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Analysis of Well ER-EC-5 Testing, Western Pahute Mesa-Oasis Valley FY 2000 Testing Program

Revision No.: 0

September 2002

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

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IT CORPORATION
P.O. Box 93838
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
C	Carbon
CAU	Corrective Action Unit
CD	Compact disc
Cl	Chlorine
DIC	Dissolved inorganic carbon
DO	Dissolved oxygen
DOE	U.S. Department of Energy
DOP	Detailed Operating Procedure
DRI	Desert Research Institute
EC	Electrical conductivity
ER	Environmental Restoration
ft	Foot (feet)
ft/d	Feet per day
ft^2/d	Square feet per day
FMP	Fluid Management Plan
fpm	Feet per minute
FS	Full scale
FY	Fiscal year
gpm	Gallon per minute
He	Helium
hp	Horsepower
HSU	Hydrostratigraphic unit
Hz	Hertz
in.	Inch(es)
ITLV	IT Corporation, Las Vegas
K	Hydraulic conductivity
LiBr	Lithium bromide
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
m	Meter

List of Acronyms and Abbreviations *(Continued)*

mg/L	Milligram per liter
NDWS	*National Drinking Water Standards*
nm	Nanometers
NNSA/NV	U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office
NTU	Nephelometric turbidity units
od	Outside diameter
pCi/L	Picocuries per liter
psi	Pounds per square inch
psig	Pounds per square inch gauge
PXD	Pressure transducer
rev/sec	Revolution(s) per second
SQP	Standard Quality Practice
T	Transmissivity
TDH	Total dynamic head
UGTA	Underground Test Area
UNLV-HRC	University of Nevada, Las Vegas - Harry Reid Center
VSD	Variable-speed drive
WDHTP	Well Development and Hydraulic Testing Plan
WPM-OV	Western Pahute Mesa-Oasis Valley
°C	Degrees Celsius
δO	Delta oxygen
δD	Delta deuterium
µg/L	Microgram per liter
µmhos/cm	Micromhos per centimeter

1.0 Introduction

This report documents the analysis of the data collected for Well ER-EC-5 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-5 Data Report for Development and Hydraulic Testing*.

1.1 Well ER-EC-5

Well ER-EC-5 is one of eight groundwater wells that were tested as part of FY 2000 activities for the U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office (NNSA/NV), Underground Test Area (UGTA) Project. Figure 1-1 shows the location of the WPM-OV Environmental Restoration (ER) wells. Drilling and well construction information for Well ER-EC-5 was obtained from a draft of the *Completion Report for Well ER-EC-5* (Townsend, 2000).

Hydraulic testing and groundwater sampling were conducted at Well ER-EC-5 to provide information on the hydraulic characteristics of hydrostratigraphic units (HSUs) and the chemistry of local groundwater. Well ER-EC-5 is constructed with three completion intervals which are isolated from each other by blank casing sections with annular seals. The completion intervals extend over substantial vertical distances and access different HSUs and/or lithologies. Figures illustrating the well construction and lithology are provided in Section 3.0. The testing and sampling activities were designed to assess the completion intervals individually.

1.2 WPM-OV Testing Program

The testing program included:

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

6. Collection of composite groundwater characterization samples

7. Flow measurements and water quality parameter logging under natural gradient flow

1.3 Analysis Objectives and Goals

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

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

Section 2.0 of this report discusses the analysis of the nonpumping natural-gradient well hydrology, and evaluates opportunities for deriving hydraulic parameters for the completion intervals. Section 3.0 discusses the well hydraulics during pumping and the flow logging results. Hydraulic parameters for the well in general and for the upper completion interval in particular are presented. This section is completed with comments on working with deep, multiple completion wells. Section 4.0 discusses the groundwater samples 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-5 for monitoring are discussed.

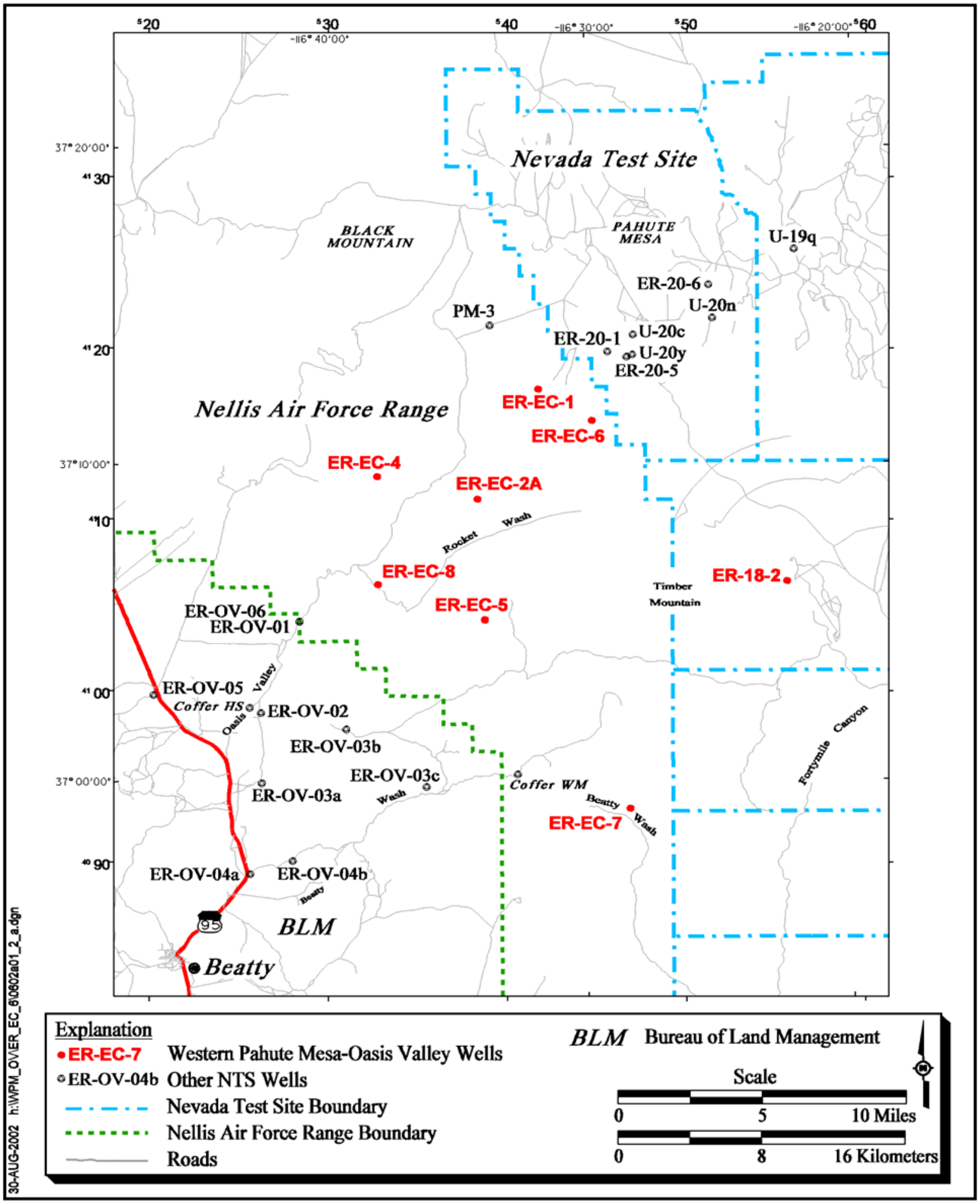

Figure 1-1
Location Map for WPM-OV ER Wells

2.0 Equilibrium Well Hydraulics

This section discusses many aspects of well hydraulics for Well ER-EC-5 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, each composed of alternating slotted casing and blank casing. At the top of both the upper and middle completion intervals there are two adjacent joints of slotted casing counted together as one screen. The completion intervals are isolated from each other outside the well casing by cement annular seals. Within each completion interval, the annulus is filled with continuous gravel pack extending above and below the screens. Downhole flow features are often discussed with reference to individual screens. The convention for referencing screens is by the consecutive number (e.g., first, second, third) of the screen from the top downward.

2.1 Composite Equilibrium Water Level

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

2.2 Barometric Efficiency

The barometric efficiency of the well is used in the analyses of the hydraulic tests to refine the 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 involved overlaying the water level monitoring record and the barometric record, and determining the proportion (barometric efficiency) of water level change to barometric change. The analysis yielded an efficiency of 88 percent. Figure 2-1 shows the pressure transducer (PXD) record corrected for barometric variation. The corrected record exhibits a slight downward trend in the water level and semidiurnal earth tide responses. The earth tides have a periodic variation in magnitude of about 14 days. This pattern of periodic variation of the earth tide magnitude has also been observed in the corrected records from the other wells.

2.3 Completion Interval Heads

Table 2-1 lists calculated head values for the composite and individual completion intervals determined from the bridge-plug pressure measurement following equilibration of the different intervals to the isolation of the interval. However, the analysis of the uncertainty in the measurements indicates that these head differences may not be meaningful. Note that the measurements were made progressively during the day as the equipment was installed, not a simultaneous "snapshot" of heads. The reported differences may include effects of trends in head, barometric changes, and earth tides. Head values are presented rounded to the nearest 0.01 feet (ft) and pressure values are reported to the 0.01 pounds per square inch (ps)i as recorded by the instrumentation. The accuracy of the head values is then evaluated. Equilibration of each interval occurred quickly, with the head changes showing up in the reference water level measurements because the adjustments were increases in the interval head as lower intervals were blocked off with the bridge plugs. The head in each interval was stable over the course of monitoring after the initial equilibration.

Table 2-1
Well ER-EC-5 Composite and Interval-Specific Head Measurements

Location in Well	Head as Depth Below Ground Surface		Change from Composite Head
	Feet	Meters	Feet
Composite Static WL (e-tape)	1,017.50	310.13	--
Upper Interval (e-tape)	1,017.39	310.10	+ 0.11
Middle Interval (calculated)	1,017.42	310.10	+ 0.08
Lower Interval (calculated)	1,017.50	310.13	0.00

Water level measurements were made successively as each bridge plug was installed using the same e-tape, see Table A.3-1. There was an apparent decrease in water level of 0.04 ft after the lower bridge plug was set. This decrease is well within the measurement uncertainty and is contrary to the general direction of adjustment of the completion interval heads. There was a 0.15 ft rise in the measured water level after the uppermost plug was installed. These changes are similar in magnitude to the repeatability of e-tape measurements, generally 0.10 ft per 1,000 ft, and may not be meaningful. The water level for the uppermost completion interval had risen by 0.15 ft at the end of the five-day monitoring period, but this was entirely due to decreased barometric pressure.

The calculated head difference between the upper and middle intervals is 0.03 ft, and 0.08 ft between the middle and lower intervals. These head differences are very small and may be substantially affected by measurement uncertainty. The accuracy of the head computed for each completion interval is the result of the accuracy of the water level measurement used for the reference head and the accuracy of the measurement of head change. The following discussion considers the measurement process and offers estimates of the accuracy of the derived head changes.

The middle completion interval head was calculated using the pressure change observed when the bridge plug isolated the interval. The head for the middle interval appeared to increase by 0.05 psi immediately based on a trend in the pressure values, and then stayed constant for the remainder of the monitoring. However, this change is the same magnitude as the resolution of the PXD, and may not meaningful. The manufacturer's specification for accuracy of these PXDs is 0.1 percent of the full-scale measurement. The PXD used in the lower interval, a 750-psi unit (SN# 21014), has a nominal accuracy of 0.75 psi (1.75 ft of head) and a resolution of .06 psi (0.14 ft of head). There was no apparent change in the pressure in the lower interval following setting of the bridge plug and remained constant throughout the monitoring period.

2.4 Variable Density/Viscosity of Water in the Wellbore

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

Figure 2-2 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, further discussed in Section 2.5.1. The pressures calculated from this exercise are within -0.33 to -0.37 percent of the measured pressure at the various depths of the bridge plug measurements. For the middle completion interval, the discrepancy in pressure between the PXD measurement and the calculated pressure is from -1.05 to -1.19 psi. As discussed in Section 2.3, the PXD used for the middle interval had a nominal accuracy of 0.75 psi, and a calibration accuracy of 0.02 psi. For the lower completion interval, the discrepancy was -1.71 to -1.90 psi. That PXD had a nominal accuracy of 1.00 psi and a calibration accuracy of 0.19 psi. These numbers indicate that much of the discrepancy is not due to uncertainty in the PXD measurement. 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. There is also some uncertainty due to uncertainty in the depths specified for the PXD measurements, although this factor would be negligible at these depths. However, the 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.

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 a 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

Temperature logs were run prior to completion of this well by both Schlumberger and Desert Research Institute (DRI) (ChemTool). A postcompletion temperature log (DRI, ChemTool) was run under nonpumping conditions with the ChemTool 13 days after the constant-rate test. These logs are shown in Figure 2-3 along with the DRI precompletion and postdevelopment thermal flow measurements, discussed in the next section. The three temperature logs have similar form although they differ in detail. The DRI logs, collected with the same tool at different times, almost overlay each other while the Schlumberger log is about 2.5°F cooler. The higher temperatures recorded on the DRI logs, about 85.5°F to 86°F, are very close to the temperature of produced water recorded at the surface during pumping and the PXD temperature during most of the constant-rate test. At the time the precompletion logs were run, the water level in the well was still recovering from drawdown due to water production during drilling. The DRI log was run two days later than the Schlumberger log, so the temperature difference between the logs may be related to thermal equilibrations and flow in the well due to water level recovery. Some of the difference may also be the result of discrepancy in the calibration of the two different tools.

Temperature logs give an indication of the entry, direction, and exit of flow from the borehole, but do not provide any rate information. The postdevelopment temperature profile show temperatures and gradient representative of the geothermal gradient from the static water level of about 1,017.5 ft to a depth of about 1,300 ft. Below this depth the temperature gradient decreases to almost isothermal. This appears to indicate downward flow in the well under the natural gradient, from the upper completion interval to the middle and lower intervals.

2.5.2 Flow Measurements (Thermal Flowmeter)

Thermal flowmeter measurements were made during precompletion logging and following the testing. The precompletion measurements probably do not indicate natural gradient flow because, as mentioned in the preceding section, the water level in the well was still recovering at the time of the measurements. Flow in the well under natural gradient (i.e., nonpumping, equilibrium conditions) was measured using the thermal flowmeter after recovery following the constant-rate test. The flow measurements are tabulated in Table A.2-10 of Appendix A. The measurements indicate downward flow from the upper completion interval to the middle and lower intervals (see Figure 2-3), in agreement with the temperature log. However, the values of -2.2 gallons per minute (gpm) are at the upper limit of the flowmeter range and these values may only indicate that flow was greater than that value. The high natural flow rate is consistent with the almost isothermal temperature profile below the upper interval.

2.5.3 Derived Hydraulic Properties

General estimates of the transmissivity of the completion intervals can be derived from information on the flow from and/or into the completion intervals and the hydraulic gradients associated with the flow. An estimate could be made using the empirical equation $T=2000Q/s_w$ (Driscoll, 1986), where Q is the flow rate in gpm and s_w is the drawdown in feet. The head change data and the flow data both have substantial relative uncertainty, but can be used to derive general estimates. For the upper interval, a downward gradient of 0.11 ft with 2.2 gpm resultant flow yields a T of 5,350 square feet per day (ft^2/d), and a hydraulic conductivity (K) of 20 feet per day (ft/d). This estimate could also be considered to generally apply to the lower interval since the interval thickness is similar. This is only an order-of-magnitude lower bound estimate since the downward head difference has some uncertainty, and the flow rate is a minimum rate.

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. These methods could be applied to wells when pumping tests are not run, and to the deeper completion intervals when there was no production during the pumping tests.

2.6 Pressure Equilibration Following Setting of Bridge Plugs

The pressure equilibration records for each completion interval following setting the bridge plugs also have the potential for providing information on the transmissivity of the completion interval formation. For the upper completion interval, the recovery record could be analyzed if it could be captured with sufficient early-time data to define the recovery curve accurately. However, necessary early-time data is usually lost before water level measurements can be made and the PXD can be installed for recording. This is true for Well ER-EC-5 data.

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 of Appendix A. As mentioned in Section 2.3, neither record shows an equilibration curve. Consequently the pressure fall-off analysis cannot be done.

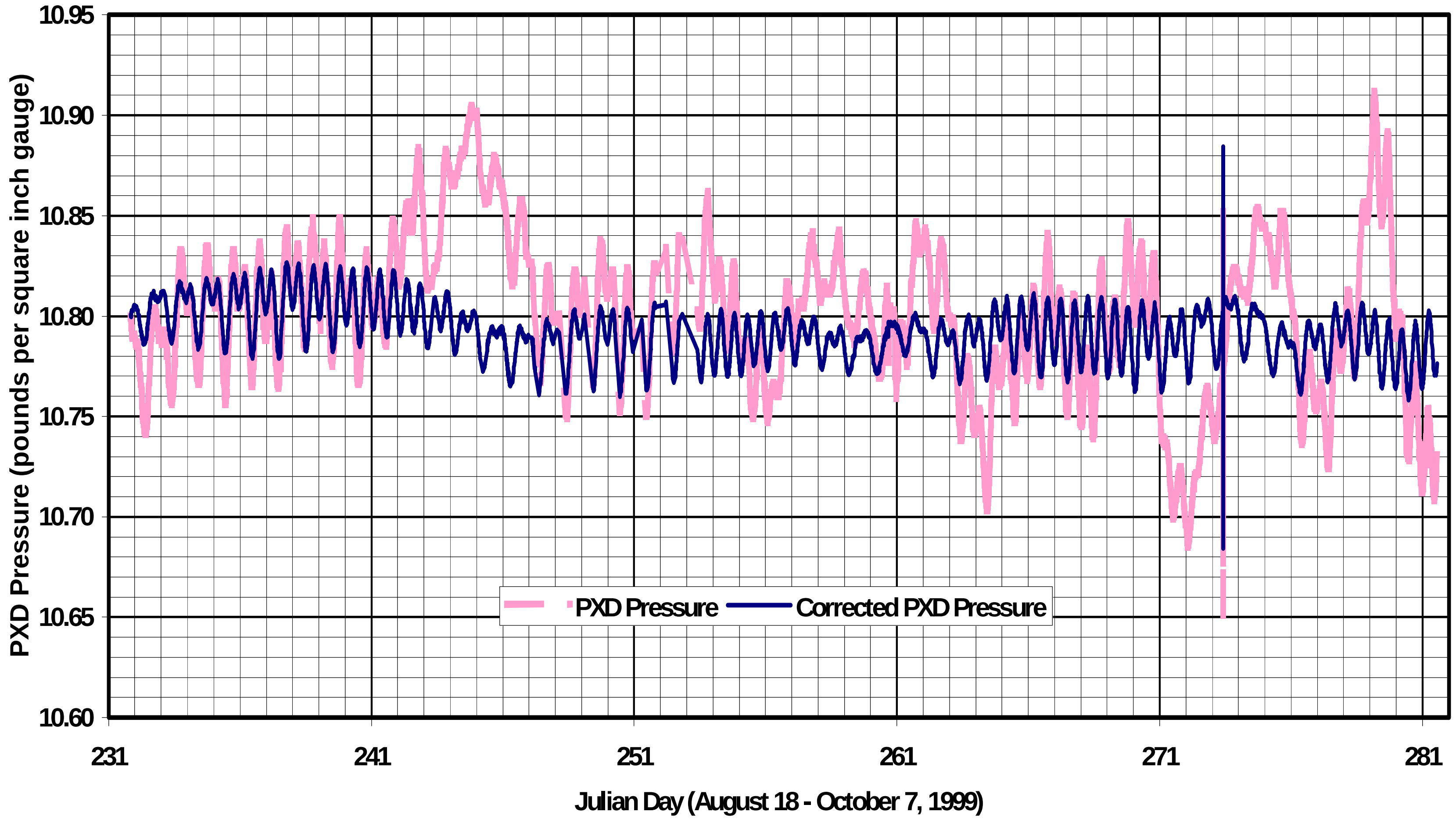

Figure 2-1
Barometric-Corrected Monitoring Record

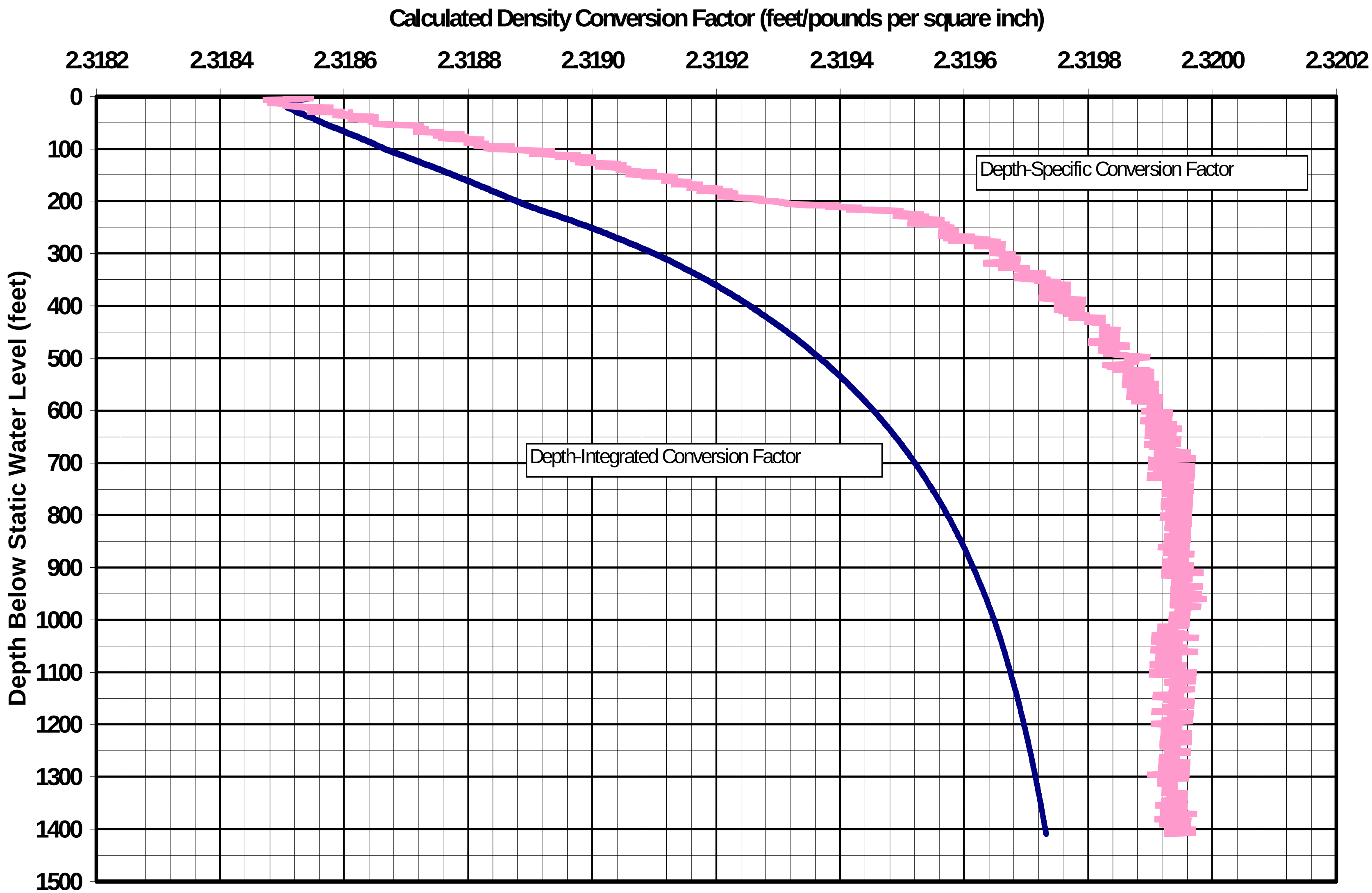

Figure 2-2
Temperature-Dependent Density Variation

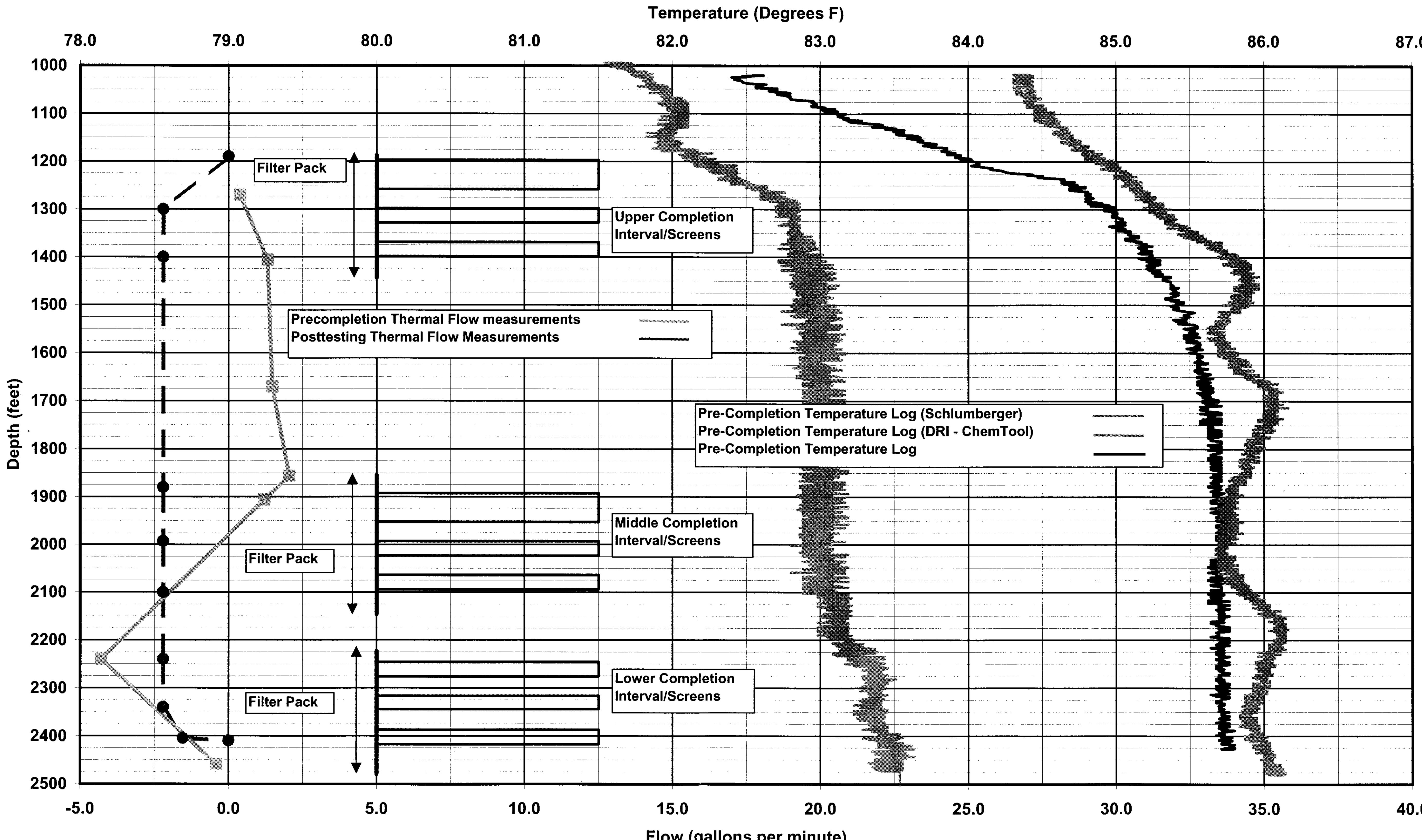

Figure 2-3
Nonpumping Temperature and Flow Logs

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 that was conducted during pumping and a detailed analysis of the well losses.

3.1 Measured Discrete Production

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

Flow logging in conjunction with the testing and sampling allows the interpretation to be made specific to the origin of the produced water and the specific response of each completion interval, or even part of a completion interval. For example, as discussed later in this section, the flowmeter results show that the production was very different between the completion intervals, even after accounting for the different lengths of the completion intervals. Consequently, the derived hydraulic conductivity is substantially greater for the 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 ec5mov8 run while pumping at a nominal rate of 161 gpm; but all of the logs show very similar results. Figure 3-2 and Figure 3-3 show the completion intervals and examples of the flow logs for each of the three pumping rates that were used. These figures include depth, lithology, hole diameter, and well construction. Flow log ec5mov2 is presented for 61 gpm, ec5mov5 for 111 gpm, and ec5mov8 for 161 gpm.

The flowmeter logs typically show inflow to the well starting from the bottom of the lower completion interval. Increases in flow generally correspond with the locations of the screens, with relatively steady flow in the blank casing between the screens and completion intervals. The flow logs exhibit some unusual behavior for the upper completion interval; the flow rate decreases upwards across the lower part of several screens, and then increases at the top of the screens. This situation was also observed in Well ER-EC-7. The flow at the top of screen #3 is the same as at the bottom, indicating no additional inflow. The flow at the top of screens #2 and #1 increased over the flow at the bottom of the screens, indicating inflow. These flow profiles probably indicate that some fraction of the flow in the casing is exiting the well casing in the lower part of the screen and reentering in the upper part of the screen. This could occur if such a flowpath resulted in lower overall flow losses. Constriction of flow around the borehole flowmeter may also result in this effect.

3.1.1 Temperature Logs

Figure 3-1 shows the temperature log from the ec5mov8 flowlog. This log is typical of the temperature logs from all of the flowmeter runs. The low temperature and very narrow range of temperature from bottom to top is not explained. The temperatures in general are significantly less than typically observed at these depths, and do not increase with depth.

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 eight logging runs were made at different logging speeds and different pumping rates. In addition, a series of nine stationary measurements were taken while the well was pumping and the meter held stationary at one depth. A summary of these different logging runs is presented in Table 3-1. The listed pumping rates have been updated based on tabulation of the flowmeter records to more accurately reflect the actual average pumping rates.

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

The flowmeter impeller spins in response to water moving through the meter. The rate of revolution is related to water velocity and flow via an equation which accounts for pipe diameter and the trolling speed of the flowmeter. The coefficients of the equation relating the impeller response to the discharge are determined via calibration. In theory, the meter could be calibrated in the laboratory using the same pipe as the well and no further calibration would be necessary. In reality, the flowmeter response is influenced by a large number of 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-5, the

Table 3-1
Summary of Impeller Flow Logs

Run Number	Direction of Run	Line Speed (fpm)	Pumping Rate (gpm)	Run Start/Finish (ft bgs)
ec5mov2	Down	20	60.7	1,174-2,415
ec5mov3	Up	60	60.9	2,419-1,174
ec5mov4	Up	40	111.4	2,419-1,141
ec5mov5	Down	20	111.6	1,145-2,415
ec5mov6	Up	60	111.8	2,419-979
ec5mov7	Up	40	162.5	2,419-1,136
ec5mov8	Down	20	161.0	1,140-2,419
ec5mov9	Up	60	160.7	2,422-1,139
ec5stat1	Stationary	0	61	1,176.8
ec5stat2	Stationary	0	61	1,550.8
ec5stat3	Stationary	0	61	2,244.7
ec5stat4	Stationary	0	111	1,177.3
ec5stat5	Stationary	0	111	1,551.0
ec5stat6	Stationary	0	111	2,171.5
ec5stat7	Stationary	0	161	1,164.7
ec5stat8	Stationary	0	161	1,538.6
ec5stat9	Stationary	0	161	2,158.6

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

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

3.1.3 Calibration of the Borehole Flowmeter in the Well

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

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

3.1.3.1 Calibration Procedure

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

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

Data Preparation

Preparation of the flowmeter calibration data includes the following steps:

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

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

Differences in depth reporting equipment leads to errors in reported depths for the logging runs. 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-5 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 3-4 shows the flow log for ec5mov9 and the corresponding differential flow log from depths of 1,139 to 2,422.2 ft below ground surface (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 3-4 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 1,155.2 ft. Likewise, the transition from the upper blank casing to the upper screen is also apparent at a depth of 1,264.8 ft. The transition points between screens and blank sections, which were clearly depicted on all differential flow logs, were identified. The upper three screens and upper two blank casing sections could not consistently be identified on the flow logs and were not used to calculate the depth correction. 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 -0.37 ft. This process ensures that the appropriate depth intervals of the flow log are analyzed.

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

Calibration Equation and Uncertainty

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

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

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

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

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

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

where:

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

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

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

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

where:

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

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

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

(3-3)

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

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

(3-4)

and

$\hat{\sigma}$	=	Root mean sum of errors between the predicted and measured flow values
X	=	Matrix of entries that include the number of data points, sums of variables, sums of squared variables, and sums of cross terms
x^*	=	Vector of independent variables with specific values 1, x_1*, x_2* where the confidence interval is to be estimated
$t_{\alpha/2,n-k-1}$	=	Students' t-statistic at the α level of significance and n-k-1 degrees of freedom
n	=	Number of data points
k	=	Number of independent variables

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

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

3.1.3.2 Calibration Results

The original calibration dataset derived from the eight moving and two stationary flow logs consisted of 1,781 data points. However, 84 data points representing logging run ec5mov3 were removed from the original calibration dataset because the flow fluctuations were not adequately recorded for the upper part of the borehole, including the upper casing interval. The final calibration dataset consisted of 1,698 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 coefficient, the sum of the squared errors, the number of observations, and the standard errors associated with the two equations.

Table 3-2
Flowmeter Calibration Results Using all Data Collected Above the Top Screen at Well ER-EC-5

Equations 3-1 and 3-2 Solutions		
	Equation 3-1	Equation 3-2
Constant	-0.0145	0.6542
First dependent variable	0.0222	45.0802
Second dependent variable	-0.0222	0.9989
Multiple R	0.9998	-
Sum of Squared Errors	0.5625	1143.1598
Standard Error	0.0182	0.9010
Number of Observations	1698	1698

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)
ec5mov2	0.453	-20.494	1.62
ec5mov3	-1.259	61.813	1.62
ec5mov4	-0.989	46.132	1.62
ec5mov5	0.571	-25.524	1.62
ec5mov6	-1.439	64.984	1.62
ec5mov7	-0.92	42.38	1.62
ec5mov8	0.585	-25.417	1.62
ec5mov9	-1.403	64.1	1.62

Note: Impeller rate and line speed values were taken from depths ranging between 2,400 and 2,415 ft below ground surface, corresponding to near-zero flow rates measured for this well.

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

In addition, Table 3-2 contains the 95 percent confidence intervals for specific sets of independent variable values that lead to predicted flow values near zero. The accuracy of the predictions near zero flow are of concern because certain screened sections of the well appear to produce little or no flow. The 95 percent confidence interval determined for specific pairs of flowmeter response and line speed that produced predicted discharge near zero provides an estimate of the measured discharge that is statistically indistinguishable from zero. No analysis for interval hydraulic conductivity was performed for measurements that are statistically indistinguishable from zero. As shown in Table 3-2, the 95 percent confidence interval is approximately 1.62 gpm. Measured flow rates less than 1.62 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-5 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. However, this method was 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 was 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-5 has a negligible impact on the flowmeter calibration.

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

Following calibration of the flowmeter, the flowmeter readings were converted to flow rates using the calibration equation (3-2) and the coefficients obtained using the full dataset (Table 3-2). For each moving flow log, each depth where a flowmeter response and line speed were recorded, the values were inserted into equation (3-2), with the coefficient values provided in Table 3-2, and the flow rate in the well at that depth was calculated. This generated the flow log values used for later analysis.

3.1.5 Resolution Effects of Well Construction

The physical construction of the screens and the limited screen length within the completion interval defined by the filter pack results in several limitations for resolving the origin of inflow from the aquifer. The slotting (3-in. slots, 18 per row) for each screen starts 2.5 ft on-center from the end of the casing joint, leaving 5 ft of unslotted casing between 25-ft lengths of closely spaced rows of slots (6-in. on-center). Also, the filter pack extends a substantial distance beyond the ends of the screen. The drawdown imposed by pumping is distributed in some manner throughout the filter pack and stresses the aquifer behind the blank casing. However, there is no way of accurately determining the distribution of inflow behind the blank casing. Some qualitative interpretation may be made of the increase in production at the edges of each screen on the flow logs, attributing some of that production to vertical flow from behind the blank casing; but this is speculative. The hydraulics of vertical flow in the filter pack and end effects for the screens are undefined. The main impact of this 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-5. The step-drawdown test analysis was used to determine the laminar and turbulent losses, and the laminar losses were attributed to aquifer drawdown. Flow losses inside the well were calculated independently, and subtracted from the turbulent losses to evaluate flow losses into the well. This breakdown of the total drawdown into its components provides better understanding of the hydraulics of water production and better estimates of aquifer properties. While there are some uncertainties in the accurate determination of the components of the drawdown, the calculated component values are better estimates of the actual values than the gross drawdown. This provides more accurate results and reveals details of the hydraulics of production.

3.2.1 Step-Drawdown Test

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

The left side of Table 3-3 shows the basic data derived from the step-drawdown test, and Figure 3-5 shows the resultant graph of that data with the equation for the trendline. The coefficients of the trendline are substituted in the equation for losses, in the form of $s_w = BQ_n + CQ_n^2$ where s_w is the total drawdown in the well, Q_n is the net production rate, B is the linear loss coefficient, and C is the nonlinear loss coefficient. Evaluating this equation at the average production rate for the flow logging of 161 gpm gives a nonlinear component of 3.88 ft, which is generally equated to turbulent losses in the well. The turbulent losses include flow losses from the aquifer into the wellbore (skin losses), entrance losses into the well casing through the screen slots, and flow losses up the casing to the pump. The linear component of the losses are generally considered to be the laminar losses of the flow in the aquifer. The predicted losses for all three flow logging pumping rates are tabulated in Table 3-3. It is recognized that this approach is not completely accurate, but it is believed to provide a reasonable estimate of the well losses. The results are used to estimate the aquifer drawdown and this drawdown value is used to calculate hydraulic conductivity for each of the screens. This was particularly important for this well because the calculated well losses are a large fraction (2/3) of the total drawdown.

Table 3-3
Step-Drawdown Results and Application

Duration Days	Ave Pumping Rate - Q (gallons per minute)	Drawdown s_w (feet)	s_w/Q	Flow Logging Pumping Rate (gallons per minute)	Predicted s_w (feet)	Laminar Losses (feet)	Turbulent Losses (feet)
0.0826	60.36	1.263	0.021	62.3	1.30	0.74	0.58
0.0825	100.13	2.670	0.027	111.6	2.98	1.33	1.86
0.0556	160.90	5.768	0.036	161.4	5.79	1.92	3.88

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 3-4 presents a tabulated profile of calculated friction losses showing the cumulative loss at various locations down the well from the pump intake. The flow rates attributed to each screen section of the well were the average of the inflows from the flow logs that were conducted at pumping rates of about 161.4 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

Table 3-4
Calculated Flow Losses

Location in Well	Flow at Location (gpm)			Cumulative Friction Loss Inside Casing (ft)			Incremental Flow Losses Into Casing Per Screen (ft)			Total Flow Losses at Center of Screen (ft)		
	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3	Step 1	Step 2	Step 3
Pump Intake	62.3	111.6	161.4									
Bottom of Pump Motor	62.3	111.6	161.4	.038	0.108	0.207						
Bottom of 7 5/8-in. Casing - Top of Crossover	62.3	111.6	161.4	.048	0.135	0.260						
Crossover	62.3	111.6	161.4	.083	0.234	0.451						
Top of Screen 1	62.3	111.6	161.4	.087	0.246	0.474	0.000	0.000	0.004	0.13	0.37	0.73
Bottom of Screen 1	59.1	100.9	144.2	.184	0.507	0.973						
Top of Screen 2	59.1	100.9	144.2	.215	0.586	1.122	0.000	0.000	0.006	0.23	0.64	1.23
Bottom of Screen 2	54.4	93.7	133.3	.257	0.697	1.329						
Top of Screen 3	54.4	93.7	133.3	.284	0.767	1.460	0.000	0.000	0.000	0.30	0.82	1.56
Bottom of Screen 3	54.4	92.9	132.9	.323	0.869	1.651						
Top of Screen 4	54.4	92.9	132.9	.647	1.707	3.232	0.000	0.000	0.026	0.66	1.77	3.41
Bottom of Screen 4	37.1	64.3	89.0	.709	1.856	3.531						
Top of Screen 5	37.1	64.3	89.0	.722	1.897	3.595	0.000	0.030	0.105	0.62	1.86	3.73
Bottom of Screen 5	17.0	31.9	45.0	.737	1.925	3.664						
Top of Screen 6	17.0	31.9	45.0	.740	1.936	3.683	0.000	0.000	0.012	0.72	1.94	3.70
Bottom of Screen 6	8.6	16.0	30.2	.741	1.938	3.692						
Top of Screen 7	8.6	16.0	30.2	.745	1.949	3.727	0.000	0.000	0.006	0.74	1.97	3.74
Bottom of Screen 7	6.4	11.5	20.1	.746	1.952	3.738						
Top of Screen 8	6.4	11.5	20.1	.747	1.954	3.742	0.000	0.000	0.006	0.75	1.97	3.75
Bottom of Screen 8	4.4	6.3	9.3	.748	1.956	3.747						
Top of Screen 9	4.4	6.3	9.3	.748	1.956	3.748	0.000	0.000	0.005	0.74	1.97	3.75
Bottom of Screen 9	0	0	0									

Blank = Not applicable

best applicability of flow logging data, flow logging should take place only after sufficient continuous pumping at each rate to achieve relatively stable drawdown.

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

This analysis was done for the flow logging pumping rates for use in the flow logging analysis. However, the constant-rate test pumping rate was very close to the 161 gpm flow logging rate, and the calculated flow losses would be very similar for the constant-rate test.

3.3 Head Distribution Under Pumping

The column in Table 3-4 labeled Cumulative Friction Loss Inside Casing tabulates the loss of head down the well casing due to flow up the casing. These values can be subtracted from the total measured drawdown to calculate the head at each tabulation point down the casing. For example, during the flow log runs at 161.4 gpm, the drawdown in the well would have been approximately 5.79 ft. This estimate is based on the equation derived from the step-drawdown test. During flow logging, the PXD was removed to allow access downhole, and drawdown could not be measured directly. At this time, the drawdown in the casing at the top of the first screen would have been about 5.34 ft (5.79 to 0.464), and the drawdown at the top of the second screen would have been about 4.70 ft. The column labeled Total Flow Losses at Center of Screen provides the total calculated flow loss from the aquifer into the casing and up to the pump intake. Subtracting this value from the total drawdown gives the aquifer drawdown at the center of each screen. The average drawdown for the flow inside casing across the first screen would have been about 5.09 ft (5.80 to 0.71). The calculated total friction loss inside casing is 3.66 ft, a large part of the turbulent losses of 3.88 ft calculated from the equation derived from the step-drawdown data. The flow losses for flow through the slots accounts for the remaining turbulent losses.

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

3.4 Constant-Rate Test Analysis

The constant-rate test provides data for determining the overall transmissivity of the well. Figure 3-6 shows a graph of the constant-rate test data. The features of the record are explained in Section A.3.4.2 of Appendix A. The average pumping rate for the test was 160.16 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 (804 ft) for the producing section of the upper completion interval for aquifer thickness. This solution yields a K of 9.48 ft/day with an associated T of 7,623 ft^2/d. Figure 3-7 shows a solution using the combined length of the producing screens (289.3 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 27.10 ft/day, yielding a T of 7,840 ft^2/d.

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

The analysis in Section 2.5.3 for the upper completion interval hydraulic conductivity produced a value of about 20 ft/d, which is of the same order of magnitude as values derived from the pumping test analysis.

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 screened sections. These data provide the basis for determining differences in hydraulic conductivity across different sections of the producing interval. This analysis will be used later in modeling groundwater flow in the corresponding aquifer.

3.5.1 The Borehole Flowmeter Method - Concept and Governing Equations

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

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

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

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

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

(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):

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

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

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

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

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

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

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

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

3.5.2 Calculation Process to Determine Interval Hydraulic Conductivity Values

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

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

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

3.5.3 Selection of Depth Intervals to Calculate Hydraulic Conductivity

To determine the hydraulic conductivity of an interval, the interval must be defined by top and bottom depths so inflow to the well can be determined. Previous applications of the flowmeter method (Rehfeldt et al., 1989; Hufschmeid, 1983; and Molz et al., 1989) calculated hydraulic conductivity at small intervals within fully screened wells in unconfined aquifers. One criterion to determine the size of the interval is to assess the minimum interval necessary to ensure that a statistically significant amount of flow enters the well between one flowmeter measurement and the next. The confidence intervals determined from equation (3-2) suggest that the difference in discharge should be greater than 1.62 gpm to be statistically significant. A criterion such as this would produce a variable interval depending on inflow, that might be as small as 0.2 ft or as large as 10 ft or more.

In partially penetrating wells, or irregularly screened wells such as ER-EC-5, 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-5 has nine screened intervals. Each screened interval is composed of one or two slotted sections of pipe. The length of a single slotted section is approximately 30 ft with slots beginning about 2.5 ft 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:

- The interval flow rates (Q_i)
- The term $r_w^2 S$.
- The drawdowns (s_w and s_i) at selected times (t)
- The formation transmissivity
- The 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 screen may be calculated from the flow in the well measured in the blank sections of pipe above and below each screen. The average discharges within the blank sections of pipe were determined for the portions of pipe centered between the ends of the blank section. This corresponds to a length of 30 ft for all blank sections except for the lowest blank section. A length of 20 ft was used for this section. Since flow was not recorded along the deepest blank casing section of Well ER-EC-5 during flow logging, it was assumed to be zero. The average discharge values are tabulated in Table 3-5 for the blank casing sections and in Table 3-6 for the screens numbered one through nine, beginning with the uppermost intervals.

Hydraulic conductivity will be calculated only for screens for which flow rates extracted from reliable flow logs exceed 1.62 gpm. As seen in Table 3-5 and Table 3-6, several flow rates observed in Well ER-EC-5 are statistically equal to zero (less than 1.62 gpm). Flow rates calculated for Screen 3 using all moving flow logs are less than 1.62 gpm. The flow rate calculated for Screen 6 using the erec5mov7 flow log is also less than 1.62 gpm.

Table 3-5
Average Flow Rates Through the Blank-Casing Sections in gpm During the Flow Logging Runs of Well ER-EC-5
(Page 1 of 2)

Pumping Rate = 62 gpm				
Logging Run				
Blank Number	ec5mov2	ec5mov3		Average
1	60.73	63.87		62.30
2	54.90	63.27		59.09
3	51.91	56.89		54.40
4	52.04	56.72		54.38
5	34.78	39.35		37.07
6	14.55	19.36		16.95
7	6.46	10.81		8.63
8	3.86	8.93		6.39
9	1.68	7.07		4.38
Pumping Rate = 111 gpm				
Logging Run				
Blank Number	ec5mov4	ec5mov5	ec5mov6	Average
1	111.40	111.60	111.77	111.59
Pumping Rate = 111 gpm				
Logging Run				
Blank Number	ec5mov4	ec5mov5	ec5mov6	Average
1	111.40	111.60	111.77	111.59
2	101.12	99.63	101.85	100.87

Table 3-5
Average Flow Rates Through the Blank-Casing Sections in gpm During the Flow Logging Runs of Well ER-EC-5
(Page 2 of 2)

Pumping Rate = 111 gpm				
	Logging Run			
Blank Number	**ec5mov4**	**ec5mov5**	**ec5mov6**	**Average**
3	93.84	92.84	94.38	93.69
4	92.90	92.63	93.24	92.92
5	63.10	63.23	66.44	64.26
6	34.71	29.34	31.55	31.87
7	17.78	14.65	15.53	15.99
8	13.34	10.19	11.07	11.53
9	7.93	4.75	6.26	6.31
Pumping Rate = 161 gpm				
	Logging Run			
Blank Number	**ec5mov7**	**ec5mov8**	**ec5mov9**	**Average**
1	162.45	160.98	160.70	161.38
2	145.36	142.80	144.37	144.18
3	134.11	132.77	133.14	133.34
4	133.37	132.52	132.67	132.86
5	91.94	90.98	84.15	89.02
6	43.13	43.06	48.88	45.02
7	42.73	21.29	26.46	30.16
8	24.62	15.26	20.37	20.08
9	9.37	7.01	11.58	9.32

Note: Flow from the bottom of the well below the deepest screened interval is assumed to be zero.

Table 3-6
Average Flow Rates Through the Screened Sections in gpm During the Flow Logging Runs of Well ER-EC-5
(Page 1 of 2)

Pumping Rate = 62 gpm				
Logging Run				
Screen Number	**ec5mov2**	**ec5mov3**		**Average**
1	5.83	0.59		3.21
2	3.00	6.38		4.69
3	-0.13	0.17		0.02
4	17.26	17.38		17.32
5	20.24	19.99		20.11
6	8.09	8.55		8.32
7	2.60	1.89		2.24
8	2.17	1.86		2.02
9	1.68	7.07		4.38
Pumping Rate = 111 gpm				
Logging Run				
Screen Number	**ec5mov4**	**ec5mov5**	**ec5mov6**	**Average**
1	10.28	11.98	9.92	10.73
2	7.29	6.79	7.47	7.18
3	0.94	0.21	1.14	0.76
4	29.80	29.40	26.80	28.67
5	28.39	33.89	34.89	32.39
6	16.93	14.70	16.02	15.88
7	4.45	4.46	4.46	4.45
8	5.41	5.44	4.82	5.22
9	7.93	4.75	6.26	6.31
Pumping Rate = 161 gpm				
Logging Run				
Screen Number	**ec5mov7**	**ec5mov8**	**ec5mov9**	**Average**
1	17.09	18.18	16.33	17.20
2	11.25	10.03	11.23	10.84
3	0.74	0.24	0.46	0.48
4	41.43	41.55	48.52	43.83
5	48.81	47.92	35.27	44.00

Table 3-6
Average Flow Rates Through the Screened Sections in gpm During the Flow Logging Runs of Well ER-EC-5
(Page 2 of 2)

Pumping Rate = 161 gpm				
	Logging Run			
Screen Number	**ec5mov7**	**ec5mov8**	**ec5mov9**	**Average**
6	0.40	21.77	22.42	14.86
7	18.11	6.03	6.09	10.08
8	15.25	8.25	8.79	10.76
9	9.37	7.01	11.58	9.32

Note: Flow from the bottom of the well below the deepest screened interval is assumed to be zero.

The Term $r_w^2 S$.

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

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

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

(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 3-4 weighted by the intervals' flow rates

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

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

Q= 62 gpm			
Screen	**(1) Flow Rate into Well (gpm)**	**(2) Total Flow Losses at Center of Screen (ft)**	**(1) X (2)**
Screen 1	5.83	0.13	0.76
Screen 2	3.00	0.23	0.69
Screen 3	-0.13	0.3	-0.04
Screen 4	17.26	0.66	11.39
Screen 5	20.24	0.62	12.55
Screen 6	8.09	0.72	5.83
Screen 7	2.60	0.74	1.92
Screen 8	2.17	0.75	1.63
Screen 9	1.68	0.74	1.25
Total Flow	60.73		
Weighted Average Flow Loss in the Well = 0.592 ft			
Q= 111 gpm			
Screen 1	10.73	0.37	3.97
Screen 2	7.18	0.64	4.60
Screen 3	0.76	0.82	0.62
Screen 4	28.67	1.77	50.74
Screen 5	32.39	1.86	60.24
Screen 6	15.88	1.94	30.81
Screen 7	4.45	1.97	8.78
Screen 8	5.22	1.97	10.29
Screen 9	6.31	1.97	12.43
Total Flow	111.59		
Weighted Average Flow Loss in the Well = 1.635 ft			
Q= 161 gpm			
Screen 1	17.20	0.73	12.56
Screen 2	10.84	1.23	13.33
Screen 3	0.48	1.56	0.75
Screen 4	43.83	3.41	149.46
Screen 5	44.00	3.73	164.12
Screen 6	14.86	3.7	55.00
Screen 7	10.08	3.74	37.68
Screen 8	10.76	3.75	40.36
Screen 9	9.32	3.75	34.95
Total Flow	161.38		
Weighted Average Flow Loss in the Well = 3.149 ft			

To capture the range of uncertainty associated with drawdowns during the flow logging, two values of drawdown were used for each pumping rate to assess the uncertainty associated with drawdown. These drawdowns were calculated using the Cooper and Jacob (1946) equation applied to the whole well. The well transmissivity value derived from the constant-rate test was used in these calculations. The drawdowns were calculated for the time period between 0.0417 and 0.9167 day, after pumping began. The calculated drawdowns ranged between 1.25 and 1.65 ft, 2.8 and 3.53 ft, and 4.83 and 5.88 ft for the three pumping rates of 62 gpm, 111 gpm, and 161 gpm, respectively. The period considered for drawdown calculations approximately corresponds to the time during which the flow logging was conducted. The formation drawdown was calculated by substrating the weighted average flow loss in the well (shown in Table 3-7) 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 3-4 and Table 3-7 as "Total Flow Losses at Center of Screen."

Transmissivity of the Formation

The transmissivity of the formation is the well transmissivity as calculated from the constant-rate test adjusted for well flow losses. An estimate of the formation transmissivity was then derived by multiplying the transmissivity derived from the constant-rate pumping test (Q = 161 gpm) by the ratio of the formation drawdown to the well drawdown at t = 0.9167 days. The well drawdown @ 0.9167 day is 5.5 ft. As shown in Table 3-7, the average well flow losses at 161 gpm are equal to 3.095 ft. Therefore, the estimated formation losses are equal to 2.41 ft. As a result, the ratio of the formation drawdown to the well drawdown is equal to 0.44. As reported earlier, the transmissivity derived from the constant-rate pumping test is equal to 7,623 ft2/d (for well thickness=filter pack). The derived estimate of formation transmissivity is 17,433 ft^2/d.

Individual Interval's Transmissive Thickness (b_i)

The interval thickness is not precisely known because flow to the screen may be derived, in part, from behind the blank section of pipe above or below the screen. The minimum contributing thickness is assumed to be the length of the slotted section of a given screen. The lengths of these screens vary between 25 and 56 ft. These lengths do not include the non-slotted parts of the sections located at both ends of a given continuous string of slotted sections. The maximum contributing thickness is assumed to be equal to the lengths of the filter packs (which varies between approximately 70 ft and 118 ft).

3.5.4.2 Procedure and Results

For equation (3-10), the interval transmissivity is determined using an iterative approach. Equation (3-10) is solved iteratively by estimating K_i, then solving for T_i, dividing by b_i, and then substituting back into the equation. After 10 to

18 iterations, a value of T_i is determined. The Term $r_w^2 S$ is calculated using the formation transmissivity and a pair of known time-drawdown pair. The hydraulic conductivity of each interval is the interval transmissivity from equations (3-8) and (3-10) divided by the interval thickness.

The interval hydraulic conductivities from equations (3-8) and (3-10) are given in Table 3-8 for each of the logging runs and each of the cases considered. The hydraulic conductivity of each interval is the interval transmissivity from equations (3-8) and (3-10) divided by the interval thickness. The sum of the individual interval transmissivities represent the transmissivity of the formation with a maximum error of about 20 percent.

3.5.5 Sources of Uncertainty

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

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

The parameter uncertainty comes from uncertainty in the flow rate, drawdown, and 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 1.62 gpm. This means that flow uncertainty is a small factor for screened intervals which produced the most water, but could be a significant factor for intervals that produced small amounts of water. The drawdown in the aquifer is uncertain because it relies on corrections for well losses, both inside and outside the well. The well loss corrections are similar down the well, but the impact of the uncertainty will be larger for screened intervals that have lower flow rates.

The parameters within the logarithmic term of equation (3-10) are another source of uncertainty. The time at which flowmeter measurements are taken relative to the total time of pumping will influence calculated hydraulic conductivity as will the estimate for the effective radius - storage coefficient product. As seen in equation (3-10), time is a parameter in this equation. If the time of measurement is long after pumping began, the change in drawdown and well hydraulic condition will be small both during the logging run and between logging runs. If one logging run is made too close to the start of pumping, it seems likely that parameters from that run could differ from later runs. Table 3-8 summarizes the hydraulic conductivity for each interval for each logging run using a range of

Table 3-8
Interval Hydraulic Conductivities Calculated From Flow Logging Data for Well ER-EC-5
(Page 1 of 2)

Logging Run	Screen	Interval Thickness = Length of Screen				Interval Thickness = Filter Pack			
		Interval Thickness (ft)	Hydraulic Conductivity (ft/d)			Interval Thickness (ft)	Hydraulic Conductivity (ft/d)		
			(Equation 3-10)		(Equation 3-8)		(Equation 3-10)		(Equation 3-8)
			$s_{t=0.0417\ d}$ [a]	$s_{t=0.9167\ d}$ [b]	-		$s_{t=0.0417\ d}$	$s_{t=0.9167\ d}$	-
erec5mov2	Screen 1	56.25	15.91	20.04	30.60	90.79	9.86	12.42	18.43
erec5mov3	Screen 1	56.25	-	6.47	10.50	90.79	-	4.01	6.33
erec5mov4	Screen 1	56.25	12.16	16.43	29.43	90.79	7.53	10.18	17.73
erec5mov5	Screen 1	56.25	14.39	19.31	34.29	90.79	8.92	11.96	20.65
erec5mov6	Screen 1	56.25	11.69	15.82	28.40	90.79	7.24	9.80	17.10
erec5mov7	Screen 1	56.25	14.70	15.25	33.72	90.79	9.11	9.45	20.31
erec5mov8	Screen 1	56.25	15.69	16.28	35.85	90.79	9.72	10.09	21.59
erec5mov9	Screen 1	56.25	13.98	14.51	32.19	90.79	8.66	8.99	19.39
erec5mov2	Screen 2	25.38	20.37	24.73	34.87	70.58	7.32	8.89	12.19
erec5mov3	Screen 2	25.38	46.55	54.86	74.28	70.58	16.74	19.73	25.97
erec5mov4	Screen 2	25.38	22.79	29.10	46.23	70.58	8.19	10.47	16.16
erec5mov5	Screen 2	25.38	21.07	27.00	43.06	70.58	7.58	9.71	15.05
erec5mov6	Screen 2	25.38	23.41	29.86	47.38	70.58	8.42	10.74	16.56
erec5mov7	Screen 2	25.38	24.90	25.69	49.22	70.58	8.96	9.24	17.21
erec5mov8	Screen 2	25.38	22.00	22.71	43.84	70.58	7.91	8.17	15.33
erec5mov9	Screen 2	25.38	24.82	25.61	49.07	70.58	8.93	9.21	17.15
erec5mov2	Screen 4	55.55	106.95	100.45	91.76	117.99	50.36	47.29	43.20
erec5mov3	Screen 4	55.55	107.75	101.17	92.39	117.99	50.73	47.63	43.50
erec5mov4	Screen 4	55.55	101.80	95.05	86.39	117.99	47.93	44.75	40.67
erec5mov5	Screen 4	55.55	100.31	93.70	85.23	117.99	47.23	44.12	40.13
erec5mov6	Screen 4	55.55	90.72	85.02	77.70	117.99	42.72	40.03	36.58
erec5mov7	Screen 4	55.55	96.35	95.45	82.77	117.99	45.36	44.94	38.97
erec5mov8	Screen 4	55.55	96.58	95.68	82.95	117.99	45.47	45.05	39.06
erec5mov9	Screen 4	55.55	113.86	112.74	96.83	117.99	53.61	53.08	45.59
erec5mov2	Screen 5	25.41	275.09	258.73	235.24	70.65	98.95	93.06	84.61
erec5mov3	Screen 5	25.41	271.41	255.35	232.31	70.65	97.62	91.85	83.56
erec5mov4	Screen 5	25.41	248.99	217.21	179.92	70.65	89.56	78.13	64.71
erec5mov5	Screen 5	25.41	301.48	261.62	214.81	70.65	108.44	94.10	77.26
erec5mov6	Screen 5	25.41	310.97	269.63	221.07	70.65	111.85	96.98	79.52
erec5mov7	Screen 5	25.41	318.00	309.87	213.18	70.65	114.38	111.46	76.68
erec5mov8	Screen 5	25.41	311.70	303.75	209.18	70.65	112.12	109.26	75.24
erec5mov9	Screen 5	25.41	225.09	219.56	153.88	70.65	80.96	78.97	55.35
erec5mov2	Screen 6	25.4	123.71	110.23	94.11	102.37	30.70	27.35	23.35
erec5mov3	Screen 6	25.4	131.22	116.72	99.38	102.37	32.56	28.96	24.66
erec5mov4	Screen 6	25.4	156.96	132.95	107.32	102.37	38.94	32.99	26.63
erec5mov5	Screen 6	25.4	134.67	114.59	93.17	102.37	33.41	28.43	23.12
erec5mov6	Screen 6	25.4	147.83	125.44	101.54	102.37	36.68	31.12	25.19
erec5mov8	Screen 6	25.4	132.37	129.51	95.05	102.37	32.84	32.13	23.58

Table 3-8
Interval Hydraulic Conductivities Calculated
From Flow Logging Data for Well ER-EC-5
(Page 2 of 2)

Logging Run	Screen	Interval Thickness = Length of Screen				Interval Thickness = Filter Pack			
		Interval Thickness (ft)	Hydraulic Conductivity (ft/d)			Interval Thickness (ft)	Hydraulic Conductivity (ft/d)		
			(Equation 3-10)		(Equation 3-8)		(Equation 3-10)		(Equation 3-8)
			$s_{t=0.0417\ d}$ [a]	$s_{t=0.9167\ d}$ [b]	-		$s_{t=0.0417\ d}$	$s_{t=0.9167\ d}$	-
erec5mov9	Screen 6	25.4	136.54	133.58	97.87	102.37	33.88	33.14	24.28
erec5mov2	Screen 7	25.4	37.58	34.14	30.22	73.15	13.05	11.85	10.49
erec5mov3	Screen 7	25.4	26.47	24.35	21.93	73.15	9.19	8.45	7.61
erec5mov4	Screen 7	25.4	38.10	33.19	28.18	73.15	13.23	11.53	9.79
erec5mov5	Screen 7	25.4	38.20	33.28	28.25	73.15	13.27	11.56	9.81
erec5mov6	Screen 7	25.4	38.25	33.32	28.29	73.15	13.28	11.57	9.82
erec5mov7	Screen 7	25.4	111.78	109.23	79.15	73.15	38.82	37.93	27.48
erec5mov8	Screen 7	25.4	34.55	33.90	26.31	73.15	12.00	11.77	9.14
erec5mov9	Screen 7	25.4	34.90	34.25	26.57	73.15	12.12	11.89	9.23
erec5mov2	Screen 8	25.4	31.60	28.61	25.27	70.66	11.36	10.28	9.08
erec5mov3	Screen 8	25.4	26.66	24.28	21.63	70.66	9.58	8.73	7.77
erec5mov4	Screen 8	25.4	47.25	40.86	34.32	70.66	16.99	14.69	12.34
erec5mov5	Screen 8	25.4	47.46	41.03	34.46	70.66	17.06	14.75	12.39
erec5mov6	Screen 8	25.4	41.58	36.11	30.53	70.66	14.95	12.98	10.97
erec5mov7	Screen 8	25.4	93.69	91.56	66.64	70.66	33.68	32.91	23.95
erec5mov8	Screen 8	25.4	48.65	47.65	36.03	70.66	17.49	17.13	12.95
erec5mov9	Screen 8	25.4	52.00	50.93	38.36	70.66	18.69	18.31	13.79
erec5mov2	Screen 9	25.4	23.40	21.62	19.59	113.20	5.25	4.85	4.40
erec5mov3	Screen 9	25.4	111.44	97.81	82.16	113.20	25.01	21.95	18.44
erec5mov4	Screen 9	25.4	71.61	61.06	50.25	113.20	16.07	13.70	11.28
erec5mov5	Screen 9	25.4	41.00	35.62	30.14	113.20	9.20	7.99	6.76
erec5mov6	Screen 9	25.4	55.33	47.58	39.66	113.20	12.41	10.68	8.90
erec5mov7	Screen 9	25.4	55.75	54.58	40.94	113.20	12.51	12.25	9.19
erec5mov8	Screen 9	25.4	40.87	40.06	30.61	113.20	9.17	8.99	6.87
erec5mov9	Screen 9	25.4	69.81	68.29	50.55	113.20	15.66	15.32	11.34

[a]Drawdown in the well 0.0417 days after pumping started.
[b]Drawdown in the well 0.9167 days after pumping started.

interval thickness and a range of drawdowns. As can be seen, for a given screen, the differences between logging runs is relatively small, considering that the logging runs were made at different times after pumping began. Therefore, the time of measurement was not a significant source of error in the interpretation. This is consistent with the expectation that the effect of these parameters is not too large because the logarithm has the effect of moderating the impact.

Perhaps the single biggest source of uncertainty is the selection of the length of the contributing interval for each screen. As noted earlier, the thickness could vary between 25 and 118 ft. This uncertainty in the contributing thickness produces an uncertainty in interval hydraulic conductivity that is about a factor of two to five for Well ER-EC-5.

In summary, the interval hydraulic conductivity values are uncertain, with greater uncertainty associated with the small hydraulic conductivity intervals. The interval hydraulic conductivity values are probably no more accurate than about a factor of two to five. 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 testing in this multiple-completion well worked well, yielding results for all three completion intervals. The hydraulics of Well ER-EC-5 were similar to Well ER-EC-7, producing substantial flow from the lower completion interval(s) and providing data for determining hydraulic conductivity for those interval(s). This is different from Wells ER-EC-1 and ER-EC-6, for which production was limited to the upper completion intervals, only yielding results for those intervals. The differences in production behavior between these two sets of wells are in the different patterns and values of relative hydraulic conductivity between the completion intervals.

The analysis of the WPM-OV testing has identified a variety of relationships between testing factors that affect how good the data will be for determining hydraulic conductivities of individual completion intervals, especially lower intervals. These relationships are a function of trying to derive accurate results for multiple intervals from a multiple completion well. Drawdown should substantially exceed the vertical gradient. The overall transmissivity should be high enough to yield production rate differences substantially above the noise level of the flow logging instrumentation. The overall transmissivity should be low enough to produce drawdown differences between different flow rates that produce results above the noise level of the analysis. The required differences are a function of drawdown monitoring and the magnitude of the estimated flow losses. The transmissivities of the different intervals should be similar enough that production from each of the completion intervals is sufficient to observe instrument responses above the noise level. Finally, the relative transmissivity for the lower interval should not be so high that high production from lower interval(s) results in large flow losses across upper completion intervals.

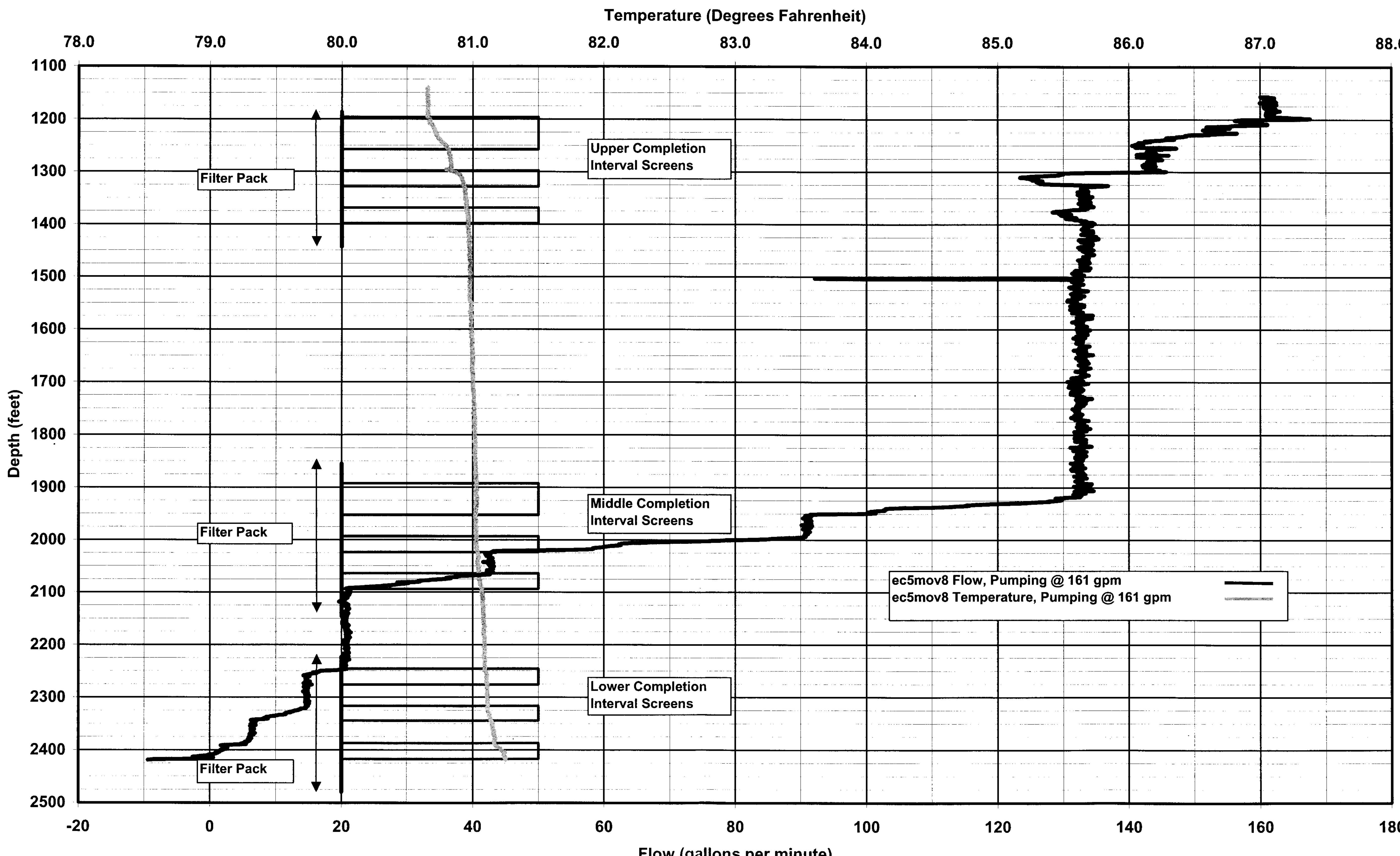

Figure 3-1
Pumping Temperature and Flow Logs

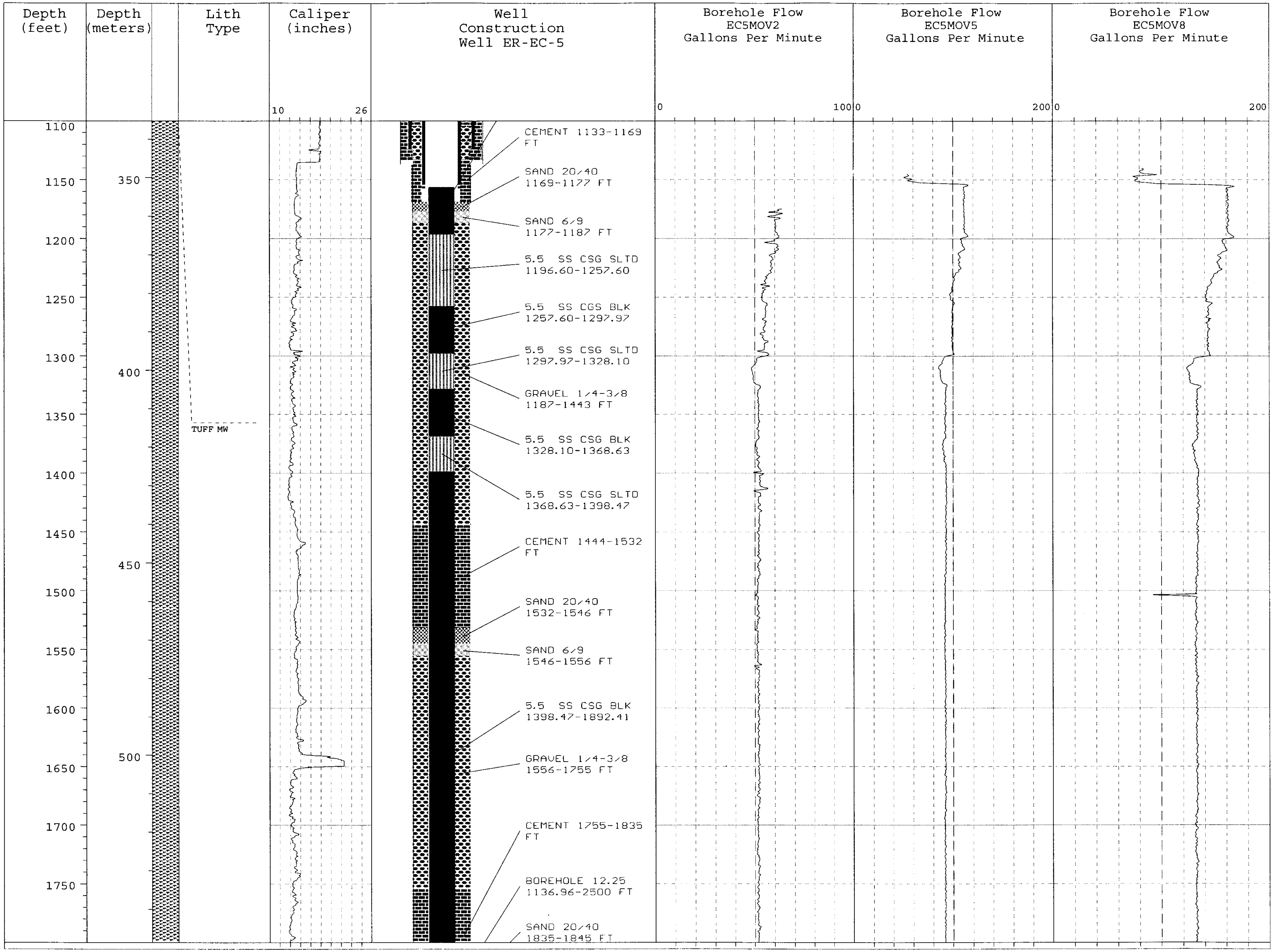

Figure 3-2
Geology and Well Construction for the Upper Completion Interval

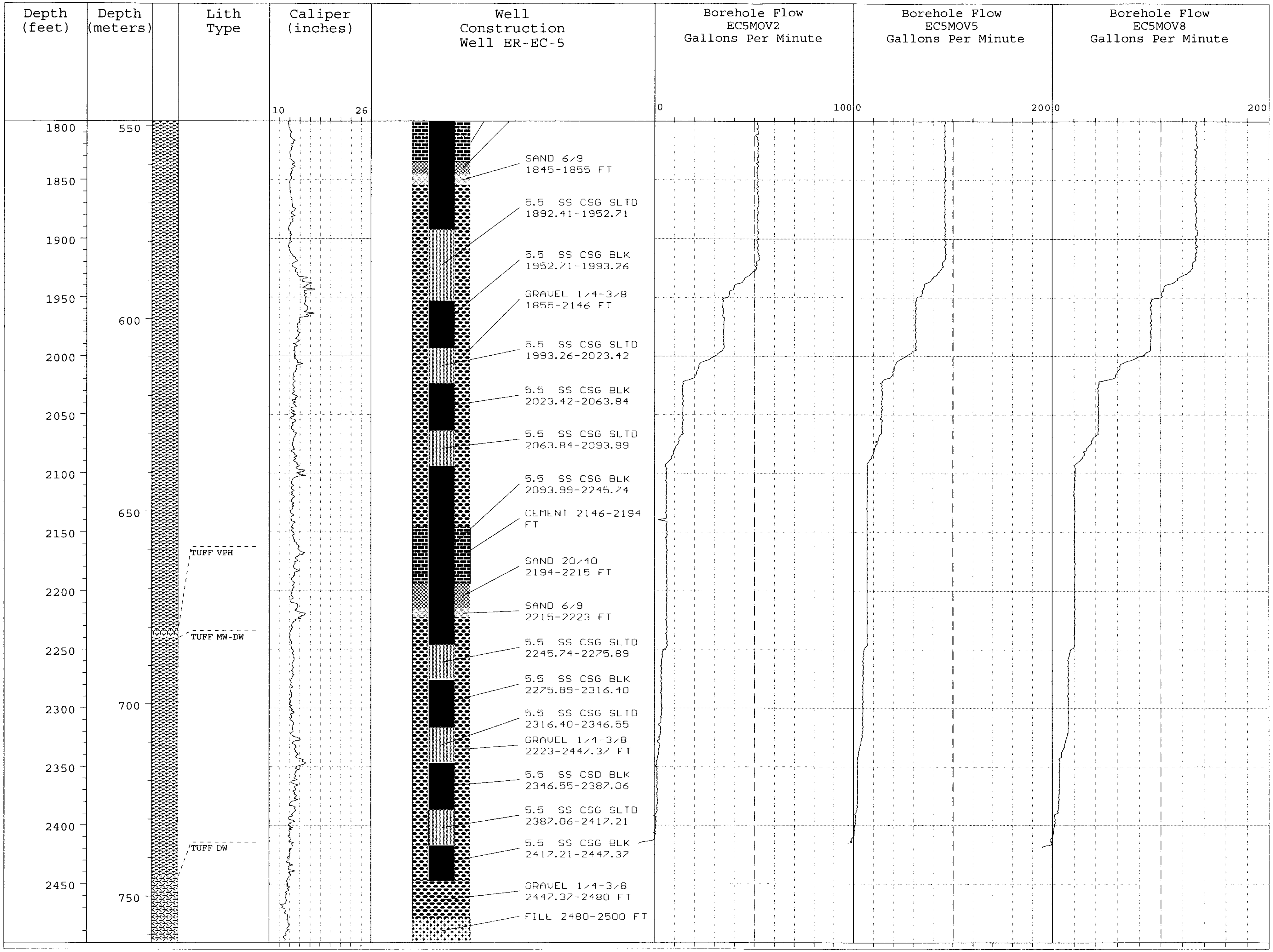

Figure 3-3
Geology and Well Construction for the Middle and Lower Completion Intervals

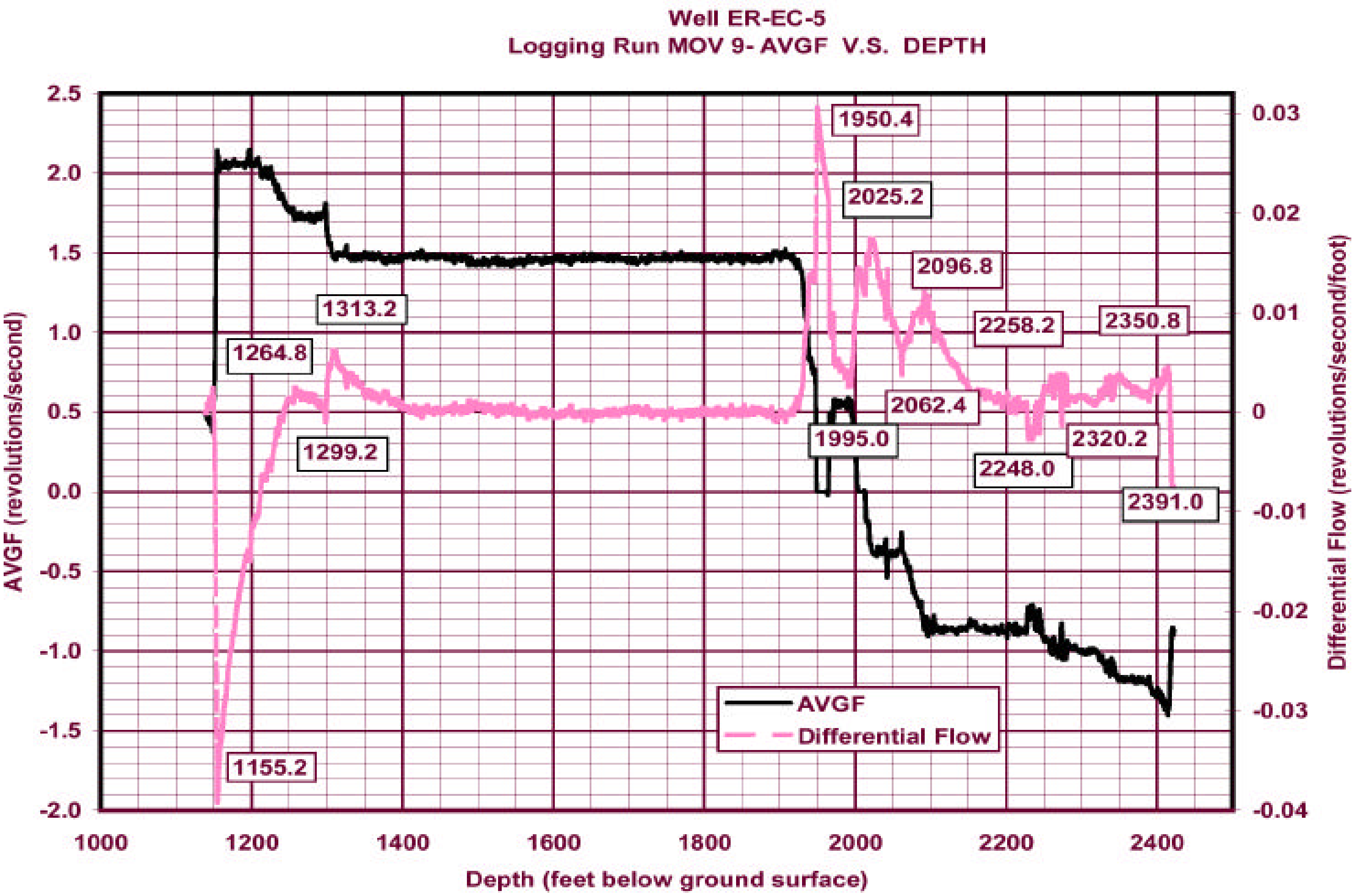

Figure 3-4
Example of Differential Flow Log Superposed on Flow Log (Flow Log ec5mov9)

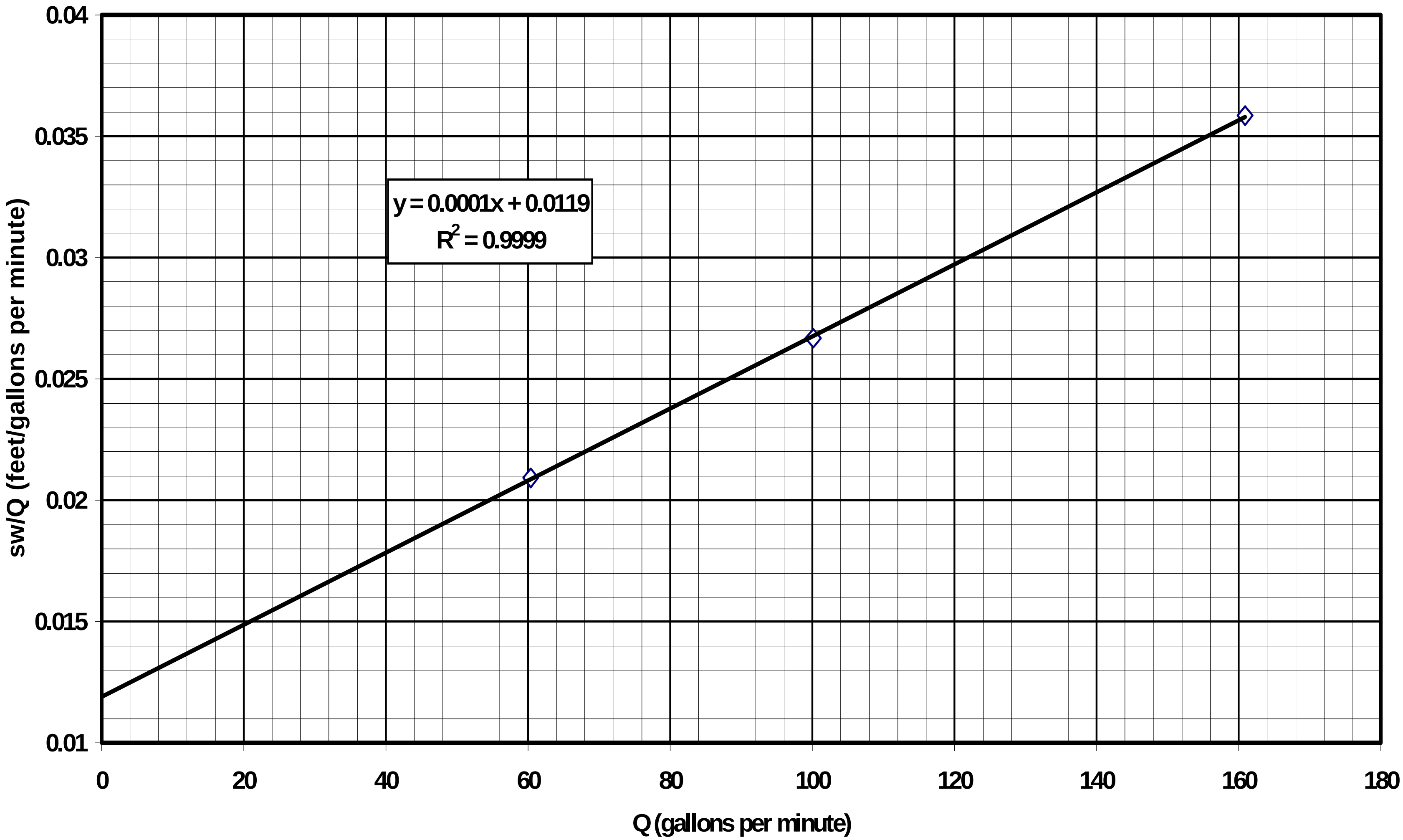

Figure 3-5
Step-Drawdown Analysis

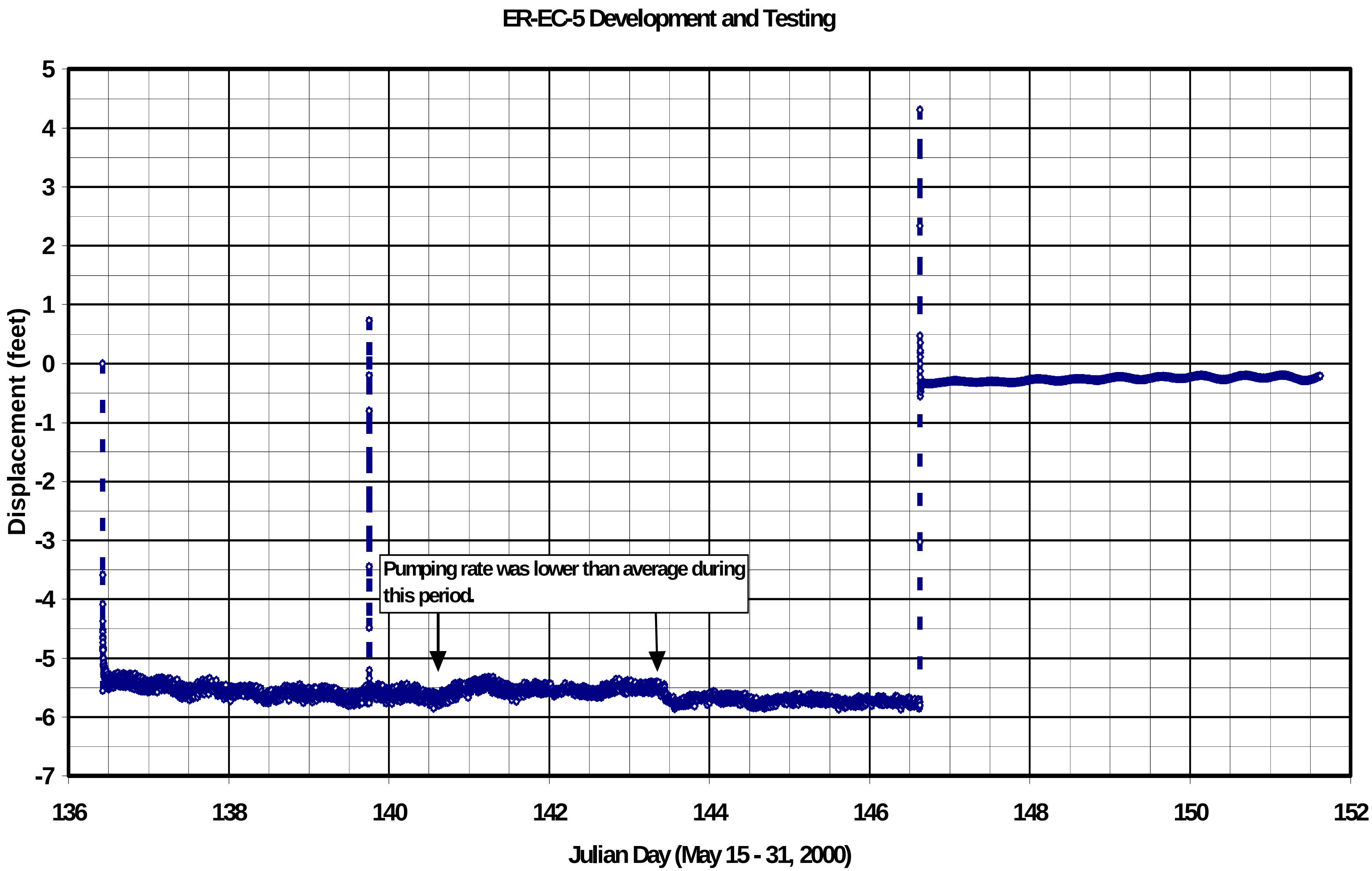

Figure 3-6
Constant-Rate Test Data

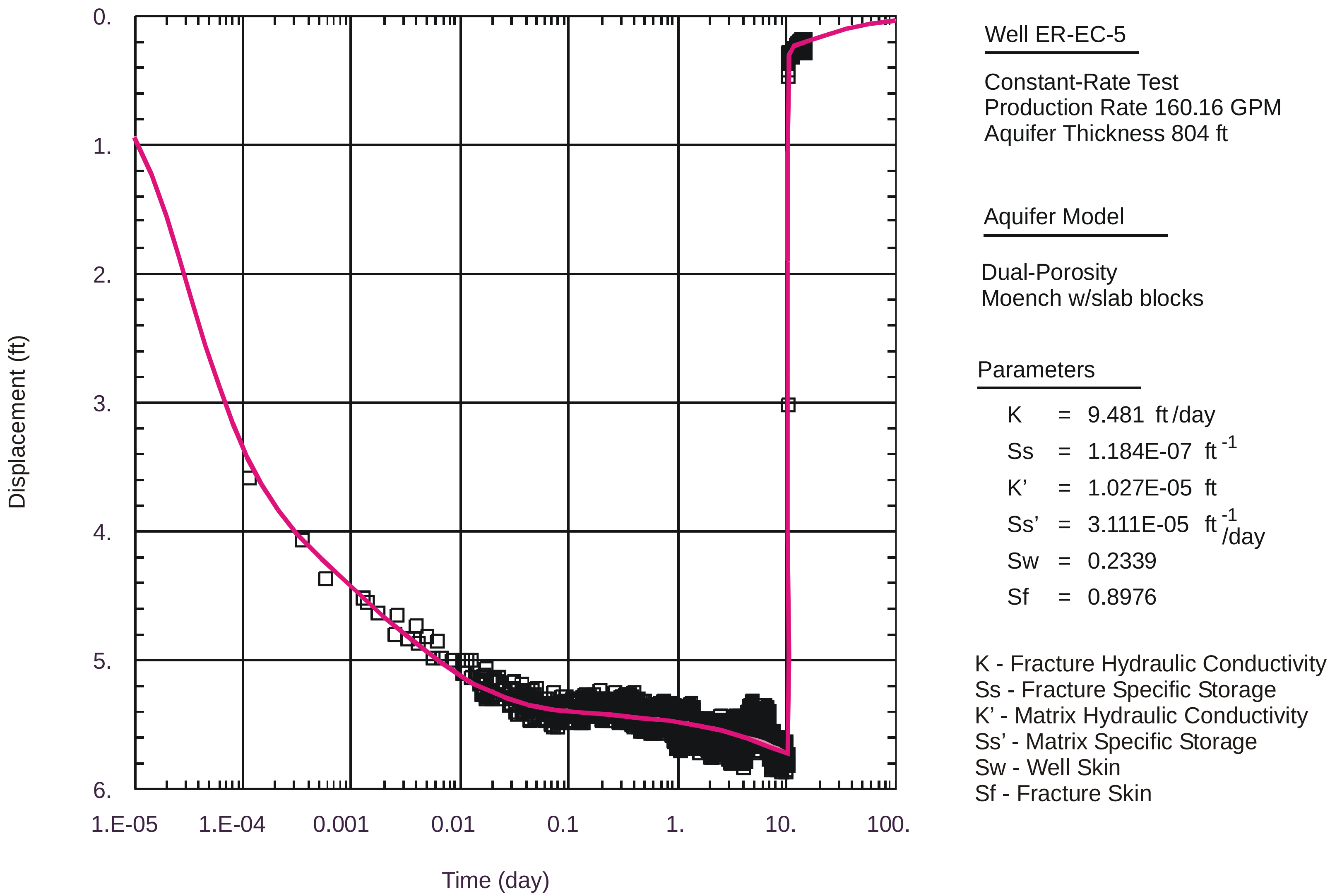

Figure 3-7
Moench Analysis of the Constant-Rate Test

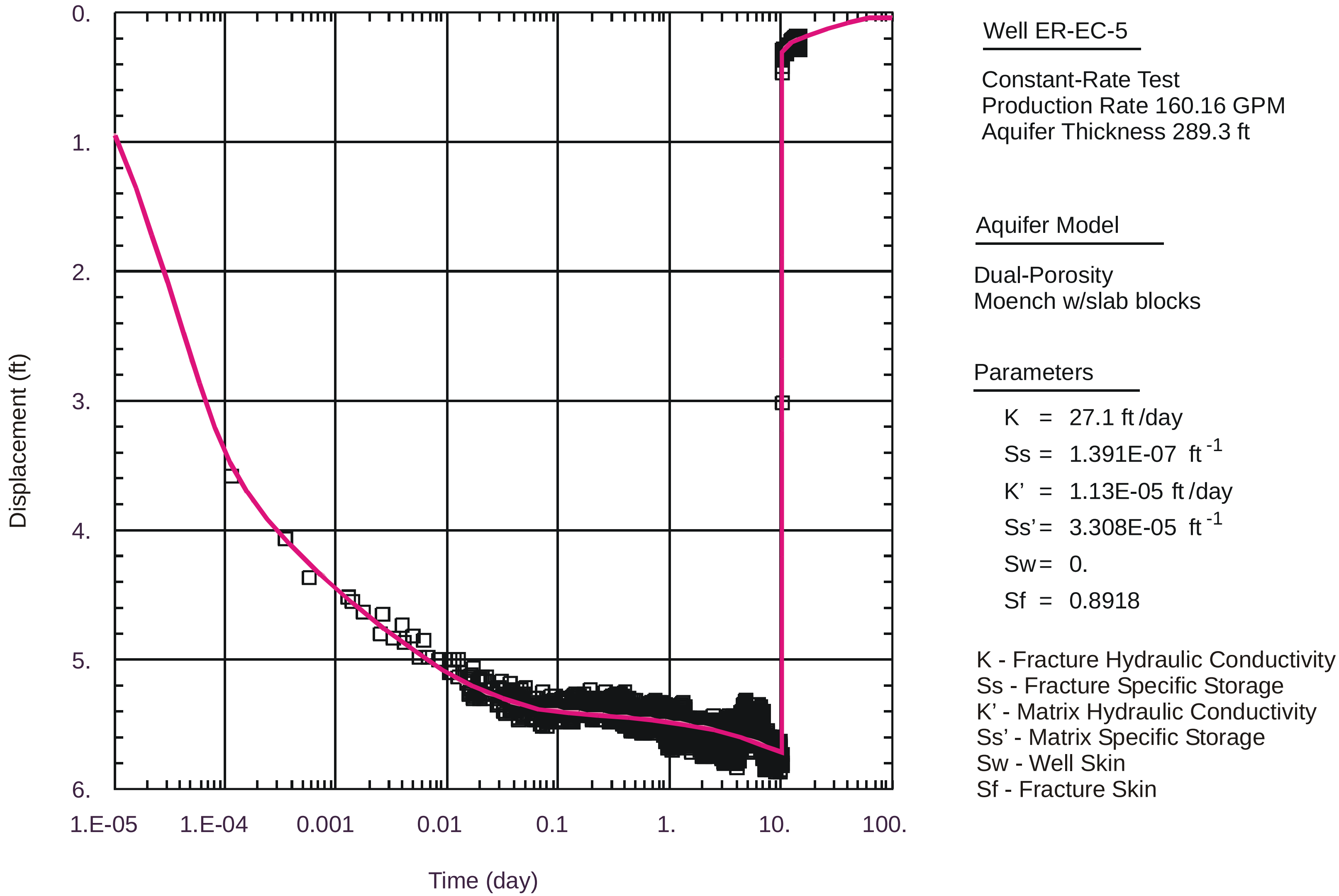

Figure 3-8
Moench Analysis of the Constant-Rate Test - Alternate Aquifer Thickness

4.0 Groundwater Chemistry

This section presents an evaluation of the analytical results for the groundwater characterization samples collected during well development and hydraulic testing activities at Well ER-EC-5. Two discrete bailer samples 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-5 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-5 will be discussed in this section, and then compared to the groundwater chemistry of other nearby wells.

4.1.1 ER-EC-5 Groundwater Characterization Sample Results

On May 4, 2000, two discrete bailer samples (#EC-5-050400-2 and #EC-5-050400-3) were obtained from depths of 1,980 and 2,370 ft below ground surface, respectively, at a pumping rate of approximately 160 gpm. The samples were obtained using a DRI logging truck and discrete bailer (see Section A.2.10.1 of Appendix A). On May 25, 2000, a composite groundwater characterization sample (#EC-5-052500-1) was collected from the wellhead sampling port directly into sample bottles. A constant production rate of 160 gpm was maintained during the sampling event. At the time of composite sampling, approximately 3.5×10^6 gallons of groundwater had been pumped from the well during development and testing activities (see Section A.2.10.2 of Appendix A). The results for these two samples have been tabulated and are presented in Table ATT.3-1, Table ATT.3-2, and Table ATT.3-3, Attachment 3, Appendix A.

Examination of Table ATT.3-1, Attachment 3, Appendix A reveals that an assessment of the groundwater chemistry for Well ER-EC-5 is difficult because almost all of the analytical results have been qualified in some form or another. For example, it can be seen that a significant number of the analytes were not detected at the given detection limits as indicated by the “U” qualifier. It can also be seen from the table that for both discrete bailer samples and the composite groundwater characterization sample all of the results in the "Metals" and "Inorganics" sections were estimated or rejected as indicated by either the "J" or "R" qualifiers, respectively. The "J" qualifier was assigned to all of the analytes because there was either no documentation that the samples were kept at the appropriate temperature or that the holding time was exceeded. The "R" qualifier was assigned to nondetects when the holding time for a given parameter was exceeded. There are, however, several qualitative observations that can be made from the data taking into account that the analytical results are estimated and cannot be relied upon to be completely accurate. The estimated values appear to be consistent with those of the other WPM-OV ER wells. It can be seen from the table that sodium and calcium are the predominate cations in all three groundwater characterization samples with minor amounts of potassium and magnesium. The table also reveals that bicarbonate, sulfate, and chloride are the predominate anions in the groundwater characterization samples with minor amounts of fluoride and bromide. It can also be seen from the table that all the groundwater characterization samples have a slightly basic pH that ranged from 8 to 8.3, and a total dissolved solids concentration that ranged from 260 to 270 milligrams per liter (mg/L).

Inspection of the "Age and Migration Parameters" section of Table ATT.3-1, Attachment 3, Appendix A for the composite groundwater sample reveals several interesting things. For example, the helium-3/helium-4 ($^3He/^4He$) ratio in Well ER-EC-5 groundwater ($R=1.50x10^{-6}$) is slightly greater than the atmospheric ratio ($R_a=1.38x10^{-6}$), giving a R/R_a value of 1.08. According to LLNL (2001), elevated R/R_a values are observed at a number of wells and springs in the Pahute Mesa-Oasis Valley flow system. Lawrence Livermore National Laboratory (LLNL) (2001) states that this suggests that deep gases or fluids are transmitted upward along deep faults throughout the region. They also state that the ^4He concentration in Well ER-EC-5 groundwater is elevated relative to the expected atmospheric helium solubility for this location. Elevated ^4He concentrations are derived from the *in situ* α-decay of naturally occurring radioactive elements in the host rock (LLNL, 2001). LLNL (2001) states that correcting the ^4He data for the presence of nonequilibrium "excess-air" (dissolved during recharge), and assuming a ^4He in-growth rate of $1.2x10^9$ atoms/year, the ^4He apparent age of the groundwater is approximately 3,000 years (LLNL, 2001). Further inspection of Table ATT.3-1, Attachment 3, Appendix A reveals that the carbon-14 (^{14}C) value of dissolved inorganic carbon (DIC) in Well ER-EC-5 groundwater is 6.3 percent modern, yielding an uncorrected ^{14}C age of 22,900 years. LLNL (2001) points out that this value is substantially greater than the ^4He apparent age, implying the DIC has reacted with ^{14}C-absent carbonate minerals in the aquifer. Lawrence Livermore National Laboratory (2001) states that the $\delta^{13}C$ value of the DIC suggests that Well ER-EC-5 groundwater has partially equilibrated with calcite occurring along fractures in the saturated volcanic aquifers. It can also be seen from the table that the chlorine-36/chlorine ($^{36}Cl/Cl$) ratio for Well ER-EC-5 groundwater is $6.53x10^{-13}$. LLNL (2001) states that this value is at the upper end of the range of previously reported values for Pahute Mesa-Oasis Valley volcanic aquifer groundwater, and may indicate limited mixing with a young, high $^{36}Cl/Cl$ groundwater.

Table ATT.3-2, Attachment 3, Appendix A presents the results of the colloid analyses for Well ER-EC-5. It can be seen from the table that both discrete bailer samples have relatively similar total colloid concentrations for colloids in the size range of 50 to 1,000 nanometers (nm). The table reveals that the total colloid concentrations for the discrete bailer samples ranged from 2.29×10^{7} particles per milliliter (particles/mL) to 3.31×10^{7} particles/mL. It can also be seen from Table ATT.3-2, Attachment 3, Appendix A that the composite groundwater characterization sample had a total colloid concentration of 2.01×10^{6} particles/mL, which is approximately an order of magnitude less than the total colloid concentrations of discrete bailer samples. Further inspection of the table for all three groundwater characterization samples reveals that the colloid concentrations decrease as the particle size increases. For the smaller sized ranges (up to approximately 200 nm), the colloid concentrations in each particle size range decrease at roughly the same rate for the two types of groundwater characterization samples. However, for the coarser size fractions (> 200 nm), the discrete bailer samples contain greater concentrations relative to the composite sample.

While the three groundwater characterization samples have relatively similar analytical results, differences can be seen taking into account the uncertain nature of the data in Table ATT.3-1, Attachment 3, Appendix A. For example, one potential discrepancy between the three groundwater characterization samples can be seen in the oxidation-reduction sensitive parameters: iron and manganese. Table ATT.3-1, Attachment 3, Appendix A indicates that the concentrations of iron and manganese in the discrete bailer samples are, at least, an order of magnitude higher in the total analyses than in the dissolved analyses. This may indicate that iron and manganese are predominantly present in the total phase rather than the dissolved phase for the discrete bailer samples. However, further inspection of the table reveals that the total and dissolved concentrations of iron and manganese in the composite groundwater sample are similar discounting the fact that the analytes were not detected at the given minimum detectable limit. This implies that the analytes in the composite groundwater sample are predominantly present in the dissolved phase. This discrepancy between the two types of characterization samples can likely be attributed to some type of sampling artifact. For example, it is possible that the bailer sampling procedure could introduce a coarser sized fraction of colloids composed of iron and manganese oxides to the discrete samples. This would result in a greater concentration of those elements in the total analyses that would be filtered out in the dissolved analyses. In addition, Fetter (1988) points out that sampling processes can create colloids in groundwater that were not originally present, such as the precipitation of colloidal iron due to oxygenation of water. The observed differences in colloid concentrations at Well ER-EC-5 could be an indication that analyte concentrations in groundwater are impacted by the sampling method. Variations in colloid concentrations could potentially affect both total and “dissolved” concentrations, because filtering typically removes only particles greater than 0.45 micrometers (450 nm) in size from the “dissolved” samples.

In general, the geochemical compositions of all three 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.

Lithologic logs for the well indicate that the completion intervals for this well are within the Ammonia Tanks Member of the Timber Mountain Tuff (Townsend, 2000).

4.1.2 Radionuclide Contaminants

Radionuclide contaminants were not detected in the samples from Well ER-EC-5.

4.1.3 Comparison of ER-EC-5 Groundwater Chemistry to Surrounding Wells

Table 4-1 presents groundwater chemistry data for Well ER-EC-5 and recently collected samples from wells and springs in close proximity to Well ER-EC-5. Note that the available data includes samples collected both with bailers and by pumping, in well that have been developed to varying degrees. Consequently, the representativeness of the water quality data is not uniform. 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-5 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 right corner of the cation triangle. For Well ER-EC-5, this assumes that the estimated values from the groundwater characterization samples are representative of the actual groundwater chemistry in that well. Further inspection of the anion triangle in Figure 4-1 reveals that Well ER-EC-5 and most of the wells and springs can 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 left corner of the anion triangle. Once again, it must be assumed for Well ER-EC-5 that the geochemical data are representative of the actual groundwater chemistry in the well. 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 interval (e.g., ER-OV-03a2). 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 the figure 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

Table 4-1
Groundwater Chemistry Data for Well ER-EC-5 and Surrounding Sites
(Page 1 of 2)

Analyte	ER-EC-5 Bailer at 1980' bgs		ER-EC-5 Bailer at 2370' bgs		ER-EC-5 Wellhead Composite		Coffer's Ranch, Windmill Well	Coffer Ranch Spring	ER-20-5 #1	ER-20-5 #3	ER-OV-01	ER-OV-02	ER-OV-03a	ER-OV-03a2	ER-OV-03a3	ER-OV-03c
	Total	Dissolved	Total	Dissolved	Total	Dissolved										
Metals (mg/L)																
Aluminum	UJ 0.091	UJ 0.038	UJ 0.12	UJ 0.051	UJ 0.065	UJ 0.054	0.0009	<0.00004	3.1	11	0.0512	0.003	0.0182	0.5011	0.0198	0.0113
Arsenic	J 0.0061	J 0.0088	J 0.0073	J 0.0078	J 0.0054	J 0.0074	0.00836	0.0064	0.042	B 0.0085	0.003	0.003	0.0031	0.0224	0.004	0.0149
Barium	J 0.0075	J 0.0053	J 0.015	UJ 0.013	J 0.0037	J 0.0038	0.00161	0.0098	< 0.01	B 0.0076	0.0026	0.0039	0.0113	0.0254	0.0079	0.0019
Cadmium	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	0.000019	< 0.000016		0.005	0.001	0.001	0.001	0.001	0.001	0.001
Calcium	J 21	J 21	J 22	J 19	J 20	J 20	19.3	21.8	7.18	3.14	5.7	13.6	13.8	5.7	12.7	14.4
Chromium	UJ 0.0021	UJ 0.00083	UJ 0.003	UJ 0.0017	UJ 0.00076	UJ 0.00081	0.00013	0.0008		0.0792	0.0015	0.0015	0.0044	0.0138	0.0013	0.001
Iron	J 2.8	UJ 0.045	J 0.88	UJ 0.055	UJ 0.042	UJ 0.064	0.1933		0.39	8.48	0.0036	0.0034	0.0026	0.0599	0.0045	0.0023
Lead	UJ 0.003	UJ 0.003	UJ 0.003	UJ 0.003	UJ 0.003	UJ 0.003	0.000274	0.000013	0.001	0.0206	0.002	0.002	0.002	0.0046	0.002	0.002
Lithium	J 0.11	J 0.11	J 0.11	J 0.11	J 0.11	J 0.11	0.12	0.166	0.09	0.0696	0.175	0.192	0.146		0.143	0.123
Magnesium	J 0.53	J 0.52	J 0.65	J 0.61	J 0.47	J 0.47	0.21	1.52	0.27	0.09	0.05	0.59	1.01	1.03	1.06	0.38
Manganese	J 0.048	J 0.0025	J 0.016	UJ 0.0013	UJ 0.0019	UJ 0.0018	0.0082	0.00034	0.02	0.305	0.0005	0.001	0.0008		0.0007	0.0005
Potassium	J 1.6	J 1.7	J 1.7	J 1.8	J 1.7	J 1.7	0.91	9.54	5.65	3	6.56	5.41	5.04	84.7	5.37	1.19
Selenium	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	0.00053	0.00057	< 0.01	< 0.005	0.00082	0.00079	0.00084	0.004	0.00082	0.00041
Silicon	J 20	J 20	J 21	J 21	J 19	J 20			38.4	41.7						
Silver	UJ 0.01	UJ 0.01	UJ 0.01	UJ 0.01	UJ 0.01	UJ 0.01	0.00002	< 0.00002		< 0.01	0.001	0.001	0.001	0.001	0.001	0.001
Sodium	J 74	J 74	J 74	J 74	J 73	J 73	72.2	176	105	73	142	146	121	331	124	81.9
Strontium	J 0.14	J 0.14	J 0.15	J 0.15	J 0.13	J 0.13	0.181	0.163	0.02	B 0.027	0.0047	0.0474	0.0752	0.167	0.0755	0.102
Uranium	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2	0.00586	0.0154	0.014	< 0.5	0.0085	0.018319	0.009114	0.0098	0.00795	0.004187
Mercury	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002			< 0.0002	0.00029	0.0002	0.0002	0.0002	0.0002	0.0002	0.0002
Inorganics (mg/L)																
Chloride	J 16		J 16		J 16		7.6	65.8	21.7	17.8	44.4	49.2	41.6	262	43.3	17.5
Flouride	J 4.6		J 4.5		J 4.7		3.29	3.32	10.1	3.16	2.04	2.34	2.29		2.14	4.55
Bromide	J 0.078		J 0.11		J 0.086		0.035	0.31	0.103	< 0.25	0.22	0.263	0.202		0.228	0.066
Sulfate	J 35		J 35		J 35		31	110	39	35.1	82	86	76	295	79	44
pH	J 8		J 8.3		J 8.1		8.43	7.13	8.6	8.8	8.54	8.29	8.48	9.08	8.5	8.38
Total dissolved solids	J 260		J 270		J 270		194	445	436	489	338	366	308	1100	320	218
Carbonate as CaCO3	R 10		R 10		UJ 10						1.7			41.6		
Bicarbonate as CaCO3	J 140		J 140		J 140		189	281.82	186	109	197	232	186	154	186	164
Age and Migration Parameters (pCi/L) - unless otherwise noted																
Carbon-13/12 (per mil)	N/A		N/A		-3.4 +/- 0.2		-3.4		-2.82	-5.75	-1.43	-2.17	-2.48	-4.7	-2.35	-2.9
Carbon-14, Inorganic (pmc)	N/A		N/A		6.3		9.6		81657	1346	5	16.2	16.3	21	16.5	6.8
Carbon-14, Inorganic age (years)*	N/A		N/A		22,900		19350				24,830	15,050	14,990	12,900	14,875	22,280
Chlorine-36	N/A		N/A		3.47E-04					0.01102						
Helium-3/4, measured value (ratio)	N/A		N/A		1.50E-06				0.157	0.001						
Helium-3/4, relative to air (ratio)	N/A		N/A		1.08		0.85		114000	723	1.13	1.51	1.1			0.88
Oxygen-18/16 (per mil)	N/A		N/A		-15.1 +/- 0.2		-14.2 +/- 0.2		-14.9	-15.1	-14.7 +/- 0.2	-14.6 +/- 0.2	-14.7 +/- 0.2	-14.5 +/- 0.2	-14.6 +/- 0.2	-14.7 +/- 0.2
Strontium-87/86 (ratio)	N/A		N/A		0.709124 +/- 0.000015		0.70922		0.71104 +/- 6E-5	0.70868 +/- 3E-5	0.71058	0.71006	0.71029	0.70809	0.71003	0.70924
Uranium-234/238 (ratio)	N/A		N/A		0.000351				0.000165	0.000158						
Hydrogen-2/1 (per mil)	N/A		N/A		-112 +/- 1		-104 +/- 1		-115	-113	-112 +/- 1	-112 +/- 1	-111 +/- 1	-109 +/- 1	-110 +/- 1	-109 +/- 1
Radiological Indicator Parameters-Level I (pCi/L)																
Tritium	U -30 +/- 160		U -10 +/- 170		U -60 +/- 160		0.47 +/- 0.86		60400000	142000	3.33 +/- 0.90					
Gross Alpha	5.7 +/- 2.5		6.8 +/- 2.7		U 5 +/- 3				C 23.7	37.3	14.7	27.5	14.5	19.8	17.9	10.7
Gross Beta	U 0.9 +/- 2.1		U 1.7 +/- 1.9		U -0.5 +/- 2.2				C 29.6	24.8	11.8	10.1	9.89	58.9	8.8	3.45
Radiological Indicator Parameters-Level II (pCi/L)																
Carbon-14	U -210 +/- 180		U -110 +/- 180		U -40 +/- 180				260	-3.8						
Strontium-90	N/A		N/A		U 0.03 +/- 0.13				0.5	0.43						
Plutonium-238	U -0.004 +/- 0.012		U 0.002 +/- 0.013		U -0.004 +/- 0.012				< 0.062	< 0.31						
Plutonium-239	U -0.004 +/- 0.012		U 0 +/- 0.011		U -0.003 +/- 0.012											
Iodine-129	N/A		N/A		U 0.52 +/- 0.67				<570	-0.6						
Technetium-99	N/A		N/A		U -0.2 +/- 1.8				< 1.88	< 5.17						

Table 4-1
Groundwater Chemistry Data for Well ER-EC-5 and Surrounding Sites
(Page 2 of 2)

Analyte	ER-OV-06a	GEXA Well #4	Goss Spring, 11S/47E-10bcc	Goss Spring, 11S/47E-10db	Goss Springs North, 11S/47E-10bad	PM-3	PM-3, 3019 feet	Rita Mullen Spring, 11S/47E-03cdb	U-20ao	U-20c	UE-18r	Unnamed Spring, 10S/47E-33aab	Unnamed Spring, 11S/47E-03cdb	Unnamed Spring, 11S/47E-10ccb	Unnamed Well, 10S/47E-27a1
Metals (mg/L)															
Aluminum	0.688		< 0.06		0.0033	0.03	< 0.01	0.0084		< 0.1	< 0.06	0.012	0.0124	0.014	
Arsenic	0.0085	0.014	0.012111		0.00752		0.004	0.00725			< 0.1				
Barium	0.0021	0.018	0.005		0.00497	0.004	0.002	0.00438			20	0.025	0.0082	0.0054	
Cadmium	0.001	< 0.01			< 0.0000163		< 0.001	< 0.000016							
Calcium	2.32	11	17.475	4.8	16.2	30.1	36	6.1	8.82	2.8	21.5	30	16	12	24
Chromium	0.0016	< 0.001			0.00132	0.01	0.002	0.00118							
Iron	0.0082	0.015	< 0.02		0.0073	0.24	0.06	0.003		0.03	< 0.02	0.018	0.0201	0.0089	
Lead	0.002	< 0.1	< 0.001		0.000007		< 0.005	0.000012			< 0.01				
Lithium	0.167		0.145	0.07	0.146	0.278		0.147		0.01	0.08		0.15	0.16	
Magnesium	0.72	0.34	1.29	5.3	1.14	0.79	1.5	1.05	1.24	< 0.1	0.92	4.6	1.1	0.9	2
Manganese	0.0024	0.01	< 0.01		0.0001	0.014	0.014	0.0004		< 0.01	< 0.03				
Potassium	7.7	3.1	5.073	13	4.79	10.9	10	4.95	1.9	1.4	3.49	9	4.8	4.6	
Selenium	0.004	< 0.001	< 0.01		0.0005		< 0.001	0.00049			< 0.01				
Silicon		48	23.54				63			42	21.6		47	50	
Silver	0.001	< 0.001			< 0.00001		< 0.001	< 0.00001							
Sodium	141	73	116.49	170	104	140	130	103	38	95	73.1	169	122	124	
Strontium	0.0105	0.03384	0.09		0.0916		0.081	0.0861		0.04	0.08	0.19	1	0.13	
Uranium	0.005237	0.0039	0.0095		0.00923			0.00949			0.0035				
Mercury	0.0002	< 0.0001					< 0.1								
Inorganics (mg/L)															
Chloride	47.5	14	45	65	42.4	93.5	98	42.5	3.2	8.1	6.9	68	45	45	66
Flouride	3.07	3	2.79	3.1	2.45	2.5	2.4	2.45		6.4	3	4.4	2.9	2.7	3.7
Bromide	0.224				0.16			0.183							
Sulfate	80.9	44	78.1	80	76	129	130	76	8.1	18	23	103	90	82	34
pH	8.4	7.9	7.73	7.1	8.35	8.73	7.9	8.2	8.14		8.05	7.8	7.7	8.1	8
Total dissolved solids	426	263.4615		150	306	441	555.6241	311		264	208		430	422	712
Carbonate as CaCO3	3														
Bicarbonate as CaCO3	196	154	181	290	186	159	150	186	114	130	227	296	188	185	288
Age and Migration Parameters (pCi/L) - unless otherwise noted															
Carbon-13/12 (per mil)	-1.8				-2.4			-2.39			-1.4	-4.91		-6.3	
Carbon-14, Inorganic (pmc)	6		20.75		21.8			18.2			6.7+/-0.06			27.6	
Carbon-14, Inorganic age (years)*	23,330				12,600			14,090							
Chlorine-36											0.0001342				
Helium-3/4, measured value (ratio)															
Helium-3/4, relative to air (ratio)	1.16				1.12						1.128+/-2				
Oxygen-18/16 (per mil)	-14.7 +/- 0.2		-14.7		-14.7 +/- 0.2			-14.7 +/- 0.2			-14.7	-14.02			
Strontium-87/86 (ratio)	0.70932	0.70974	0.7105		0.71039			0.71027			0.70909				
Uranium-234/238 (ratio)															
Hydrogen-2/1 (per mil)	-113 +/- 1		-111.7		-110 +/- 1			-111 +/- 1			-110	-108			
Radiological Indicator Parameters-Level I (pCi/L)															
Tritium	1.94 +/- 0.87					16		1			8 +/- 1.9				
Gross Alpha	9.74														
Gross Beta	7.46													6.6	
Radiological Indicator Parameters-Level II (pCi/L)															
Carbon-14															
Strontium-90															
Plutonium-238															
Plutonium-239															
Iodine-129															
Technetium-99											< 5				

B = Result less than the Practical Quantitation Limit but greater than or equal to the Instrument Detection Limit.

C = Lockheed Analytical Services radiological parameter qualifier - The minimum detectable activity exceeded the reporting detection limit due to residue forcing a volume reduction.

J = Estimated value

N/A = Not Applicable for that sample

pmc = Percent modern carbon

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

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

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

shows that the groundwater chemistry for Well ER-EC-5 is relatively similar to the surrounding wells and springs at least in terms of the major ionic constituents.

The groundwater chemistry data in Table 4-1 were also used to construct Figure 4-2. The figure shows the stable oxygen and hydrogen isotope compositions of groundwater for Well ER-EC-5 and for selected sites within twelve and a half miles of Well ER-EC-5. 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-5 and its' nearby neighbors. For example, it can be seen that the delta oxygen-18 ($\delta^{18}O$) values vary from approximately -13.5 per mil to approximately -15 per mil, while the delta deuterium (δD) values vary from approximately -105 per mil to approximately -115 per mil. In general, it can be seen from the figure that the wells and springs tend to plot isotopically lighter than the precipitation data suggesting little to no influence of modern atmospheric recharge. One possible explanation for the isotopically lighter groundwater of these wells is that the recharge areas for the groundwater in those wells 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). Because 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 the groundwater data. This tends to suggest that the isotopic shift in wells surrounding Well ER-EC-5 can likely be attributed to sublimation of snowpack or fractionation during infiltration.

4.2 Restoration of Natural Groundwater Quality

A primary purpose for well development was to restore the natural groundwater quality of the completion intervals so that any future groundwater samples taken from the well would accurately represent the water quality of the producing formations. The formations exposed in each completion interval had potentially been affected by drilling and completion operations as well as crossflow from other completion intervals occurring under the natural head gradient. Various aspects of the restoration of the natural groundwater quality will be discussed in this section.

4.2.1 Evaluation of Well Development

Water quality monitoring of the well discharge was conducted during pumping to provide information on water chemistry and to indicate when natural groundwater conditions predominate in the pumping discharge. The values of certain geochemical parameters (e.g., pH, turbidity, dissolved oxygen) were expected to decline and stabilize as development progressed, indicating restoration of natural groundwater quality as opposed to water affected by drilling and completion activities. The results from the water quality monitoring were examined in a previous report (see Section A.3.5 of Appendix A), but these groundwater characterization samples can also help to address the effectiveness of well development. For example, during drilling operations for Well ER-EC-5, the makeup water was tagged with a lithium bromide (LiBr) tracer to help determine such things as the water production during drilling. The makeup water was tagged with a LiBr concentration of approximately 5 mg/L to a little over 130 mg/L (see Section A.2.6.1 of 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. For example, if the groundwater characterization samples contained bromide concentrations of 20 mg/L after well development, it would tend to suggest that the well might still not be completely developed. It can be seen in Table 4-1 that all three groundwater characterization samples have relatively low bromide concentrations. For example, the table shows that the discrete bailer samples had estimated bromide concentrations of 0.078 and 0.11 mg/L, while the composite groundwater characterization sample had an estimated bromide concentration of 0.086 mg/L. It can also be seen from the table that the highest bromide concentration in the surrounding wells and springs was 0.31 mg/L for Coffer Ranch Spring. These estimated bromide concentrations are at least two orders of magnitude lower than the concentrations of bromide used during drilling and likely indicate that the well was sufficiently developed to restore groundwater quality back to its natural condition. This conclusion only pertains to the formations producing water during pumping.

4.2.2 Evaluation of Flow Between Completion Intervals

Well ER-EC-5 was drilled and completed in June and July of 1999 with three discrete completion intervals. In order to determine flow in the well under ambient, static conditions, thermal flow logging was conducted. The results from the thermal flow logging were addressed in a previous report (see Section A.2.11 of Appendix A), but, in general, indicated that groundwater flows under a natural downward vertical gradient from the upper completion intervals to the lowermost completion interval.

4.2.3 Source Formation(s) of Groundwater Samples

As discussed in Section 3.5.4, flow logging during pumping indicated that about 70 to 72 percent of the total production in the well originated from the middle completion interval (1,892 to 2,094 ft below ground surface). The upper completion interval contributed 17 to 18 percent of the remaining flow, and the lower completion interval contributed about 12 percent to the total flow. Preliminary lithologic and stratigraphic logs indicate that all of the completion intervals are located within the Ammonia Tanks Member of the Timber Mountain Tuff. As a result, it can be concluded that the groundwater for both discrete bailer samples and the composite groundwater characterization sample are derived from the same source, which was the Ammonia Tanks Member of the Timber Mountain Tuff.

4.3 Representativeness of Water Chemistry Results

During the development and testing program about 3.5 million gallons of water were produced from the well. Based on the flow logging, the distribution of production was about 0.63 million gallons from the upper completion interval, 2.45 million from the middle interval, and 0.42 million gallons from the lower interval. Based on the thermal flow logging measurements, 2.2+ gpm flows down the well from the upper interval and to the lower interval under the natural gradient. The thermal flow logging does not indicate any flow into or from the middle interval, but the measurements were all at the maximum range of the tool. During the 9.5 months between completion of the well and the start of testing, at least 0.9 million gallons of water would have entered the lower interval from the natural gradient flow. Only half this amount was removed during pumping, so the water quality results for the lower interval may reflect the source of this water, the upper interval. The data do not provide information on the natural gradient flow into or out of the middle interval, so the ratio of any inflow to the middle interval to the amount of water produced from that interval during pumping is not known. However, the amount produced from the middle interval was much greater than the known flow down the well.

The analytical results from the groundwater characterization samples support the conclusion that the origin of the groundwater for all of the samples, regarding chemical identity, was similar. Either all the groundwater was originally derived from only one completion interval or the groundwater came from multiple intervals in the same formation having the same or similar geochemistry. There are no major geochemical differences between the discrete bailer samples and the composite groundwater characterization sample, within the uncertainty of the data. In addition, there is no evidence of residual contamination from drilling and the groundwater can be considered to represent natural groundwater quality. Since all three completion intervals for this well are completed in the same formation, the characterization samples can be considered generally representative of the groundwater in the Ammonia Tanks Member of the Timber Mountain Tuff.

4.4 Use of ER-EC-5 for Future Monitoring

The flow logging indicates that all three completion intervals contributed water at the lowest pumping rate that flow logging was conducted, with almost 17 percent coming from the upper interval, almost 72 percent from the middle interval and almost 12 percent from the lower completion interval. The permanent sampling pump that was installed after testing has a maximum capacity of about 40 gpm, and the distribution of production should be approximately the same, with perhaps a slightly greater percentage from the middle interval. Sampling conducted with this pump should produce water that represents a composite water quality of all three completion intervals in the proportions of interval production. However, the same situation will apply to future sampling as was described concerning the origin of the groundwater characterization samples. The direction of natural-gradient flow in the well is downwards, with a measured flow of 2.2+ gpm from the upper completion interval to the lower completion interval(s). Consequently, the upper completion interval should not become contaminated with any foreign water between pumping episodes. However, the lower interval will be flooded with water from the upper interval during the periods when the well is not being pumped: a bridge plug was not installed in this well to prevent crossflow. It is not known if the middle interval may also be contributing or receiving water from natural gradient crossflow. Substantial purging would be required to produce water from the lower interval(s) that is actually representative of the water quality in the lower interval(s). This would require pumping a much greater amount of water than was pumped during development and testing. Consequently, groundwater samples collected with the sampling pump probably will only represent water quality in the upper completion interval.

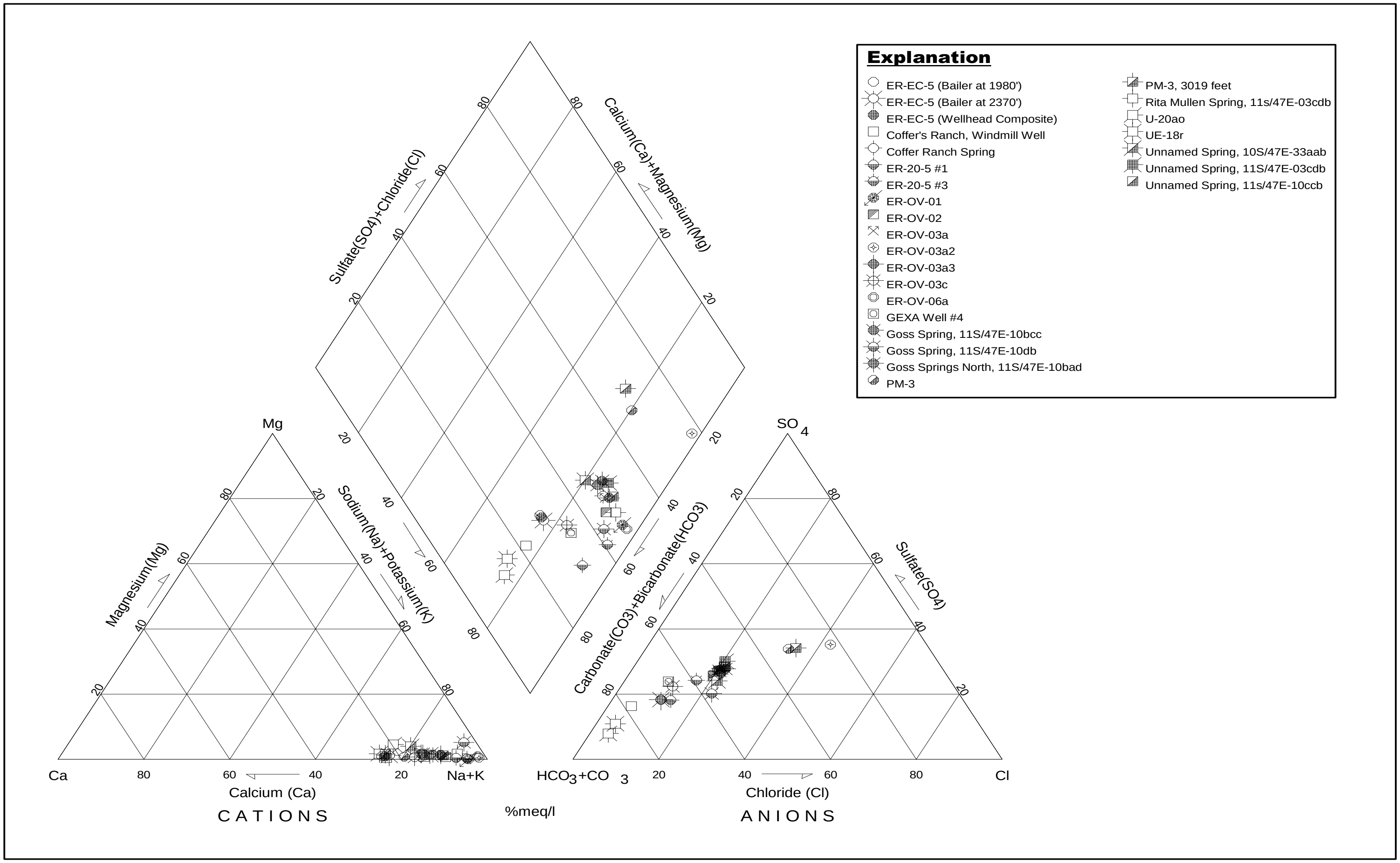

Figure 4-1
Piper Diagram Showing Relative Major Ion Percentages

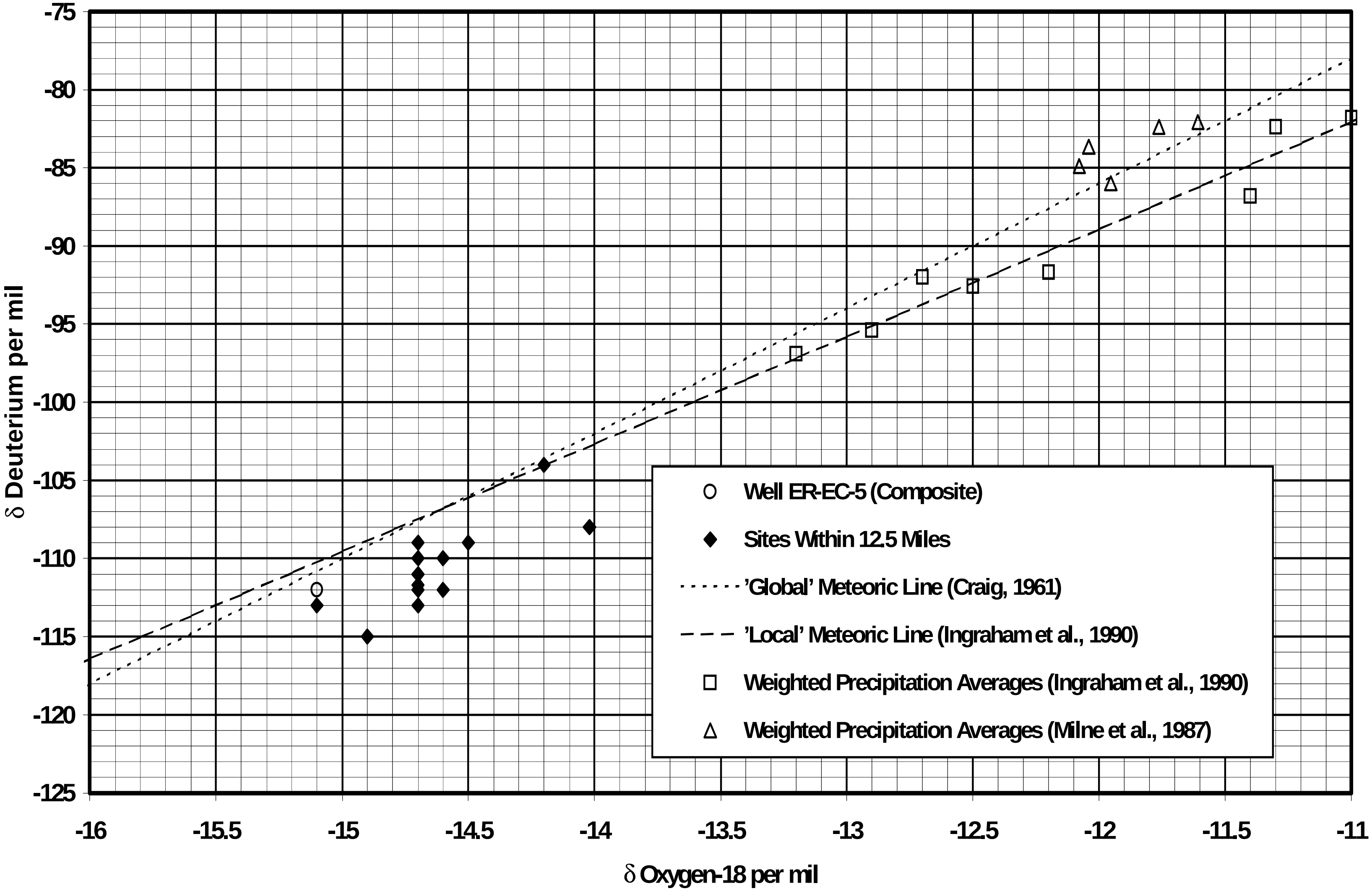

Figure 4-2
Stable Isotope Composition of Groundwater for Well ER-EC-5 and Nearby Sites

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Appendix A

Western Pahute Mesa - Oasis Valley Well ER-EC-5 Data Report for Development and Hydraulic Testing

A.1.0 Introduction

Well ER-EC-5 is one of seven groundwater wells that were completed as part of FY 1999 activities for the NNSA/NV UGTA Project. Figure A.1-1 shows the location of the WPM-OV wells. Hydraulic testing and groundwater sampling were conducted at Well ER-EC-5 to provide information on the hydraulic characteristics of HSUs and the chemistry of local groundwater. Well ER-EC-5 is constructed with three completion intervals, intervals of slotted casing with gravel-pack, separated by blank casing sections with cement seals in the annular space. The three completion intervals are separated by distances of about 494 ft (upper to middle completion interval) and 151 ft (middle to lower completion interval), all within the welded tuff aquifer of the Ammonia Tanks Tuff.

This document presents the data collected during well development and hydraulic testing for Well ER-EC-5 and the analytic results of groundwater samples taken during this testing.

The objectives of the development and testing program were:

1. Increase the hydraulic efficiency of the well.

2. Restore the natural groundwater quality.

3. Determine the hydraulic parameters of the formations penetrated.

4. Collect discrete samples from discrete locations and/or specific completion intervals to characterize spatial variability in downhole chemistry.

5. Collect groundwater characterization samples to evaluate composite chemistry.

Well ER-EC-5 was the fifth of the WPM-OV wells to be developed and tested. Activities began February 7, 2000, and were completed by June 14, 2000. A variety of testing activities were conducted including discrete head measurements for each completion interval, flow logging under ambient conditions and during pumping, a constant-rate pumping test, water quality parameter monitoring, and groundwater sampling of individual producing intervals and of the composite discharge.

A.1.1 Well ER-EC-5 Specifications

The drilling and completion specifications of Well ER-EC-5 were obtained from a draft of the *Completion Report for Well ER-EC-5* (Townsend, 2000). This report also contains the contains the lithologic and stratigraphic interpretation for this well. The schematic well construction is illustrated in various figures in this report which show logging information.

A.1.2 Development and Testing Plan

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

The testing program was structured to assess the hydrology and groundwater quality of formation accessed by the well completion. The elements of the testing can be found in *Well Development and Hydraulic Testing Plan for Western Pahute Mesa - Oasis Valley Wells*, Rev. 0, November 1999 (WDHTP) (IT, 1999d) and associated technical change records.

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

A.1.3 Schedule

The generic schedule developed for the Well ER-EC-5 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 and flow logging (estimated 7 days).

4. Water level recovery (estimated 5 days).

5. Constant-rate pumping test and discrete and groundwater characterization sampling (estimated 10 days).

6. Water level recovery (estimated 5 days).

7. Removal of downhole equipment and water level measurement (estimated 1 day).

8. Thermal flow logging and discrete sampling (estimated 2 days).

9. Installation of dedicated sampling pump and possible groundwater characterization sampling (estimated 4 days).

A brief history of the testing program at Well ER-EC-5 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. There were several delays related to fitting the pumping system with a back-pressure valve, generator failures, and check valve leaks.

A.1.4 Governing Documents

Several documents govern the field activities presented in this document. The document describing the overall plan is the WDHTP (IT, 1999d). The implementation of the testing plan is covered in *Field Instruction for Western Pahute Mesa - Oasis Valley Well Development and Hydraulic Testing Operations*, Rev. 0, December 1999 (FI) (IT, 1999b), as modified by Technical Change No. 1, 12/22/1999. This document calls out a variety of Detailed Operating Procedures (DOPs) (IT, 1999a) and Standard Quality Practices (SQPs) (IT, 2000), specifying how certain activities are to be conducted. The work was carried out under the *Site-Specific Health and Safety Plan for Development, Testing, and Sampling of Clean Wells, 1999* (IT, 1999c). Specifications for the handling and analyses of groundwater samples are listed in the Underground Test Area Quality Assurance Project Plan, Rev. 2 (DOE/NV, 1998).

A.1.5 Document Organization

This data report is organized in the following manner:

- Section A.1.0: Introduction

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

Table A.1-1
Brief History of Work Performed at ER-EC-5

Activity	Start Date	Finish Date	Duration (days)
Interval-specific head measurements (bridge plugs)	2/7/2000	2/15/2000	9
Site mobilization	4/13/2000	4/18/2000	6
Install access line and testing pump	4/17/2000	4/19/2000	3
Install back-pressure system and discharge plumbing	4/20/2000	4/20/2000	1
Check pump functionality and back-pressure system	4/20/2000	4/25/2000	6
Develop well and conduct step-drawdown testing	4/26/2000	5/3/2000	8
Flow logging (impeller flowmeter) while pumping	5/3/2000	5/4/2000	2
Discrete downhole sampling	5/4/2000	5/4/2000	1
Install check valve, shutdown pump and monitor for recovery and pretest	5/5/2000	5/15/2000	11
Constant-rate test	5/15/2000	5/25/2000	11
Composite wellhead sampling	5/25/2000	5/25/2000	1
Monitor recovery	5/25/2000	5/30/2000	6
Remove access line and testing pump	6/6/2000	6/7/2000	2
Flow logging (thermal flowmeter) under ambient conditions	6/7/0200	6/7/2000	1
Install sampling pump and test for functionality	6/8/2000	6/9/2000	2
Demobilize from site	6/9/2000	6/14/2000	6

test, water quality monitoring, groundwater sampling, thermal-flow logging and ChemTool logging.

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

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

- Section A.5.0: References.

- Attachment 1: Manufacturer’s Pump Specifications.

- Attachment 2: Water Quality Monitoring - Grab Sample Results. This appendix shows the field laboratory results for temperature, electrical conductivity (EC), pH, dissolved oxygen (DO), turbidity, and bromide in relation to date/time and gallons pumped.

- Attachment 3: Water Quality Analyses - Composite Characterization Sample and Discrete Samples.
- Attachment 4: Fluid Management Plan Waiver for WPM-OV Wells.
- Attachment 5: Electronic Data Files Readme.txt. This attachment contains the readme file text included with the electronic data files to explain the raw data files included on the accompanying Compact Disc (CD).

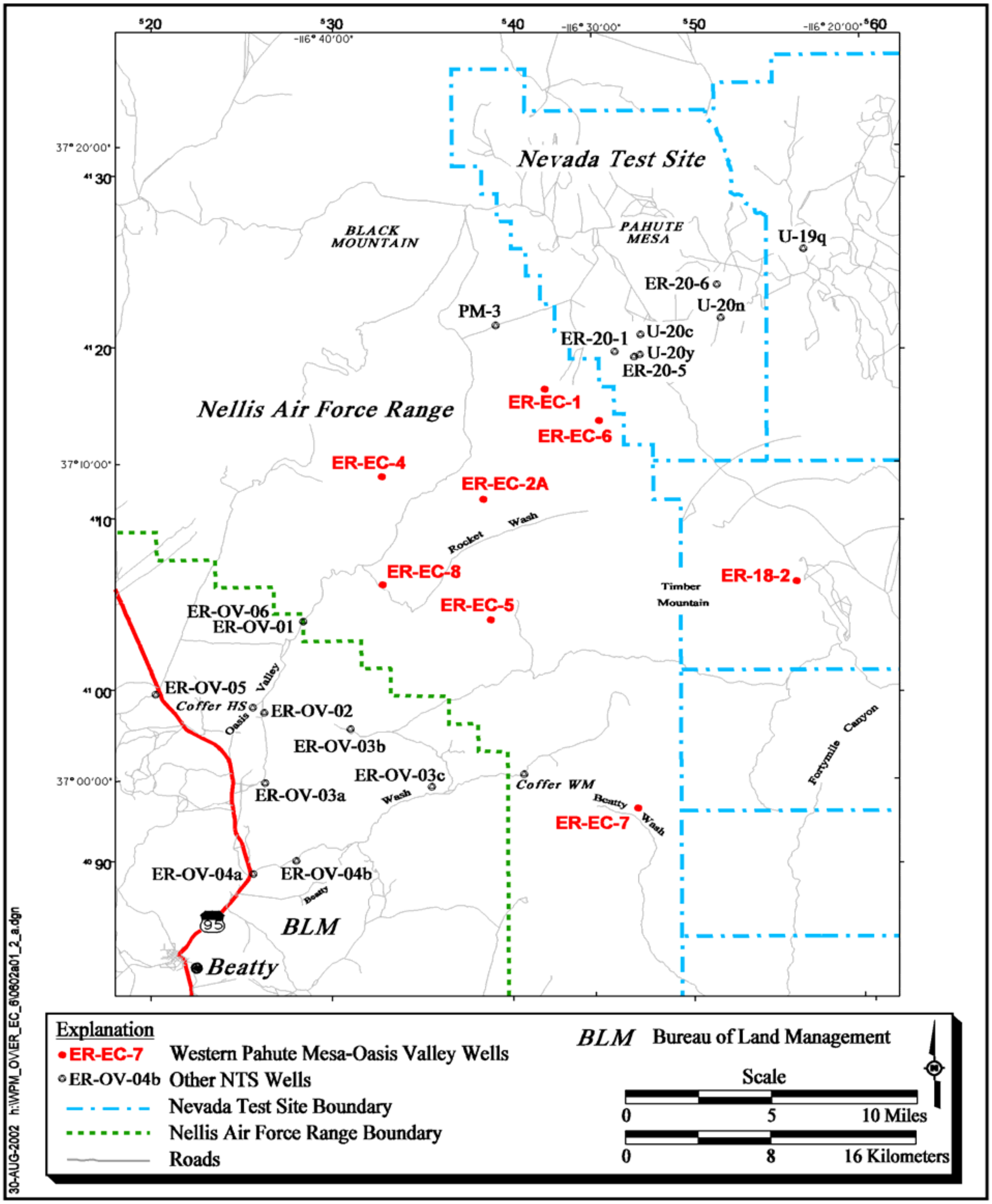


Figure A.1-1
Area Location Map

A.2.0 Summary of Development and Testing

This section presents details of the well development and testing activities, the associated data collection activities, and summaries and depictions of the unprocessed data that were collected. The detailed history of Well ER-EC-5 development and testing is shown in Table A.2-1.

A.2.1 Water Level Measurement Equipment

Following is a general description of the equipment used by IT Corporation, Las Vegas (ITLV), for measurements and monitoring during development and testing. Other equipment used for specific parts of the program are described in the appropriate section. Depth-to-water measurements were made with a metric Solinst e-tape equipped with either a conductivity sensor or a float switch. The PXDs were Design Analysis 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. 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 PTA 427A Barometer housed with the datalogger. All equipment was in calibration.

A.2.1.1 Data Presentation

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

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

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

Date	Activities
8/18/1999	ITLV installs 0-15 psig PXD for predevelopment water level monitoring.
10/7/1999	ITLV removes PXD.
2/7/2000	Baker Hughes runs basket and gauge to 2,250 ft bgs without problem. ITLV measures water level at 1,017.50 ft bgs. Baker Hughes then installs lower bridge plug/PXD at 2,150 ft bgs. ITLV measures subsequent water level at 1,017.54 ft bgs. Baker Hughes then installs upper bridge plug/PXD at 1,789 ft bgs. ITLV measures subsequent water level at 1,017.39 ft bgs. ITLV then installs 0-15 psig PXD.
2/15/2000	ITLV removes PXD and measures water level at 1,017.24 ft bgs. Baker Hughes removes upper bridge plug/PXD and lower bridge plug/PXD.
4/14/2000	Begin mobilization of drill rig to the site.
4/17/2000	Drill rig is set up and 2 3/8-in. access line is run to a depth of 1,110.06 ft bgs. Testing pump is assembled and readied for installation.
4/18/2000	Waiting on tubing to run pump downhole.
4/19/2000	Wire pump and install pump. Bottom of pump assembly is landed at 1,100.03 ft bgs, placing intake at 1,053.25 ft bgs.
4/20/2000	ITLV measures water level at 1,016.45 ft bgs, and installs PXD for hydraulic response monitoring. The back-pressure system and discharge plumbing are installed. The pump is started for functionality testing, but the VSD cannot maintain stability at specific frequency (Hertz) settings. Centrilift will repair VSD.
4/24/2000	Pump is started, back-pressure system is tested and modified. VSD settings adjusted in Modes 1 and 2.
4/25/2000	The pump is started and stopped repeatedly to test VSD. During pumping, calibrate gpm versus Hertz. Troubleshoot problems with the VSD frequency control and the generators.
4/26/2000	Additional pumping and troubleshooting of VSD control problems. Begin well development. Pumping continues overnight.
4/28/2000	Pumping discontinued due to failure of surface pressure gauge. On standby waiting for replacement pressure gauge.
4/30/2000	Resume pumping and conduct step-drawdown protocol. Pump overnight.
5/1/2000	Pump turned on and off for surging. Pump overnight.
5/2/2000	Conduct step-drawdown protocol. Troubleshoot generator problem. Pump overnight.
5/3/2000	ITLV removes PXD. DRI conducts flow logging during pumping. Pump overnight.
5/4/2000	DRI completes flow logging and collects downhole discrete samples. Samples collected at 1,980 ft bgs and at 2,370 ft bgs. Pump is stopped and check valve is installed. Pump is started to test check valve; valve comes loose from “R” nipple. Pump is stopped, and check valve is reset. Pump is started to fill production tubing and then stopped. Check valve does not hold.
5/5/2000	DRI reseats and tests check valve several times. Check valve still leaking at end of day. Pumping discontinued.
5/8/2000	BN works on generators. One overheats and radiator will be removed for service. Brief pumping period for testing.
5/9/2000	BN filters diesel fuel stored on site in tanker to remove debris in fuel.
5/10/2000	DRI retrieves check valve and installs new seals. Check valve is reset twice, and appears to hold the second time.
5/11/2000	ITLV measures water level at 1,016.55 ft bgs. ITLV then sets 0-15 psig PXD.
5/11-15/2000	Monitor water level for pretest conditions.
5/15-25/2000	Start constant-rate test, pumping at 160 gpm. Back pressure set to 275 psig.
5/18/2000	Pump shut down for 40 seconds to change generator supplying power.
5/19/2000	Spill of diesel from inactive generator contained and cleaned up.
5/25/2000	Groundwater characterization sampling by ITLV, LLNL, DRI, and UNLV-HRC. Pump shut down at 15:03.
5/25-30/2000	Monitor recovery.
5/30/2000	ITLV removes PXD. DRI removes check valve.
6/6/2000	BN removes access line and begins to remove testing pump.
6/7/2000	BN removes testing pump. DRI runs ChemTool and makes thermal flow log measurements at ten locations.
6/8/2000	BN installs permanent sampling pump.

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

Date	Activities
6/9/2000	BN and ITLV test function of the permanent sampling pump.
6/9-14/2000	Demobilize equipment from site.

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

processed to various forms of head, with or without barometric correction. The required additional data to process the data into any desired form 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.3.1, 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/pounds per square inch). This is a convenient form for use in calculations. Later in the text, the derived densities are discussed in terms of specific gravity.

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

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

A.2.2 Predevelopment Water Level Monitoring

Following completion of Well ER-EC-5, the water level in this well was monitored with a PXD and datalogger for a period of almost eight 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 ER-EC-5 Water Level Monitoring.xls.

A.2.3 Depth-to-Water Measurements

A series of depth-to-water measurements were made in Well ER-EC-5 as part of the various testing activities. Table A.2-2 presents all of the equilibrium, composite water level measurements made during the testing program. Measurements representing nonequilibrium or noncomposite water levels are presented in the appropriate section for the testing activity involved.

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

Date	Time	Depth-to-Water bgs		Barometric Pressure (mbar)
		Feet	Meters	
8/19/1999	18:34	1,016.80	309.92	845.54
10/8/1999	14:31	1,017.00	309.98	848.78
4/20/2000	07:30	1,016.74	309.90	847.47
5/11/2000	09:22	1,016.85	309.94	843.37
5/30/2000	16:16	1,016.86	309.94	838.24

bgs - Below ground surface
mbar - Millibars

A.2.4 Interval-Specific Head Measurements

The representative hydraulic head of the individual completion intervals were measured to provide information on the vertical hydraulic gradients. This was accomplished by isolating the completion intervals from each other with bridge plugs and measuring the pressure or head in each interval. The bridge plugs contained pressure transducers and dataloggers to measure and record the pressure in the interval below the bridge plug. The head in the uppermost interval was monitored using a PXD installed on a wireline. After removal of the PXD, corresponding water levels were measured with an e-tape. The bridge plugs remained in their downhole stations for five days to monitor pressure changes in the intervals.

A.2.4.1 Bridge Plug Installation and Removal

The procedure for installing the bridge plugs included:

1. Run gauge and basket to 2,250 ft bgs to verify that bridge plugs would fit through casing.

2. Measure the static water level to establish the reference head (head is assumed to be in equilibrium).

3. Run lower bridge plug to set-depth minus 50 ft and collect four or more pressure readings (bridge plug <u>not</u> set).

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

5. Raise bridge plug to set-depth, collect four or more pressure readings, then set bridge plug to isolate lower completion interval. Record 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 record head change in uppermost interval.

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

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

A.2.4.2 Pressure/Head Measurements

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

Table A.2-3 shows the interval-specific pressure and head measurements, including the calibration data. Graphs of the interval monitoring are included in Section A.3.0. Note that the corrected depths for the bridge plug are slightly different from the PXD set depths that had been specified and listed in the morning reports. The set depths were located by keying off of casing collars, and the calibration of the wireline depth measurement was used to correct the set depths. The adjustment of the set depths does not affect the data analysis. The location corrections are discussed in Section A.3.1.1. The datalogger files for the pressure transducers can be found on the enclosed CD, labeled as follows: gradient.xls (upper interval), EREC5U.xls (middle interval), and EREC5L.xls (lower interval). A readme text file is included in Attachment 5, which explains how the data may be accessed.

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 (#01F83185 and #01F83184) with 43 stages each, and a 130 horsepower (hp)

Table A.2-3
Interval-Specific Head Measurements

Interval	Comment	Depth ft bgs	Depth m bgs	PXD Measurement psig
Upper	Final Head	1,017.24 (e-tape)	310.05	--
Middle	Reference Head - composite of upper two intervals	1,017.54 (e-tape)	310.15	331.95
	Bridge Plug set depth minus 50 ft	1,738.90	530.02	310.53
	Bridge Plug set depth - post set	1,788.28	545.07	332.00
	Bridge Plug set depth plus 50 ft	1,837.75	560.15	353.24
Lower	Reference Head - composite of all three intervals	1,017.50 (e-tape)	310.13	488.22
	Bridge Plug set depth minus 50 ft	2,099.78	640.01	466.74
	Bridge Plug set depth - post set	2,149.16	655.06	488.22
	Bridge Plug set depth plus 50 ft	2,198.64	670.15	509.53

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

motor (375 Series, 2 sections - #21D47843 and #21D47849). 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 1,100.03 ft bgs, which placed the pump intake at 1,053.25 ft bgs.

An Electra Speed 2250-VT Variable Speed Drive (VSD) was used to regulate the production of the pump. To maintain a constant production rate for testing, the transmitter of the Foxboro 1.5-in. magnetic flowmeter was connected to the VSD in a feedback loop to supply the VSD with continuous flowrate information. The VSD automatically adjusts the frequency of the power supplied to the pump to maintain a constant production rate. The flowmeter record shows that this worked very well and a constant production rate could be maintained as drawdown progressed.

A.2.5.2 Pump Performance

Pump performance is indicated by the records as shown in Table A.2-4. These production rates are in line with performance projections supplied by the manufacturer for this pump with similar pumping parameters. The pump was operated with an additional backpressure of 275 psig imposed at the surface to meet the operational requirements of the pump. Because this well exhibited an initial quick drawdown to a quasi-stable level, the drawdown values in Table A.2-4 approximately represent characteristic drawdowns. This information indicates the range of drawdowns experienced during development and testing.

Table A.2-4
Pump Performance

Date	Time	VSD Setting (Hz)	Production Rate (gpm)	Approximate Drawdown[a] (ft)
4/25/2000	11:36	55	72	N/A
4/25/2000	12:23	58.4	140	N/A
4/25/2000	13:10	60	152	N/A
4/26/2000	12:40	54.3	60.6	1.39
4/26/2000	15:43	59.7	147	5.22
4/27/2000	11:55	55.8	60.49	1.19
4/27/2000	14:50	63.8	160.27	5.84
4/30/2000	7:40	54.2	60.37	1.43
4/30/2000	9:46	56.5	100.44	2.93
4/30/2000	16:44	63.8	160.24	5.38
5/01/2000	12:30	63.7	160.16	5.77
5/02/2000	10:30	54.3	60.37	1.38
5/02/2000	12:40	56.8	100.14	2.79
5/02/2000	18:50	63.5	160.93	5.64
5/03/2000	7:19	62.9	160.66	5.65
5/03/2000	19:12	57.3	110.86	N/A

Note: Significant figures reported as recorded from field documents.

[a]Drawdown derived from PXD pressure data using a density of 2.307 ft/psi.

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

The data in Table A.2-4 shows that there was an apparent small reduction in the well drawdown at the same production rates during the course of development. No significant changes were observed. Three flow rates were selected for the steps to be used in development activities: 60, 110, and 160 gpm. In practice there may be small variations in actual pumping rates that result from variable 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 left over 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 intended to accomplish hydraulic development in preparation for hydraulic testing.

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

Restoration of natural groundwater quality is mostly a function of the total volume of water produced. Discrete sampling for groundwater characterization was scheduled at the end of the development stage, which provided the maximum development possible before downhole sampling without interfering with the constant-rate test. An evaluation of the status of development at the time of sampling is presented in Section A.3.6.

The history of the development phase for Well ER-EC-5 is shown in Table A.2-1. The generic plan allowed seven days for this phase, but additional time was required to sort out problems with the pump and to adjust the schedule to fit into the overall work scheme for UGTA field activities.

A.2.6.1 Methodology and Evaluation

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

Monitoring during development included hydraulic performance data and a variety of general water quality parameters intended to evaluate both the effectiveness of the development activities and the status of development. These parameters included drawdown associated with different production rates (to evaluate improvement in well efficiency), visual observation of sediment production and turbidity (to evaluate removal of sediment), and water quality parameters (temperature, pH, electrical conductivity [EC], turbidity, dissolved oxygen [DO], and bromide [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 5 mg/L to over 130 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. The amount of drawdown in Well ER-EC-5 was unexpectedly small. The 0-50 psig PXD initially installed was found to have an unnecessarily large range and was replaced with a 0-15 psig PXD for the constant-rate test. Information on the 0-50 psig PXD installation and calibration is presented in Table A.2-5.

The method of installing these PXDs does not provide a direct measurement of the total depth of the PXD. The uncertainty in the total measured depth is due to uncertainty in the hanging length of the PXD vent cable, which is difficult to measure accurately. Therefore, the installation depth is calculated from the depth-to-water and calibration measurements made during installation. The pressure reading of the PXD at the installation depth is multiplied by the water density conversion factor to give the depth below the static water level, which is then added to the measured depth-to-water level. The water density conversion factor is determined from the calibration measurements. Note that the Cal 1 PXD psig value was a measurement in air above the water surface, and is not used for the water density calculation.

The well was pumped for a total time of about six 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 used several times to assess well and pump performance. Water quality was monitored using both field laboratory

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

Design Analysis H-310 PXD SN 2268, 0-50 psig					
Install Date: 4/20/2000					
Installation Calibration Data: 4/20/2000					
Static water level depth 1,016.74 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
WRL/TOC[a]	800.00	825.00	850.00	875.00	900.00
PXD psig	-0.0045	9.9745	20.637	31.285	41.922
Delta depth (ft): Cal5 - Cal2					75.00
Delta psi: Cal5 - Cal2					31.9475
Density ft of water column/psi: delta depth / delta psi (in ft/psi)					2.3476
Equivalent ft water: PXD psig (at Cal 5) x density of water (ft/psi)					98.42
Calculated PXD installation depth: static water level + equiv. ft water					1,115.16

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

bgs - Below ground surface
PXD - Pressure transducer
psi - Pounds per square inch
psig - Pounds per square inch gauge
ft - Foot (feet)

grab sample testing and with an in-line Hydrolab® cell with instrumentation recorded by a datalogger.

A.2.6.2.1 Pumping Rates and Hydraulic Response

Figure A.2-2 shows the datalogger record of the pumping rate and hydraulic response during the development phase. Figure A.2-3 shows the datalogger record of the hydraulic response and barometric pressure. An electronic file of these data can be found on the attached CD with the file name EC-5_AQTEST_WD.xls. The first five days of the data record (April 20 to 24) show no activity while the VSD was being repaired. The next several days (April 25 and 26) show the initial testing of the pump/VSD to determine the operating range of the pump (see Table A.2-4) and resultant drawdown. The pump was generally operated at a rate of about 160 gpm for the remainder of the development phase. This production rate was close to the maximum pumping rate. Maximum drawdown during pumping was on the order of 6 ft. The barometric record shows that the barometric pressure was proportionately constant relative to the PXD pressure. The stress that could be applied to the completions for development was limited by the production capacity of the pump.

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. When the pump was restarted, sufficient water had to be pumped to fill the tubing and surface hose before production would register at the flowmeter. This produces a lag time of approximately 2 minutes between the start of a drawdown response and the start of the flowmeter readings. Also note the brief surge that registered with the flowmeter just after the pump was started. This is probably residual water from development remaining in a low spot of the surface hose that was pushed through the flowmeter by air compressed ahead of the rising water column.

Second, because there was little head on top of the pump at startup, the initial pumping rate was much higher than the rate when the final, stable total dynamic head (TDH) was reached. The pumping rate decreased as the TDH increased until the discharge system was filled and TDH stabilized. This phenomenon is illustrated in Figure A.2-4. Dividing the volume of the discharge system by the time lag for production to reach the surface gives a production rate much greater than the VSD setting would produce under stable pumping conditions. As a result of this situation, the initial drawdown (both the rate of drawdown and the magnitude) was much greater until the stable pumping rate was reached. 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, at ER-EC-5 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.

Also, to avoid problems from the initial production of sediment each time the pump is started during development, the initial production is bypassed around the flowmeter and Hydrolab®. Consequently, there is a delay before flowrate is registered and recorded. If the pump were to be turned on directly in Mode 2, the VSD would accelerate the pump until the flowmeter reading equals the pumping rate setting. However, since the feedback from the flowmeter is zero until production reaches the flowmeter, the VSD would initially accelerate to the upper clamp setting, usually set at the maximum pumping rate. This would result in correspondingly high pumping rates and drawdown until the flowmeter returned accurate pumping rate information. The VSD would then de-accelerate 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 that 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.

A.2.6.2.2 Surging and Step-Drawdown Protocol

Figure A.2-2 and Figure A.2-3 show each instance when the pump was stopped, and also the step-drawdown protocol that was conducted several times. Stopping the pump produced a surging effect in the well which can be seen very clearly in Figure A.2-5. This figure shows a representative instance of surging expanded to illustrate the detail. When the pump is stopped, the water in the production casing backflows through the pump into the well, raising the water level in the well. This is referred to as the “U-tube” effect. The water level in the well casing temporarily rises above the instantaneous head in the formation around the completion because the rate of backflow down the casing is faster than the rate the water is injected into the formation under the instantaneous head differential. This action produces a reverse head differential which “surges” the well. The reverse flow may simply speed the apparent recovery of the well or result in a rise above the equilibrium water level, followed by a decline to the equilibrium head. The surge rapidly dissipates, merging into the recovery curve. This effect was substantial in this well. The “U-tube” effect resulted in a rise in the water level in the well of approximately 4 feet above the equilibrium water level.

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.

For the step drawdown protocol, the pump was run for a certain period of time at each of three progressively higher rates (60, 110, and 161 gpm), producing drawdowns of 1.4, 2.8, and 5.8 feet. Drawdowns at the end of each pumping period could then be compared to evaluate the well performance and any improvement in hydraulic efficiency since the last time the protocol was run. Figure A.2-6 shows a representative closeup of the step-drawdown protocol. The same rates were used for flow logging. The performance of this well showed a small improvement during development. The erratic data at the beginning of the step-drawdown test was due to the need to reset the VSD Hz clamps to accommodate the rate for the initial step of the test.

A.2.6.2.3 Other Observations

During development, visual observations were made of the water discharge, primarily whenever the pump was started, to monitor the amount of sediment produced. Logbook entries indicated that there was initial reddish-brown turbidity in the water for several seconds each time the pump was started, after which the water cleared.

A.2.7 Flow Logging During Pumping

Downhole flow logging was conducted after the development phase. Data on the proportional in-flow of water from different completion intervals would be used for tuning the production rate used for 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 Well ER-EC-5 that are completed across a great vertical range with multiple completion intervals in different formations. The flow logging directly measured the amount and location of incremental water production downhole.

A.2.7.1 Methodology

The information on water production from each completion interval was collected at different pumping rates to evaluate the linearity of effects for use in later interpretation. The same rates were used for the step-drawdown protocol during development (60, 110 and 161 gpm) so that results could be directly compared with previous observations.

Flow logging was conducted by the DRI from May 3 to May 4, 2000. A complete program of flow logging was run, including both stationary measurements and trolling logs. A temperature log was also recorded in combination with the flow logging to help in identifying production patterns and specific production locations. Logging runs at three different speeds and in both directions were run to evaluate flow under all test conditions. All the trolling log runs were successful except the first one, ec5mov1, the results of which were not provided by DRI.

A.2.7.1.1 Equipment and Calibration

The DRI flow-logging system consists of, from top to bottom (all Flexstak equipment): telemetry cartridge, a centralizer, a temperature tool, another centralizer, and a fullbore flowmeter. All logging tools and the data acquisition system are manufactured by Computalog. This tool string has a maximum diameter of 1 1/16-in., is temperature rated to 176 degrees Celsius (°C), and pressure rated to 17,000 psi. The fullbore flowmeter needs a minimum of 5-15 fpm to activate the impeller. This minimum flow past the impeller, known at the stall speed, can vary depending upon the condition of the impeller/flowmeter.

The fullbore flowmeter has a collapsible impeller that opens to cover a much larger percentage of the casing cross section than a standard fixed-blade impeller. Centralizers are run in conjunction with the sensor tools to center the tool string in the wellbore. The temperature tool is run to provide gradient and differential temperature information with high resolution. In conjunction with information from the spinner tool, the temperature tool yields information useful in fluid flow analysis.

Calibration is completed by comparing the raw flowmeter readings of counts-per-second to known velocities. Low flow-rate calibration data are obtained from a DRI calibration facility which can produce 0 to 60 gpm flow through 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

Eight trolling flow logs were run 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 1,140 to 2,400 ft bgs. The logging runs were made in the following order: (1) stationary flow measurements conducted while going down, (2) an up run at 40 fpm, (3) a down run at 20 fpm, and (4) an up run at 60 fpm. This four-step sequence was repeated for each of three discharge rates, 60, 111, and 161 gpm. Stationary flow measurements (tool held motionless in the well) were taken at the following locations: above the upper completion interval (1,164.7 - 1,177.3 ft bgs), between the upper and the middle completion intervals (1,538.6 - 1,551.0 ft bgs), and between the middle and the lower completion intervals (2,158.6 - 2,244.7 ft bgs). Table A.2-6 lists the trolling flow logs that were run. Stationary measurements are listed in Table A.2-7.

Table A.2-6
Listing of Trolling Flow Logs

Run Number	Date of Run	Direction of Run	Run Speed (fpm)	Surface Discharge (gpm)	Run Start/Finish (ft bgs)
ec5mov2	5/3/2000	Down	20	60	1,174 - 2,415
ec5mov3	5/3/2000	Up	60	60	2,419 - 1,174
ec5mov4	5/3/2000	Up	40	111	2,419 - 1,141
ec5mov5	5/3/2000	Down	20	111	1,145 - 2,415
ec5mov6	5/3/2000	Up	60	111	2,419 - 979
ec5mov7	5/4/2000	Up	40	161	2,419 - 1,136
ec5mov8	5/4/2000	Down	20	161	1,140 - 2,419
ec5mov9	5/4/2000	Up	60	161	2,422 - 1,139

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 (gpm)
ec5stat1	Above upper CZ	80.7	60	1,176.8	60.7
ec5stat2	Between upper and middle CZ	81.0		1,550.8	51.6
ec5stat3	Between middle and lower CZ	81.1		2,244.7	0
ec5stat4	Above upper CZ	80.7	111	1,177.3	111.4
ec5stat5	Between upper and middle CZ	81.0		1,551.0	91
ec5stat6	Between middle and lower CZ	81.1		2,171.5	0.26
ec5stat7	Above upper CZ	80.7	161	1,164.7	161.4
ec5stat8	Between upper and middle CZ	81.0		1,538.6	131.1
ec5stat9	Between middle and lower CZ	81.1		2,158.6	0.21

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

A.2.7.2 Flow Logging Results

The results of the trolling flow logs are presented in Figures A.2-7 through A.2-12. Figure A.2-7 and Figure A.2-8 show flow logs for two different trolling speeds (20 fpm downwards and 60 fpm upwards, respectively) at a well production rate of 60 gpm. Figure A.2-9 and Figure A.2-10 depict flow logs for two trolling speeds (20 fpm downwards and 40 fpm upwards) at a production rate of 111 gpm. Figure A.2-11 and Figure A.2-12 show two trolling logs at a production rate of 161 gpm, at 20 fpm downwards and 60 fpm upwards, respectively. The optimal logging speed/direction was downwards at 20 fpm, producing the least amount of noise and fluctuations. This configuration seemed to provide the most sensitivity with the least induced disturbance. Only six of the eight successful trolling log runs are shown in figures, depicting the range of logging results.

The flow logs indicate that most of the production in the well originated from the middle completion interval (1,892 - 2,094 ft bgs). The logs run at 20 fpm for all production rates show an anomalous flow loss in the middle of the upper completion interval that was not indicated at any of the other trolling speeds. A similar flow loss also occurred in Well ER-EC-7 in the upper completion interval. The distribution of production throughout the completion intervals have been tabulated and are discussed in more depth in Section A.3.3.2.

The results from the stationary flow measurements indicate that between 81 and 85 percent of the total flow originated from the middle completion interval. The upper completion interval contributed most of the remainder of the flow, and the lower interval added less then one percent to the flow. The upper interval produced from 15 to 19 percent of the total flow, the higher rate occurring at the 161 gpm production rate.

A.2.8 Constant-Rate Test

A constant-rate pumping test was conducted following well development to collect hydraulic response data for determination of aquifer parameters. Prior to the test, the water level in the well was monitored to observe recovery to ambient head from development pumping and to establish baseline pretest conditions. Pumping for this test commenced on May 15, 2000, and continued for 10 days until May 25, 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 five days until May 30, 2000.

A.2.8.1 Methodology

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

A pumping rate of 160 gpm was chosen for the test. This rate was near the maximum rate the pump was able to sustain and resulted in sufficient drawdown to produce a good record. Based on experience during the early part of development, PXD with a range of 0-15 psig was installed after flow logging for the pretest monitoring and constant-rate test. This provided an appropriate range of measurement for the maximum anticipated drawdown. Use of the lowest possible range maximizes the accuracy of the pressure measurements, which are proportional to the overall measurement range of the PXD.

The PXD was installed on May 11, 2000, at a calculated depth of 1,036.46 ft bgs based on the calibration. Table A.2-8 shows the calibration and PXD installation data for the constant-rate test.

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. These graphs illustrate the datalogger record and major features of the respective activities. Pumping started on May 15, 2000, and was terminated on May 25, 2000. The average pumping rate was 160.16 gpm. A minor problem occurred at the start of the constant-rate test when the VSD initially over sped the pump due to lack of signal from the flowmeter. The uninterruptible power supply powering the flowmeter had been tripped out by a power problem. Since the test is started with the VSD in

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

Design Analysis H-310 PXD SN 2265, 0-15 psig					
Install Date: 5/11/2000					
Installation Calibration Data: 5/11/2000					
Static water level depth 1,016.85 ft bgs					
Stations	Cal 1	Cal 2	Cal 3	Cal 4	Cal 5
WRL/TOC[a]	900.00	925.00	930.00	935.00	940.00
PXD psig	-0.00045	1.9839	4.139	6.2957	8.4454
Delta depth (ft): Cal5 - Cal2					15.00
Delta psi: Cal5 - Cal2					6.462
Density ft of water column/psi: delta depth / delta psi (in ft/psi)					2.3216
Equivalent ft water: PXD psig (at Cal 5) x density of water (ft/psi)					19.61
Calculated PXD installation depth: static water level + equiv. ft water					1,036.46

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

ft - Foot (feet)
bgs - Below ground surface
PXD - Pressure transducer
psi - Pounds per square inch
psig - Pounds per square inch gauge

Mode 2 with the target pumping rate as the control parameter, the VSD continues to increase power to the pump until the flow rate is achieved or until the upper Hz limit is reached. The result can be seen in the drawdown record as initial excess drawdown. Once the flowmeter signal was established, the VSD slowed the pump to the target flow rate.

The data file is EC-5_AQTEST_HT.xls on the accompanying CD. The data records contain only a small amount of noise in the drawdown PXD record. Note that the barometric record has been scaled proportionate to the PXD record. The barometric record shows that the barometric pressure was proportionately constant relative to the PXD pressure changes.

A.2.9 Water Quality Monitoring

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

The standard parameters that were monitored during development and testing of Well ER-EC-5 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, 2000). In-line monitoring data was collected continuously for all the standard parameters except bromide. Grab samples were obtained every two hours when possible and analyzed for all the water quality parameters.

Pumping for well development was initiated on April 26, 2000, at approximately 8:20. In-line monitoring began at approximately 17:00 with the operation of a Hydrolab® H20 Multiprobe. The Hydrolab® fed directly to the datalogger where data could be continuously accessed via a portable laptop computer. Grab sample monitoring was initiated earlier on April 24, 2000, at 10:45, as the field laboratory was fully operational during functionality testing of the pump.

A.2.9.1 Grab Sample Monitoring

Grab samples were obtained from a sample port located on the wellhead assembly. For the development phase, beginning April 24, grab samples were collected and analyzed every two hours, primarily during daylight hours, until 11:25 on May 4. For the constant rate pumping test, four to six grab samples were obtained daily beginning on May 15 and ending on May 24, 2000.

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

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

The results of grab sample monitoring have been compiled and are presented in Attachment 2 and in Section A.4.0. The results have been related to the pumping rate, the total discharge, and the phase of development or testing. Additionally, two graphs have been made showing water quality parameters versus total discharge in gallons. Figure A.2-15 shows EC, pH, and DO. Figure A.2-16 shows turbidity and Br^- concentration.

As shown in Figure A.2-15, the pH, EC and DO remained fairly constant throughout the constant-rate phase of the monitoring. Fluctuations mostly occurred during the development phase with all three parameters. EC leveled off at about 425 µmhos, pH at about 7.9, and DO at about 5.1 mg/L. Among all WPM-OV wells that were developed to date, this well exhibited the most stability in these water quality parameters.

Turbidity stayed mostly below 0.5 nephelometric turbidity units (NTU) with a few values up to 3.4 NTU (Figure A.2-16). The initial turbidity on April 24 was the highest measurement at 7.2 NTU. All of these values represent very low turbidity, and the measurements can be influenced by entrained air at this level. The bromide concentration fluctuated between 0.0 and 0.45 mg/L, which is below the measurement detection limit. There were no clear long-term trends in turbidity or Br^- concentration which indicate any continuing progress in development.

The temperature of the samples remained fairly constant, averaging 30EC and varying only a few degrees between 27.9 and 31.1EC. The most extreme swings occurred during the first two days. Temperature results are not depicted. Temperature differences can often fluctuate depending on ambient air temperature and the speed 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 results of lead and tritium monitoring is presented in Section A.4.0, Environmental Compliance.

A.2.9.2 In-Line Monitoring

In-line monitoring was conducted using a Hydrolab® H2O Multiprobe. The Campbell Scientific datalogger recorded data at various sampling intervals ranging from 5 seconds to 5 minutes. These intervals varied depending on changes in pressure and head. The parameters temperature, EC, and pH were recorded continuously when the pump was running for well development between April 26, 2000, at 18:30 and May 2, 2000, at 19:00. In-line data were also recorded every two hours on a “Water Quality Data Form” for comparison with grab sample results. The Hydrolab® was calibrated and maintenance was performed at the beginning of operations and on April 30 at 8:30, in accordance with DOP ITLV-UGTA-312. The Hydrolab® was taken off-line during the constant rate.

Two figures have been derived from the in-line monitoring data. Figure A.2-17 shows EC and pH related to total discharge in gallons. Figure A.2-18 depicts the temperature over the same pumping period. The EC record in Figure A.2-17 shows fluctuations between 100 and 450 micromhos per centimeter (Fmhos/cm), with most of the readings falling between 330 and 380 Fmhos/cm. The grab sample results for EC had a range between 370 and 450 Fmhos/cm during well development, with most of the readings between 400 and 450 Fmhos/cm. Comparing the two records, the grab samples were generally higher by about 60 to 70 Fmhos/cm for EC and the fluctuations were much narrower. The pH record from in-line monitoring fluctuated between 8.0 and 8.45, which is not a great deal of variation considering the changes in pumping rate and stopping/starting during the development phase. The cyclic pattern in the record corresponds to starting and stopping of the pump. The grab samples ranged from 7.0 to 8.45 during this same phase. The temperature record in Figure A.2-18 shows that the temperature through the Hydrolab® was consistently close to 30EC which corresponds with the grab sample average of 30EC. There was a disruption in the Hydrolab® data during the period between about 413,000 and 418,000 total gallons discharged. The in-line data are contained in the Excel® file "Hlab-wd.xls" on the accompanying CD.

A.2.10 Groundwater Sample Collection

Two types of well samples were collected for characterization of the groundwater in Well ER-EC-5: 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, usually under nonpumping conditions, 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. The discrete sampling interval was determined after initial well development and downhole flow and temperature logging.

On May 4, 2000, discrete samples were obtained from two depths, 1,980 and 2,370 ft bgs, at a pumping rate of approximately 160 gpm. The samples were obtained using a DRI logging truck, and discrete bailer. The bailer was decontaminated using the methodology in DOP ITLV-UGTA-500, "Small Sampling Equipment Decontamination," and SQP ITLV-0405, "Sampling Equipment Decontamination." An equipment rinsate sample was collected from the decontaminated bailer prior to collection of the discrete sample. The samples were processed according to the following procedures: DOP ITLV-UGTA-302, "Fluid Sample Collection"; SQP ITLV-0402, "Chain of Custody"; and SQP ITLV-0403, "Sample Handling, Packaging, and Shipping." Samples were immediately stored with ice and transported to a 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), LLNL, and DRI.

The validated results of the May 4, 2000, discrete samples have been tabulated and are presented in Attachment 3. These results are similar for most of the parameters in comparison to the results of the discrete groundwater characterization sample taken during drilling (before the well was completed). That sample was obtained on July 8, 1999, from a depth of 1,450 ft bgs.

A.2.10.2 Groundwater Composite Sample

The purpose of this sample is to obtain a composite of as much of the well as possible. The composite groundwater characterization sample was collected at the end of the constant rate pumping test from the sampling port at the wellhead. Since this sample is meant to represent a composite of the whole well, there are two criteria for the sample to be the most representative: (1) the sample should be obtained after pumping for the longest possible time, and (2) the pumping rate should be as great as possible in order for the component water production to include as many completion intervals as possible. 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 81 percent of the flow into the well occurred in the middle completion interval between 1,892 and 2,094 ft bgs at a production rate of 161 gpm.

On May 25, 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 160 gpm was maintained during the sampling event, the same rate used during the constant-rate test. At the time of sampling, approximately 3,500,000 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 a secure refrigerated storage. Samples were collected for the following laboratories: Paragon, UNLV-HRC, LLNL, LANL, and DRI.

The final, validated results of the May 25, 2000, composite sample have been tabulated and are presented in Attachment 3. Examination of the results show that they are similar to the July 8, 1999, discrete sample.

A.2.11 Thermal Flow Log and ChemTool Log

Thermal flow logging was conducted at the very end of the development and testing program to determine flow in the well under ambient, static conditions. The resulting flow information may differ from that of the thermal flow logging conducted in the open borehole before well completion because it is specific to the completion intervals, and reflects remediation of conditions imposed by drilling. The ChemTool provides a depth log of temperature, pH, and EC. The thermal flow and ChemTool logging was conducted June 7, 2000, by DRI.

A.2.11.1 Methodology

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

A.2.11.2 Results

The results of the ChemTool logging are presented in Figure A.2-19. The ChemTool log shows relatively constant EC from above the upper completion interval down to the bottom of the lower completion interval. The log is rather noisy, but the range of fluctuation is narrow (about 270 to 320 Fmhos/cm). Both pH and temperature change significantly along the upper screen of the upper completion. Below this, pH is quite stable and temperature increases only slightly in a gradual stabilization to a constant value below the upper completion interval.

The thermal flow log data was provided by DRI and is presented in Table A.2-9. The data was collected under non-pumping conditions at 10 stations between 1,190 ft bgs and 2,410 ft bgs. All stations except the uppermost and lowermost indicated a downward flow. These stations were above the upper completion and below the lower completion, respectively. All but the lowermost reading in the lower completion were at the upper limit of the flowmeter range. Note that the top of sediment was tagged at 2,430 ft bgs during flow logging.

Table A.2-9
Thermal Flow Log Results

Station Depth (ft)	Response (sec)	Flow Rate (gpm)	Velocity (fpm)
1,190	20.0 +/- 20.0	0.000 +/- 0.000	0.000 +/- 0.000
1,300	-.50 +/- 0.00	-2.200 +/- 0.001	-2.157 +/- 0.001
1,400	-.50 +/- 0.00	-2.200 +/- 0.001	-2.157 +/- 0.001
1,880	-.52 +/- 0.020	-2.200 +/- 0.085	-2.157 +/- 0.083
1,993	-.50 +/- 0.00	-2.200 +/- 0.001	-2.157 +/- 0.001
2,100	-.50 +/- 0.00	-2.200 +/- 0.001	-2.157 +/- 0.001
2,240	-.50 +/- 0.00	-2.200 +/- 0.001	-2.157 +/- 0.001
2,340	-.50 +/- 0.00	-2.200 +/- 0.001	-2.157 +/- 0.001
2,405	-1.20 +/- 0.40	-1.542 +/- 0.514	-1.511 +/- 0.504
2,410	20.0 +/- 20.0	0.000 +/- 0.000	0.000 +/- 0.000

ft - Feet
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 Installation

On June 8, 2000, a dedicated sampling pump was installed in Well ER-EC-5 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 1,186.83 ft bgs. A 2.0-ft stickup makes the entire string a length of 1,188.83 ft. The pump intake is at 1,167.4 ft bgs and the top of the pump assembly is at 1,160.83 ft bgs. The total length of the pump assembly, not including the crossover, is 26.0 ft. Table A.2-10 lists the pump assembly components. The manufacturer's specifications for the pump are provided in Attachment 1.

Table A.2-10
Dedicated Sampling Pump

Pump Component	Type/Model	Serial Number	Other Information
ESP Pump	TD 800	2D8I15042	52 Stage
ESP Protector	TR3-STD	3B8I07992	Not Applicable
ESP Motor	TR3-375/THD 13	3B8I06461	30 hp, 740 V, 30 A

ESP - Electrical Submersible Pump Systems
hp - Horsepower
V - Volts
A - Amps

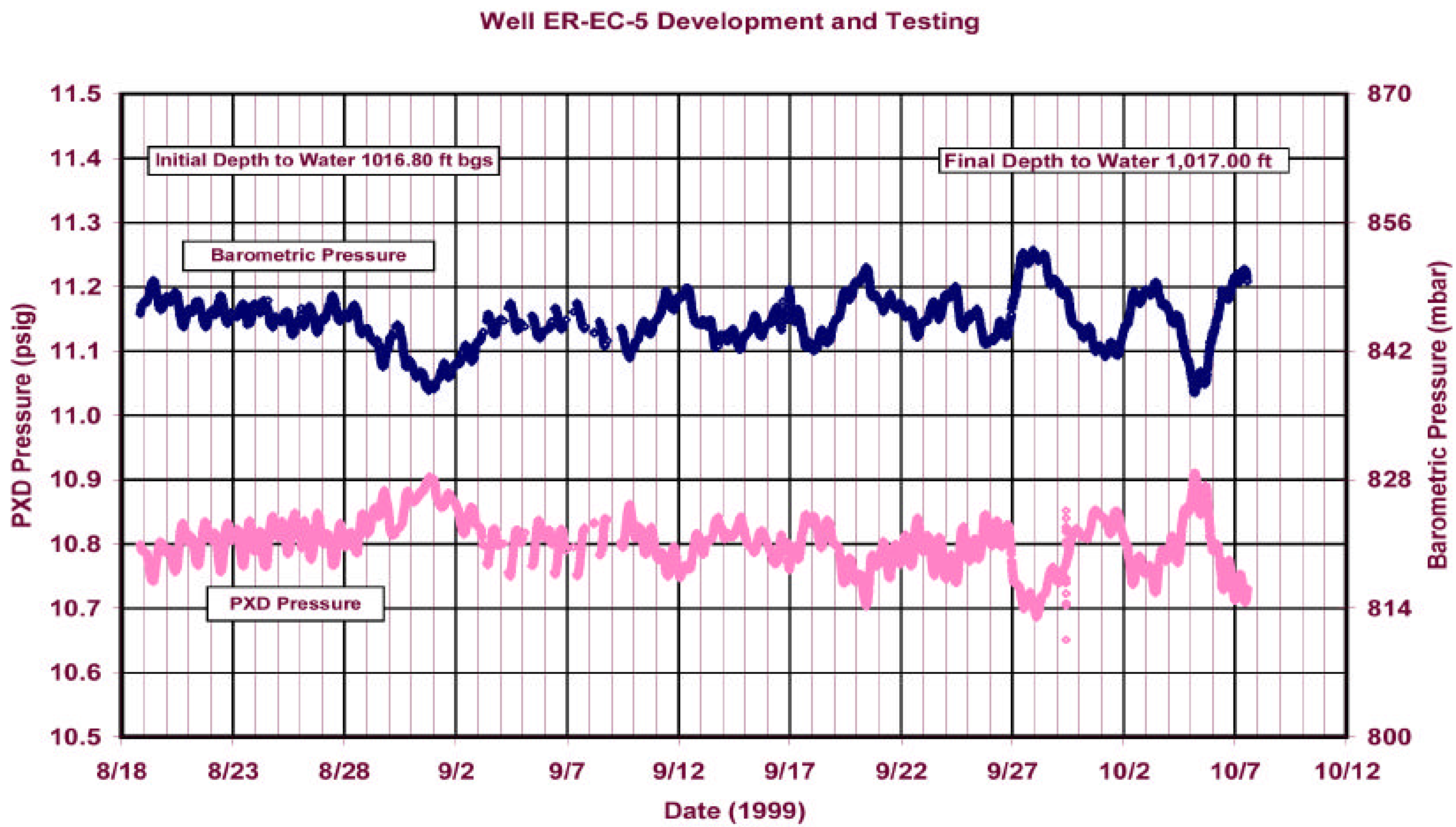
The pump string was landed on a 1-in. landing plate at the wellhead. Figure A.2-20 depicts the final wellhead configuration. A VSD was wired to the pump. On June 9, 2000, a functionality test was conducted on the pump after appropriate wellhead plumbing was attached to the pump string. The discharge was routed to the lined Sump #1. At about 9:20, the pump was started and discharge occurred at the surface 6 minutes, 21 seconds later. The pump was run at six different VSD frequencies over about 40 minutes total run time. Table A.2-11 shows the results of the functionality test. Approximately 1,000 gallons were pumped during the functionality test. No problems were encountered.

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

Time	VSD Frequency (Hz)	Flow Rate Magnetic Flow Meter (gpm)	Downhole Amps	Downhole Voltage	Voltage to Ground
9:27	60	32	N/A	N/A	N/A
9:40	60	32	23	664	380
9:45	70	41	30	770	448
9:52	50	19	N/A	N/A	N/A
9:53	47	13	17	523	300
9:58	55	27	N/A	N/A	N/A
10:00	65	38	N/A	N/A	N/A

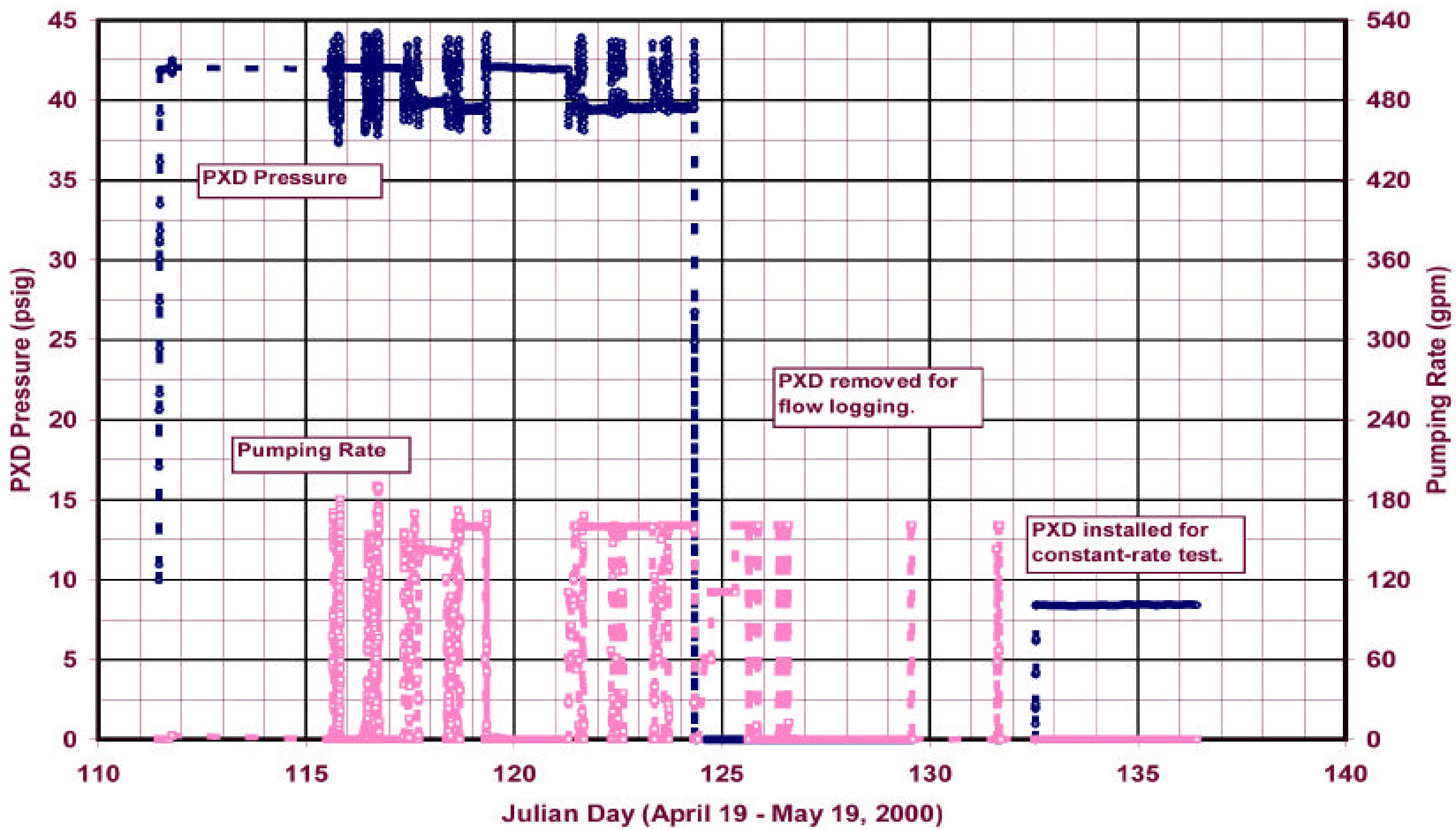
Note: Amps and voltage are mean values of three phases. Wellhead pressure remained at 0 psi throughout testing.

Hz - Hertz (cycles)
gpm - Gallons per minute
N/A - Not applicable



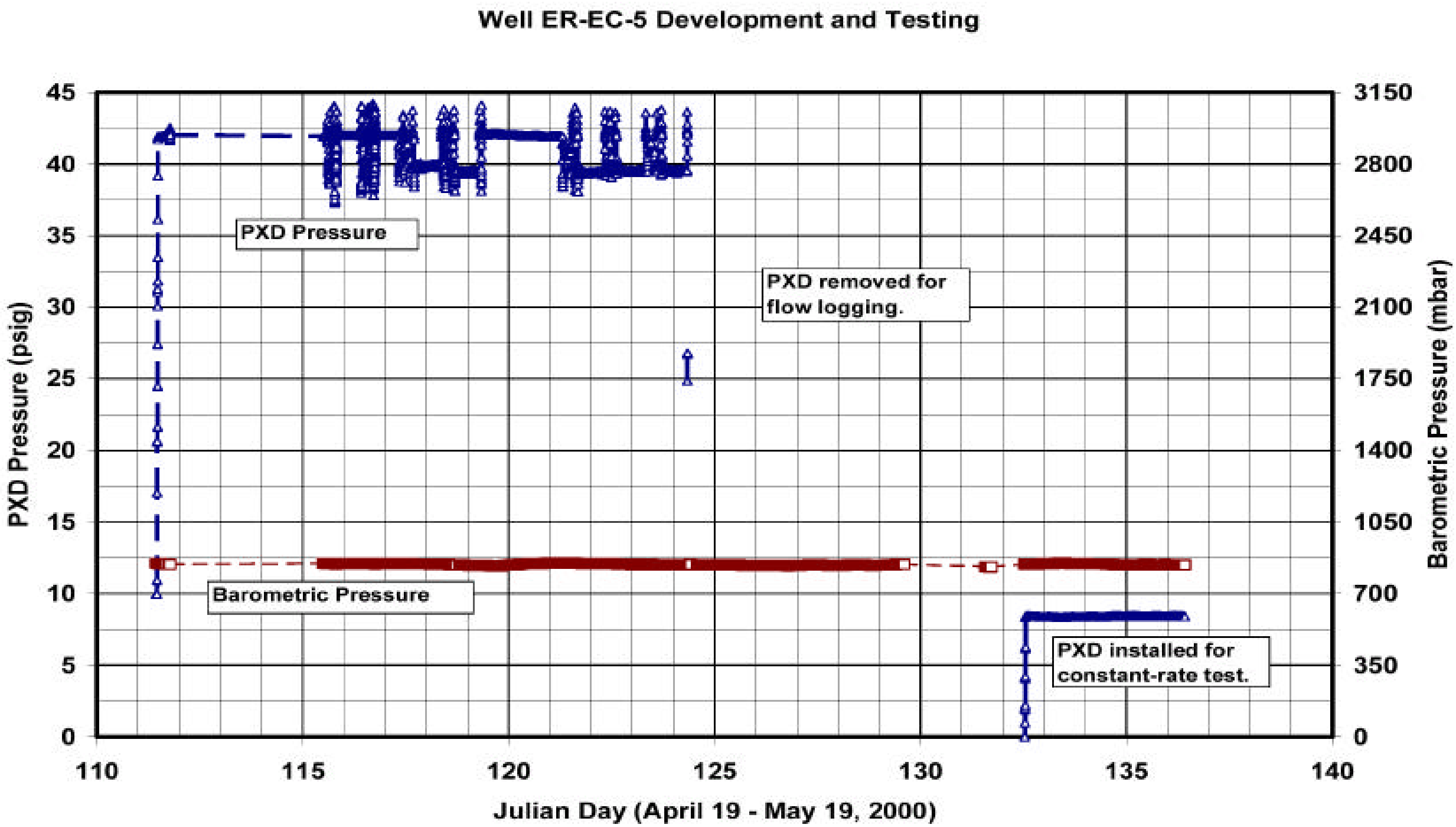
ft bgs - Feet below ground surface
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-1
Predevelopment Water Level Monitoring



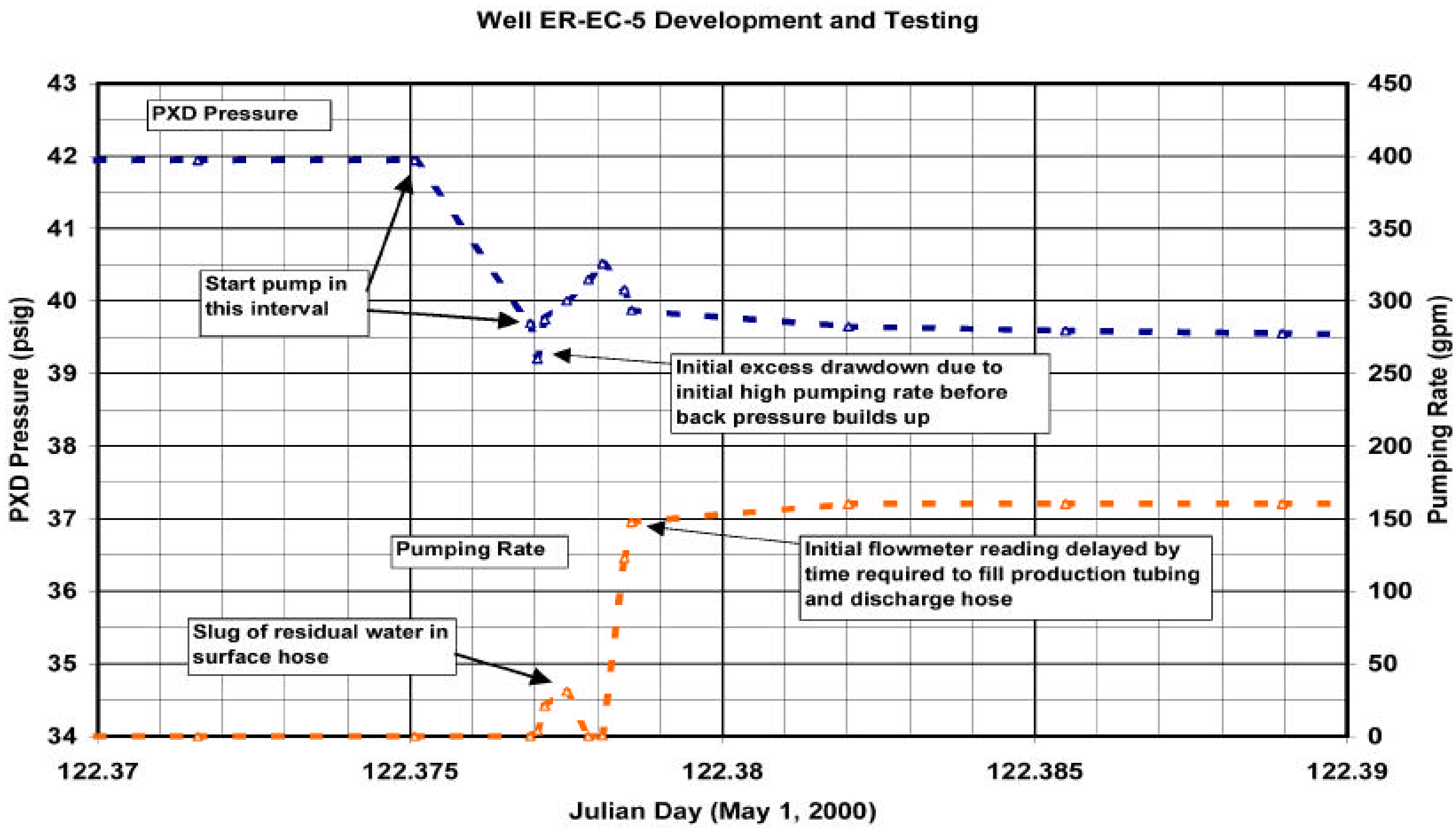
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



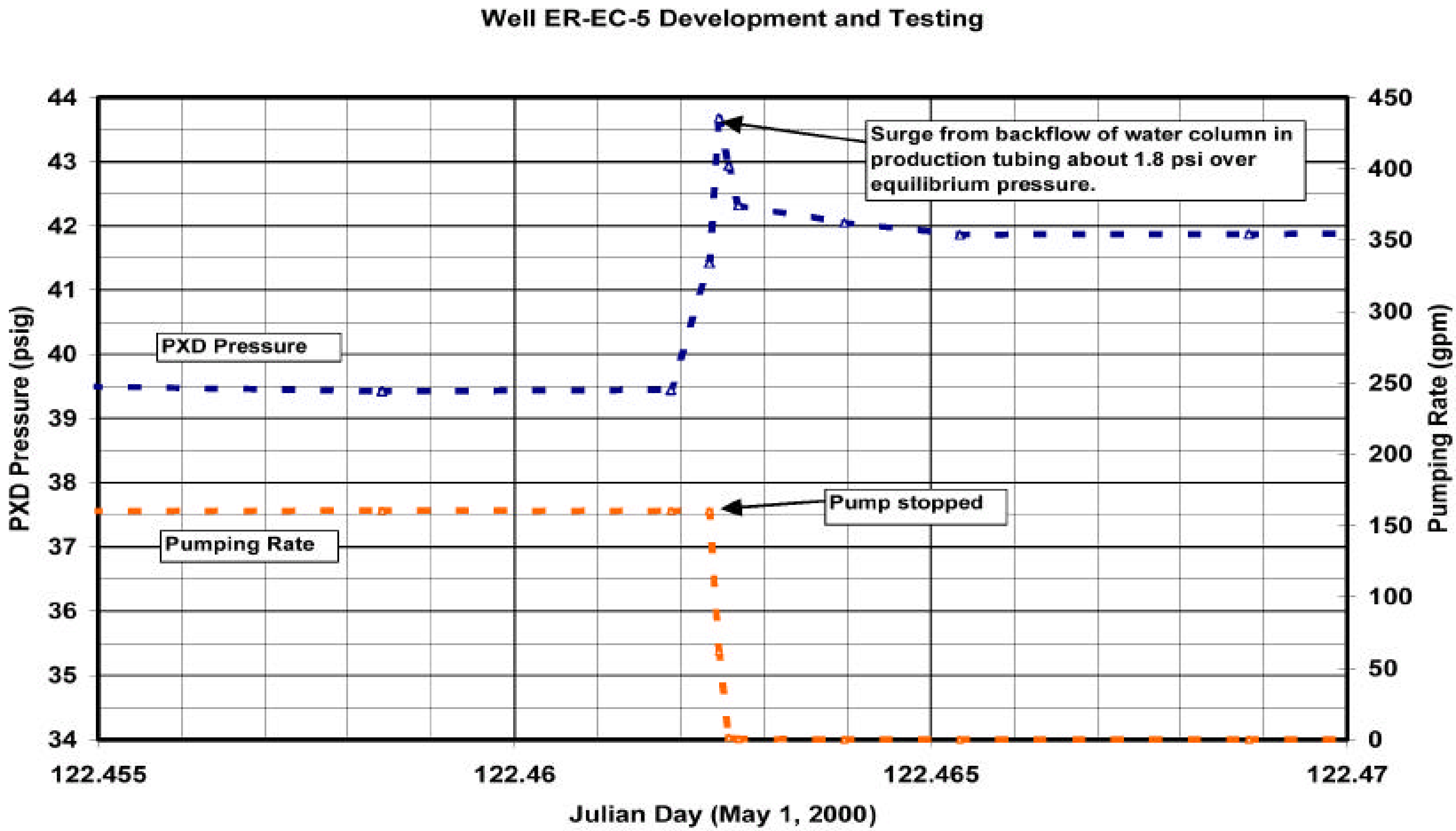
mbar - Millibars
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



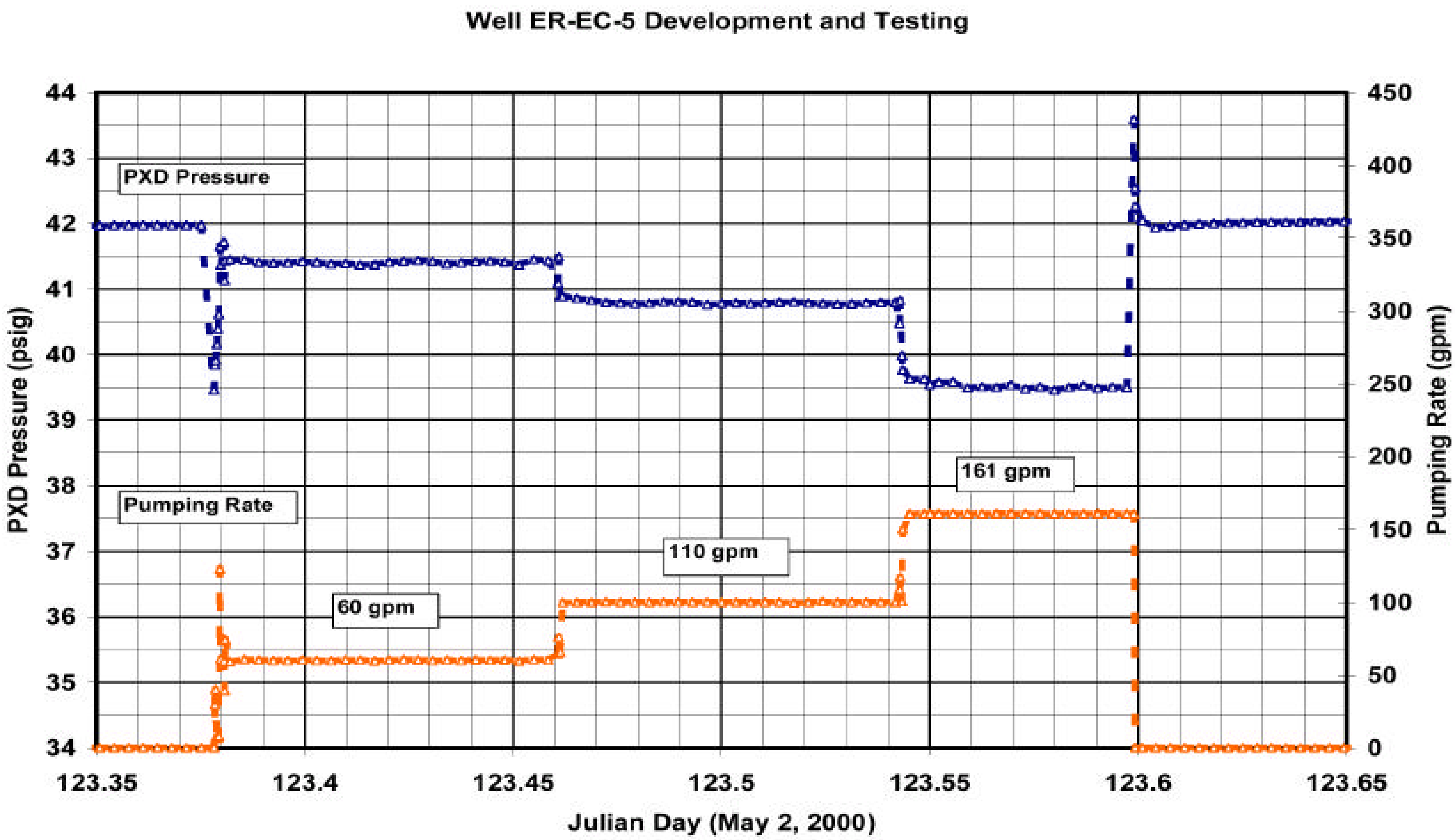
gpm - Gallons per minute
psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.2-4
Detail of Startup Effects



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

Figure A.2-5
Detail of Surging Action



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

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

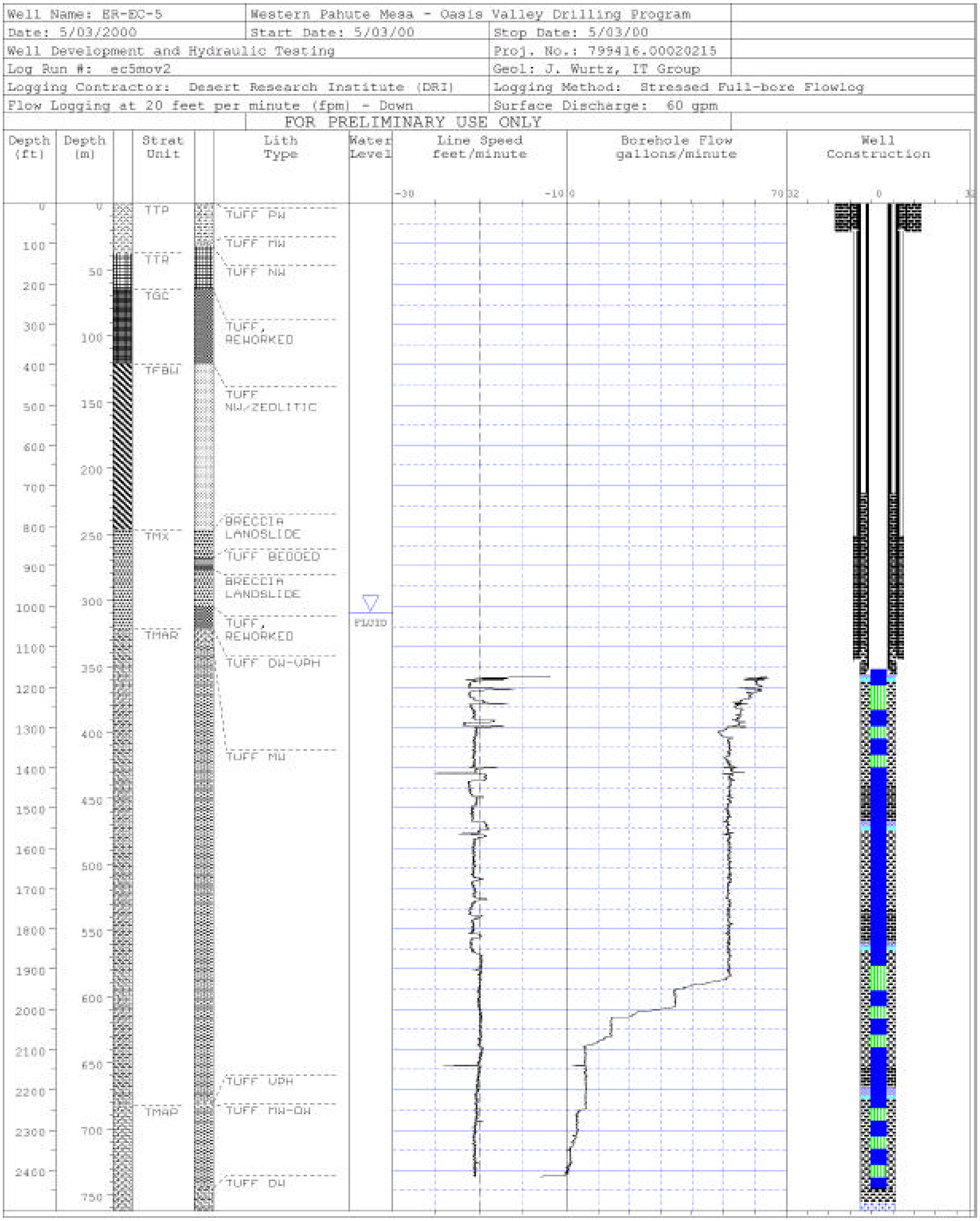


Figure A.2-7
Flow Log at 60 gpm Production Rate and 20 fpm Downward Trolling Rate

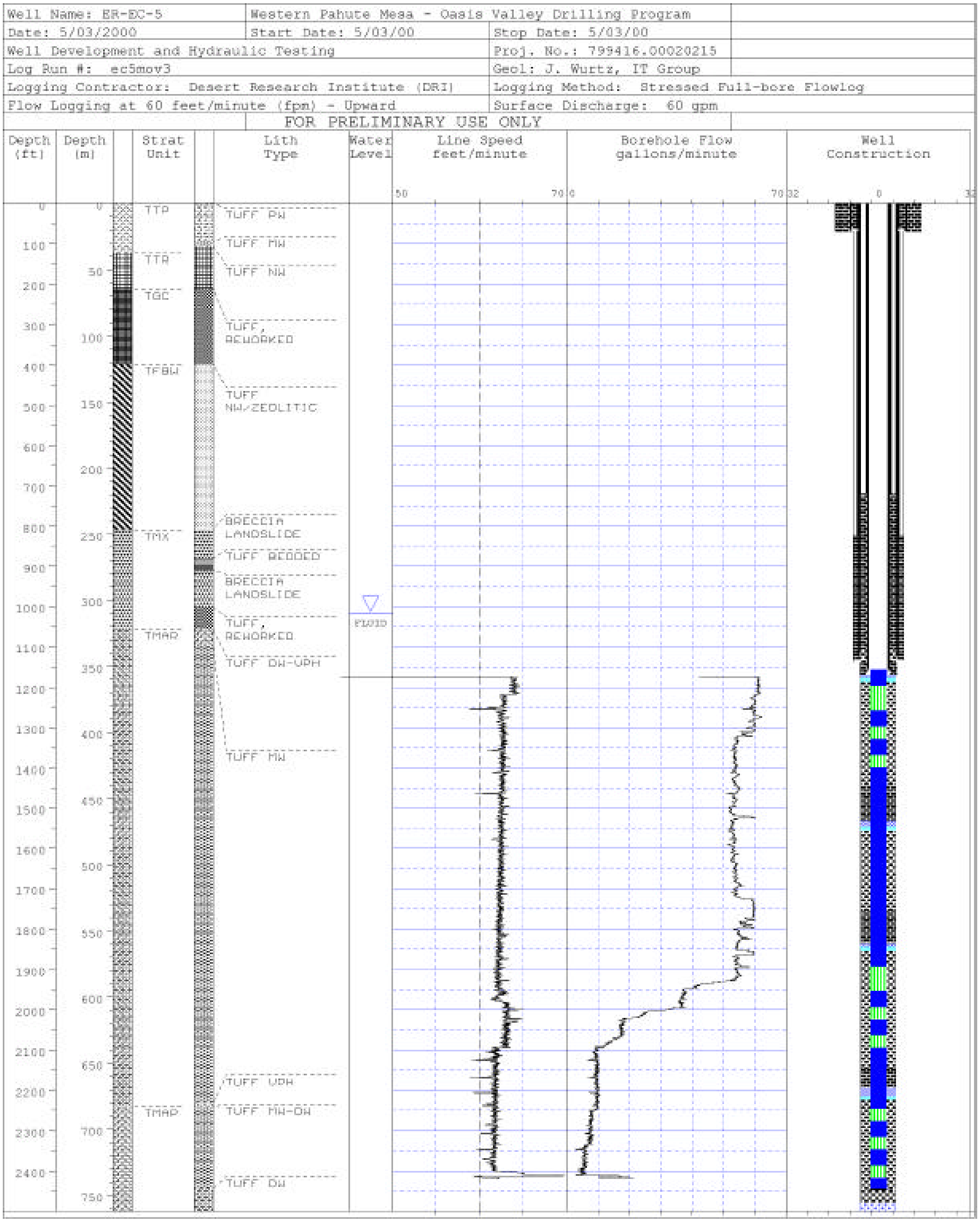


Figure A.2-8
Flow Log at 60 gpm Production Rate and 60 fmp Upward Trolling Rate

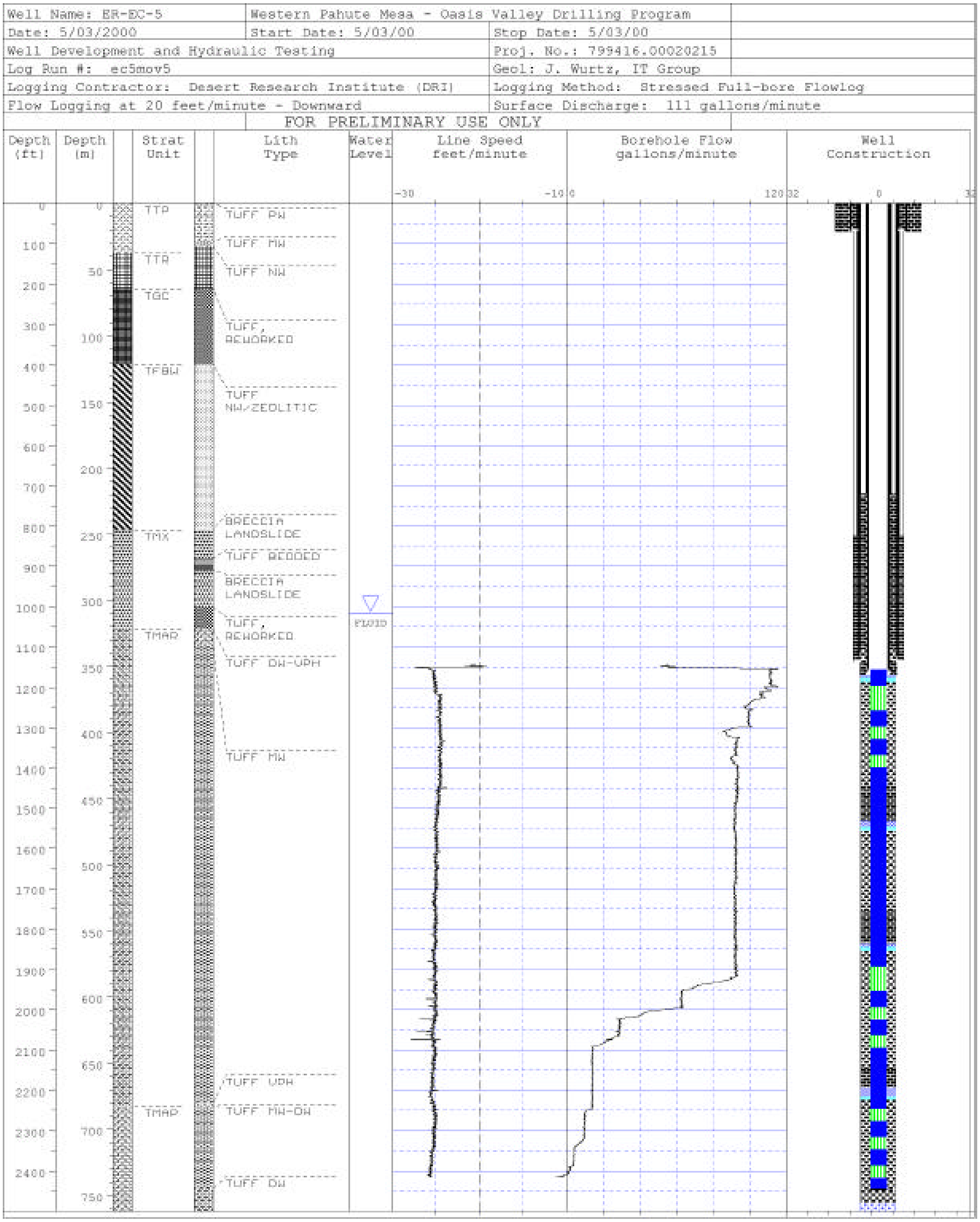


Figure A.2-9
Flow Log at 111 gpm Production Rate and 20 fpm Downward Trolling Rate

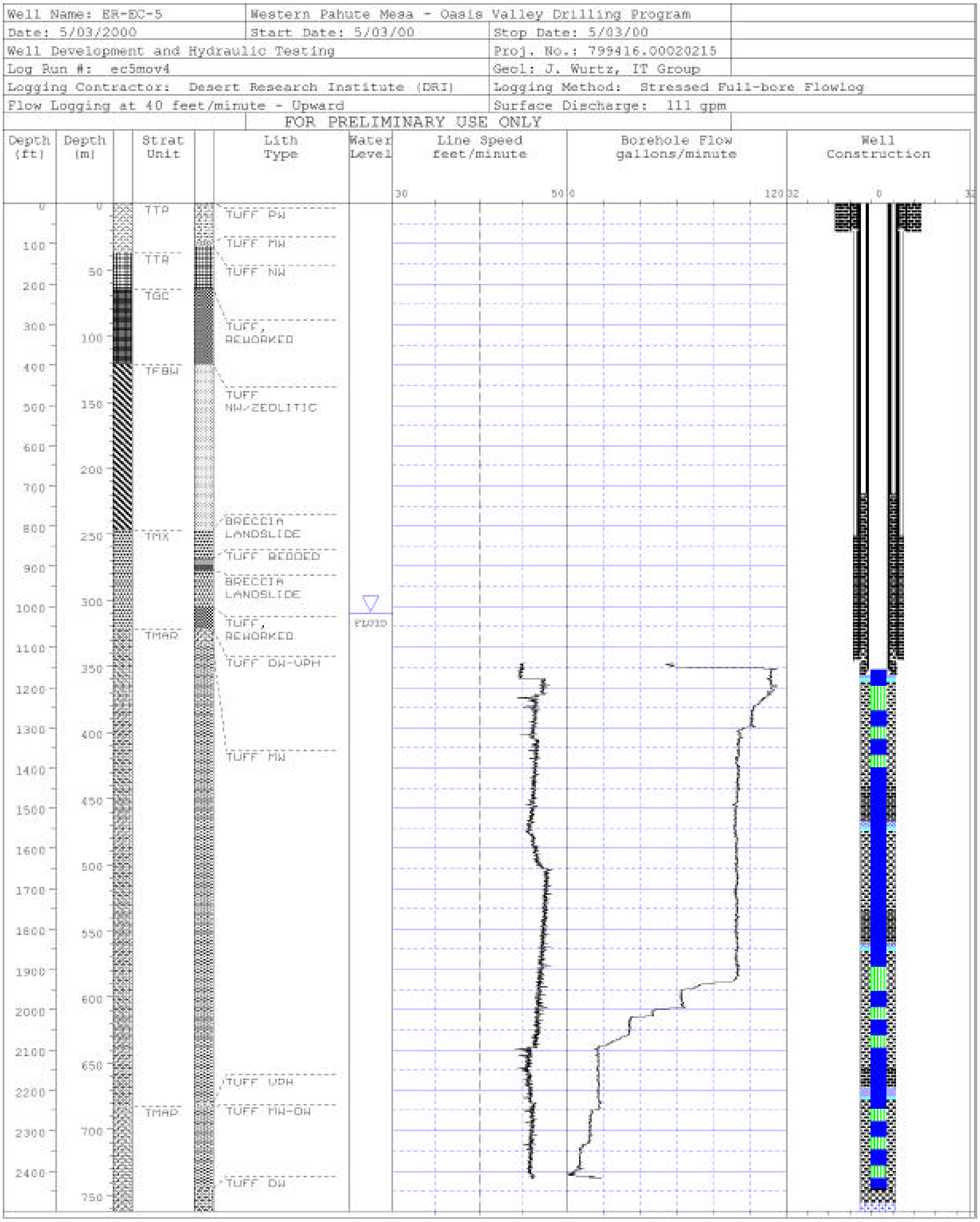


Figure A.2-10
Flow Log at 111 gpm Production Rate and 40 fpm Upward Trolling Rate

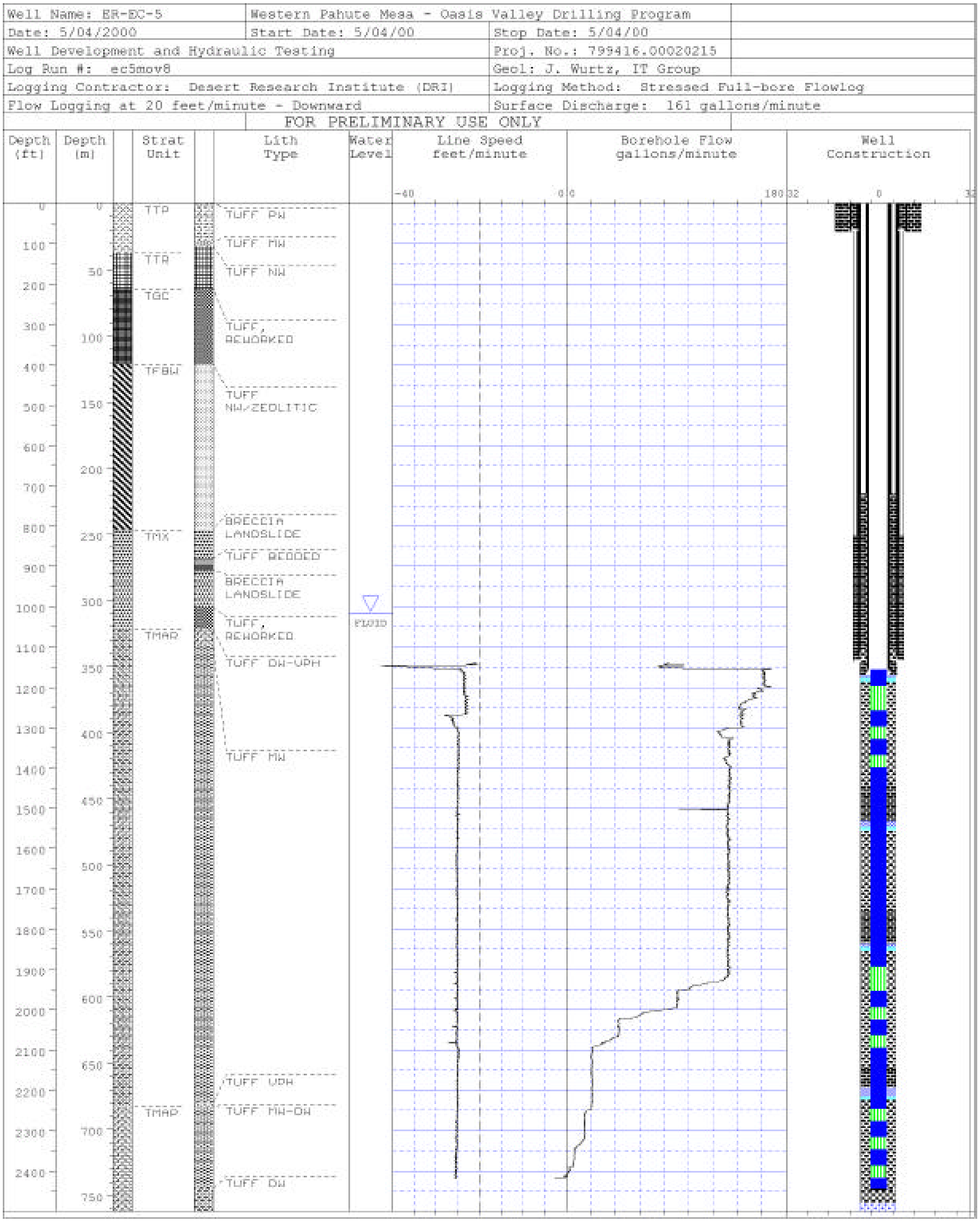


Figure A.2-11
Flow Log at 161 gpm Production Rate and 20 fpm Downward Trolling Rate

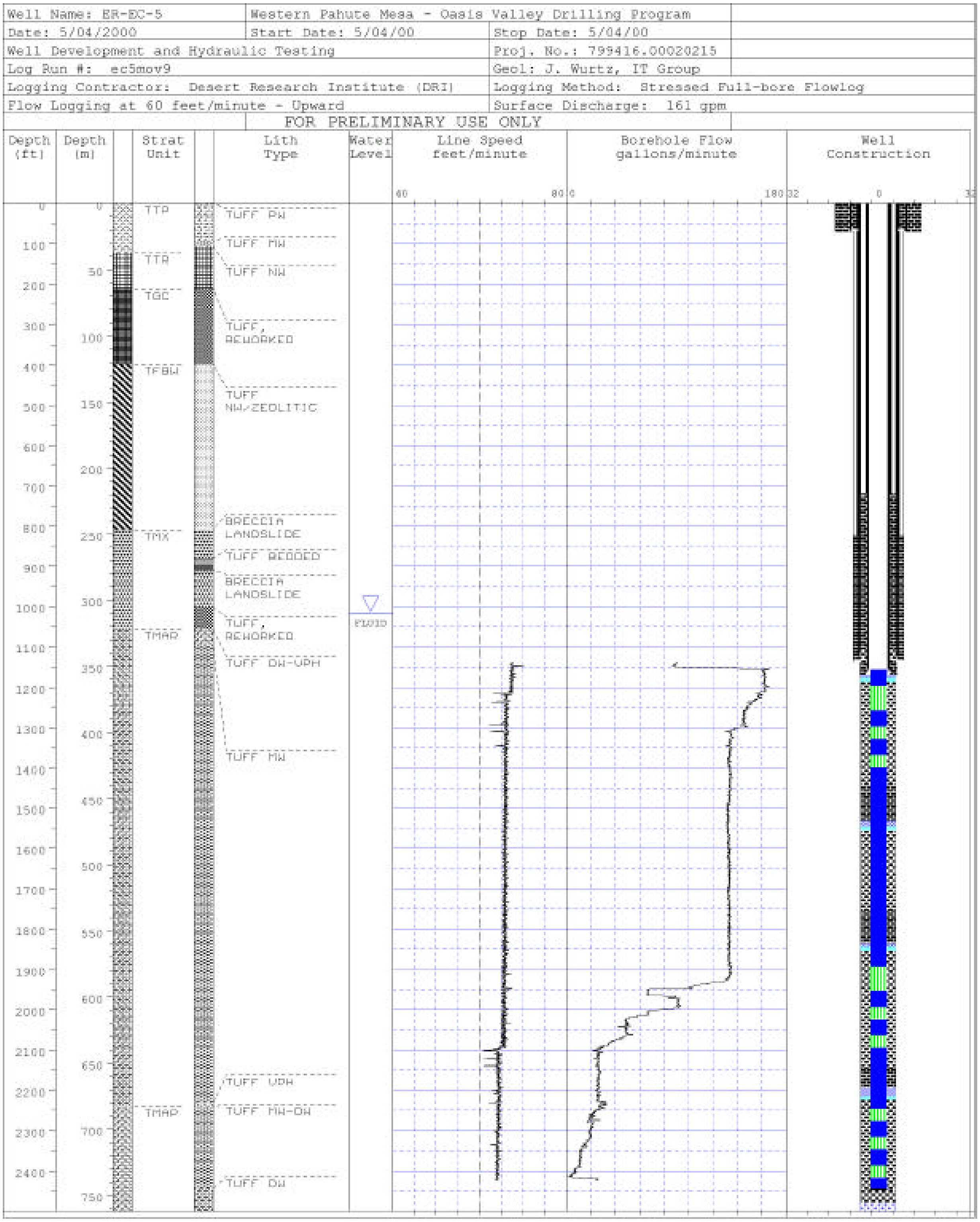
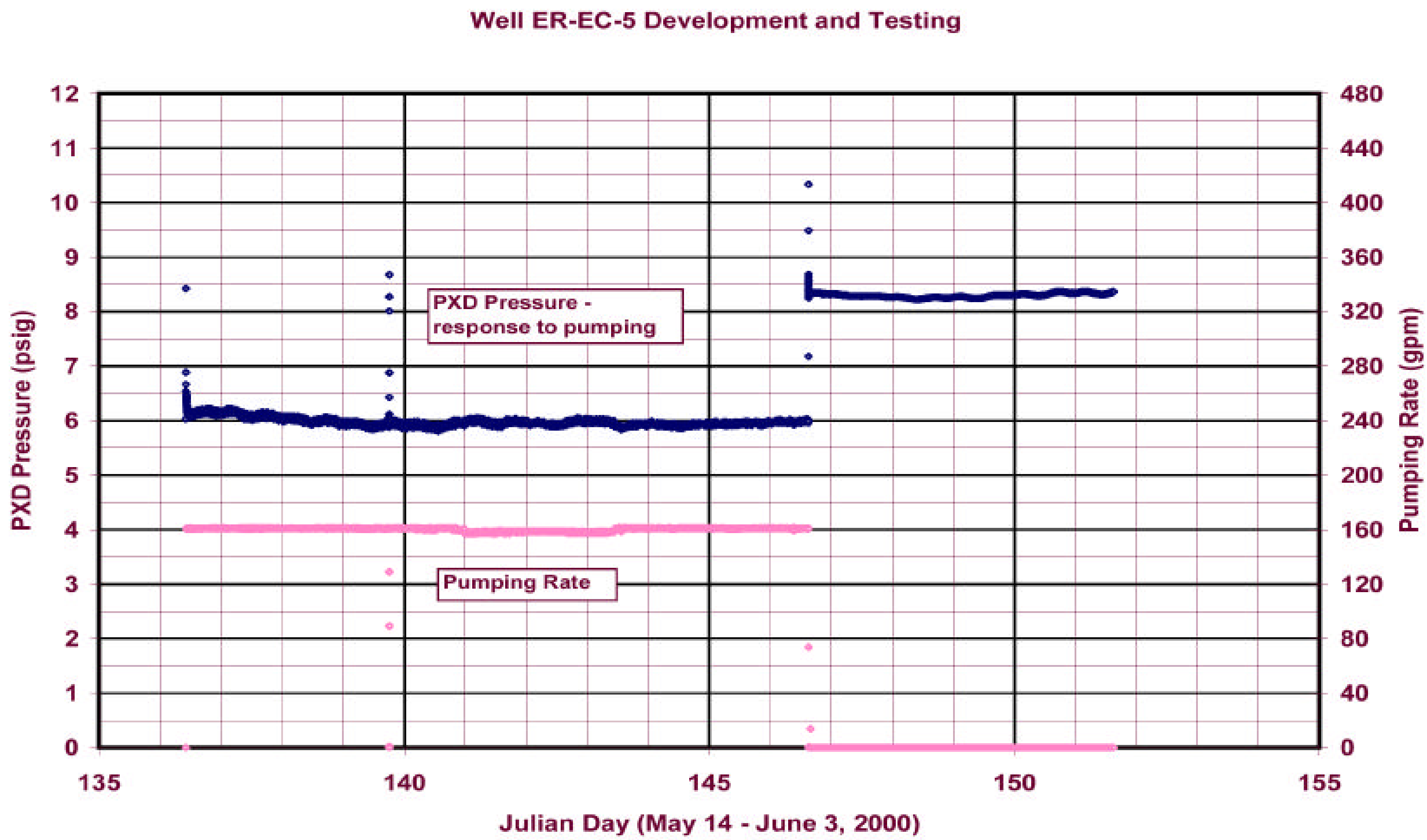
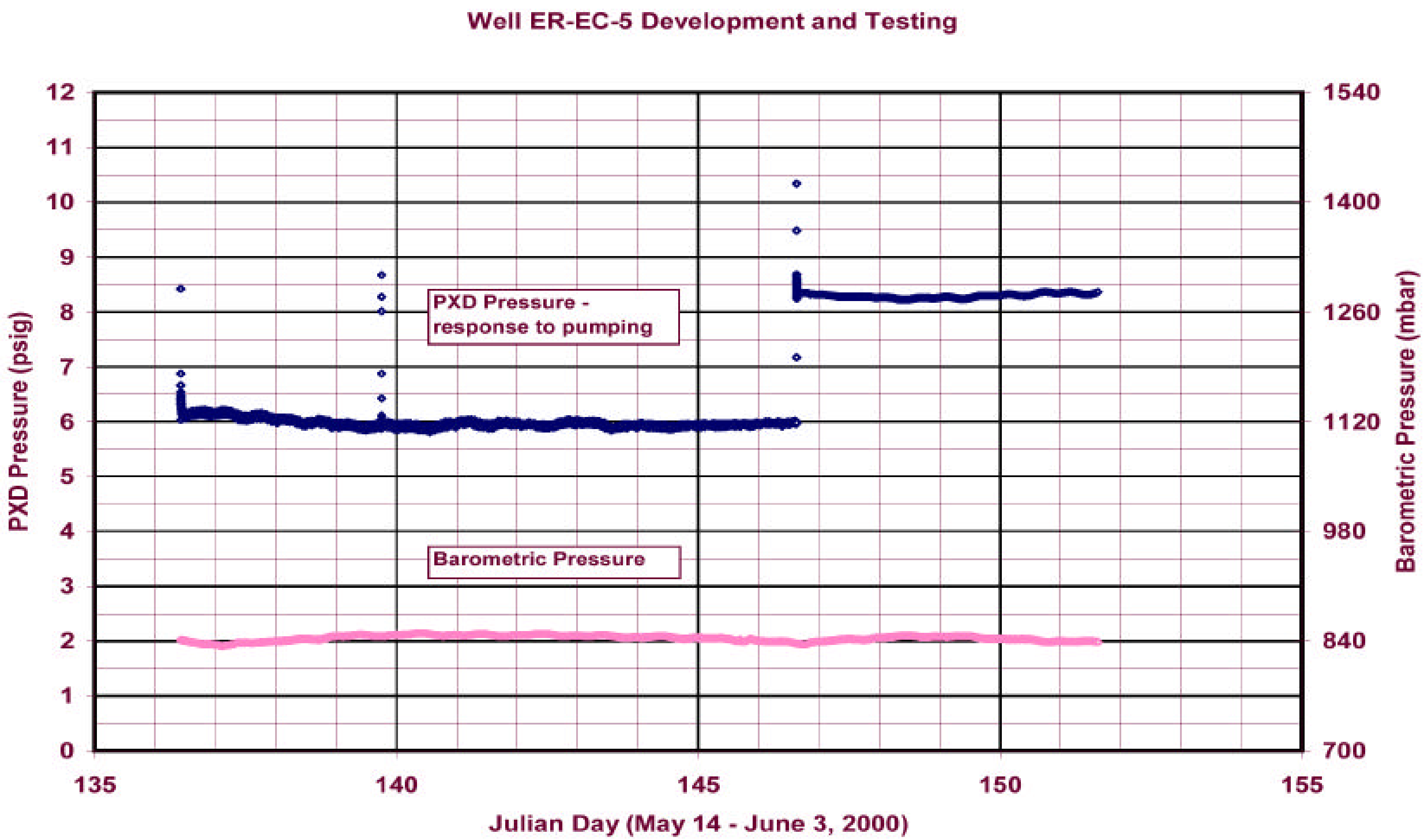


Figure A.2-12
Flow Log at 161 gpm Production Rate and 60 fpm Upward Trolling Rate



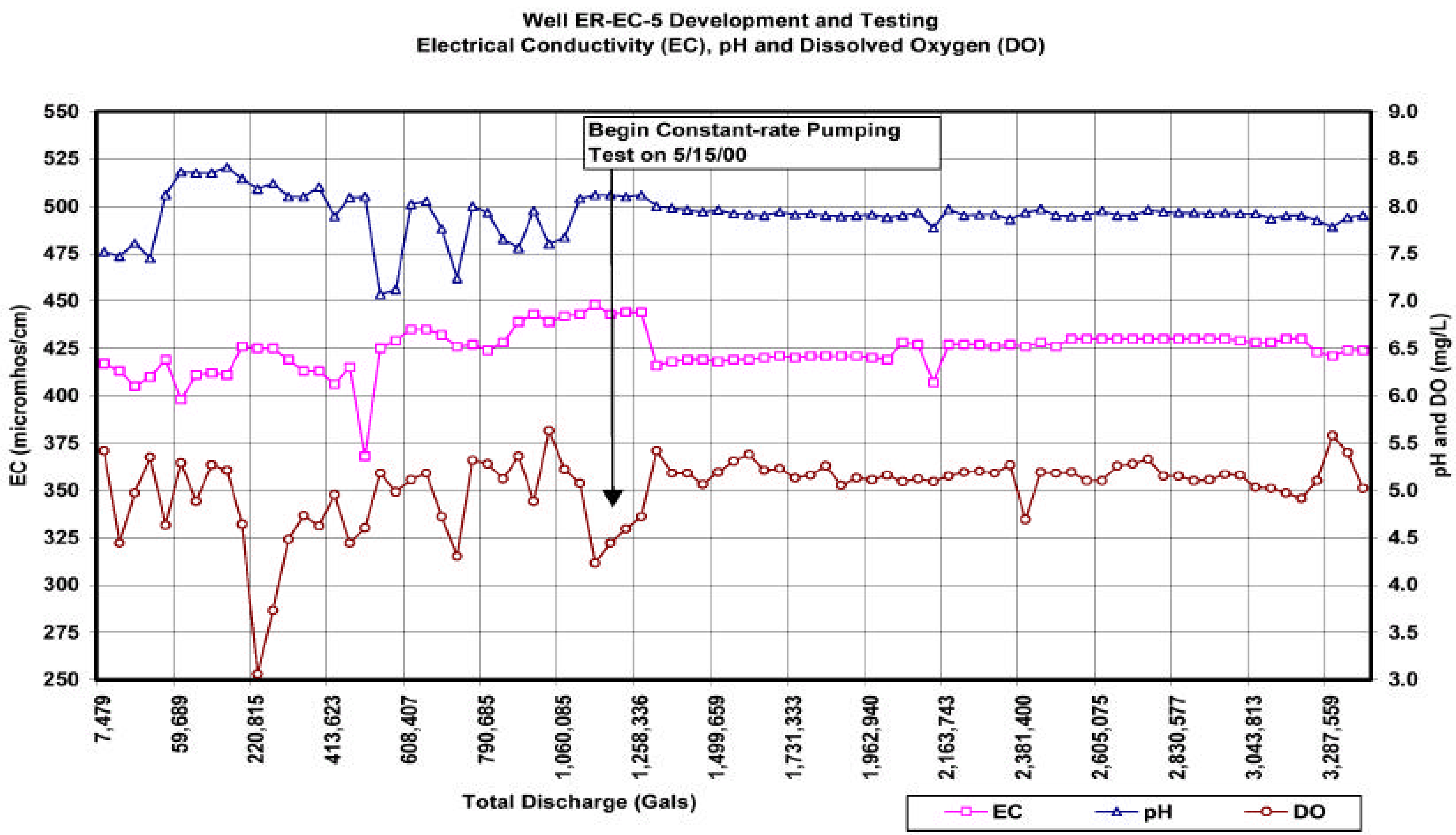
gpm - Gallons per minute
psig - Pounds per square inch
PXD - Pressure transducer

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



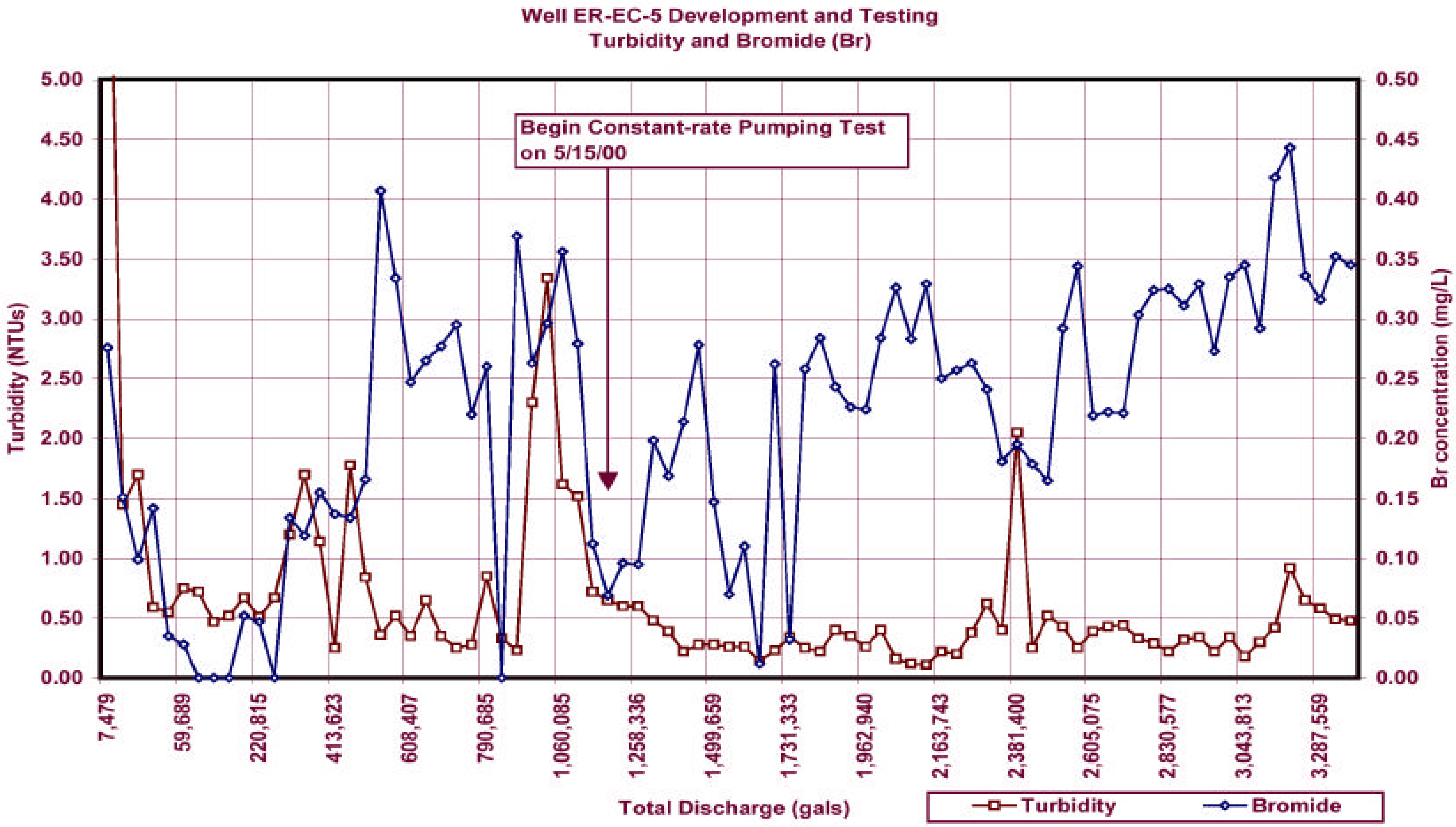
mbar - Millibars
psig - Pounds per square inch
PXD - Pressure transducer

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



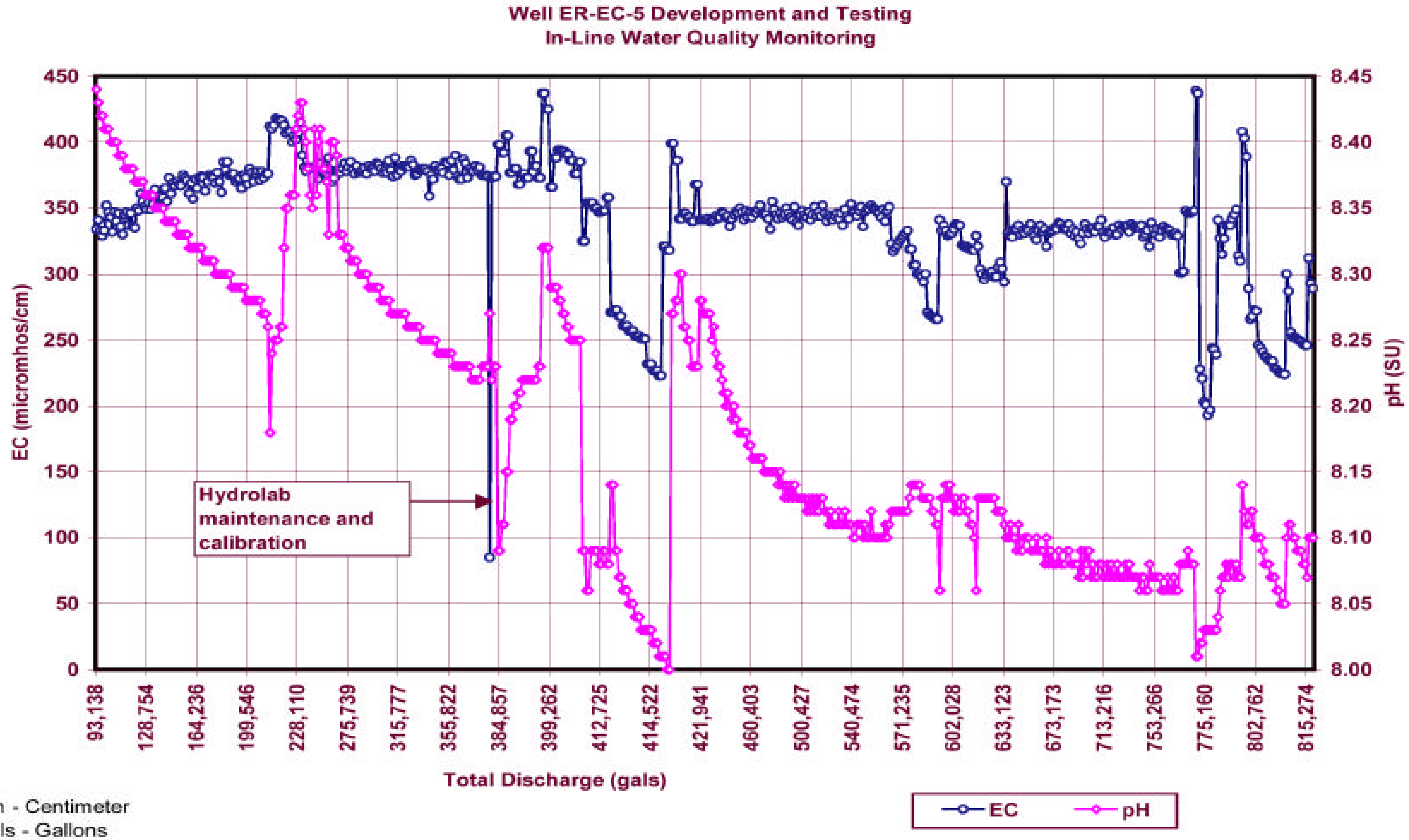
mg/L - Milligrams per liter
gals - Gallons
cm - Centimeter

Figure A.2-15
Grab Sample Monitoring for EC, pH, and DO



NTUs - Nephelometric Turbidity Units
mg/L - Milligrams per liter

Figure A.2-16
Grab Sample Monitoring for Bromide and Turbidity



cm - Centimeter
gals - Gallons
SU - Standard units
EC - Electrical Conductivity

Figure A.2-17
In-Line Monitoring for EC and pH

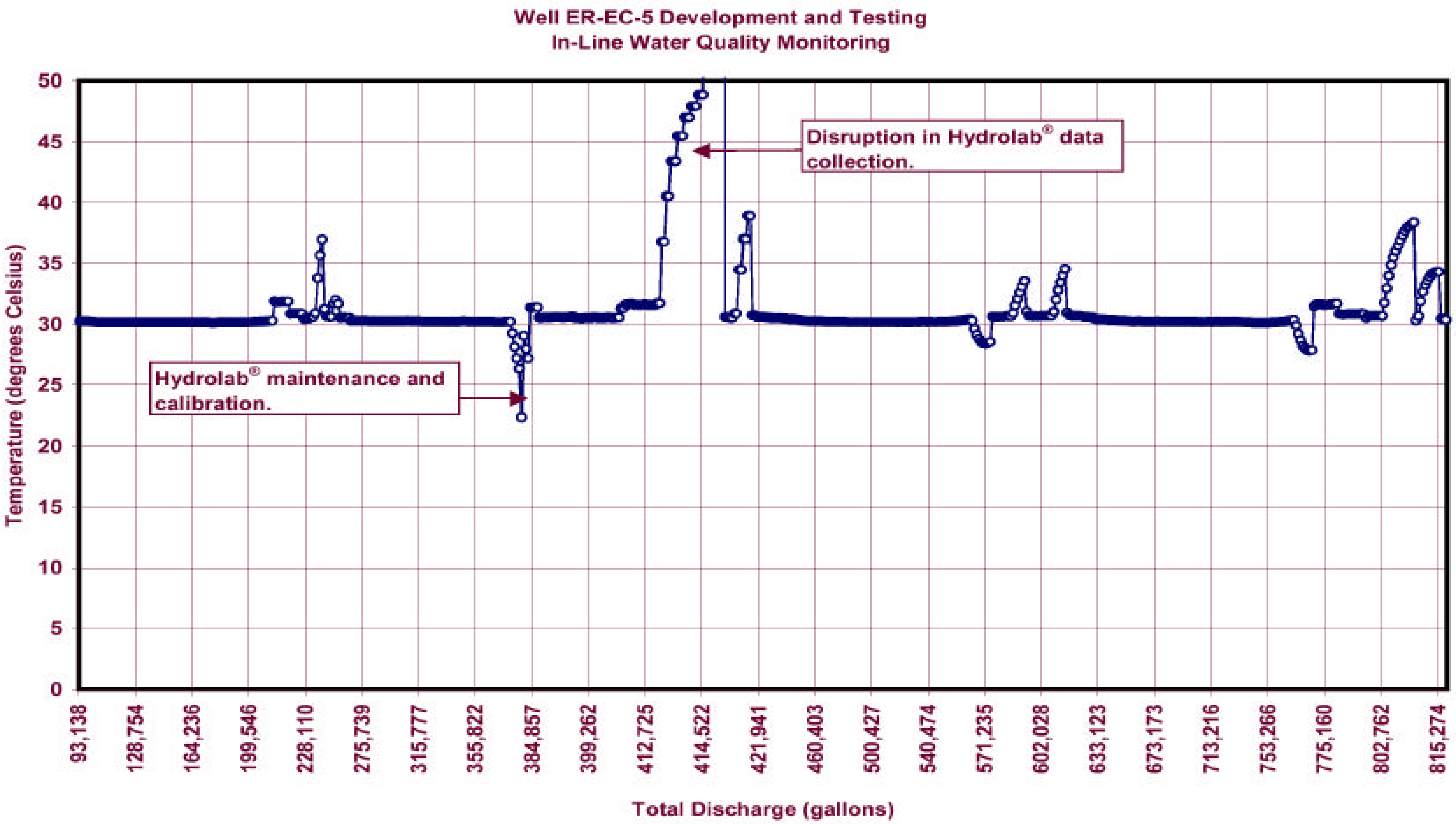


Figure A.2-18
In-Line Monitoring for Temperature

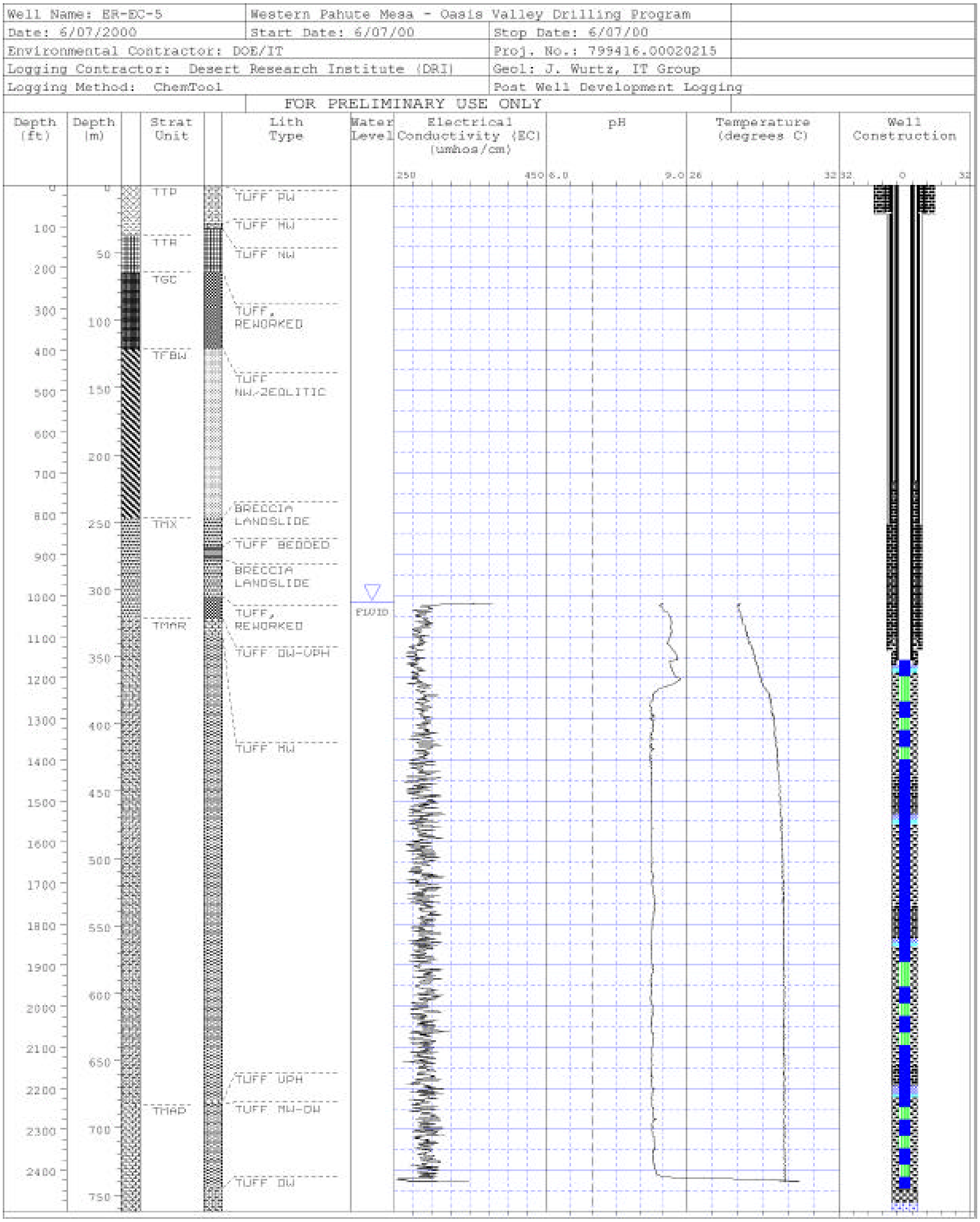


Figure A.2-19
ChemTool Log

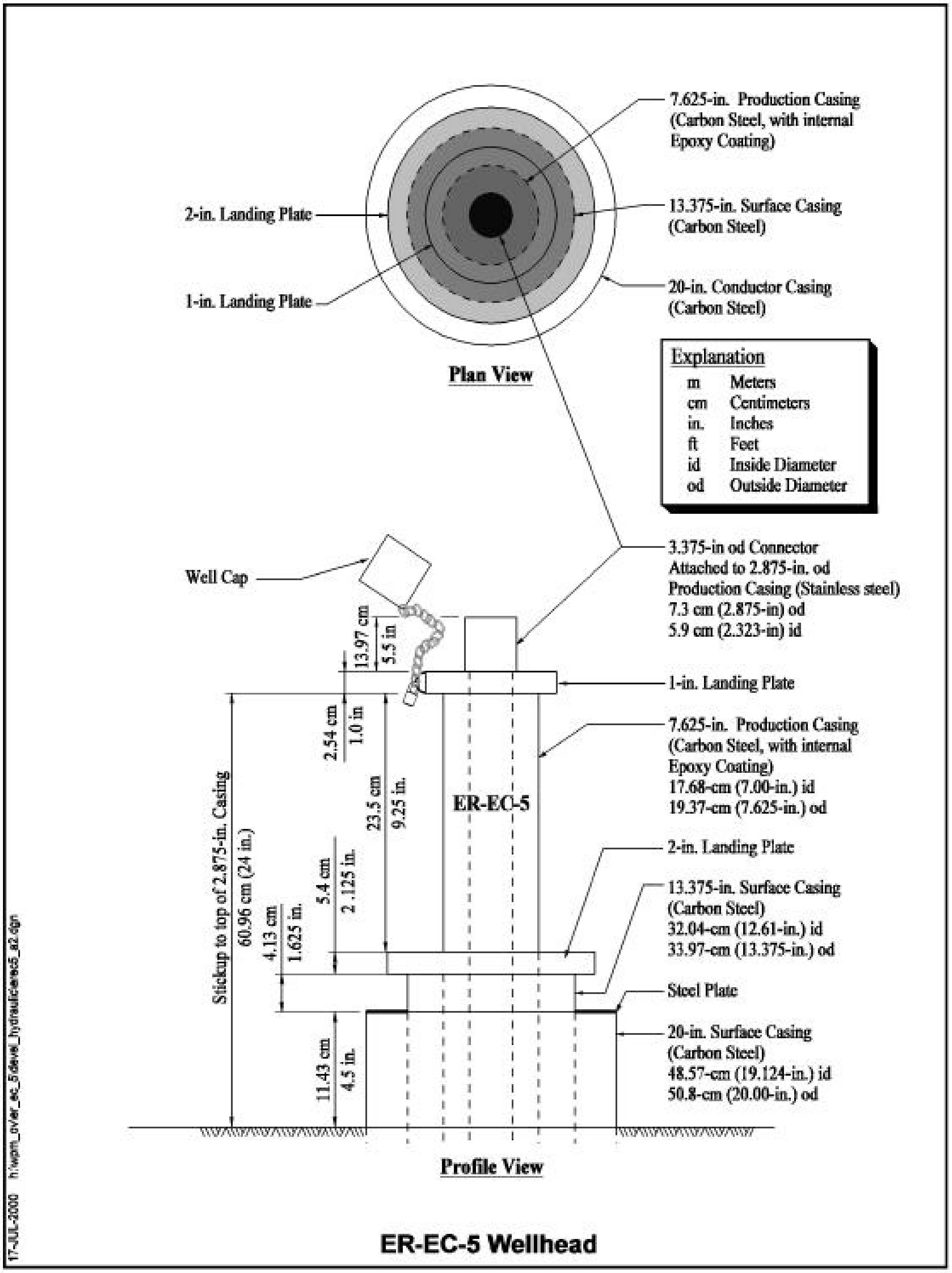


Figure A.2-20
Wellhead Completion Diagram After Sampling Pump Installation

A.3.0 Data Reduction and Review

This section presents basic reduction and processing of data collected during the Well ER-EC-5 development and testing program. Data review and preliminary examination of the results are offered, clarifications of details are provided, and points of interest are noted. Any data interpretations in this section are preliminary and subject to change in future data analysis tasks.

A.3.1 Vertical Gradient and Borehole Circulation

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

A.3.1.1 Methodology

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

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

A.3.1.2 Data Reduction

Figure A.3-1 shows the PXD monitoring record for the upper interval. Since the upper interval was open to atmospheric pressure in the well, the head was affected by barometric pressure changes during the equilibration period. The graph of the upper interval monitoring shows the PXD pressure record and the barometric record for that period, and a pressure record corrected for barometric change using a barometric efficiency of 0.75 calculated from the record. The method for calculating the barometric efficiency will be discussed in Section A.3.4.1. This barometric efficiency pertains only to the upper interval and is slightly different from that calculated for the entire well. The adjusted record indicates a slight downward trend in the water level during this period. The head of the upper interval progressively rose above the composite water level 0.11 ft as the bridge plugs were set. This is similar to the general repeatability of the e-tape measurement of 0.10 ft per 1,000 ft.

The calibration and equilibration 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 odd pressure reading after the lower calibration readings on each figure occurred as the bridge plug was being moved to the upper calibration station. Note the steadiness in the pressure readings for the calibration data points, indicating the PXD temperatures were fairly stable by the beginning of the record segments. The equilibration records show that the intervals had equilibrated during the period of measurement.

No pressure adjustment was observed for the lower interval, and possibly the middle interval pressure rose 0.05 ft. This is of the same order as the resolution of the PXD, so this apparent change may not be accurate. Figure A.3-3 and Figure A.3-5 show that the PXD readings fluctuate a certain amount both above and below a central value, representing limitations in the resolution of the instrumentation. For this analysis, the final value of the central values was used as the representative value. Table A.3-1 shows interval-specific head information for Well ER-EC-5. The methodology for calculating the head for the middle and lower intervals depends upon the e-tape reference head measurement and the change in PXD pressure from before to after the bridge plug is set. This method is insensitive to wireline errors for the PXD set depth. There has been no correction for friction losses due to gradient-driven circulation in the well.

The data indicate a slight downward hydraulic gradient: the head of the middle interval was 0.03 ft less than the head of the upper interval, and the head of the lower interval was 0.08 ft less than the head of the middle interval. The head adjustments for both the middle and upper intervals were upwards, and the lower interval representative head was the same as the well composite head. This would suggest that the lower interval is the most transmissive and is the primary control for the composite head.

These differences in calculated head between intervals are much smaller in magnitude to the absolute potential measurement errors. Quoted accuracy for the PXDs is 0.1 percent of Full Scale. Treating the nominal accuracy as measurement uncertainty, the potential uncertainty for the middle interval pressure measurement is +/- 0.75 psi, and for the lower interval is +/- 1.0 psi. These uncertainties result in potential uncertainty in the head difference of +/- 0.75 psi (approximately 1.8 ft) between the upper and upper middle interval, and 1.75 psi (approximately 4 ft) between the middle and the lower interval. However, the data reduction method uses relative changes for which the uncertainty is less. The uncertainty will be analyzed in more detail in the analysis report.

Table A.3-1
ER-EC-5 Interval-Specific Heads

Measurement	Well Composite	Upper Interval	Middle Interval	Lower Interval
Head - Depth ft bgs	1,017.50	1,017.39	1,017.42	1,017.50
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			+0.12	0.0
Composite Water Density Conversion Factor ft/psi	---	---	2.318	2.322
Representative Pressure psig	---	---	332.00	488.22
Preset Pressure psig	---	---	331.95	488.22
Reference Head ft	---	---	1,017.54	1,017.50
PXD Set Depth ft	---	---	1,788.28	2,149.16
PXD Serial Number	---	---	21014	21016
PXD Range psig	---	---	0-750	0-1,000

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

A.3.1.3 Correction of Bridge Plug Set Depths

As mentioned in Section A.2.4, the bridge plug set depths have been corrected from the originally specified set depths. Table A.3-2 shows the specified and the corrected depths. These corrections were supplied by BN Geophysics, who oversaw these measurements. The bridge plugs were located by placing them a specified distance from a reference casing collar that was located downhole based on the casing tallies from well construction. Corrections were required for 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 @ +50 ft	2,199.50	670.41	2,198.64	670.15
Lower Interval Calibration @ -50 ft	2,100.70	640.29	2,099.78	640.01
Lower Interval Set Depth	2,150.00	655.32	2,149.16	655.06
Middle Interval Calibration @ +50 ft	1,839.00	560.53	1,837.75	560.15
Middle Interval Calibration @ -50 ft	1,739.50	530.20	1,738.90	530.02
Middle Interval Set Depth	1,789.00	545.29	1,788.28	545.07

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.3.1.4 Composite Water Density

The calculated composite density conversion factors were 2.322 and 2.318 ft of water column/psi (0.984 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 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 gravities of 0.984) calculated from the PXD installation for monitoring drawdown for the constant-rate test. 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.3.1.5 Thermal Flow Logging

The thermal flow logging found downward flow of 2.2 gpm starting in the upper two slotted joints of the upper completion interval, and disappearing in the lower two slotted joints of the lower completion interval. However, the flow measurement values are at the upper limit of the thermal flow log instrument range, and actual downward flow rates may be higher. Consequently, the measurements cannot indicate whether downward flow rates increased or decreased in the middle completion interval.

A.3.2 Well Development

Well development actions did not appear to have a large effect on improving the hydraulic efficiency of the well. Very little sediment was produced. A small improvement in specific capacity (drawdown divided by production rate) of the well during development was noted.

A.3.3 Flow Logging During Pumping

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

A.3.3.1 Optimal Flow Logging Run

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

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

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

Where:

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

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

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.3.3.2 Intervals of Inflow

The trolling flow logging during pumping indicates that the middle interval produced the greatest proportion of the water produced, approximately 69 to 77 percent. Figure A.2-7 through Figure A.2-12 showed the stressed flow logging for Well ER-EC-5. Figure A.2-7, Figure A.2-9, and Figure A.2-11 show the flow logs at 20 fpm down-line speed for the three different pumping rates. This logging configuration appears to be optimal for producing good information. Table A.3-3 is a tabulation of the approximate cumulative water production from the three completion intervals based on the graphical log for the 20 fpm down-line speed.

Table A.3-3
Water Production From Completion Intervals During Pumping
(From Trolling Flow Logging)

Completion Interval	Percentage of Total Production		
	60 gpm	111 gpm	161 gpm
Upper	13	17	18
Middle	77	70	69
Lower	10	13	13

The results for different pumping rates are very similar, with several minor trends apparent. As the pumping rate was increased, the upper interval appeared to produce proportionally more while the middle interval produced proportionally less. This may be a result of increasing friction losses for the deeper production as the velocity in the completion increased. The apparent increase in the lower interval may be an actual response to the increased drawdown or just indicate the uncertainty in the measurements. The graphical flow logs show that the logged production within the completion intervals increased stepwise corresponding to the locations of the slotted sections of the completion casing. For the lower two intervals, production can be interpreted to increase consistently across the interval. However, the full production for the middle interval appears to have been reached by the middle of the upper double-set of slotted casing joints. The logging across the upper interval does not show a clean pattern, which may be the result of fluctuations in line speed.

The stationary flow measurements during pumping produced somewhat different results. The major discrepancy is in the production from the lower completion interval. The stationary measurements indicated less than 1 percent from the lower interval during pumping versus the 10+ percent indicated by the trolling logging. The low stationary measurements above the lower interval may be affected by the low uphole velocities, which would be near the lower limit of the capabilities of the instrument.

The bridge plug measurements determined very little vertical head gradient. This would suggest that most of the difference in production between the completion intervals can be attributed to different transmissivities of the formations in the intervals, after accounting for flow losses uphole. This line of reasoning would attribute the greatest transmissivity to the middle interval. However, other evidence suggests that the lower interval has the greatest transmissivity. This difference may be resolved when the downhole hydraulics of the well are analyzed, incorporating the vertical gradient and especially friction losses of flow from the lower intervals. These factors may be relatively large proportionate to the drawdown, which was less than 6 feet. In particular, the friction losses of flow in the completion casing are probably a significant factor due to the relatively long length of the completion.

A.3.4 Constant-Rate Test

The drawdown and recovery data from the constant-rate pumping test have been processed to adjust for the influences of barometric pressure changes.

A.3.4.1 Barometric Efficiency

Barometric efficiency is a measure of the proportional response of the head (water level) in the well to a change in barometric pressure; when barometric pressure rises, the head will be depressed by some fractional amount. The response of the upper completion interval to barometric changes was determined from the monitoring record for the upper interval during the bridge plug measurement. This was used to correct the upper interval equilibration record, as discussed in Section A.3.1.2. The barometric efficiency for the entire well (all three completion intervals) was determined from the predevelopment water level monitoring record, and this result was used for correction of the constant-rate test. The method used for determining barometric efficiency was to overlay the barometric record onto the PXD pressure record and adjust it with a scaling factor and a trend until a best fit was obtained. The trend is added to remove the effect of any trend in the water level not due to barometric response. To overlay the barometric record onto the PXD record, the barometric record was converted into psi, offset onto the PXD record, and reversed to match the sense of the response. The resultant factors are the barometric efficiency and a linear trend characterizing the PXD pressure record.

Figure A.3-6 shows the PXD pressure record for the predevelopment monitoring period with the barometric record adjusted for a best-fit overlay. The best-fit result was a barometric efficiency of 88 percent with a trend of -0.0006 psi/day. This is somewhat different from the best-fit factors for the upper completion interval, which were barometric efficiency of 75 percent and a trend of -0.007 psi/day. The overlay of the adjusted barometric record onto the PXD pressure record for the upper interval monitoring is shown in Figure A.3-7. The higher barometric efficiency of the entire well seems reasonable since it includes the middle completion interval, which was the most productive interval and/or the lower interval, which may be the most transmissive. Both PXD pressure records seemed to have downwards trends, although the apparent trend during the upper interval equilibration was an order of magnitude greater. This trend, in particular, is counterintuitive since the interval head rose following setting of the bridge plug. However, the adjustment was only 0.26 ft, which may have occurred rapidly before the PXD was installed. The trend may, in fact, be unrelated to the equilibration following setting of the bridge plug. The magnitude of these measurements of changes are all within the uncertainty of our ability to measure.

A.3.4.2 Drawdown Record

Figure A.3-8 shows the resultant record for the constant-rate test and recovery period. The pressure drawdown record was converted to equivalent change in groundwater head using a conversion value for pressure to water head derived from the head measurement and pressure data collected when the PXD was removed after testing. This information is presented in Table A.2-8. The correction for barometric variation did not have a great effect on the drawdown curve because the magnitude of the drawdown was proportionally much greater, but the effect of the correction is noticeable on the recovery curve.

Figure A.3-9 and Figure A.3-10 provide expanded views of the start of the pumping test and the beginning of the recovery monitoring, respectively. These expanded views show that there is a smooth curve for interpretation, and that the drawdown response and the recovery occurred very quickly. There are also several other features to note. During startup, shown in Expanded View of the Start of the Constant-Rate Test (Figure A.3-9), the drawdown initially overshot the drawdown curve for the target flowrate and then recovered back to it when the pumping rate was reduced to the correct value. This was the result of the VSD overspeeding the pump due to lack of signal from the flowmeter, as mentioned in Section A.2.8.2. Figure A.3-10 shows the time period just before the shutdown of the pump through the early-time of the recovery response. The initial response following pump shutdown indicates that the check valve did not hold and that the water in the production tubing above the pump backflowed into the well. It is thought that the check valve became unseated during the pumping phase of the test. The water level in the well immediately rose above the equilibrium level and then decayed back to the actual recovery curve. The magnitude of the effect is similar to that observed during development without a check valve installed.

These problems do not invalidate the test, but do produce more uncertainty in interpretation of the curves, especially the recovery curve. A large proportion of the high-curvature section of the recovery curve is affected by the reinjection of water in the production tubing above the pump. The effect is exacerbated by the very quick response of the well since the effects obscure a large portion of the most important part of the curve. The installation of the check valve in this well was problematic, so the failure of the check valve to hold would not be surprising.

A.3.5 Water Quality

A variety of general water quality parameter information was collected, including parameters for grab samples taken during pumping, some data collected using a Hydrolab® flow-through cell, and DRI ChemTool logs run both before Well ER-EC-5 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.3.5.1 Grab Sample and Hydrolab® Results

Water quality parameter values measured for grab samples taken from produced water are shown in Attachment 2. During the course of pumping pH declined from somewhat erratic values in the low 8's and upper 7's to fairly consistent values in the high 7's (7.8 - 8.0). This is illustrated in Figure A.3-11, which shows the change in pH versus the total gallons pumped for development. Also shown on this graph is the pumping rate versus total gallons pumped. This juxtaposition of parameters illustrates the relationship of the instantaneous pH value with the recent pumping history. Whenever the pumping is stopped and/or the pumping rate changed the pH values respond with an adjustment. There is a rebound effect whenever pumping is stopped that appears to diminish with time. There may also be an indication that the pH values are lower during lower pumping rates. The EC values were consistently in the low 400s μmhos/cm, and became more consistent with pumping. Values did not substantially change during development. Figure A.3-11 also shows EC plotted with the pumping rate to show the response to pumping changes, which are much less significant.

In comparing grab sample results to Hydrolab® results, it should be noted that all the Hydrolab® data was collected during development when the water quality parameter values were much more erratic than during the constant-rate test. This is probably due both to incomplete development and constantly changing pumping conditions. The Hydrolab® pH values are very similar to the grab sample values, while the EC values are somewhat lower. In general, the Hydrolab® data may be judged as in agreement with the grab sample data, and shows the recurrent equilibration of parameter values to changes in pumping conditions.

A.3.5.2 Precompletion Versus Postdevelopment

The ChemTool log of downhole water quality parameters was run at the very end of the testing program, and gives another type of picture of the effectiveness of the development and testing activities on water quality restoration. The next three figures show the ChemTool logs that were run following drilling, but prior to well completion side-by-side with the logs that were run following well development and testing. Figure A.3-12 shows temperature logs, Figure A.3-13 shows the pH logs, and Figure A.3-14 shows EC logs. Included in these figures are lithologic information and well completion details.

The predevelopment and posttesting temperature logs show slight differences. The temperature above the upper completion interval is lower for the posttesting log, presumably due to the decrease in heat evolution from the cement in the annulus of the surface casing. The temperatures from the upper completion downwards are very similar. The posttesting log does not show the small temperature increases along the sections where the casing was cemented. The parameters pH and EC can generally be interpreted to give an indication of the representativeness of the water within the well relative to formation water. The postdevelopment pH log indicates pH between 8.2 and 8.3 throughout the water column, higher than the precompletion pH log which showed pH between 7.7 and 7.8. The EC log indicates significantly lower EC values postdevelopment, generally between 275 and 300 μmhos/cm versus about 430 μmhos/cm precompletion. This log appears noisy but consistent. Both logs show consistency from the bottom of the well through the upper completion interval.

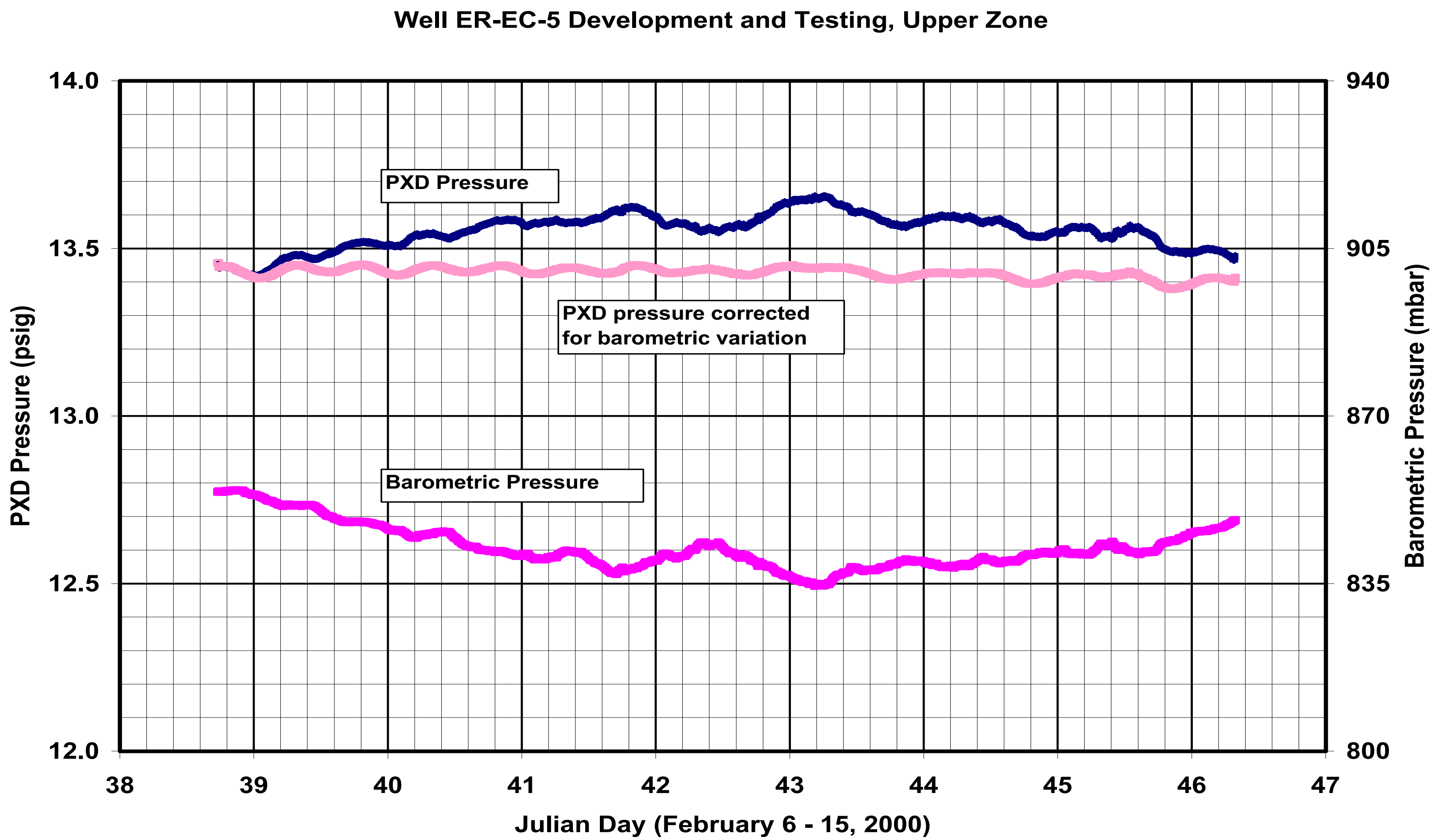
A.3.5.3 Grab Sample Results Versus ChemTool Results

The grab sample results (see Table ATT.2-1, Attachment 2) showed pHs in the low 8s for the first 7.5 hrs of the constant-rate test declining to upper 7s. This difference may be the result of a rebound effect or a higher pH in the upper completion which spreads downward due to downward flow under the natural gradient. Also, the calibrations of the different instruments used for these measurements should be compared to make sure they are consistent. Otherwise, the different conditions under which the measurements are made (e.g., wellhead versus downhole) may produce results which are not exactly comparable. The grab sample results for EC during the constant-rate test were in the 420-430 μmhos/cm range, consistent with the precompletion EC log, but not with the posttesting log. This discrepancy may also be due to a change in downhole water chemistry due to natural gradient flow versus pumping production, or there may have been a calibration discrepancy between the instruments.

A.3.6 Representativeness of Hydraulic Data and Water Samples

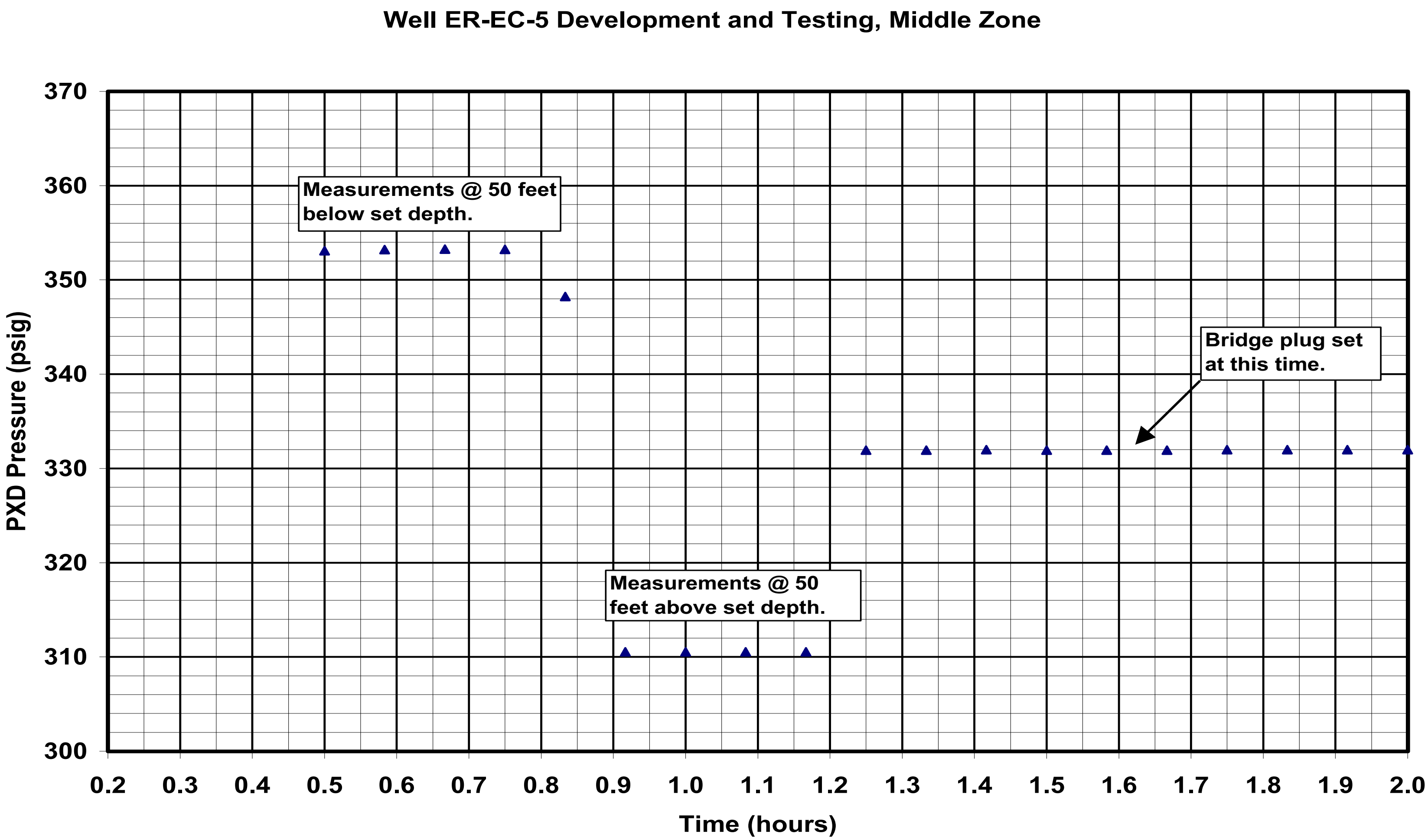
The results of testing Well ER-EC-5 for water quality, development, hydraulic testing, and composite sampling can be considered to represent the entire well as completed. The constant-rate test produced good data for all three completion intervals and the analysis for hydraulic parameters can be apportioned to those intervals individually.

Likewise, the water quality information obtained (both general parameters from grab samples and results of laboratory analyses of samples) can be interpreted to provide information on all three completion intervals. All three completion intervals can probably be considered to be developed to varying degrees. Judgement as to the representativeness of the samples from the lower two intervals will depend somewhat on the results of the discrete sampling and a tabulation of the cross flow in the well versus the amount produced from each of the lower intervals. Since natural flow in the well appears to be downward, the upper completion interval continually produces water, and does not naturally receive water from any source. Therefore, this interval will probably maintain its individual character for future sampling. The thermal flow log data does indicate downward flow to the lower two intervals. However, it is not clear if the downward flow from the upper completion interval enters the middle completion interval or continues intact downwards to the lower completion interval. There may be some interchange of water in the middle completion interval, but this cannot be determined from the thermal flow logging. Consequently, the volume required for purging of the middle interval for future sampling cannot be specifically determined. However, the lower interval appears to receive at least 2.2 gpm continuously, and would require substantial purging to regain its unique geochemical character.



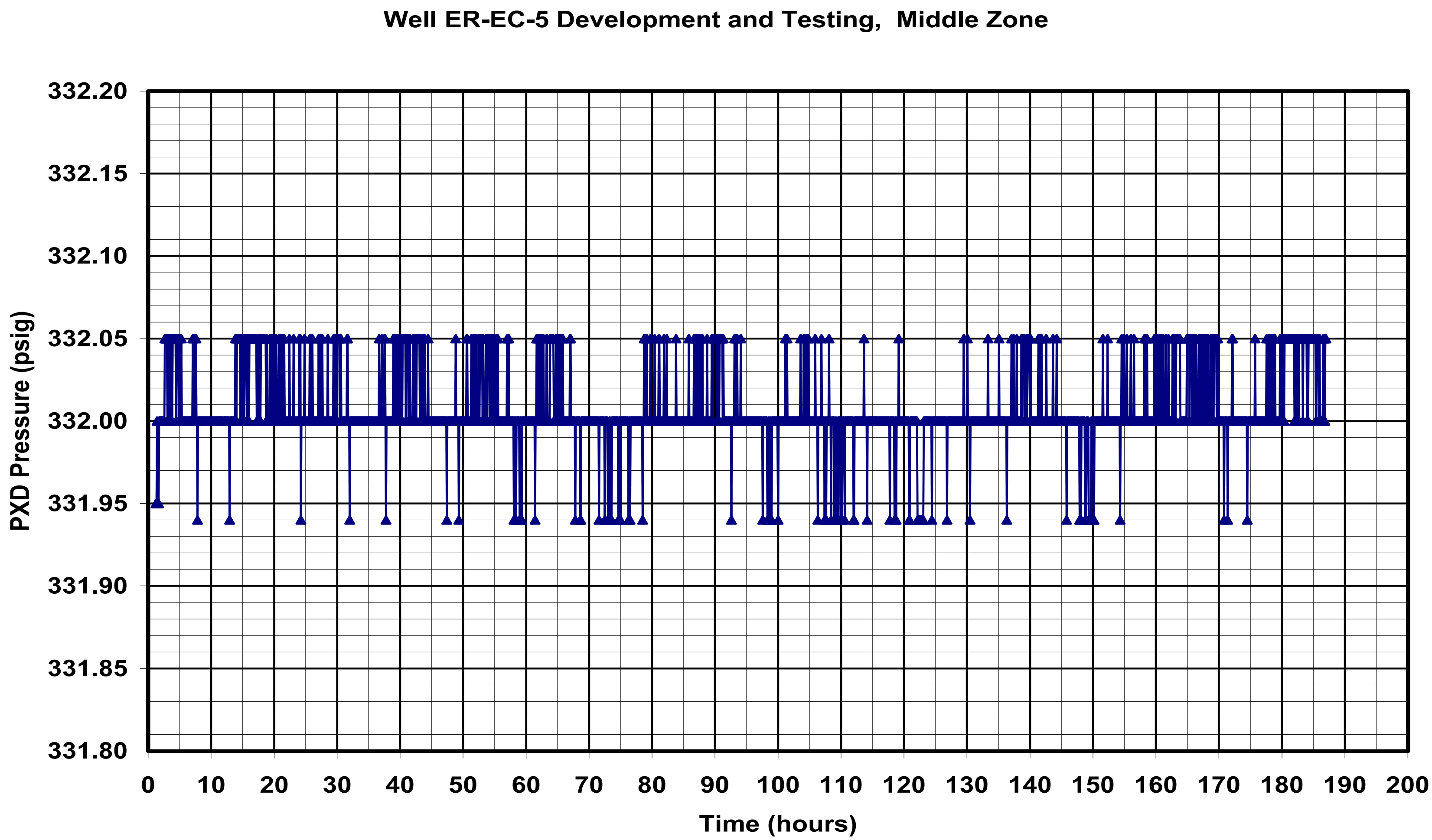
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



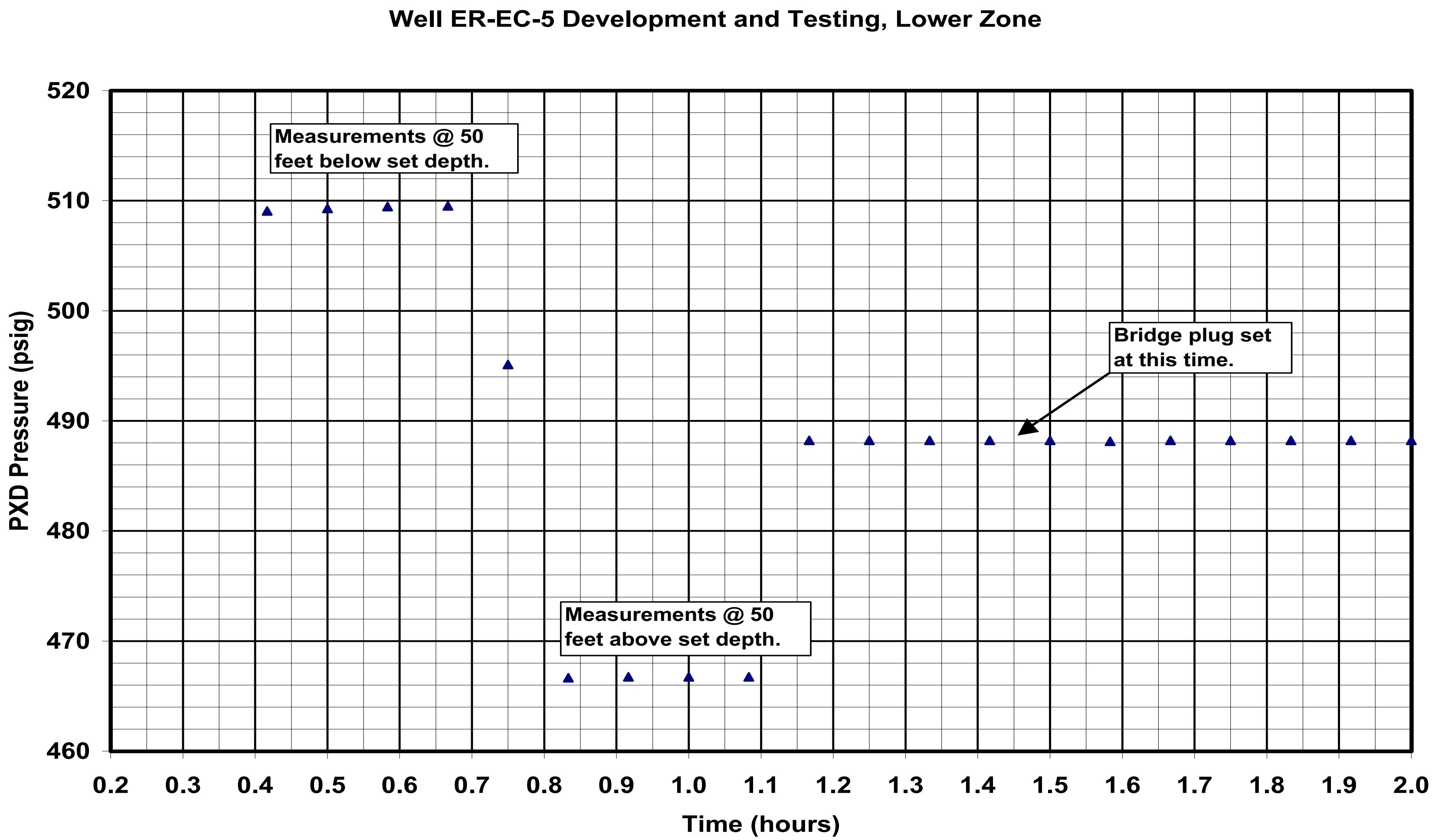
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



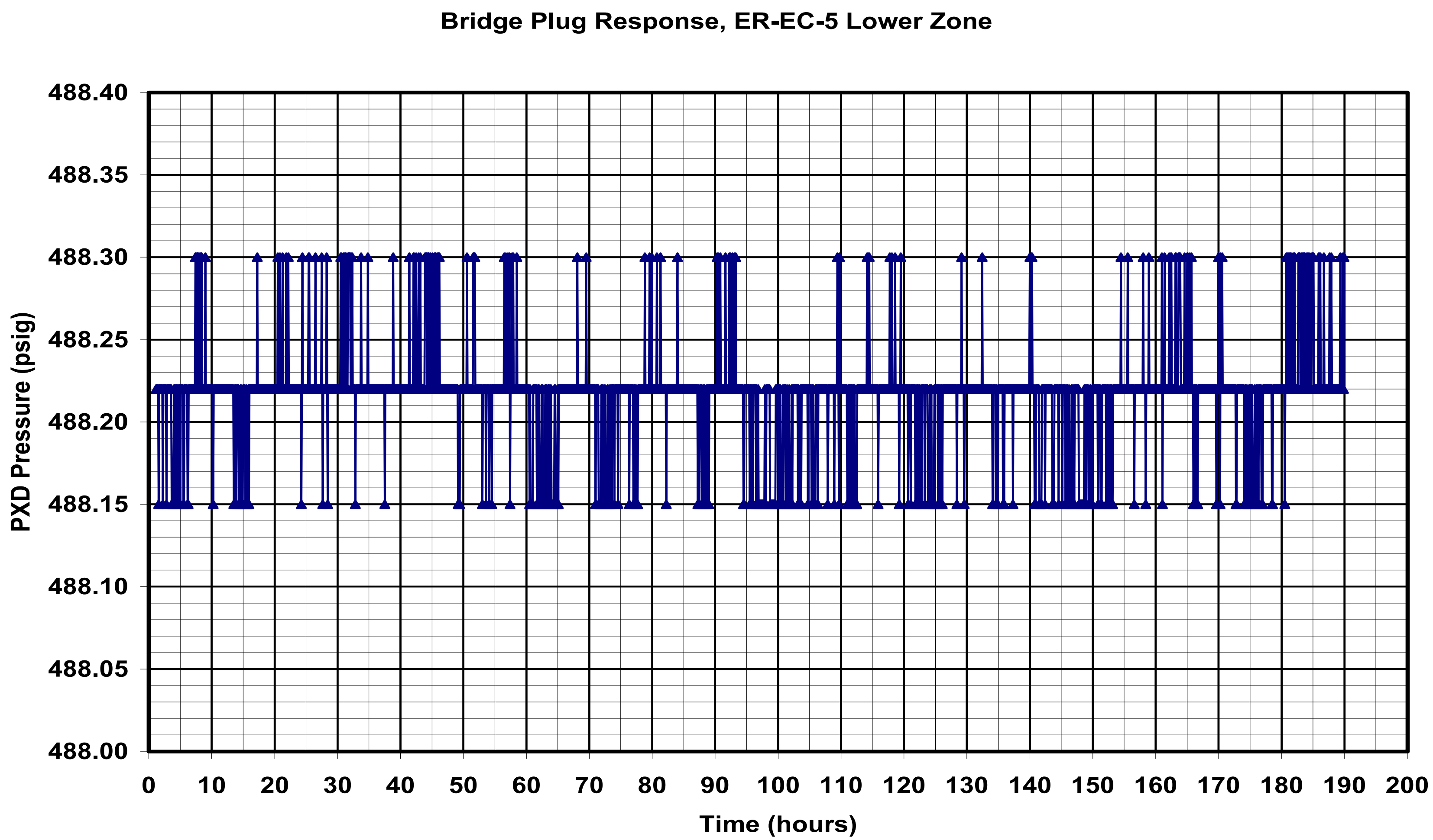
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



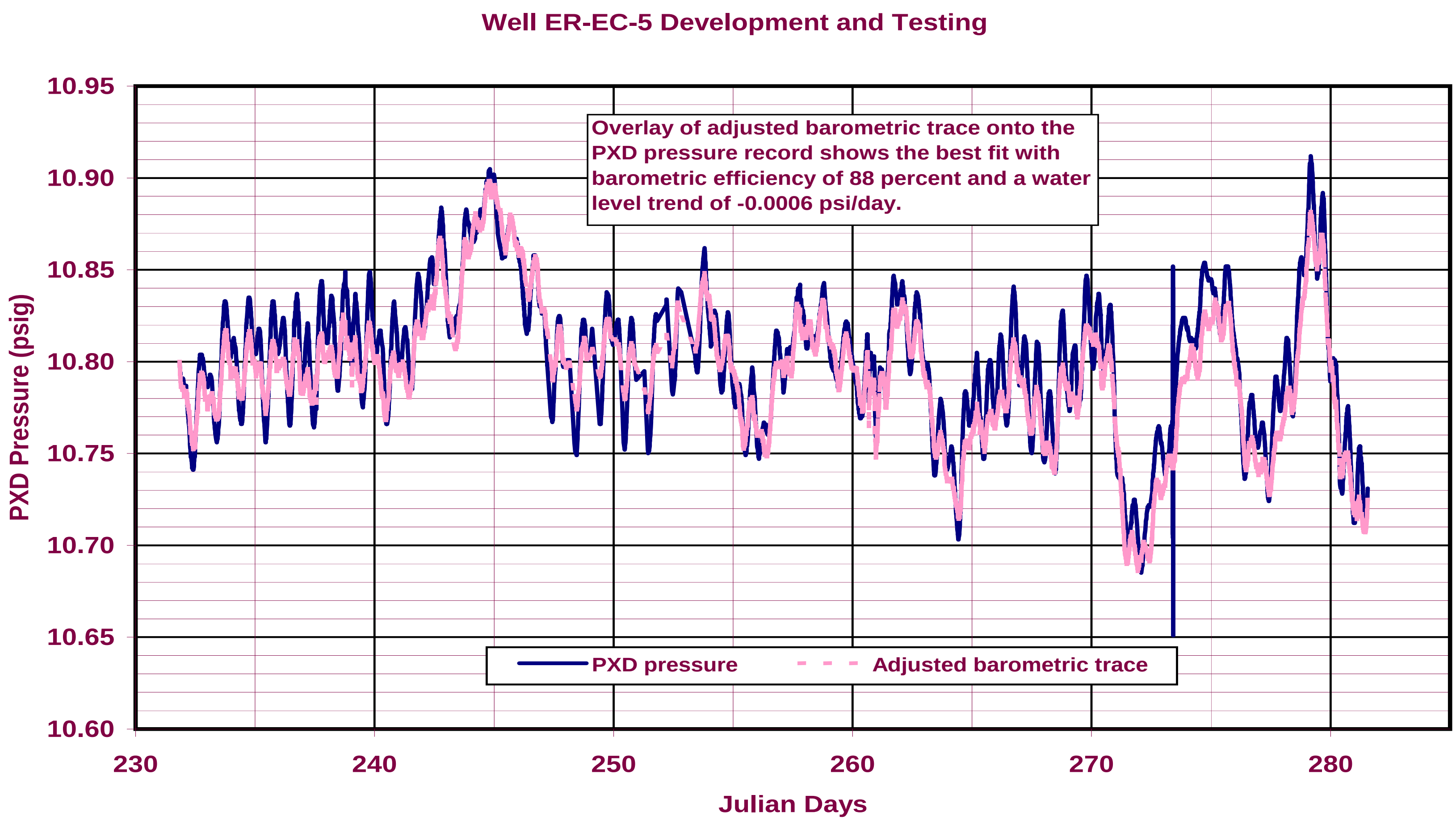
psig - Pounds per square inch gauge
PXD - Pressure transducer

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



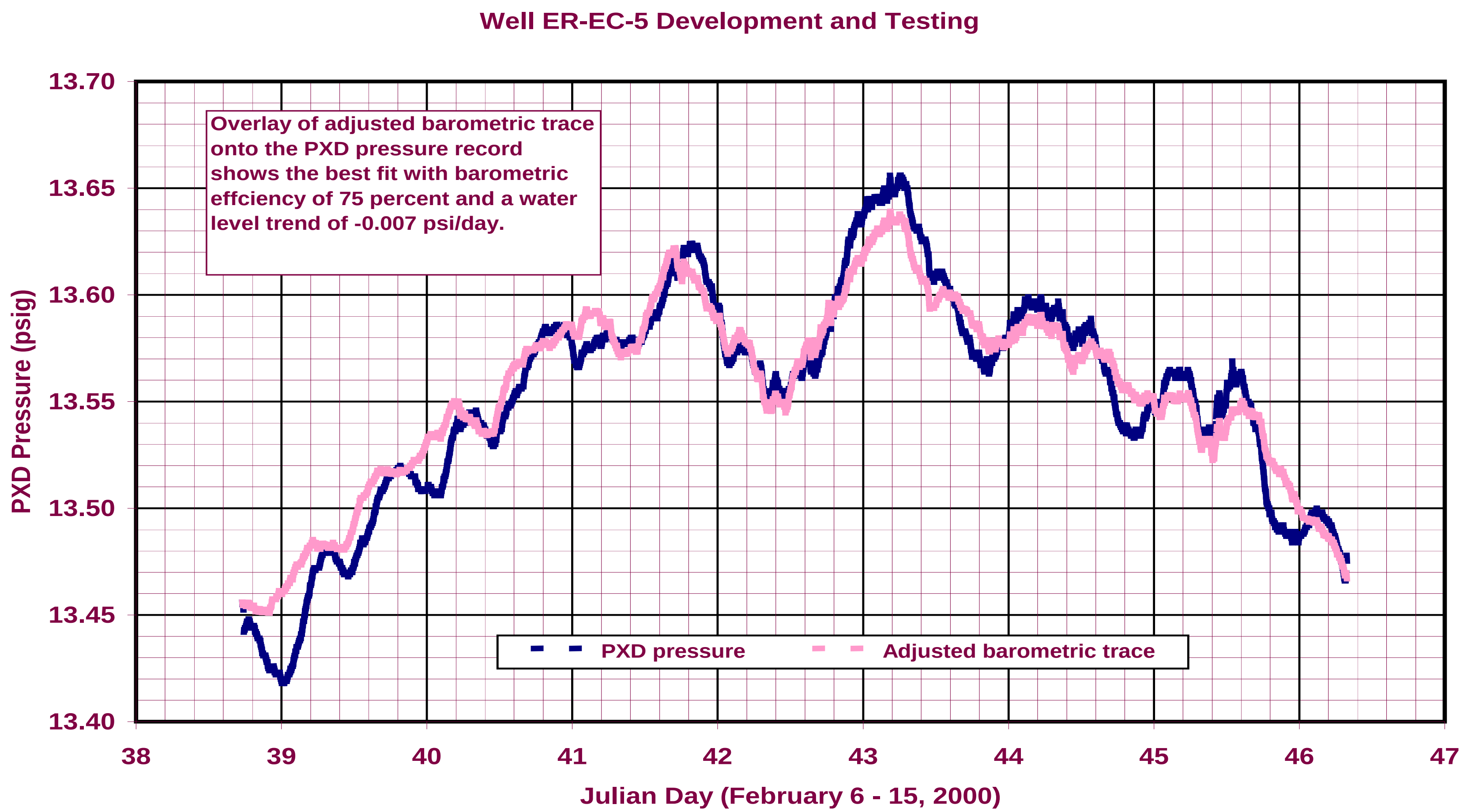
psig - Pounds per square inch gauge
PXD - Pressure transducer

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
Barometric Efficiency Overlay for Predevelopment Water Level Monitoring



psig - Pounds per square inch gauge
PXD - Pressure transducer

Figure A.3-7
Barometric Efficiency Overlay for Upper Interval Water Level Monitoring

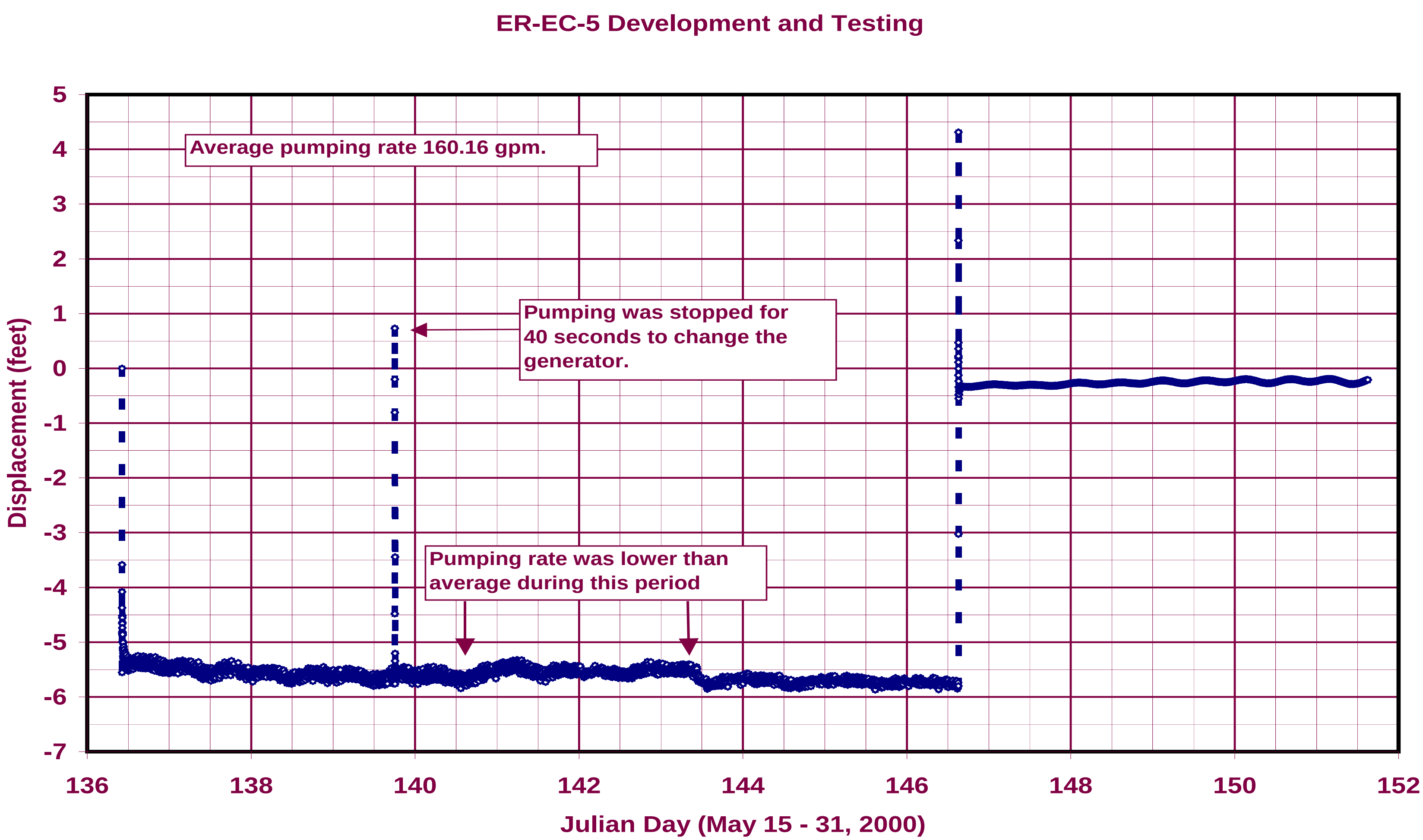


Figure A.3-8
Constant-Rate Pumping Test with Barometric Correction

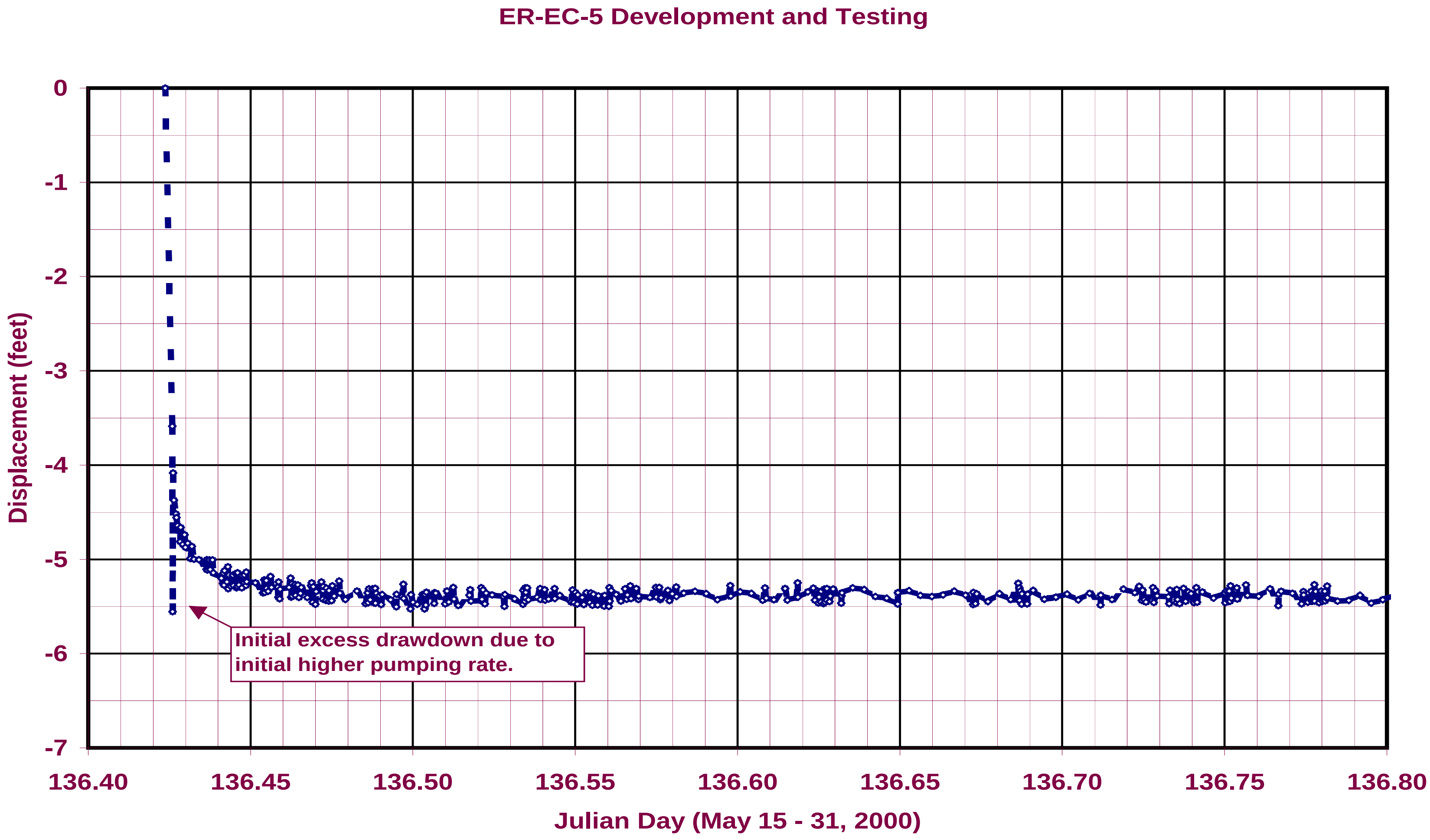


Figure A.3-9
Expanded View of the Start of the Constant-Rate Test

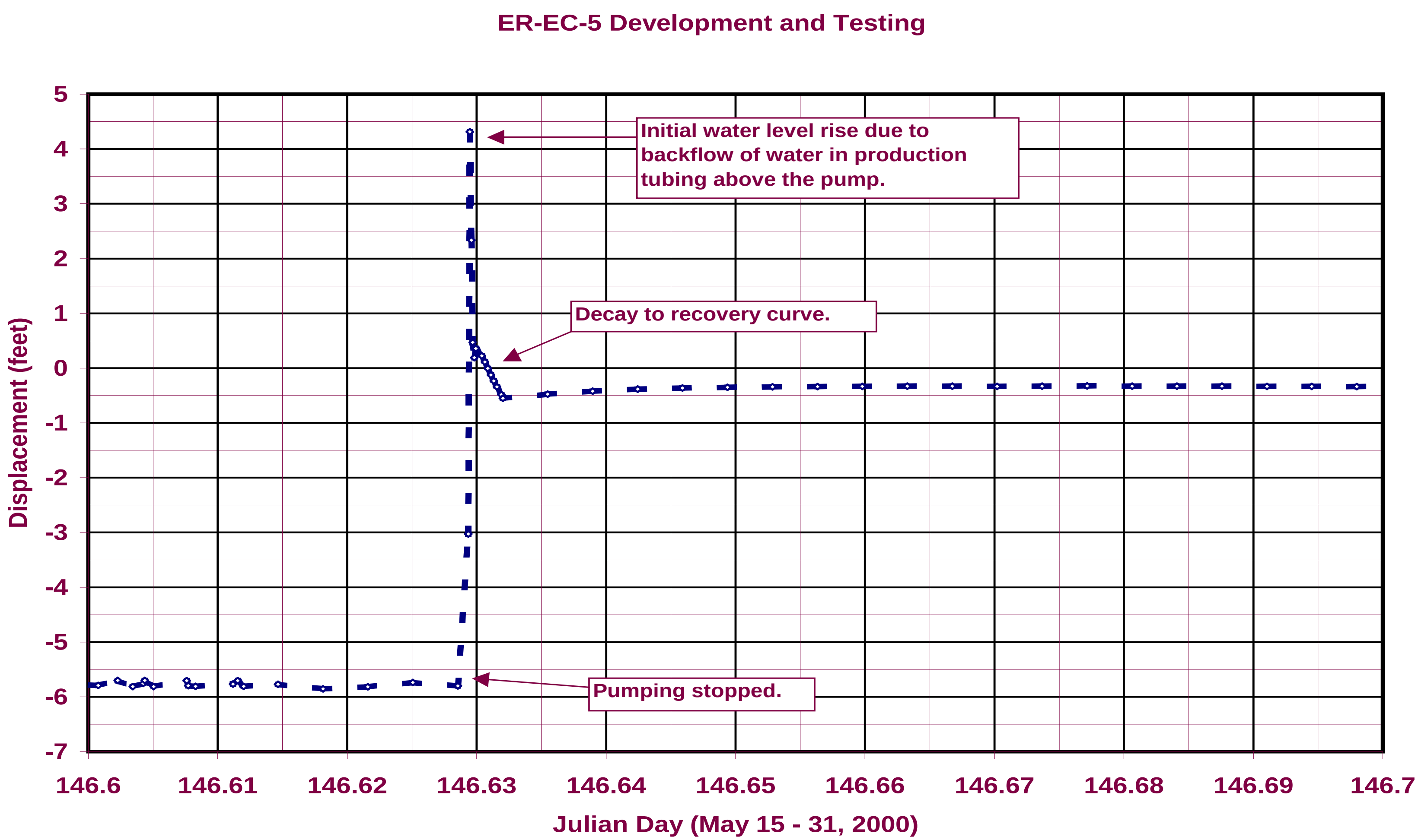
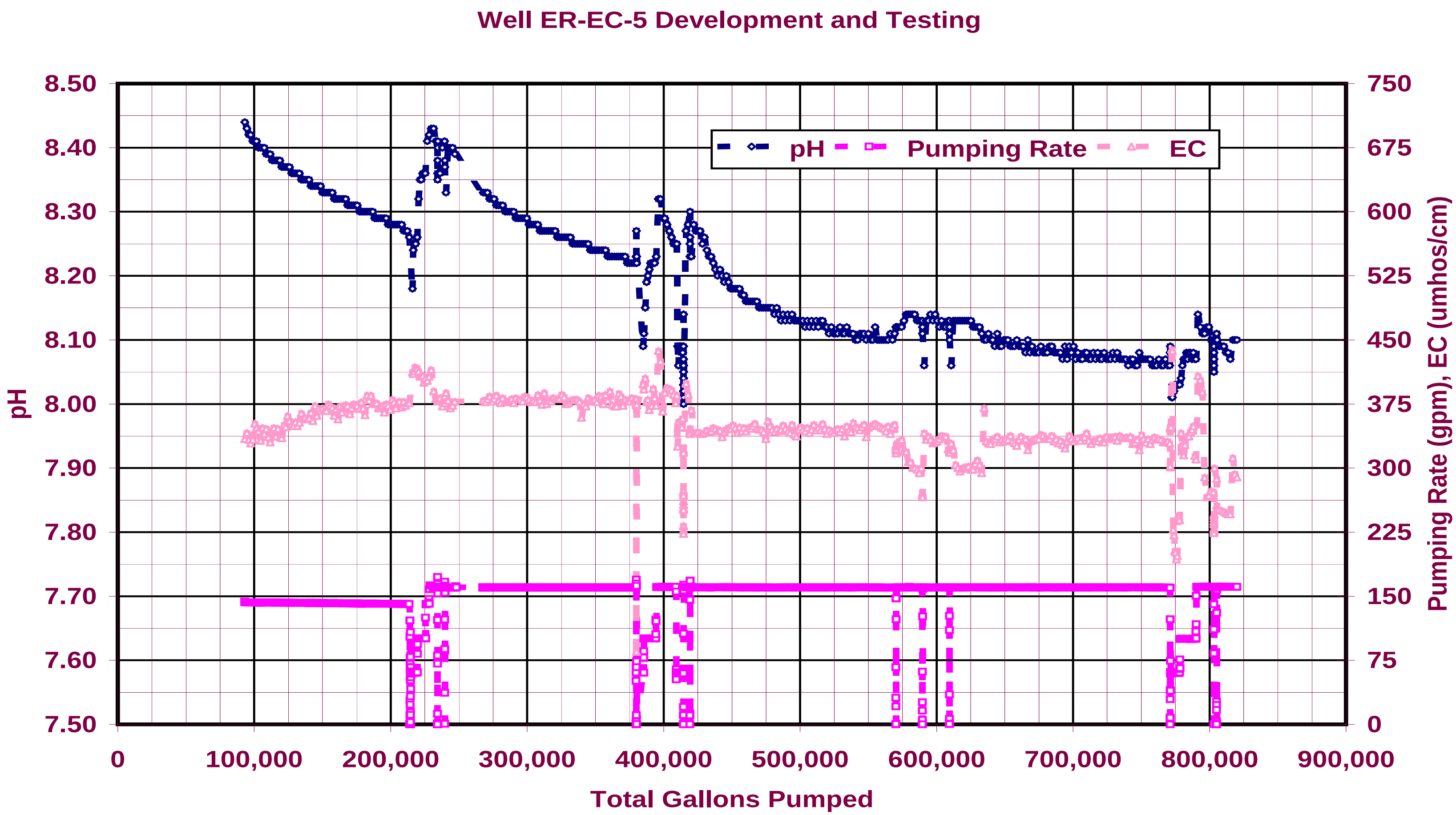


Figure A.3-10
Expanded View of the Start of Recovery



EC - Electrical conductivity
gpm - Gallons per minute
umhos/cm - Micromhos per centimeter

Figure A.3-11
pH and EC Versus Pumping Rate

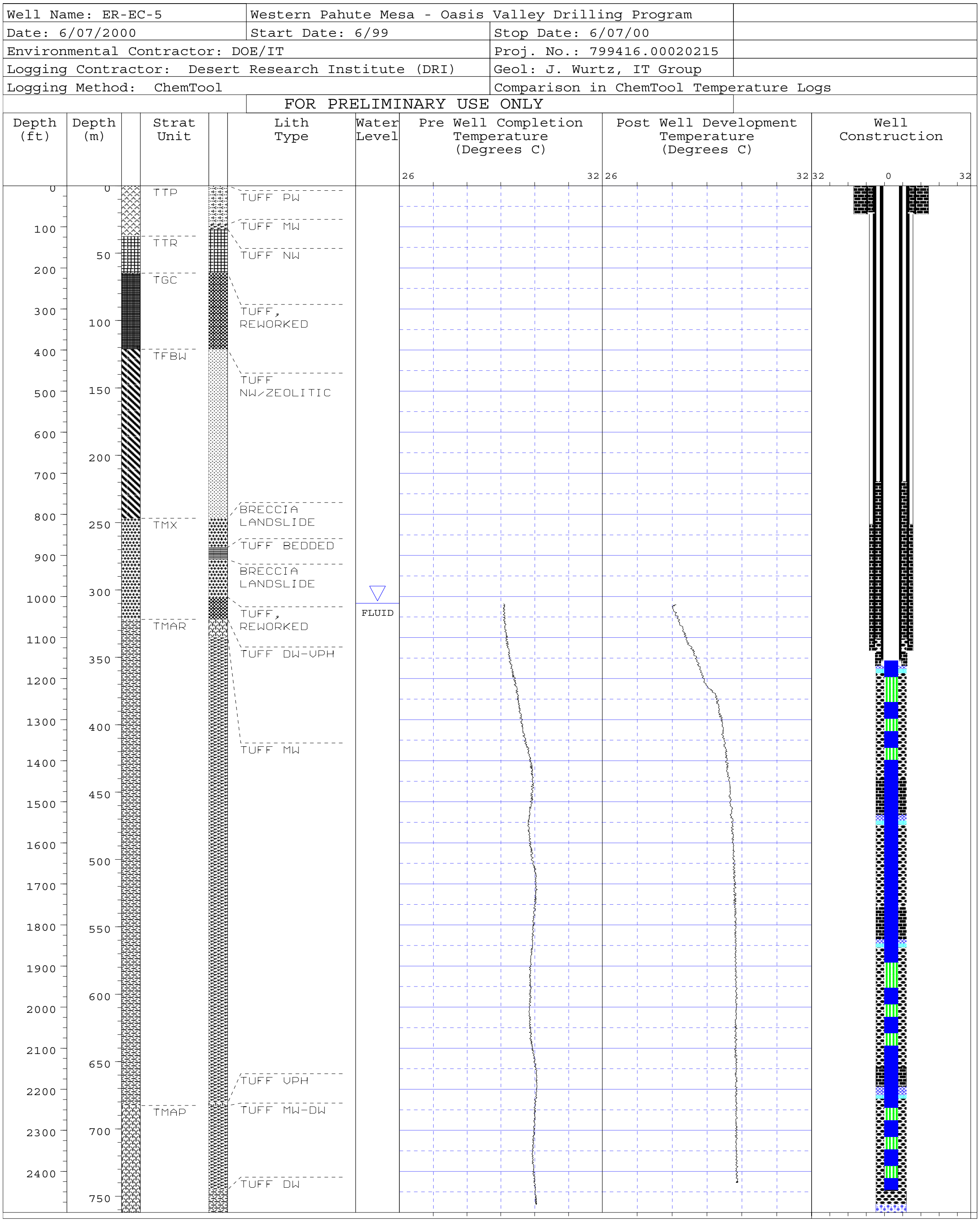


Figure A.3-12
Temperature Log Prior to Completion Versus Postdevelopment

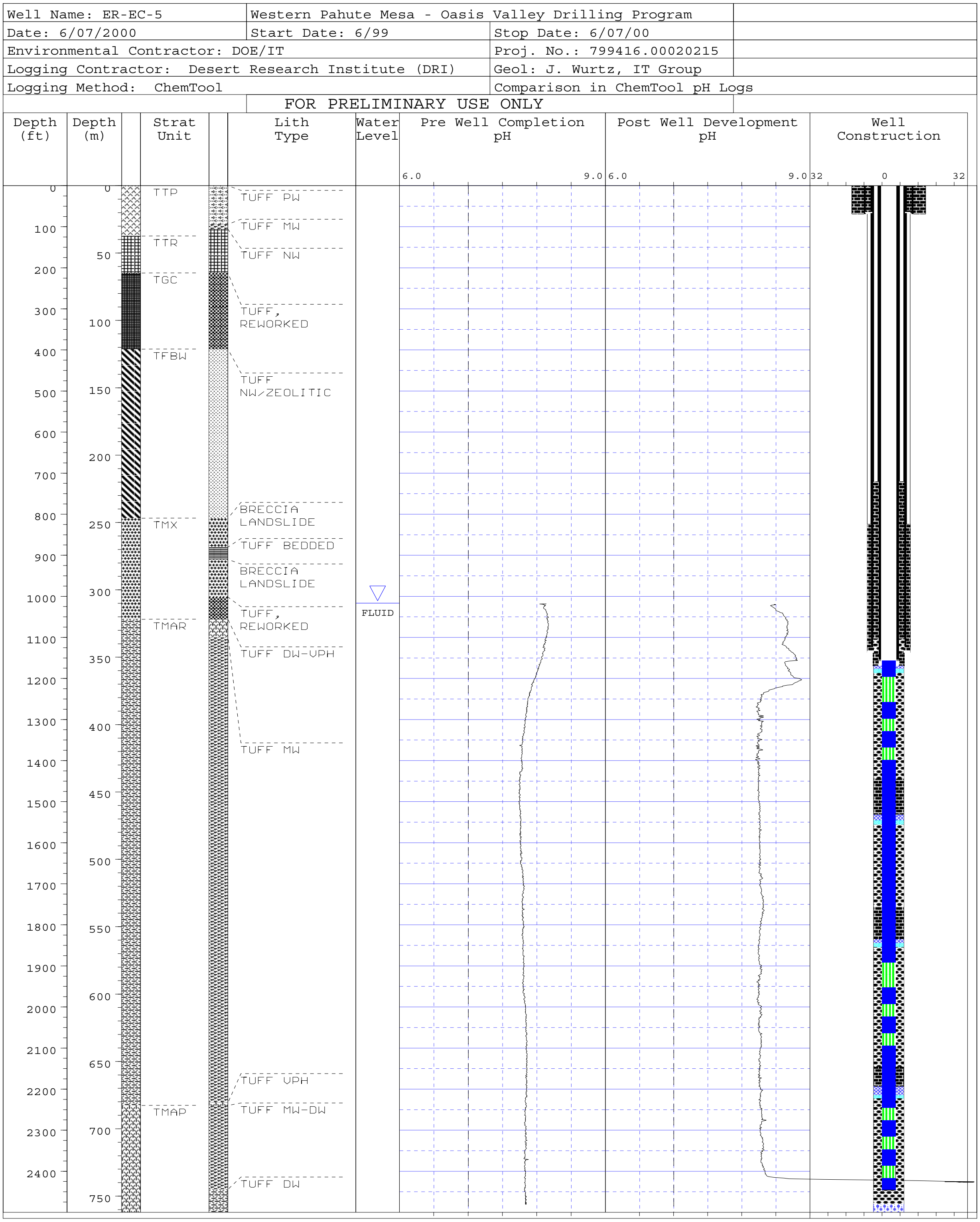


Figure A.3-13
pH Log Prior to Completion Versus Postdevelopment

Well Name: ER-EC-5	Western Pahute Mesa - Oasis Valley Drilling Program		
Date: 6/07/2000	Start Date: 6/99	Stop Date: 6/07/00	
Environmental Contractor: DOE/IT		Proj. No.: 799416.00020215	
Logging Contractor: Desert Research Institute (DRI)		Geol: J. Wurtz, IT Group	
Logging Method: ChemTool		Comparison in ChemTool EC Logs	

FOR PRELIMINARY USE ONLY

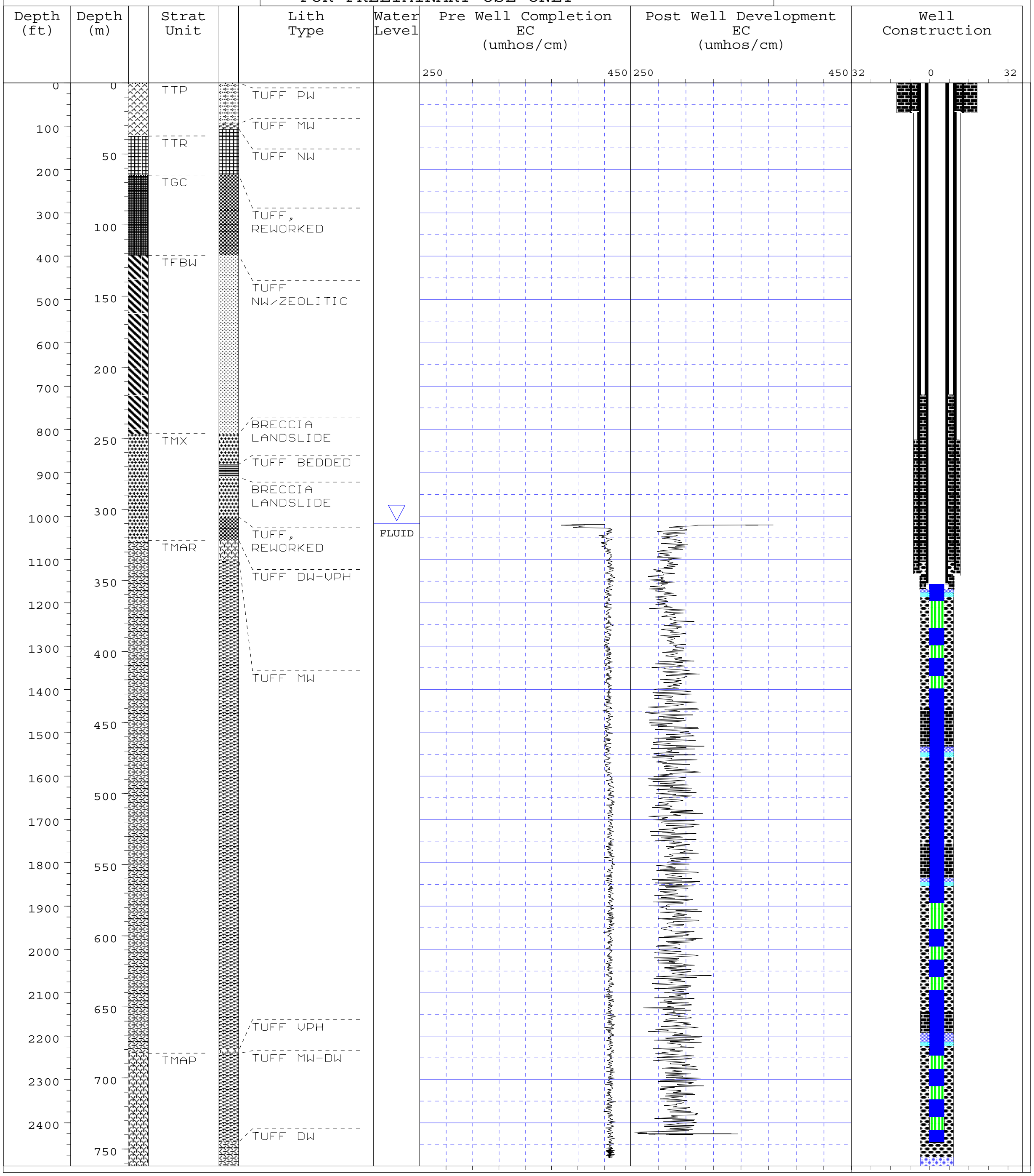


Figure A.3-14
EC Log Prior to Completion Versus Postdevelopment

A.4.0 Environmental Compliance

A.4.1 Fluid Management

All fluids produced during well development and hydraulic testing activities were managed according to the *Fluid Management Plan for the Underground Test Area Subproject* (FMP) (DOE/NV, 1999) and associated state-approved waivers. In accordance with the FMP and the waivers, the fluids produced during drilling were monitored and tested for tritium and lead daily. Several samples of water were collected from the sumps and analyzed at a certified laboratory for total and dissolved metals, gross alpha/beta, and tritium. Based on this process knowledge, the DOE/NV requested a waiver for the disposal of fluids produced during well development/hydraulic testing for Wells ER-EC-1, ER-EC-4, ER-EC-5, ER-EC-7, ER-EC-7, ER-EC-8, and ER-18-2. The DOE/NV's proposal was to conduct activities at these well sites under far-field conditions with a reduced frequency of on-site monitoring. In October 1999, the Nevada Division of Environmental Protection (NDEP) granted DOE/NV a waiver to discharge fluids directly to the ground surface during well development (NDEP, 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 Standard [NDWS]), then sampling must occur every 12 hours until two consecutive nondetects occur. Sampling and testing may then resume on the 24-hour schedule.

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

A.4.1.1 Water Production and Disposition

At Well ER-EC-5, 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 at approximately 7.7 ft from the bottom. Discharge to the ground surface occurred after 343,200 gals had been pumped into the sump.

A total of approximately 3,556,300 gals of groundwater were pumped from Well ER-EC-5 during well development, hydraulic testing, and sampling activities. Table A.4-1 contains the Fluid Disposition Reporting Form for the testing program.

A.4.1.2 Lead and Tritium Monitoring

Lead and tritium samples were collected daily according to the FMP and 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 1,981.5 picocuries per liter (pCi/L). 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 May 25, 2000, and sent to Paragon. The FMP parameters of total and dissolved metals, gross alpha and beta, and tritium were requested for analysis. The laboratory results are presented in Table A.4-3 and compared to the NDWS.

A.4.2 Waste Management

Wastes generated during well development and testing activities were managed in accordance with the *Underground Test Area Subproject Waste Management Plan,* Revision 1 (DOE/NV, 1996); the *Waste Management Field Instructions for the Underground Test Area Subproject* (IT, 1997); SQP ITLV-0501, “Control of

Table A.4-1
Fluid Disposition Reporting Form

Site Identification: ER-EC-5
Site Location: Nellis Air Force Range
Site Coordinates: N 4,104,137, E 538,702 (UTM Zone 11, NAD 83, meters)
Well Classification: ER
IT Project No.: 799416.00020215

Report Date: July 18, 2000
DOE/NV Subproject Manager: Bob Bangerter
IT Project Manager: Janet Wille
IT Site Representative: Jeff Wurtz
IT Environmental Specialist: Patty Gallo

Well Construction Activity	Activity Duration		#Ops. Days[a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes[c] (m^3)		Volume of Infiltration Area (m^3)	Other[d] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids[b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	6/24/99	6/28/99	5	346.5	537.4	67.8	280.9	N/A	N/A	280.9	N/A	YES
Phase I: Saturated-Zone Drilling	6/30/99	7/4/99	5	415.5	702.7	47.8	1,057	12.5	1,247.1	2,304.1	N/A	YES
Phase II: Initial Well Development	4/13/00	5/11/00	10	762	0	N/A	4,642.7	N/A	N/A	4,642.7	N/A	YES
Phase II: Aquifer Testing	5/11/00	5/30/00	11	762	0	N/A	8,817.9	N/A	N/A	8,279.2	N/A	YES
Phase II: Final Development	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
Cumulative Production Totals to Date:			31	762	992.1	115.6	14,798.5	12.5	1,247.1	15,506.9	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] Optional fluid management devices not installed for this well site.
[d] Other refers to fluid conveyance to other fluid management locations or facilities away from the well site, such as vacuum truck transport to another well site.

N/A = Not Applicable; m = Meters; m^3 = Cubic meters;
Total Facility Capacities: Sump #1 = 1,460.8 m^3 Sump #2 = 1,971.1 m^3

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

Remaining Facility Capacity (Approximate) as of 6/15/00: Sump #1 = 922.1 m^3 (63%) Sump #2 = 1,971.1 m^3 (100%)

Current Average Tritium = 469.4 pCi/L
Notes:

IT Authorizing Signature/Date: Janet Wille 8-7-00

Table A.4-2
Results of Tritium and Lead Monitoring at ER-EC-5

Sampling Date	Sample Number	Lead Results[1]	Tritium Results[2]
		µg/L	pCi/L[a]
4/24/2000	EC-5-042400-1	1.0	357.9
4/25/2000	EC-5-042500-1	1.0	1,981.5
4/26/2000	EC-5-042600-1	< 1.0	858.4
4/27/2000	EC-5-042700-1	< 1.0	197.3
4/30/2000	EC-5-043000-1	0.5	1,560.5
5/1/2000	ER-EC-5-050100-1	< 1.0	76
5/2/2000	ER-EC-5-050200-1	1.0	583.7
5/3/2000	ER-EC-5-050300-1	< 1.0	389.9
5/4/2000	ER-EC-5-050400-1	1.0	452.7
5/15/2000	EC-5-051500-1	< 1.0	262
5/16/2000	EC-5-051600-1	< 1.0	203
5/17/2000	EC-5-051700-1	< 1.0	39
5/18/2000	EC-5-051800-1	< 1.0	35
5/19/2000	EC-5-051900-1	< 1.0	210
5/20/2000	EC-5-052000-1	1.0	386
5/21/2000	EC-5-052100-1	1.0	376
5/22/2000	EC-5-052200-1	1.0	239
5/23/2000	EC-5-052300-1	1.0	242
5/24/2000	ER-EC-5-052400-1	< 1.0	NA
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
NA - Not analyzed

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

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.

Table A.4-3
Analytical Results of Sump Fluid Management Plan Sample at Well ER-EC-5

Analyte	CRDL	Laboratory	NDWS	Results of Sump Composite Sample #EC-5-052500-4	
Metals (mg/L)					
				Total	**Dissolved**
Arsenic	0.01	Paragon	0.05	UJ 0.0059	UJ 0.0055
Barium	0.2	Paragon	2.0	J 0.0042	J 0.0041
Cadmium	0.005	Paragon	0.005	UJ 0.005	UJ 0.005
Chromium	0.01	Paragon	0.1	UJ 0.00086	UJ 0.00082
Lead	0.003	Paragon	0.015	UJ 0.003	UJ 0.003
Selenium	0.005	Paragon	0.05	UJ 0.005	UJ 0.005
Silver	0.01	Paragon	0.1	UJ 0.01	UJ 0.01
Mercury	0.0002	Paragon	0.002	UJ 0.0002	UJ 0.0002
Analyte	**MDC**	**Laboratory**	**NDWS**	**Result**	**Error**
Radiological Indicator Parameters-Level I (pCi/L)					
Tritium	280	Paragon	20,000	U 100	+/- 170
Gross Alpha	3.6	Paragon	15	U 6.2	+/- 2.9
Gross Beta	3.7	Paragon	50	U 0.9	+/- 2.1

U - Result not detected at the given minimum detectable limit or activity
J - Insufficient documentation that the sample's environmental temperatures were kept at 4 degrees C +/- 2 degrees
UJ - Same as J and also not detected
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

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

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

- Hydrocarbon: Two drums of hydrocarbon waste were produced containing oily/diesel-stained absorbent pads, soil, and debris.

- Hazardous Waste: Approximately 1/2 gallon of solid hazardous waste was generated from the installation of bridge plugs/packers. This material consists of combustion byproducts. This waste was removed from the site and consolidated with the bridge plug waste from other Nevada Test Site WPM-OV well sites. The waste was stored in a Satellite Accumulation Area at the ER-EC-5 well site. Monthly inspections were conducted of this area until the waste was transported off site for disposal.

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

A.5.0 References

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

IT, see IT Corporation.

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

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

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

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

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

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

NDEP, see Nevada Division of Environmental Protection.

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

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

Townsend, M., Bechtel Nevada. 2000. Communication regarding completion and geology of Well ER-EC-5. Las Vegas, NV.

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.

Attachment 1

Manufacturer’s Pump Specifications

High-Capacity Testing Pump

RFQ # 023 HIGH VOLUME ELECTRIC SUBMERSIBLE PUMP SYSTEMS

BECHTEL NEVADA CORPORATION

YUCCA MOUNTAIN PROJECT

NEVADA TEST SITE

TERRY FLETCHER

CENTRILIFT

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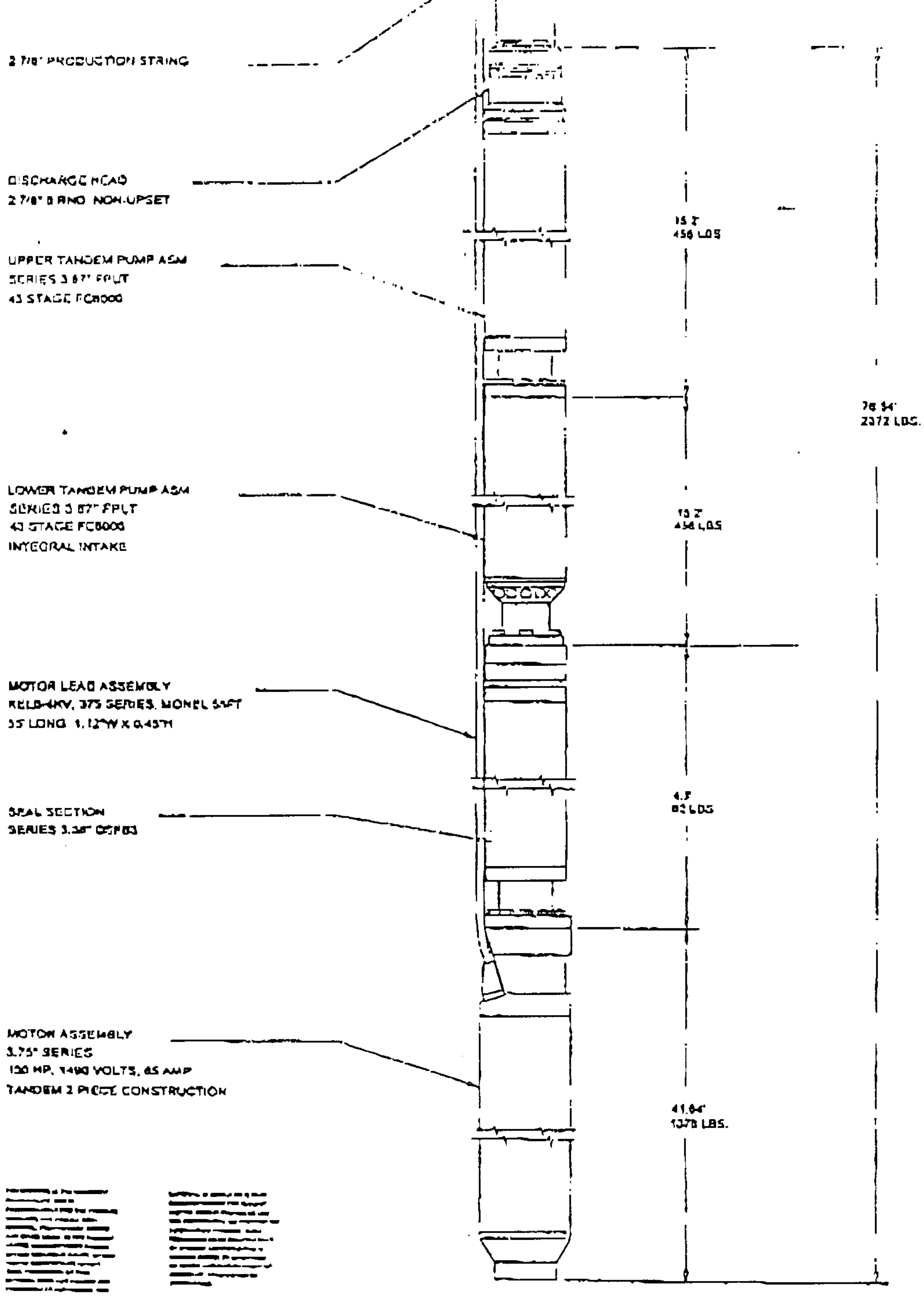
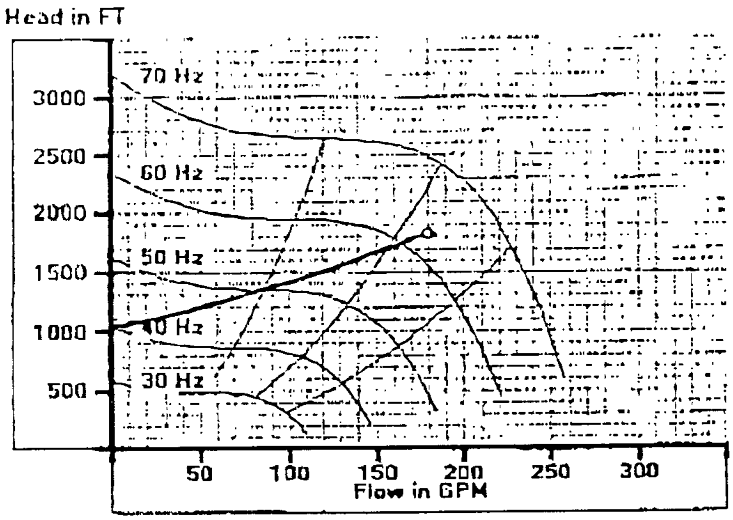
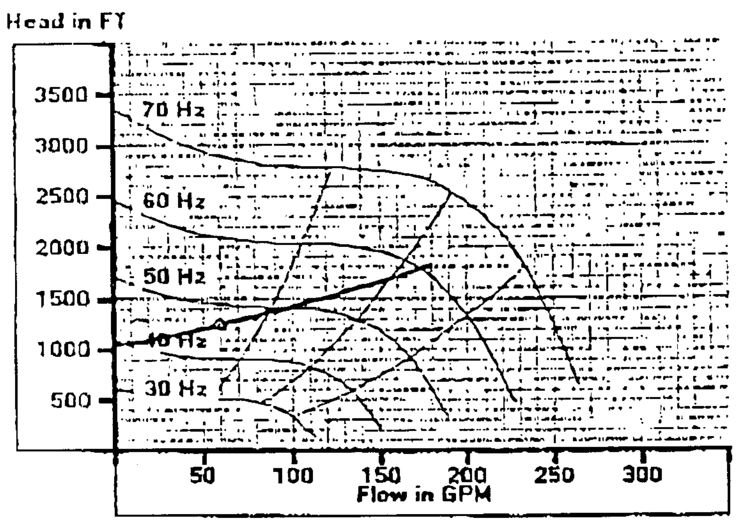


60-180 G.P.M. OPERATION
AT 1000 FT PUMP SETTING DEPTH (300 PSI tubing pressure)





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	61.26
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	**Pump:**	86-FC6000 [400Series]
Customer:	Bechtel Nevada	**Seal:**	DSFB3 [338Series]
Well:	Various	**Motor:**	DMF 130 HP 1490V 65 A [375Series]
Engineer:	Mr. Ken Ortego	**Cable:**	#4 CPNR 3kV ,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:	**Saturated Visc:**	**UnderSaturated:**	**Gas Visc:**
Beggs & Robinson	Beggs & Robinson	Vasquez & Beggs	Lee
Oil Compress:	**Formation Vol:**	**Z factor:**	**Bubble Point P:**
Vasquez & Beggs	Standings	Hall & Yarborough	Standings

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

AutographPC V3.5 File:Bechtel180GPM1000ft.apc

BEST AVAILABLE COPY

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

October 10,1999

Operating Parameters / Selection:

Design Point:

Desired flow (total)	= 6171 BPD	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

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

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

Seal Selection:

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

Oil temperature at thrust chamber = 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

Silm-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 ----

AutographPC V3.5 File.Bechtel180GPM1000ft.apc

BEST AVAILABLE COPY

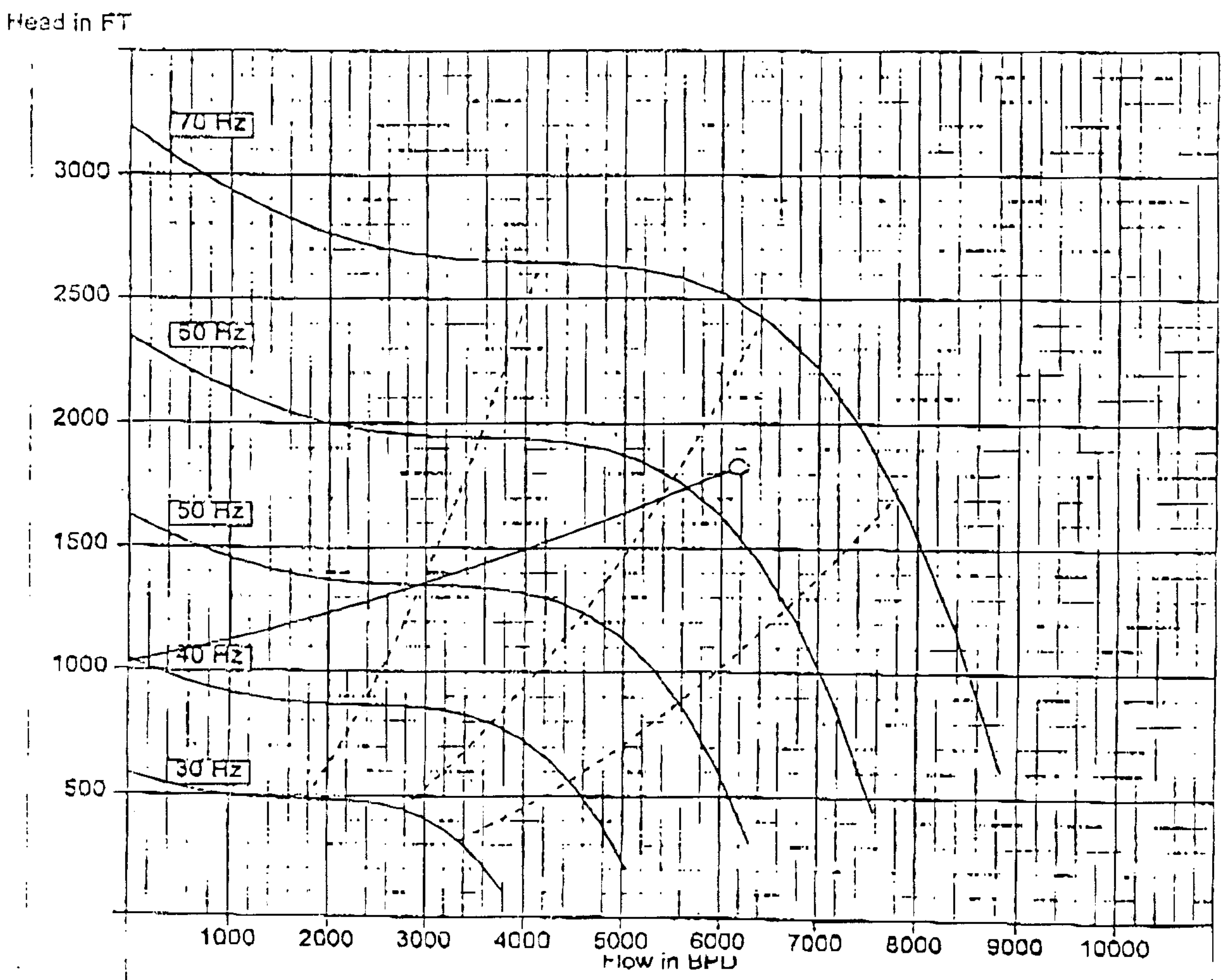
Centrilift - A Baker Hughes company
(714) 893-8511 (800) 755-8976 (714) 892-9945 FAX (714) 397-0941 MOBILE
5421 Argosy Drive Huntington Beach, CA 92649
Terry Fletcher- Sales Engineer E-Mail: Terry.Fletcher@Centrilift.com

October 10, 1999

Project:	Nevada Test Site	Pump:	86-FC6000 [400Series]
Customer:	Bechtel Nevada	Seal:	DSFB3 [338Series]
Well:	Various	Motor:	DMF 130 HP 1490V 65 A [375Series]
Engineer:	Mr. Ken Ortego	Cable:	#4 CPNR 3kV ,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

86-FC6000 Series: 400



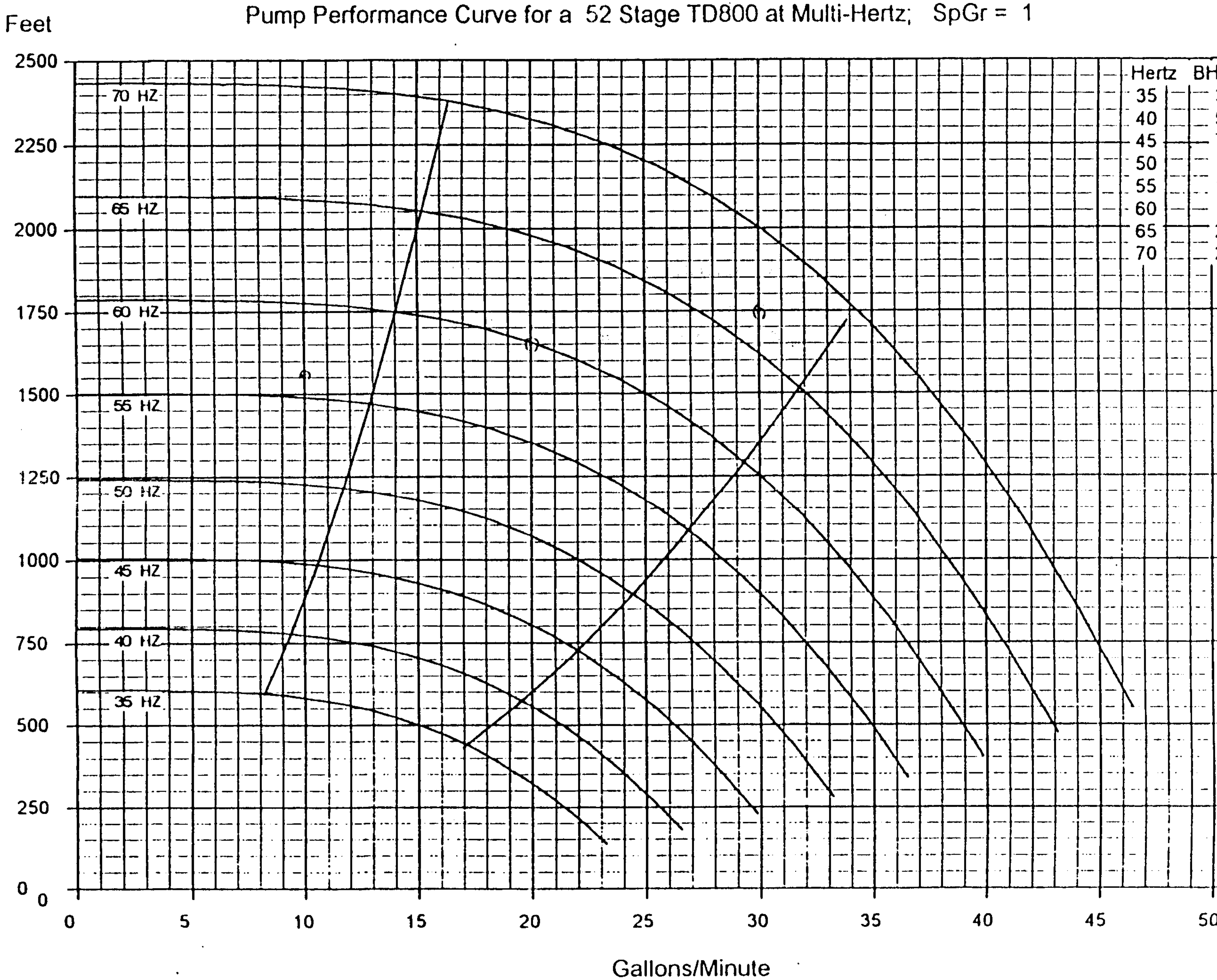
AutographPC V3.5 File:Bechtel180GPM1000ft.apc

Dedicated Sampling Pump

Plot Program by Electric Submersible Pumps,Inc

4.00 ESP Pumps

Pump Performance Curve for a 52 Stage TD800 at Multi-Hertz; SpGr = 1



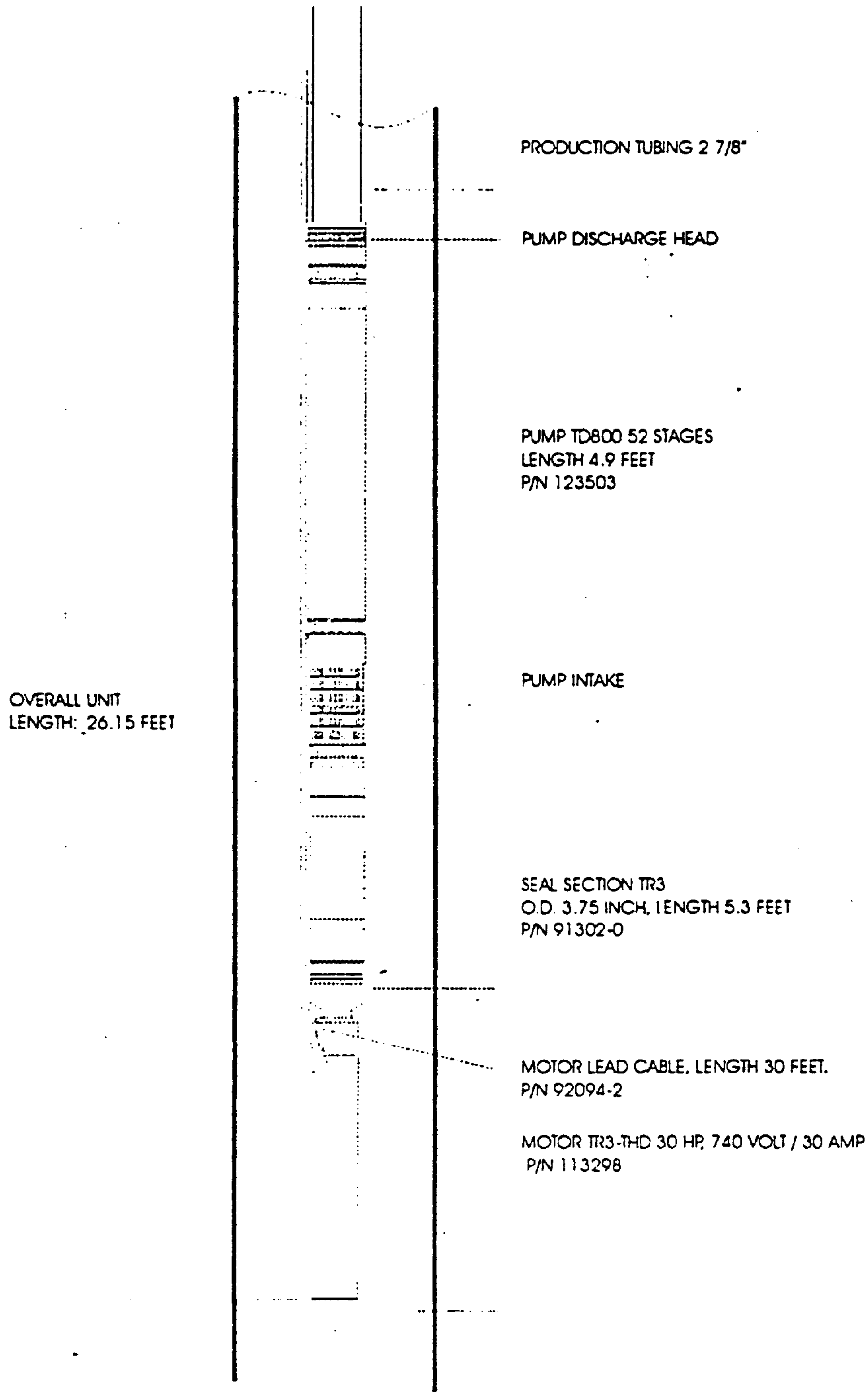
Hertz	BHP	NPHP
35	3.5	6
40	5.2	7.9
45	7.5	10
50	10.2	12.3
55	13.6	14.9
60	17.7	17.7
65	22.5	20.8
70	28.1	24.1

Att-9

ESP

Bechtel Nevada
Las Végas Nevada
Item Number 0002

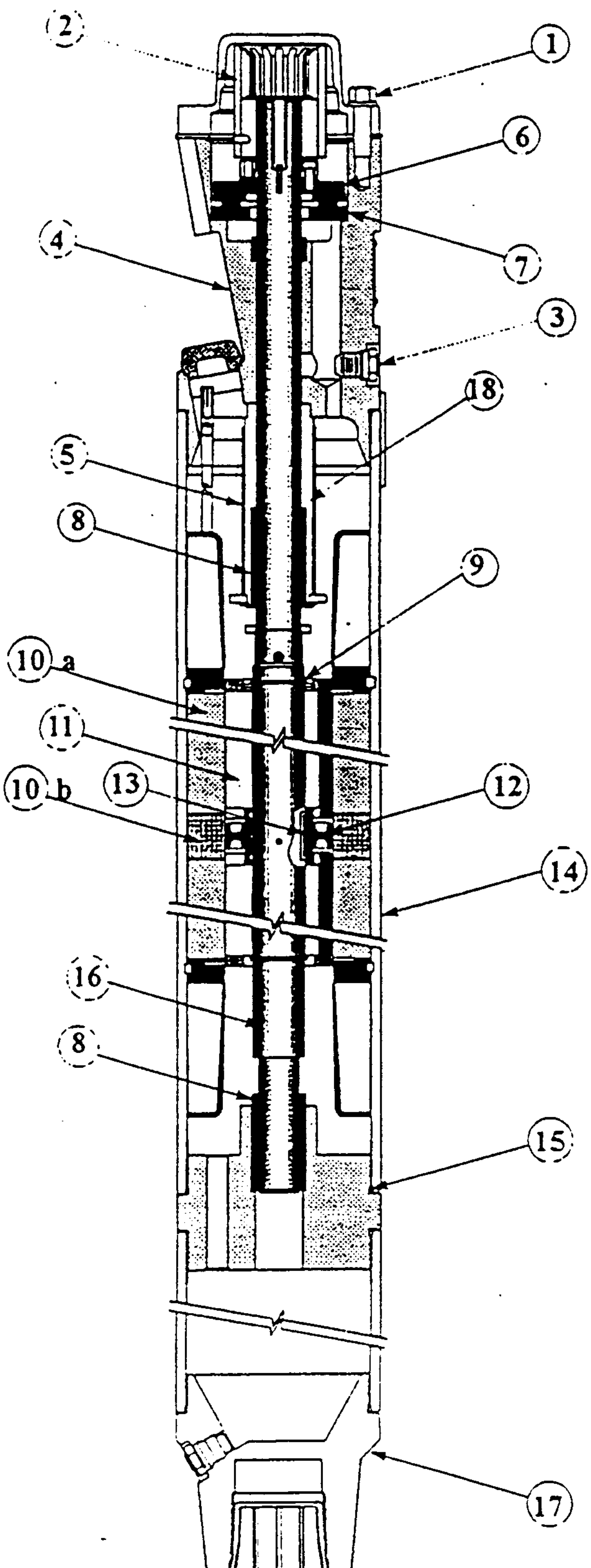
WOOD GROUP



NOT TO SCALE

ESP WOOD GROUP

MOTOR, SINGLE 30HP, 740 V 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 - 13.3FEET
WEIGHT -495 LBS

QUALITY RUNS DEEP AT ESP

materials\mtr,tr-sgl.cdr

New Release 15 May 1997

ESP

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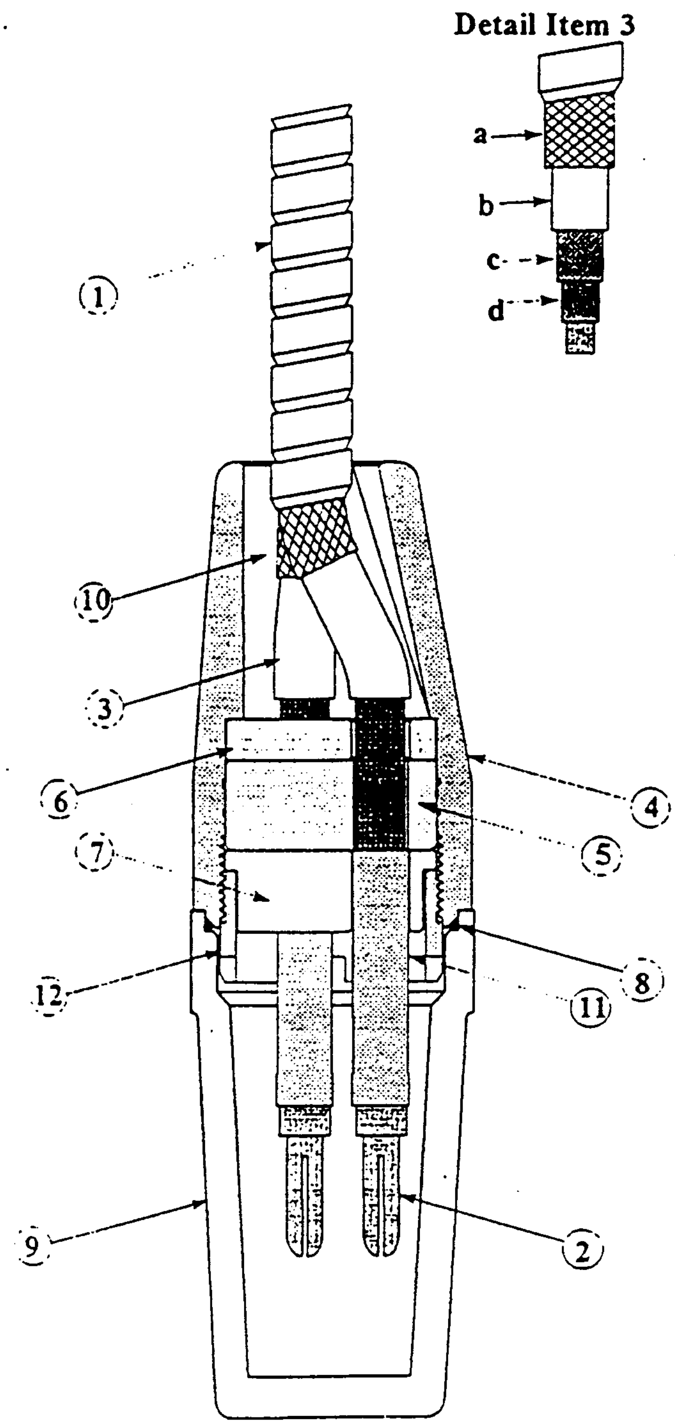
WOOD GROUP

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

Quality Runs Deep at ESP

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

New Release
27 May 1997

ESP

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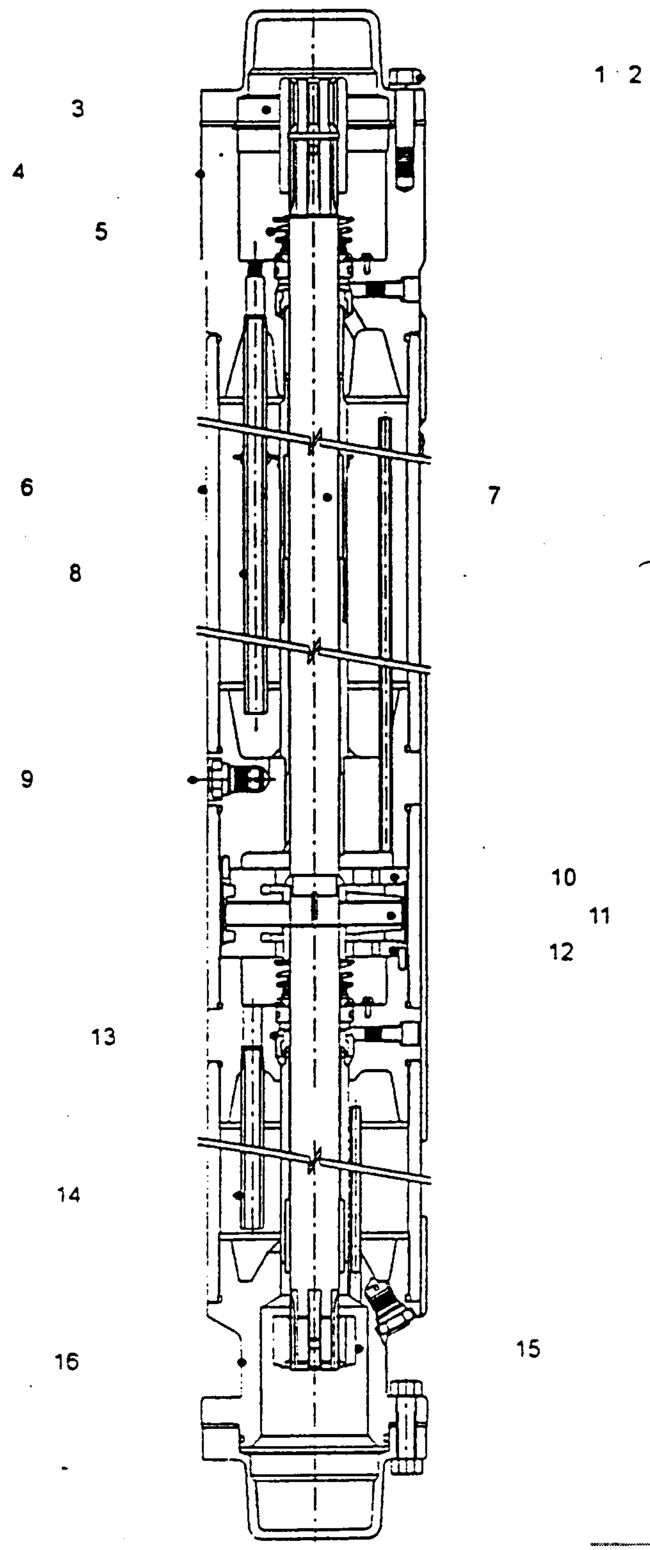
Standard Seal



WOOD GROUP

PARTS LIST

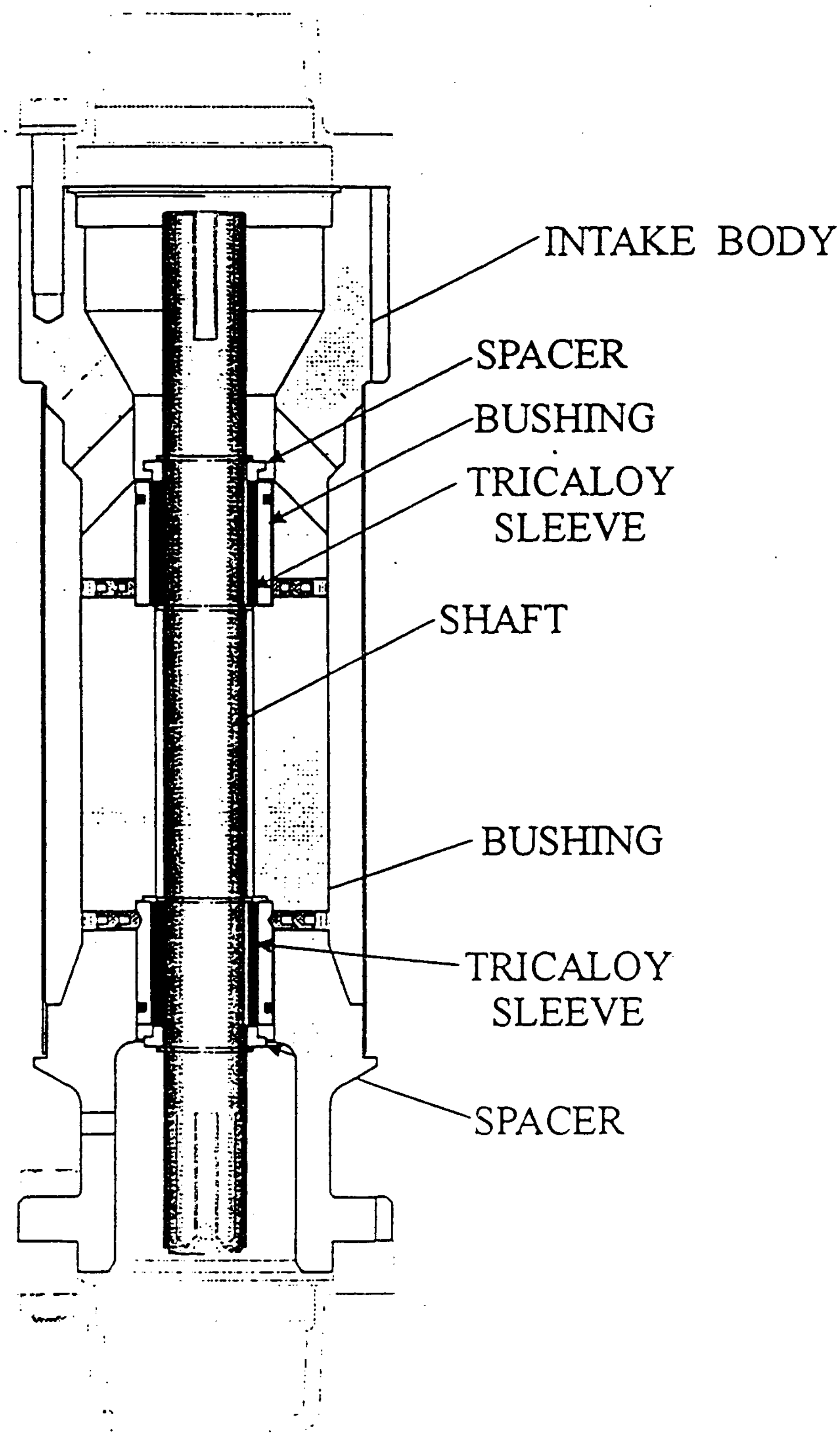
ITEM	DESCRIPTION
1	Screw, Hex Head - Monel
2	Washer, Lock - Monel
3	Coupling - Monel
4	Head, Seal
5	Seal, Mechanical
6	Housing
7	Shaft
8	Breather Tube
9	Valve, Drain/Fill
10	Bearing, Up-Thrust
11	Runner, Thrust
12	Bearing, Down-Thrust
13	Water Shedder
14	Breather Tube
15	Coupling Adapter
16	Base

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

tr-std.cdr

BEST AVAILABLE COPY

3.87 INTAKE



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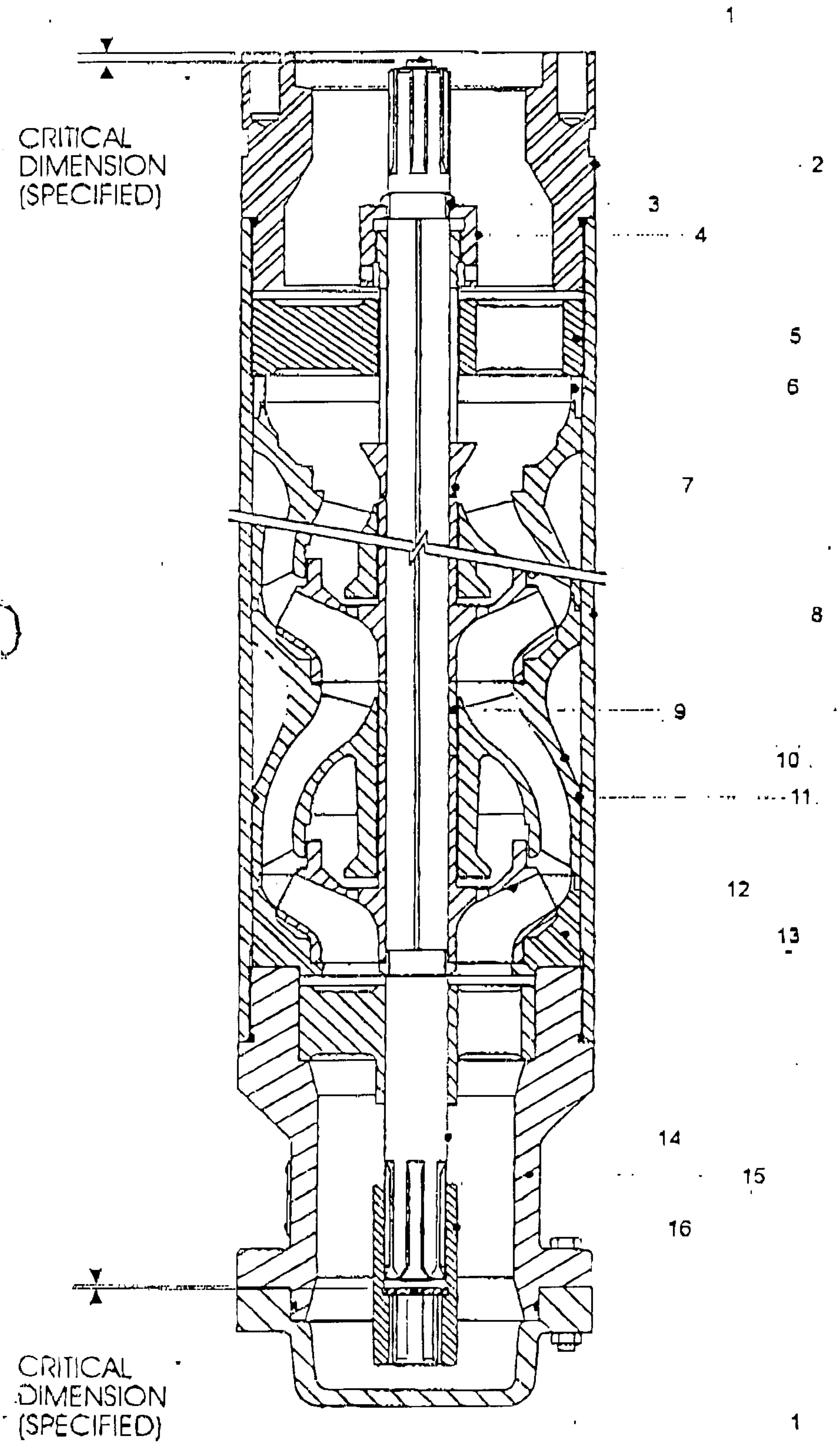
ESP

Standard Pump (Floater Stage Design)

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

TD800
51STAGE
3.87O.D.
4.9 FT
2 3/8 8RD DISCHARGE
BOLT ON INTAKE

cmp-mix.cdr

Attachment 2

Water Quality Monitoring - Grab Sample Results for Well ER-EC-5

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

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
4/24/2000	18:30	27.9	417	7.52	5.42	7.24	0.276	No Reading	7,479	Pump, VSD and back-pressure system are tested
4/25/2000	11:35	29.2	413	7.47	4.44	1.45	0.151	30.3	11,827	Functionality testing on pump/VSD
4/25/2000	15:50	31.1	405	7.61	4.97	1.70	0.099	59.9	28,217	
4/26/2000	9:05	29.9	410	7.45	5.35	0.59	0.142	141.9	35,739	Begin well development, conduct step-drawdown, pump overnight
4/26/2000	11:50	30.7	419	8.12	4.63	0.55	0.035	61.9	49,732	
4/26/2000	13:50	30.0	398	8.36	5.29	0.75	0.028	118.7	59,689	
4/26/2000	15:50	30.2	411	8.35	4.88	0.72	0.000	147.5	76,005	
4/26/2000	18:00	29.9	412	8.35	5.27	0.47	0.000	143.4	89,007	
4/26/2000	19:00	29.9	411	8.41	5.21	0.52	0.000	142.6	97,346	
4/27/2000	7:45	29.8	426	8.29	4.64	0.67	0.052	141.0	205,778	
4/27/2000	13:14	30.0	425	8.18	3.06	0.51	0.047	100.3	220,815	
4/27/2000	16:03	29.7	425	8.24	3.73	0.67	0.000	160.3	238,244	
4/30/2000	8:40	30.6	419	8.10	4.48	1.20	0.134	60.4	384,243	Pump shut down, wait for a new pressure gauge between 4/28 & 4/30
4/30/2000	10:25	29.8	413	8.10	4.73	1.70	0.119	100.5	393,938	Conduct step-drawdown testing, pump overnight at 160 gpm
4/30/2000	11:30	29.4	413	8.20	4.62	1.14	0.155	160.7	404,044	
4/30/2000	13:15	30.6	406	7.89	4.95	0.25	0.137	60.6	413,623	
4/30/2000	15:05	29.9	415	8.09	4.44	1.78	0.134	No Reading	414,522	
4/30/2000	16:30	29.4	368	8.10	4.60	0.84	0.166	160.4	420,311	
5/1/2000	9:35	29.7	425	7.07	5.18	0.36	0.407	160.1	575,214	Conduct surging by turning pump on and off, pump overnight at 160 gpm
5/1/2000	12:14	30.0	429	7.12	4.98	0.52	0.334	160.2	591,601	

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-5

(Page 2 of 4)

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
5/1/2000	14:00	29.5	435	8.02	5.11	0.35	0.247	160.1	608,407	
5/1/2000	16:00	28.9	435	8.05	5.18	0.65	0.265	160.2	618,674	
5/1/2000	17:30	29.4	432	7.76	4.72	0.35	0.277	160.3	633,097	
5/2/2000	9:12	30.1	426	7.24	4.30	0.25	0.295	59.2	771,533	Step-drawdown at 60 gpm
5/2/2000	11:15	29.2	427	8.00	5.32	0.28	0.220	100.1	779,509	Step-drawdown at 100 gpm
5/2/2000	13:05	29.6	424	7.93	5.28	0.85	0.260	160.9	790,685	Step-drawdown at 160 gpm
5/2/2000	18:44	29.8	428	7.65	5.12	0.33	0.000	161.0	817,662	Pump off between 1440 & 1630 due to generator problems
5/3/2000	7:51	29.4	439	7.56	5.36	0.23	0.369	160.7	943,887	DRI conducts flow logging, pump overnight at 110 gpm
5/3/2000	15:10	30.6	443	7.95	4.88	2.30	0.263	60.6	954,634	
5/3/2000	18:23	29.9	439	7.60	5.63	3.34	0.296	111.0	968,017	
5/4/2000	8:04	29.6	442	7.67	5.22	1.62	0.356	160.7	1,060,085	DRI completes flow logging, collects discreet samples, installs check valve
5/4/2000	11:25	29.7	443	8.08	5.07	1.52	0.279	160.8	1,092,244	
5/15/2000	10:30	29.8	448	8.12	4.23	0.72	0.112	160.9	1,205,259	Start of constant-rate test at 160 gpm
5/15/2000	12:00	29.7	443	8.12	4.44	0.65	0.069	160.7	1,219,734	
5/15/2000	14:00	29.8	444	8.10	4.59	0.60	0.096	160.9	1,239,036	
5/15/2000	16:00	29.7	444	8.12	4.72	0.60	0.095	160.9	1,258,336	
5/16/2000	9:00	29.8	416	8.00	5.42	0.48	0.198	160.8	1,422,497	
5/16/2000	11:00	29.7	418	7.98	5.18	0.39	0.169	160.6	1,441,770	
5/16/2000	13:00	29.9	419	7.96	5.18	0.22	0.214	161.0	1,461,046	
5/16/2000	15:00	29.8	419	7.94	5.06	0.28	0.278	160.9	1,480,355	
5/16/2000	17:00	29.8	418	7.96	5.19	0.28	0.147	161.2	1,499,659	
5/17/2000	8:55	29.7	419	7.92	5.31	0.26	0.070	160.8	1,653,299	
5/17/2000	11:00	29.7	419	7.91	5.38	0.26	0.110	160.8	1,673,405	

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

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
5/17/2000	13:00	29.8	420	7.90	5.21	0.14	0.012	161.0	1,692,709	
5/17/2000	15:00	29.9	421	7.94	5.23	0.23	0.262	161.1	1,712,025	
5/17/2000	17:00	29.9	420	7.91	5.13	0.34	0.032	161.4	1,731,333	
5/18/2000	8:50	29.7	421	7.92	5.16	0.25	0.258	160.6	1,884,158	
5/18/2000	11:00	30.1	421	7.90	5.26	0.22	0.284	160.7	1,905,037	
5/18/2000	13:00	30.1	421	7.89	5.05	0.40	0.243	160.9	1,924,342	
5/18/2000	15:00	30.2	421	7.90	5.13	0.35	0.226	161.0	1,943,659	
5/18/2000	17:00	30.1	420	7.91	5.11	0.26	0.224	160.9	1,962,940	
5/18/2000	18:20	30.2	419	7.88	5.16	0.40	0.284	160.8	1,975,688	At 18:02 power shut down for 40 sec.
5/19/2000	8:25	30.1	428	7.90	5.09	0.16	0.326	160.8	2,111,586	
5/19/2000	10:00	30.1	427	7.93	5.12	0.12	0.283	159.7	2,126,843	
5/19/2000	11:50	30.1	407	7.77	5.09	0.11	0.329	159.8	2,144,486	
5/19/2000	13:50	30.1	427	7.97	5.15	0.22	0.250	161.0	2,163,743	
5/19/2000	15:45	30.2	427	7.90	5.19	0.20	0.257	160.5	2,182,261	
5/19/2000	16:45	30.2	427	7.91	5.20	0.38	0.263	161.0	2,191,923	
5/20/2000	9:00	30.1	426	7.91	5.18	0.62	0.241	158.3	2,346,665	
5/20/2000	10:40	30.1	427	7.86	5.27	0.40	0.181	158.0	2,362,431	
5/20/2000	12:40	30.3	426	7.93	4.69	2.05	0.195	158.7	2,381,400	
5/20/2000	15:00	30.3	428	7.97	5.19	0.25	0.179	158.6	2,403,595	
5/20/2000	16:50	30.2	426	7.90	5.18	0.52	0.165	158.7	2,421,019	
5/21/2000	8:00	29.9	430	7.89	5.19	0.43	0.292	158.9	2,565,411	
5/21/2000	10:00	30.2	430	7.90	5.10	0.25	0.344	158.7	2,584,457	
5/21/2000	12:10	30.4	430	7.95	5.10	0.39	0.219	158.3	2,605,075	
5/21/2000	14:00	30.3	430	7.90	5.26	0.43	0.222	158.7	2,622,630	
5/21/2000	16:00	30.2	430	7.90	5.28	0.44	0.221	157.9	2,641,560	

Table ATT.2-1
Water Quality Monitoring - Grab Sample Results for Well ER-EC-5

(Page 4 of 4)

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
5/22/2000	8:01	30.1	430	7.96	5.33	0.33	0.303	158.2	2,793,248	
5/22/2000	10:00	30.2	430	7.94	5.15	0.29	0.324	158.3	2,812,210	
5/22/2000	11:55	30.3	430	7.93	5.15	0.22	0.325	160.4	2,830,577	
5/22/2000	12:45	30.4	430	7.93	5.10	0.32	0.311	160.9	2,838,619	
5/22/2000	15:30	30.3	430	7.92	5.11	0.34	0.329	160.9	2,865,182	
5/22/2000	17:00	30.3	430	7.93	5.17	0.22	0.273	161.2	2,879,680	
5/23/2000	8:20	30.2	429	7.92	5.16	0.34	0.335	160.7	3,027,757	
5/23/2000	10:00	30.4	428	7.92	5.03	0.18	0.345	160.8	3,043,813	
5/23/2000	12:00	30.4	428	7.87	5.02	0.30	0.292	161.0	3,063,103	
5/23/2000	14:00	30.4	430	7.90	4.97	0.42	0.418	160.9	3,082,426	
5/23/2000	16:00	30.3	430	7.90	4.91	0.92	0.443	161.1	3,101,745	
5/24/2000	9:10	30.2	423	7.85	5.10	0.65	0.336	160.8	3,267,476	
5/24/2000	11:15	30.1	421	7.78	5.58	0.58	0.316	160.7	3,287,559	
5/24/2000	13:10	30.2	424	7.88	5.40	0.49	0.352	160.9	3,306,031	
5/24/2000	15:10	30.2	424	7.90	5.02	0.48	0.345	160.9	3,325,338	Continue constant-rate overnight

EC - Electrical conductivity
DO - Dissolved oxygen
DRI - Desert Research Institute
gpm - Gallons per minute
GW - Groundwater
hr:min - Hour:minute
in. - Inch(es)
mg/L - Milligrams per liter
NTUs - Nephelometric turbidity units
SU - Standard units
µmhos/cm - Micromhos per centimeter

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-5
(Page 1 of 4)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-5-050400-2		Results of Discrete Bailer Sample #EC-5-050400-3		Results of Wellhead Composite Sample #EC-5-052500-1	
Metals (mg/L) - (continued)								
			Total	Dissolved	Total	Dissolved	Total	Dissolved
Aluminum	0.2	Paragon	UJ 0.091	UJ 0.038	UJ 0.12	UJ 0.051	UJ 0.065	UJ 0.054
Arsenic	0.01	Paragon	J 0.0061	J 0.0088	J 0.0073	J 0.0078	J 0.0054	J 0.0074
Barium	0.1	Paragon	J 0.0075	J 0.0053	J 0.015	UJ 0.013	J 0.0037	J 0.0038
Cadmium	0.005	Paragon	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005
Calcium	1	Paragon	J 21	J 21	J 22	J 19	J 20	J 20
Chromium	0.01	Paragon	UJ 0.0021	UJ 0.00083	UJ 0.003	UJ 0.0017	UJ 0.00076	UJ 0.00081
Iron	0.1	Paragon	J 2.8	UJ 0.045	J 0.88	UJ 0.055	UJ 0.042	UJ 0.064
Lead	0.003	Paragon	UJ 0.003	UJ 0.003	UJ 0.003	UJ 0.003	UJ 0.003	UJ 0.003
Lithium	0.01	Paragon	J 0.11	J 0.11	J 0.11	J 0.11	J 0.11	J 0.11
Magnesium	1	Paragon	J 0.53	J 0.52	J 0.65	J 0.61	J 0.47	J 0.47
Manganese	0.01	Paragon	J 0.048	J 0.0025	J 0.016	UJ 0.0013	UJ 0.0019	UJ 0.0018
Potassium	1	Paragon	J 1.6	J 1.7	J 1.7	J 1.8	J 1.7	J 1.7
Selenium	0.005	Paragon	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005	UJ 0.005
Silicon	0.05	Paragon	J 20	J 20	J 21	J 21	J 19	J 20
Silver	0.01	Paragon	UJ 0.01	UJ 0.01	UJ 0.01	UJ 0.01	UJ 0.01	UJ 0.01
Sodium	1	Paragon	J 74	J 74	J 74	J 74	J 73	J 73
Strontium	0.01	Paragon	J 0.14	J 0.14	J 0.15	J 0.15	J 0.13	J 0.13
Uranium	0.2	Paragon	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2	UJ 0.2

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-5
(Page 2 of 4)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-5-050400-2		Results of Discrete Bailer Sample #EC-5-050400-3		Results of Wellhead Composite Sample #EC-5-052500-1	
Metals (mg/L)								
Mercury	0.0002	Paragon	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002	UJ 0.0002
Inorganics (mg/L) - unless otherwise noted								
Chloride	0.2	Paragon	J 16		J 16		J 16	
Fluoride	0.1	Paragon	J 4.6		J 4.5		J 4.7	
Bromide	0.2	Paragon	J 0.078		J 0.11		J 0.086	
Sulfate	1	Paragon	J 35		J 35		J 35	
pH (pH units)	0.1	Paragon	J 8		J 8.3		J 8.1	
Total Dissolved Solids	20	Paragon	J 260		J 270		J 270	
Electrical Conductivity (micromhos/cm)	1	Paragon	J 390		J 380		400	
Carbonate as CaCO3	10	Paragon	R 10		R 10		UJ 10	
Bicarbonate as CaCO3	10	Paragon	J 140		J 140		J 140	
Organics (mg/L)								
Total Organic Carbon	1	Paragon	J 0.91		J 1.1		UJ 1	
Redox Parameters (mg/L)								
Total Sulfide	5	Paragon	R 5		R 5		UJ 5	
Age and Migration Parameters (pCi/L) - unless otherwise noted								
Carbon-13/12 (per mil)	Not Provided	DRI	N/A		N/A		-3.4 +/- 0.2	

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-5
(Page 3 of 4)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-5-050400-2	Results of Discrete Bailer Sample #EC-5-050400-3	Results of Wellhead Composite Sample #EC-5-052500-1
Age and Migration Parameters (pCi/L) - unless otherwise noted					
C-14, Inorganic (pmc)	Not Provided	LLNL	N/A	N/A	6.3
C-14, Inorganic age (years)*	Not Provided	LLNL	N/A	N/A	22,900
Chlorine-36	Not Provided	LLNL	N/A	N/A	3.47E-04
Cl-36/Cl (ratio)	Not Provided	LLNL	N/A	N/A	6.53E-13
He-4 (atoms/mL)	Not Provided	LLNL	N/A	N/A	7.09E+12
He-3/4, measured value (ratio)	Not Provided	LLNL	N/A	N/A	1.50E-06
He-3/4, relative to air (ratio)	Not Provided	LLNL	N/A	N/A	1.08E+00
Oxygen-18/16 (per mil)	Not Provided	DRI	N/A	N/A	-15.1 +/- 0.2
Strontium-87/86 (ratio)	Not Provided	LLNL	N/A	N/A	0.709124 +/- 0.000015
Uranium-234/238 (ratio)	Not Provided	LLNL	N/A	N/A	0.000351
H-2/1 (per mil)	Not Provided	DRI	N/A	N/A	-112 +/- 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'	All nuclides reported with a 'U'
Tritium	280	Paragon	U -30 +/- 160	U -10 +/- 170	U -60 +/- 160
Gross Alpha	3.1, 3.1, 4.2	Paragon	5.7 +/- 2.5	6.8 +/- 2.7	U 5 +/- 3
Gross Beta	3.6, 3.2, 3.8	Paragon	U 0.9 +/- 2.1	U 1.7 +/- 1.9	U -0.5 +/- 2.2

Table ATT.3-1
Analytical Results of Groundwater Characterization Samples at Well ER-EC-5
(Page 4 of 4)

Analyte	Laboratory Detection Limit[a]	Laboratory	Results of Discrete Bailer Sample #EC-5-050400-2	Results of Discrete Bailer Sample #EC-5-050400-3	Results of Wellhead Composite Sample #EC-5-052500-1
Radiological Indicator Parameters-Level II (pCi/L)					
Carbon-14	300	Paragon	U -210 +/- 180	U -110 +/- 180	U -40 +/- 180
Strontium-90	0.22	Paragon	N/A	N/A	U 0.03 +/- 0.13
Plutonium-238	0.031, 0.036, 0.031	Paragon	U -0.004 +/- 0.012	U 0.002 +/- 0.013	U -0.004 +/- 0.012
Plutonium-239	0.031, 0.011, 0.039	Paragon	U -0.004 +/- 0.012	U 0 +/- 0.011	U -0.003 +/- 0.012
Iodine-129	1.1	Paragon	N/A	N/A	U 0.52 +/- 0.67
Technetium-99	3.2	Paragon	N/A	N/A	U -0.2 +/- 1.8

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

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

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

Table ATT.3-2
Colloid Analyses for Well ER-EC-5
(Page 1 of 2)

Analyte	Laboratory	Results of Discrete Bailer Sample #EC-5-050400-2	Results of Discrete Bailer Sample #EC-5-050400-3	Results of Wellhead Composite Sample #EC-5-052500-1
Colloid Particle Size Range (in nanometers)		Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)
50 - 60	LANL	3.08E+06	5.83E+06	3.85E+05
60 - 70	LANL	3.51E+06	5.98E+06	3.85E+05
70 - 80	LANL	2.60E+06	3.70E+06	2.85E+05
80 - 90	LANL	2.05E+06	3.25E+06	2.15E+05
90 - 100	LANL	1.80E+06	2.25E+06	1.30E+05
100 - 110	LANL	1.73E+06	2.43E+06	1.40E+05
110 - 120	LANL	1.45E+06	1.90E+06	7.00E+04
120 - 130	LANL	1.08E+06	1.00E+06	7.50E+04
130 - 140	LANL	6.01E+05	1.00E+06	4.00E+04
140 - 150	LANL	6.01E+05	1.08E+06	4.50E+04
150 - 160	LANL	8.26E+05	8.75E+05	4.00E+04
160 - 170	LANL	4.76E+05	5.25E+05	4.00E+04
170 - 180	LANL	5.01E+05	5.00E+05	2.00E+04
180 - 190	LANL	4.51E+05	6.00E+05	2.50E+04
190 - 200	LANL	3.01E+05	4.50E+05	4.00E+04
200 - 220	LANL	7.26E+05	5.75E+05	3.50E+04
220 - 240	LANL	3.47E+05	2.95E+05	1.44E+04
240 - 260	LANL	1.72E+05	1.91E+05	7.08E+03
260 - 280	LANL	1.04E+05	1.14E+05	3.00E+03
280 - 300	LANL	5.98E+04	6.44E+04	2.04E+03
300 - 400	LANL	1.11E+05	1.65E+05	4.68E+03
400 - 500	LANL	2.16E+04	4.18E+04	9.60E+02

Table ATT.3-2
Colloid Analyses for Well ER-EC-5
(Page 2 of 2)

Analyte	Laboratory	Results of Discrete Bailer Sample #EC-5-050400-2	Results of Discrete Bailer Sample #EC-5-050400-3	Results of Wellhead Composite Sample #EC-5-052500-1
Colloid Particle Size Range (in nanometers)		Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)	Colloid Concentration (particles/mL)
500 - 600	LANL	4.20E+04	6.44E+04	9.60E+02
600 - 800	LANL	6.94E+04	1.12E+05	1.08E+03
800 - 1000	LANL	2.46E+04	4.30E+04	4.80E+02
>1000	LANL	1.48E+05	1.16E+05	7.20E+02
Total Concentration, Particle Size Range, 50-1000 nm	LANL	2.29E+07	3.31E+07	2.01E+06

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

Analyte	Detection Limit	Laboratory	Qualifier	Results of Discrete Bailer Sample #EC-5-050400-3	Qualifier	Results of Discrete Bailer Sample #EC-5-050400-2	Unit
Ag, Dissolved	0.16	UNLV-HRC	<	0.16	<	0.16	µg/L
Al, Dissolved	0.17	UNLV-HRC		14.7		9.58	µg/L
As, Dissolved	0.02	UNLV-HRC		7.30		7.75	µg/L
Au, Dissolved	0.030	UNLV-HRC	<	0.030	<	0.030	µg/L
Ba, Dissolved	0.006	UNLV-HRC		14.5		5.61	µg/L
Be, Dissolved	0.018	UNLV-HRC		0.028		0.059	µg/L
Bi, Dissolved	0.004	UNLV-HRC	<	0.004	<	0.004	µg/L
Cd, Dissolved	0.006	UNLV-HRC		0.016		0.027	µg/L
Co, Dissolved	0.006	UNLV-HRC		0.174		0.059	µg/L
Cr, Dissolved	0.012	UNLV-HRC		1.05		0.682	µg/L
Cs, Dissolved	0.003	UNLV-HRC		2.10		3.16	µg/L
Cu, Dissolved	0.011	UNLV-HRC		0.180		0.192	µg/L
Ga, Dissolved	6.3	UNLV-HRC		40		31	ng/L
Ge, Dissolved	0.006	UNLV-HRC		1.04		1.10	µg/L
Hf, Dissolved	0.015	UNLV-HRC	<	0.015	<	0.015	µg/L
In, Dissolved	0.004	UNLV-HRC	<	0.004	<	0.004	µg/L
Ir, Dissolved	8	UNLV-HRC	<	8	<	8	ng/L
Li, Dissolved	0.015	UNLV-HRC		115		114	µg/L
Mn, Dissolved	0.01	UNLV-HRC		1.76		3.72	µg/L
Mo, Dissolved	0.01	UNLV-HRC		8.97		8.89	µg/L
Nb, Dissolved	5.1	UNLV-HRC	<	5.1	<	5.1	ng/L
Ni, Dissolved	0.006	UNLV-HRC		0.290		0.889	µg/L
Pb, Dissolved	0.04	UNLV-HRC	<	0.04	<	0.04	µg/L
Pd, Dissolved	0.021	UNLV-HRC	<	0.021		0.037	µg/L
Pt, Dissolved	0.006	UNLV-HRC	<	0.006		0.008	µg/L
Rb, Dissolved	0.003	UNLV-HRC		4.79		4.97	µg/L
Re, Dissolved	0.004	UNLV-HRC	<	0.004	<	0.004	µg/L
Rh, Dissolved	0.004	UNLV-HRC	<	0.004	<	0.004	µg/L
Ru, Dissolved	0.005	UNLV-HRC	<	0.005	<	0.005	µg/L
Sb, Dissolved	0.004	UNLV-HRC		0.293		0.196	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-5-050400-3	Qualifier	Results of Discrete Bailer Sample #EC-5-050400-2	Unit
Se, Dissolved	0.09	UNLV-HRC		0.39		0.37	µg/L
Sn, Dissolved	0.004	UNLV-HRC		0.020		0.029	µg/L
Sr, Dissolved	0.01	UNLV-HRC		151		138	µg/L
Ta, Dissolved	0.009	UNLV-HRC	<	0.009	<	0.009	µg/L
Te, Dissolved	0.008	UNLV-HRC		0.009		0.009	µg/L
Ti, Dissolved	0.009	UNLV-HRC		0.769		0.525	µg/L
Tl, Dissolved	0.009	UNLV-HRC		0.109		0.074	µg/L
U, Dissolved	0.005	UNLV-HRC		3.14		3.15	µg/L
V, Dissolved	0.009	UNLV-HRC		2.50		1.95	µg/L
W, Dissolved	0.004	UNLV-HRC		0.594		0.471	µg/L
Zn, Dissolved	0.2	UNLV-HRC		15.3		3.99	µg/L
Zr, Dissolved	0.018	UNLV-HRC		0.036		0.072	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-5 Development and Testing Data Report:

This README file identifies the included data files.

Included with this report are 25 files containing data that were collected electronically during the development and testing program for Well ER-EC-6. The .xls data files were originally collected in ASCII format by datalogger, and the data have been imported into Microsoft EXCEL 97 with minimal changes. Files 4, 5, and 6 contain two sheets, a RAW DATA sheet and a PROCESSED DATA sheet. The PROCESSED DATA sheet references the Raw Data sheet and performs basic processing on the data. Please consult the data report for more information on the data.

The files are:

1) EREC5L.xls
Bridge plug monitoring data for the lower interval.

2) EREC5U.xls
Bridge plug monitoring data for the upper middle interval.

3) EC5gradient.xls
Monitoring data for the upper interval during the bridge plug measurements.

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

5) EC-5_Aqtest_HT.xls
Complete monitoring record of testing.

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

7) EC5Hydrolab.xls
Hydrolab monitoring data during development.

8) DRIFileInfoGeneric.txt
DRI log head information.

9) ec5mov2, ec5mov3, ec5mov4, ec5mov5, ec5mov6, ec5mov7, ec5mov8, and ec5mov9.txt
DRI flow logs.

10) ec5stat1, ec5stat2, ec5stat3, ec5stat4, ec5stat5, ec5stat6, ec5stat7, ec5stat8, and ec5stat9.txt - DRI static impeller tool flow measurements.

Distribution

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