2, a pseudo-blank section corresponding to the middle portion of this screen was created. The only purpose of this pseudo-blank section is to calculate flow rates through the upper and lower portions of Screen 2.

The upper and lower producing portions of Screen 2 are labeled Screen 2-1 and Screen 2-2, respectively. Screen 2-1 is located between screen joint 12 (3,076.71 ft bgs) and screen joint 17 (3,291.26 ft bgs). Screen 2-2 is located between screen joint 17 (3,291.26 ft bgs) and the observed bottom of the second filter pack described above (3,500 ft bgs). The lengths of these screens vary between 204 and 467 ft. These lengths do not include the nonslotted parts of the slotted sections located at both ends of a given continuous string of slotted sections. The average discharge values are tabulated in Table 3-4 for the blank sections and in Table 3-5 for the screens numbered one through three, beginning with the uppermost intervals. Flow from the bottom of the well below the deepest screen is assumed to equal zero for all flow logs.

Hydraulic conductivity will be calculated only for screens for which flow rates extracted from reliable flow logs exceed 2.6 gpm. As seen in Table 3-4 and

Table 3-4
Average Flow Rates Through the Blank-Casing Sections in gpm During the Flow Logging Runs of Well ER-EC-2a[a]

Pumping Rate = 71 gpm				
Blank Number	**ec2amov01**	**ec2amov02**	**ec2amov03**	**ec2a Average[b]**
1	69.44	70.28	71.93	71.11
2	47.42	43.59	48.83	46.21
Pseudo-blank	-1.08	3.91	3.07	3.49
3	-8.72	-1.74	1.84	0.05
Pumping Rate = 121 gpm				
Blank Number	**ec2amov04**	**ec2amov05**	**-**	**Average**
1	122.47	121.12	-	121.79
2	82.88	81.36	-	82.12
Pseudo-blank	13.74	12.08	-	12.91
3	0.98	2.45	-	1.71
Pumping Rate = 171 gpm				
Blank Number	**ec2amov06**	**ec2amov07**	**-**	**Average**
1	170.45	170.60	-	170.53
2	110.01	110.51	-	110.26
Pseudo-blank	17.90	16.55	-	17.23
3	1.29	2.13	-	1.71

[a]Flow from bottom of well is assumed to be zero.
[b]Average does not include ec2amov01 values.

Table 3-5, several flow rates observed in Well ER-EC-2a are statistically equal to zero (less than 2.6 gpm) or are unreliable. Screen 3 produced flow rates less than 2.6 gpm for all moving flow logs. In addition, flow rates calculated using the ec2amov01 and ec2amov02 flow logs are considered to be unreliable for screens 2-2 and 3. Thus, even though Screen 2-2 also shows measurable flow rates at a pumping rate of 71 gpm for flow logging runs 1 and 2, these numbers are unreliable. Screens 1 and 2-1 produced reliable and measurable flow (greater than 2.6 gpm) for all moving flow logs. Screen 2-2 produced reliable and measurable flow only at the higher pumping rates of 121 and 171 gpm.

The Term $r_w^2 S$.

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

Table 3-5
Average Flow Rates Through the Screened Sections in gpm During the Flow Logging Runs of Well ER-EC-2a

Pumping Rate = 71 gpm				
Screen Number	**ec2amov01**	**ec2amov02**	**ec2amov03**	**Average[a]**
1	22.02	26.69	23.10	24.89
2-1	48.50	39.69	45.77	42.73
2-2	7.64	5.64	1.23	3.44
3	-8.72	-1.74	1.84	0.05
Pumping Rate = 121 gpm				
Screen Number	**ec2amov04**	**ec2amov05**	**-**	**Average**
1	39.59	39.76	-	39.67
2-1	69.14	69.28	-	69.21
2-2	12.77	9.64	-	11.20
3	0.98	2.45	-	1.71
Pumping Rate = 171 gpm				
Screen Number	**ec2amov06**	**ec2amov07**	**-**	**Average**
1	60.44	60.10	-	60.27
2-1	92.11	93.96	-	93.03
2-2	16.62	14.42	-	15.52
3	1.29	2.13	-	1.71

[a]Average does not include ec2amov01 values.

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

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

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 $r_w^2 S$ for any given time t.

Formation and Interval Drawdowns (s and s_i)

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

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

Screen	(1) Flow Rate into Well (gpm)	(2) Total Flow Losses at Center of Screen (ft)	(1) X (2)
Q = 71 gpm			
Screen 1	24.89	0.421	10.48
Screen 2-1	42.73	1.598	68.28
Screen 2-2	3.44	1.657	5.70
Total Flow	71.06		
Weighted Average Flow Loss in the Well = 1.189 ft			
Q = 121 gpm			
Screen 1	39.67	1.095	43.44
Screen 2-1	69.21	4.249	294.05
Screen 2-2	11.20	4.41	49.39
Total Flow	120.08		
Weighted Average Flow Loss in the Well = 3.222 ft			
Q = 171 gpm			
Screen 1	60.27	1.99	119.93
Screen 2-1	93.03	7.515	699.14
Screen 2-2	15.52	7.787	120.85
Total Flow	168.82		
Weighted Average Flow Loss in the Well = 5.568 ft			

To capture the range of uncertainty associated with drawdowns during the flow logging, two sets of time-drawdown pairs were used. The drawdowns in the well corresponding to a pumping rate of 121 gpm were obtained from the time-drawdown data recorded during the constant-rate test. Drawdowns in the well for the other two pumping rates were estimated using the Cooper-Jacob (1946) equation applied to the whole well. The well transmissivity value derived from the constant-rate test was used in these calculations. The drawdown in the well was calculated for 0.54 and 1.67 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 3-6) from the well drawdown values described above.

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

Transmissivity of the Formation

The transmissivity of the formation is the well transmissivity as calculated from the constant-rate test adjusted for well flow losses. An estimate of the formation transmissivity was then derived by multiplying the transmissivity derived from the constant-rate pumping test (Q=121 gpm) by the ratio of the formation drawdown to the well drawdown at t =1.67 day. The well drawdown @ 1.67 day is 250.41 ft. As shown in Table 3-6, the average well flow losses at 121 gpm are equal to 3.22 ft. The estimated formation losses are, therefore, equal to 250.41 ft. As a result, the ratio of the formation drawdown to the well drawdown is equal to 0.99. As reported earlier, the transmissivity derived from the constant-rate pumping test is equal to 58 ft^2/d. The derived estimate of formation transmissivity is 58.75 ft^2/d or 59 ft^2/d. As a result of the small magnitude of the flow losses relative to the well drawdown, the transmissivities of the well and the formation are practically the same.

Individual Interval's Transmissive Thickness (b_i)

The interval thickness is not precisely known because flow to the screen may be derived, in part, from behind the blank section of pipe above or below the screen. The minimum contributing thickness is assumed to be the length of screen (between 204 ft and 467 ft depending on the screen) and the maximum is assumed to be equal to the lengths of the filter packs (between 208 and 580 ft).

3.5.4.2 Procedure and Results

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

The interval hydraulic conductivities from equations (3-8) and (3-10) are given in Table 3-7 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 3-7
Interval Hydraulic Conductivities Calculated From Flow Logging Data for Well ER-EC-2a

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)
			$s_{t=0.54\,d}$ [a]	$s_{t=1.67\,d}$ [b]	-		$s_{t=0.54\,d}$	$s_{t=1.67\,d}$	-
ec2amov1	Screen 1	467.0	0.032	0.033	0.036	580.0	0.026	0.026	0.035
ec2amov2	Screen 1	467.0	0.040	0.041	0.043	580.0	0.032	0.033	0.042
ec2amov3	Screen 1	467.0	0.034	0.034	0.037	580.0	0.027	0.028	0.037
ec2amov4	Screen 1	467.0	0.034	0.034	0.038	580.0	0.027	0.028	0.037
ec2amov5	Screen 1	467.0	0.034	0.035	0.038	580.0	0.027	0.028	0.037
ec2amov6	Screen 1	467.0	0.037	0.038	0.041	580.0	0.030	0.030	0.040
ec2amov7	Screen 1	467.0	0.037	0.037	0.040	580.0	0.029	0.030	0.039
ec2amov1	Screen 2-1	209.8	0.211	0.203	0.175	244.3	0.181	0.175	0.182
ec2amov2	Screen 2-1	209.8	0.167	0.162	0.143	244.3	0.143	0.139	0.149
ec2amov3	Screen 2-1	209.8	0.197	0.190	0.165	244.3	0.169	0.164	0.172
ec2amov4	Screen 2-1	209.8	0.171	0.166	0.146	244.3	0.147	0.143	0.152
ec2amov5	Screen 2-1	209.8	0.172	0.166	0.146	244.3	0.147	0.143	0.152
ec2amov6	Screen 2-1	209.8	0.160	0.156	0.138	244.3	0.138	0.134	0.144
ec2amov7	Screen 2-1	209.8	0.164	0.159	0.141	244.3	0.141	0.137	0.146
ec2amov4	Screen 2-2	204.0	0.024	0.025	0.028	208.7	0.023	0.024	0.027
ec2amov5	Screen 2-2	204.0	0.017	0.018	0.021	208.7	0.016	0.017	0.020
ec2amov6	Screen 2-2	204.0	0.021	0.022	0.026	208.7	0.021	0.022	0.025
ec2amov7	Screen 2-2	204.0	0.018	0.019	0.022	208.7	0.017	0.018	0.022

[a]Drawdown in the well 0.54 day after pumping started
[b]Drawdown in the well 1.67 days after pumping started

ft/d = Feet per day

3.5.5 Sources of Uncertainty

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

The parameter uncertainty comes from uncertainty in the flow rate, the drawdown, and the parameters within the logarithm of equation (3-10). The flow rate determined from the flowmeter and line speed measurements is accurate to within about plus or minus 2.6 gpm. This means that flow uncertainty is a small factor for the intervals which produced the most water, but could be a significant factor (up to perhaps 50 percent of the value for Screen 2-2) based on lowest reliable value of flow rate available. In general, the drawdown in the aquifer is uncertain because it relies on corrections for well losses, both inside and outside the well. In general, the well loss corrections are similar down the well, but the impact of the uncertainty is usually larger for screens which have lower flow rates. In the case of Well ER-EC-2a, corrections for well losses represented a negligible percentage of the observed drawdowns.

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 3-7 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. Usually, the single biggest source of uncertainty is the selection of the length of the contributing interval for each screen. However, in the case of Well ER-EC-2a, the differences between the minimum and maximum lengths of the producing intervals were relatively small, producing a narrow range of hydraulic conductivities.

Perhaps the single biggest source of uncertainty is the selection of the length of the transmissive interval for each screen. As was noted earlier, the thickness could vary between 208 and 580 ft. This uncertainty in the contributing thickness is small and produces a proportionally small uncertainty in interval hydraulic conductivity for Well ER-EC-2a.

In summary, the interval hydraulic conductivity values calculated for Well ER-EC-2a are uncertain, with greater uncertainty associated with the smaller hydraulic conductivity interval. The interval hydraulic conductivity values are probably no more accurate than a factor of 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 well worked fairly well, yielding results for the two upper completion intervals. A combination of factors allowed the hydraulics of the well operation to produce significant amounts of water from all three completion intervals. These factors include high-enough hydraulic conductivities in the lower completion intervals, the not-too-dissimilar hydraulic conductivities of the two intervals, lack of substantial vertical gradient relative to the drawdown, and sufficient drawdown to observe responses above the noise level. The large drawdown did cause some problems in data capture, and the slow recovery after pumping resulted in the loss of some analysis opportunities due to superposition of multiple effects.

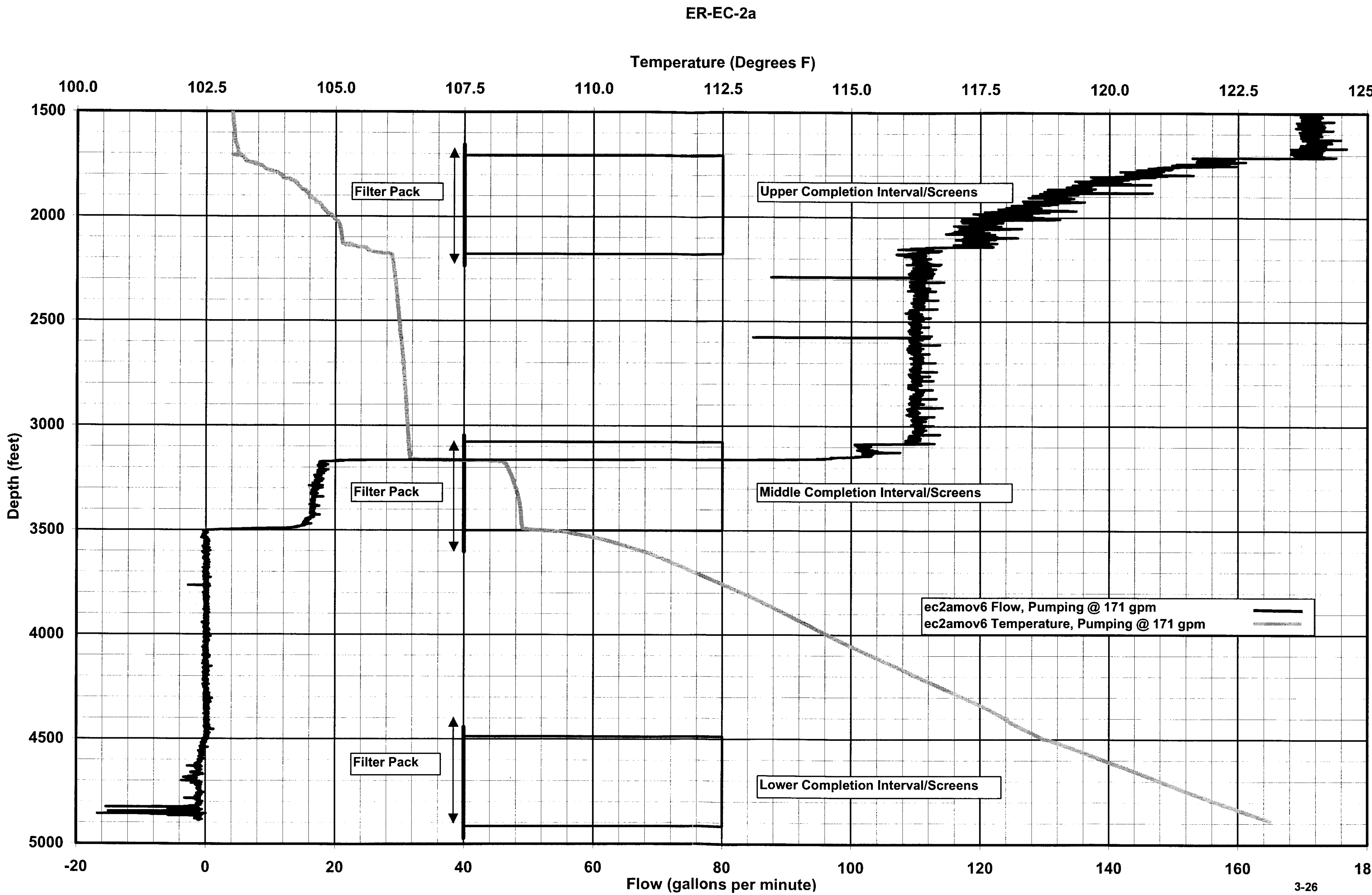

Figure 3-1
Pumping Temperature and Flow Logs

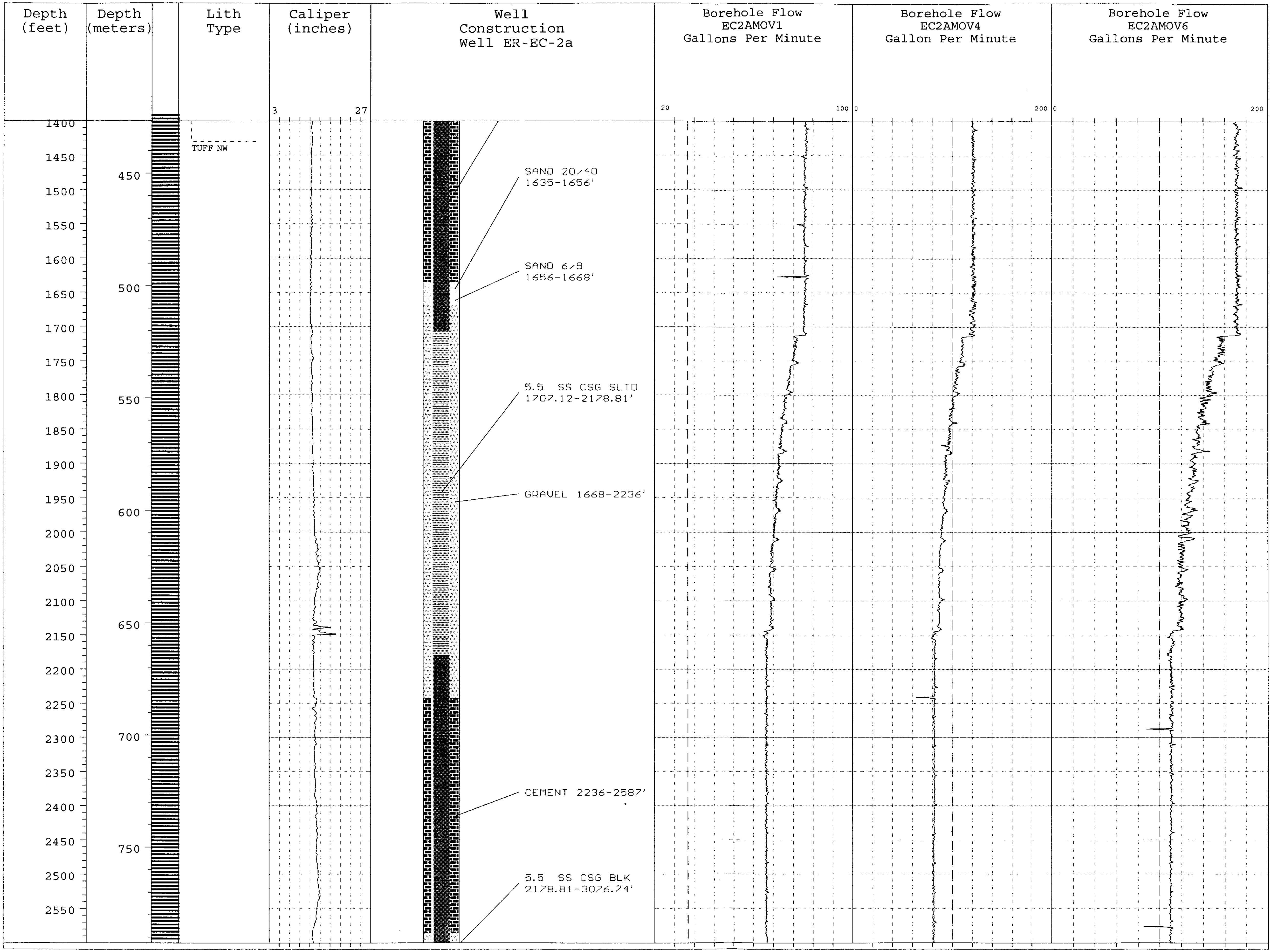

Figure 3-2
Geology and Well Construction for the Upper Completion Interval

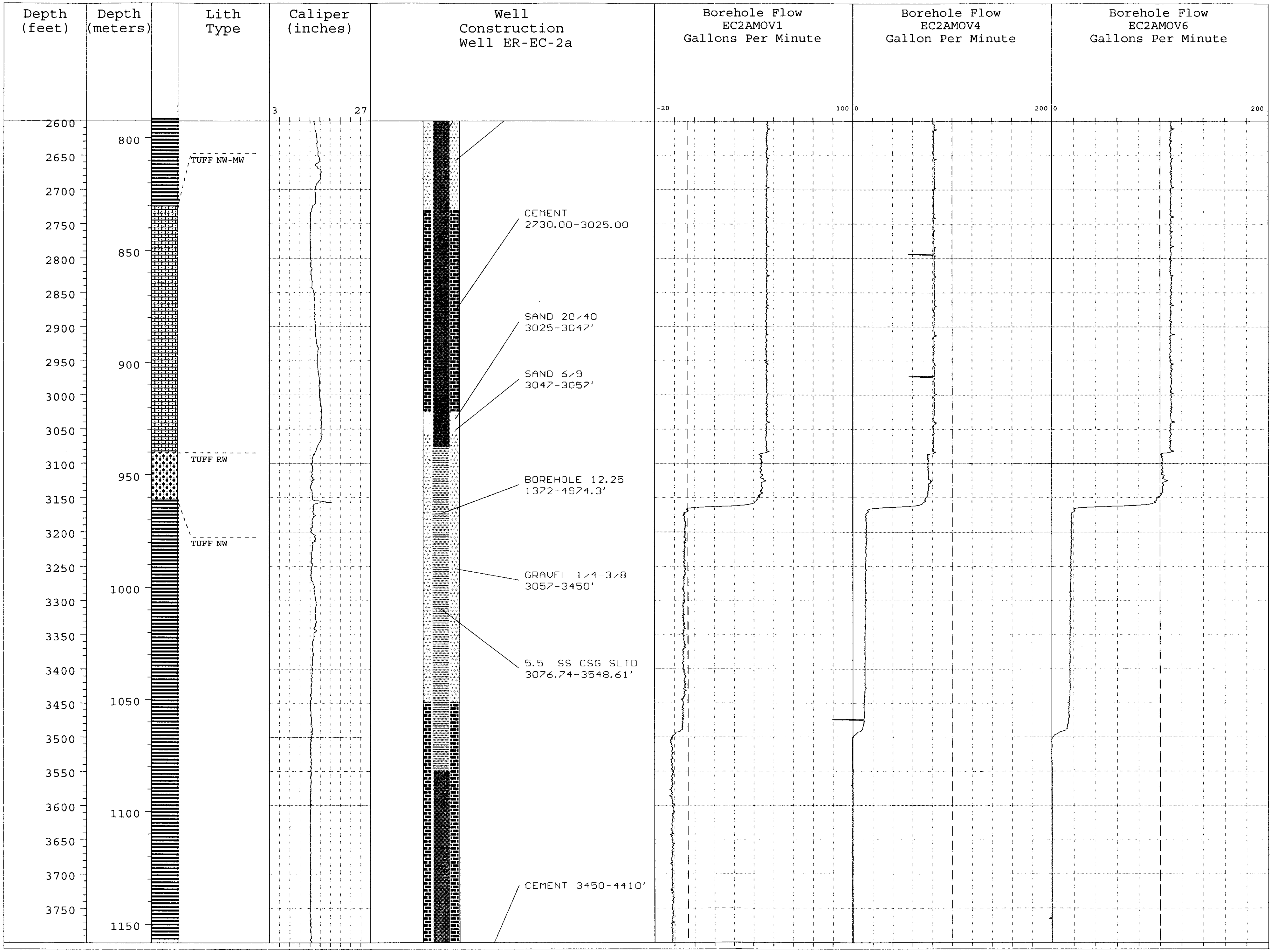

Figure 3-3
Geology and Well Construction for the Middle Completion Interval

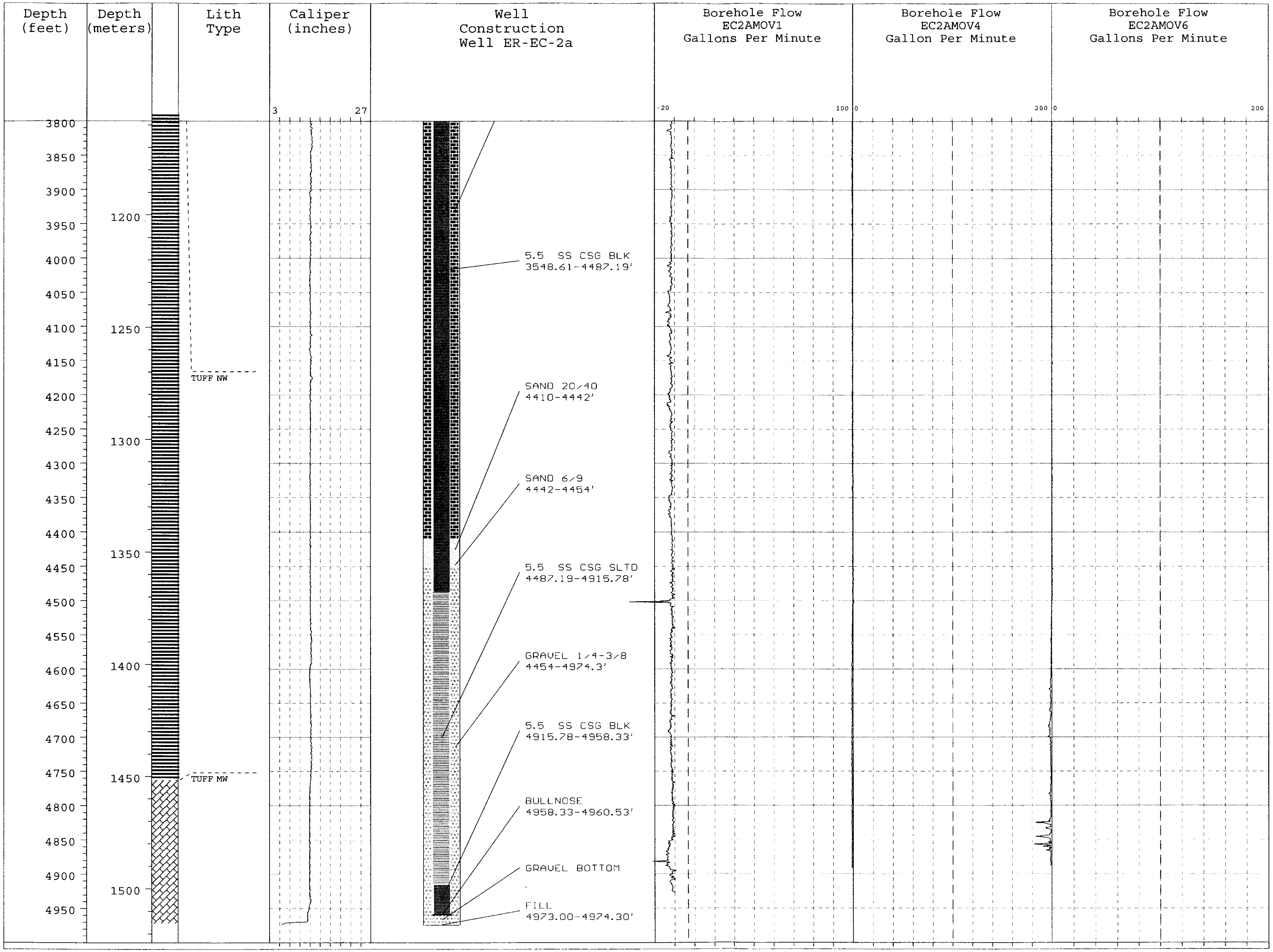

Figure 3-4
Geology and Well Construction for the Lower Completion Interval

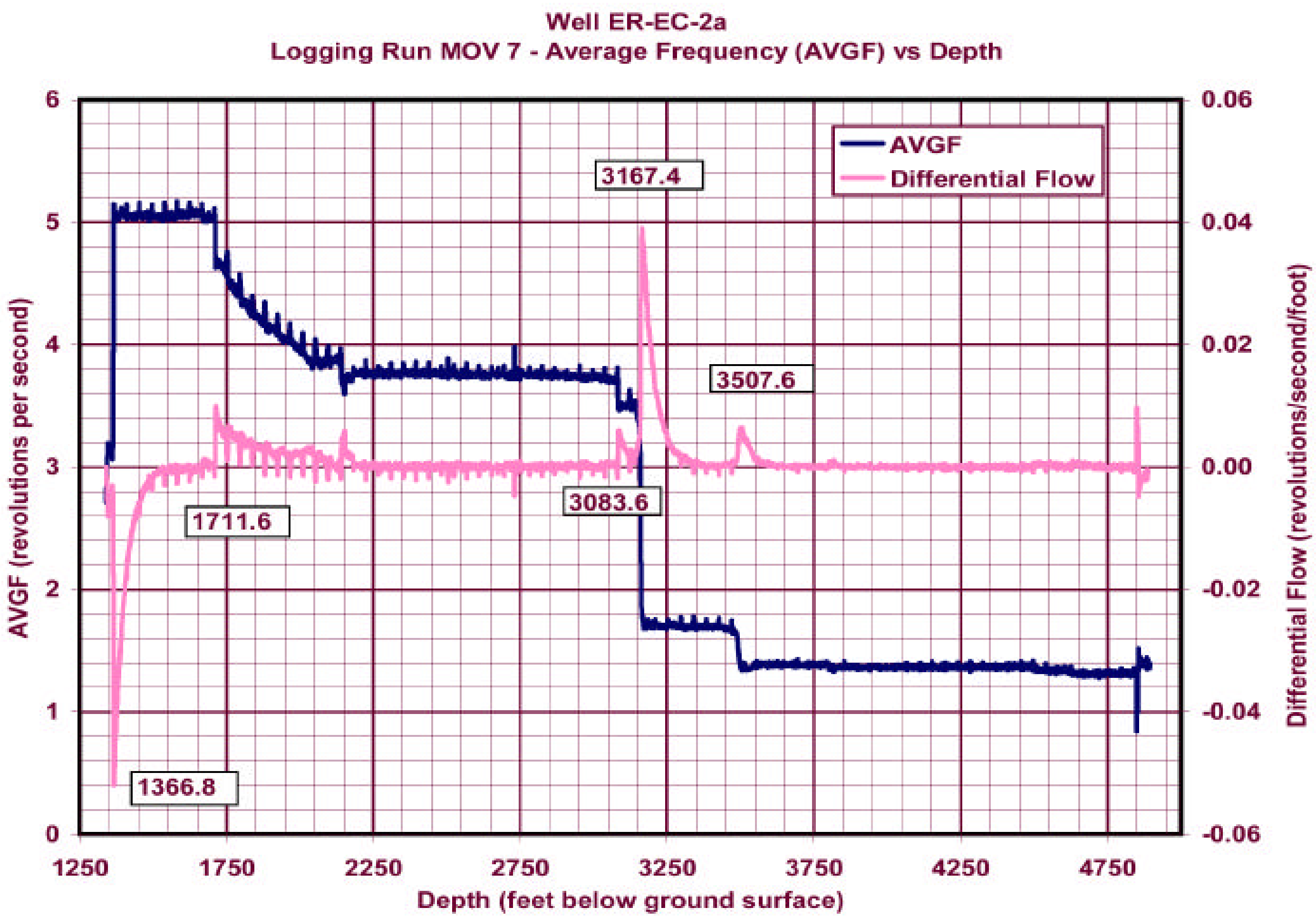

Figure 3-5
Example of Differential Flow Log Superposed on Flow Log (Flow Log ec2amov07)

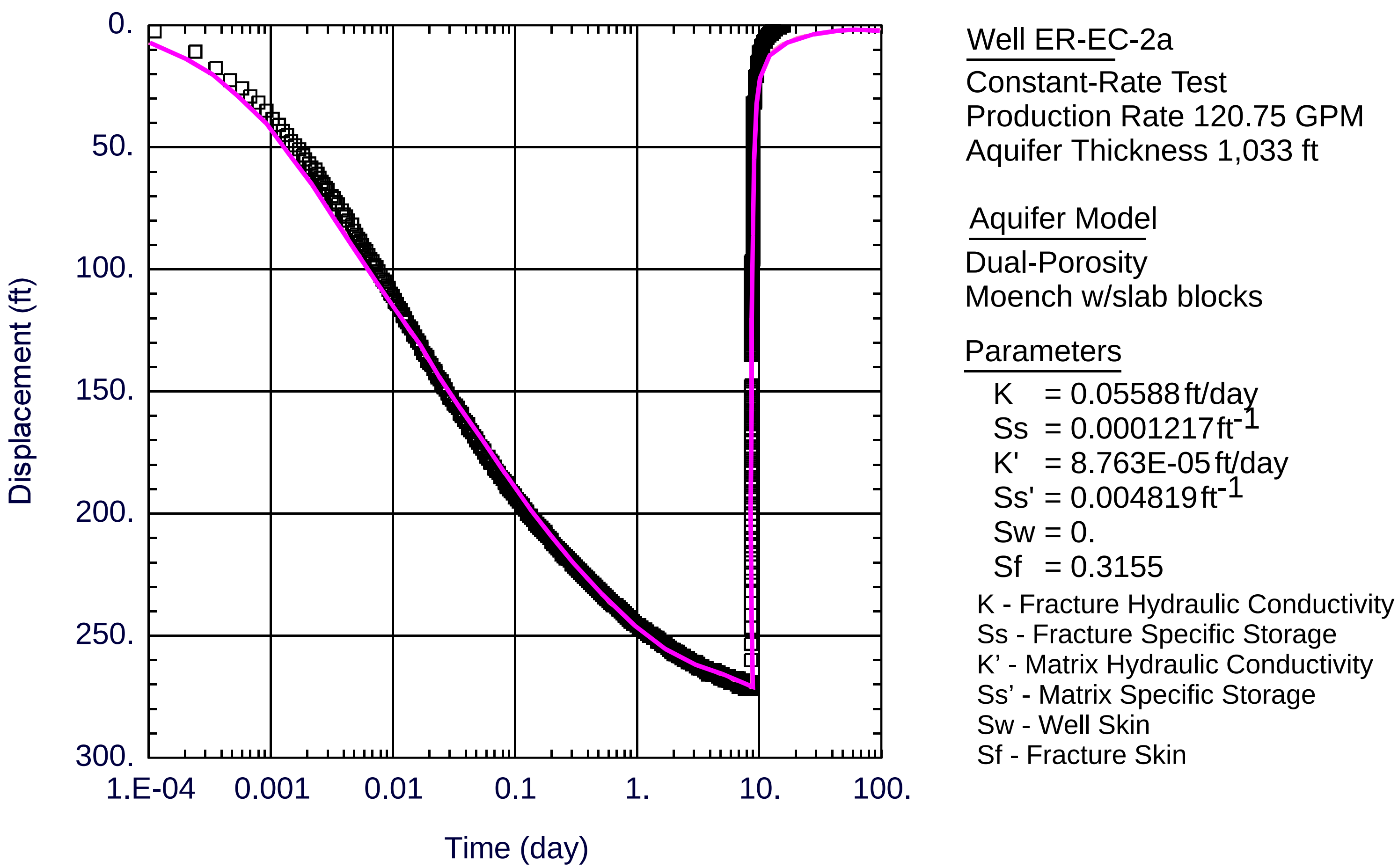

Figure 3-6
Moench Analysis of the Constant-Rate Test

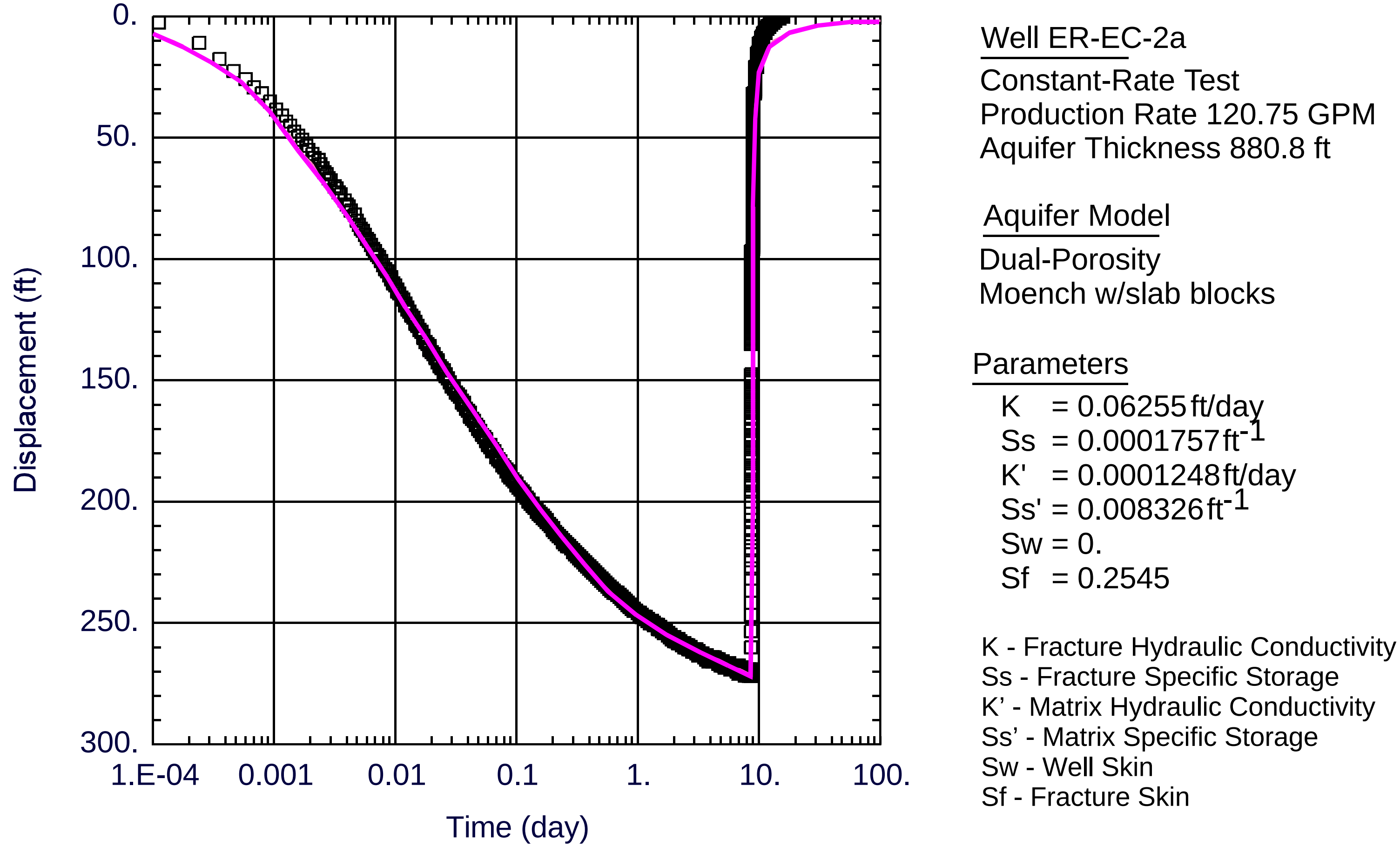

Figure 3-7
Moench Analysis of the Constant-Rate Test - Alternate Aquifer Thickness

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-2a. One discrete bailer sample and one composite groundwater sample were collected at this site. The purpose of a discrete bailer sample is to target a particular depth interval for sampling under either static or pumping conditions, while the purpose of a composite sample 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-2a 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-2a will be discussed in this section and compared to the groundwater chemistry of other nearby wells.

4.1.1 ER-EC-2a Groundwater Characterization Sample Results

On July 5, 2000, a discrete bailer sample (#EC-2A-070500-2) was obtained from a depth of 3,300 ft bgs at a pumping rate of approximately 170 gpm. The sample was obtained using a DRI logging truck, wireline, and discrete bailer (Section A.2.10.1). On July 27, 2000, a composite groundwater characterization sample (#EC-2A-072700-1) was collected from the wellhead sampling port directly into sample bottles. A constant production rate of about 120 gpm was maintained during the sampling event. This same pumping rate was used during the constant-rate test. At the time of composite sampling, approximately 2.4×10^6 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.

Appendix A, Attachment 3, Table ATT.3-1 shows that essentially all of the analytical results for the discrete bailer sample have been qualified. It can also be seen that a significant number of the analytical results for the composite groundwater characterization sample have also been qualified. Consequently, the discussion of the analytical results for Well ER-EC-2a must be generalized to accommodate the uncertainties. There are, however, several qualitative observations that can be made from the analytical data. For example, inspection of the table reveals that both groundwater characterization samples have relatively similar analytical results taking into account the uncertain nature of the estimated data. It can be seen from the table that sodium and calcium are the predominant cations in both groundwater characterization samples. The table shows that the discrete bailer sample had an estimated dissolved sodium concentration of 120 milligrams per liter (mg/L) and an estimated dissolved calcium concentration of 45 mg/L. The table reveals that the composite groundwater characterization sample had a dissolved sodium concentration of 120 mg/L and a dissolved calcium concentration of 13 mg/L. It can also be seen from the table that bicarbonate is the predominant anion for both groundwater characterization samples. For example, the discrete bailer sample had an estimated bicarbonate concentration of 220 mg/L as CaCO3 and the composite groundwater sample had a bicarbonate concentration of 150 mg/L as CaCO3. Further inspection of the table reveals that the discrete bailer sample had an estimated pH of 7.3, while the composite groundwater characterization sample had an estimated pH value of 8. The table also reveals that both groundwater characterization samples have similar silicon concentrations. Specifically, the discrete bailer had an estimated silicon concentration of 14 mg/L, while the composite sample had a silicon concentration of 18 mg/L.

Inspection of the "Age and Migration Parameters" section in Appendix A, Attachment 3, Table ATT.3-1 for the composite groundwater characterization sample also reveals several interesting things. For example, it can be seen in the table that the helium-3/helium-4 ($^{3}He/^{4}He$) ratio (R) in Well ER-EC-2a groundwater is 1.30×10^{-6}. Lawrence Livermore National Laboratory (LLNL) (2001) states that this value is slightly lower than the natural atmospheric ratio (R_a) of 1.38×10^{-6}, giving a R/R_a value of 0.94. According to LLNL (2001), this value does not suggest a strong mantle helium contribution. It can also be seen from the table that Well ER-EC-2a has a ^{4}He concentration of 7.92×10^{12} atoms/milliliter (mL). LLNL (2001) states that this concentration is greater than the expected amount of helium in groundwater recharge and implies the accumulation of excess ^{4}He from α-decay of natural radioactive elements in the aquifer host rock. LLNL (2001) also states that a ^{4}He groundwater model age of approximately 4,000 years is obtained assuming a ^{4}He in-growth rate of 1.2×10^{9} atoms per year and after applying corrections for recharge solubility and excess air. However, 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-2a groundwater is 7.7 percent modern, yielding an uncorrected ^{14}C age of 21,200 years. This value, however, is substantially greater than the ^{4}He 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 since carbonate minerals generally contain no radiocarbon, the equilibration process results in groundwater ^{14}C ages that are substantially greater than the mean aquifer residence time. It can also be seen from the table that the chlorine-36/chlorine ($^{36}Cl/Cl$) ratio for Well ER-EC-2a groundwater is 5.33×10^{-13}. LLNL (2001) states that this value is within the range of previously reported values for environmental wells in this region.

Appendix A, Attachment 3, Table ATT.3-2 presents the results of the colloid analyses for Well ER-EC-2a. It can be seen from the table that the discrete bailer sample had a total colloid concentration of 3.79×10^6 particles per milliliter (particles/mL) for colloids in the size range of 50 to 1,000 nanometers (nm). The composite groundwater characterization sample, on the other hand, had a total colloid concentration of 4.57×10^7 particles/mL for colloids in the size range of 50 to 1,000 nm. The total colloid concentration for the composite groundwater characterization sample is almost an order of magnitude greater than the total colloid concentration for the discrete bailer sample. However, it can be seen from the table that the colloid concentrations for the first three particle size ranges account for approximately 85 percent of the total colloid concentration for the composite groundwater characterization sample. In other words, the composite groundwater characterization sample is composed of a greater proportion of smaller colloids than the discrete bailer sample. The table also reveals that after the particle size range 180 to 190 nm, the discrete bailer sample has the greater colloid concentrations. Further inspection of the table reveals that for both groundwater characterization samples the colloid concentrations in 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 much greater rate than the colloid concentrations for the discrete bailer sample.

While the two groundwater characterization samples have relatively similar analytical results, differences can be seen taking into account the uncertain nature of the data in Appendix A, Attachment 3, Table ATT.3-1. For example, an obvious discrepancy between the two groundwater characterization samples can be seen in the calcium and magnesium concentrations. The discrete bailer sample had an estimated dissolved calcium concentration of 45 mg/L and an estimated dissolved magnesium concentration of 15 mg/L. The composite groundwater characterization sample, on the other hand, had a dissolved calcium concentration of 13 mg/L and a dissolved magnesium concentration of 2.6 mg/L. Another discrepancy between the two groundwater characterization samples can be seen in the bicarbonate and electrical conductivity measurements. The discrete bailer sample had an estimated bicarbonate concentration of 220 mg/L as $CaCO3$ and an electrical conductivity of 910 micromhos per centimeter (μmhos/cm). The composite groundwater characterization sample, on the other hand, had a bicarbonate concentration of 150 mg/L as $CaCO3$ and an electrical conductivity of 580 μmhos/cm. The differences between the two groundwater characterization samples tend to emphasize that the discrete bailer data are uncertain and should be treated as such.

Despite the discrepancies, 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 lithologic logs for the well indicated that the completion intervals for this well were within rhyolitic tuff of the Beatty Wash Formation and tuffaceous rocks of both the Fortymile Canyon and the Ammonia (NNSA/NV, 2001).

4.1.2 Radionuclide Contaminants

A radiological indicator parameter was possibly detected in the composite groundwater characterization sample. For example, it can be seen in Appendix A, Attachment 3, Table ATT.3-1 that ^{14}C was detected in sample #EC-2A-072700-1 at an activity of 1,540 +/- 280 picocuries per liter (pCi/L), which was above the minimum detectable activity. This value, however, is somewhat suspect and tends to conflict with the carbon-14 (percent modern carbon) [pmc]) value that was determined by LLNL for the “Age and Migration Parameters.”

4.1.3 Comparison of ER-EC-2a Groundwater Chemistry to Surrounding Wells

Table 4-1 presents groundwater chemistry data for Well ER-EC-2a and recently collected samples from wells and springs in close proximity to Well ER-EC-2a. 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-2a 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. The discrete bailer sample data were not plotted due to the uncertain nature of the data and the fact that some of the major ion data were reported as nondetects. Further inspection of the anion triangle in Figure 4-1 reveals that most of the wells and springs can also be classified as 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 from the anion triangle, however, that there are a number of sites whose relative anion concentrations do not fall within the bicarbonate type zone including the composite groundwater characterization sample from Well ER-EC-2a 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 from 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; however, there is a much greater 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-2a is relatively similar to the surrounding wells and springs at least in terms of the major ionic constituents.

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

Analyte	ER-EC-2a				Coffer's Ranch, Windmill Well	Coffer Ranch Spring	ER-20-5 #1	ER-20-5 #3	ER-OV-01	ER-OV-02	ER-OV-03c	ER-OV-06a	PM-3	PM-3, 3019 feet	U-20 Water Well	U-20a #2 Water Well
	Bailer at 3,300' bgs		Wellhead Composite													
	Total	Dissolved	Total	Dissolved												
Metals (mg/L)																
Aluminum	J 0.57	UJ 0.093	U 0.099	U 0.1	0.0009	<0.00004	3.1	11	0.0512	0.003	0.0113	0.688	0.03	< 0.01	0.0053	< 0.01
Arsenic	J 0.014	J 0.011	B 0.0067	B 0.007	0.00836	0.0064	0.042	B 0.0085	0.003	0.003	0.0149	0.0085		0.004	0.00589	
Barium	J 0.023	J 0.027	B 0.0057	B 0.0057	0.00161	0.0098	< 0.01	B 0.0076	0.0026	0.0039	0.0019	0.0021	0.004	0.002	0.00008	
Cadmium	UJ 0.005	UJ 0.005	U 0.00019	U 0.005	0.000019	< 0.000016		< 0.005	0.001	0.001	0.001	0.001		< 0.001	< 0.000016	
Calcium	J 50	J 45	13	13	19.3	21.8	7.18	3.14	5.7	13.6	14.4	2.32	30.1	36	6.8	6.34
Chromium	J 0.011	UJ 0.01	U 0.0017	U 0.00041	0.00013	0.0008		0.0792	0.0015	0.0015	0.001	0.0016	0.01	0.002	0.00025	
Iron	J 1.2	UJ 0.063	U 0.26	U 0.15	0.1933		0.39	8.48	0.0036	0.0034	0.0023	0.0082	0.24	0.06	0.0767	0.09
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	0.002		< 0.005	0.000263	
Lithium	J 0.15	J 0.16	0.16	0.16	0.12	0.166	0.09	0.0696	0.175	0.192	0.123	0.167	0.278		0.063	0.065
Magnesium	J 16	J 15	2.5	2.6	0.21	1.52	0.27	0.09	0.05	0.59	0.38	0.72	0.79	1.5	0.27	0.24
Manganese	J 0.81	J 0.69	0.058	0.058	0.0082	0.00034	0.02	0.305	0.0005	0.001	0.0005	0.0024	0.014	0.014	0.0496	0.01
Potassium	J 5.1	J 5.2	3.6	3.6	0.91	9.54	5.65	3	6.56	5.41	1.19	7.7	10.9	10	1.37	2.27
Selenium	J 0.004	J 0.003	U 0.005	U 0.005	0.00053	0.00057	< 0.01	< 0.005	0.00082	0.00079	0.00041	0.004		< 0.001	0.00051	
Silicon	J 15	J 14	18	18			38.4	41.7						63		48
Silver	UJ 0.01	UJ 0.01	B 0.00071	U 0.01	0.00002	< 0.00002		< 0.01	0.001	0.001	0.001	0.001		< 0.001	< 0.00001	
Sodium	J 120	J 120	120	120	72.2	176	105	73	142	146	81.9	141	140	130	59.5	62.6
Strontium	J 0.15	J 0.15	0.044	0.044	0.181	0.163	0.02	B 0.027	0.0047	0.0474	0.102	0.0105		0.081	0.0263	0.03
Uranium	UJ 0.2	UJ 0.2	U 0.2	U 0.2	0.00586	0.0154	0.014	< 0.5	0.0085	0.018319	0.004187	0.005237			0.002302	
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		< 0.1		
Inorganics (mg/L)																
Chloride	UJ 52		59		7.6	65.8	21.7	17.8	44.4	49.2	17.5	47.5	93.5	98	11.1	11.2
Fluoride	UJ 4.9		5.6		3.29	3.32	10.1	3.16	2.04	2.34	4.55	3.07	2.5	2.4	2.23	2.7
Bromide	UJ 0.72		0.31		0.035	0.31	0.103	< 0.25	0.22	0.263	0.066	0.224			0.064	
Sulfate	UJ 180		95		31	110	39	35.1	82	86	44	80.9	129	130	31	38.4
pH	J 7.3		J 8		8.43	7.13	8.6	8.8	8.54	8.29	8.38	8.4	8.73	7.9	8.56	7.7
Total dissolved solids	J 600		420		194	445	436	489	338	366	218	426	441	555.6241	166	201
Carbonate as CaCO3	UJ 100		U 20						1.7			3			6.1	
Bicarbonate as CaCO3	J 220		150		189	281.82	186	109	197	232	164	196	159	150	101	112
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	-2.9	-1.8			-6.2	-13.47
Carbon-14, Inorganic (pmc)	N/A		7.7 +/- 0.1		9.6		81657	1346	5	16.2	6.8	6			8.6	15.3
Carbon-14, Inorganic age (years)*	N/A		21,200		19,350				24,830	15,050	22,280	23,330			20260	
Chlorine-36	N/A		1.11E-03					0.01102								
Helium-3/4, measured value (ratio)	N/A		1.30E-06				0.157	0.001							4.74E-07	
Helium-3/4, relative to air (ratio)	N/A		0.94		0.85		114000	723	1.13	1.51	0.88	1.16			0.34	
Oxygen-18/16 (per mil)	N/A		-15.0 +/- 0.2		-14.2 +/- 0.2		-14.9	-15.1	-14.7 +/- 0.2	-14.6 +/- 0.2	-14.7 +/- 0.2	-14.7 +/- 0.2			-14.7 +/- 0.2	-14.75
Strontium-87/86 (ratio)	N/A		0.709387 +/- 0.000029		0.70922		0.71104 +/- 6E-5	0.70868 +/- 3E-5	0.71058	0.71006	0.70924	0.70932			0.71126	
Uranium-234/238 (ratio)	N/A		0.000225				0.000165	0.000158							0.000259	
Hydrogen-2/1 (per mil)	N/A		-113 +/- 1.0		-104 +/- 1		-115	-113	-112 +/- 1	-112 +/- 1	-109 +/- 1	-113 +/- 1			-113 +/- 1	-114
Radiological Indicator Parameters-Level I (pCi/L)																
Tritium	U -230 +/- 160		UJ -10 +/- 160		0.47 +/- 0.86		60400000	142000	3.33 +/- 0.90			1.94 +/- 0.87	16		3.8 +/- 0.93	
Gross Alpha	81 +/- 12		13.3 +/- 2.7				C 23.7	37.3	14.7	27.5	10.7	9.74				0.0053
Gross Beta	16.8 +/- 3.3		U 3.7 +/- 1.6				C 29.6	24.8	11.8	10.1	3.45	7.46				5.6
Radiological Indicator Parameters-Level II (pCi/L)																
Carbon-14	U 70 +/- 190		1540 +/- 280				260	-3.8								
Strontium-90	N/A		UJ 0.14 +/- 0.32				0.5	0.43							0.13	
Plutonium-238	U 0.004 +/- 0.012		U 0.005 +/- 0.013				< 0.062	< 0.31							0.43	
Plutonium-239	U -0.003 +/- 0.012		U 0 +/- 0.013													
Iodine-129	N/A		U 0.00 +/- 0.86				<570	-0.6								
Technetium-99	N/A		U 7.9 +/- 4.1				< 1.88	< 5.17							3.22	

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

Analyte	U-20ai (Jefferson)	U-20al (Egmont)	U-20ao (Goldstone)	U-20c	U-20f	U-20n PS#1 DDH (Cheshire)	UE-18r	UE-20d	UE-20f (13686 feet)	UE-20f (4543 feet)	UE-20j Water Well	UE-20n #1	Unnamed Well 10S/47E-27a1
Metals (mg/L)													
Aluminum				< 0.1	0.26	0.97	< 0.06	0.09	0.07	0.07	0.01	4.6	
Arsenic						J 0.0089	< 0.1						
Barium						< 0.02	20						
Cadmium						< 0.002							
Calcium	4.29	13.1	8.82	2.8	14	3	21.5	8.5	4.8	4.8	46	7	24
Chromium						< 0.01						0.36	
Iron				0.03	0.04	0.58	< 0.02		0.56	0.56	4.8	480	
Lead						< 0.003	< 0.01						
Lithium				0.01	0.04	0.11	0.08	0.075					
Magnesium	1.05	2.05	1.24	< 0.1	0.1	0.45	0.92	0.1		0.1	1.2	0.7	2
Manganese				< 0.01	0.02	0.15	< 0.03	0.39	0.14	0.14			
Potassium	7.17	11.1	1.9	1.4	3	B 2	3.49	2.6	2	2	6.4	0.5	
Selenium					0.02	< 0.005	< 0.01	0.01					
Silicon				42	39	25.6	21.6	45	47	47	44		
Silver						< 0.01							
Sodium	115	122	38	95	82	61	73.1	107	113	113	138	1.6	
Strontium				0.04	0.07	B 0.015	0.08	< 0.01					
Uranium						< 0.3	0.0035				0.0085		
Mercury						< 0.0001							
Inorganics (mg/L)													
Chloride	63.5	32.8	3.2	8.1	15	13.8	6.9	24	40	40	115		66
Fluoride	2.9			6.4	3.7	4.8	3	3	5	5	2.2		3.7
Bromide						0.4							
Sulfate	26	77.6	8.1	18	65	34	23	40	48	48	135		34
pH	8.43	8.3	8.14		8.4	8.8	8.05	8.5		7.2	7		8
Total dissolved solids				264	268	251	208	327	368	368	583		712
Carbonate as CaCO3													
Bicarbonate as CaCO3	175	250	114	130	140	88	227	192	164	164	150		288
Age and Migration Parameters (pCi/L) - unless otherwise noted													
Carbon-13/12 (per mil)							-1.4						-5.33
Carbon-14, Inorganic (pmc)						160450	6.7 +/- 0.06						38.9
Carbon-14, Inorganic age (years)*													
Chlorine-36						0.4966	0.0001342						
Helium-3/4, measured value (ratio)						0.2168							
Helium-3/4, relative to air (ratio)						160000	1.128 +/- 2						
Oxygen-18/16 (per mil)						-15	-14.7						
Strontium-87/86 (ratio)						0.71009 +/- 2E-5	0.70909						
Uranium-234/238 (ratio)						0.000223							
Hydrogen-2/1 (per mil)						-124	-110						
Radiological Indicator Parameters-Level I (pCi/L)													
Tritium	16					J 69409830	8 +/- 1.9						
Gross Alpha						< 22.3509							
Gross Beta					2.1	J 1246.545		3.2			13		14
Radiological Indicator Parameters-Level II (pCi/L)													
Carbon-14						< 304							
Strontium-90						J 202.2122							
Plutonium-238													
Plutonium-239													
Iodine-129						< 0.714							
Technetium-99							< 5						

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 μg/L = Micrograms per liter pCi/L = Picocuries per liter
* = The carbon-14 age presented is not corrected for reactions along the flow path.

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-2a and for selected sites within 12.5 miles of Well ER-EC-2a. 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-2a and its nearby neighbors. For example, it can be seen that the delta oxygen-18 ($\delta^{18}O$) values vary from approximately -14 per mil to approximately -15 per mil, while the delta deuterium (δD) values vary from approximately -105 per mil to 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 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-2a 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 Section A.3.6 of Appendix A. The groundwater characterization samples can also help to evaluate the effectiveness of well development. During drilling operations for Well ER-EC-2a, 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 10 mg/L to approximately 100 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 also provide a means to further ascertain the effectiveness of the well development. 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. The table shows that the discrete bailer sample had a bromide concentration that was not detected (UJ 0.72 mg/L), while the composite groundwater characterization sample had a bromide concentration of 0.31 mg/L. It can also be seen from the table that the highest bromide concentration in the surroundings wells and springs was 0.4 mg/L for U-20n PS#1 DDH. The bromide concentration in the composite groundwater characterization sample is at least an order of magnitude lower than the concentration of bromide used during drilling. This likely indicates 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

In order to determine flow in the well under ambient, static conditions, thermal flow logging was conducted prior to well completion, and again following the constant-rate testing. Downward flow was observed during logging before well completion. As has been discussed, immediately after well completion the well was apparently in a transient situation due to differing head recoveries of each completion intervals. The evolution of the recoveries and resulting crossflow would be difficult to evaluate with the very limited available data. The results from the thermal flow logging after the constant-rate test were addressed in a previous report, Section A.2.11.2 of Appendix A, and indicated downward flow of about 0.5 gpm at 1,870 ft bgs in the upper completion interval; downward flow of 2.2 + gpm at 3,300 ft bgs in the middle completion interval; and no flow at

3,700 ft bgs which was between the middle and lower completion intervals. These results indicate groundwater flow from the upper completion interval downwards to the middle completion interval, but no flow from the middle completion interval down to the lowermost completion interval. However, the head relationship that was observed following the constant-rate test was upward, suggesting upward flow. This contradiction has not been resolved. However, based on the preponderance of production from the upper and middle intervals, and the short time between well completion and sampling, the effects of crossflow may have been remediated during development and testing. In any case, bridge plugs were installed in this well following the constant-rate test to prevent future crossflow.

4.2.3 Source Formation(s) of Groundwater Samples

As has been discussed in Section 3.1, flow logging during pumping indicated that approximately 1/3 of the produced water came from the upper completion interval and 2/3 of the produced water came from the middle completion interval. The flow logging during pumping also indicated that the lower completion interval did not contribute any substantial production during pumping. Based on the flow logging during pumping, it can be concluded that the composite groundwater characterization sample is composed of a mixture of groundwater from both the upper and middle completion intervals. Preliminary lithologic and stratigraphic logs indicated that the upper completion interval is completed within rhyolitic tuff of the Beatty Wash Formation, while the middle completion interval is completed within tuffaceous rocks of the Fortymile Canyon and the Ammonia Tanks groups. These formations must be considered the source formations for the composite groundwater characterization sample. The discrete bailer groundwater characterization sample, on the other hand, should only represent the lower part of the middle completion interval. This implies that the source formation for the discrete bailer groundwater characterization sample is the tuffaceous rocks of the Fortymile Canyon and the Ammonia Tanks groups.

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 geochemical differences between the two groundwater characterization samples. These differences may be a result of the characterization samples deriving groundwater from different sources, or it may be related to the qualification of the discrete bailer data. However, since there was no direct evidence of residual contamination from drilling it can likely be assumed that the composite groundwater characterization sample is representative of the source formations for the upper and middle completion intervals. In addition, the discrete bailer groundwater characterization sample from 3,300 ft bgs should be representative of the groundwater from the lower part of the middle completion interval. However, the lower completion interval cannot be considered developed. This interval may, in fact, still be affected by drilling-induced fluids.

4.4 Use of ER-EC-2a for Future Monitoring

Natural-gradient flow in the well has been stopped by the installation of bridge plugs to isolate the completion interval from each other. Consequently, the sampling pump will only produce water from the upper completion interval. The upper completion interval should not become contaminated with any foreign water between pumping episodes unless leakage occurs past the bridge plug beneath it. The upper interval may have received some water from the middle interval during recovery after the constant-rate test due to the apparent upwards gradient. Purging prior to future sampling should be sufficient to remediate this.

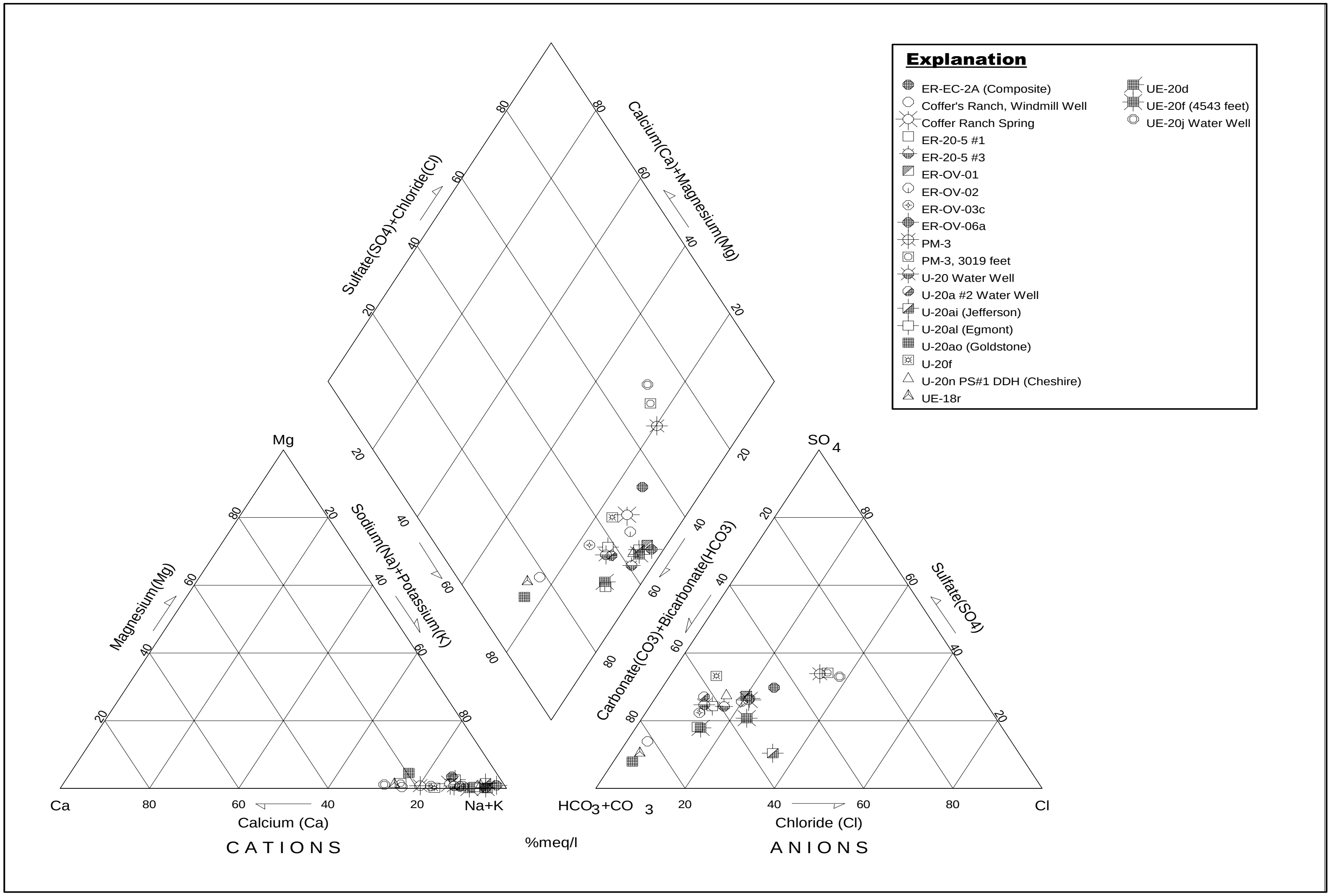

Figure 4-1
Piper Diagram Showing Relative Major Ion Percentages

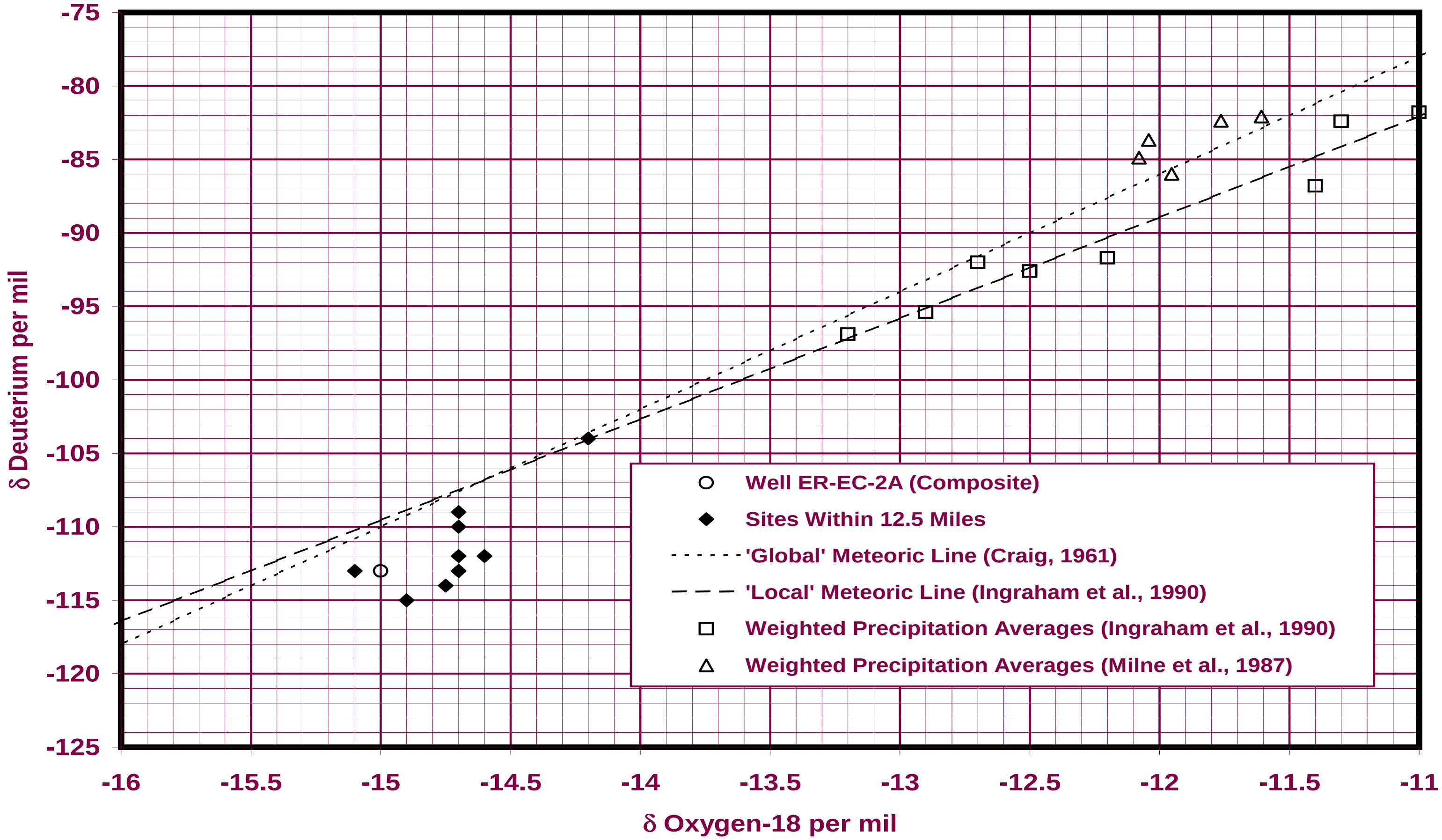

Figure 4-2
Stable Isotope Composition of Groundwater

5.0 References

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Appendix A

Western Pahute Mesa-Oasis Valley Well ER-EC-2a Data Report for Development and Hydraulic Testing

A.1.0 Introduction

Well ER-EC-2a is one of eight groundwater wells that were drilled as part of the WPM-OV drilling program for the NNSA/NV UGTA Project. This well was completed at the beginning of FY 2000. Figure A.1-1 shows the location of the WPM-OV wells. Hydraulic testing and groundwater sampling were conducted at Well ER-EC-2a to provide information on the hydraulic characteristics of HSUs and the chemistry of local groundwater. Well ER-EC-2a is constructed with three completion intervals (i.e., 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 between screens of 898 ft (upper to middle completion interval) and 939 ft (middle to lower completion interval). The upper interval is located within the Ammonia Tanks Formation, the middle is located within Timber Mountain Landslide Breccia, and the lower interval is located within the Rainier Mesa Tuff.

This document presents the data collected during well development and hydraulic testing for Well ER-EC-2a and the analytical results of groundwater samples taken during this testing.

The objectives of the development and testing program were:

1. Increase the hydraulic efficiency of the well.

2. Restore the natural groundwater quality.

3. Determine the hydraulic parameters of the formations penetrated.

4. Collect samples from discrete depth 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-2a was the seventh of the WPM-OV wells to be developed and tested. Activities began February 18, 2000, and were completed by August 26, 2000, with a total of 55 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, a constant-rate pumping test, water quality parameter monitoring, and groundwater sampling of individual producing intervals and of the composite discharge.

A.1.1 Well ER-EC-2a Specifications

The drilling and completion specifications of Well ER-EC-2a can be found in the *Completion Report for Well ER-EC-2a* (NNSA/NV, 2002). 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 pumping 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 measurements 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 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 dataloggers for the lower intervals and a wireline-set pressure transducer for the uppermost interval; (2) flow logging during pumping to determine the extent of the open formation actually producing water and locations of discrete production; (3) flow logging under ambient head conditions to determine circulation in the well under the natural gradient; (4) a constant-rate pumping test to determine hydraulic parameters for the formation(s); (5) discrete downhole sampling during pumping to capture samples that can be determined to represent specific formations or portions of formations; (6) a composite groundwater characterization sample of water produced during pumping after the maximum possible development; and (7) step-drawdown testing to determine specific capacity and optimum pumping rates.

A.1.3 Schedule

The generic schedule developed for the Well ER-EC-2a 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 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 history of the testing program at Well ER-EC-2a 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 in order to coordinate with other activities. The testing period was also extended because of greater than anticipated well recovery periods.

A.1.4 Governing Documents

Several documents govern the field activities presented in this document. The document describing the overall plan is the WDHTP (IT, 1999d). The implementation of the testing plan is covered in *Field Instruction for Western Pahute Mesa - Oasis Valley Well Development and Hydraulic Testing Operations* (FI) (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, 1993) 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 the 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).

A.1.5 Document Organization

This data report is organized in the following manner:

- Section A.1.0: Introduction

Table A.1-1
Brief History of Work Performed at Well ER-EC-2a

Activity	Start Date	Finish Date	Duration (days)
Interval-specific head measurements (bridge plugs).	2/18/2000	2/23/2000	6
Site mobilization.	6/19/2000	6/22/2000	4
Install access line and testing pump. Check pump functionality.	6/22/2000	6/28/2000	7
Develop well and conduct step-drawdown testing.	6/28/2000	7/3/2000	6
Conduct flow logging while pumping and discrete downhole sampling. Install check valve and shut down pump.	7/4/2000	7/5/2000	2
Monitor for recovery and pretest conditions.	7/5/2000	7/20/2000	16
Constant-rate test.	7/20/2000	7/29/2000	9
Composite well sampling.	7/27/2000	7/27/2000	1
Monitor recovery.	7/29/2000	8/7/2000	9
Remove access line and testing pump.	8/8/2000	8/9/2000	2
Thermal flow and ChemTool logging under ambient conditions.	8/9/2000	8/9/2000	1
Run GyroData survey (well deviation).	8/10/2000	8/10/2000	1
Install bridge plugs.	8/11/2000	8/11/2000	1
Install sampling pump and test for functionality.	8/14/2000	8/15/2000	2
Demobilize from site.	8/16/2000	8/26/2000	10

- 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).

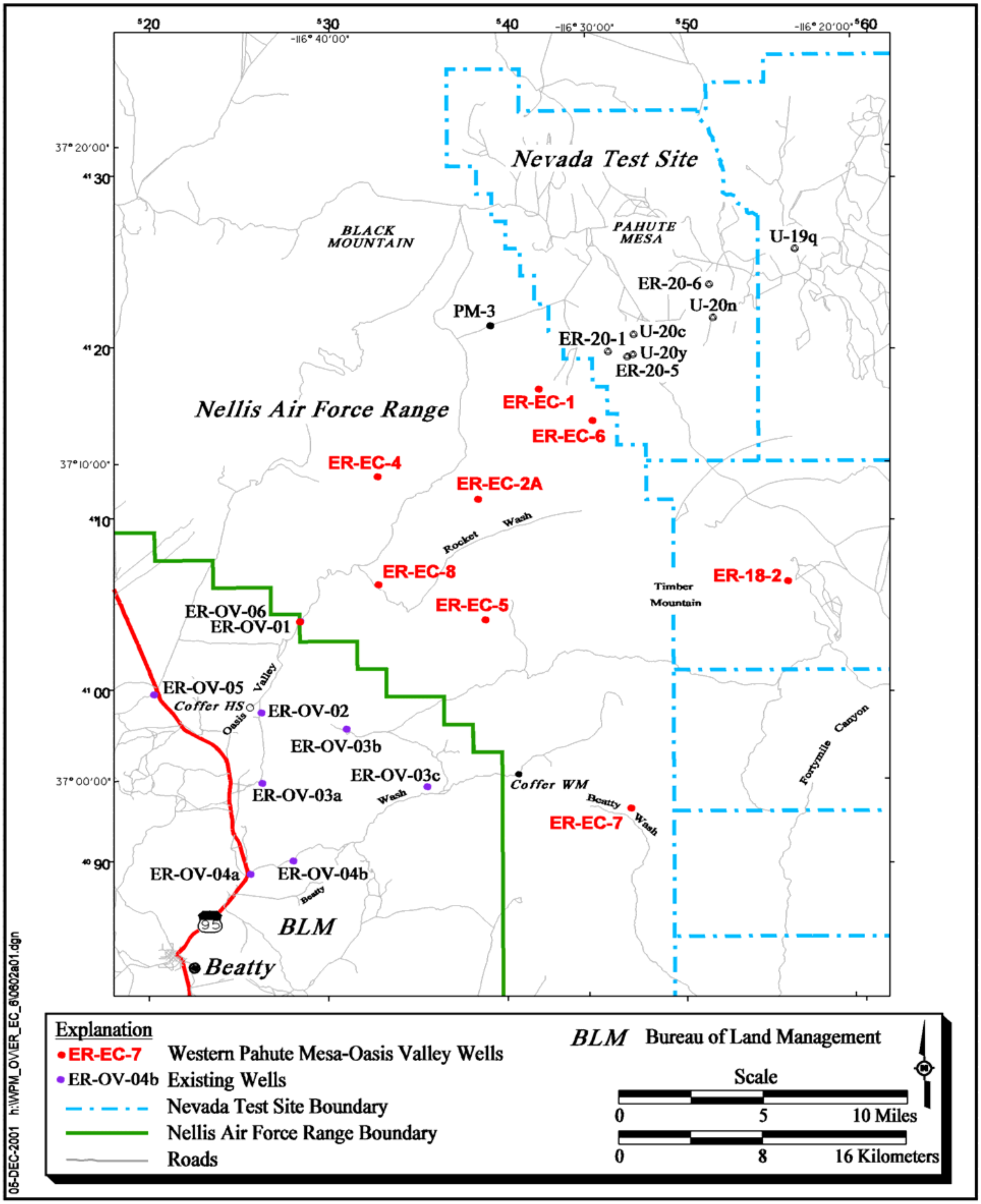


Figure A.1-1
Area Location Map

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

A.2.1 Water Level Measurement Equipment

Following is a general description of the equipment used by ITLV for measurements and monitoring during development and testing. Other equipment used for specific parts of the program are described in the appropriate section. Depth-to-water measurements were made with a metric Solinst e-tape equipped with a conductivity sensor. The primary pressure transducers (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 was 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. A nonvented Geokon PXD (Model 4500 HD S500, vibrating wire type) was also employed for a short time. Data is transmitted uphole digitally to a Campbell Scientific CR10X datalogger located on the surface using SDI 12 protocol. The rated accuracy of the PXDs are 0.02 percent full scale (FS). Barometric pressure was measured with a Vaisala Model PTB 101B barometer housed with the datalogger. The flow rate was measured using an inline Foxboro magnetic flowmeter. 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 all monitoring is in Julian Days, as recorded by the datalogger. Julian Days are consecutively numbered days starting with January 1 for any year. This format maintains the correspondence of the presentation with the actual data, and presents time as a convenient continuous length scale for analysis purposes.

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

Date	Activities
2/18/2000	Baker Hughes runs basket and gauge to 4,450 ft bgs. ITLV measures water level at 760.93 ft bgs. Baker Hughes sets lower bridge plug/PXD at 4,375 ft bgs. ITLV subsequently measures water level at 761.24 ft bgs. Baker Hughes sets upper bridge plug/PXD at 2,950 ft bgs. ITLV subsequently measures water level at 758.10 ft bgs. ITLV then installs Design Analysis 0-15 psig PXD.
2/23/2000	ITLV removes PXD, and measures water level at 754.59 ft bgs. Baker Hughes removes both bridge plugs.
3/14/2000	ITLV measures water level at 750.11 ft bgs, then installs Design Analysis 0-15 psig PXD for predevelopment water level monitoring.
4/14/2000	ITLV removes PXD and subsequently measures water level at 747.92 ft bgs. Note that the static water level has risen 2.19 ft.
6/19/2000	Begin mobilization to site. Level of Sump #1 is 5.6 ft (from drilling activities).
6/22/2000	Drill rig on site and set up. Access line run to 1,309.2 ft bgs.
6/27/2000	Pump on site, assembled, and wired. Pump and sixteen joints run into well.
6/28/2000	Pump landed at 1,290.83 ft bgs; intake at 1,244.58 ft bgs. ITLV measures water level at 747.65 ft bgs. ITLV installs Design Analysis 0-30 psig PXD. Start pump. Drawdown is unexpectedly large. Shut pump down and replace PXD with Design Analysis 0-75 psig PXD. Start pump and check functionality up to 109 gpm. Large drawdown requires that PXD be lowered to follow increasing drawdown.
6/29/2000	Check drawdown response at pumping rates up to 120 gpm; PXD must be lowered to follow drawdown. Surge well by periodically stopping pump. Pump overnight at 100 gpm.
6/30/2000	Check drawdown response at pumping rates up to 180 gpm. PXD must be lowered to follow drawdown. Pump overnight at 170 gpm.
7/1/2000	Surge well by shutting down periodically. Pump overnight at 70 gpm.
7/2/2000	Pump during the day at 70, 120, and 170 gpm. Lower PXD to follow increasing drawdown. Pump overnight at 170 gpm.
7/3/2000	ITLV removes PXD. Pump is shut down. DRI rigs up for flow logging. Pump is started at 70 gpm; pump overnight at 70 gpm.
7/4/2000	DRI conducts flow logging while pumping at 70 and 120. Pump overnight at 170 gpm.
7/5/2000	DRI conducts flow logging while pumping at 170 gpm. ITLV and DRI collect discrete bailer samples from 3,300 ft bgs. The pump was shut down and DRI installs a check valve. The pump was restarted to fill the production tubing, and then shut down.
7/6/2000	ITLV and DRI install Geokon 0-500 psig PXD to monitor recovery.
7/6-18/2000	Monitor water level recovery.
7/18/2000	Begin constant-rate test pumping at 120 gpm. PXD output becomes erratic. Pump is shut down. Monitor recovery overnight.
7/19/2000	Restart constant-rate test pumping at 120 gpm. PXD output again becomes erratic. Pump is shut down. Begin to install Design Analysis 0-75 psig PXD; troubleshoot PXD problems.
7/20/2000	Install 0-75 psig PXD. Start constant-rate test pumping at 120 gpm, backpressure 145-150 psig. PXD must be lowered as drawdown approaches PXD set depth.
7/20-29/2000	Constant-rate test.
7/27/2000	ITLV, LLNL, DRI, and UNLV-HRC collect wellhead composite samples.
7/29/2000	Shut down pump. Raise PXD as water level rises and pressure on PXD nears upper end of range.
7/29-8/7/2000	Monitor water level recovery.
8/7/2000	ITLV removes PXD. Recovery is not complete, water level is still approximately 3 ft below static water.
8/8/2000	DRI removes check valve. BN begins to remove pump.
8/9/2000	BN removes pump from well. DRI runs ChemTool logs. DRI runs spinner flow log to depth of 4,910 ft bgs. DRI runs thermal flow logs.
8/10/2000	GyroData runs deviation log.
8/11/2000	Baker Hughes runs junk catcher/wireline feeler to 3,900 ft bgs. Baker Hughes then sets a lower bridge plug at 3,700 ft bgs and an upper bridge plug at 2,450 ft bgs.
8/14/2000	BN begins to run permanent sampling pump.

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

Date	Activities
8/15/2000	BN lands permanent sampling pump at 1,395.58 ft bgs; intake set at 1,372.39 ft bgs. Test functionality of pump after troubleshooting electrical problems. Load VSDs for return to manufacturer.
8/16/2000	ITLV measures water level at 757.77 ft bgs, and installs 0-15 psig PXD to monitor remainder of recovery. Begin site demobilization.
8/16-26/2000	Demobilization from site.

BN - Bechtel Nevada
ft - Feet
DRI - Desert Research Institute
gpm - Gallons per minute
ITLV - IT Corporation, Las Vegas Office
VSD - Variable speed drive
UNLV-HRC - University of Nevada at Las Vegas - Harry Reid Center
psig - Pounds per square inch gauge
LLNL - Lawrence Livermore National Laboratory
PXD - Pressure transducer
bgs - Below ground surface
in. - Inch(es)

- 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 processed to various forms of head, with or without barometric correction. The additional required data, which may be needed for further processing, is included in this report. Note that the data files contain a column in which the raw pressure measurement has been processed to a head measurement in terms of feet of water column above the PXD. The conversion was based on an approximate standard density for water, and was for field use in monitoring downhole conditions. In Section A.3.2, a well-specific value for the water density is derived and used for the processing of the drawdown response into 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. Atmospheric pressure (i.e., 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 approximately equal to 69 mbar. For presentation convenience, the scales are not matched exactly, but are close enough so that the relative magnitude of the pressure changes is apparent. Complete electronic data files are included on an accompanying CD which allows the user to evaluate details of barometric changes and aquifer response, as desired.

- The data on water density in this report are presented in terms of the 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/psi). This is a convenient form for use in calculations. Later in the text, the derived densities are discussed in terms of specific gravity.

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

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

A.2.2 Predevelopment Water Level Monitoring

Following construction of Well ER-EC-2a, the water level was monitored with a PXD and datalogger for a period of about five and one-half weeks to establish the equilibrium composite head for this well. Figure A.2-1 shows the results of this monitoring. An electronic copy of this data record can be found on the CD as file EC2a_Water-LevelMon.xls. A readme text file is included in Attachment 5, which explains how the data may be accessed.

A.2.3 Depth-to-Water Measurements

Table A.2-2 presents composite depth-to-water measurements made in Well ER-EC-2a following well completion. These measurements indicate that the water level continued to rise for a long period after drilling, including during the bridge plug/PXD measurements. The last two measurements (4/14/2000 and 6/28/2000) may closely approximate composite equilibrium conditions. Figure A.2-2 shows a plot of these water levels and also includes several water-level measurements taken during logging after drilling. The plot suggests a long-term recovery curve. This will be discussed further in Section A.3.1 and Section A.3.2.

A.2.4 Interval-Specific Head Measurements

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

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

Date	Time	Depth-to-Water bgs		Barometric Pressure (mbar)
		Feet	Meters	
2/18/2000	10:30	760.93	231.93	- - -
3/14/2000	10:30	750.11	228.63	853.57
4/14/2000	8:30	747.92	227.97	843.13
6/28/2000	- - -	747.65	227.88	849.68

bgs - Below ground surface
mbar - Millibar

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 pressure 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 not set).

4. Lower bridge plug to set-depth plus 50 ft and collect four or more pressure readings (bridge plug not 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.

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

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

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

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

12. After five days, measure water level in upper interval with an e-tape, then remove equipment and download dataloggers.

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

A.2.4.2 Pressure/Head Measurements

The bridge plug/PXD assemblies were supplied and installed by Baker Hughes Corporation on their own wireline. The PXDs were Sunada Model STC8064A with a rated measurement accuracy of 0.1 percent FS. PXDs with various pressure ranges were used to suit the depth of installation. Information was collected by a built-in datalogger recording on a time interval of 5 minutes following an initial 20-minute delay from the start of the datalogger. The datalogger time is in decimal hours. Since there was no data connection to the surface once the bridge plugs were 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 to determine the behavior of the intervals.

Table A.2-3 shows the interval-specific pressure and head measurements, including the calibration data. Graphs of the interval monitoring are included in Section A.3.0. Note that the corrected depths for the bridge plug given in Table A.2-3 are slightly different from the PXD set depths that had been specified and listed in the Morning Reports. The depth location corrections are discussed in Section A.3.2.1. Also note that the upper interval water level shown is probably not the actual equilibrium head for the upper interval. As mentioned in Section A.2.3, the well composite water level continued to rise for at least two months after the bridge plug head measurements. The datalogger files for the monitoring of the pressure transducers can be found on the enclosed CD, labeled as follows: EC2Agradient.xls (upper interval), EREC2AU.xls (middle interval), and EREC2AL.xls (lower interval).

Table A.2-3
Interval-Specific Head Measurements

Interval	Comment	Depth (ft bgs)	Depth (m bgs)	PXD Measurement (psig)
Upper	Final Head[a]	754.59 (e-tape)	230.00	--
Middle	Reference Head - composite of upper two intervals	761.24 (e-tape)	232.03	942.42
	Bridge Plug set depth minus 50 ft	2,899.00	883.61	920.83
	Bridge Plug set depth - post set	2,948.99	898.85	942.19
	Bridge Plug set depth plus 50 ft	2,998.99	914.09	963.86
Lower	Reference Head - composite of all three intervals	760.93 (e-tape)	231.93	1,557.50
	Bridge Plug set depth minus 50 ft	4,323.96	1,317.94	1,535.93
	Bridge Plug set depth - post set	4,373.95	1,333.18	1,526.70
	Bridge Plug set depth plus 50 ft	4,423.95	1,348.42	1,579.05

[a]The well is still recovering.

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

A.2.5 Pump Installed for Development and Testing

A high-capacity pump was temporarily installed for well development and testing. This pump was later replaced with a lower capacity, dedicated pump for long-term sampling. The development and testing pump was the highest production-rate pump available that would physically fit into the well and still allow an access line to pass by. The access line was required to guide the flow logging and discrete sampling tools past the pump and into the completion intervals. 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 (#01F88215 and #01F88216) with 43 stages each, and a 130-horsepower motor assembly (375 Series, 2 sections - #21D48009 and #21D48010). Manufacturer's specifications for this pump are included in Attachment 1. Note that the pump units total 30.0 feet 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-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 1,290.83 ft bgs, which placed the pump intake at 1,244.58 ft bgs.

An Electra 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 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 the Foxboro 1.75-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 back pressure of 150 psig (nominal) imposed at the surface to meet the operational requirements of the pump. Note that the drawdown data in this table for the various pumping rates are not stabilized drawdown values, but are instantaneous values measured during development. Because this well continued to drawdown during the course of pumping, these values only provide a rough approximation of relative drawdowns. This information indicates the range of drawdowns that occurred during development and testing.

The data in Table A.2-4 may indicate that there was a small reduction in the well drawdown at the same production rates during the course of development; however, no significant changes were observed. Three flow rates were selected for the steps to be used in development activities: 70, 120, and 170 gpm. In practice there may be small variations in actual pumping rates that result from variables in pumping conditions.

A.2.6 Development

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

Table A.2-4
Pump Performance

Date	Time	VSD Setting (Hz)	Production Rate (gpm)	Approximate Drawdown[a] (ft)
6/29/2000	7:53	47.6	70.45	112.47
6/29/2000	9:07	50.4	101.11	136.34
6/29/2000	10:20	53.9	121.13	192.47
6/29/2000	11:57	51.7	100.96	172.37
7/1/2000	7:38	66.9	170.41	381.75
7/1/2000	16:52	56.2	120.79	264.87
7/1/2000	19:00	49.1	70.46	160.14
7/3/2000	9:51	68.3	170.78	388.22
7/3/2000	20:15	49.3	70.52	--

Note: Significant figures reported as recorded from field documents.

[a]Drawdown derived from PXD pressure data using a density of 2.307 feet per square inch.

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

intended to accomplish hydraulic development in preparation for hydraulic testing.

Restoration of the natural water quality includes removal of all nonnative fluids introduced by the drilling and construction activities and reversal of any chemical changes that have occurred in the formation due to the presence of those fluids. This objective of development addresses the representativeness of water quality parameter measurements and chemical analyses of samples taken from the well. Another aspect of this objective was to remove nonnative water from completion intervals receiving water due to natural gradient flow from other intervals and reverse chemical changes that have occurred as a result. Since the well completion cross-connects intervals of different heads and hydraulic conductivities, such natural circulation was presumed to have been occurring since the well was drilled. Measurement of this circulation is addressed later under flow logging during pumping (Section A.2.7) and thermal flow logging (Section A.2.11). 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.3.7.

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

Monitoring during development included hydraulic performance data and a variety of general water quality parameters intended to evaluate both the effectiveness of the development activities and the status of development. These parameters included drawdown associated with different production rates (to evaluate improvement in well efficiency), visual observation of sediment production and turbidity (to evaluate removal of sediment), and water quality parameters (temperature, pH, EC, turbidity, DO, and Br^- concentration) to evaluate restoration of natural water quality. With regard to the Br^- concentration, the drilling fluid used during drilling was “tagged” with lithium bromide to have an initial concentration from about 10 mg/L to approximately 100 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 30 psig PXD was installed, but this was replaced with a 0 to 75 psig PXD as soon as the magnitude of drawdown became apparent. The 0 to 75 psig PXD range was the greatest available, but was not sufficient to accommodate the amount of drawdown produced. Consequently, the PXD had to be moved vertically during the course of testing to match the drawdown level. This introduced discontinuities into the drawdown record. While not ideal, the various segments of the record can be adjusted to produce smooth, accurate drawdown curves. To guide such adjustment, the pumping rate record must be consulted to distinguish PXD movement from changes in pumping. Information on the 0 to 75 psig PXD installation and calibration is presented in Table A.2-5. On July 6, 2000, a Geokon PXD (0 to 500 psig) was installed to monitor recovery. The Geokon was removed prior to the constant-rate test.

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

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

Design Analysis H-310 PXD SN 2270, 0-75 psig					
Install Date: 6/28/2000					
Installation Calibration Data: 6/28/2000					
Static water level depth: 752.86 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
WRL/TOC[a]	490.00	515.00	530.00	545.00	560.00
PXD psig	0.7598	11.478	17.824	24.149	30.537
Delta depth (ft): Cal5 - Cal2					45.00
Delta psi: Cal5 - Cal2					19.059
Density ft of water column/psi: delta depth/delta psi (ft/psi)					2.361
Equivalent ft water: PXD psig (at Cal 5) x density of water (ft/psi)					72.10
Calculated PXD installation depth: static water level + equiv. ft water					824.96

[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 - Pounds per square inch
psig - Pounds per square inch gauge

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 seven 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 several times to assess well and pump performance. However, the usefulness of results is limited since the well neither recovered beforehand nor stabilized during the segments of the protocol. Water quality was monitored using field laboratory analysis of grab samples.

A.2.6.2.1 Pumping Rates and Hydraulic Response

Figure A.2-3 shows the datalogger record of the pumping rate and hydraulic response during the development phase. The barometric pressure variation during development is not presented since the barometric variation was so small relative to the drawdown that it does not significantly factor into the apparent response. Figure A.2-4 shows an expanded view of a representative segment of the development to illustrate more clearly the response. An electronic file of these data can be found on the attached CD (file name EC-2a_Aqtest_WD.xls). The first day shows the initial testing of the pump/VSD to determine the operating range of the pump (Table A.2-4) and resultant drawdown. Days two through four show surging and step-drawdown protocol. The pump was generally operated at rates of about 70, 120, and 170 gpm during the development phase. The latter production rate was close to the maximum pumping rate. Maximum drawdown during pumping was on the order of 400 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 tubing and surface hose 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 much less than the other WPM-OV wells. Secondly, there is a delay due to the startup procedure, which bypasses the initial production around the instrumentation to avoid affects of sediment on the instruments. The typical total delay for flowmeter readings to begin is several minutes, as can be seen on Figure A.2-5. Thirdly, 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 decreases as the TDH increased until the discharge system was filled and TDH stabilized. This effect can be seen in the early-time drawdown; an example is also presented in Figure A.2-5. 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 specific 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. 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 back pressure system. Bechtel Nevada (BN) protocol for starting the pump requires the back pressure valve be initially open, and it is then closed to produce the required back pressure after the full flow is established. The additional back pressure causes a reduction in pumping rate, which is then compensated by the VSD in Mode 2. This can also be seen in Figure A.2-5. This procedure applies both to development and the constant-rate test. In Well ER-EC-2a, the application of back pressure is proportionally a larger adjustment relative to the head buildup above the pump as the production tubing is filled compared to the other WPM-OV wells. This is due to the shallow depth to water; the combination of head from the lift to the surface, friction losses, and the back pressure has to achieve the minimum required TDH for the pump.

A.2.6.2.2 Surging and Step-Drawdown Protocol

Figure A.2-3 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 the water is injected into the formation under the instantaneous head differential. This action produces a reverse head differential which “surges” the well. However, this effect is not obvious in the well response due to large drawdown and attendant casing storage. In this case, the reverse flow simply speeds the apparent recovery of the well. The volume of backflow is similar to the storage volume of the casing over the early-time portion of the recovery curve where there is a very high rate-of-change and a discontinuity with the later curve. Figure A.2-5 shows a representative instance of surging expanded to illustrate the detail. The surge merges into the recovery curve. On startup, a similar effect can be seen in the drawdown curve. Also, the effect of the low initial TDH discussed earlier further increases the rate of initial drawdown.

These 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, assuming the back pressure valve was not opened very much 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 70, 120, and 170 gpm), producing drawdowns of the order of 160, 260, and 390 feet. Drawdown 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.2-4 shows a representative instance of the step-drawdown protocol. The step-drawdown protocol was of limited use in evaluating changes in well performance for the following reasons. The well did not approach equilibrium before the protocol was initiated, and did not approach an equilibrium drawdown during the period of each step. The well, in fact, was still drawing down at a fairly high rate at the end of each step. The schedule for development could not accommodate the much longer time frame that would have been required to use the protocol correctly.

A.2.6.2.3 Other Observations

During development, visual observations were made of the water discharge, primarily whenever the pump was started, to monitor the amount of sediment produced. Logbook entries indicated that produced water was typically turbid for about a minute, after which the water cleared.

A.2.7 Flow Logging During Pumping

Downhole flow logging (spinner tool) while pumping was conducted after the development phase. Data on the proportional inflow of water from different completion intervals would be used for determining 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-2a 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 for the step-drawdown protocol during development (i.e., 70, 120, and 170 gpm) so that results could be directly compared with previous observations.

Flow logging (spinner tool) was conducted by the DRI on July 4 and 5, 2000. A complete program of flow logging was run, including both stationary measurements and trolling logs. A temperature log was also recorded in combination with the flow logging to help in identifying production patterns and specific production locations. Logging runs at three different speeds and in both directions were run to evaluate flow under all test conditions.

A.2.7.1.1 Equipment and Calibration

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

The fullbore flowmeter has a collapsible impeller that opens to cover a much larger percentage of the casing cross section than a standard fixed-blade impeller. Centralizers are run in conjunction with the sensor tools to center the tool string in the wellbore. The temperature tool is run to provide temperature 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 a 5.5-in. casing. The flow logging tool calibration was also checked on site against the production flowmeter readings at the three pumping rates by measuring uphole velocities in the 5.5-in. casing above the uppermost screen.

A.2.7.1.2 Logging Methodology

Seven 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 1,300 to 4,890 ft bgs. The bottom of the well (soft sediment) was tagged by DRI at 4,965 ft bgs. The logging runs were 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 going up. This four-step sequence was repeated for each of three discharge rates, 70, 120, and 170 gpm. Stationary flow measurements (tool held motionless in the well) were taken at the following locations: above the upper completion interval (1,500 ft bgs), between the upper and the middle completion intervals (2,600 ft bgs), and between the middle and the lower completion intervals (3,800 ft bgs). Table A.2-6 lists the trolling flow logs that were run. Stationary measurements are listed in Table A.2-7.

A.2.7.2 Flow Logging Results

The results of the trolling flow logs are presented in Figures A.2-6 through A.2-11. Figure A.2-6 and Figure A.2-7 show flow logs for two different trolling speeds (20 fpm downwards and 60 fpm downwards) at a well production rate of 70 gpm. Figure A.2-8 and Figure A.2-9 show flow logs for the same two trolling

Table A.2-6
Listing of Trolling Flow Logs

Run Number	Date of Run	Direction of Run	Run Speed (fpm)	Surface Discharge (gpm)	Run Start/Finish (ft bgs)
ec2amov01	7/04/2000	Down	20	70	1,318 - 4,926
ec2amov02	7/04/2000	Up	40		4,892 - 1,341
ec2amov03	7/04/2000	Down	60		1,342 - 4,892
ec2amov04	7/04/2000	Down	20	120	1,342 - 4,891
ec2amov05	7/04/2000	Down	60		1,338 - 4,888
ec2amov06	7/05/2000	Down	20	170	1,340 - 4,888
ec2amov07	7/05/2000	Down	60		1,339 - 4,894

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 (gpm)
ec2asta01	Between middle and lower CZ	112.58	70	3,800	0.0
ec2asta02	Between upper and middle CZ	105.90		2,600	48.18
ec2asta03	Above upper CZ	102.83		1,500	70.87
ec2asta04	Between middle and lower CZ	112.71	120	3,800	0.0
ec2asta05	Between upper and middle CZ	106.18		2,600	80.63
ec2asta06	Above upper CZ	103.09		1,500	121.22
ec2asta07	Between middle and lower CZ	112.96	170	3,800	0.0
ec2asta08	Between upper and middle CZ	106.32		2,600	109.32
ec2asta09	Above upper CZ	103.02		1,500	171.20

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

configurations at a production rate of 120 gpm, and Figure A.2-10 and Figure A.2-11 show logs of the same two trolling configurations at a production rate of 170 gpm. Only six of the seven trolling log runs are presented; the one upward run, at 40 fpm/70 gpm, produced results that were noisy and inconsistent. The upwards trolling configuration seems to produce results that are somewhat suspect.

The trolling flow logs indicate that approximately one-third of the total production in the well originated from the upper completion interval (1,635 to 2,244 ft bgs) and about two-thirds from the middle completion interval (3,027 to 3,597 ft bgs).

A more complete discussion of the distribution of production can be found in Section A.3.4.2.

The results from the stationary flow measurements also indicate that about one third of the total flow originated from the upper completion interval; the remainder of the flow originated from the middle interval. No flow was measured from the lower interval.

A.2.7.3 Recovery After Flow Logging

After flow logging and discrete sampling was completed, the check valve was installed and then a PXD was installed to monitor recovery. In order to accommodate the great pressure range involved by the large water-level changes anticipated for recovery and for the subsequent constant-rate test, a high-range PXD was installed. However, it was not installed until the day after the pumping was terminated, so the early part of the recovery record was not recorded. Figure A.2-12 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 very 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 July 20, 2000, and continued for 9 days until July 29, 2000. In addition, pumping during the constant-rate test served to continue and complete the development process to restore natural water quality for sampling purposes. Following the pumping period, head recovery was monitored for nine days until August 7, 2000. Again, due to the very slow rate of recovery for the last several feet of head, recovery monitoring was discontinued prior to full recovery to accommodate the work schedule for installing bridge plugs and the permanent sampling pump.

A.2.8.1 Methodology

A continuous datalogger record was captured for barometric pressure and head pressure on the PXD in the well 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 daily.

A pumping rate of 120 gpm was chosen for the test. This rate resulted in sufficient drawdown, below the head in the lower completion interval, to substantially stress that interval. There was no advantage to inducing greater drawdown, and would have caused additional disruption for the PXD data collection. The Geokon PXD, used to monitor recovery for development, failed to work at the start of the constant-rate test and was pulled on July 19, 2000. A PXD with a range of 0 to 75 psig, the maximum available, was installed for the constant-rate test. The PXD was installed on July 20, 2000, at a calculated depth of 920.48 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 2271, 0-75 psig					
Install Date: 7/20/2000					
Installation Calibration Data: 7/20/2000					
Static water level depth: 749.42 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
WRL/TOC[a]	475.00	525.00	568.00	611.00	654.00
PXD psig	--	17.911	36.326	54.586	72.841
Delta depth (ft): Cal5 - Cal2					129.00
Delta psi: Cal5 - Cal2					54.930
Density ft of water column/psi: delta depth/delta psi (ft/psi)					2.348
Equivalent ft water: PXD psig (at Cal 5) x density of water (ft/psi)					171.06
Calculated PXD installation depth: static water level + equiv. ft water					920.48

[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 - Pounds per square inch
psig - Pounds per square inch gauge

A.2.8.2 Hydraulic Data Collection

Figure A.2-13 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.2-14 shows the head record for both the pumping period and the recovery period as well as the barometric pressure record. Note that the barometric record in Figure A.2-14 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. These graphs illustrate the datalogger record and major features of the respective activities. To accommodate the full extent of the drawdown, the PXD had to be lowered once during the pumping period, and was then raised once during recovery. Figure A.2-15 shows an expanded view of the

PXD drawdown record to illustrate the reset of the PXD; the reset during recovery is similar. The average pumping rate was 120.75 gpm. The data file on the accompanying CD is EC2a_Aqtest_HT.xls. The data record was initially clean, but became slightly noisy toward the end of the test. The cause of the noise is not known, but it is not believed to be an instrumentation problem. Rather, the PXD noise may be the result of noise from the pump and/or pumping rate fluctuations. Figure A.2-16 shows an expanded view of the PXD pressure and pumping-rate records, and illustrates that the noise in the PXD pressure record and fluctuations in the pumping-rate record both seem to increase with time.

A.2.9 Water Quality Monitoring

Water quality monitoring of the well discharge was conducted during pumping to provide information on water chemistry and to indicate when natural groundwater conditions predominate in the pumping discharge. Certain parameters such as Br^- ion concentration, pH, EC, turbidity, and DO were expected to decline as development progressed, indicating natural groundwater quality as opposed to water affected by drilling and completion activities. Also, parameter values should stabilize after prolonged pumping and development as natural groundwater permeates the well environment. Rebound of parameter values at the beginning of each cycle of pumping was expected to decline toward the values observed toward the end of the previous cycle as development progressed.

The standard parameters that were monitored during development and testing of Well ER-EC-2a include the following: pH, EC, temperature, turbidity, DO and Br^- ion. In addition, lead and tritium were sampled in compliance with the schedule in the Fluid Management Plan (including waivers) (DOE/NV, 1999). Grab samples were obtained every two hours when possible and analyzed for all the water quality parameters.

Pumping for well development was initiated on June 28, 2000. In-line monitoring was not conducted at this well as the Hydrolab® H20 Multiprobe was not installed. The failure to perform this water quality monitoring was an oversight and a nonconformance report is being filed. Grab sample monitoring was conducted as usual, being initiated on June 28, 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 June 28, grab samples were collected and analyzed every two hours, primarily during daylight hours until 16:20 on July 5, 2000. For the constant-rate pumping test, samples were collected and analyzed every two hours, twenty-four hours a day, beginning on July 20 and ending on July 29, 2000.

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

- YSI 58 (DO)
- YSI 3500 Multimeter (for pH, EC, and temperature)
- HF Scientific DRT-15C Turbimeter (turbidity)
- Orion 290A (bromide)
- HACH DR100 Colorimeter Kit (lead)

The results of grab sample monitoring have been compiled and are presented in Attachment 2. The results have been related to the pumping rate, total discharge, and phase of development or testing. Additionally, two graphs have been derived showing water quality parameters versus total discharge in gallons. Figure A.2-17 shows EC, pH, and DO. Figure A.2-18 shows turbidity and Br^- concentration.

As shown in Figure A.2-17, the pH remained fairly constant throughout the constant-rate test. EC and DO showed slightly more variations, but within the range of normal field laboratory error. Fluctuations mostly occurred during the development phase with all three parameters. At the end of the constant-rate test, EC leveled off at about 710 µmhos/cm, pH at about 7.9, and DO at about 3.0 mg/L.

Turbidity remained mostly below 1.0 nephelometric turbidity units (NTU) with only a few spikes during development up to 31 NTU (Figure A.2-18). The second highest measurement, 15.3 NTU, was measured from a bailer sample obtained from the middle completion interval (3,300 ft bgs). The bromide concentration fluctuated between 0.4 and 1.0 mg/L, averaging a little higher than other WPM-OV wells at around 0.75 mg/L. There were no long-term trends in turbidity or Br^- concentration which indicate any continuing progress in development.

The temperature of the samples remained fairly constant, averaging 40.1EC and varying only 2.5 degrees between 38.5 and 41.0EC. Grab sample temperature results are not depicted graphically. Temperature differences can often fluctuate depending on ambient air temperature and the efficiency with which the temperature of the wellhead sample is measured. Downhole temperature values are discussed in Section A.2.11 where ChemTool logging results are presented. The PXD also collected temperature data, but the results are not depicted. This information is contained in the CD (files EC2a_Aqtest_WD.xls and EC2a_Aqtest_HT.xls). The results of lead and tritium monitoring are presented in Section A.4.0, Environmental Compliance.

The bailer sample from 3,300 ft bgs (middle completion interval) produced anomalous results of 7.12 for pH, 918 µmhos/cm for EC, and 5.45 mg/L for DO. For the Br^- concentration there was a large spike to 3.17. The same bailer sample produced a dubious temperature measurement of 35.1EC, probably due to the time lag for handling at the surface.

A.2.9.2 In-Line Monitoring

In-line monitoring was not conducted at this well as explained in Section A.2.9.

A.2.10 Groundwater Sample Collection

Two types of fluid samples were collected for characterization of the groundwater in Well ER-EC-2a: downhole discrete bailer samples and composite samples from the wellhead.

A.2.10.1 Downhole Discrete Sampling

There are two different purposes for the collection of discrete downhole samples. The first is to collect at a particular depth to obtain a sample that represents the specific water quality at that depth or in the corresponding completion interval. The second purpose is to collect a sample that represents 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 will be collected, and (2) a pumping rate can be maintained that will ensure a representative sample of the interval. Discrete sampling intervals are typically determined after initial well development and downhole flow and temperature logging.

On July 5, 2000, a discrete sample was obtained from a depth of 3,300 ft bgs, at a pumping rate of approximately 170 gpm. The sample was obtained using a DRI logging truck, wireline, and discrete bailer. The bailer was decontaminated using the methodology in DOP ITLV-UGTA-500, “Small Sampling Equipment Decontamination,” and SQP ITLV-0405, “Sampling Equipment Decontamination.” An equipment rinsate sample was collected from the decontaminated bailer prior to collection of the discrete samples. The samples were processed according to the following procedures: DOP ITLV-UGTA-302, “Fluid Sample Collection”; SQP ITLV-0402, “Chain of Custody”; and SQP ITLV-0403, “Sample Handling, Packaging, and Shipping.” Samples were immediately stored with ice and transported to secure refrigerated storage. Samples were obtained for the following laboratories: Paragon, Los Alamos National Laboratory (LANL), University of Nevada, Las Vegas - Harry Reid Center (UNLV-HRC), and LLNL.

The final, validated results of the July 5, 2000, discrete samples have been tabulated and are presented in Attachment 3. These results can be compared to the results of the discrete groundwater characterization sample taken during drilling (before well completion). That sample was obtained by bailer on February 9, 2000, from a depth of 952 ft bgs (NNSA/NV, 2001).

A.2.10.2 Groundwater Composite Sample

The purpose of this sample is to obtain a composite of as much of the well as possible. The composite groundwater characterization sample was collected at the end of the constant-rate pumping test from the sampling port at the wellhead. Since this sample is meant to represent a composite of the whole well, there are two criteria for the sample to be the most representative: (1) the sample should be obtained after pumping for the longest possible time, and (2) the pumping rate should be as great as possible in order for the component water production to include as many completion intervals as possible. From the results of the flow logging, the proportional composition of the composite sample was also determined. As discussed in Section A.2.7.2, the flow logging showed that about 64 percent of the flow into the well originated in the middle completion interval (at a production rate of 170 gpm).

On July 27, 2000, a composite characterization sample was collected from the wellhead sampling port directly into sample bottles. A field duplicate sample was obtained concurrently. A constant production rate of 120 gpm was maintained during the sampling event, the same rate used during the constant-rate test. At the time of sampling, approximately 2,400,000 gallons of groundwater had been pumped from the well during development and testing activities. The samples were processed according to the same procedures used for the discrete sampling. Samples were immediately put on ice and transported to secure refrigerated storage. Samples were collected for the following laboratories: Paragon, UNLV-HRC, LLNL, LANL, and DRI. The final, validated results of the July 27, 2000, composite sample have been tabulated and are presented in Attachment 3.

A.2.11 Thermal Flow Log and ChemTool Log

Thermal flow logging was conducted at the very end of the development and testing program to determine flow in the well under ambient conditions. The resulting flow information may differ from that of the thermal flow logging conducted in the open borehole before well completion because it is specific to the completion intervals, and reflects remediation of conditions imposed by drilling. The ChemTool provides a depth log of temperature, pH, and EC. The thermal flow and ChemTool logging was conducted by DRI on August 9, 2000. In addition, a spinner flow log was run because apparent flow rates exceeded the maximum range of the thermal flow log.

A.2.11.1 Methodology

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

A.2.11.2 Results

The results of the ChemTool logging are presented in Figure A.2-19. The ChemTool log shows relatively constant EC from above the upper completion interval down to about 4,300 ft bgs, the top of the lower completion interval. The log is fairly clean and the values fluctuate within a narrow range of 750 to 800 μmhos/cm. At about 4,300 ft bgs, the EC values trend sharply upward, which may be related to the apparent stagnant condition in the lower interval. There is also a large spike at the top of the well which may be attributed to a slug of turbid water release by the removal of the check valve on August 8. The pH is also fairly stable from the top of the upper completion interval to the bottom of the well, ranging between 8.3 and 8.6. The log shows a pH decrease above the upper completion interval. At the bottom of the well below 4,300 ft bgs, the pH also sharply rises, approaching 11.0. Again, this may be related to the apparent stagnant conditions in the lower completion. The similarities of the pH and EC logs, along with the results of flow logging, indicate that the bottom of the well was not affected by development. The temperature log shows a gradual increase with depth from 34EC to 50EC, with the largest deflection occurring at the bottom of the middle completion interval.

The thermal flow log data, as supplied by DRI, is presented in Table A.2-9. The data were collected under nonpumping conditions at four stations: 1,870; 2,600; 3,300; and 3,700 ft bgs. Downward flow was measured at 1,870 and 3,300 ft bgs, and no flow was indicated at 3,700 ft bgs. The measurement at 2,600 ft bgs produced no response. In addition, a spinner-tool log was run to a depth of 4,910 ft bgs to measure flow rates higher than the thermal flow log upper limit. This log is shown in Figure A.2-20.

Table A.2-9
Thermal Flow Log Results

Station Depth (ft bgs)	Response (sec)	Flow Rate (gpm)	Velocity (fpm)
1,870	-2.20 +/- 0.790	-0.458 +/- 0.165	-0.449 +/- 0.1614
3,300	-0.56 +/- 0.108	-2.200 +/- 0.424	-2.157 +/- 0.416
3,700	15.00 +/- 15.000	0.000 +/- 0.000	0.000 +/- 0.000

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

Internal diameter at all stations was 5.0 inches.

Note: Positive values indicate upward flow; negative values indicate downward flow.

A.2.12 Sampling Pump and Bridge Plug Installation

On August 11, 2000, Baker-Hughes, with oversight from a BN logging engineer, tripped-in and set two bridge plugs. Prior to setting the bridge plugs, Baker-Hughes ran a gauge basket into the well to a depth of 3,900 ft bgs to check the well for passage of the bridge plug setting assembly and collect any debris. Upon removal of the tool, some filter pack sand was observed in the gauge basket. The bottom bridge plug was set at 3,700 ft bgs (top of plug at 3,700, rubber seals at 3,702.2, and bottom of plug at 3,704 ft bgs). The top bridge plug was set at 2,450 ft bgs (top of plug at 2,450, rubber seals at 2,452.2, and the bottom of plug at 2,454 ft bgs). Crossflow between the completion intervals is prevented by the bridge plugs.

On August 15, 2000, a dedicated sampling pump was installed in Well ER-EC-2a by BN with the assistance of the Electrical Submersible Pump (ESP) Systems representative. The pump assembly was placed using 2 7/8-in. outside diameter (od) stainless steel pipe. The bottom of the pump assembly was landed at 1,395.53 ft bgs. A 3.05 ft stickup makes the entire string a length of 1,398.58 ft. The pump intake is at 1,372.39 ft bgs and the top of the pump assembly is at 1,363.01 ft bgs. The total length of the pump assembly, not including the crossover, is 32.5 ft. Table A.2-10 summarizes the details of the pump assembly components. Note that the top of sediment was tagged at 4,965 ft bgs during flow logging.

The submersible pump string was landed to a 1-in. landing plate at the wellhead. Figure A.2-21 shows the final wellhead configuration. A VSD was wired to the pump. On August 15, 2000, a functionality test was conducted on the pump after appropriate wellhead plumbing was attached to the pump string. The discharge was routed to the unlined Sump #1. At 11:14, the pump was started (after two failed starts) at 60 Hz (~40 gpm) and discharge occurred at the surface 4 minutes, 12 seconds later. The discharge was initially moderately turbid, clearing in about 1.5 minutes. A second slug of turbid water was observed approximately 3 minutes later, clearing in about one minute. The pump was run at eight different frequencies for a total period of about 55 minutes. The results of the functionality testing are shown in Table A.2-11. Approximately 1,900 gallons (gals) were pumped during the functionality test. No major problems were encountered, and the VSD was transported off site.

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

Pump Component	Type/Model	Serial Number	Other Information
ESP Pump	TD 800	2D8I15036	87 Stage
ESP Seal/Protector	TR3-STD	3B8I07087	Not Applicable
ESP Motor	TR3-UT/17 THD	1B8I06462	40 hp, 750 V, 40 A

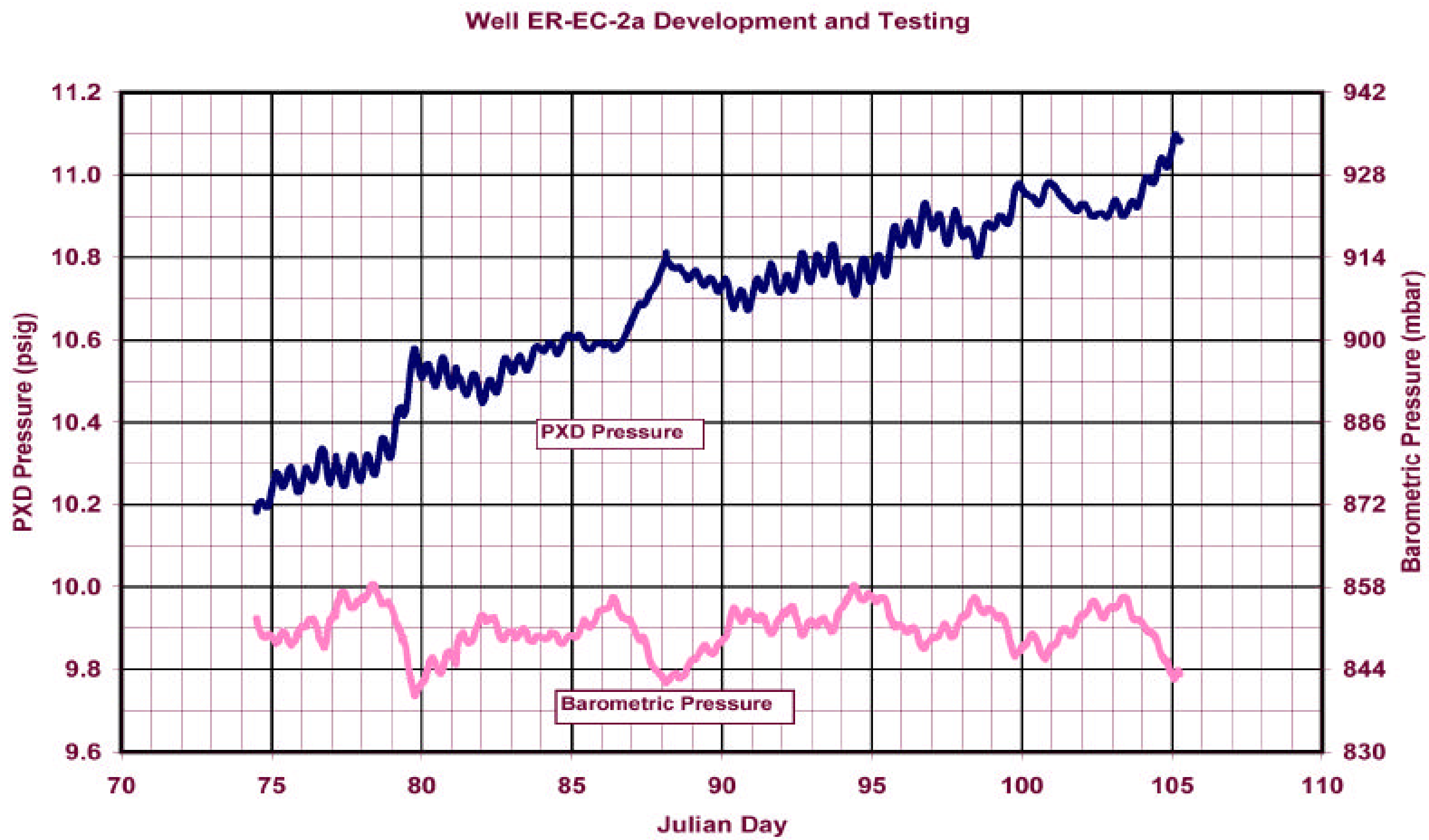
ESP - Electrical Submersible Pump Systems
hp - Horsepower
V - Volt
A - Amp

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

Time	VSD Frequency (Hz)	Flow Rate Magnetic Flowmeter (gpm)	Downhole Amps	Downhole Voltage	Voltage at VSD
11:27	60	39.25	34	745	439
11:50	66	43.5	39	826	483
11:58	63	41.0	- - -	- - -	- - -
12:00	50	30.0	- - -	- - -	- - -
12:03	45	25.0	- - -	- - -	- - -
12:05	40	19.8	21	502	289
12:09	43	24.0	- - -	- - -	- - -
12:10	48	28.5	- - -	- - -	- - -

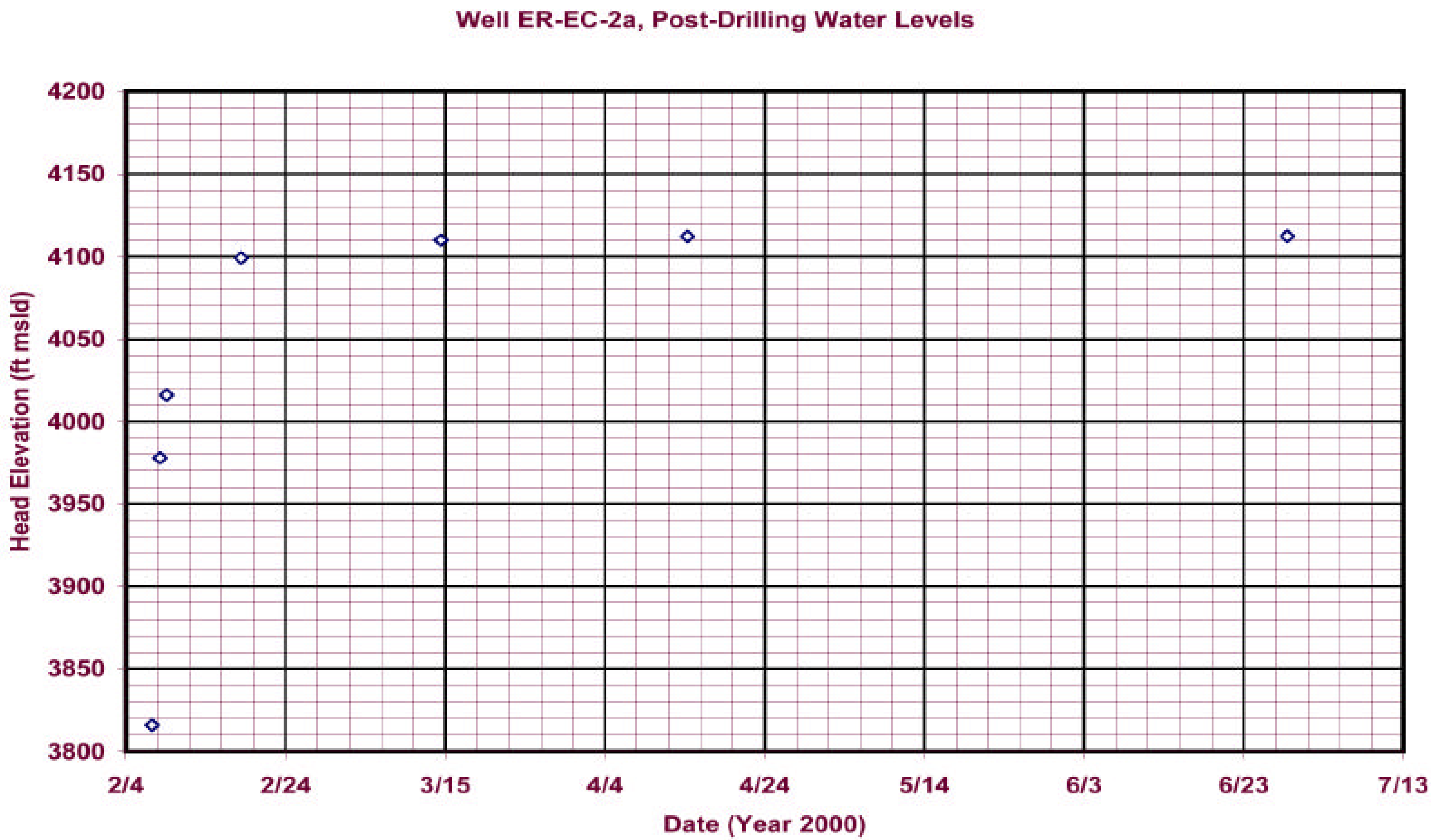
Note: Amps and voltage are mean values of three phases. Wellhead pressure remained at 0 pounds per square inch throughout testing.

Hz - Hertz (cycles)
gpm - Gallons per minute



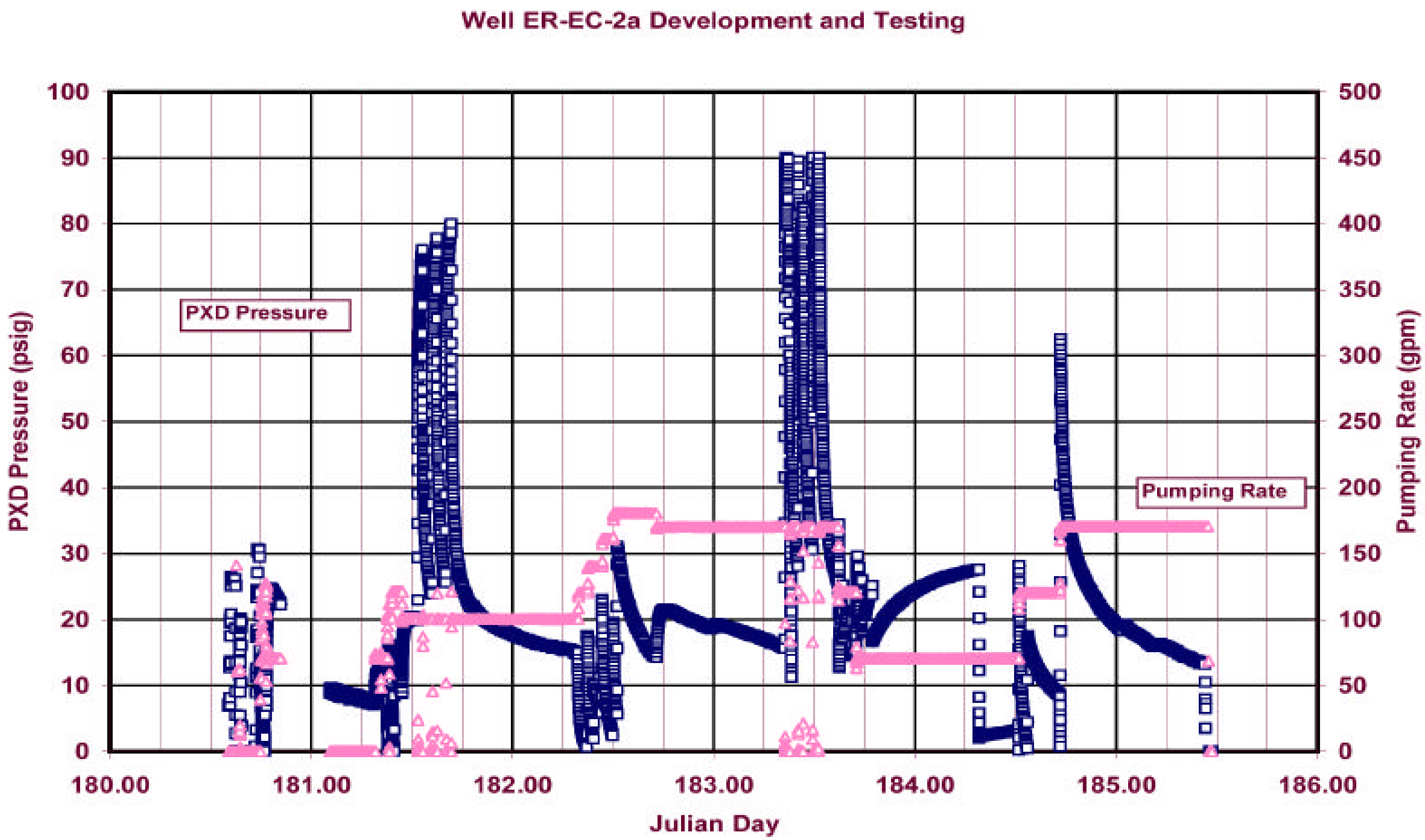
psig - Pounds per square inch gauge
PXD - Pressure transducer
mbar - Millibars

Figure A.2-1
Predevelopment Water Level Monitoring



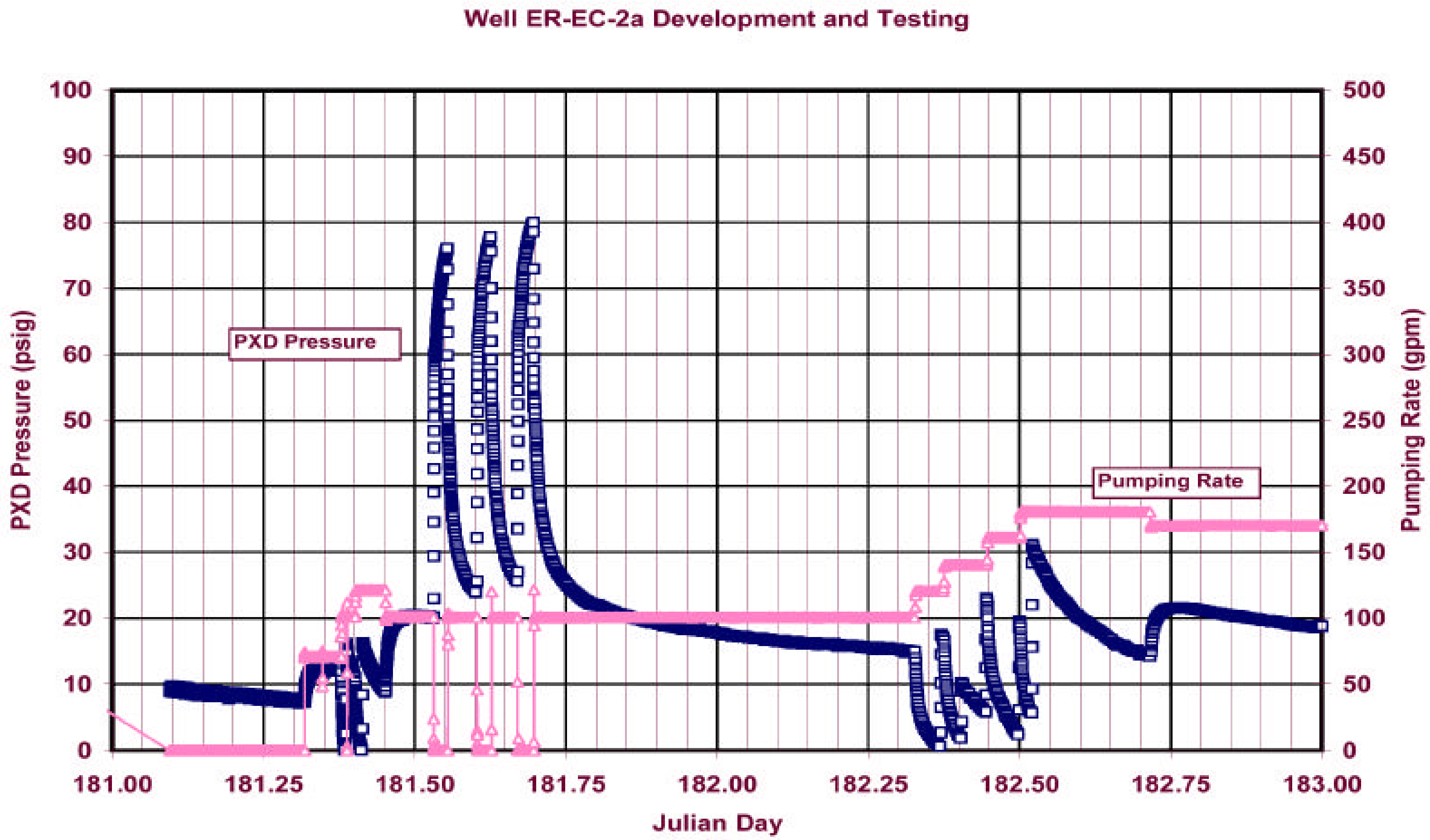
ft msld - Feet above mean sea level datum

Figure A.2-2
Composite Water Level Measurements



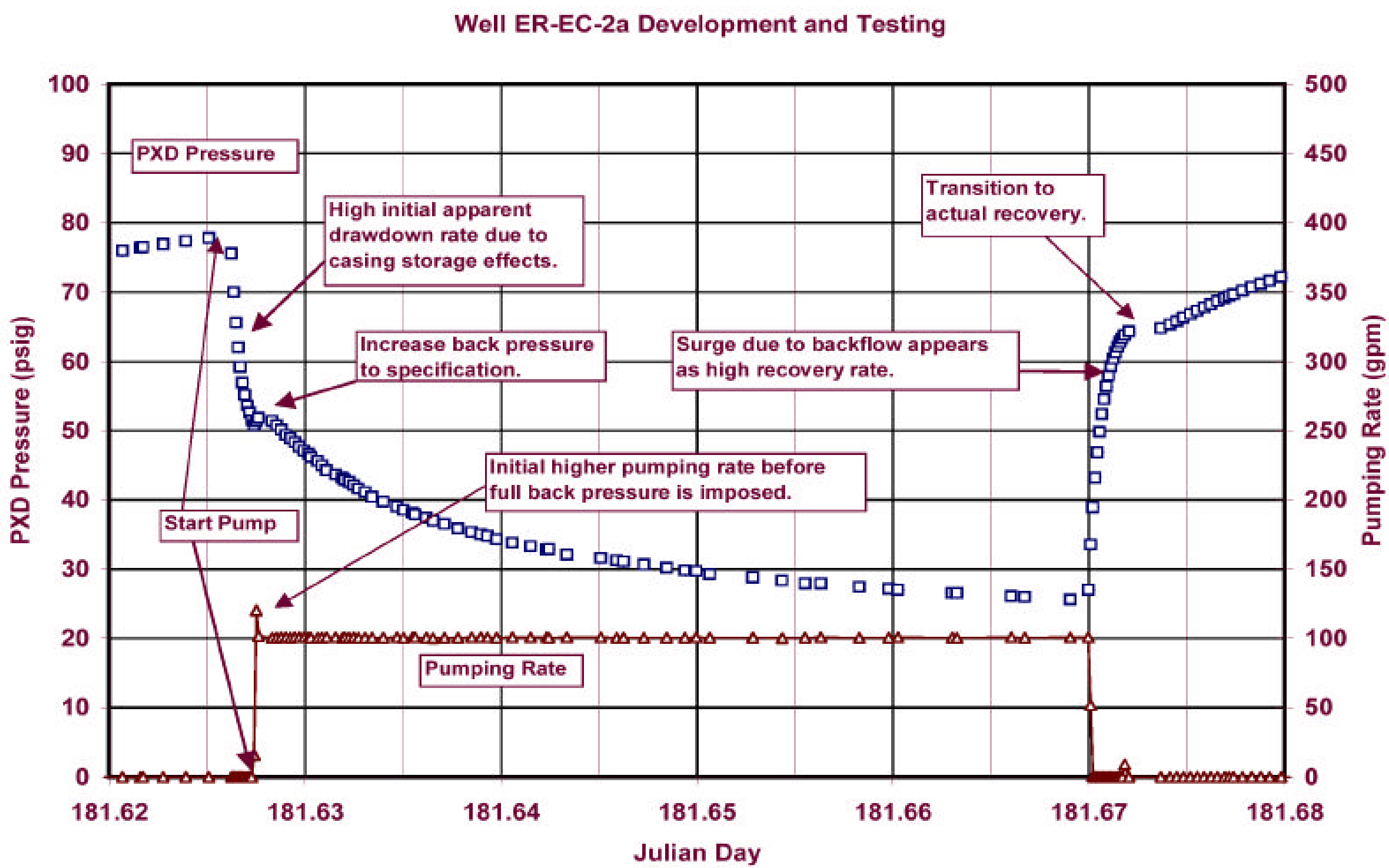
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-3
Pumping Rate and Hydraulic Response During Development



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

Figure A.2-4
Expanded View of a Representative Segment of the Pumping Rate and Hydraulic Response During Development



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

Figure A.2-5
Detail of Drawdown and Recovery Effects

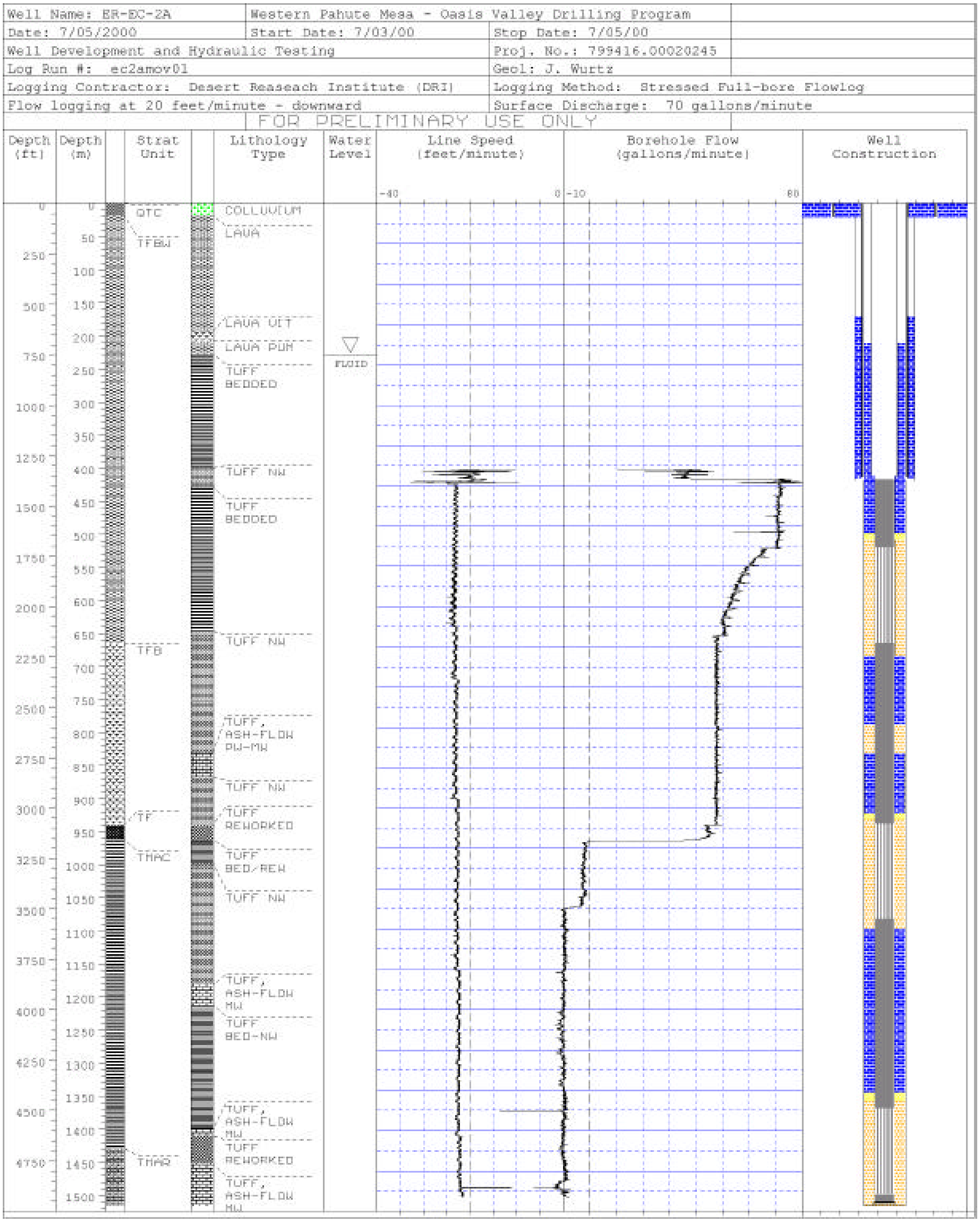


Figure A.2-6
Flow Log at 70 gpm Production Rate and 20 fpm Downward Trolling Rate

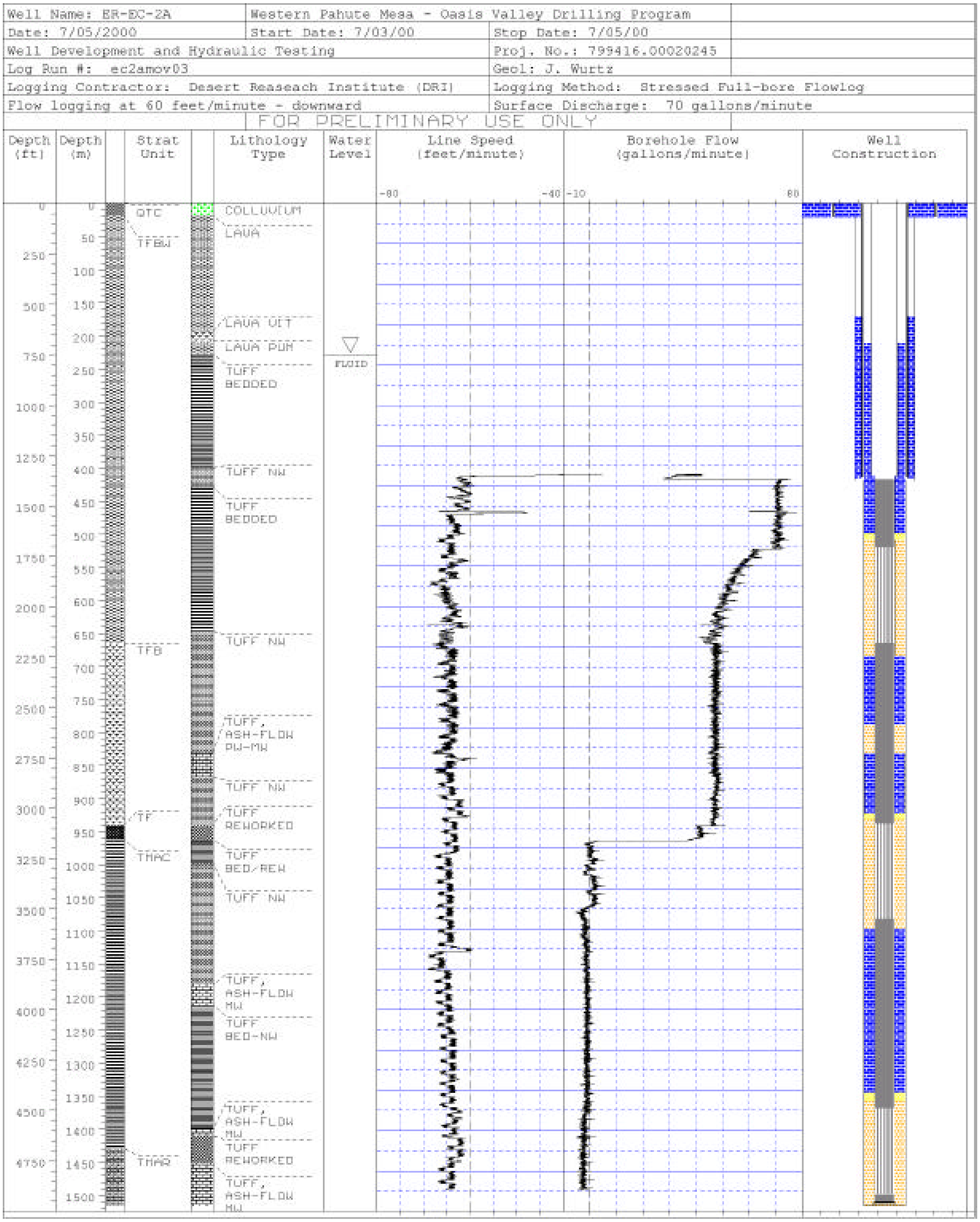


Figure A.2-7
Flow Log at 70 gpm Production Rate and 60 fpm Downward Trolling Rate

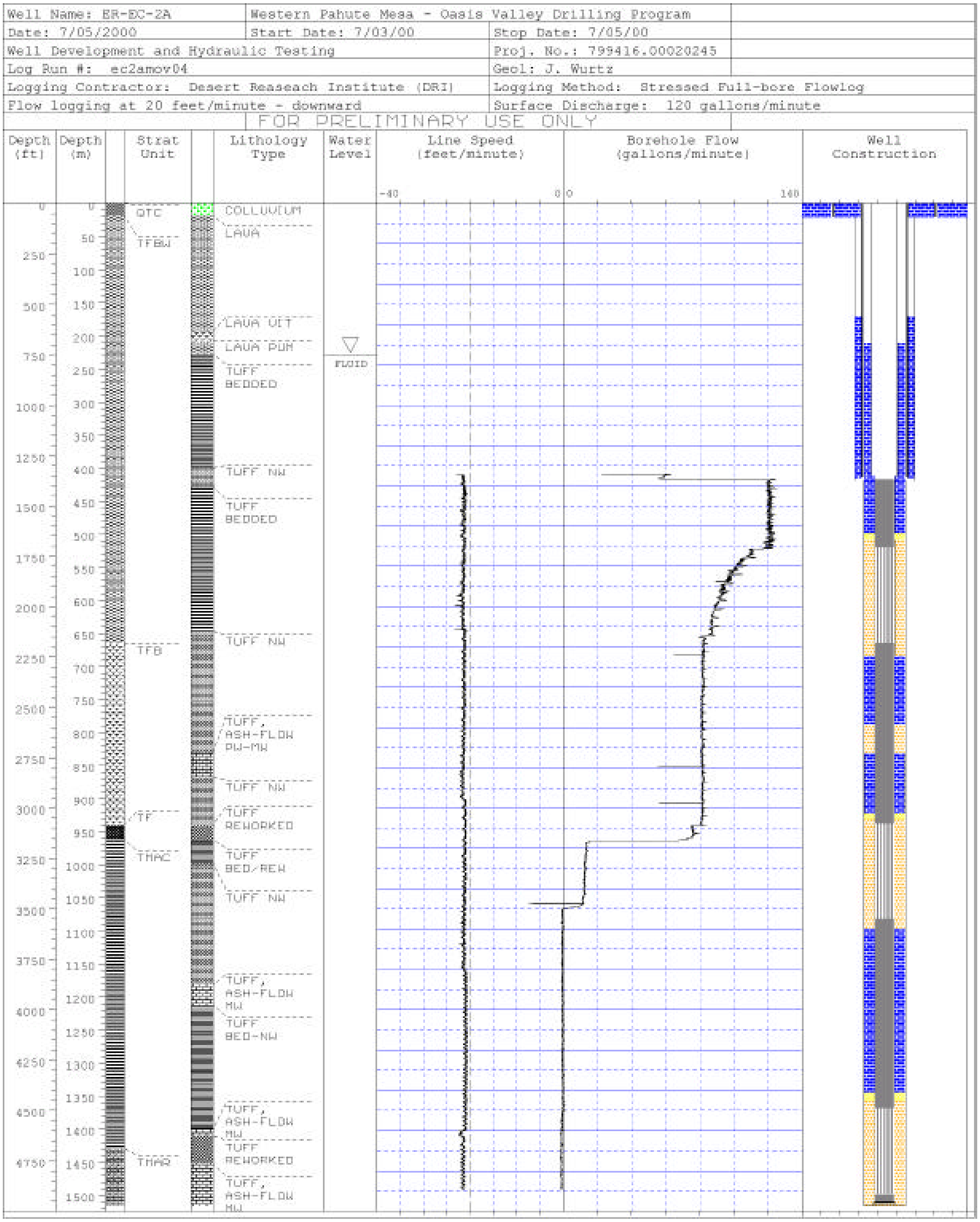


Figure A.2-8
Flow Log at 120 gpm Production Rate and 20 fpm Downward Trolling Rate

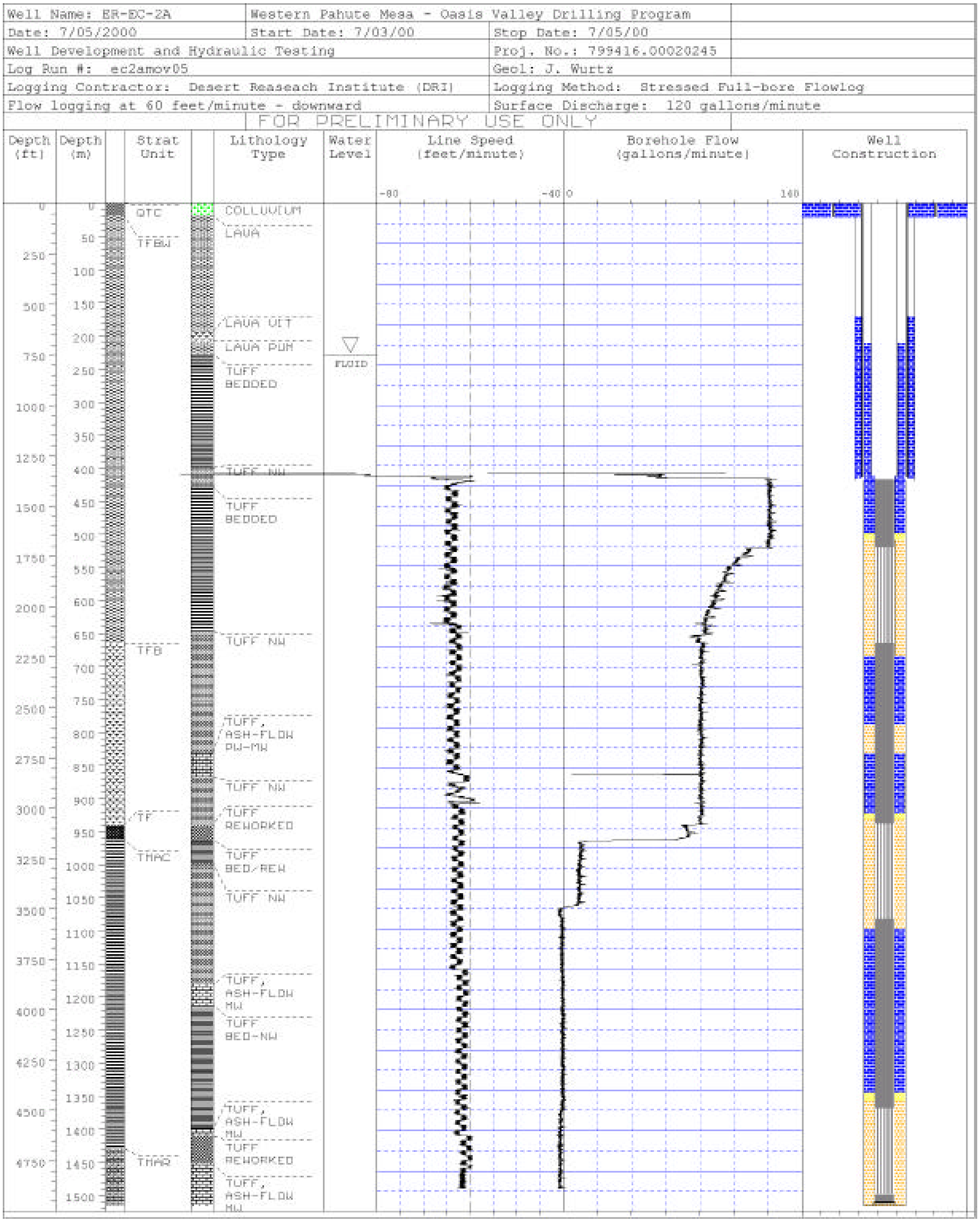


Figure A.2-9
Flow Log at 120 gpm Production Rate and 60 fpm Downward Trolling Rate

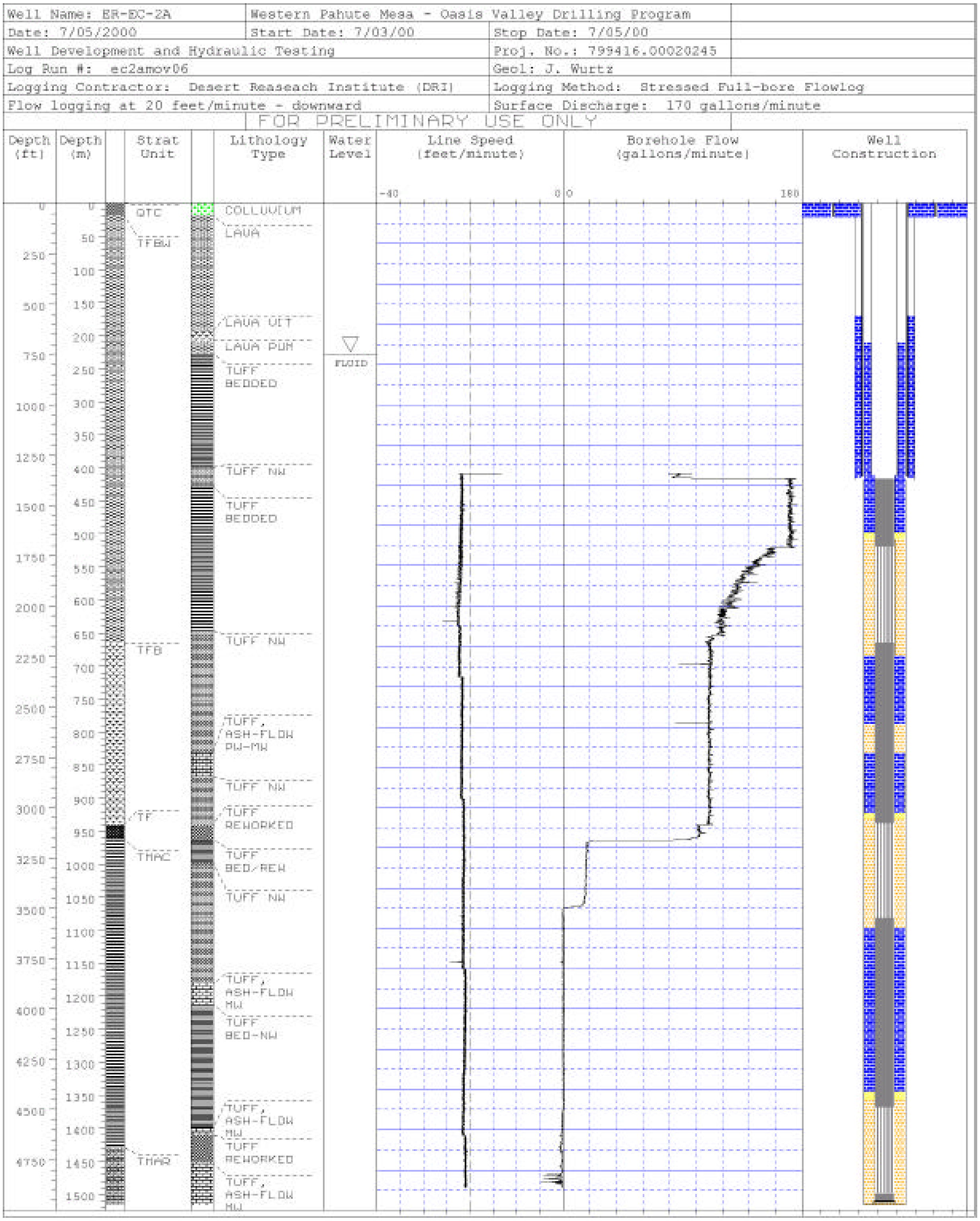


Figure A.2-10
Flow Log at 170 gpm Production Rate and 20 fpm Downward Trolling Rate

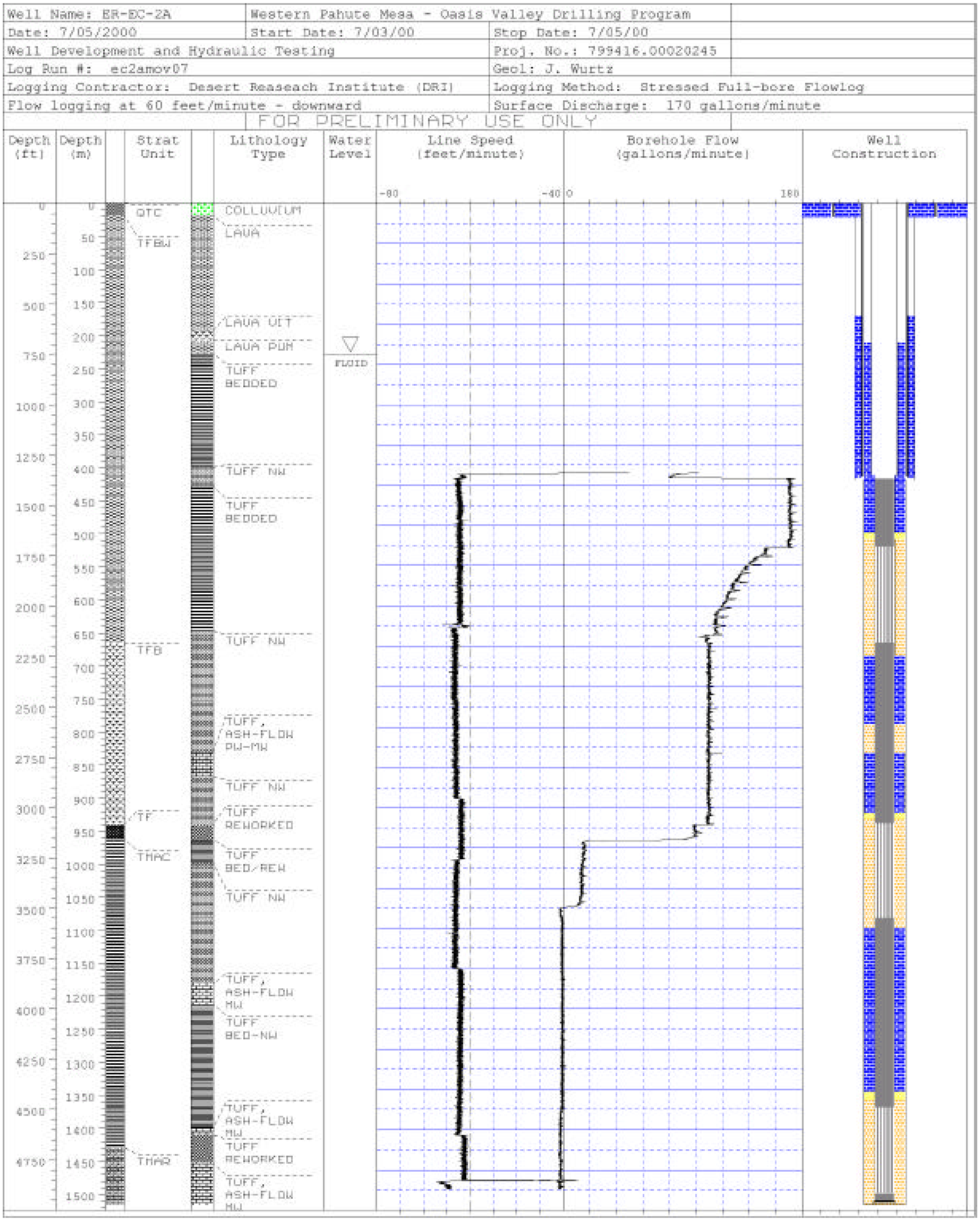
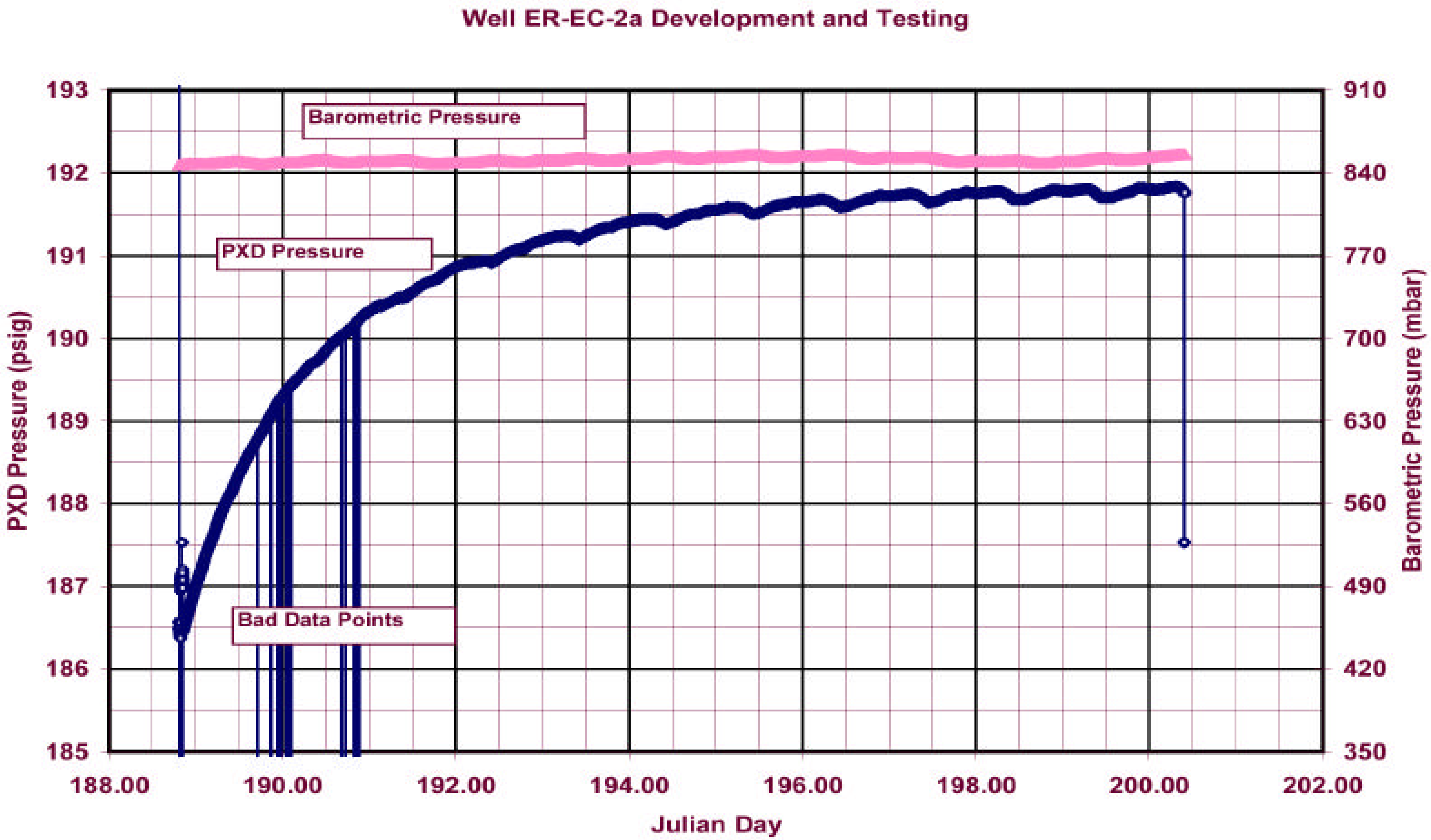
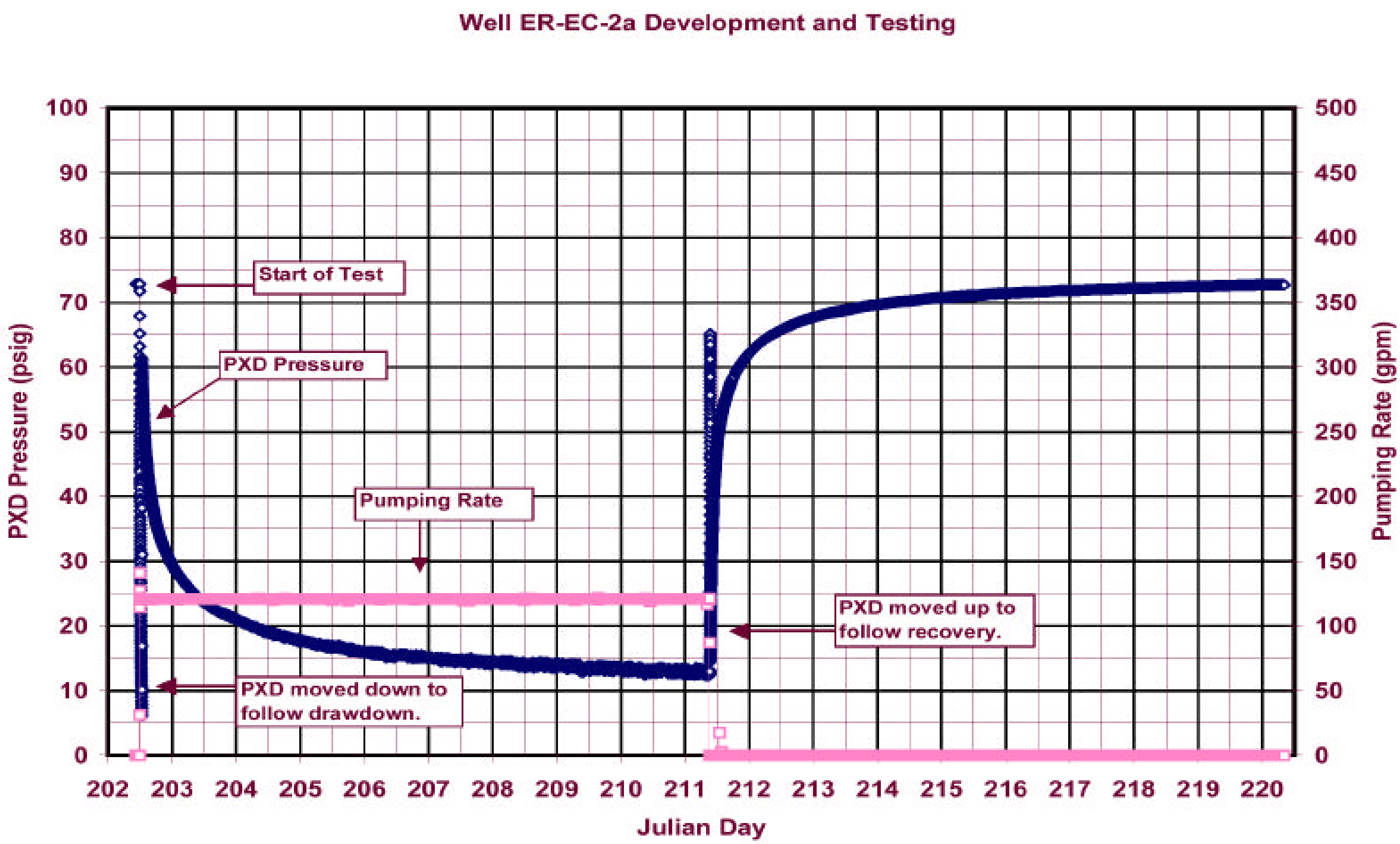


Figure A.2-11
Flow Log at 170 gpm Production Rate and 60 fpm Downward Trolling Rate



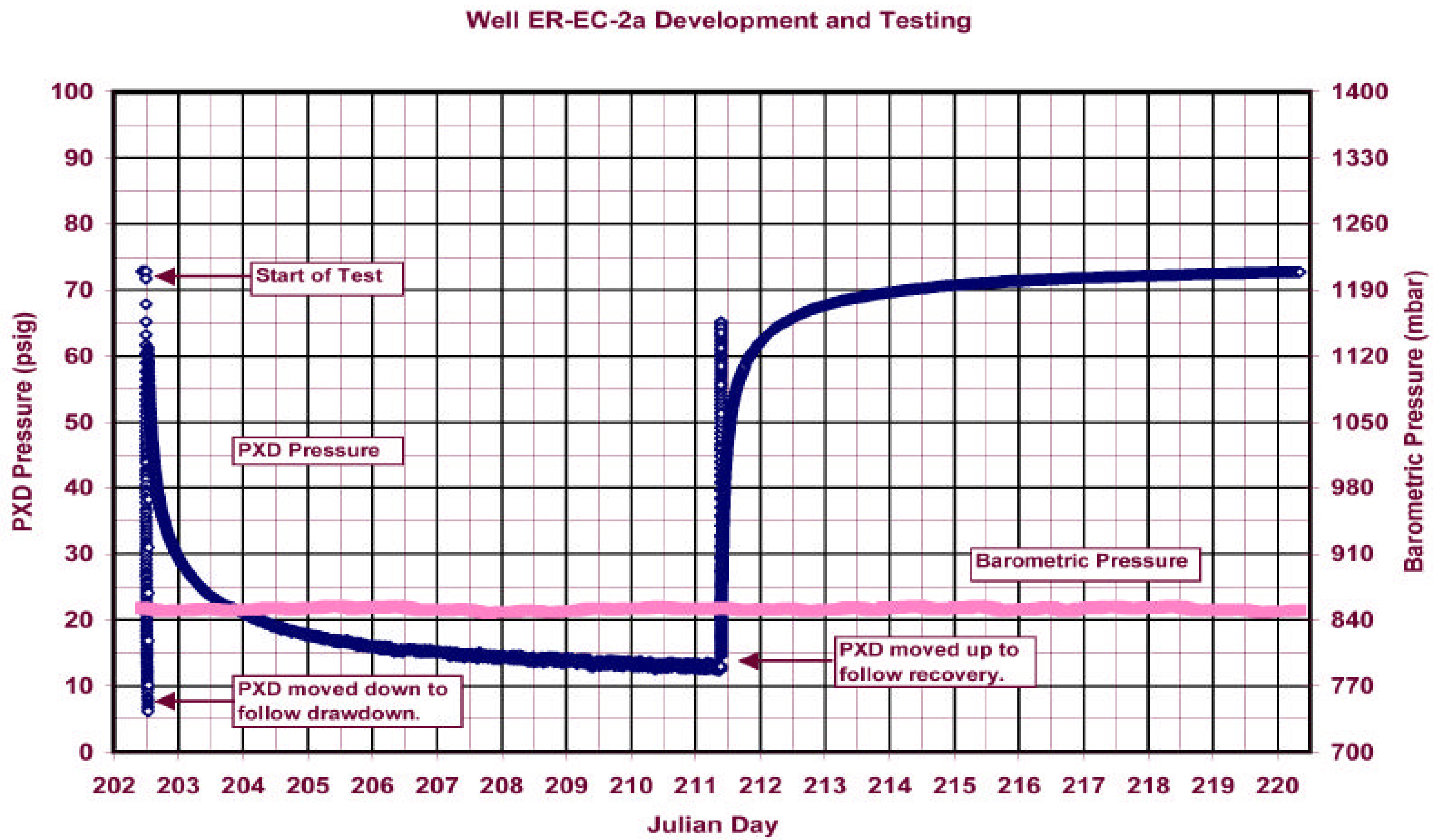
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-12
Recovery From Development



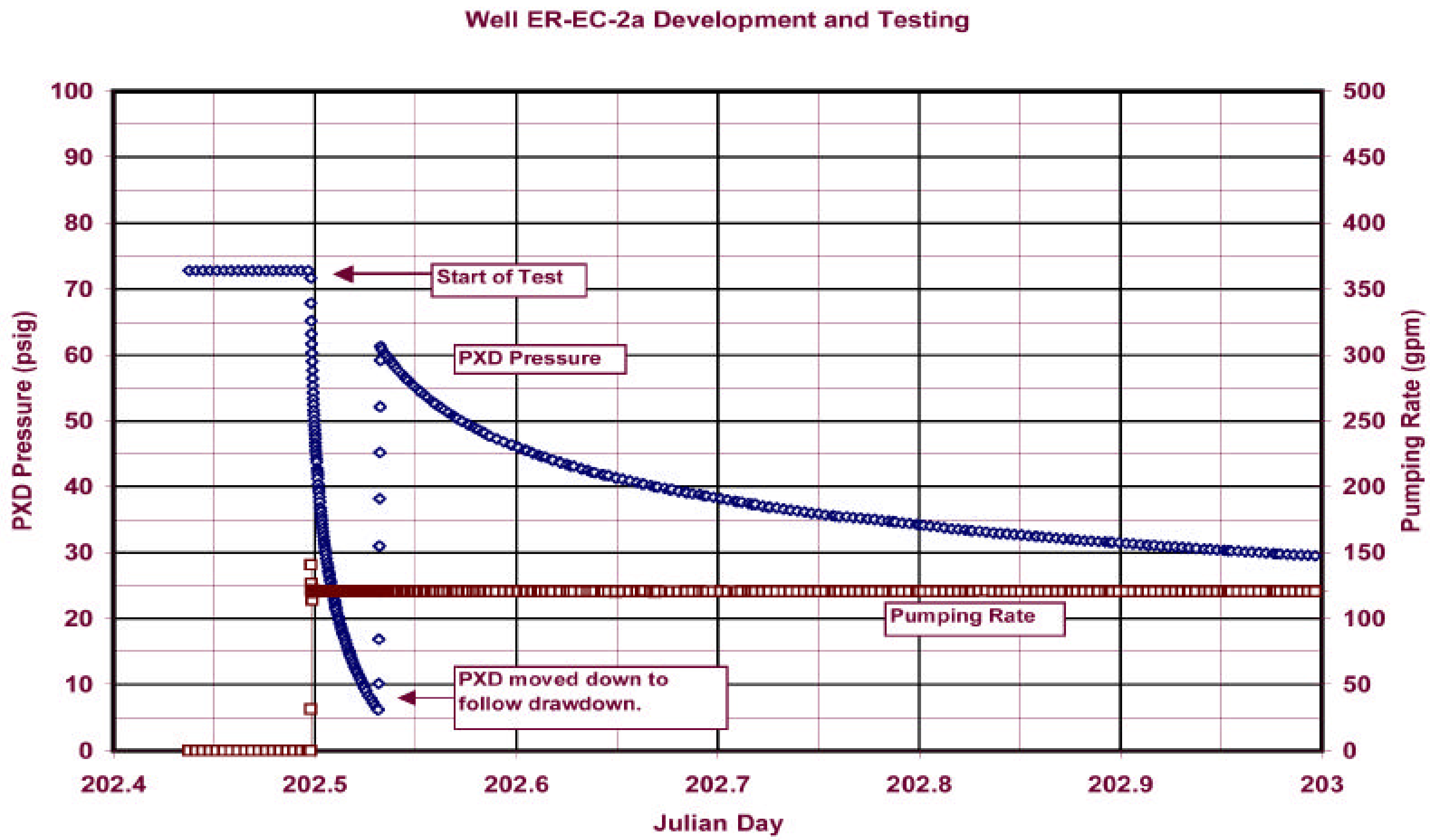
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-13
Pumping Rate and Hydraulic Response During the Constant-Rate Test



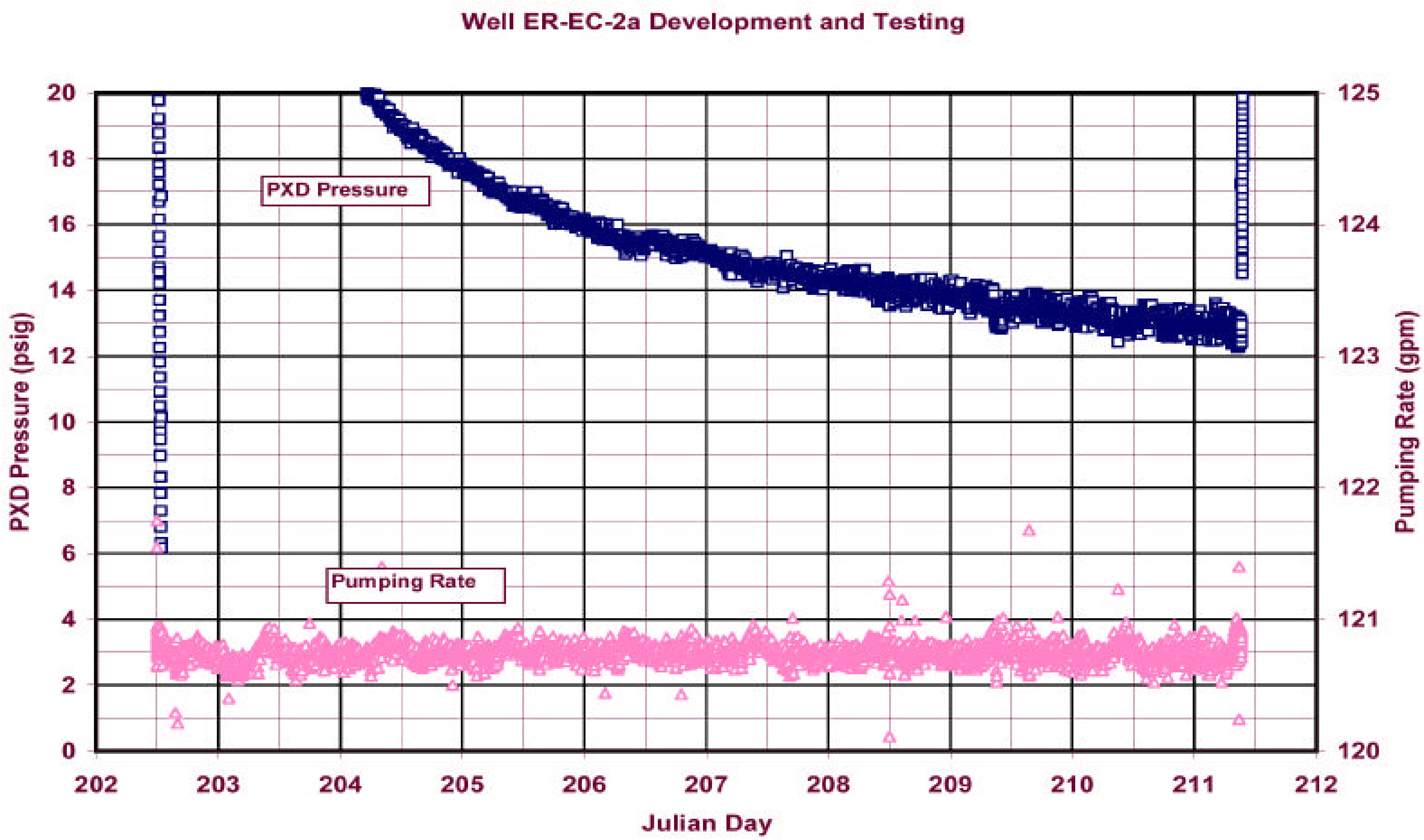
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-14
Hydraulic Response and Barometric Pressure During the Constant-Rate Test



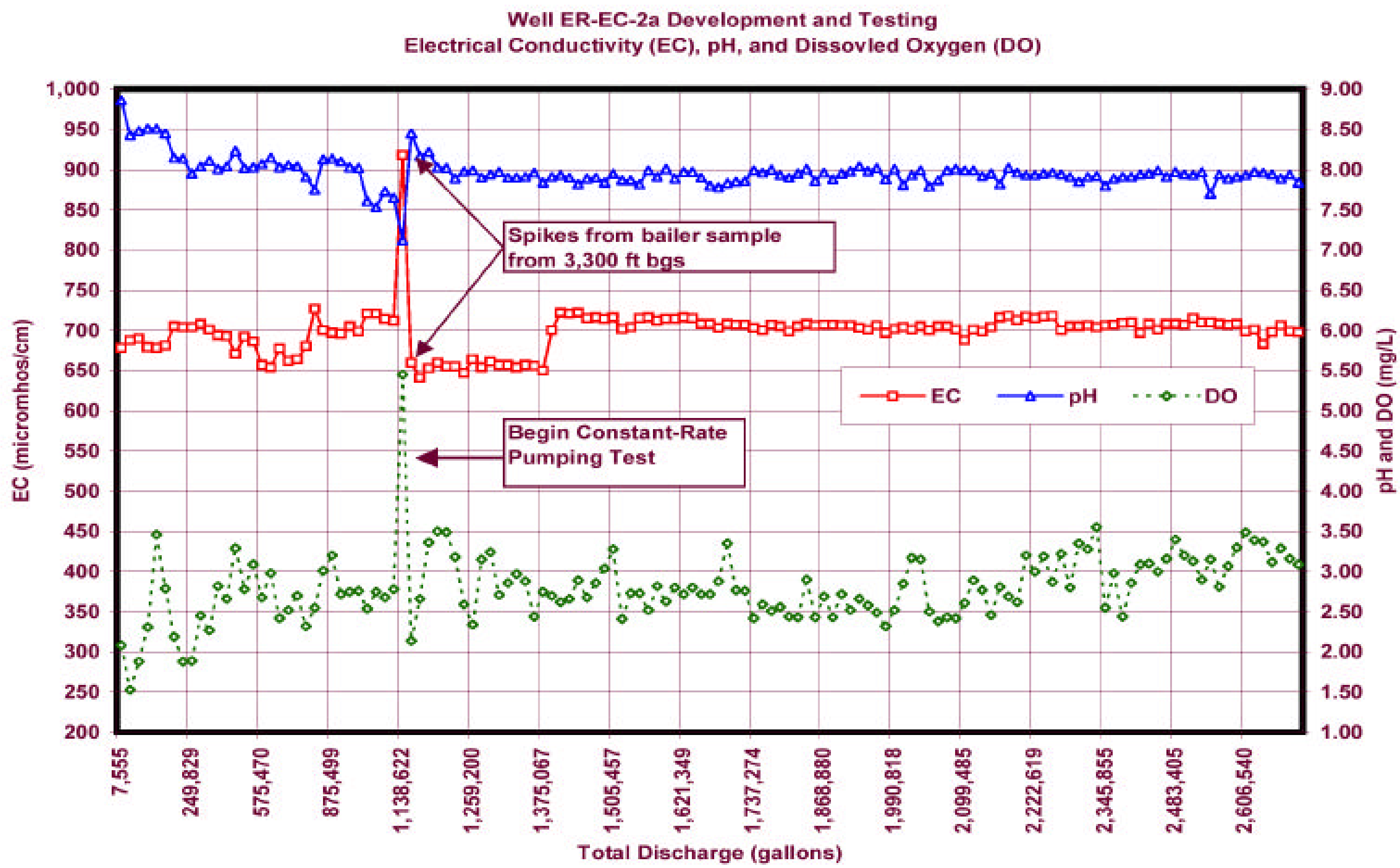
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-15
Expanded View of PXD Pressure Record Showing Reset of PXD



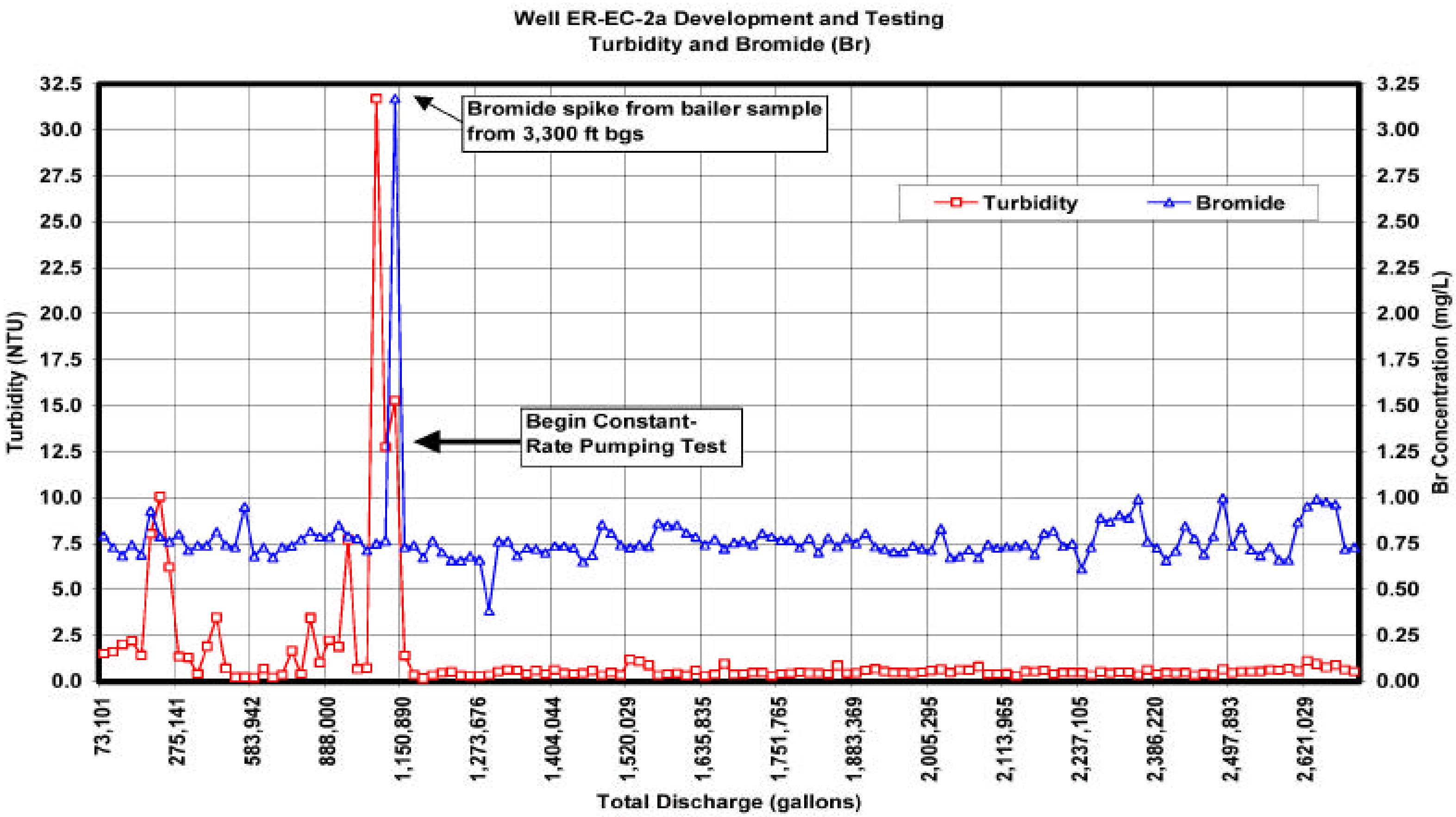
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-16
Expanded View of PXD Pressure and Pumping Rate Fluctuations



mg/L - Milligrams per liter
cm - Centimeters

Figure A.2-17
Grab Sample Monitoring for EC, pH, and DO



NTU - Nephelometric turbidity unit(s)
mg/L - Milligrams per liter

Figure A.2-18
Grab Sample Monitoring for Bromide and Turbidity

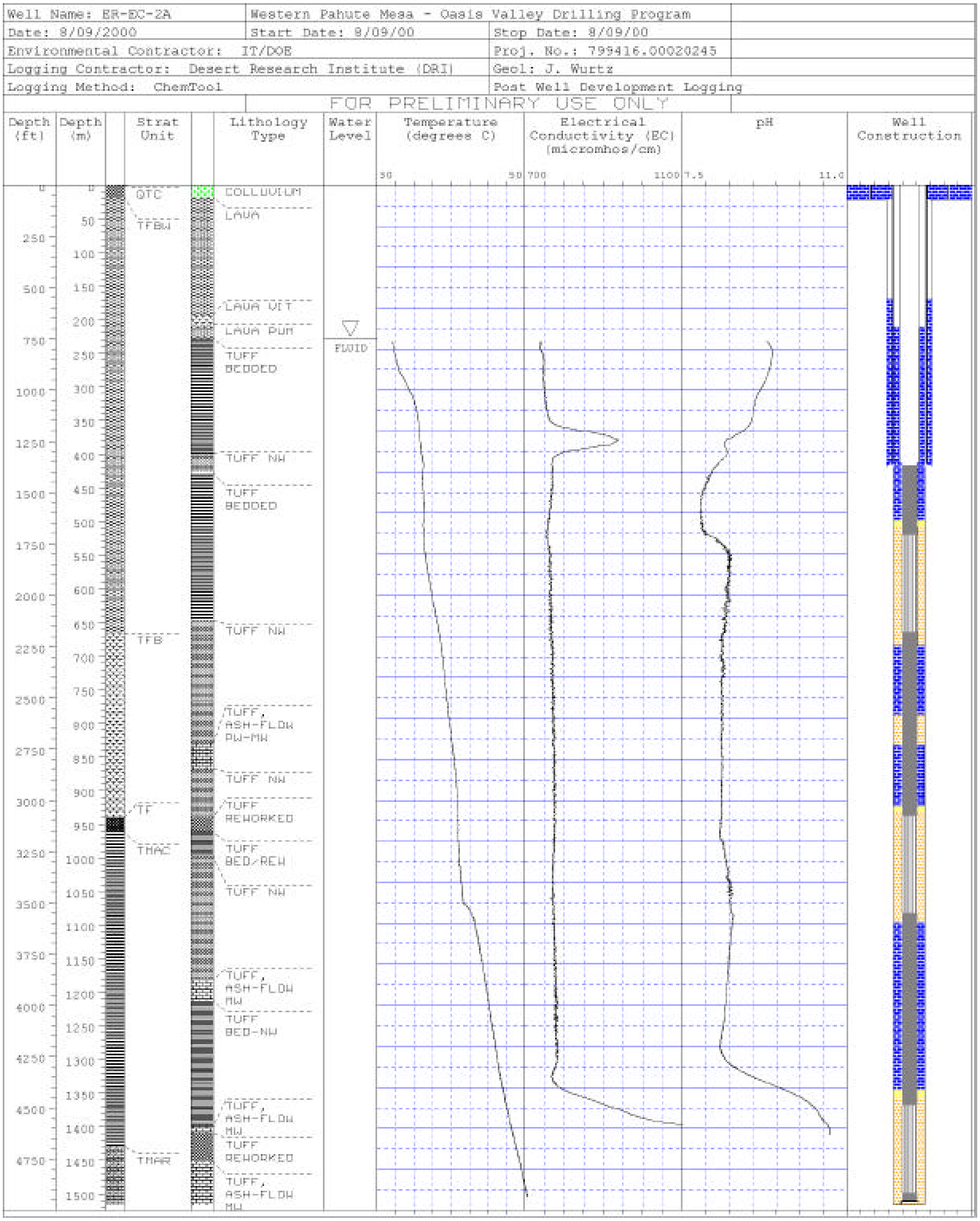


Figure A.2-19
ChemTool Log

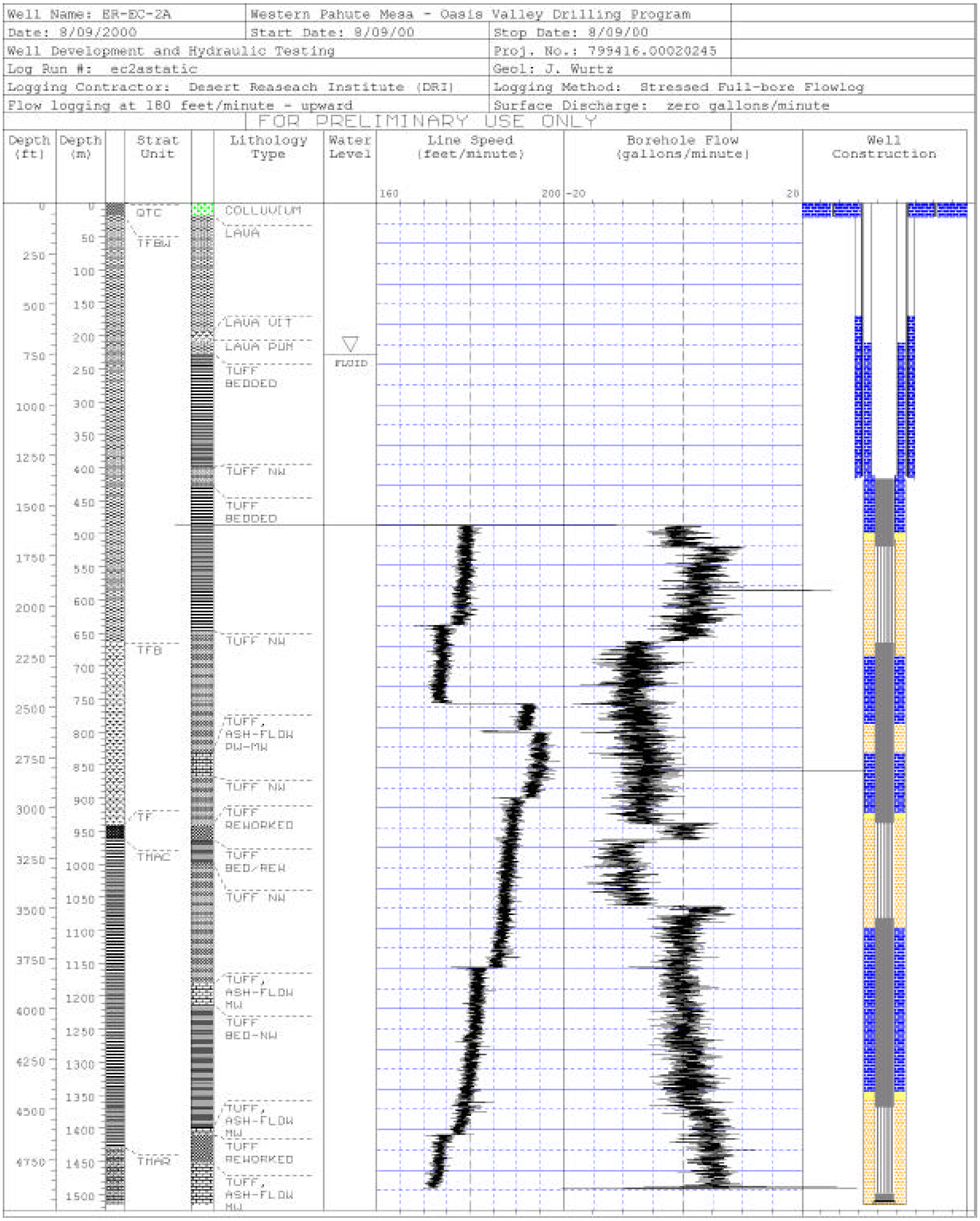


Figure A.2-20
Ambient-Flow Spinner-Tool Log

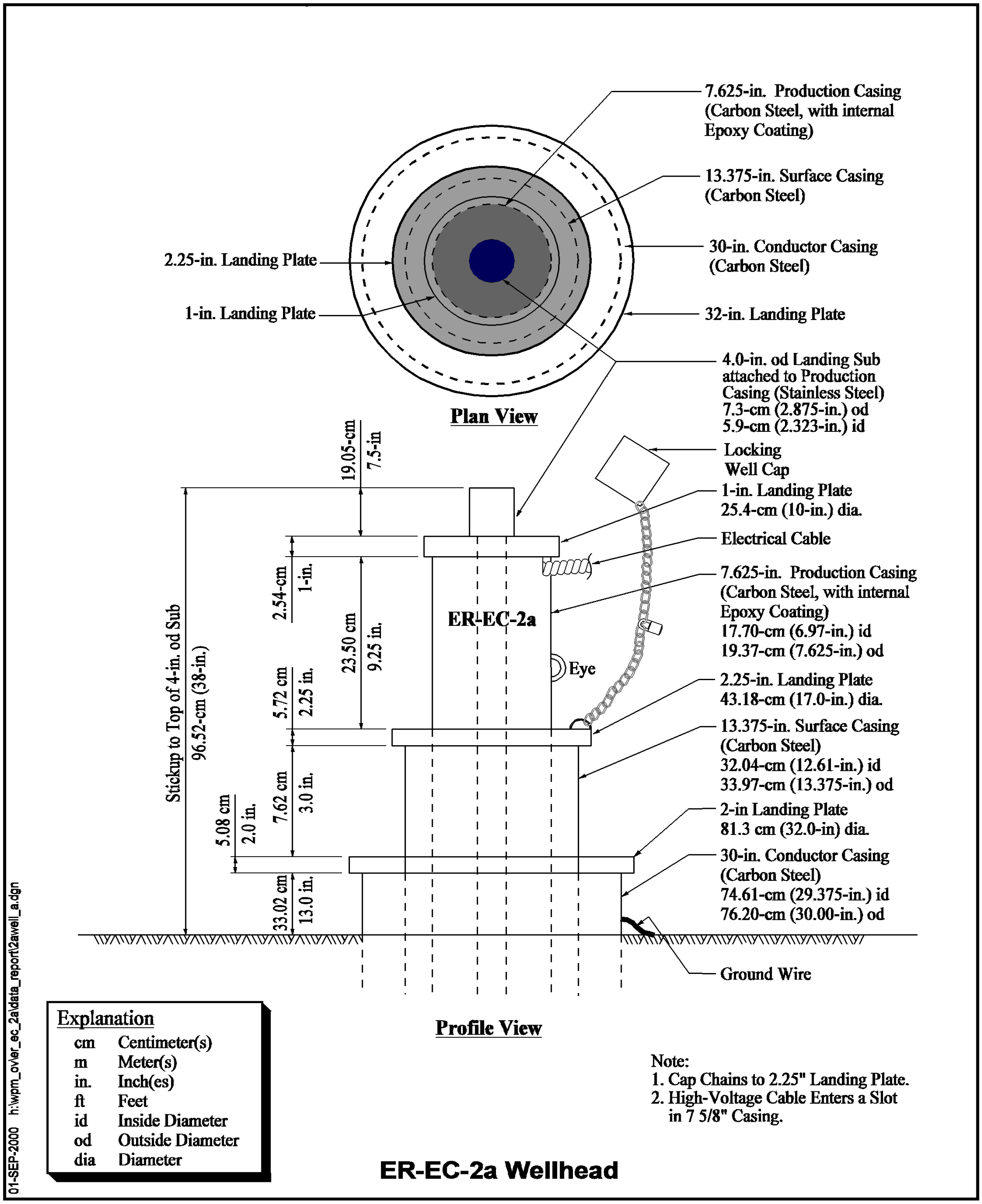


Figure A.2-21
Wellhead Completion Diagram After Sampling Pump Installation

A.3.0 Data Reduction and Review

This section presents basic reduction and processing of data collected during the Well ER-EC-2a development and testing program. Data review and preliminary examination of the results are offered, clarifications of details are provided, and points of interest are noted. Any data interpretations in this section are preliminary and subject to change in future data analysis tasks.

A.3.1 Equilibrium Water Level

As mentioned in Section A.2.2, the water level in the well was recovering from drilling for a long time after testing activities started, and only the last two composite water levels measured prior to development and testing may represent the equilibrium well-composite water level. These water levels were very close, only 0.27 feet apart.

A.3.2 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 reflecting the effects of flow in the well.

A.3.2.1 Methodology

The heads for the middle and lower intervals were calculated from representative pressures for the intervals measured after the intervals were isolated with bridge plugs/PXDs. The heads were computed by multiplying the pressure for the interval by the composite density of the water in the well above the PXD to determine the interval head relative to 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. The height of the water column was determined from a reference water level taken before the bridge plug was run into the well, and the PXD set depth. This measurement accounted for any composite head adjustment that occurred due to isolating the lower interval(s). While there is a chance that this water level may not have completely stabilized, it provides a better estimate of the height of the water column than the total well composite water level. Determining the composite density from the actual pressure of the water column was required to calibrate the head calculation to the water density. Because of the high values of pressure, the calculation of equivalent head was very sensitive to density, which is not specifically known or otherwise measured. This is discussed further in Section A.3.2.4. This method is also insensitive to wireline depth measurement errors.

The intervals were monitored for 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.3.2.2 Data Reduction

Figure A.3-1 shows the PXD pressure record for the upper interval. The head in the upper interval was still recovering from drawdown associated with drilling during the monitoring period, and did not appear to achieve a stable water level. Since the upper interval was open to atmospheric pressure in the well, the head was affected by barometric pressure changes during the monitoring 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 0.8, calculated from the predevelopment monitoring record, was used to make the correction. The method for calculating the barometric efficiency will be discussed in Section A.3.5.1. Figure A.3-8 shows the fitting of the barometric efficiency overlay. After correcting for barometric variation, the resultant water level trace shows a daily pattern of two peaks which may be earth tides.

The upwards trend in the water level is reflected in the higher well composite water level that was measured after the bridge plug head measurements as well as even higher levels measured later (see Table A.2-2). The rate of water level rise is low and not very clear without the barometric correction. However, the trend apparently persisted through the predevelopment water level monitoring period that ended April 14, 2000, almost two months after the bridge plug measurements. Consequently, the upper interval head determined from the bridge plug measurements was not accurate.

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 PXD pressure values were stable and consistent during the calibration measurements. The monitoring records show that neither interval equilibrated to a stable value during the period of measurement. For both intervals the pressure in the interval initially dropped after the bridge plug was set, and then started to increase. For the middle interval, the pressure dropped about 0.3 psi before starting to increase. At the end of the 5-day record, the pressure was above the preset pressure and still increasing. For the lower interval, the pressure dropped over 30 psi before starting to increase. At the end of the

5-day record, the pressure had not recovered to the preset pressure, but was still increasing.

Two alternate interpretations for this behavior are offered. One interpretation is based on the indications that the head in the well was in recovery from drilling during the time of these measurements. The latter part of each monitoring record shows a recovery curve for the individual completion interval. The early part of the record shows an equilibration from the composite head to the instantaneous head in each interval. The pattern indicates that the drawdown was progressively greater for deeper completion intervals. There are no representative equilibrium heads for the completion intervals in these records.

The second interpretation is that the heads in the lower intervals are progressively lower than the well-composite head (reference head) measured prior to the bridge plug set. After isolation by the bridge plugs, the early part of the monitoring records would then show the equilibration to the equilibrium pressure. Some time later, leakage paths from the higher head in the upper interval developed under the differential pressure across the bridge plug. It is not known where the leakage might have occurred (e.g., in the bridge plug seal or external to the well in the annular seal or in the formation). It should be noted that the bridge plugs were set only 4 to 6 days following well completion, and perhaps the cement annular seals were not yet cured to full strength. This is the only well in this set of wells where differential pressures between completion intervals were this high.

Based on this latter interpretation of the pressure monitoring data, the minimum pressure that was observed in each interval was used as the equilibrium pressure for the interval in the following analysis. Figure A.3-6 and Figure A.3-7 show expanded views of the equilibration records through the time of occurrence of minimum pressure. Figure A.3-6 and Figure A.3-7 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, perhaps representing limitations in the resolution of the instrumentation. The values selected as minimum pressure were the dominant values during the period of apparent equilibration. Table A.3-1 shows interval-specific head information for Well ER-EC-2a. The methodology for calculating the head for the middle and lower intervals depends upon the e-tape reference head measurements and the change in PXD pressures from before to after bridge plug sets, and is insensitive to wireline errors for the PXD set depths. There has been no correction for friction losses due to gradient-driven circulation in the well.

The results indicate a downward hydraulic gradient. The calculated head of the middle interval was 14.12 ft less than the calculated head of the upper interval, and the calculated head of the lower interval was 70.61 ft less than the calculated head of the middle interval. The initial head adjustments of the middle and lower intervals after the bridge plugs were installed were downward, while the upper interval adjusted upward. The following discussion on potential error in these measurements indicates that the potential error is substantially less than the calculated head differences.

The quoted accuracy for the PXDs is 0.1 percent of full scale. Treating the nominal accuracy as measurement uncertainty, the potential uncertainty for the middle interval pressure measurement is +/- 1.0 psi, and for the lower interval is +/- 2.5 psi. These uncertainties result in potential uncertainty in the head difference of +/-1.0 psi (approximately 2.3 ft) between the upper and upper-middle intervals, and 3.5 psi (approximately 8 ft) between the middle and the lower intervals. In addition, there is also some unquantified uncertainty in the e-tape measurements. 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, direct measurement. Since two different e-tape measurements are used to determine the lower interval head and the upper interval head, the measurement uncertainty of e-tape measurements affects the calculated head difference between the upper and lower intervals. This uncertainty is probably in the range of one-tenth of a foot.

Table A.3-1
ER-EC-2a Interval-Specific Heads

Measurement	Well Composite	Upper Interval	Middle Interval	Lower Interval
Head - Depth ft bgs	747.65	747.65	761.77	823.38
Determination Method	Direct Measurement Using E-Tape	Direct Measurement Using E-Tape	Calculated from Bridge Plug Data	Calculated from Bridge Plug Data
Change in Head ft	---	---	-0.53	-62.45
Composite Water Density Conversion Factor ft/psi	---	---	2.321	2.320
Minimum Pressure psig	---	---	942.19	1,526.70
Preset Pressure psig	---	---	942.42	1,557.50
Water Column Height ft	---	---	2,187.75	3,613.02
Reference Head ft	---	---	761.24	760.93
PXD Set Depth ft	---	---	2,948.99	4,373.95
PXD Serial Number	---	---	21016	01227
PXD Range psig	---	---	0-1,000	0-2,500

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

A.3.2.3 Correction of Bridge Plug Set Depths

As mentioned in Section A.2.4, the bridge plug set depths have been corrected from the originally specified set depths. Table A.3-2 shows the specified and the corrected depths. These corrections were supplied by BN Geophysics, who oversaw these measurements. The bridge plugs were located by placing them a specified distance from a reference casing collar that was located downhole based on the casing tallies from well construction. Corrections were required for 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	4,425.00	1,348.74	4,423.95	1,348.42
Lower Interval Calibration at -50 ft	4,325.00	1,318.26	4,323.96	1,317.94
Lower Interval Set Depth	4,375.00	1,333.50	4,373.95	1,333.18
Middle Interval Calibration at +50 ft	3,000.00	914.40	2,998.99	914.09
Middle Interval Calibration at -50 ft	2,900.00	883.92	2,899.00	883.61
Middle Interval Set Depth	2,950.00	899.16	2,948.99	898.85

ft - Feet
bgs - Below ground surface
m - Meter

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

A.3.2.4 Composite Water Density

The calculated composite density conversion factors were 2.321 and 2.320 ft of water column/psi (i.e., 0.995 and 0.996 in terms of specific gravity corrected for temperature), respectively, for the middle interval and the lower interval. The specific gravity values are based on calculations relative to values for standard temperature-corrected weight density of water (Roberson and Crowe, 1975). These values seem reasonable considering they must accommodate effects of dissolved and entrained gases, suspended solids, and dissolved 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 may reasonably be expected because they apply to the upper part of the water column, which should have less suspended sediment and a greater proportion of entrained gas. A conversion factor value of 2.348 ft of water column/psi (specific gravity 0.983) was calculated from the PXD installation for monitoring drawdown for the constant-rate test, which followed development. The slightly reduced density may be related to reduced suspended sediment or increased dissolved or entrained gas as effects of development.

A.3.2.5 Ambient Flow Logging

The thermal flow logging indicated the downward flow to be approximately 0.5 gpm at 1,870 ft bgs in the middle of the upper completion interval, and about 2.2 gpm (the upper limit of the tool) at 3,300 ft bgs in the middle of the middle completion interval. There was no response for the measurement at 2,600 ft bgs, between the upper and middle intervals, which is inconclusive about flow. The measurement at 3,700 ft bgs, between the middle and lower intervals, found no flow. The results indicate flow from the upper completion interval downwards to the middle completion interval, but no flow from the middle interval down to the lower completion interval. These results do not provide a well-defined picture of ambient flow in the well, but suggest the general configuration of such flow. The downward flow from the upper to the middle interval is consistent with the vertical gradient measurements and the productivity of those intervals. However, the lack of flow from the middle to lower interval must be the result of low hydraulic conductivity in the lower interval in view of the fairly high vertical gradient. Low hydraulic conductivity of the lower interval was also indicated by the lack of production from that interval during pumping, and is reflected in the apparent stagnant water quality in that interval.

A spinner log was run in the well under ambient conditions to a depth of 4,910 ft bgs. This log is very noisy, probably related to the high line speed and the induced disturbance in the completion. However, it may indicate downward flow from the upper interval to the middle interval at rates greater than 2.2 gpm and no flow from the middle interval to the lower interval.

A.3.3 Well Development

Because of the slow recovery of this well, the step-drawdown protocol was not useful in assessing any improvement in the hydraulic efficiency of the well during development.

A.3.4 Flow Logging During Pumping

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

Figures A.2-6 through A.2-11 showed the stressed flow logging for Well ER-EC-2a. The trolling flow logging during pumping indicates that about one third of the water produced came from the upper interval and two thirds came from the middle interval. This result was consistent between all of the logs at all three pumping rates, with a small increase in the proportional amount from the upper interval at higher pumping rates.

Table A.3-3 shows a tabulation of the proportional production from each interval by flow log run. The production from the upper interval was distributed almost linearly across the completion interval while the production from the middle interval occurred in two steps. About 13 to 16 percent of the middle interval production occurred as a step increase at the bottom of the completion interval, and the rest of the middle interval production (83 to 86 percent) occurred as a step increase in the upper part of the completion interval at about 3,150 ft bgs. This depth coincides with spikes on several of the geophysical logs that were run after drilling including caliper, density, neutron porosity, resistivity, and gamma ray logs.

Table A.3-3
Proportional Production From Completion Intervals During Pumping

Completion Interval	Pumping Rate					
	70 gpm		120 gpm		170 gpm	
	Trolling	Stationary	Trolling	Stationary	Trolling	Stationary
Upper	31-32 %	32 %	32-33 %	33 %	36 %	36 %
Middle	68-69 %	68 %	67-68 %	67 %	64 %	64 %
Lower	0 %	0 %	0 %	0 %	0 %	0 %

A.3.4.1 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 in different directions under identical conditions shifts the depths within the borehole where this is occurring so that the flow occurring in all depths of the borehole can be logged.

A.3.4.2 Intervals of Inflow

The two interpretations of the bridge plug measurement data yielded different conclusions about the vertical gradient. The first interpretation was not able to define the vertical gradient while the second interpretation indicated a substantial downward gradient, approximately 85 feet from the upper interval to the lower interval. However, even this large gradient is only about one third of the drawdown that was produced by pumping, approximately 260 feet (at 120 gpm). Therefore, all three completion intervals were significantly stressed by the drawdown under either interpretation, although production was only observed from the upper and middle intervals. Much of the difference in production between the completion intervals must be attributed to different transmissivities of the completion intervals. The middle interval appears to have the greatest transmissivity, especially after accounting for the lower head than the upper interval and greater friction losses from the greater distance of flow. With regard to the lower interval, the lack of measured production indicates very low transmissivity relative to the other two intervals. This agrees with the results of the thermal flow logging, which did not measure any flow to the lower interval. The distribution of transmissivity between the upper and middle intervals will be clarified when the downhole hydraulics of the well are analyzed, incorporating the vertical gradient and friction losses for flow from each completion interval.

A.3.5 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 and PXD relocations.

A.3.5.1 Barometric Efficiency

Barometric efficiency is a measure of the proportional response of the head (water level) in the well to a change in barometric pressure; when barometric pressure rises, the head will be depressed by some fractional amount. The method used for determining barometric efficiency was to overlay the barometric record onto the PXD pressure record and adjust it with a scaling factor, the barometric efficiency, 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, reversed to match the sense of the response, and offset.

For Well ER-EC-2a, all of the long-term ambient monitoring records were found to contain logarithmic trends indicative of slow recovery from drawdown. This is consistent with the observed long-term equilibration of the well-composite water level mentioned in Section A.2.2. The predevelopment water level record was used to determine the barometric efficiency for the composite well (all three completion intervals). This record appears to have been near equilibration, and the trend of that record could more closely be approximated by a linear trend allowing the use of the method described above.

A barometric efficiency of 80 percent was determined to provide the best fit of the overlay. Since the record had a logarithmic trend, the linear trend used for the overlay progressively departed from the record. However, it can be seen that the 80 percent efficiency closely approximates the magnitude of the barometric effect. This efficiency was used to correct the PXD water-level measurements of the upper interval during the bridge plug monitoring, Figure A.3-1, as well as the water level record from the constant-rate test. While this barometric efficiency does not strictly apply to the upper interval individually, it was the best available approximation. Figure A.3-8 shows the PXD pressure record for the predevelopment monitoring period with the barometric record adjusted for a best-fit overlay. Again, the best-fit result was a barometric efficiency of 80 percent. Figure A.3-9 shows the predevelopment water level monitoring corrected for barometric pressure variation. This record also exhibits the twice daily peaks superimposed on the water level trend, which may be earth tides.

A.3.5.2 Drawdown Record

The drawdown and recovery records were corrected for the repositioning (vertical movement) of the PXD that was required to follow drawdown and recovery. This involved shifting the subsequent PXD data record each time the PXD was repositioned, accounting for changes in the values of pressure before, during, and after PXD movement. The shifts of the record included adjustments for changes in head that occurred during the repositioning using a linear extrapolation of the data trend just before the PXD was moved. Data points recorded during PXD movement were deleted. Figure A.3-10 shows the resultant corrected record for the constant-rate test and subsequent recovery period. The drawdown record (as pressure) was converted to an equivalent change in groundwater head using a conversion value for pressure-to-head, which was derived from the head and pressure data collected when the PXD was removed after testing. This information is presented in Table A.2-8. The correction for barometric variation did not have any substantial effect on the drawdown curve because the magnitude of barometric changes were very small relative to the drawdown. Figure A.3-11 and Figure A.3-12 show plots of drawdown and recovery, respectively, versus elapsed time t and t/t' (on logarithmic scales). Neither plot shows straight line behavior for a Jacob analysis.

A.3.6 Water Quality

A variety of water quality information was collected, including grab samples taken during pumping and DRI ChemTool logs run both before well completion and after development activities. Comparisons can be made between the water quality parameters of the well water before well completion and after well development.

A.3.6.1 Grab Sample Results

Water quality parameter values measured for grab samples taken from produced water are shown in Attachment 2. During the course of pumping, pH was generally very steady at about 8.0, as illustrated in Figure A.2-17. The grab sample EC values (Figure A.2-17) were 650 to 700 μmhos/cm during development, and became consistent around 700 μmhos/cm during the constant-rate test. The stabilization at a value slightly higher than early values is an unusual behavior. Note that the grab sample parameter values are for the composite water produced from the well, and represent a production-weighted average of the varying pH found downhole.

A.3.6.2 Precompletion Versus Postdevelopment Water Quality

The ChemTool log of downhole water quality parameters was run at the very end of the testing program under no-flow conditions. This data gives another type of picture of the effectiveness of the development and testing activities on water quality restoration. The next three figures show the ChemTool logs that were run following drilling, but prior to well completion, side-by-side with the logs that were run following well development and testing. Figure A.3-13 shows temperature logs, Figure A.3-14 shows the pH logs, and Figure A.3-15 shows EC logs. Included on these figures are lithologic information and well completion details.

Features in the temperature log generally reflect flow in the well. In particular, the postdevelopment temperature log shows a characteristic feature through the middle completion interval. There appears to be inflow at the top of the middle interval going downward and exiting at the bottom of the interval. The parameters pH and EC generally give an indication of the representativeness of the water within the well relative to formation water. The precompletion and postdevelopment pH logs generally have similar configuration down to the total depth of the post development logs, which do not extend into the lower completion. The postdevelopment pH log indicates that the water above the middle completion has pH between 8.3 and 8.6, which is higher than the precompletion pH log, which showed a pH of about 7.7 opposite the middle interval and 8.0 opposite the upper interval. Based on the ChemTool log, if the profile reflects the result of pumping, the pH in the upper interval appears to be higher than in the middle interval. However, if there is actually some downward flow under the ambient gradient, the lower pH water may originate in the lower part of the upper interval.

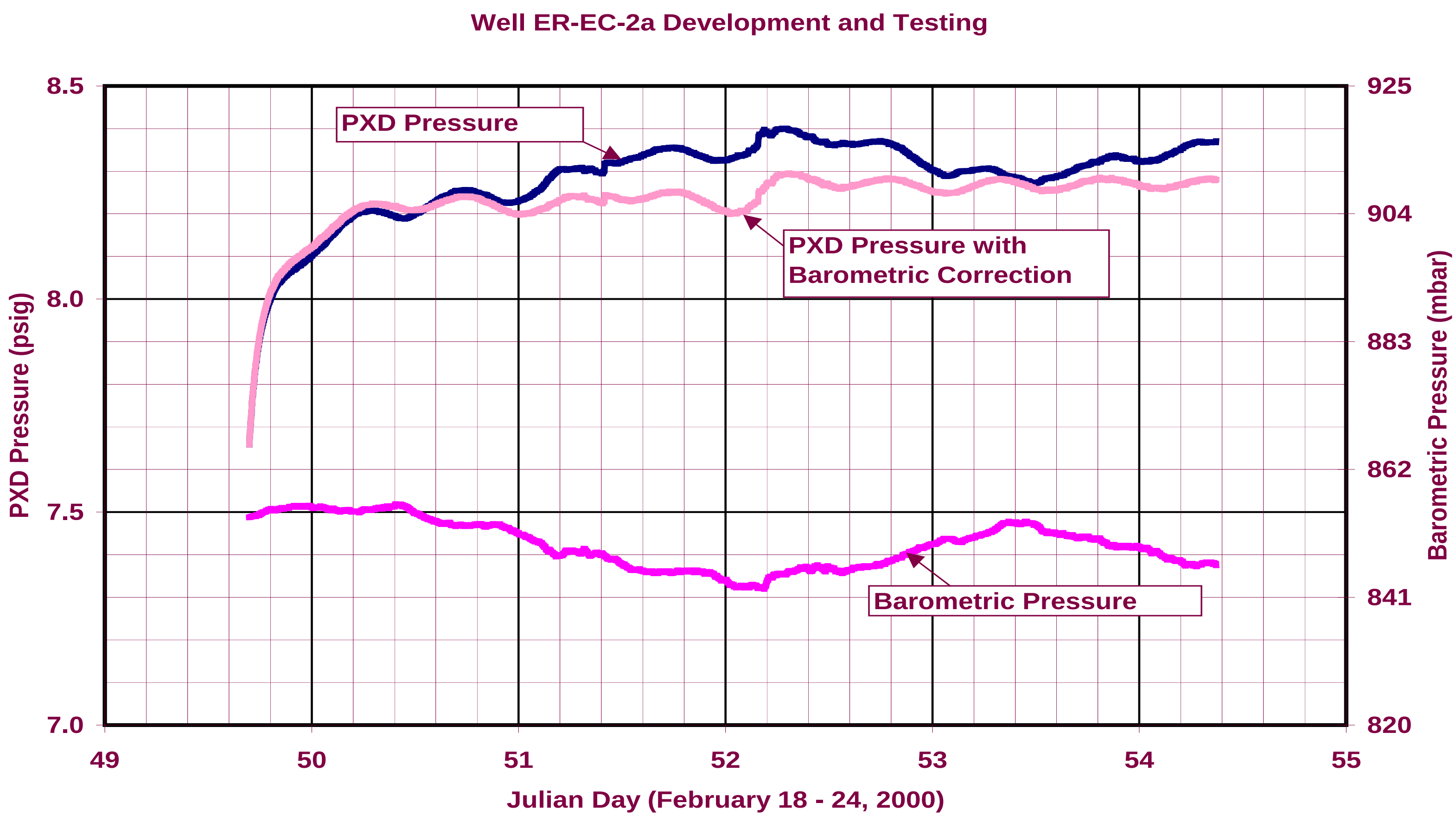
The EC log indicates significantly higher EC values postdevelopment, consistently about 775 μmhos/cm versus 500 μmhos/cm precompletion. Both the pH and EC logs are generally consistent from the upper completion to below the middle completion.

A.3.6.3 Grab Sample Results Versus ChemTool Results

The ChemTool pH values are a little higher (8.3-8.6) than the grab sample results which found pH consistently about 8. The ChemTool EC values (about 775 μmhos/cm) also do not agree with the grab samples, which were generally around 700 μmhos/cm at the end of the constant-rate test. The calibration of the different instruments used for these measurements should be compared to make sure they provide consistent values. Otherwise, the conditions under which the measurements are made (e.g., wellhead versus downhole) may produce results which are not always comparable. Both the precompletion and postdevelopment logs show more variation in the pH below the middle completion interval. Until the reason for differences between ChemTool log values in the interval of production for these parameters and grab samples values can be determined, use of these logs for parameter values is suspect. Perhaps this is primarily a calibration problem, or it may be related to differing environmental conditions between grab samples and downhole measurements.

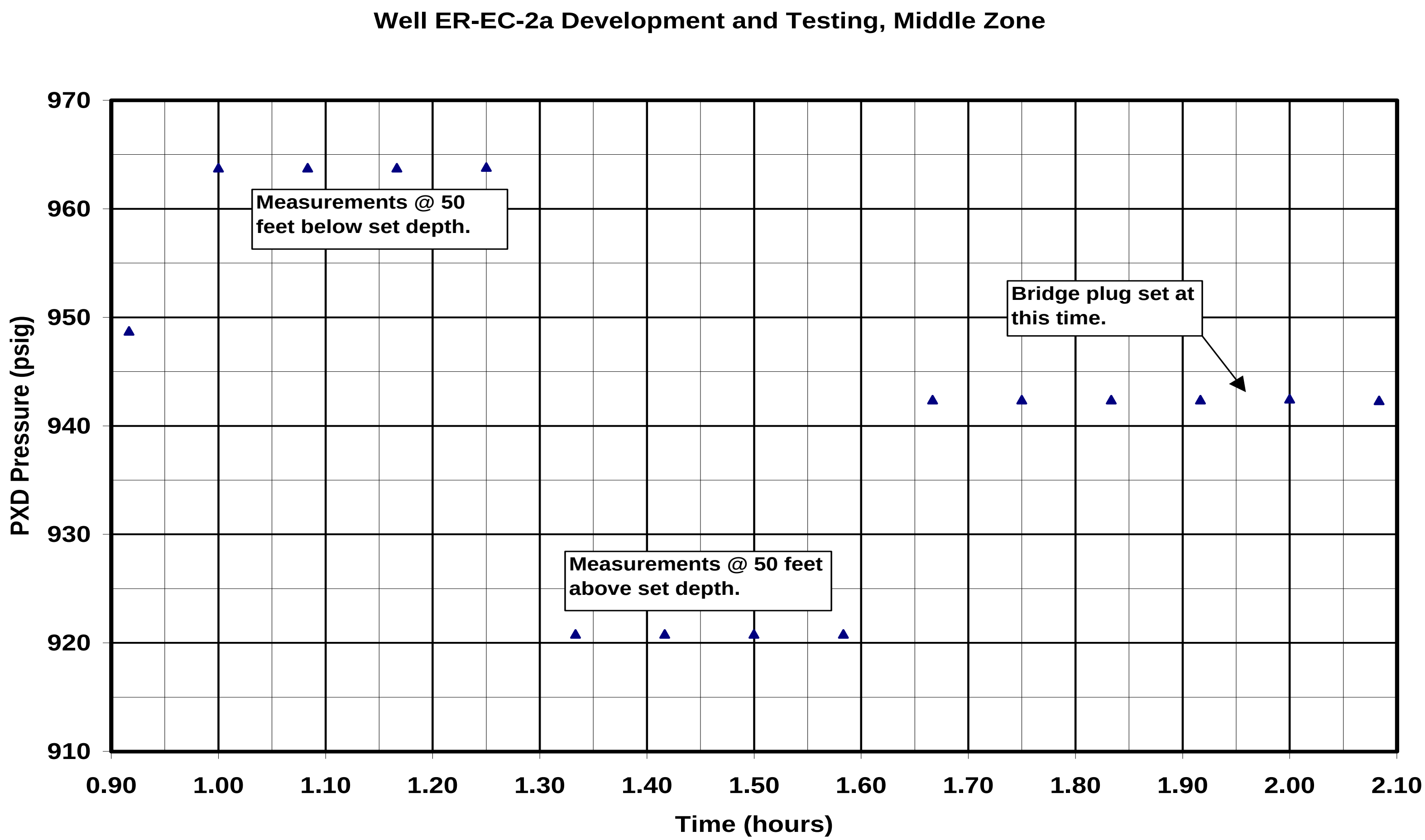
A.3.7 Representativeness of Hydraulic Data and Water Samples

The results of water quality monitoring, development, hydraulic testing, and composite sampling can be considered to only represent the upper and middle completion intervals of this well. Since the upper completion interval appears to have the highest head and any natural flow in the well would be downward, the upper completion interval does not naturally receive water from any source. Therefore, this interval will probably maintain its individual character for future sampling. The discrete sample taken in the lower part of the middle completion interval should represent the lower part of that interval. However, there was a large increase in production from that interval above the sample depth, which will not be represented in the sample. The lower completion interval cannot be considered developed, and any samples taken below the middle completion interval are suspect. This interval may, in fact, still be affected by drilling-induced fluids.



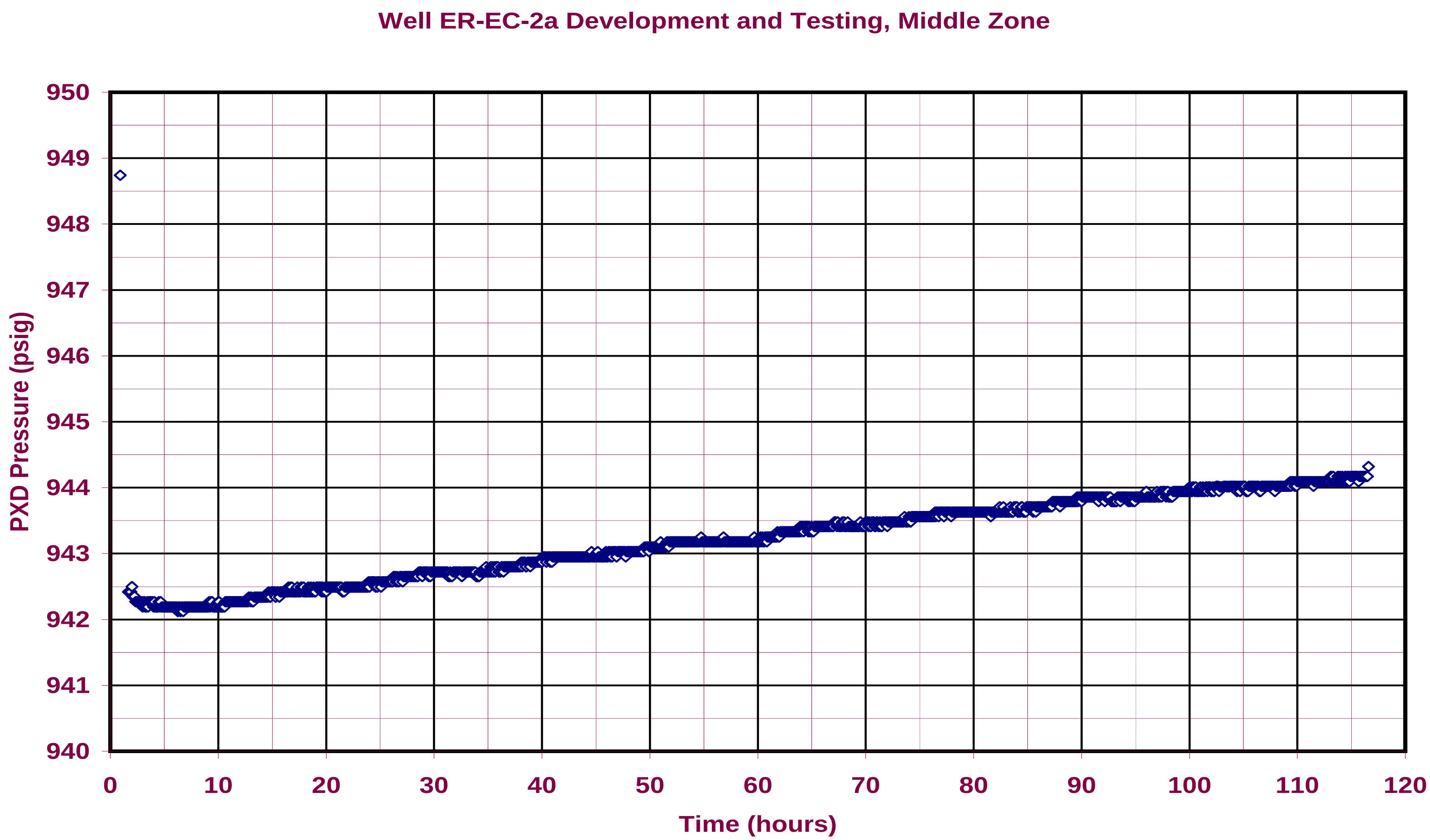
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



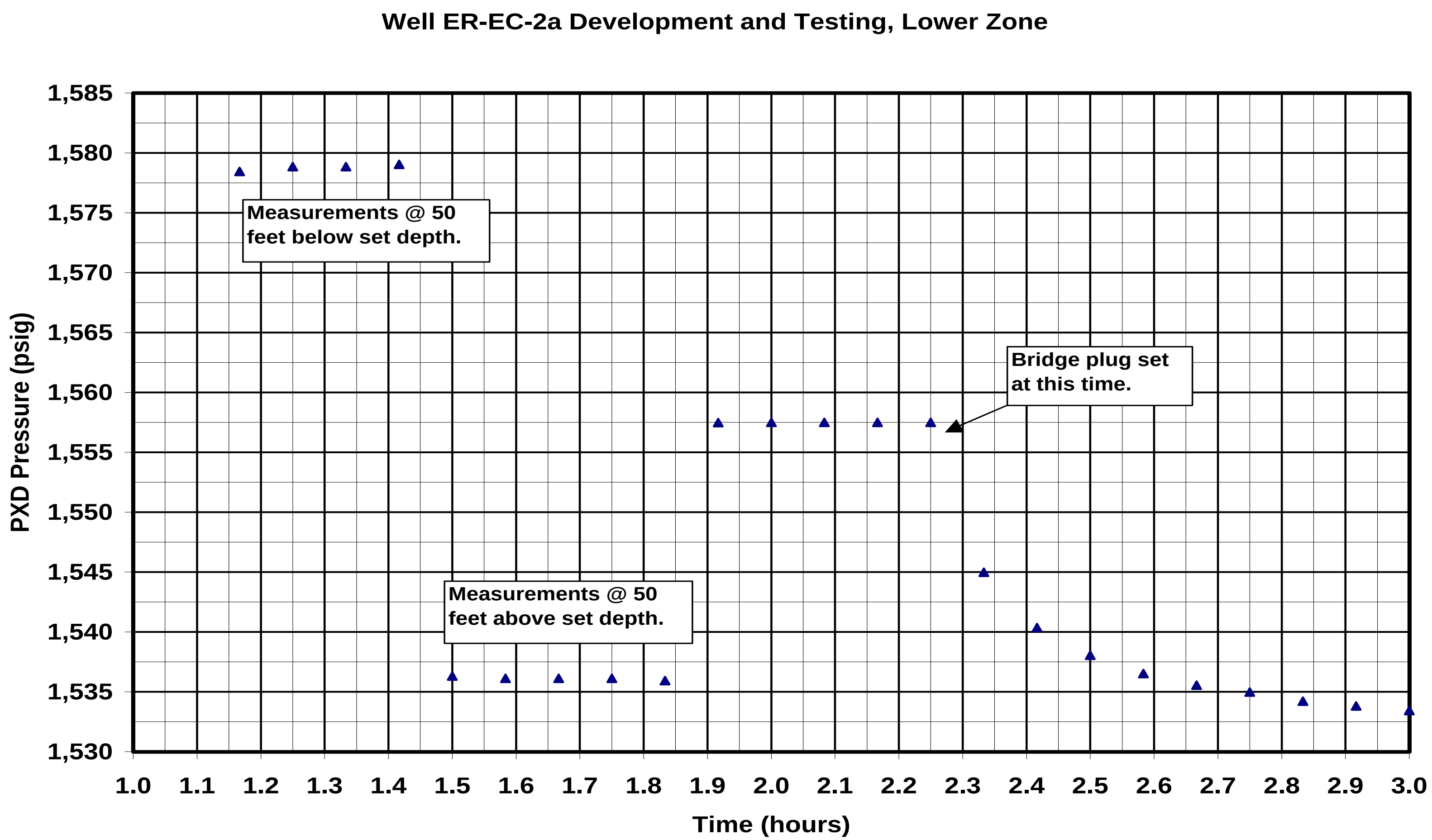
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



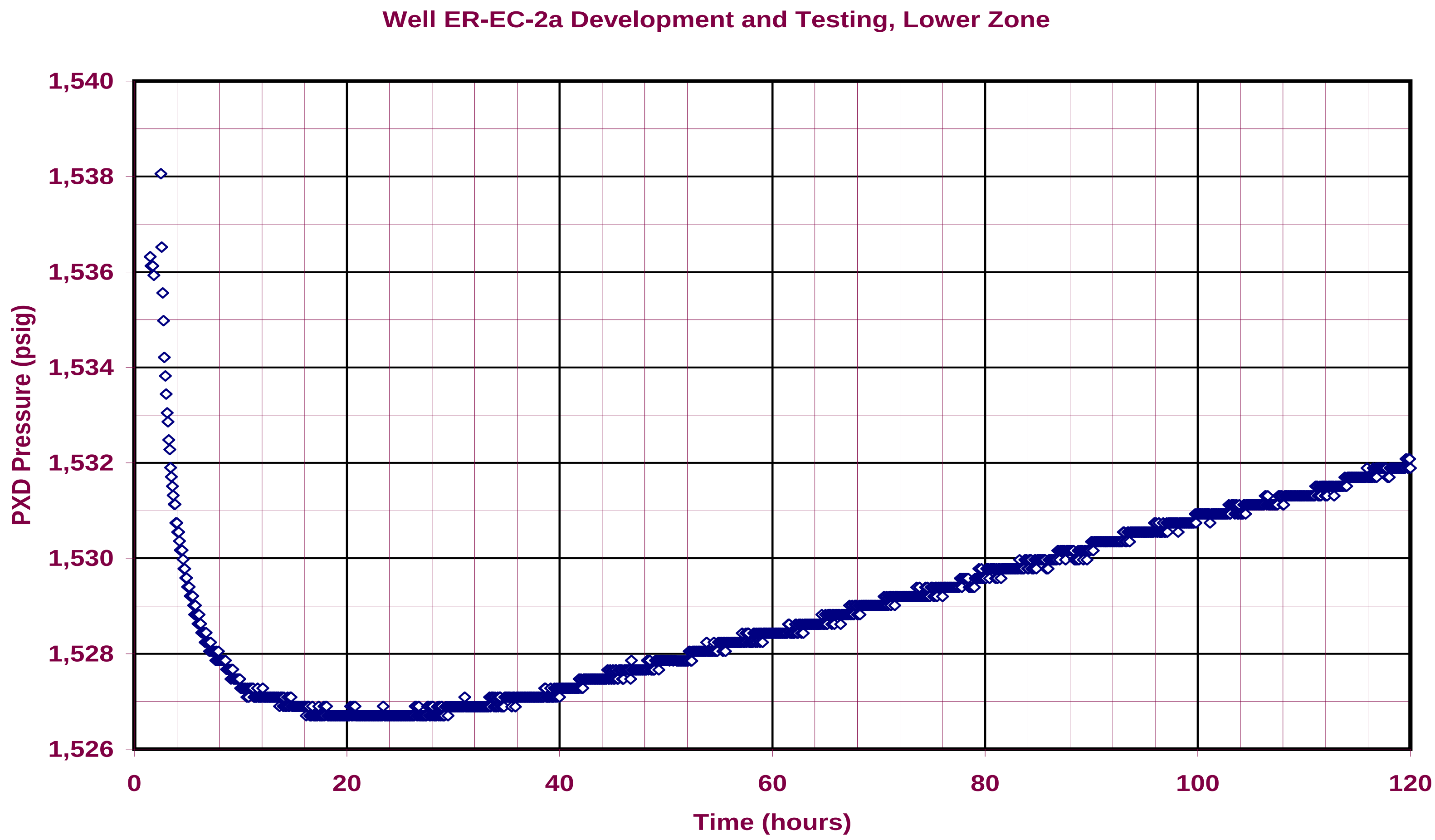
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



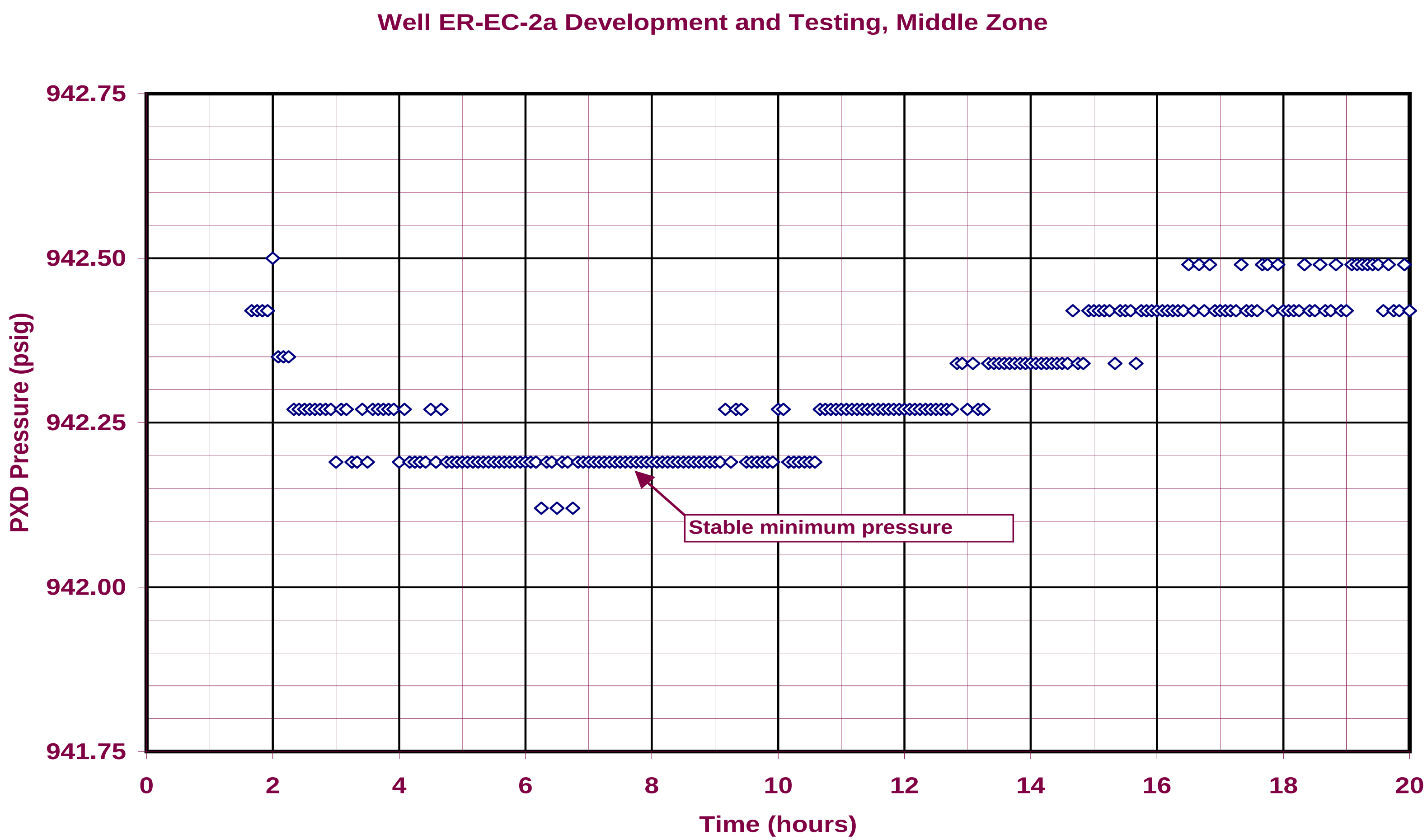
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



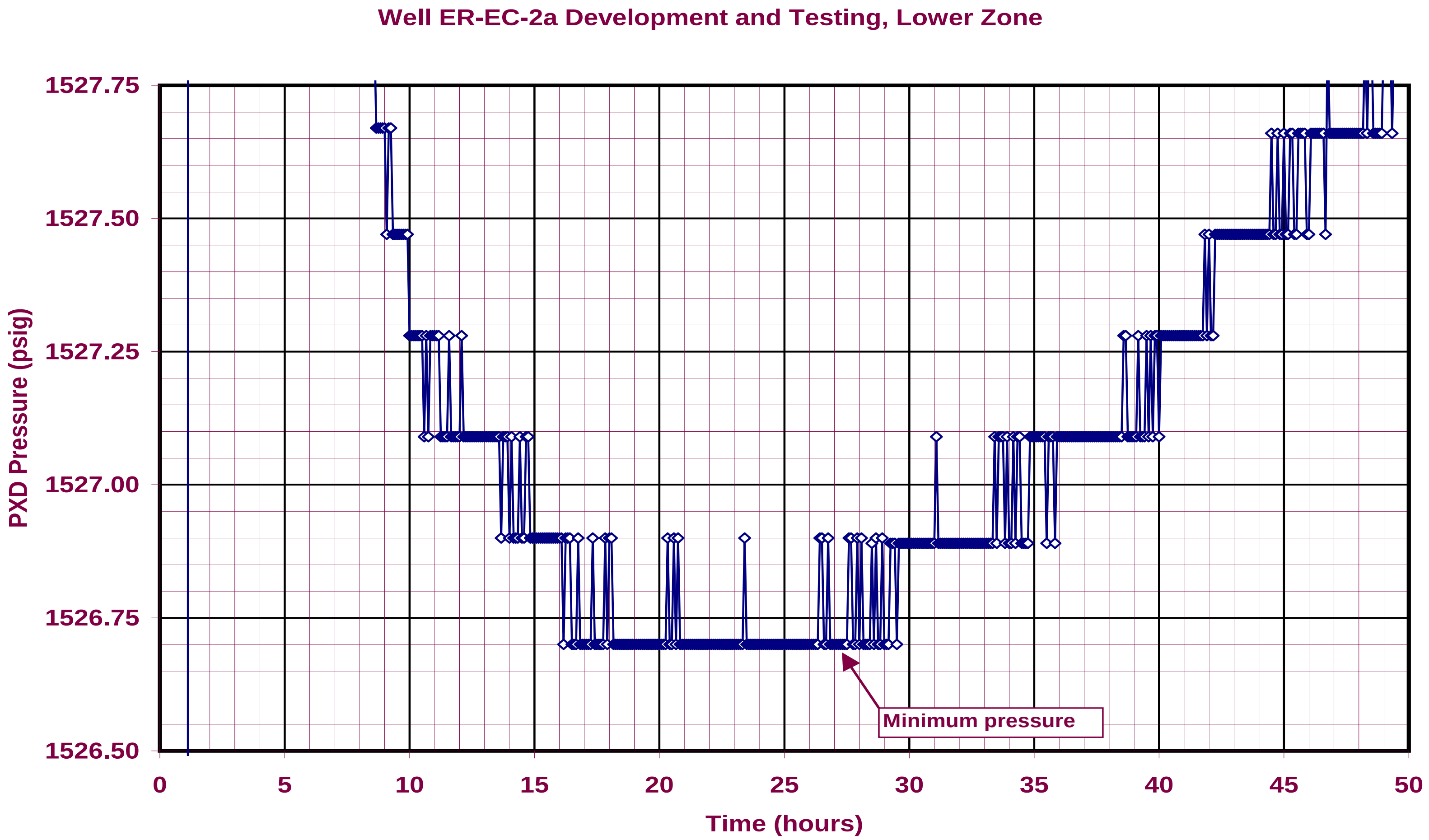
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



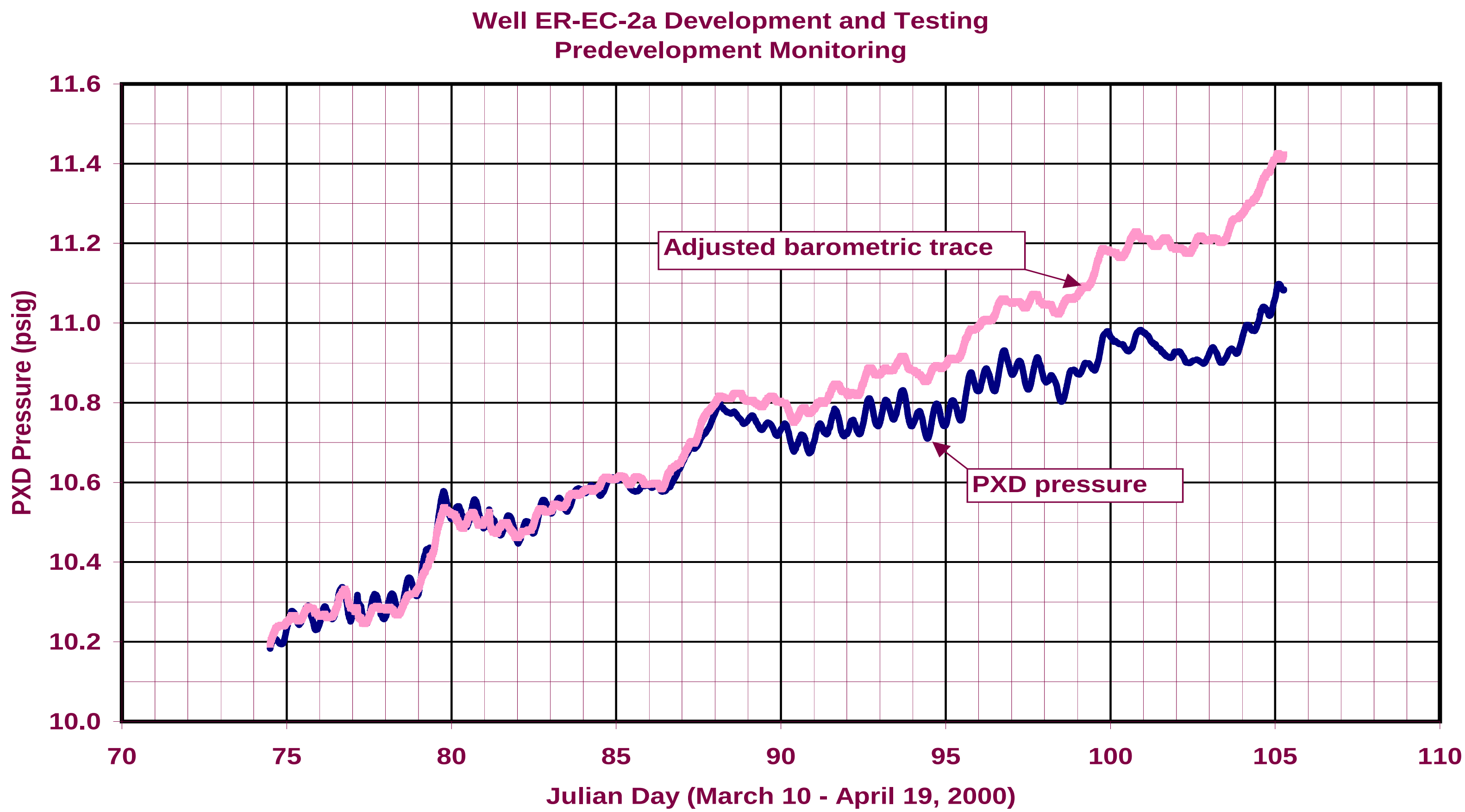
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-6
Middle Interval Minimum Pressure



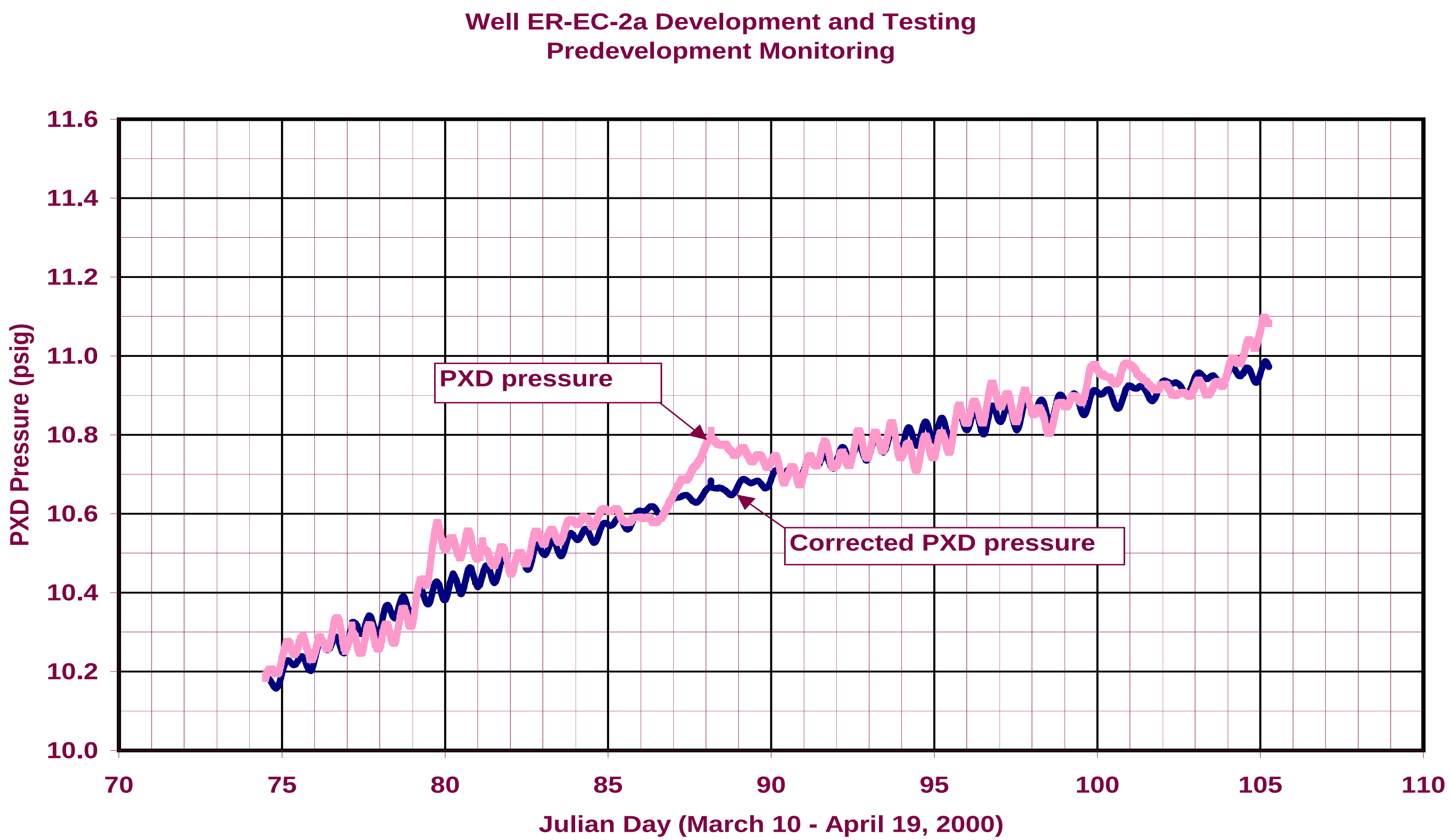
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-7
Lower Interval Minimum Pressure



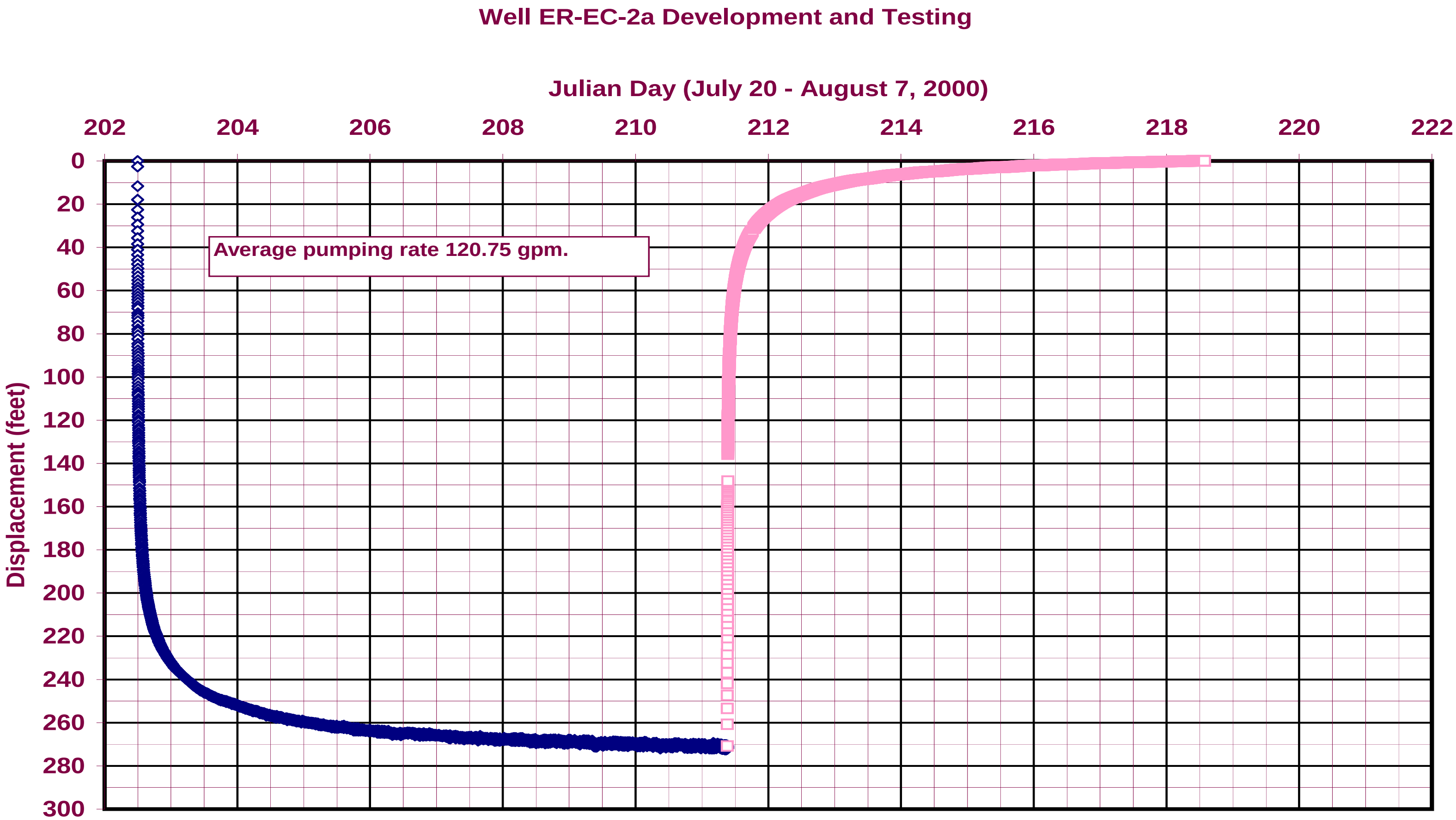
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-9
Predevelopment Water Level Monitoring Corrected for Barometric Pressure Variation



gpm - Gallons per minute

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

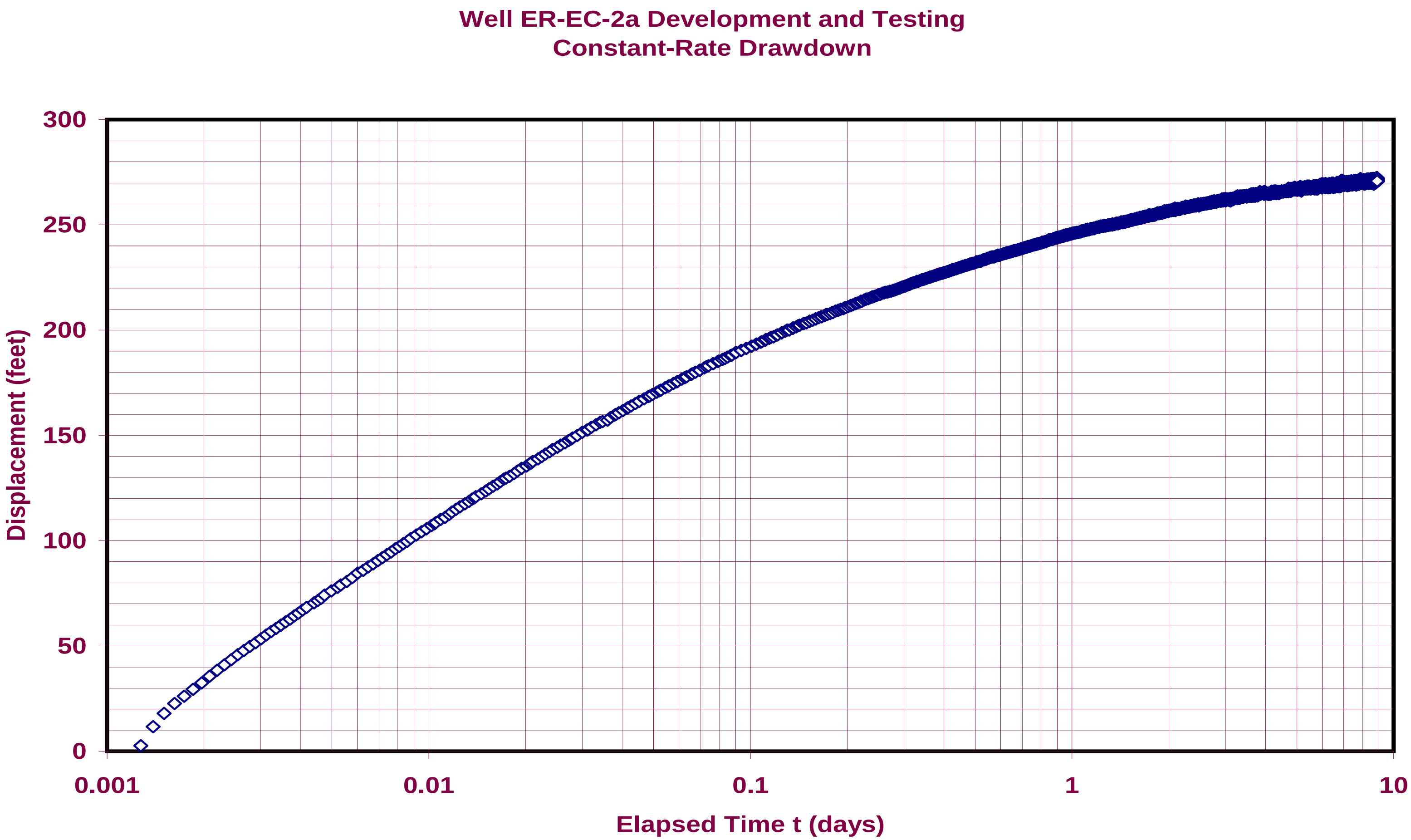


Figure A.3-11
Plot of Drawdown Versus Log Time

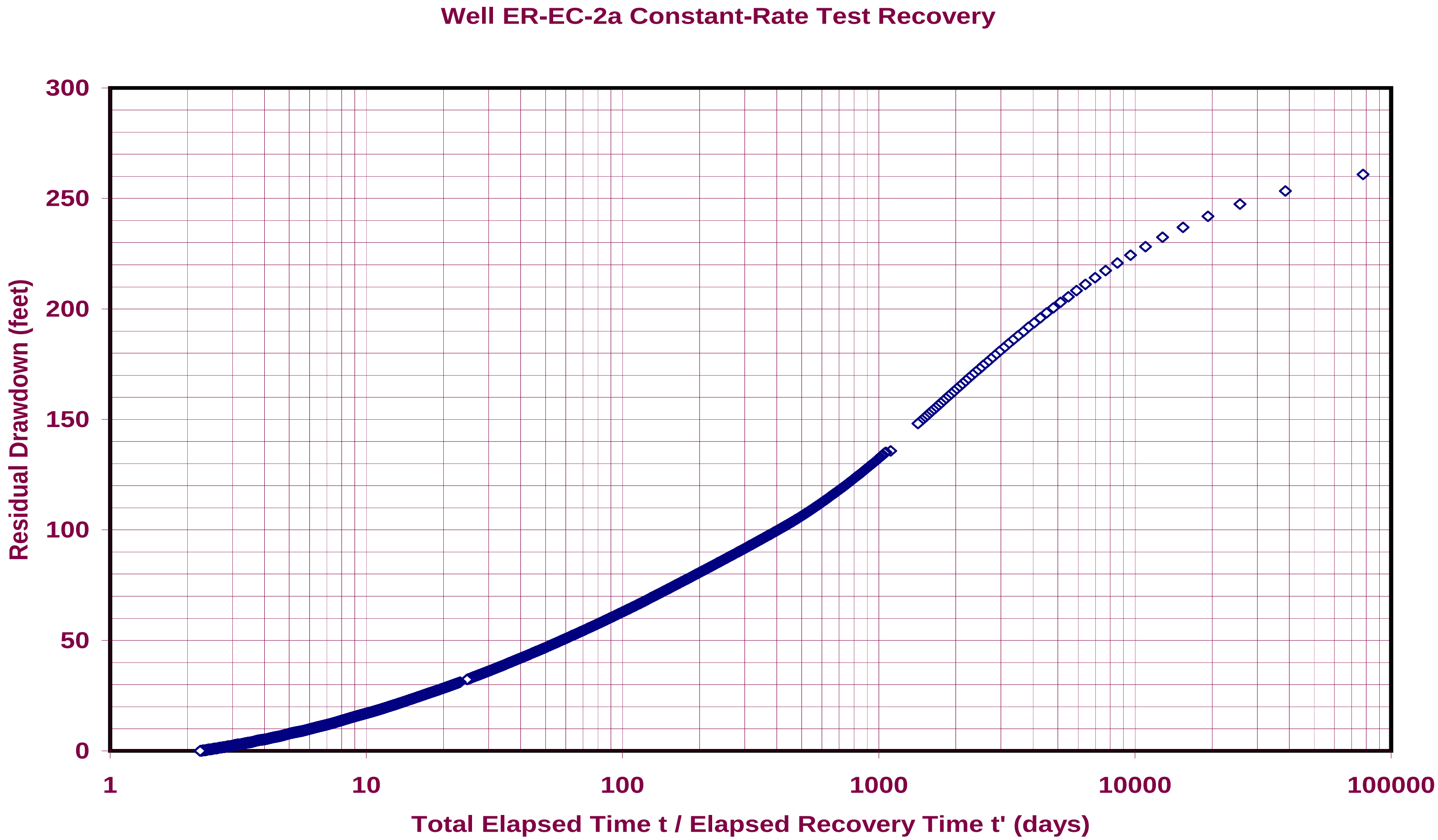


Figure A.3-12
Plot of Recovery Versus Log Time

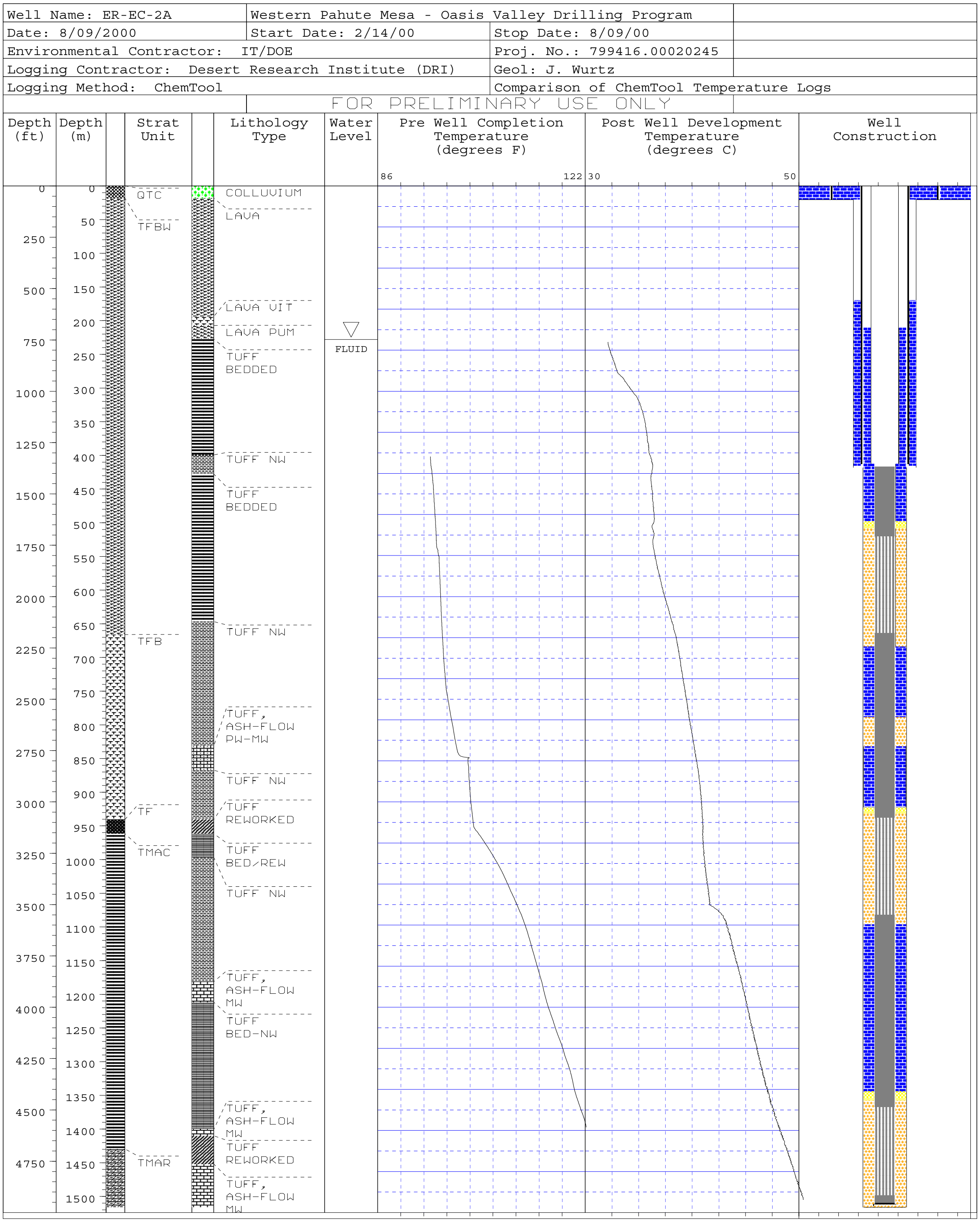


Figure A.3-13
Temperature Log Prior to Completion Versus Postdevelopment

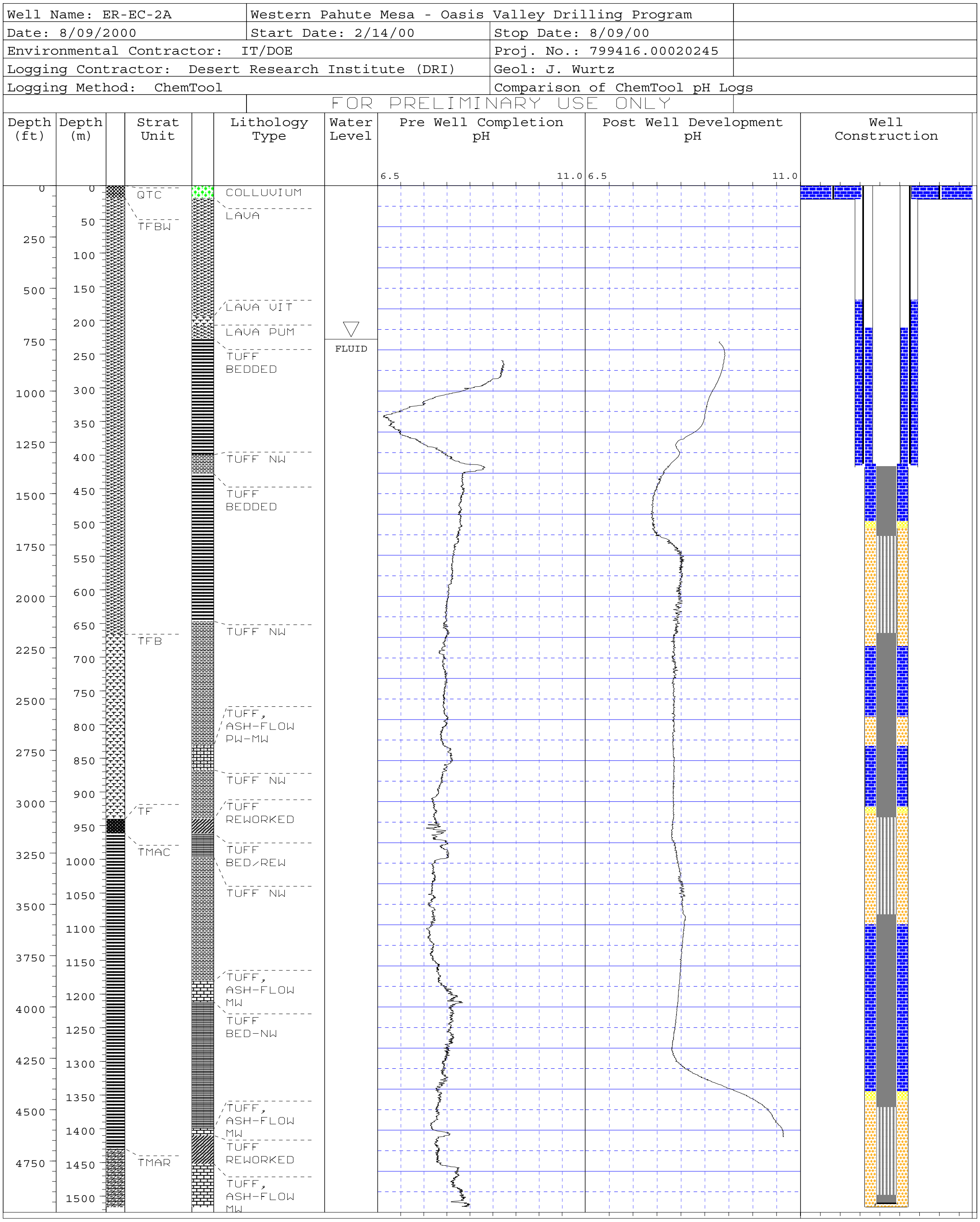


Figure A.3-14
pH Log Prior to Completion Versus Postdevelopment

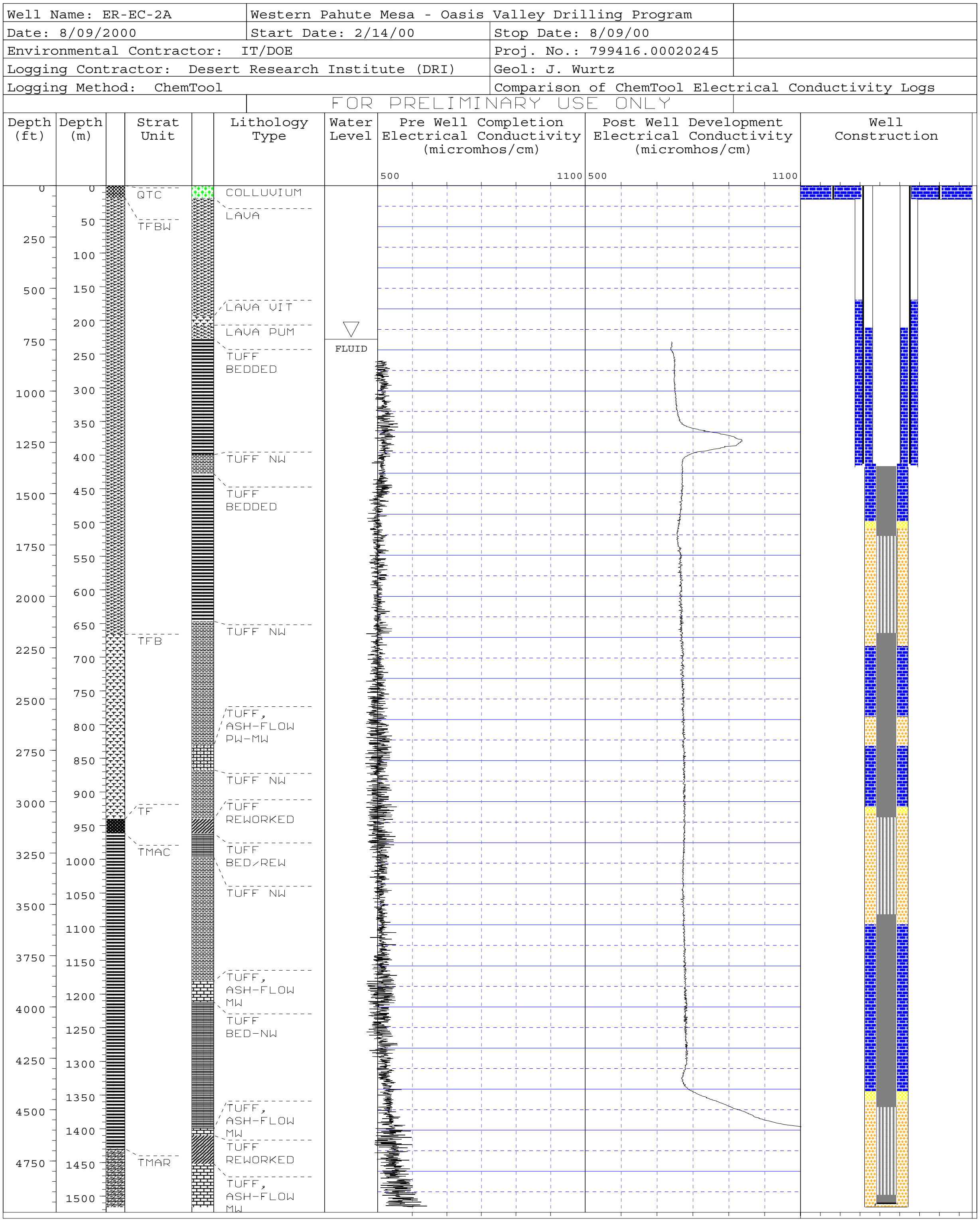


Figure A.3-15
EC Log Prior to Completion Versus Postdevelopment

A.4.0 Environmental Compliance

A.4.1 Fluid Management

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

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

sampling must occur every 12 hours until two consecutive nondetects occur. Sampling and testing may then resume on the 24-hour schedule.

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

A.4.1.1 Water Production and Disposition

At Well ER-EC-2a, all fluids from the 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 8.9 ft from the bottom. Fluids reached the overflow pipe and began discharging to the ground surface at the northeast corner of Sump #1 on June 30, 2000. Discharge to the ground surface occurred after approximately 177,000 gals had been pumped into Sump #1. The sump had residual fluids from the drilling.

A total of approximately 2,702,531 gals of groundwater were pumped from Well ER-EC-2A during well development, hydraulic testing, and sampling activities. The total is composed of 1,143,022 gals produced during well development and 1,559,509 gals during constant-rate pumping. As of August 12, 2000, the fluid level of Sump #1 had only fallen to 7.8 ft, indicating that approximately 1.1 ft of fluids had infiltrated and/or evaporated. Table A.4-1 contains an updated Fluid Disposition Reporting Form.

A.4.1.2 Lead and Tritium Monitoring

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

The NDWS were not exceeded at any time. The highest lead result was 1.0 μg/L and highest tritium activity was 556.5 pCi/L. Both of these results were well below the NDWS. The complete results of lead and tritium monitoring are presented in Table A.4-2.

A.4.1.3 Fluid Management Plan Sampling

A fluid management sample was collected from the active unlined sump at the end of well development and testing activities to confirm on-site monitoring of well effluent. The sample was collected, along with an equipment rinsate sample, on

Table 4-1
Fluid Disposition Reporting Form

Site Identification: ER-EC-2a

Site Location: Nellis Air Force Range

Site Coordinates: N 4,111,038.2; E 538,340.5 (UTM Zone 11, NAD 83, meters)

Well Classification: ER

IT Project No.: 799416.00020245

Report Date: August 30, 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 (m^3)		Sump #2 Volumes (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	1/22/2000	1/26/2000	4	257.0	577.9	55.2	406.9	N/A	N/A	406.9	N/A	YES
Phase I: Saturated-Zone Drilling	1/27/2000	2/06/2000	9	1,516.6	990.7	162.7	18,204.8	N/A	917.8	19,122.6	N/A	YES
Phase II: Initial Well Development	6/28/2000	7/17/2000	8	1,516.6	---	N/A	4,326.3	N/A	N/A	4,326.3	N/A	YES
Phase II: Aquifer Testing	7/18/2000	8/15/2000	11	1,516.6	---	N/A	5,902.7	N/A	N/A	4,492.3	N/A	YES
Phase II: Final Development	---	---	---	---	---	---	---	---	---	---	---	---
Cumulative Production Totals to Date:			32		1,568.6	217.9	28,840.7		917.8	28,348.1	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 sumps.
[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 8.9 ft) = 1,706.3 m^3 Sump #2 (at height of 9.8 ft) = 1,968.9 m^3

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

Remaining Facility Capacity (Approximate) as of 8/12/00: Sump #1 = 295.9 m^3 (17.3%) Sump #2 = 1,968.9 m^3 (100%)

Current Average Tritium = 135.7 picoCuries/liter

Notes:

IT Authorizing Signature/Date: [signature] 9-7-00

July 29, 2000, and sent to Paragon. Samples were analyzed for total and dissolved metals, gross alpha and beta, and tritium. The laboratory results are presented in Table A.4-3 and compared to the NDWS.

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

Sampling Date	Sample Number	Lead Results[1]	Tritium Results[2a]
		µg/L	pCi/L
6/28/2000	EREC2A-062800-01	1.0	0
6/29/2000	EREC2A-062900-01	<1.0	297.9
6/30/2000	EREC2A-063000-01	<1.0	0
7/1/2000	EREC2A-0701800-01	1.0	0
7/2/2000	EREC2A-070200-01	1.0	0
7/3/2000	EREC2A-070300-01	1.0	0
7/4/2000	EREC2A-070400-01	1.0	0
7/5/2000	EREC2A-070500-01	<0.5	0
7/18/2000	ER-EC-2A-071800-01	<1.0	262.2
7/20/2000	ER-EC-2A-072000-01	<0.5	0
7/21/2000	ER-EC-2A-072100-01	1.0	556.5
7/22/2000	ER-EC-2A-072200-01	1.0	121.0
7/23/2000	ER-EC-2A-072300-01	1.0	223.9
7/24/2000	ER-EC-2A-072400-01	1.0	171.7
7/25/2000	ER-EC-2A-072500-01	0.5	451.4
7/26/2000	ER-EC-2A-072600-01	0.5	59.9
7/27/2000	ER-EC-2A-072700-01	0.5	287.0
7/28/2000	ER-EC-2A-072800-01	0.5	0
7/29/2000	ER-EC-2A-072900-01	0.5	147.4
Nevada Drinking Water Standards		15.0	20,000

1 - Lower detection limit 2 ppb.
2 - Lower detection limit 500 to 1,000 pCi/L, depending upon calibration.
[a]Analysis provided by Bechtel Nevada Site Monitoring Service at the CP in Area 6

µg/L - Micrograms 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*

Table A.4-3
Preliminary Analytical Results of Sump Fluid Management Plan Sample at Well ER-EC-2a

Analyte	CRDL	Laboratory	NDWS	Results of Sump Composite Sample #EC-2a-072900-3 (F)	
Metals (mg/L)					
				Total	**Dissolved**
Arsenic	0.01	Paragon	0.05	B 0.0052	B 0.0053
Barium	0.2	Paragon	2.0	B 0.0055	B 0.0053
Cadmium	0.005	Paragon	0.005	U 0.005	U 0.005
Chromium	0.01	Paragon	0.1	B 0.0011	B 0.00076
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 0.0011	B 0.0012
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 0.0	+/- 160
Gross Alpha	3.1	Paragon	15	13.2	+/- 3.4
Gross Beta	3.8	Paragon	50	1.7	+/- 2.3

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

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 were produced containing stained absorbant pads (from pump oil, hydraulic fluid and diesel), soil, and debris.

- Hazardous Waste: Approximately two gallons of solid, potentially hazardous waste was generated from the installation of bridge plugs/packers. This material consisted of combustion by-products. The waste was stored in a Satellite Accumulation Area at the ER-EC-2A well site. Monthly inspections were conducted until the waste was transported off site for disposal.

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

The bridge plug/packer waste was sampled on August 14, 2000, for a waste characterization on the material. The waste sample, an oily sludge, was sent to Paragon and analyzed for the following: Toxicity Characteristic Leaching Procedure *Resource Conservation and Recovery Act* (RCRA) metals, volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), ignitability, corrosivity, and reactivity. The VOCs and SVOCs had to be resampled due to a malfunction of a laboratory refrigerator. The results of the analysis are shown on Table A.4-4. A preliminary evaluation of the results indicated the waste was hazardous because of elevated levels of benzene and was disposed of by Safety-Kleen.

Table A.4-4
Preliminary Results of Waste Characterization Sampling of Bridge Plug/Packer Waste at Well ER-EC-2a
(Page 1 of 2)

Analyte	Analytical Method	Reporting Limit (mg/kg)	Results of Sample # PKWS001, August 14, 2000 (mg/kg)
Reactive Cyanide	SW 9010	0.1	U 0.1
Reactive Sulfide	SW 846_7.3.2	50.0	U 50
Ignitability	SW 1010	- - -	U 0.0
RCRA Metals			
Arsenic	SW 846-6010	1.0	U 1
Barium	SW 846-6010	10.0	N 330
Cadmium	SW 846-6010	0.5	B 0.18
Chromium	SW 846-6010	1.0	N 36
Lead	SW 846-6010	0.3	20
Selenium	SW 846-6010	0.5	B 0.33

Table A.4-4
Preliminary Results of Waste Characterization Sampling of Bridge Plug/Packer Waste at Well ER-EC-2a
(Page 2 of 2)

Analyte	Analytical Method	Reporting Limit (mg/kg)	Results of Sample # PKWS001, August 14, 2000 (mg/kg)
RCRA Metals			
Silver	SW 846-6010	1.0	U 1
Mercury	SW 846-7471	0.1	U 0.1
Semivolatiles[a]			
Phenol	SW 846-8270	97.0	550
2-Methylphenol	SW 846-8270	97.0	370
4-Methylphenol	SW 846-8270	97.0	280
2, 4-Dimethylphenol	SW 846-8270	97.0	200
Naphthalene	SW 846-8270	97.0	J 70
			Results of Sample #PKWS003 August 22, 2000 (mg/kg)
Volatiles[b]			
1, 2, 4 - Trimethylbenzene	SW 846-8260B	10	11
1, 3, 5 - Trimethylbenzene	SW 846-8260B	10	22
2- Butanone	SW 846-8260B	40	J, B 18
Benzene	SW 846-8260B	10	350
Ethylbenzene	SW 846-8260B	10	45
Isopropylbenzene	SW 846-8260B	10	J 2.4
Methylene Chloride	SW 846-8260B	10	J, B 4.1
N - Propylbenzene	SW 846-8260B	10	J 1.6
Naphthalene	SW 846-8260B	10	130
Toluene	SW 846-8260B	10	130
Xylene, M + P	SW 846-8260B	10	65
Xylene, 0	SW 846-8260B	10	11

[a]All other semivolatiles were nondetects.
[b]All other volatiles were nondetects.

U = Analyte was not detected at a given reporting limit.
N = Spiked sample recovery not within control limits. A post spike is analyzed for all 6010B analyses when the matrix spike and/or spike duplicate fail and the native sample concentration is less than 4 times the spike added concentration.
B = Result was less than the Reporting Limit (RL) but greater than or equal to the Instrument Detection Limit (IDL).
J = The result is estimated because it is less than the RL but greater than or equal to the IDL.

A.5.0 References

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

IT, see IT Corporation.

IT Corporation. 1993, as amended. *ITLV Standard Quality Practices Manual*, Vol. 1 and 2. Las Vegas, NV.

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 Instruction 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.

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.

NNSA/NV, see U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office.

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*, 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, National Nuclear Security Administration Nevada Operations Office. 2002. *Completion Report for Well ER-EC-2a*, DOE/NV/11718-591, Rev. 0, March. Las Vegas, NV.

Attachment 1

Manufacturer's Pump Specifications

High-Capacity Testing Pump

RFQ # 623 HIGH VOLUME ELECTRIC SUBMERSIBLE PUMP SYSTEMS

BECHTEL NEVADA CORPORATION

YUCCA MOUNTAIN PROJECT

NEVADA TEST SITE

TERRY FLETCHER

CENTRILIFT

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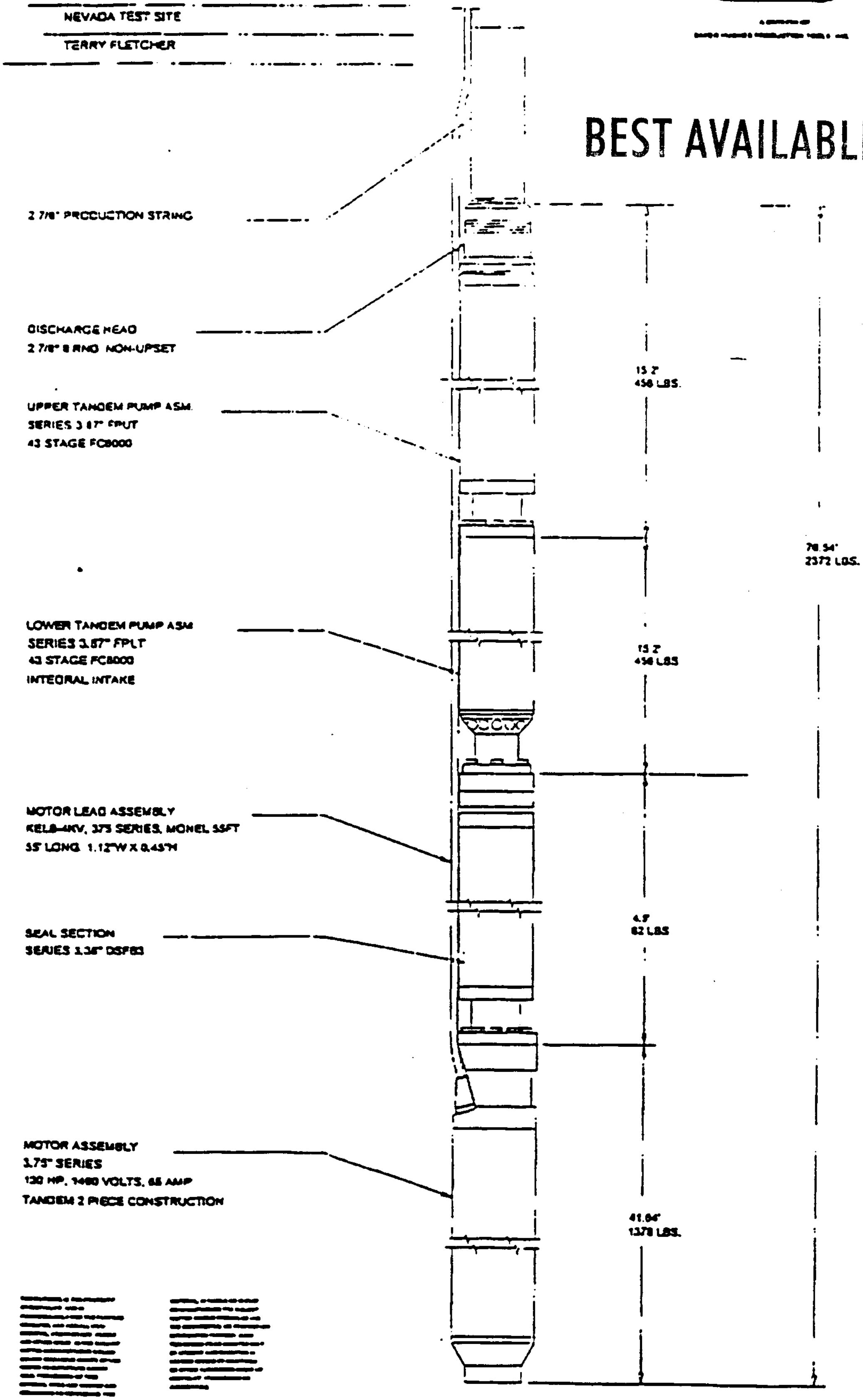
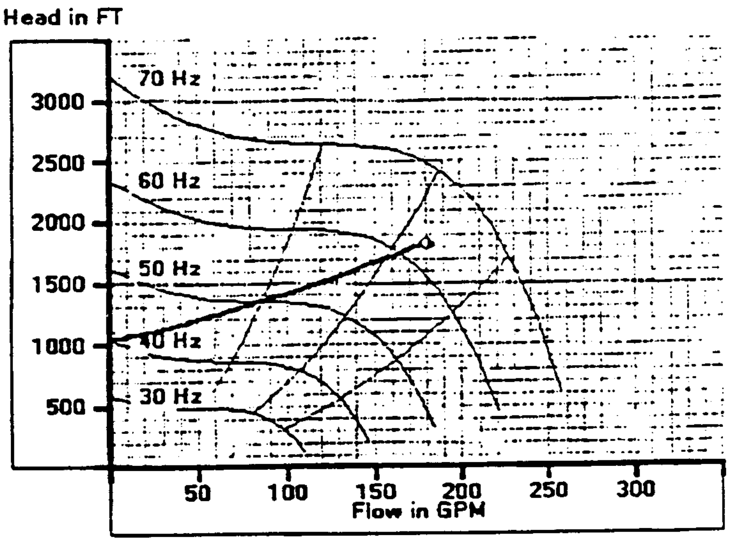


60-180 G.P.M. OPERATION
AT 1000 FT PUMP SETTING DEPTH (300 PSI tubing pressure)



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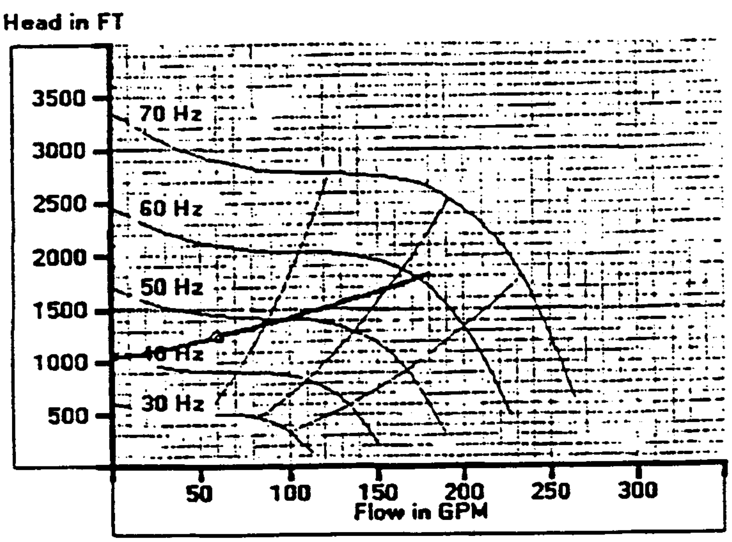

Frequency	Hz	45	50	55	60	65
Flow at Stock Tank	GPM	44.37	99	138	165	188
Pump Intake Pressure	psi	230	155	101	63.67	32.29
Total Dynamic Head	FT	1178	1409	1601	1746	1875
Fluid speed by motor	ft/sec	0.532	1.185	1.658	1.985	2.258
Motor Load	%	30.9	50.79	67.48	80.71	93
Motor Amps	A	40.6	40.96	48.83	55.22	61.25
Pump RPM	rpm	2646	2939	3204	3464	3717
Surface KVA	kVA	66.52	74.72	106	137	171

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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

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 @ 1000' pump setting depth, 47.7-63.1 Hz. operation
Slim-line design to accomodate production logging tools *NOTE: Motor ratings at 60Hz
7-5/8" casing internally coated for a drift of 6.83" i.d. * Note: Set VSD to 63.1 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 = 1000ft
Perfs V. Depth = 2500ft
Datum Static P = 284psi
Test Flow = 6171BPD
Test Pressure = 43.29psi
PI = 24.95BPD/psi
IPR Method = Composite IPR

Target:
Pump Setting Depth
(vertical) = 1000ft
Desired Flow = 6171BPD
Gas Sep Eff = 90%
Tbg Surf Press = 300psi
Csg Surf Press = 0psi

Casing & Tubing: Roughness = 0.0018 in

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

Correlations PVT:

Dead Visc: Beggs & Robinson
Saturated Visc: Beggs & Robinson
UnderSaturated: Vasquez & Beggs
Gas Visc: Lee

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

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

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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	Frequency	= 63.1 Hz
% water	= 100.0 %	GOR into pump	= 1.0 scf/STB
% Gas into pump	= 0.0 %bs /0.0 %	TDH	= 1828 FT

Pump Selection:

	Intake	Discharge
Pressure	= 43.56 psi	825 psi
Flowrate	= 6256 BPD	6243 BPD
Specific Gravity	= 0.986 rel-H2O	0.988 rel-H2O
Viscosity	= 0.511Cp	0.526Cp

60-180 GPM @ 1000' pump setting depth. 47.7-63.1 Hz. operation

Pump Selected:
86 stages Type: FC6000 [400 Series]
Shaft HP at 63.1 Hz = 117 (32 %)
Required motor shaft HP at 60.0 Hz = 115

Seal Selection:

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

Oil temperature at thrust chamber = 193°F
Chamber Cap Used (Top to Bot)=
18% 20%
Thrust bearing load =49 %
Shaft load = 67 %

Motor Selection:

Terminal Voltage	=1512.1 V	Fluid Speed	=2.16ft/s
Cable Current	=59. A		
Load acc to N.P.	=88.4 %	Internal Temp	=158°F
Shaft Load	=46.5 %	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	Wellhead Voltage	= 1545.0V
Tubing Length	= 980ft	Wellhead kVA	= 157.9kVA
MLE length	= 20.0ft	Voltage Drop	= 32.9V
Surface Temp	= 75°F	Cond Temp (main)	= 166°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	= 125.1kVA	Voltage Input	= 480V
System kW	= 120.1kW	Max Well Head Volts	= 1545V
Max Ctrl Current	= 189.9A	Max Frequency	= 63.1Hz (7.61V/Hz)
Power Cost/kWH	= 0.05$/kW	Start Frequency	= 10.0Hz
Total Power Cost	= $4322/month	Step-up Trafo	= 3.219 ratio
		Selected: VSD 2250-V*	260kVA/ 480V/ 313A

NEMA 3 design (outdoor use)

— End of Report —

Centrilift - A Baker Hughes company
(714) 893-8511 (800) 755-8976 (714) 892-9945 FAX (714) 397-0941 MOBILE
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Terry Fletcher- Sales Engineer E-Mail: Terry.Fletcher@Centrilift.com

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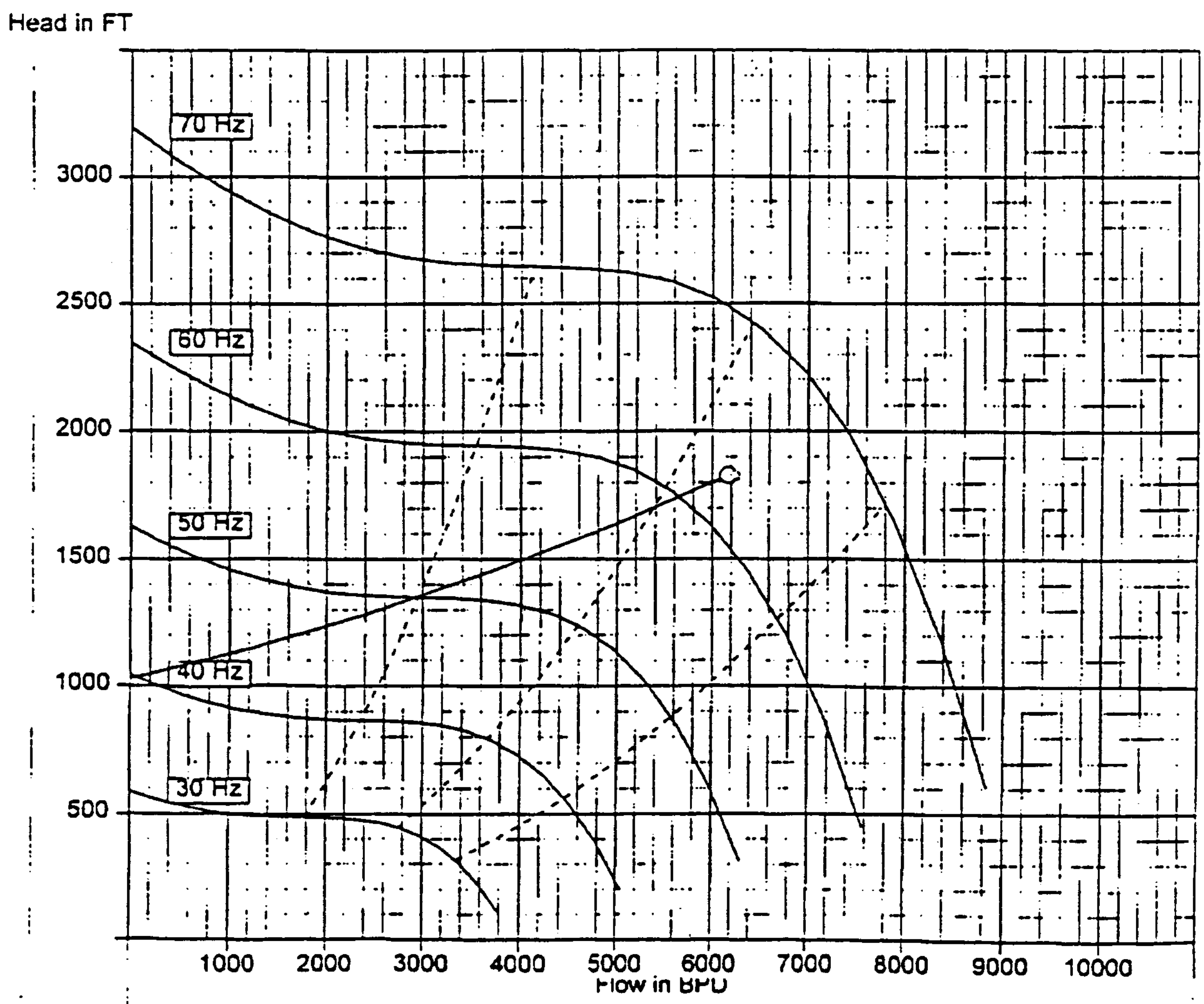
60-180 GPM @ 1000' pump setting depth, 47.7-63.1 Hz. operation
Slim-line design to accomodate production logging tools *NOTE: Motor ratings at 60Hz
7-5/8" casing internally coated for a drift of 6.83" i.d. * Note: Set VSD to 63.1 Hz

86-FC6000 Series: 400

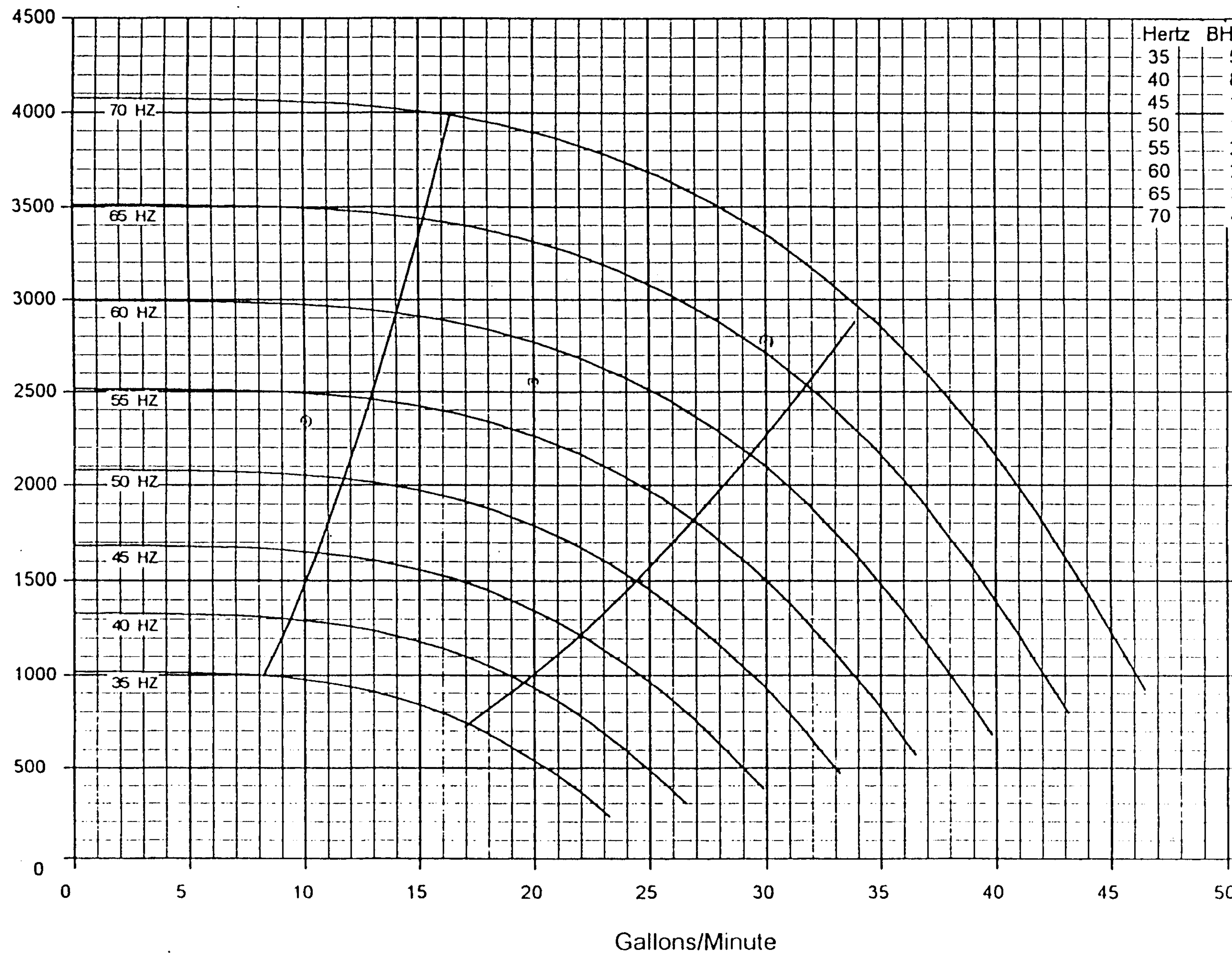


Dedicated Sampling Pump

Plot Program by Electric Submersible Pumps,Inc

4.00 ESP Pumps

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



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

Post-it® Fax Note 7671
Date 2/16/00 | # of pages ▸ 16
To D. SCHWICHTENBERG | From K. ORTEGO
Co./Dept. | Co.
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Att-9

Attachment 1

Bechtel Nevada
Las Vegas Nevada
Item Number 0001

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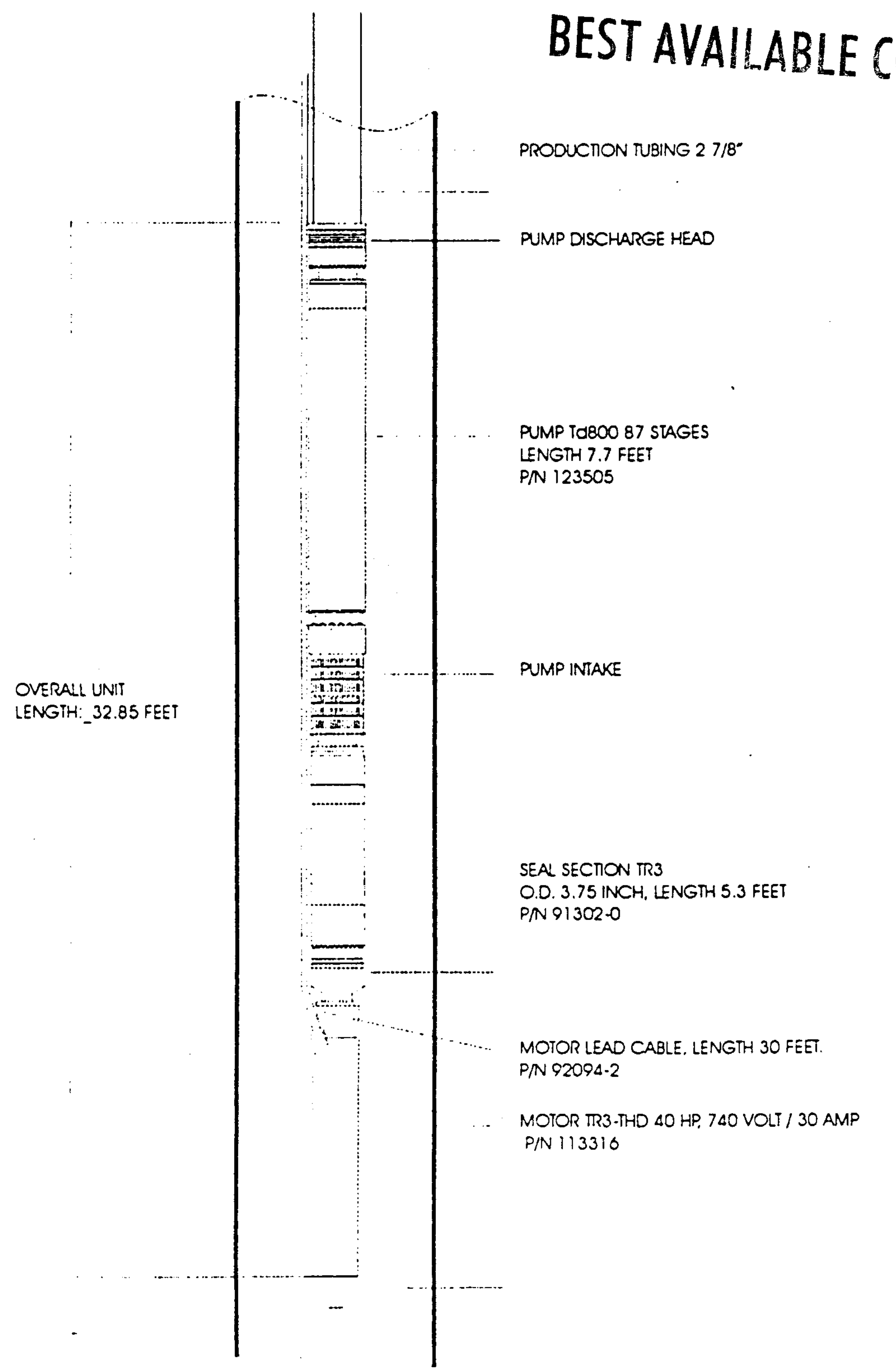

NOT TO SCALE

ESP

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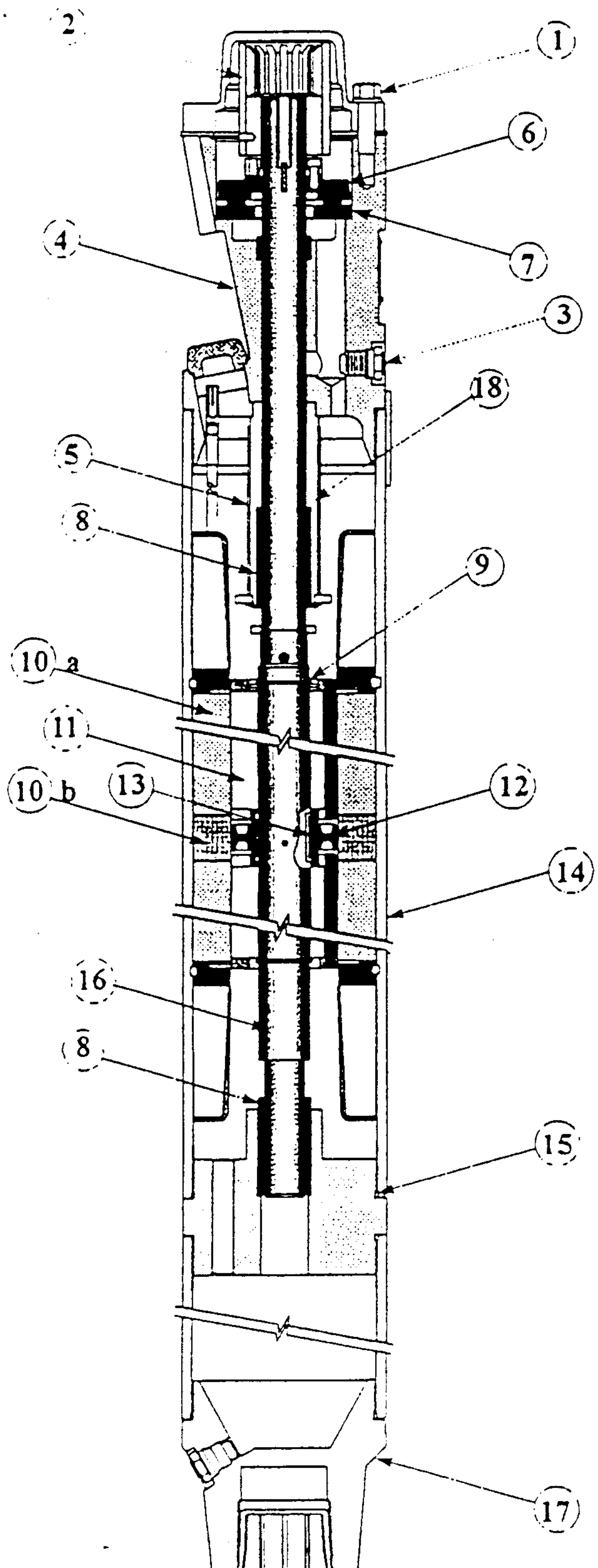
WOOD GROUP

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

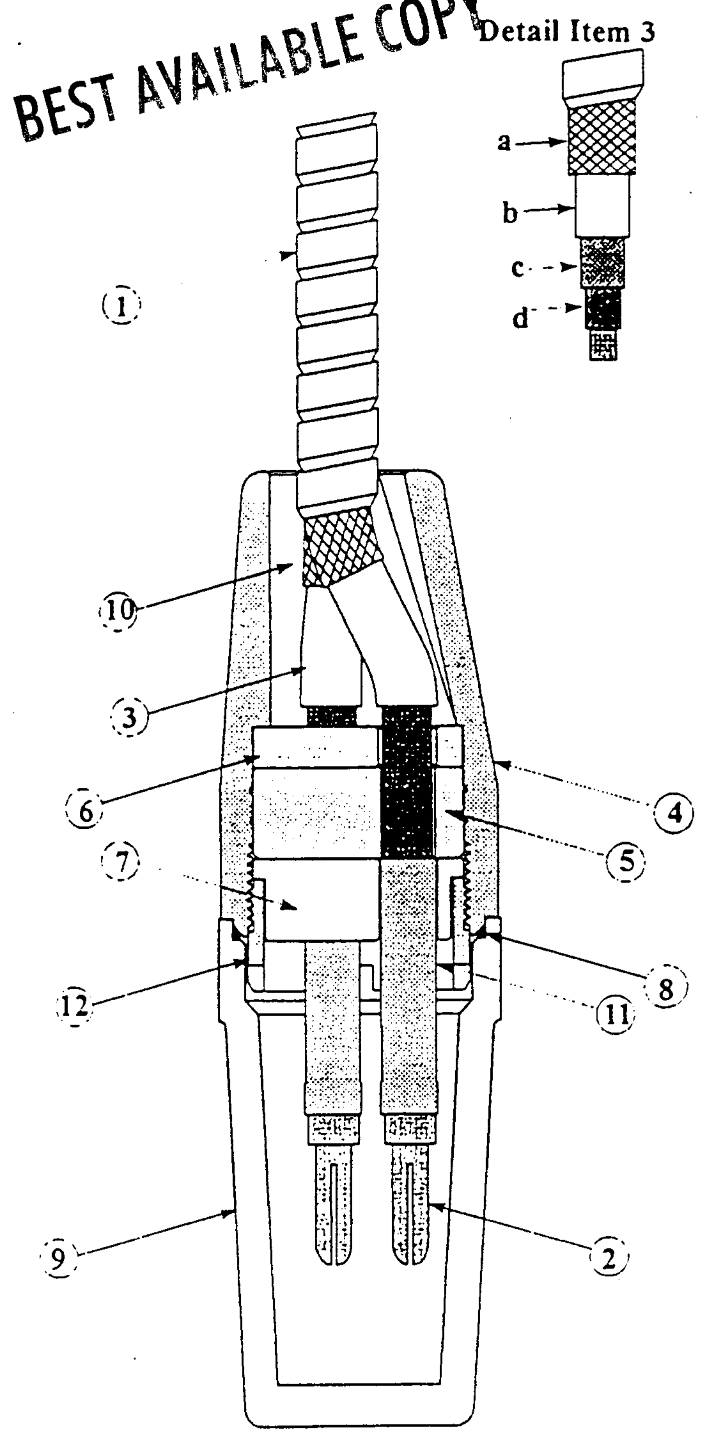
materials\mtr,tr-sgl.cdr

QUALITY RUNS DEEP AT ESP

New Release 15 May 1997

Attachment 1

MLC, Tr3 KEOTB GALV.



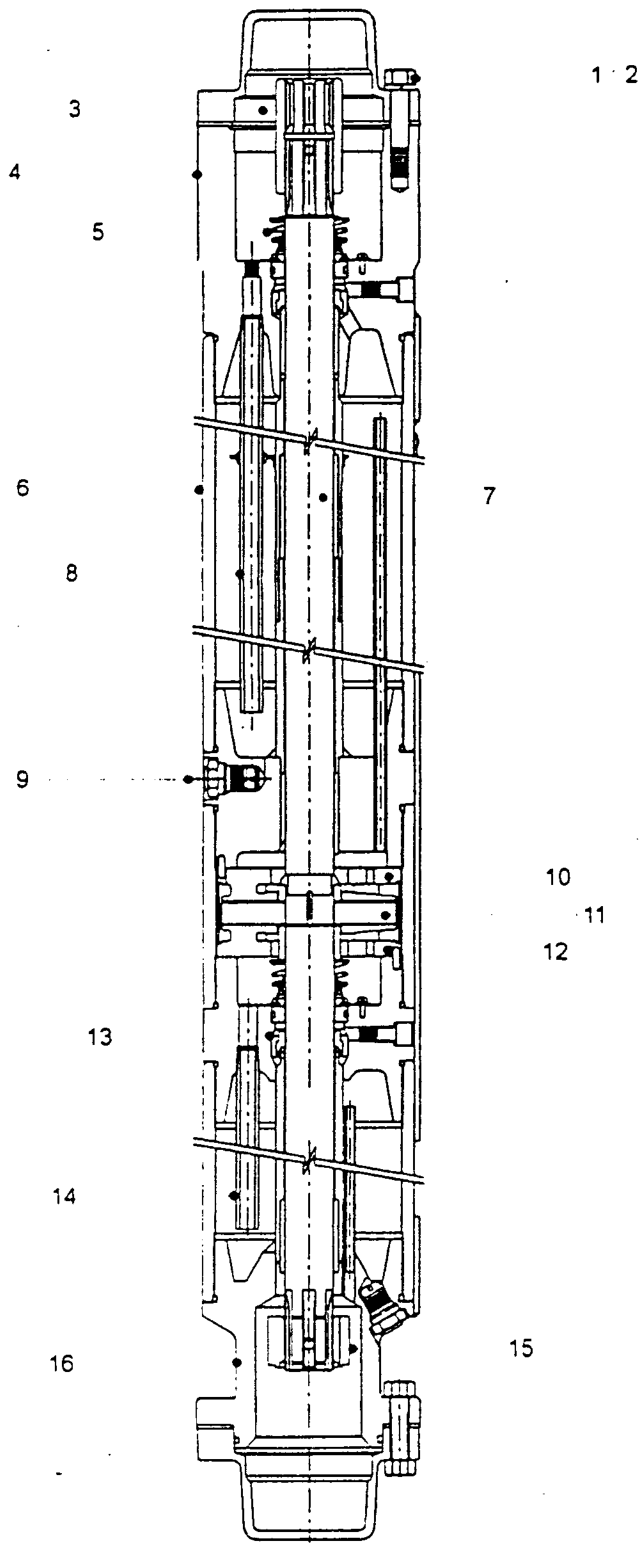
PARTS LIST

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

materials:mlc,tr5-kelb-4kv.cdr

New Release 27 May 1997

Standard Seal



PARTS LIST

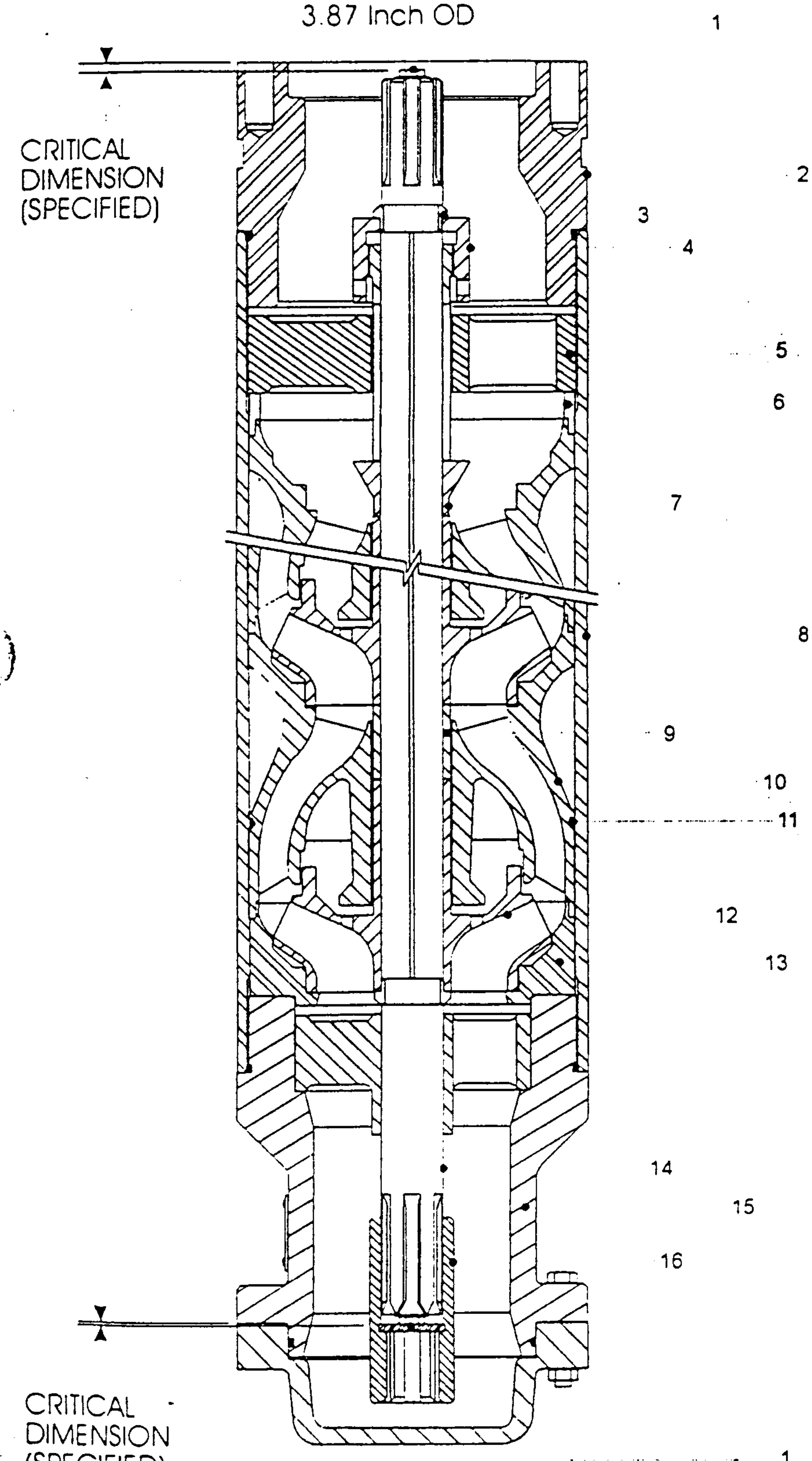
ITEM	DESCRIPTION
1	Screw, Hex Head - Monel
2	Washer, Lock - Monel
3	Coupling - Monel
4	Head, Seal
5	Seal, Mechanical
6	Housing
7	Shaft
8	Breather Tube
9	Valve, Drain/Fill
10	Bearing, Up-Thrust
11	Runner, Thrust
12	Bearing, Down-Thrust
13	Water Shedder
14	Breather Tube
15	Coupling Adapter
16	Base

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

Standard Pump
(Floater Stage Design)

ESP

WOOD GROUP



PARTS LIST

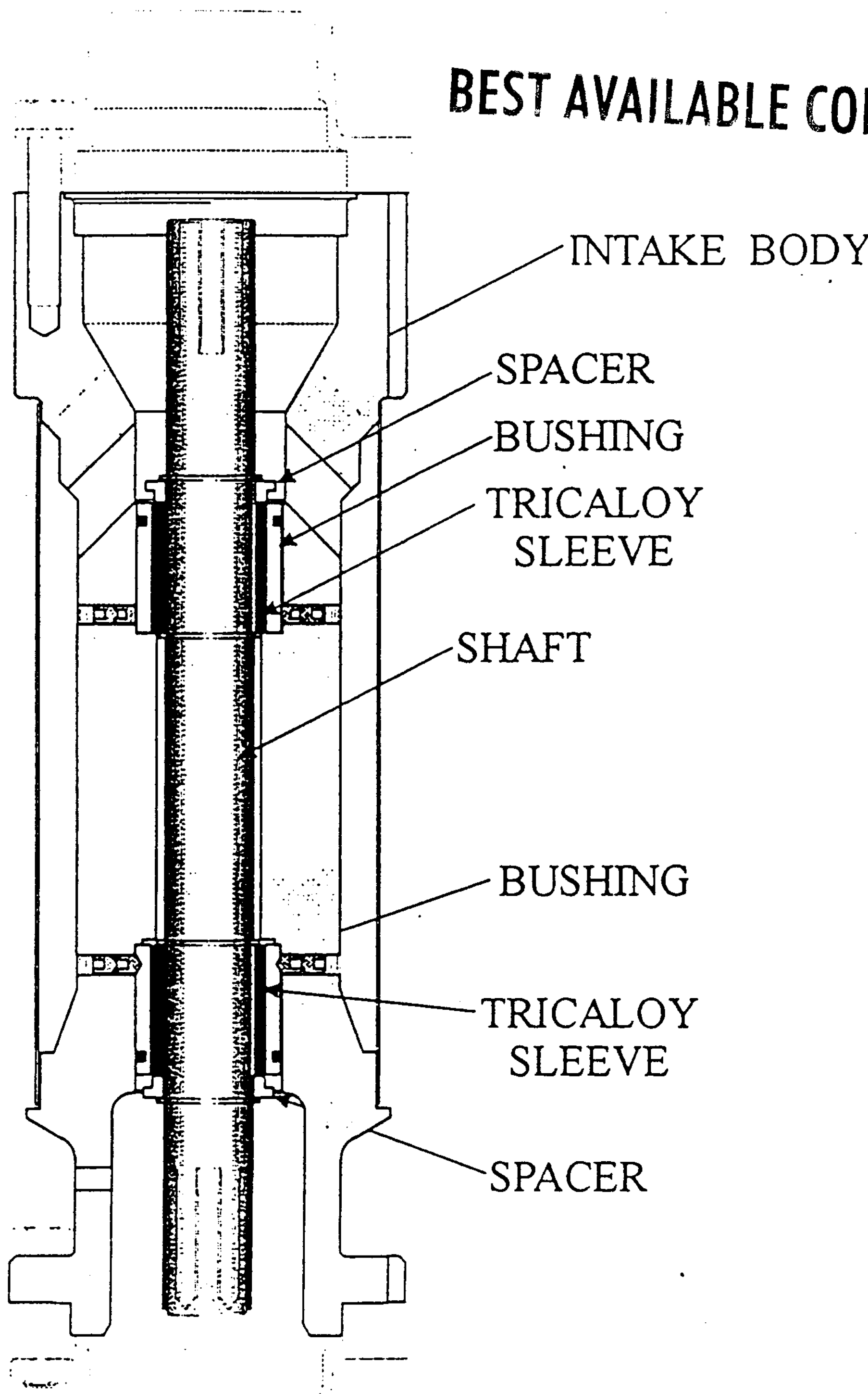
ITEM	DESCRIPTION
1	Adj. Nuts & Shims
2	Head, TDM
3	Two Piece Ring
4	Compression Nut, Sleeve & Set Screw
5	Compression Bearing
6	Compression Tube
7	Fluid Director
8	Housing
9	Spacer - Impeller
10	Diffuser
11	O'Ring, Diffuser
12	Impeller
13	Lower Diffuser
14	Shaft
15	Base, TDM S/A
16	Coupling

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

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-2a
(Page 1 of 6)

Date	Time hr:min.	Temperature °C	EC μmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
06/28/2000	19:00	38.9	678	8.86	2.08	17.02	- - -	70.56	7,555	Start pumping at 17:41 at 55 gpm, switch to 70 gpm at 18:30
06/29/2000	9:30	40.3	688	8.43	1.53	1.50	0.792	101.12	73,101	Functionality testing, pump on/off several times
06/29/2000	11:30	40.5	690	8.48	1.88	1.60	0.728	101.39	86,679	
06/29/2000	13:50	39.4	679	8.51	2.31	2.01	0.683	100.45	97,348	
06/29/2000	15:45	39.6	678	8.51	3.46	2.20	0.743	100.50	105,400	
06/29/2000	17:15	39.4	681	8.45	2.79	1.41	0.689	100.42	110,484	
06/30/2000	9:30	39.8	705	8.15	2.19	8.03	0.927	140.35	210,953	Continue functionality testing, lower PXD, pump overnight at 170 gpm
06/30/2000	11:30	40.5	704	8.14	1.88	10.04	0.788	161.09	228,767	
06/30/2000	13:30	40.2	704	7.95	1.89	6.21	0.760	180.90	249,829	
06/30/2000	15:50	40.5	708	8.04	2.45	1.35	0.801	180.76	275,141	
06/30/2000	17:36	40.8	701	8.11	2.27	1.30	0.711	170.17	293,887	
07/01/2000	7:15	40.5	694	8.01	2.82	0.42	0.738	170.58	433,561	Perform surging on the well
07/01/2000	10:58	39.9	693	8.04	2.66	1.90	0.738	170.51	459,686	
07/01/2000	13:02	41.0	671	8.23	3.29	3.48	0.813	170.58	473,511	
07/01/2000	15:00	40.1	692	8.02	2.78	0.71	0.741	120.87	493,215	Begin step-drawdown testing at 120 gpm, pump overnight at 120 gpm
07/01/2000	17:00	39.6	686	8.03	3.09	0.23	0.729	120.99	507,717	
07/02/2000	9:00	40.6	657	8.07	2.68	0.23	0.950	70.59	575,470	First step-drawdown at 70 gpm
07/02/2000	11:00	39.5	654	8.15	2.98	0.21	0.681	70.53	583,942	
07/02/2000	13:00	39.8	677	8.03	2.42	0.69	0.730	120.24	594,249	Second step at 120 gpm, begin at 12:01
07/02/2000	15:00	40.0	662	8.06	2.52	0.22	0.675	120.33	608,615	
07/02/2000	17:00	40.1	664	8.04	2.70	0.36	0.730	120.26	623,038	
07/02/2000	18:00	40.7	680	7.91	2.32	1.65	0.737	170.45	632,260	Third step at 170 gpm, begin at 17:00, pump overnight at 170 gpm
07/03/2000	9:05	39.5	727	7.75	2.55	0.41	0.771	170.60	786,644	DRI begins flow logging, pump overnight at 70 gpm

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

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
07/04/2000	9:00	40.8	700	8.13	3.01	3.45	0.815	70.60	865,000	DRI continues flow logging, pump overnight at 120 gpm
07/04/2000	11:15	40.0	697	8.14	3.20	1.02	0.787	70.68	875,499	
07/04/2000	13:50	41.0	696	8.10	2.72	2.24	0.784	120.74	888,000	
07/04/2000	17:21	40.4	705	8.03	2.75	1.88	0.850	120.65	912,000	
07/04/2000	19:00	40.4	699	8.02	2.76	7.72	0.791	120.58	925,000	
07/05/2000	10:00	40.2	721	7.61	2.54	0.68	0.777	170.30	1,073,940	DRI finishes flow logging, collect discreet bailer samples for ITLV, LANL and UNLV-HRC
07/05/2000	12:00	40.1	721	7.53	2.75	0.72	0.711	170.42	1,094,385	
07/05/2000	14:20	39.9	714	7.73	2.68	31.70	0.750	170.33	1,118,235	
07/05/2000	16:00	40.3	712	7.65	2.78	12.76	0.765	170.60	1,135,216	
07/05/2000	16:20	35.1	918	7.12	5.45	15.28	3.170	170.27	1,138,622	Bailer sample from 3,300 ft bgs
07/18/2000	11:00	39.6	660	8.45	2.14	1.40	0.730	120.59	1,150,890	Begin constant-rate test at 120 gpm, pump shut down for trouble shooting
07/20/2000	14:00	40.1	641	8.17	2.66	0.36	0.740	120.73	1,172,459	Restart constant-rate test at 11:55
07/20/2000	16:00	40.0	653	8.22	3.36	0.17	0.673	120.61	1,186,945	
07/20/2000	18:00	39.9	660	8.03	3.50	0.33	0.764	120.67	1,201,408	
07/20/2000	20:00	40.0	655	8.02	3.49	0.47	0.703	120.85	1,215,899	
07/20/2000	22:00	39.9	655	7.89	3.18	0.52	0.660	120.76	1,230,389	
07/21/2000	0:00	39.8	647	7.98	2.59	0.32	0.657	120.72	1,244,715	
07/21/2000	2:00	39.6	664	7.99	2.34	0.31	0.681	120.70	1,259,200	
07/21/2000	4:00	38.8	654	7.90	3.15	0.30	0.661	120.68	1,273,676	
07/21/2000	6:00	38.7	661	7.94	3.24	0.35	0.384	120.65	1,288,152	
07/21/2000	8:40	39.9	657	7.97	2.71	0.54	0.761	120.84	1,307,447	
07/21/2000	10:30	40.4	657	7.90	2.86	0.63	0.761	120.90	1,320,738	
07/21/2000	12:25	40.6	654	7.90	2.97	0.60	0.684	120.79	1,334,630	
07/21/2000	14:30	40.3	657	7.91	2.88	0.40	0.724	120.70	1,349,722	
07/21/2000	16:30	39.8	656	7.96	2.44	0.58	0.719	120.61	1,364,204	
07/21/2000	18:00	40.2	650	7.84	2.75	0.40	0.700	120.97	1,375,067	
07/21/2000	22:00	40.5	700	7.91	2.70	0.63	0.734	120.76	1,404,044	

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-2a
(Page 3 of 6)

Date	Time hr:min.	Temperature °C	EC μmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
07/22/2000	0:00	40.2	722	7.93	2.62	0.45	0.734	120.81	1,418,531	
07/22/2000	2:00	39.8	721	7.90	2.66	0.41	0.725	120.76	1,433,018	
07/22/2000	4:00	39.6	722	7.82	2.89	0.44	0.650	120.75	1,447,506	
07/22/2000	6:00	39.7	715	7.89	2.68	0.59	0.688	120.61	1,461,993	
07/22/2000	8:08	39.9	716	7.90	2.86	0.35	0.853	121.40	1,477,508	
07/22/2000	10:22	40.0	714	7.84	3.04	0.49	0.806	120.69	1,493,394	
07/22/2000	12:00	40.4	716	7.95	3.28	0.36	0.742	120.82	1,505,457	
07/22/2000	14:00	40.1	702	7.87	2.41	1.20	0.727	119.86	1,520,029	
07/22/2000	16:00	40.1	704	7.87	2.73	1.08	0.742	120.77	1,534,435	
07/22/2000	18:00	40.1	715	7.82	2.73	0.88	0.733	120.70	1,548,922	
07/22/2000	20:20	40.6	716	7.99	2.52	0.34	0.861	120.86	1,565,827	
07/22/2000	22:00	40.3	712	7.91	2.82	0.41	0.845	120.71	1,577,901	
07/23/2000	0:00	39.6	714	8.01	2.63	0.43	0.851	120.69	1,592,389	
07/23/2000	2:00	38.5	714	7.89	2.80	0.32	0.807	120.65	1,606,861	
07/23/2000	4:00	39.7	716	7.97	2.72	0.60	0.786	120.73	1,621,349	
07/23/2000	6:00	39.8	715	7.97	2.80	0.31	0.742	120.65	1,635,835	
07/23/2000	8:05	40.2	708	7.90	2.72	0.38	0.772	120.82	1,650,927	
07/23/2000	10:05	40.3	708	7.80	2.72	0.95	0.720	120.81	1,664,822	
07/23/2000	12:00	40.3	703	7.78	2.88	0.38	0.754	120.73	1,679,317	
07/23/2000	14:15	40.5	708	7.83	3.35	0.39	0.763	120.75	1,695,619	
07/23/2000	16:00	40.4	707	7.85	2.77	0.48	0.743	120.76	1,708,289	
07/23/2000	18:00	40.4	707	7.86	2.76	0.49	0.805	120.75	1,722,783	
07/23/2000	20:00	40.8	703	7.99	2.42	0.30	0.787	120.73	1,737,274	
07/23/2000	22:00	40.7	700	7.96	2.59	0.41	0.766	120.73	1,751,765	
07/24/2000	0:00	40.6	707	8.00	2.51	0.43	0.769	120.68	1,766,254	
07/24/2000	2:00	40.0	705	7.93	2.56	0.51	0.728	120.61	1,780,742	
07/24/2000	4:00	40.6	699	7.90	2.44	0.46	0.778	120.72	1,795,230	

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

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
07/24/2000	6:00	40.3	705	7.95	2.43	0.44	0.702	120.70	1,809,698	
07/24/2000	8:17	40.2	708	8.01	2.90	0.40	0.781	120.85	1,826,000	
07/24/2000	12:10	40.4	706	7.86	2.43	0.86	0.732	120.80	1,854,390	
07/24/2000	14:10	40.2	707	7.96	2.69	0.43	0.781	120.74	1,868,880	
07/24/2000	16:10	40.6	707	7.88	2.43	0.46	0.751	120.70	1,883,369	
07/24/2000	19:00	40.8	706	7.95	2.72	0.60	0.804	120.80	1,903,883	
07/24/2000	21:00	40.6	706	7.98	2.52	0.68	0.731	120.86	1,918,376	
07/24/2000	23:00	40.2	703	8.04	2.66	0.55	0.718	120.69	1,932,866	
07/25/2000	1:00	40.5	701	7.98	2.58	0.48	0.704	120.76	1,947,354	
07/25/2000	3:00	40.4	706	8.02	2.49	0.49	0.704	120.78	1,961,843	
07/25/2000	5:00	40.1	697	7.88	2.32	0.44	0.737	120.73	1,976,330	
07/25/2000	7:00	39.8	702	8.01	2.52	0.51	0.721	120.73	1,990,818	
07/25/2000	9:00	40.4	704	7.81	2.85	0.58	0.713	120.85	2,005,295	
07/25/2000	11:08	40.5	701	7.93	3.17	0.65	0.830	120.81	2,021,002	
07/25/2000	13:00	40.6	705	7.99	3.15	0.48	0.674	119.44	2,034,288	
07/25/2000	15:00	40.5	700	7.79	2.50	0.64	0.680	120.68	2,048,777	
07/25/2000	17:00	40.5	705	7.87	2.38	0.61	0.715	121.01	2,063,262	
07/25/2000	18:00	40.5	705	7.99	2.43	0.80	0.674	120.77	2,070,506	
07/25/2000	20:00	40.9	701	8.01	2.42	0.39	0.743	120.75	2,084,996	
07/25/2000	22:00	40.4	688	7.99	2.61	0.41	0.724	120.73	2,099,485	
07/26/2000	0:00	40.1	701	7.99	2.89	0.42	0.732	120.68	2,113,965	
07/26/2000	2:00	40.4	699	7.92	2.77	0.31	0.732	120.73	2,128,452	
07/26/2000	5:00	40.5	704	7.95	2.46	0.55	0.743	120.73	2,150,180	
07/26/2000	7:15	40.5	716	7.82	2.81	0.54	0.691	120.75	2,166,477	
07/26/2000	9:00	40.6	718	8.02	2.69	0.60	0.804	120.84	2,179,161	
07/26/2000	11:00	40.7	713	7.96	2.62	0.39	0.819	120.83	2,193,656	
07/26/2000	13:00	40.8	717	7.93	3.20	0.48	0.734	120.84	2,208,131	

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

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
07/26/2000	15:00	40.4	715	7.93	3.00	0.48	0.748	120.58	2,222,619	
07/26/2000	17:00	40.5	717	7.95	3.19	0.49	0.612	120.82	2,237,105	
07/26/2000	19:00	40.5	718	7.96	2.87	0.34	0.729	120.66	2,251,594	
07/26/2000	21:30	39.5	700	7.94	3.22	0.52	0.889	120.74	2,269,708	
07/26/2000	23:00	39.2	705	7.91	2.80	0.45	0.868	120.68	2,280,573	
07/27/2000	1:00	38.8	705	7.85	3.35	0.51	0.904	120.74	2,295,060	
07/27/2000	3:00	39.7	706	7.91	3.28	0.50	0.889	120.75	2,309,534	
07/27/2000	5:00	39.8	704	7.92	3.55	0.35	0.992	120.67	2,324,021	
07/27/2000	8:00	40.4	706	7.80	2.55	0.62	0.760	120.69	2,345,855	Collect GW composite samples for ITLV, LLNL, DRI and UNLV-HRC
07/27/2000	13:35	40.5	707	7.89	2.98	0.40	0.725	120.77	2,386,220	
07/27/2000	15:30	40.4	709	7.91	2.44	0.48	0.660	120.90	2,400,100	
07/27/2000	17:30	40.6	710	7.91	2.86	0.45	0.709	120.71	2,414,586	
07/27/2000	19:30	40.6	697	7.94	3.09	0.48	0.845	120.73	2,429,074	
07/27/2000	21:00	40.2	708	7.95	3.10	0.33	0.776	120.72	2,439,942	
07/27/2000	23:00	39.9	701	7.99	3.00	0.42	0.691	120.68	2,454,430	
07/28/2000	1:00	39.5	708	7.91	3.16	0.37	0.789	120.70	2,468,918	
07/28/2000	3:00	38.5	708	7.97	3.40	0.65	0.996	120.73	2,483,405	
07/28/2000	5:00	39.8	707	7.94	3.20	0.46	0.735	120.75	2,497,893	
07/28/2000	6:45	38.9	715	7.93	3.13	0.54	0.836	120.69	2,510,563	
07/28/2000	9:00	40.8	710	7.97	2.90	0.54	0.715	121.23	2,526,866	
07/28/2000	11:00	40.9	710	7.70	3.15	0.55	0.685	120.86	2,541,365	
07/28/2000	13:00	40.7	708	7.94	2.81	0.64	0.731	120.78	2,555,859	
07/28/2000	15:00	40.6	707	7.89	3.07	0.60	0.661	120.61	2,570,345	
07/28/2000	17:30	40.7	708	7.91	3.30	0.70	0.661	120.78	2,588,449	
07/28/2000	20:00	40.3	699	7.93	3.49	0.56	0.865	120.75	2,606,540	
07/28/2000	22:00	40.1	701	7.97	3.39	1.12	0.951	120.78	2,621,029	
07/29/2000	0:00	40.4	683	7.96	3.37	0.94	0.992	120.68	2,635,518	
07/29/2000	2:00	40.3	698	7.94	3.12	0.77	0.974	120.66	2,650,003	

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

Date	Time hr:min.	Temperature °C	EC µmhos/cm	pH SU	DO mg/L	Turbidity NTUs	Bromide mg/L	Pumping Rate gpm	Total Discharge gallons	Comments/Phase of Development or Testing
07/29/2000	4:00	40.3	706	7.89	3.29	0.89	0.963	120.75	2,664,487	
07/29/2000	6:00	40.2	699	7.94	3.16	0.64	0.718	120.72	2,678,971	
07/29/2000	8:15	40.8	698	7.84	3.09	0.53	0.730	120.85	2,695,271	End constant-rate test at 9:15

EC - Electrical conductivity
DO - Dissolved oxygen
DRI - Desert Research Institute
gpm - Gallons per minute
GW - Groundwater
hr:min - Hour: minute
in. - Inch(es)
ITLV - IT Corporation, Las Vegas Office
mg/L - Milligrams per liter
NTUs - Nephelometric turbidity units
SU - Standard units
µmhos/cm - Micromhos per centimeter
LANL - Los Alamos National Laboratory
LLNL - Lawrence Livermore National Laboratory
PXD - Pressure transducer
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-2a
(Page 1 of 3)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-2A-070500-2		Results of Wellhead Composite Sample #EC-2A-072700-1	
Metals (mg/L)						
			Total	Dissolved	Total	Dissolved
Aluminum	0.2	Paragon	J 0.57	UJ 0.093	U 0.099	U 0.1
Arsenic	0.01	Paragon	J 0.014	J 0.011	B 0.0067	B 0.007
Barium	0.1	Paragon	J 0.023	J 0.027	B 0.0057	B 0.0057
Cadmium	0.005	Paragon	UJ 0.005	UJ 0.005	U 0.00019	U 0.005
Calcium	1	Paragon	J 50	J 45	13	13
Chromium	0.01	Paragon	J 0.011	UJ 0.01	U 0.0017	U 0.00041
Iron	0.1	Paragon	J 1.2	UJ 0.063	U 0.26	U 0.15
Lead	0.003	Paragon	UJ 0.003	UJ 0.003	U 0.003	U 0.003
Lithium	0.01	Paragon	J 0.15	J 0.16	0.16	0.16
Magnesium	1	Paragon	J 16	J 15	2.5	2.6
Manganese	0.01	Paragon	J 0.81	J 0.69	0.058	0.058
Potassium	1	Paragon	J 5.1	J 5.2	3.6	3.6
Selenium	0.005	Paragon	J 0.004	J 0.003	U 0.005	U 0.005
Silicon	0.05	Paragon	J 15	J 14	18	18
Silver	0.01	Paragon	UJ 0.01	UJ 0.01	B 0.00071	U 0.01
Sodium	1	Paragon	J 120	J 120	120	120
Strontium	0.01	Paragon	J 0.15	J 0.15	0.044	0.044
Uranium	0.2	Paragon	UJ 0.2	UJ 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	UJ 52		59	
Fluoride	0.1	Paragon	UJ 4.9		5.6	

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

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-2A-070500-2	Results of Wellhead Composite Sample #EC-2A-072700-1
Inorganics (mg/L) - unless otherwise noted				
Bromide	0.2	Paragon	UJ 0.72	0.31
Sulfate	10, 1	Paragon	UJ 180	95
pH (pH units)	0.1	Paragon	J 7.3	J 8
Total Dissolved Solids	20	Paragon	J 600	420
Electrical Conductivity (micromhos/cm)	1	Paragon	910	580
Carbonate as CaCO3	100, 20	Paragon	UJ 100	U 20
Bicarbonate as CaCO3	100, 20	Paragon	J 220	150
Organics (mg/L)				
Total Organic Carbon	1	Paragon	J 1.3	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
C-14, Inorganic (pmc)	Not Provided	LLNL	N/A	7.7 +/- 0.1
C-14, Inorganic age (years)*	Not Provided	LLNL	N/A	21,200
Chlorine-36	Not Provided	LLNL	N/A	1.11E-03
Cl-36/Cl (ratio)	Not Provided	LLNL	N/A	5.33E-13
He-4 (atoms/mL)	Not Provided	LLNL	N/A	7.92E+12
He-3/4, measured value (ratio)	Not Provided	LLNL	N/A	1.30E-06
He-3/4, relative to air (ratio)	Not Provided	LLNL	N/A	0.94
Oxygen-18/16 (per mil)	Not Provided	DRI	N/A	-15.0 +/- 0.2
Strontium-87/86 (ratio)	Not Provided	LLNL	N/A	0.709387 +/- 0.000029
Uranium-234/238 (ratio)	Not Provided	LLNL	N/A	0.000225
H-2/1 (per mil)	Not Provided	DRI	N/A	-113 +/- 1.0
Colloids	Not Provided	LANL	See Table ATT.3-2	

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

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-2A-070500-2	Results of Wellhead Composite Sample #EC-2A-072700-1
Radiological Indicator Parameters-Level I (pCi/L)				
Gamma Spectroscopy	Sample-Specific	Paragon	All nuclides reported with a 'U'	All nuclides reported with a 'U'
Tritium	270	Paragon	U -230 +/- 160	UJ -10 +/- 160
Gross Alpha	2.4, 2.1	Paragon	81 +/- 12	13.3 +/- 2.7
Gross Beta	3.7, 2.5	Paragon	16.8 +/- 3.3	U 3.7 +/- 1.6
Radiological Indicator Parameters-Level II (pCi/L)				
Carbon-14	310, 300	Paragon	U 70 +/- 190	1540 +/- 280
Strontium-90	0.54	Paragon	N/A	UJ 0.14 +/- 0.32
Plutonium-238	0.012, 0.013	Paragon	U 0.004 +/- 0.012	U 0.005 +/- 0.013
Plutonium-239	0.029, 0.013	Paragon	U -0.003 +/- 0.012	U 0 +/- 0.013
Iodine-129	1.5	Paragon	N/A	U 0.00 +/- 0.86
Technetium-99	6.3	Paragon	N/A	U 7.9 +/- 4.1

U = Result not detected at the given minimum detectable limit or activity
J = The result is an estimated value
B = The result is less than the contract-required detection limit, but greater than the instrument detection limit
N/A = Not applicable for that sample
mg/L = Milligrams per liter   µg/L = Micrograms per liter   pCi/L = Picocuries per liter
micromhos/cm = Micromhos per centimeter
pmc = Percent modern carbon

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

[a]If there is only one value present, that value is the detection limit for each analysis (or there was only one analysis).

Table ATT.3-2
Colloid Analyses for Well ER-EC-2a

Analyte	Laboratory	Results of Discrete Bailer Sample #EC-2A-070500-2	Results of Wellhead Composite Sample #EC-2A-072700-1
Colloid Particle Size Range (in nanometer)		Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)
50 - 60	LANL	4.80E+05	1.79E+07
60 - 70	LANL	4.35E+05	1.36E+07
70 - 80	LANL	3.75E+05	7.24E+06
80 - 90	LANL	2.85E+05	3.25E+06
90 - 100	LANL	2.40E+05	1.69E+06
100 - 110	LANL	2.30E+05	5.42E+05
110 - 120	LANL	3.15E+05	4.21E+05
120 - 130	LANL	2.00E+05	1.81E+05
130 - 140	LANL	1.35E+05	2.61E+05
140 - 150	LANL	1.05E+05	0.00E+00
150 - 160	LANL	1.05E+05	1.20E+05
160 - 170	LANL	1.35E+05	6.02E+04
170 - 180	LANL	1.10E+05	1.40E+05
180 - 190	LANL	1.00E+05	4.02E+04
190 - 200	LANL	1.00E+05	6.02E+04
200 - 220	LANL	8.50E+04	6.02E+04
220 - 240	LANL	6.53E+04	3.47E+04
240 - 260	LANL	4.25E+04	2.22E+04
260 - 280	LANL	2.51E+04	1.06E+04
280 - 300	LANL	1.57E+04	4.80E+03
300 - 400	LANL	3.95E+04	1.88E+04
400 - 500	LANL	1.29E+04	3.36E+03
Analyte	**Laboratory**	**Results of Discrete Bailer Sample #EC-2A-070500-2**	**Results of Wellhead Composite Sample #EC-2A-072700-1**
Colloid Particle Size Range (in nanometer)		Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)
500 - 600	LANL	1.59E+04	5.76E+03
600 - 800	LANL	3.79E+04	6.24E+03
800 - 1,000	LANL	1.69E+04	2.88E+03
>1,000	LANL	8.28E+04	4.32E+03
Total Concentration, Particle Size Range, 50-1,000 nm	LANL	3.79E+06	4.57E+07

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

Analyte	Detection Limit	Laboratory	Qualifier	Results of Discrete Bailer Sample #EC-2A-070500-2	Unit
Ag, Dissolved	0.16	UNLV-HRC	<	0.16	μg/L
Al, Dissolved	0.17	UNLV-HRC		22.8	μg/L
As, Dissolved	0.02	UNLV-HRC		12.8	μg/L
Au, Dissolved	0.030	UNLV-HRC	<	0.093	μg/L
Ba, Dissolved	0.006	UNLV-HRC		31.9	μg/L
Be, Dissolved	0.018	UNLV-HRC		0.184	μg/L
Bi, Dissolved	0.004	UNLV-HRC		0.010	μg/L
Cd, Dissolved	0.008	UNLV-HRC		0.107	μg/L
Co, Dissolved	0.006	UNLV-HRC		0.832	μg/L
Cr, Dissolved	0.006	UNLV-HRC		0.169	μg/L
Cs, Dissolved	0.003	UNLV-HRC		3.71	μg/L
Cu, Dissolved	0.011	UNLV-HRC		0.491	μg/L
Ga, Dissolved	6.3	UNLV-HRC		131	ng/L
Ge, Dissolved	0.009	UNLV-HRC		0.424	μg/L
Hf, Dissolved	0.015	UNLV-HRC	<	0.015	μg/L
In, Dissolved	0.004	UNLV-HRC	<	0.004	μg/L
Ir, Dissolved	4.5	UNLV-HRC		8.9	μg/L
Li, Dissolved	0.015	UNLV-HRC		172	μg/L
Mn, Dissolved	0.01	UNLV-HRC		782	μg/L
Mo, Dissolved	0.01	UNLV-HRC		55.6	μg/L
Nb, Dissolved	5.1	UNLV-HRC		42	ng/L
Ni, Dissolved	0.006	UNLV-HRC		1.95	μg/L
Pb, Dissolved	0.04	UNLV-HRC	<	0.04	μg/L
Pd, Dissolved	0.021	UNLV-HRC		0.032	μg/L
Pt, Dissolved	0.006	UNLV-HRC		0.018	μg/L
Rb, Dissolved	0.003	UNLV-HRC		18.5	μg/L
Re, Dissolved	0.004	UNLV-HRC		0.069	μg/L
Rh, Dissolved	0.004	UNLV-HRC	<	0.004	μg/L
Ru, Dissolved	0.005	UNLV-HRC	<	0.005	μg/L
Sb, Dissolved	0.004	UNLV-HRC		3.54	μg/L
Se, Dissolved	0.12	UNLV-HRC		6.76	μg/L
Sn, Dissolved	0.004	UNLV-HRC	<	0.004	μg/L
Sr, Dissolved	0.01	UNLV-HRC		161	μg/L
Ta, Dissolved	0.009	UNLV-HRC		0.055	μg/L
Te, Dissolved	0.008	UNLV-HRC		0.011	μg/L

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

Analyte	Detection Limit	Laboratory	Qualifier	Results of Discrete Bailer Sample #EC-2A-070500-2	Unit
Ti, Dissolved	0.009	UNLV-HRC		2.05	µg/L
Tl, Dissolved	0.009	UNLV-HRC		0.616	µg/L
U, Dissolved	0.005	UNLV-HRC		79.4	µg/L
V, Dissolved	0.009	UNLV-HRC		3.97	µg/L
W, Dissolved	0.004	UNLV-HRC		1.14	µg/L
Zn, Dissolved	0.2	UNLV-HRC		27.1	µg/L
Zr, Dissolved	0.018	UNLV-HRC		0.068	µg/L

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

Attachment 4

Fluid Management Plan Waiver for WPM-OV Wells

PETER G. MORROS, Director
ALLEN BIAGGI, Administrator
(775) 687-4670
TDD 687-4678
Administration
Water Pollution Control
Facsimile 687-5856
Mining Regulation and Reclamation
Facsimile 684-5259

STATE OF NEVADA
KENNY C. GUINN
Governor

Waste Management
Corrective Actions
Federal Facilities
Air Quality
Water Quality Planning
Facsimile 687-[illegible]

DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
DIVISION OF ENVIRONMENTAL PROTECTION

333 W. Nye Lane, Room 138
Carson City, Nevada 89706-0851

October 19, 1999

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

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

Dear Ms. Wycoff:

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

<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.

Paul J. Liebendorfer -2-

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

Original Signed By:

Runore C. Wycoff

Runore C. Wycoff, Director
Environmental Restoration Division

ERD:RMB

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

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

Attachment 5

Electronic Data Files Readme.txt

ER-EC-2a Development and Testing Data Report:

This README file identifies the included data files.

Included with this report are 23 files containing data that were collected electronically during the development and testing program for Well ER-EC-2a. 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) EREC2AL.xls
Bridge plug monitoring data for the lower interval.

2) EREC2AU.xls
Bridge plug monitoring data for the upper middle interval.

3) EC2agradient.xls
Monitoring data for the upper interval during the bridge plug measurements.

4) EC2a_Aqtest_WD.xls
Complete monitoring record of development.

5) EC2a_Aqtest_HT.xls
Complete monitoring record of testing.

6) EC-2a Water-Level Mon.xls
Pre-development monitoring record.

7) DRIFileInfoGeneric.txt
DRI log head information.

8) ec2amov01, ec2amov02, ec2amov03, ec2amov04, ec2amov05, ec2amov06, and ec2amov07.txt - DRI flow logs.

9) ec2asta01, ec2asta02, ec2asta03, ec2asta04, ec2asta05, ec2asta06, ec2asta07, ec2asta08, and ec2asta09.txt - DRI static impeller tool flow measurements.

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