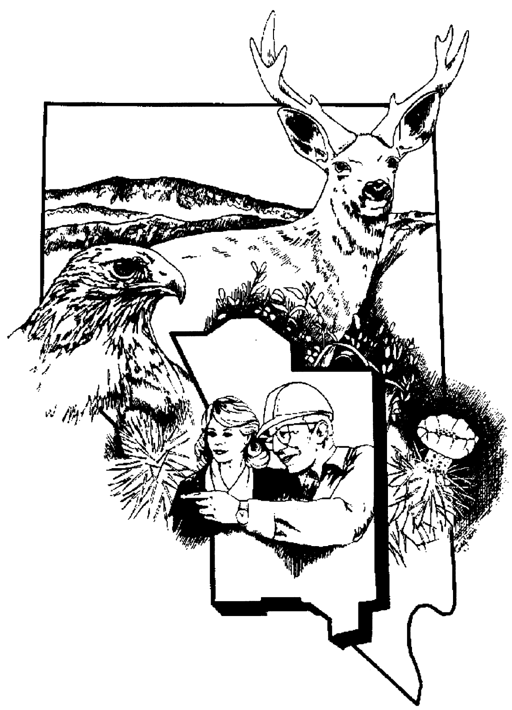
S-N/99205--028

Interpretation of Hydraulic Test and Multiple-Well Aquifer Test Data at Frenchman Flat Well Cluster ER-5-3



Revision No.: 0

September 2004

Prepared for U.S. Department of Energy under Contract No. DE-AC52-03NA99205

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INTERPRETATION OF HYDRAULIC TEST AND MULTIPLE-WELL AQUIFER TEST DATA AT FRENCHMAN FLAT WELL CLUSTER ER-5-3

Revision No.: 0

September 2004

Stoller-Navarro Joint Venture
7710 W. Cheyenne, Building 3
Las Vegas, NV 89129

Prepared for U.S. Department of Energy under Contract No. DE-AC52-03NA99205

INTERPRETATION OF HYDRAULIC TEST AND MULTIPLE-WELL AQUIFER TEST DATA AT FRENCHMAN FLAT WELL CLUSTER ER-5-3

Approved by: APPROVED SIGNATURE Date: 8/25/04

John McCord, UGTA Project Manager
Stoller-Navarro Joint Venture

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List of Acronyms and Abbreviations

AA	Alluvial aquifer
bgs	Below ground surface
BLFA	Basalt lava flow aquifer
BN	Bechtel Nevada
BOD	Biochemical oxygen demand
CZ	Completion zone
DOE	U.S. Department of Energy
DRI	Desert Research Institute
FMP	Fluid Management Plan
fpm	Feet per minute
ft	Foot (feet)
FY	Fiscal Year
gal	Gallons
gpm	Gallons per minute
HGU	Hydrogeologic Unit
hr	Hour
HSU	Hydrostratigraphic unit
Hz	Hertz (cycles per second)
in.	Inch(es)
ITLV	IT Corporation, Las Vegas
JDate	Julian date
JDay	Julian day
K	Hydraulic Conductivity
kW	Kilowatt
LCA	Lower carbonate aquifer
LiBr	Lithium Bromide
m	Meter
m^3	Cubic meter
mA	Milliamp
m/day	meters per day
mBar	Millibar
mg/L	Milligrams per liter

List of Acronyms and Abbreviations *(Continued)*

min	Minute
MWAT	Multiple-well aquifer test
NNSA/NV	U.S. Department of Energy, National Nuclear Security Administration Nevada Operations Office
NTS	Nevada Test Site
OAA	Old Alluvial Aquifer
od	Outside diameter
psi	Pounds per square inch
psia	Pounds per square inch absolute
psig	Pounds per square inch gauge
PW	Pilot well
PXD	Pressure transducer
PZ	Piezometer
RWMS	Radioactive Waste Management Site
sec	Second
SWL	Static water level
TCU	Tuff confining unit
TFM	Thermal flow meter
TMWTA	Timber Mountain Welded Tuff Aquifer
TWG	Technical Working Group
UGTA	Underground Test Area
VSD	Variable speed drive
WDT	Well Development and Testing
WTA	Welded tuff aquifer
XO	Cross over
°C	Degrees Celsius
°F	Degrees Fahrenheit

1.0 Introduction

This report documents the analysis of the hydraulic data collected at Wells ER-5-3, ER-5-3#2, and ER-5-3#3, located in northern Frenchman Flat on the Nevada Test Site (NTS), Nevada. The hydraulic testing data were derived from slug tests, step-drawdown tests, a 10-day constant rate test, and a 90-day multiple-well aquifer test. In general, the analysis results will advance the current understanding of groundwater flow and contaminant transport in the hydrostratigraphic units (HSUs) of northern Frenchman Flat. The HSU properties derived will be used in on-going characterization and groundwater flow and transport modeling efforts of the Frenchman Flat area (DOE/NV, 1999 and 2000). Specific objectives of the well development and testing program as they relate to the characterization and modeling efforts are reported in detail in *Frenchman Flat Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 2000).

1.1 Well Cluster 5-3

Well Cluster ER-5-3 was tested as part of fiscal year (FY) 2001 activities for the U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Site Office (NNSA/NSO), Underground Test Area (UGTA) Project. Well Cluster ER-5-3 is located in northern Frenchman Flat on the NTS (Figure 1-1). The cluster is comprised of three groundwater wells (ER-5-3, ER-5-3#2, and ER-5-3#3) and two piezometers. The three wells are located within 36 m (120 feet [ft]) of each other, and the two piezometer (PZ) strings are components of Well ER-5-3 (Figure 1-2).

Well Cluster ER-5-3 is a set of three wells, some with multiple completions separated by blank casing sections and annular seals. The completion intervals extend over large vertical distances and access different hydrostratigraphic units (HSUs) and/or lithologies (hydrogeologic units [HGUs]). The HSUs monitored by these wells include the old alluvial aquifer (OAA), basalt lava flow aquifer (BLFA), Timber Mountain welded tuff aquifer (TMWTA) containing minor intervals of tuff confining units (TCU), and the lower carbonate aquifer (LCA) (Table 1-1). Hydraulic testing at Well Cluster ER-5-3 included well development, slug testing, single-well hydraulic testing, short duration constant-rate tests with observation wells, and a multiple-well aquifer test (MWAT). These tests were intended to provide information on the hydraulic characteristics of HSUs in the northern portion of Frenchman Flat. The testing and sampling data collected from these wells has allowed the assessment of individual completion zones (CZs). Completion diagrams for wells ER-5-3, ER-5-3#2, and ER-5-3#3 are presented in Figure 1-3, Figure 1-4, and Figure 1-5, respectively.

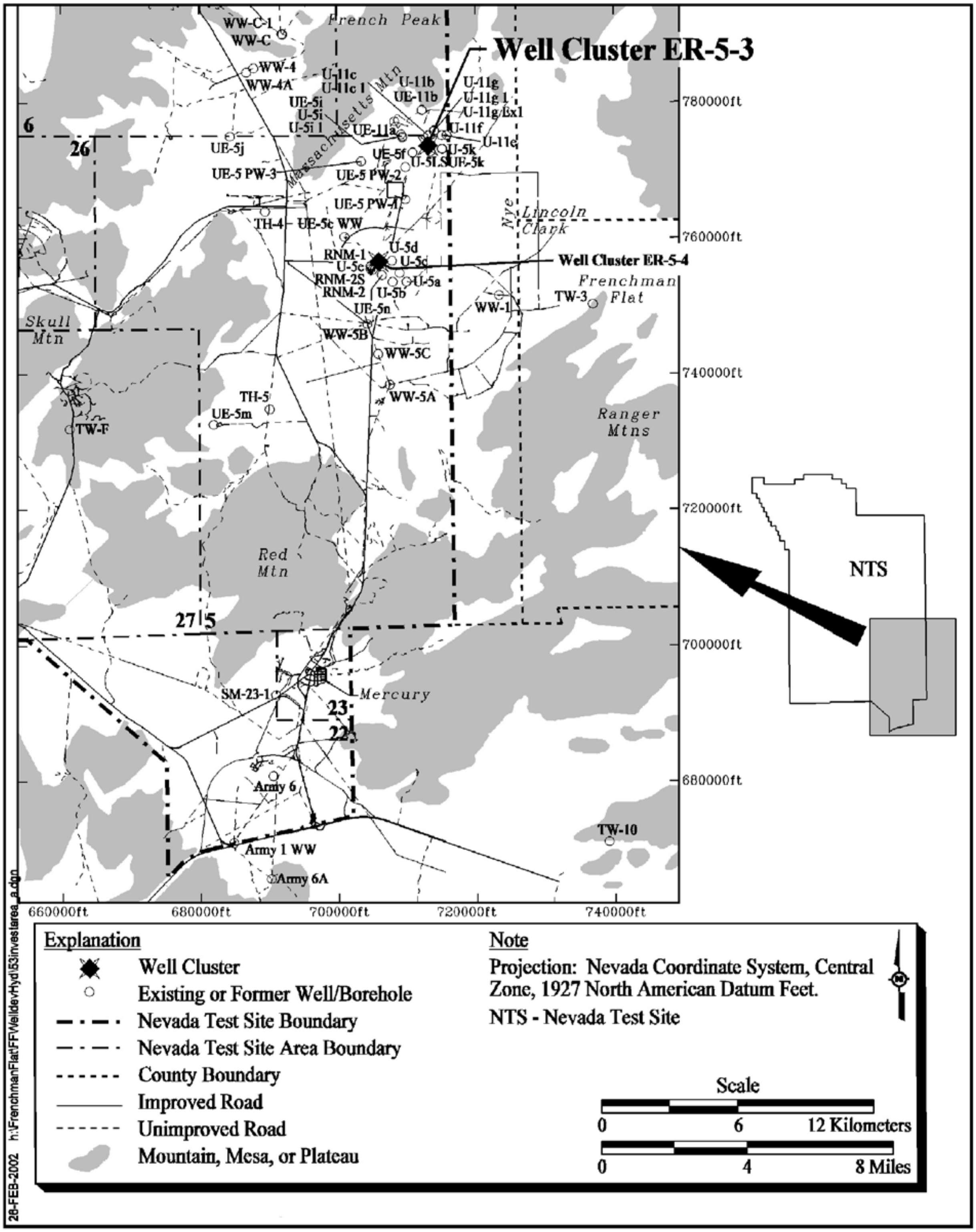


Figure 1-1
Location Map of the ER-5-3 Well Cluster

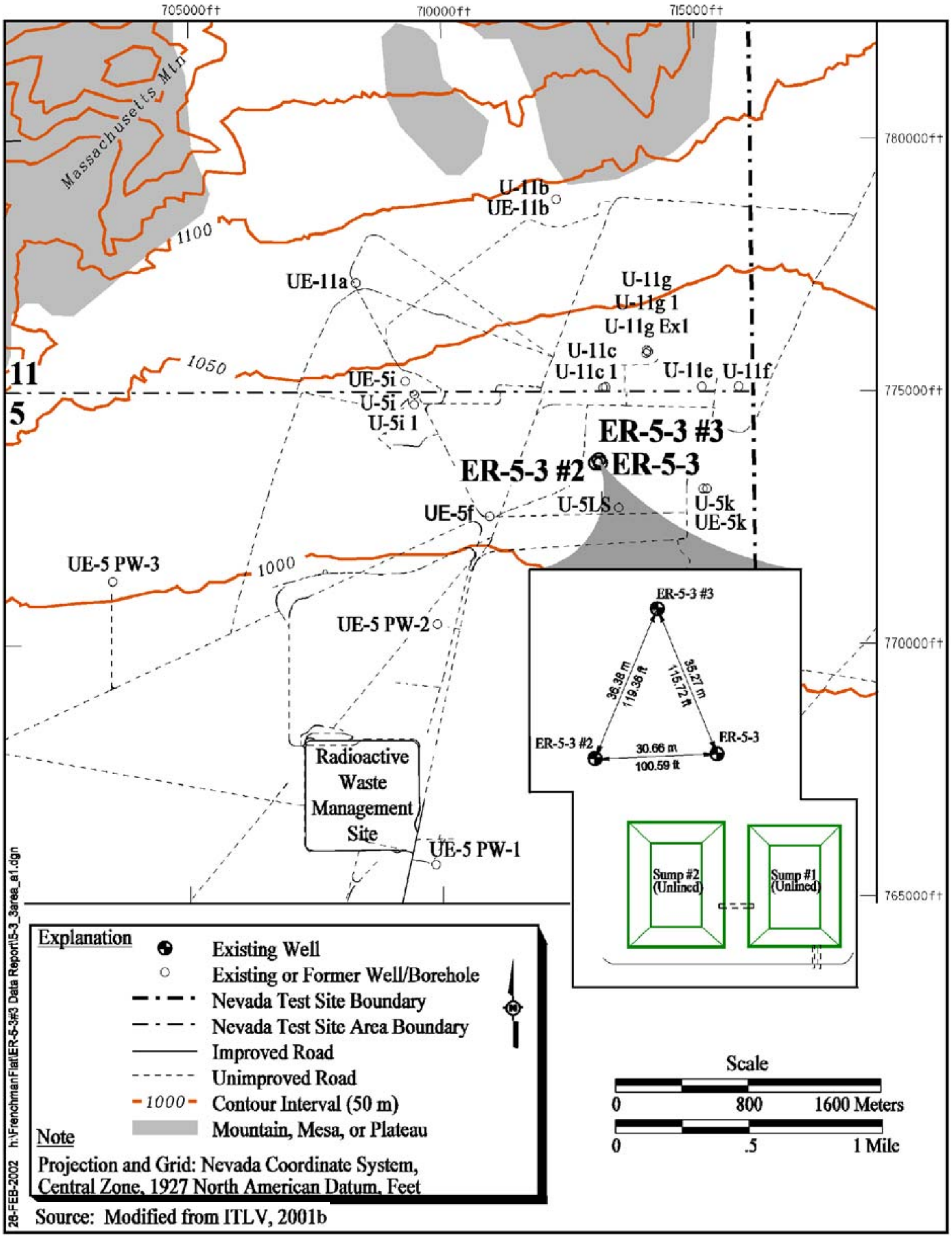


Figure 1-2
Site Layout Map

Table 1-1
Completion Information for Wells and Piezometers at Well Cluster ER-5-3

Completion Zone	Completion Zone[a]		Accessed HSU(s)
	Top (distance bgs)	Bottom (distance bgs)	
Well ER-5-3 (TD - 794 m [2,606 ft] bgs)			
Upper CZ of Production String	441 m (1,446 ft)	543 m (1,782 ft)	OAA
Lower CZ of Production String	723 m (2,372 ft)	794 m (2,606 ft)	TMWTA (+/-TCU)
Shallow PZ	283 m (928 ft)	329 m (1,080 ft)	BLFA and OAA
Deep PZ	608 m (1,995 ft)	681 m (2,235 ft)	TMWTA (+/-TCU)
Well ER-5-3#2 (TD - 1,732 m [5,683.4 ft] bgs)			
ER-5-3#2	1,425 m (4,674 ft)	1,732 m (5,683.4 ft)	LCA
Well ER-5-3#3 (TD - 549 m [1,800 ft] bgs)			
ER-5-3#3	430 m (1,412 ft)	549 m (1,800 ft)	OAA

[a]The top and bottom of the completion zones are defined by the extent of permeable materials in annular space (e.g., 6/9 and 20/40 sand, gravel, and fill).

bgs - Below ground surface
HSU - Hydrostratigraphic unit
TD - Total depth
CZ - Completion zone
SWL - Static water level
PZ - Piezometer
OAA - Old alluvial aquifer
TMWTA - Timber Mountain welded tuff aquifer
TCU - Tuff confining unit
BLFA - Basalt lava flow aquifer
LCA - Lower carbonate aquifer

1.2 Hydraulic Testing Program

The hydraulic testing program of Well Cluster ER-5-3 began as development and testing operations and finished with the 90-day multiple-well aquifer test. Table 1-2 presents a general summary of hydraulic testing activities at the Well Cluster ER-5-3.

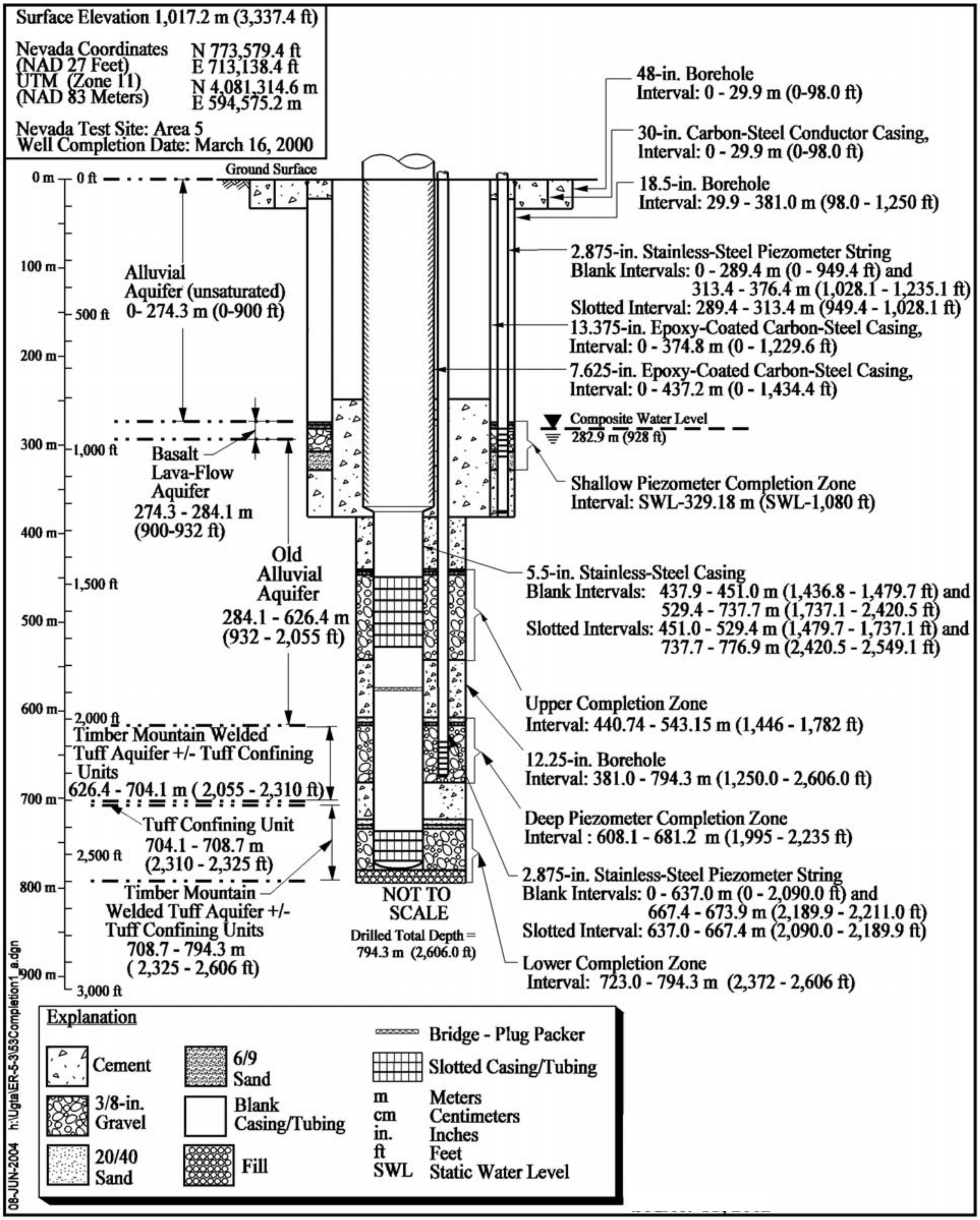


Figure 1-3
Well ER-5-3 Completion Diagram

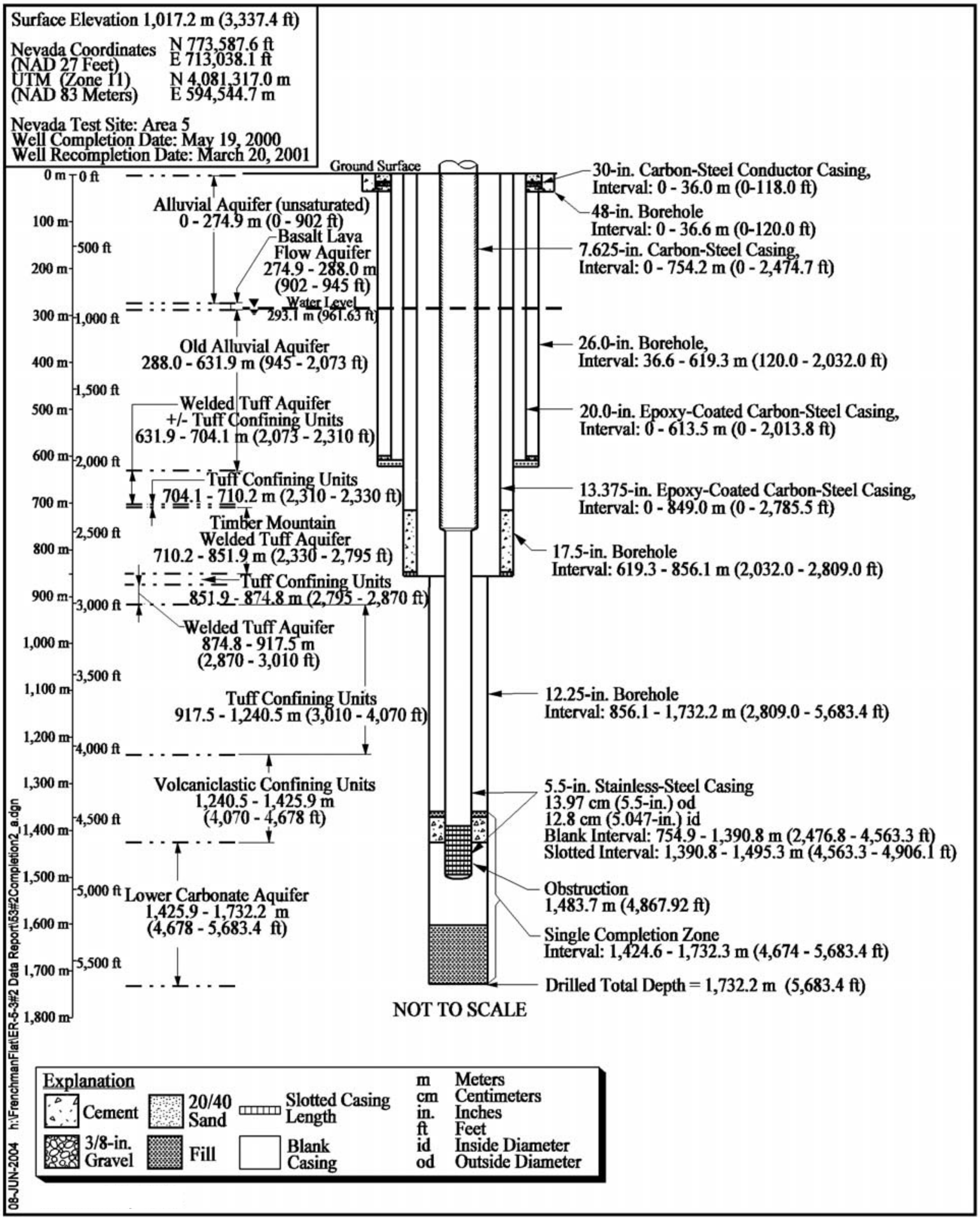


Figure 1-4
Well ER-5-3#2 Completion Diagram

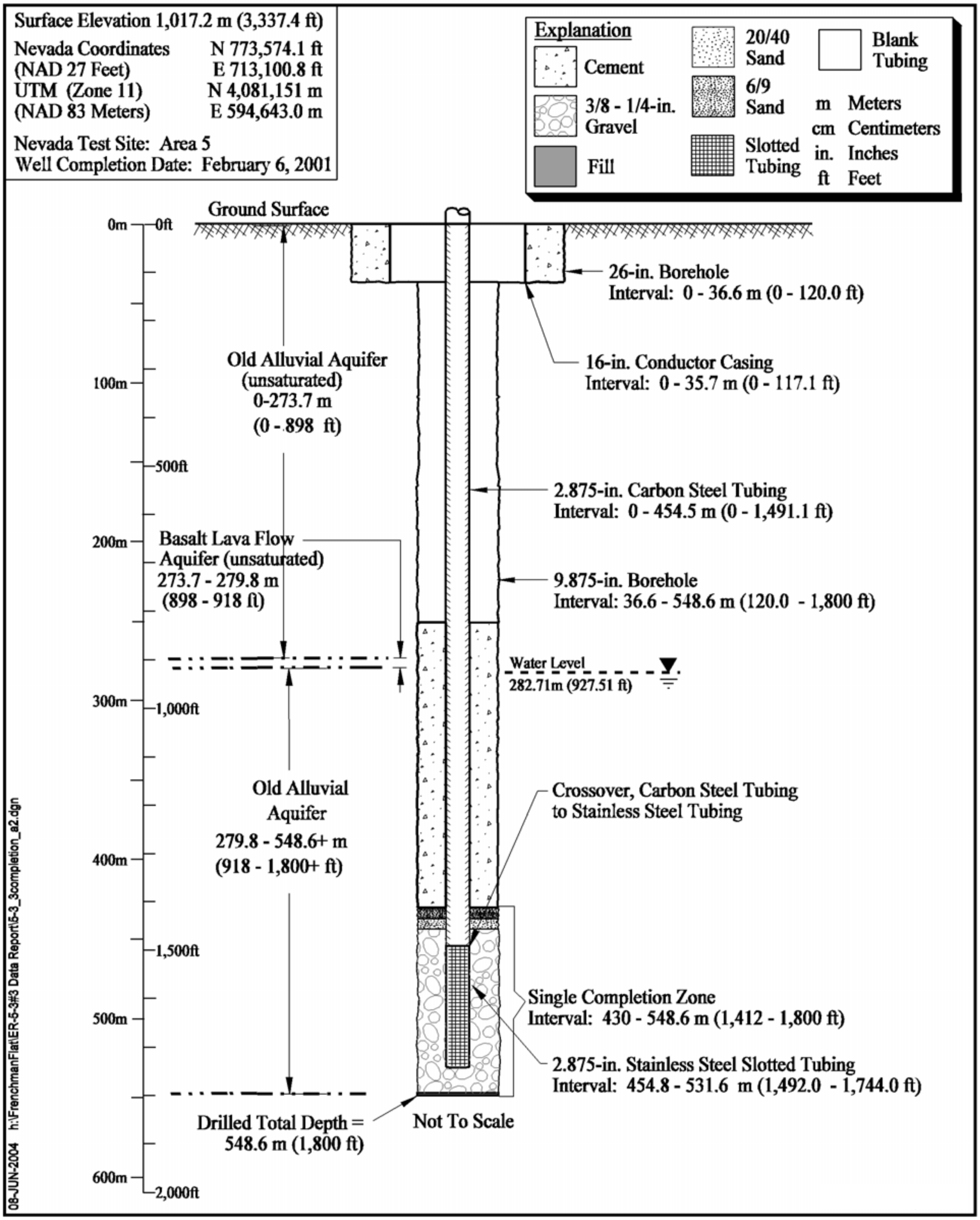


Figure 1-5
Well ER-5-3#3 Completion Diagram

Table 1-2
Summary of Hydraulic Testing Activities at Well Cluster ER-5-3

Activity	Start Date	End Date	Duration (days)
Slug Test ER-5-3#3	2/23/2001	2/23/2001	1
Slug Test Deep Piezometer in ER-5-3	3/2/2001	3/2/2001	1
Slug Test Shallow Piezometer in ER-5-3	3/13/2001	3/13/2001	1
Step Drawdown Test in ER-5-3 (post development)	3/13/2001	3/13/2001	1
Stressed Flow Logging in ER-5-3	3/14/2001	3/17/2001	3
Constant-Rate Test in ER-5-3	3/21/2001	3/30/2001	10
Recovery from the Constant-Rate Test	3/30/2001	4/8/2001	10
Step Drawdown Test in ER-5-3 #2	4/8/2001	4/8/2001	1
Step Drawdown Test in ER-5-3#2 (post development)	4/19/2001	4/19/2001	1
Recovery from Step Drawdown in ER-5-3#2	4/19/2001	4/24/2001	6
Constant-Rate Test in ER-5-3#2	4/24/2001	5/2/2001	9
Recovery from the Constant-Rate Test in ER-5-3#2	5/2/2001	5/7/2001	6
Multiple-Well Aquifer Test	5/18/2001	7/19/2001	63
Recovery from the Multiple-Well Aquifer Test	7/19/2001	9/6/2001	50

1.3 Document Organization

The document is organized into five main sections. Section 1.0 provides this introduction, Section 2.0 describes the hydraulic tests conducted and the type of data collected. The interpretation of the hydraulic data is presented in Section 3.0. Section 4.0 summarizes the interpretations. Finally, Section 5.0 provides a list of references cited in the document.

2.0 Description of Hydraulic Testing

The details of the hydraulic testing are presented in this section. The hydraulic tests and their implementation are summarized along with a presentation of the hydraulic responses.

2.1 Slug Testing in Piezometer Strings

Slugs tests were performed in the Well ER-5-3#3 and the two PZs in ER-5-3. Slug testing utilizes the instantaneous displacement of water (slug) to hydraulically stress a portion of the aquifer, thereby inducing hydraulic responses. A slug/pressure transducer (PXD) device was fabricated using a DAA H-310 PXD (0 to15 pounds per square inch [psi]). A 1.2 m (4 ft) long slug device was attached to the vented cable approximately 0.9 m (3 ft) above the top of the PXD. The entire length of the slug/PXD device was approximately 2.8 m (9 ft). A drawing of the device is presented in Figure 2-1. Information from the slug tests at Well Cluster ER-5-3 is to be used to verify the hydraulic connection of each piezometer to the formations adjacent to the CZs of the piezometers. In addition, results from the tests may provide hydraulic parameters for a small region around each piezometer.

Slug testing with the slug/PXD device was performed using the following method:

- The slug/PXD was lowered into the well with a wireline and *zeroed* just above the static water level (SWL).

- The PXD was then calibrated by lowering the slug/PXD in 0.3- to 1.2-m (1- to 4-ft) increments, allowing PXD pressure measurements (water levels) to equilibrate. Calibrations were completed at up to 12 stations. Information on PXD and barometric pressures, PXD temperatures, and time were typically recorded at each station.

The slug/PXD was then raised quickly so the slug was completely above the SWL, with the PXD sensor remaining fully submerged. The PXD pressure measurements were allowed to equilibrate. The slug/PXD was then lowered rapidly (assumed instantaneous for the purposes of the analysis) about 2.1 m (7 ft) so that the slug was completely submerged. The pressure was again allowed to equilibrate (over 10- to 20-minute (min) periods). The slug/PXD was then raised 2.1 m (7 ft), with PXD pressures allowed to equilibrate again. Depending on the number of trips, this methodology produced 3 to 5 recovery curves.

Slug testing was performed in Well ER-5-3 #3 on February 23, 2001, and the deep piezometer in Well ER-5-3 on March 2, 2001 (Figure 2-2 and Figure 2-3). The

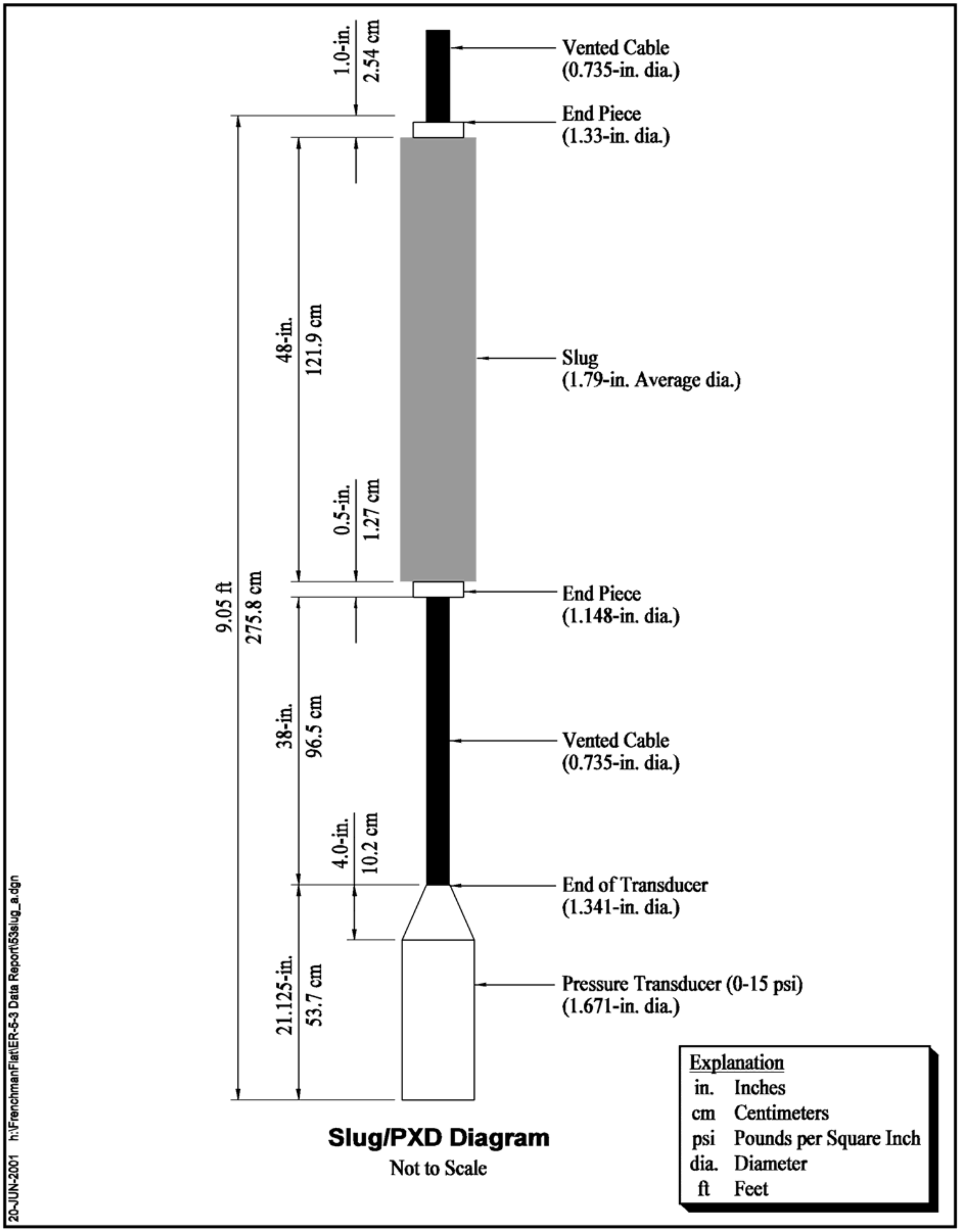
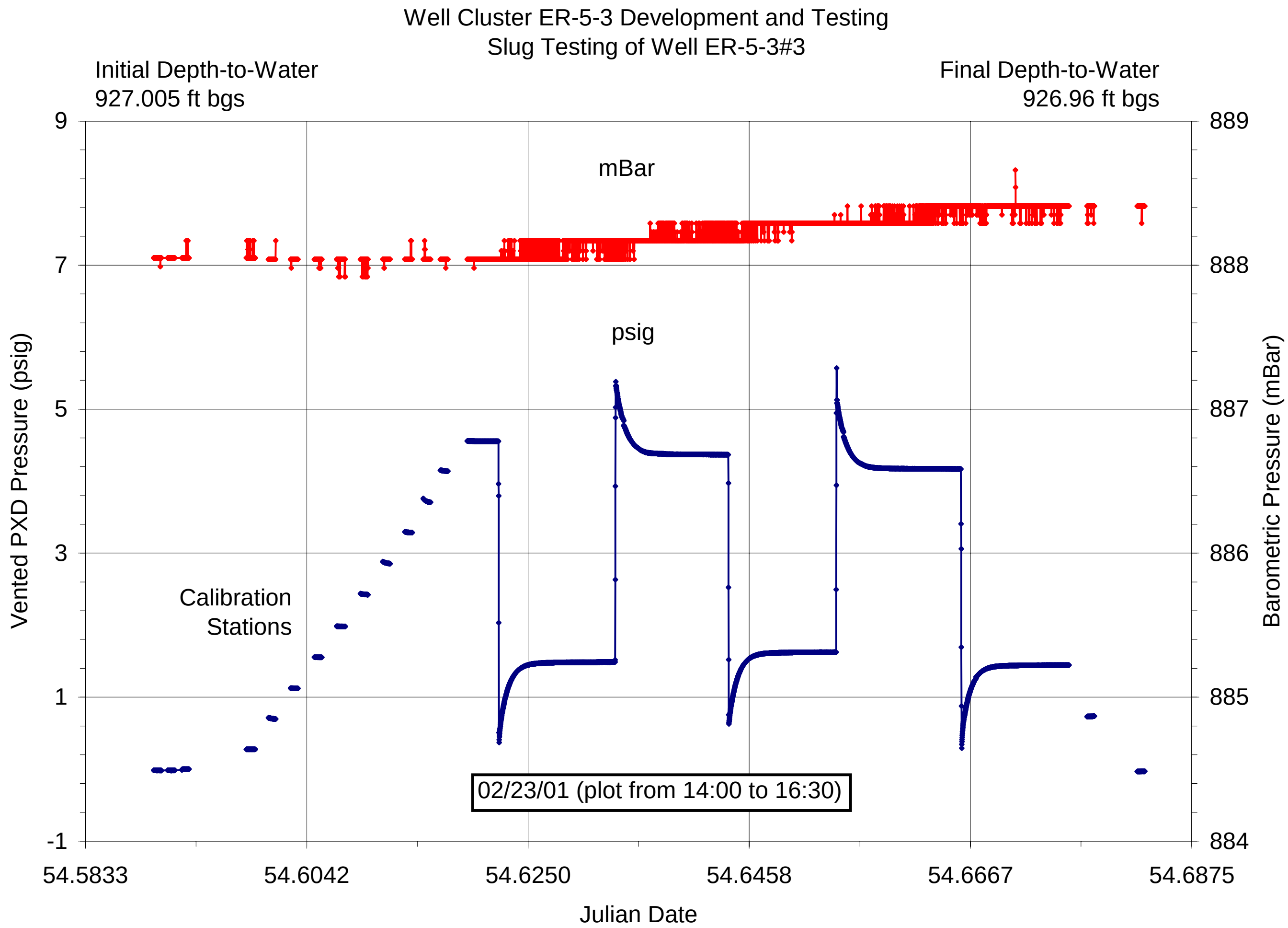


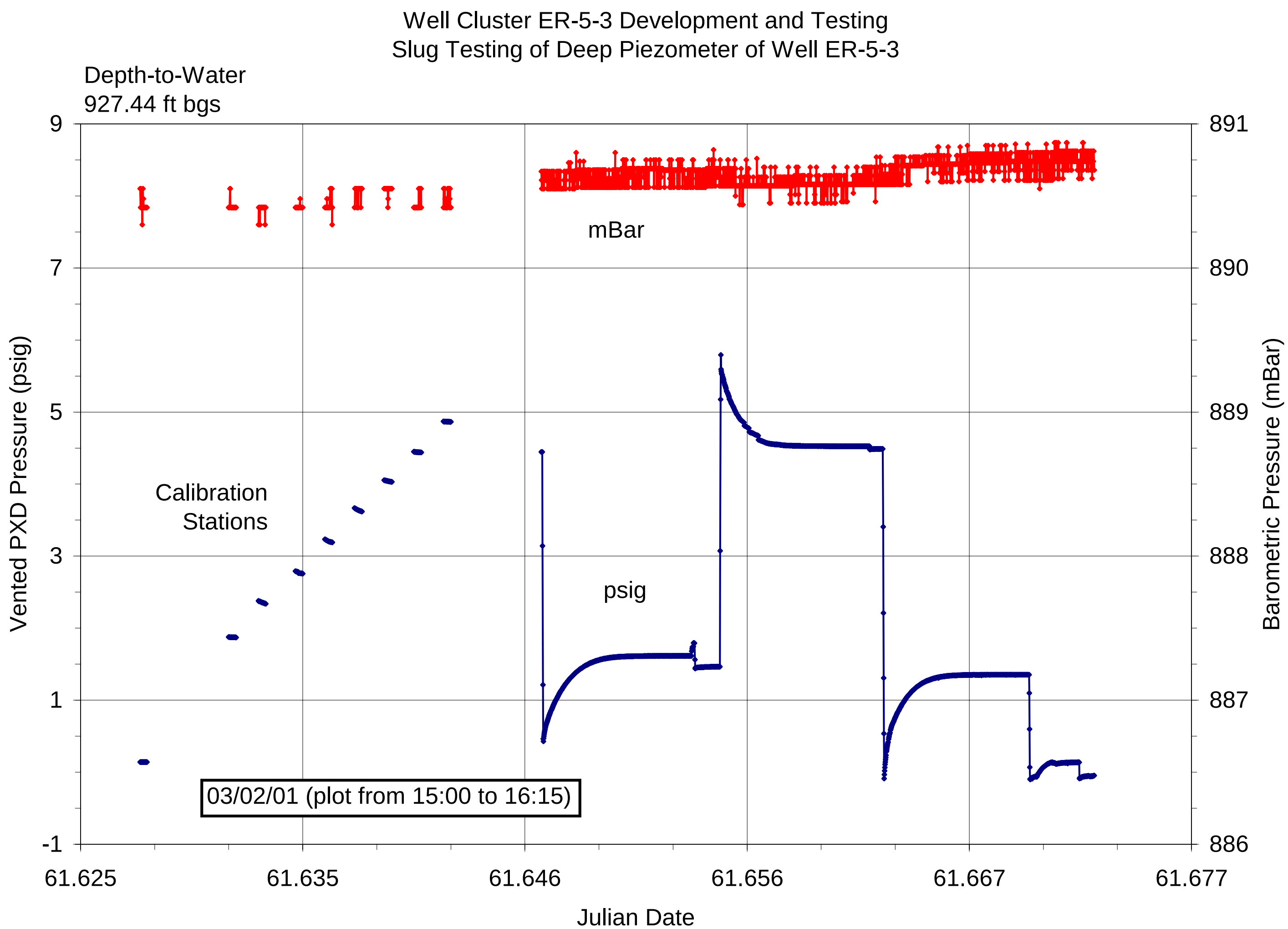
Figure 2-1
Schematic of Slug/PXD Device



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Milllibars

Figure 2-2
Slug Test Response in Well ER-5-3#3



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-3
Slug Test Response in the Deep Piezometer of Well ER-5-3

data records clearly show hydraulic (head) responses to slug injection and removal. Slug testing in the shallow piezometer could not be conducted with the slug/PXD device, as the device encountered resistance in the 0.06 m (2 3/8-inch [in.]) tubing. Instead, a slug test was performed on March 13, 2001, by pouring 0.0189 m^3 (5 gallon [gal]) of water, tagged with lithium bromide (LiBr) tracer, into the tubing of the shallow piezometer. Resultant head changes were monitored with the Keller PXD. The 0.0189 m^3 (5-gal) water slug produced a head change of 0.39 m (1.3 ft) with a return to a SWL in approximately 25 minutes (Figure 2-4).

2.2 Step Drawdown Tests in ER-5-3

The step drawdown testing protocol consisted of production over a specified period of time at a specified constant rate (*step*). Several steps at progressively increasing rates comprise a *cycle* of testing. At Well ER-5-3, production at each step was generally maintained for 1 hour (hr) at each of four progressively greater rates of production (i.e., 492, 655, 818, 920 m^3/day [90, 120, 150, and 168 gpm]) (Table 2-1). Two sets of step drawdown measurements are presented. The first set was collected during well development and the second set was collected after well development. The well efficiency increased during the three-day period between the two tests. On average, the drawdown decreased by 7 percent relative to the first step-drawdown test. This relatively small increase in efficiency may indicate that most of development occurred prior to the first step-drawdown test or that little development was necessary. For subsequent analyses, both sets of step-drawdown data will be analyzed.

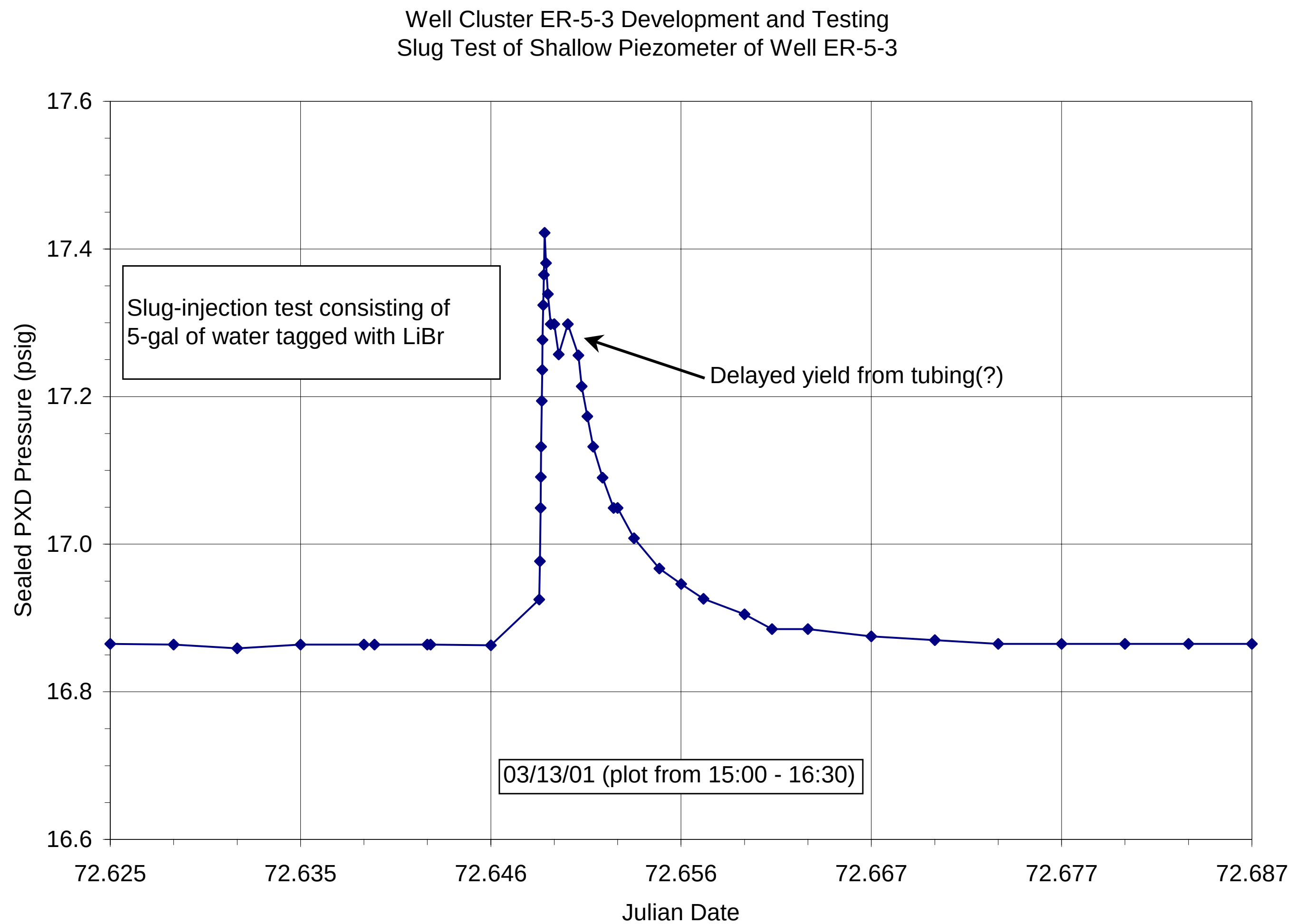
Table 2-1
Step-Drawdown Results at ER-5-3

Date of Step-Drawdown Test	Magnitude of Drawdown at Each Step			
	90 gpm	120 gpm	150 gpm	168 gpm
3/10/2001	1.78 m (5.85 ft)	2.83 m (9.27 ft)	4.00 m (13.11 ft)	4.79 m (15.71 ft)
3/13/2001	1.70 m (5.57 ft)	2.62 m (8.60 ft)	3.71 m (12.18 ft)	4.39 m (14.41 ft)

Each step was approximately 1-hr in duration
The drawdown values provided are from 30 to 45 min after the start of each step

The pumping rates were specified based on several considerations, including pump capacity (minimum and maximum rates) and well/piezometer responses (drawdown).

The magnitude of drawdown at each step (rate) can be evaluated to determine the progress of development and improvements in the hydraulic efficiency of the well. Hydraulic responses in the well and in the monitored strings at each step can be further evaluated to comprehensively characterize the hydrology of the well cluster. The development activities appear to have adequately improved the efficiency of Well ER-5-3, this is especially noticeable at higher production rates. It is also evident in the data record from the testing that the water levels in the



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge

Figure 2-4
Slug Test Response in the Shallow Piezometer of Well ER-5-3

production string approached equilibrium before the subsequent step was initiated (Figure 2-5).

2.2.1 Other Observations

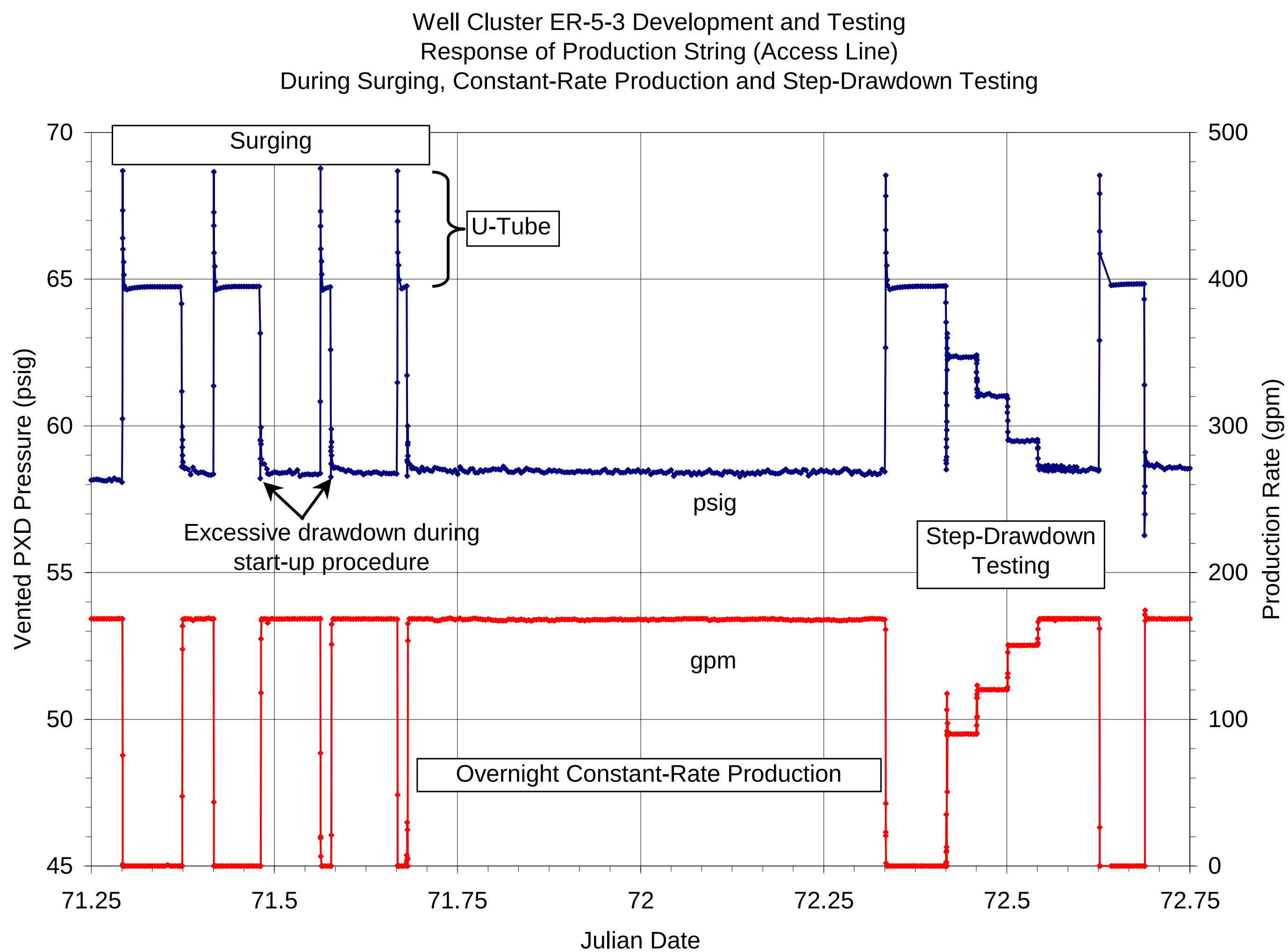
Early in development, visual observations of the initial discharge after starting production were reported as highly to moderately turbid. Later in development, visual observations of discharge were typically noted as turbid. In addition, the initial discharge after each period of starting production was typically noted as (dark) reddish brown, yellowish brown, and grayish green in color. As expected, turbidity generally diminished more rapidly as development progressed. Early in development discharge remained turbid for about 3 min, this decreased to less than 1 min later in the development operations. Overall, the produced water was clear, with little sediment suspended in the discharged water.

Visual observations and qualitative measurements for entrained air in the discharged water were also conducted. The measured contents were initially elevated (1.5 to 2.0 percent) and decreased over time with most measurements indicating contents that were less than 1 percent. The method used to measure the entrained air was not an exact measurement and depended on some visual judgements. It involved obtaining a full biological oxygen demand (BOD) bottle with groundwater, allowing the water to de-gas, and then measuring the volume of water in a graduated cylinder. Visual observations of entrained air indicated similar decreases in the content of air in the discharged water over time. Initial observations indicated high to moderate air contents, with low to moderate air content recognized as operations progressed.

2.3 Stressed Flow Logging in ER-5-3

Downhole stressed flow logging was conducted while the well was under production. The logging, which was conducted with a spinner (impeller) tool, was performed as part of the final activities of the development operations. It can be safely assumed that different CZs will not respond uniformly to production due to the influence of vertical hydraulic gradients, differences in hydraulic conductivities of the adjacent HSUs, and flow losses in and near the well.

The flow logging directly measured the magnitude and location of water production in the well completion. The logging provided data on the proportional contributions of water into the well (inflow) from each CZ and from discrete locations within the CZs. The logging also provides information on water-loss locations (outflow), where water exits the well completion and enters the adjacent filterpack and/or HSUs. Information from the logging was used, in part, to determine the production rate for the subsequent constant-rate test. The information can also be utilized for quantifying and enhancing the understanding of the hydraulic and analytical data obtained during the WDT program. The measurements of the spinner tool were cumulative upward. The uppermost measurements in the 5 1/2-in. production casing, above the upper CZ, coincided with the surface production rates.



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

Figure 2-5
Detail of Surging and Step Drawdown Response in Well ER-5-3 Production String

2.3.1 Methodology

The information on water production within each CZ was acquired at different rates of production. The rates specified for the stressed flow logging corresponded with those used during the step-drawdown testing (i.e., 492, 818, 920 m³/day [90, 50, and 168 gpm]). This was done so the logging results could be directly compared with the information obtained during the step-drawdown testing. This also permits for additional evaluation of the linearity of effects during later interpretations and analyses.

Flow logging with the spinner tool was conducted by DRI on March 14 and 15, 2001. A complete suite of flow logging runs were completed. A temperature log was acquired simultaneously to better define discrete zones of production. The logging suite included calibrations under no production, stationary measurements, and trolling logs. Logging runs were conducted at four line-speeds (i.e., 6.1, 9.1, 12.2, 18.3 meters per minute [m/min] [20, 30, 40, and 60 feet per minute [fpm]]). The runs were conducted in upward and downward directions to comprehensively evaluate flow under various test conditions.

2.3.2 Equipment and Calibration

The DRI flow-logging system consists of all Flexstak equipment. The configuration of the tool included, from top to bottom: a telemetry cartridge, an upper centralizer, the temperature sensor, a lower centralizer, and the fullbore flowmeter. All logging tools and the data acquisition system are manufactured by Computalog. The tool string has a maximum diameter of 0.043 m (1 11/16-in.).

The fullbore flowmeter has a minimum measurement of 1.52 m/min (5 fpm) and a resolution of 0.1 percent. The flowmeter has a collapsible impeller that opens to cover a much larger percentage of the casing cross section than a standard fixed-blade impeller. The temperature sensor is rated to a maximum of 176 degrees Fahrenheit (°F) and is pressure-rated to 17,000 psi. The temperature sensor is run to provide high-resolution information on gradient and differential temperature. In conjunction with information from the spinner tool, the temperature provides information that is useful in fluid flow analyses. Centralizers are run in conjunction with the various sensors to center the tool in the well.

Calibration of the tool is completed by comparing measured flow at the surficial magnetic flowmeter (actual flow rates) to the readings of counts-per-second and flow velocity of the tool. Calibration data at low flow rates are obtained from a DRI calibration facility, where calibration runs can produce 0 to 327 m³/day (60 gpm) of flow through 0.14 m (5 1/2-in.) casing. The calibration of the flow logging tool was also field-verified in the production string of the well. This was accomplished by comparing tool measurements against the actual production rates (i.e., 492, 818, 920 m³/day [90, 150, and 168 gpm]) of the logging suite. The tool acquired stationary (upward velocity) measurements while positioned in the 0.14 m (5 1/2-in.) casing above the upper CZ.

2.3.3 Logging Methodology

Fourteen successful trolling logs were recorded at the four line speeds from just above the top of the upper CZ to the bottom of the lower CZ, typically from approximately 427 - 774 m (1,400 to 2,540 ft) below ground surface (bgs). The bottom of the well completion was tagged by DRI at 776 m (2,545 ft) bgs, where their sinker bar encountered a soft set. This depth is about 1.2 m (4 ft) above the bottom of the lower slotted interval.

Initially, two trolling logs were acquired under ambient conditions (no production). One run was conducted in a downward direction at a line speed of 9.1 m/min (30 fpm) and the second was conducted in an upward direction at 6.1 m/min (20 fpm). The remaining stressed flow logging runs occurred in the following order: (1) stationary measurements at two stations, (2) downward run at 6.1 m/min (20 fpm), (3) upward run at 12.2 m/min (40 fpm), (4) downward run at 12.2 m/min (40 fpm), and (5) upward run at 18.3 m/min (60 fpm). This five-step sequence was repeated for each of the three production rates (i.e., 492, 818, 920 m^3/day [90, 150, and 168 gpm]). The line-speed for the trolling logs was increased (30.5 - 33.5 m/min [100 to 110 fpm]) in the blank casing between the completion zones to expedite the logging operations (Table 2-2).

Table 2-2
Trolling Flow Logs in Well ER-5-3
(Source: IT, 2001b)

Run Number	Date	Direction of Run	Line Speed (fpm)	Surface Discharge (gpm)	Start - Finish (ft bgs)
er53mov01	3/14/2001	Down	30	0	1,388.4 - 2,508.2
er53mov02		Up	20		2,508.3 - 1,390.2
er53mov03		Down	20	90	1,399.2 - 2,539.4
er53mov04		Up	40		2,539.5 - 1,400.6
er53mov05		Down	40		1,400.6 - 2,539.2
er53mov06		Up	60		2,539.3 - 1,399.5
er53mov07	3/15/2001	Down	20	150	1,399.8 - 2,540.0
er53mov08		Up	40		2,540.1 - 1,399.7
er53mov09		Down	40		1,399.7 - 2,540.2
er53mov10		Up	60		2,540.3 - 1,398.4
er53mov11		Down	20	168	1,400.1 - 2,539.9
er53mov12		Up	40		2,540.1 - 1,399.9
er53mov13		Down	40		1,399.9 - 2,539.9
er53mov14		Up	60		2,540.0 - 1,399.7
er53mov15	[a] 4/10/2001	Down	30	0	916.4 - 2,536.1
er53mov16		Up	30		2,535.8 - 1,296.0

[a] Obtained during ambient logging after the constant-rate test.

Stationary measurements of flow were also obtained. One suite of stationary logs were acquired above the upper CZ at a depth of 445 m (1,460 ft) bgs, with a second suite obtained between the CZs at a depth of 640 m (2,100 ft) bgs (Table 2-3).

Table 2-3
Stationary Flow Measurements in Well ER-5-3
(Source: IT, 2001b)

Log Run	Date	Location	Average Temperature (°F)	Pumping Rate (gpm)	Depth (ft bgs)	Average Flow (gpm)
er53stat01	3/14/2001	Above upper CZ	79.56	90	1,460	90.41
er53stat02		Between upper and lower CZ	79.87		2,100	87.62
er53stat03	3/15/2001	Above upper CZ	79.72	150	1,460	151.39
er53stat04		Between upper and lower CZ	79.89		2,100	148.90
er54stat05		Above upper CZ	79.73	168	1,460	168.53
er53stat06		Between upper and lower CZ	79.89		2,100	166.15

°F - Degrees Fahrenheit

2.3.4 Flow Logging Results

The results of the 16 trolling flow logs under ambient and pumping conditions were compiled. The ambient log presented in this document was run at 6.1 m/min (20 fpm) upward (Figure 2-6). One trolling log during pumping (Figure 2-7), collected at a discharge rate of 818 m^3/day (150 gpm) and a line speed of 6.1 m/min (20 fpm) downward, is shown in this report for discussion purposes. The other trolling logs have nearly identical features. Except for minor differences in noise and the magnitude of fluctuations, all of the trolling logs for a given production rate are similar. A temperature log has been included in both figures for reference.

2.4 Constant-Rate Test in ER-5-3

A constant-rate pumping test was conducted following well development to collect additional data (i.e., hydraulic responses of the monitored strings over a greater period of time). These data can be used for more comprehensive evaluations and analyses of the local hydrology and aquifer parameters at Well Cluster ER-5-3. In addition to providing additional data, production during the test served to continue the development process with the continued removal of groundwater.

Prior to the test, the various strings were monitored to observe water-level recovery/equilibration after production during the development operations. This also allowed for the establishment of baseline (pretest) water levels. Pumping for the constant-rate test commenced on March 21, 2001, at 10:46, and continued without interruption until the variable speed drive (VSD) was shutdown at 09:00 on March 30, 2001. Prior to the shutdown of the VSD, which ended the constant-rate test, composite groundwater characterization samples were collected from the wellhead. Production during the test facilitated the restoration of natural water quality prior to the sampling. Water-level recovery after the test was monitored for five days, until April 4, 2001.

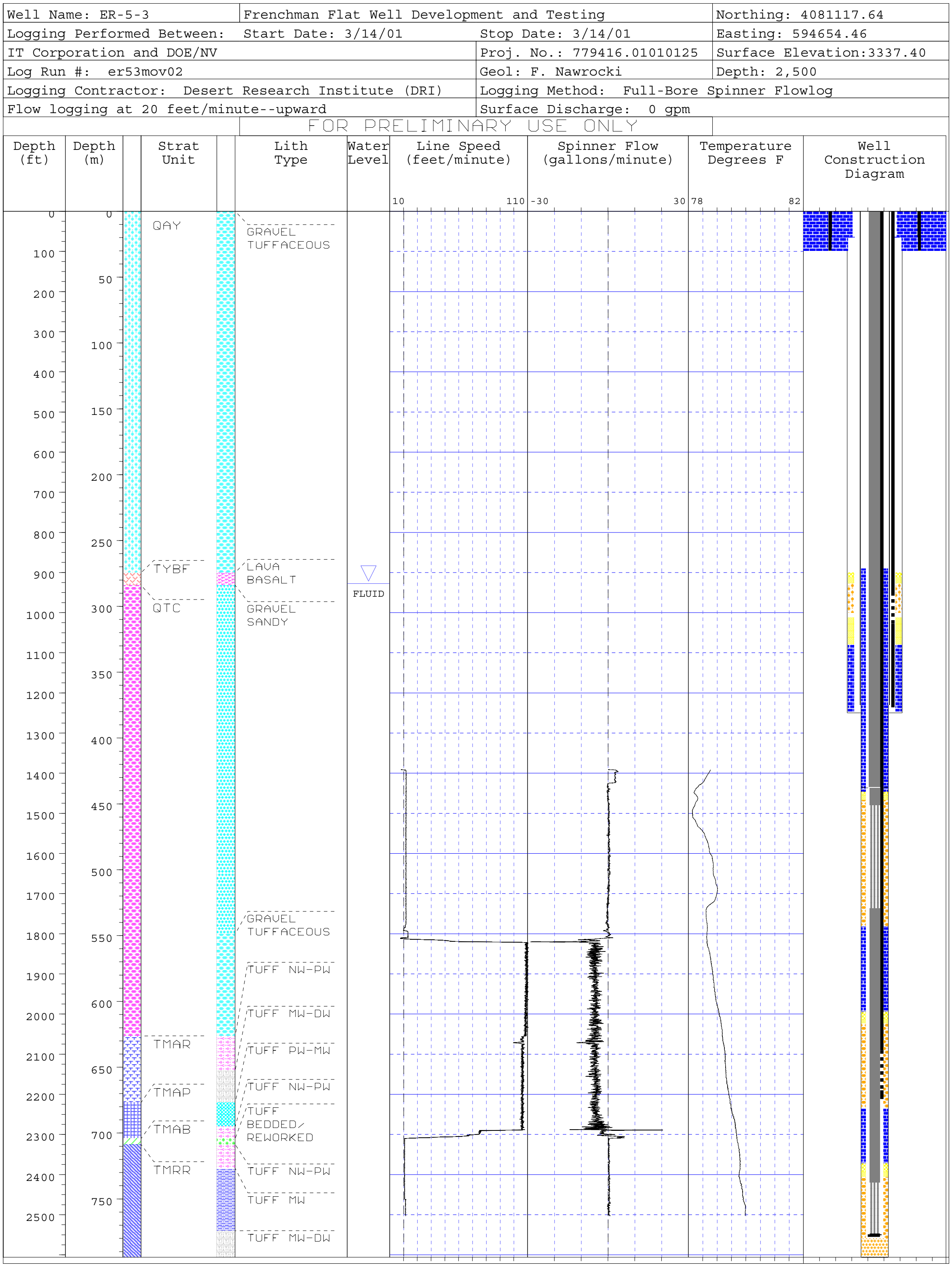


Figure 2-6
Ambient Flow Log with 20 fpm Upward Trolling Rate in ER-5-3

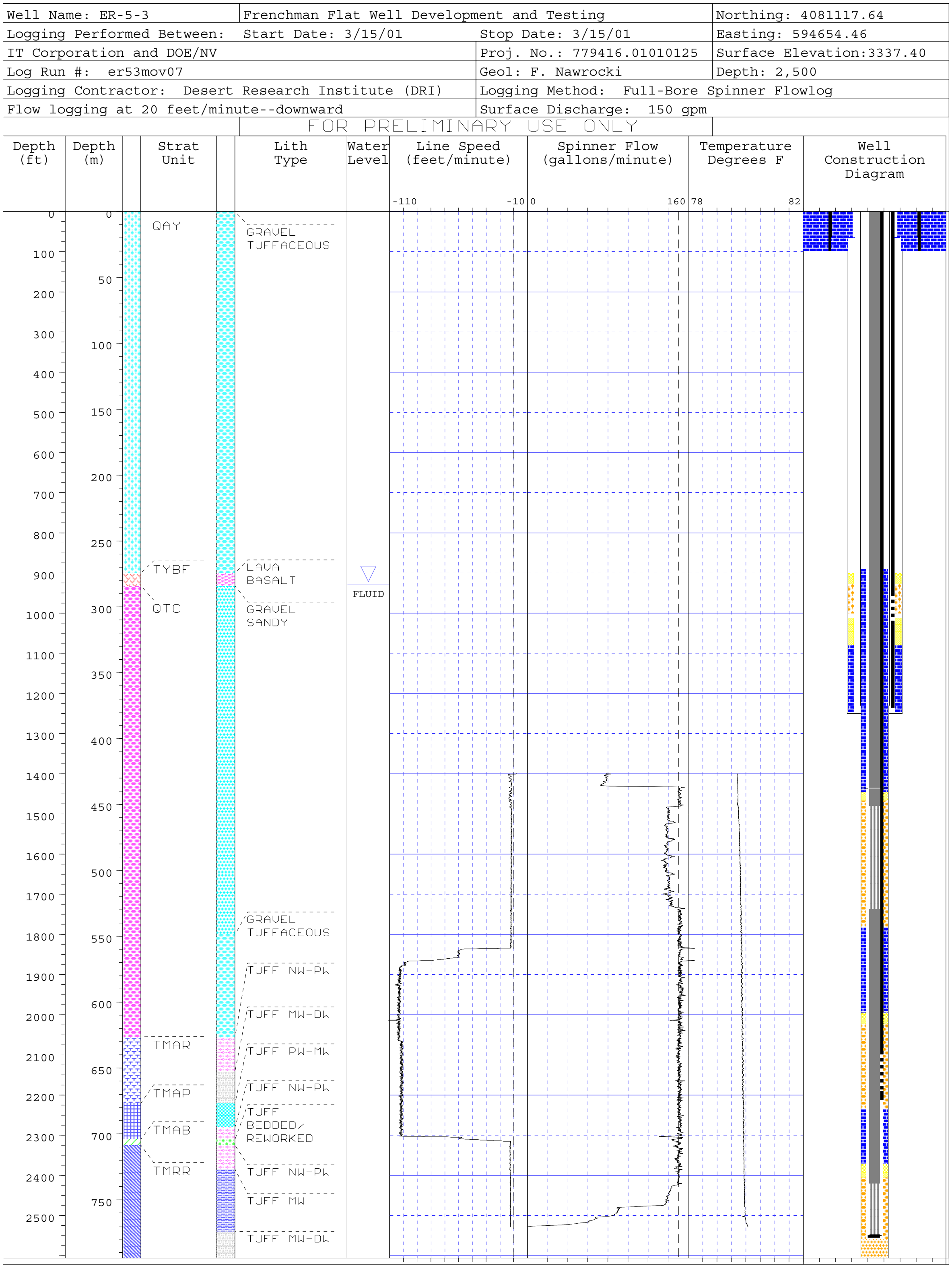


Figure 2-7
Stressed Flow Log (at 150 gpm and 20 fpm Downward Trolling Rate) in ER-5-3

2.4.1 Methodology

Continuous data records were captured during the test. The data acquisition included PXD pressures (three observation points in Well ER-5-3 and Well ER-5-3#3), barometric pressure (at two dataloggers), production rates, and continued water-quality monitoring. Datalogger records were obtained throughout the testing period (i.e., pretest water-level equilibration, 9 days of production, and 3 day water-level recovery after the production phase of the test). Constant rates of production were maintained via the control signal from the magnetic flow meter. A production rate of 818 m^3/day (150 gpm) was specified for the constant-rate test. This rate was less than the maximum capacity (992 m^3/day [182 gpm]) of the testing pump, but was considered sufficient to achieve the scientific objectives of the test. Water-quality monitoring was achieved via an in-line system (continuous) and grab sampling and analysis, which occurred approximately every 2 hours during daylight shifts.

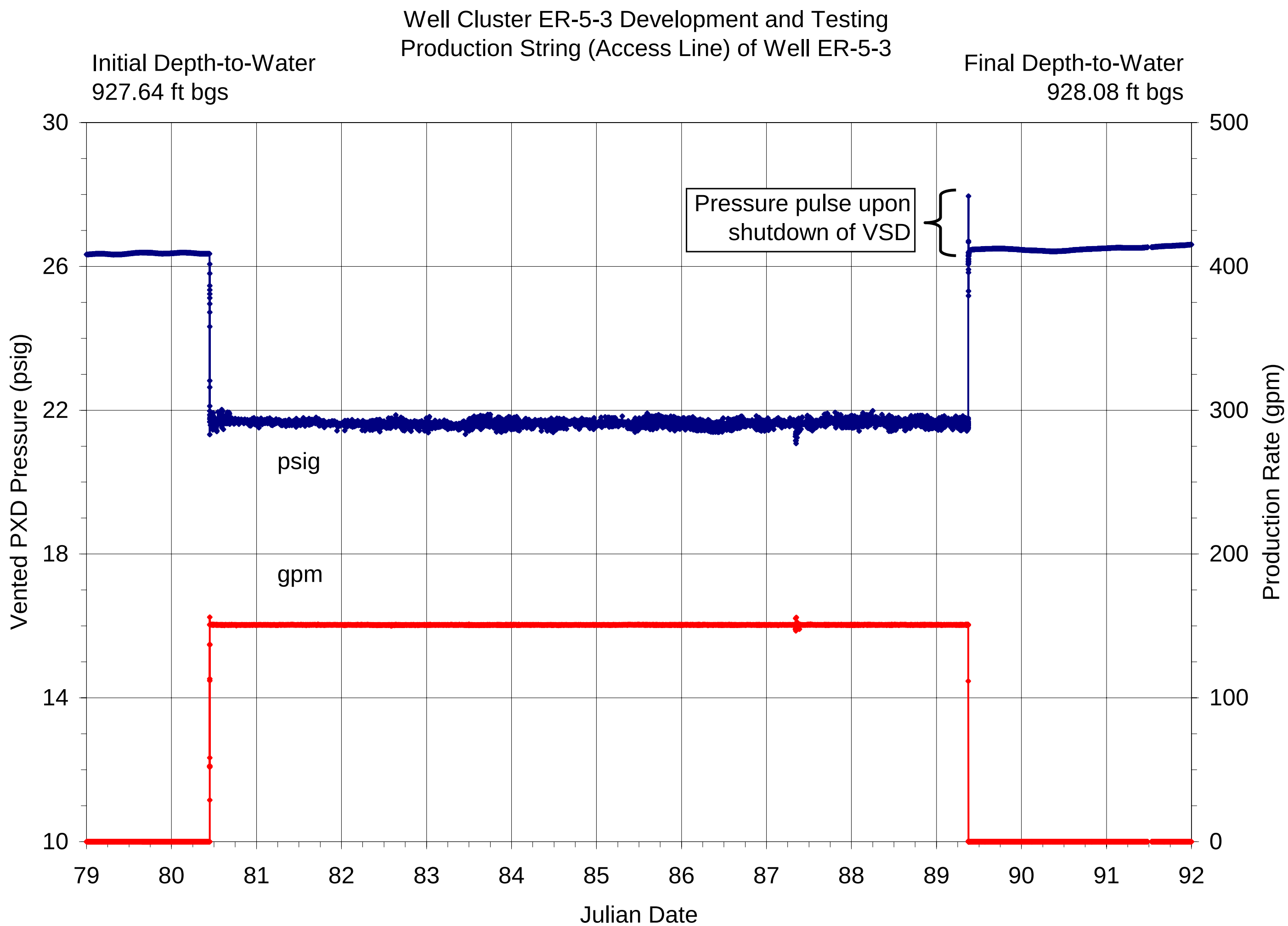
2.4.2 Hydraulic Data Collection

The data records for the production string during the constant-rate test have been compiled. These records include information on the hydraulic response (PXD pressure) of the string, along with coinciding production rates and barometric pressure (Figure 2-8 and Figure 2-9). During the constant-rate test, production remained consistent, with an average rate of 818 m^3/day (150.50 gpm) being maintained throughout the production phase of the test. Changes in barometric pressure were generally constant relative to the changes in PXD pressure. One exception would be a fairly large decrease in barometric pressure near the end of the test (Julian Date [JDate] 91).

The pressures measured by the PXD in the production string fluctuated over a range of approximately 0.5 pounds per square inch gauge (psig), which translates to a noise band of about 0.37 m (1.2 ft), or 1.7% of the PXD operational range (0-30 psig). Considering the overall hydraulic response (drawdown) of about 5 psig (approximately 3.7 m [12 ft]), the noise is acceptable and within the range of bands recognized in previous constant-rate records.

Data records from the three observation points (piezometers of Well ER-5-3 and Well ER-5-3#3) have also been processed and are provided. The records include the hydraulic responses of the observation points relative to production rates (Figure 2-10, Figure 2-12, and Figure 2-14) and the same hydraulic-response records relative to barometric pressure (Figure 2-11, Figure 2-13, and Figure 2-15). Changes in barometric pressure seem to have impacted the water-level responses in the deep piezometer and Well ER-5-3 #3 (Figure 2-11 and Figure 2-15). On the contrary, the hydraulic responses of the shallow piezometer appear to be unaffected by changes in barometric pressure (Figure 2-13).

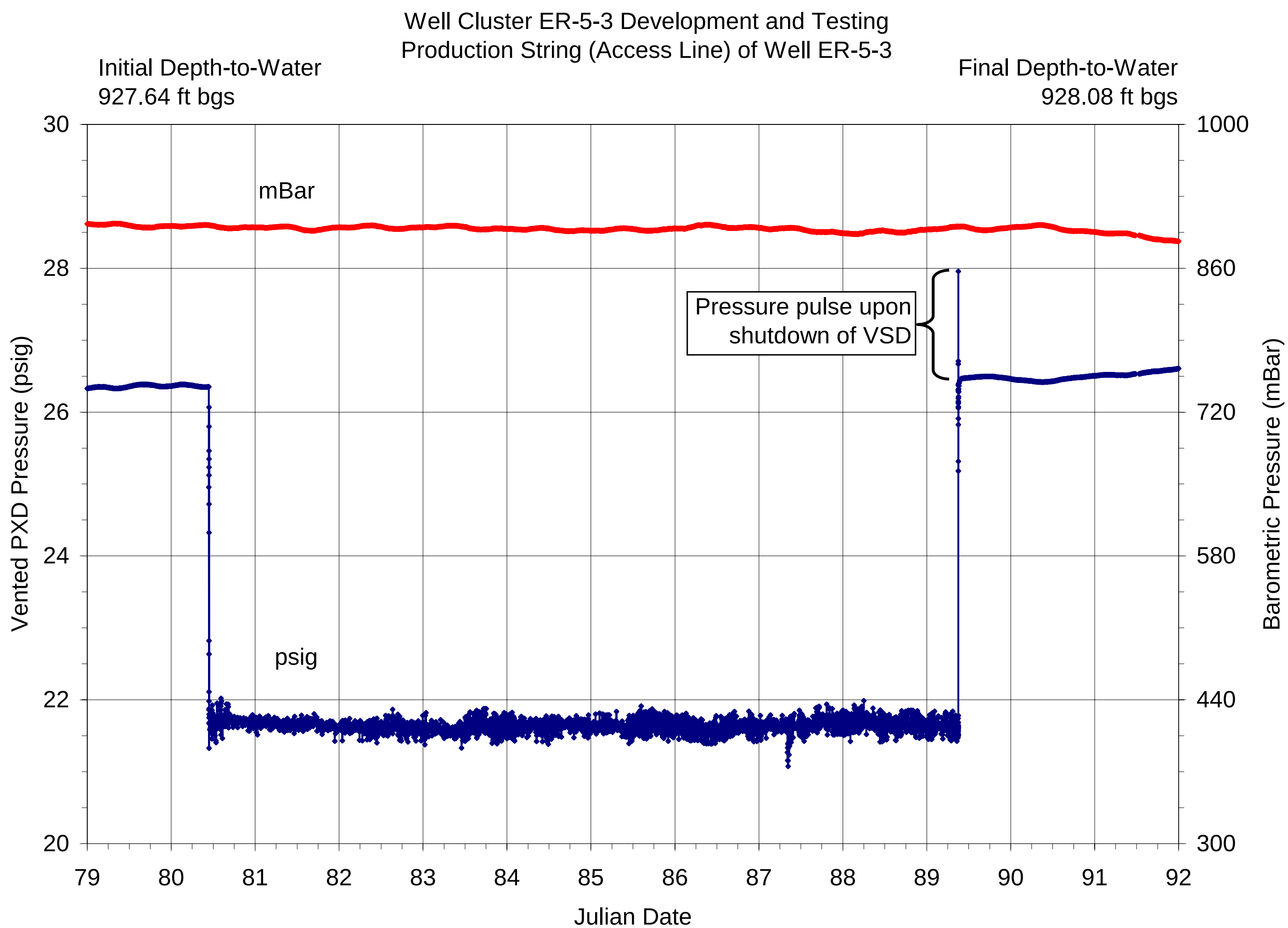
Slight warming trends can be recognized in the downhole (PXD) temperature records of the production and deep piezometer strings of Well ER-5-3 (Figure 2-16). Fairly rapid changes in groundwater temperatures are noted



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

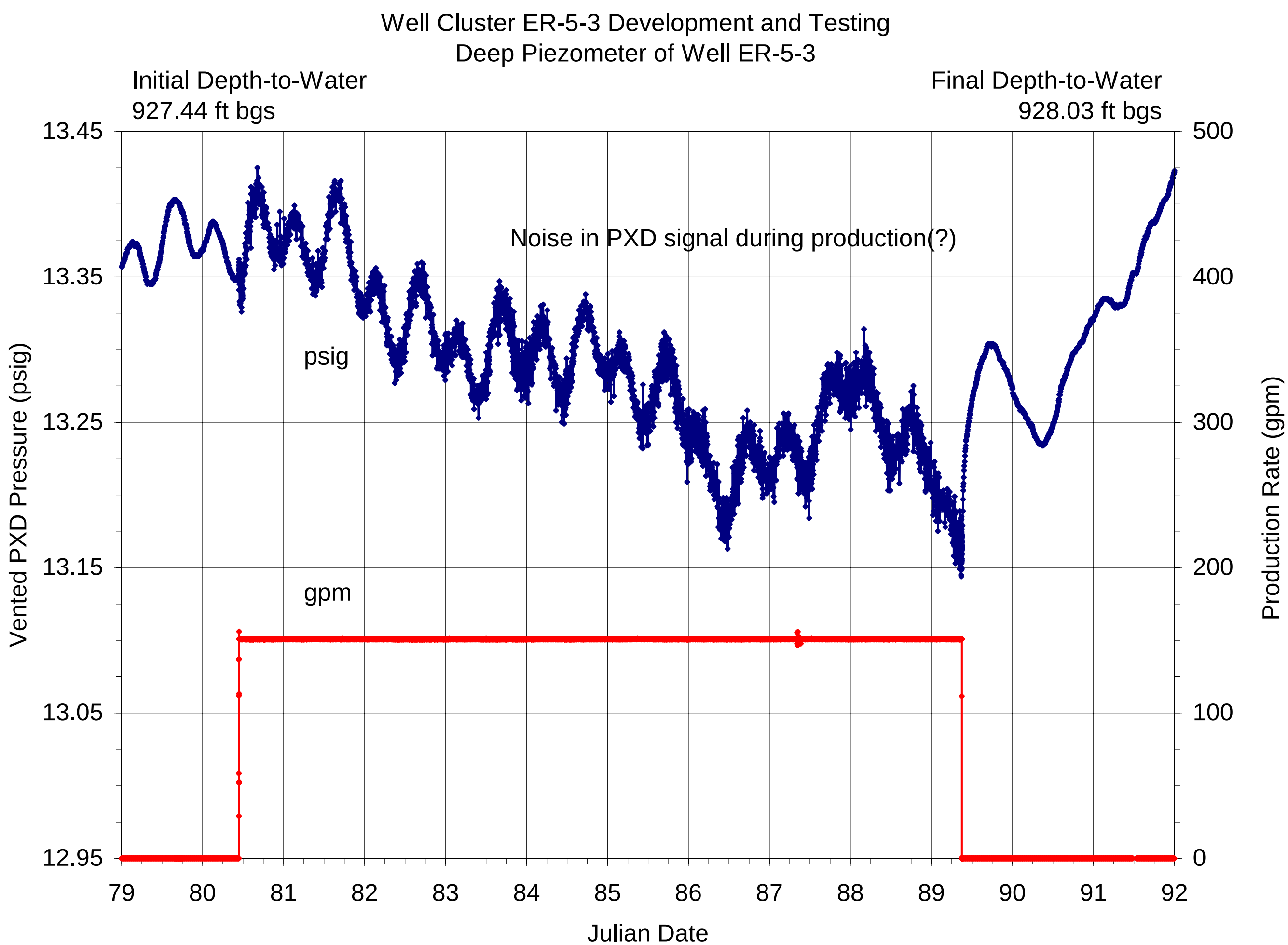
Figure 2-8
PXD Pressure and Production Rates for Well ER-5-3 Production String During the ER-5-3 Constant-Rate Test



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

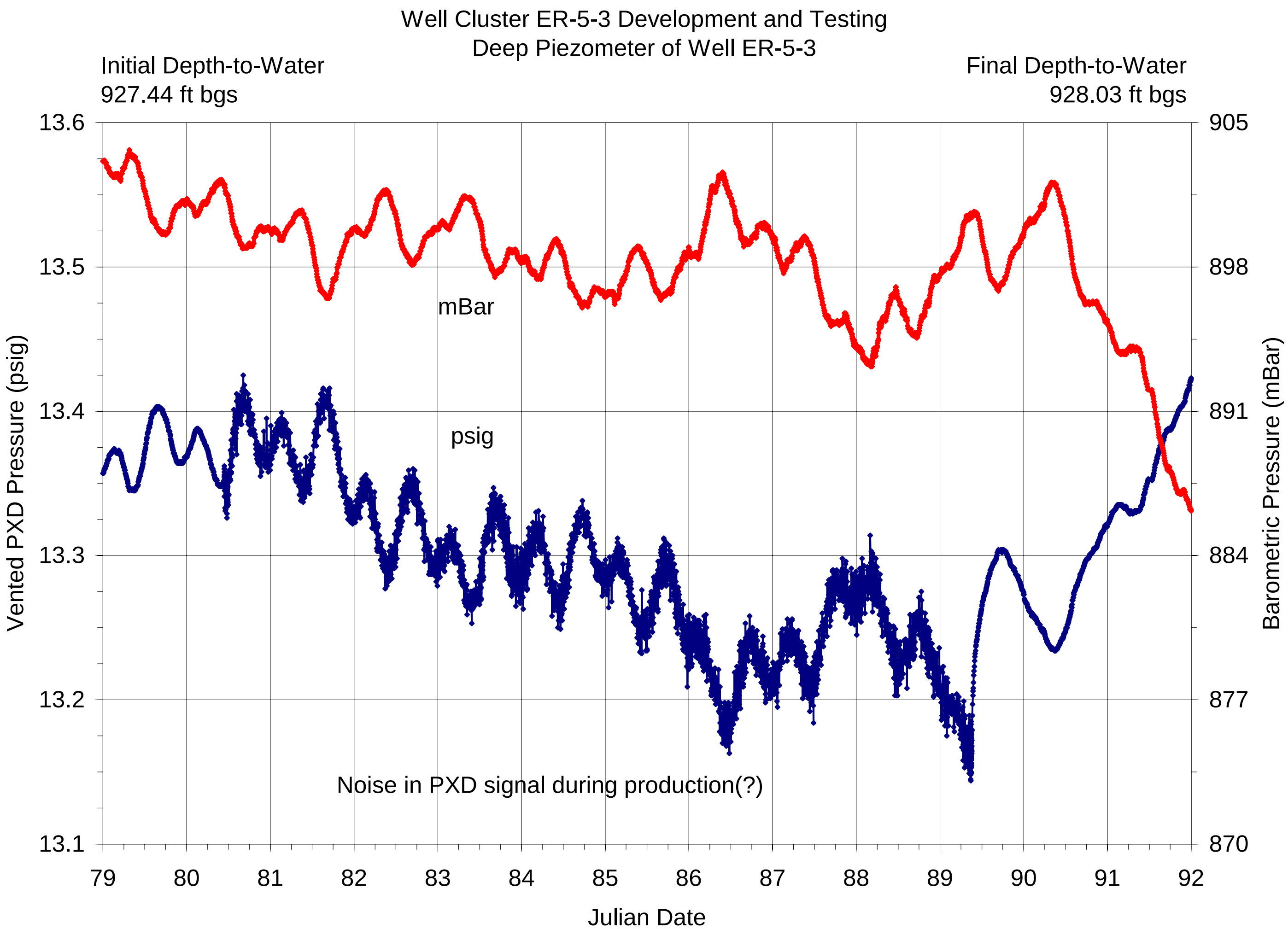
Figure 2-9
Barometric Pressure and PXD Pressure for Well ER-5-3 During the ER-5-3 Constant-Rate Test



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

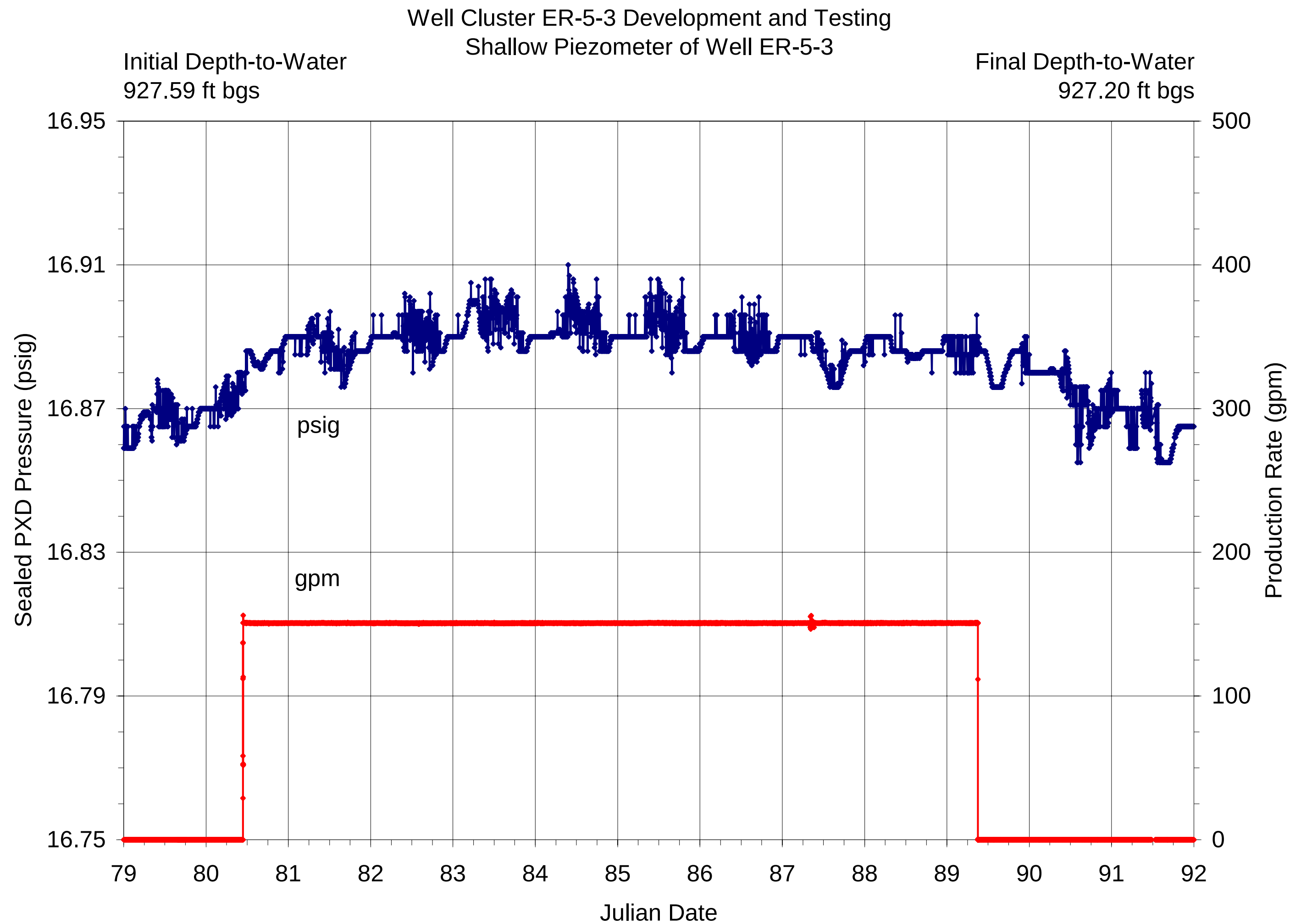
Figure 2-10
Production Rates and PXD Pressure for the Deep PZ in Well ER-5-3 During the ER-5-3 Constant-Rate Test



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

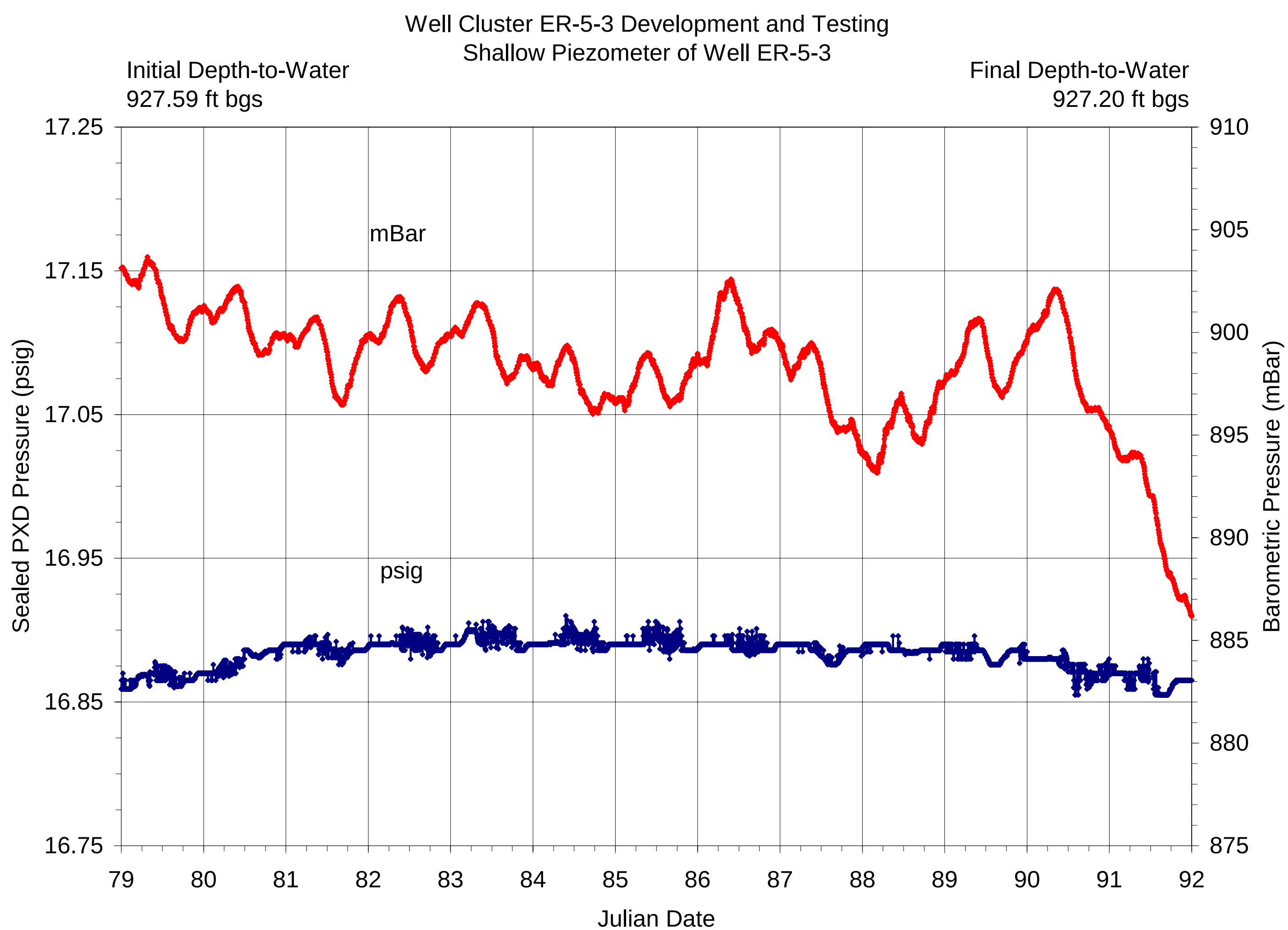
Figure 2-11
Barometric Pressure and PXD Pressure for the Deep PZ in Well ER-5-3 During the ER-5-3 Constant-Rate Test



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

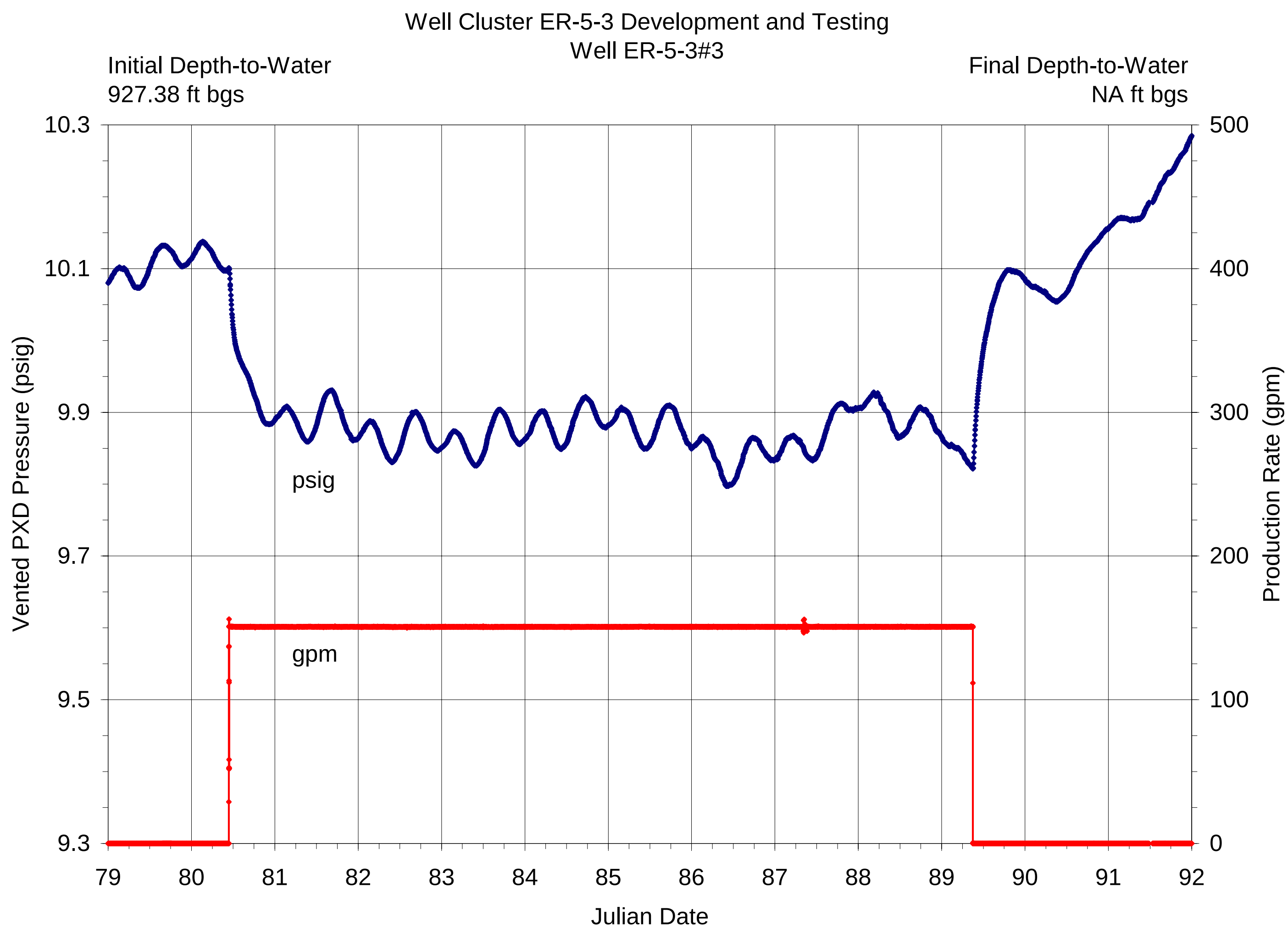
Figure 2-12
Production Rates and PXD Pressure for the Shallow PZ in Well ER-5-3 During the ER-5-3 Constant-Rate Test



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-13
Barometric Pressure and PXD Pressure in the Shallow PZ of Well ER-5-3 During the ER-5-3 Constant-Rate Test



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

Figure 2-14
Production Rate and PXD Pressure in Well ER-5-3#3 During the ER-5-3 Constant-Rate Test

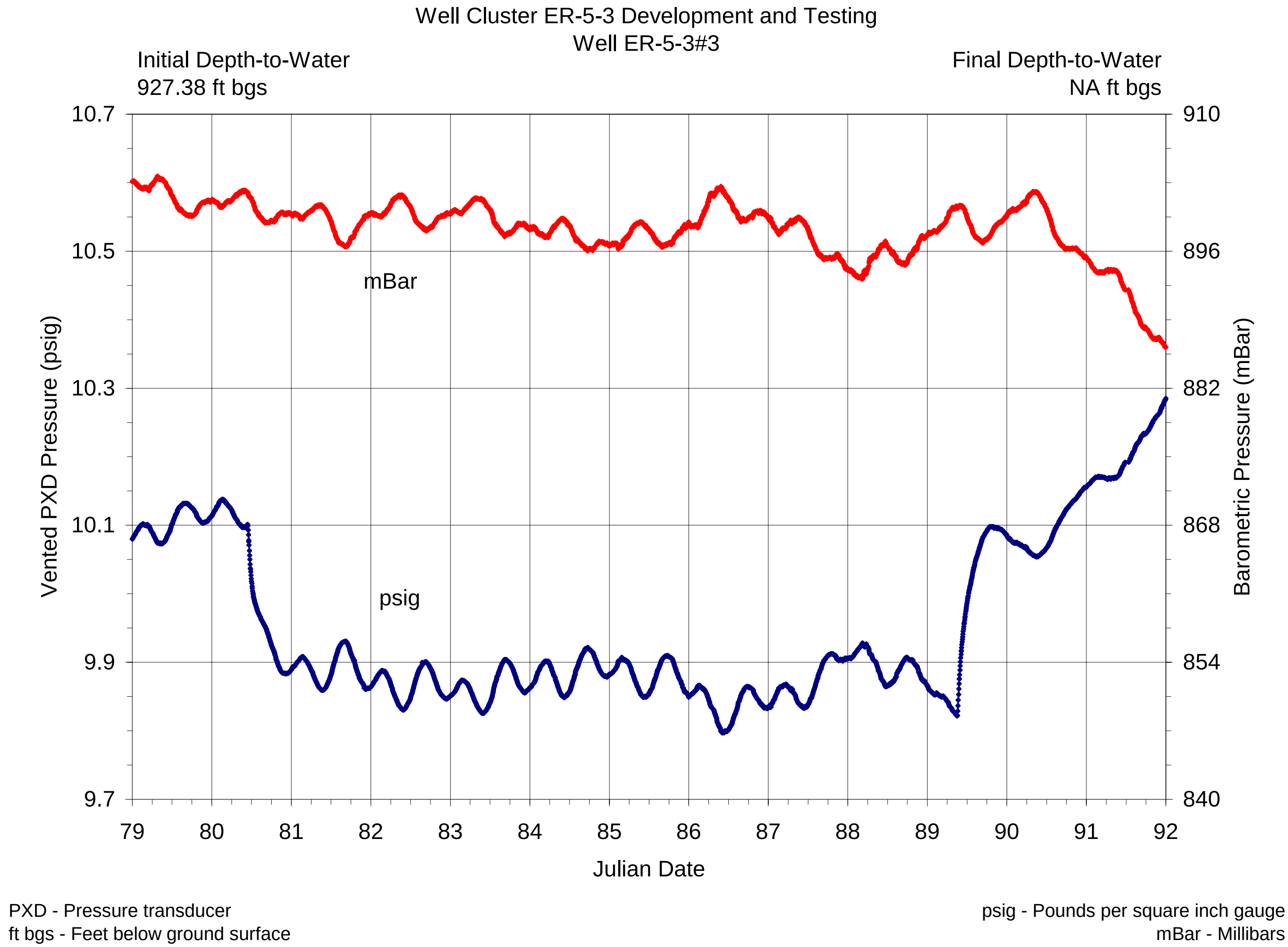
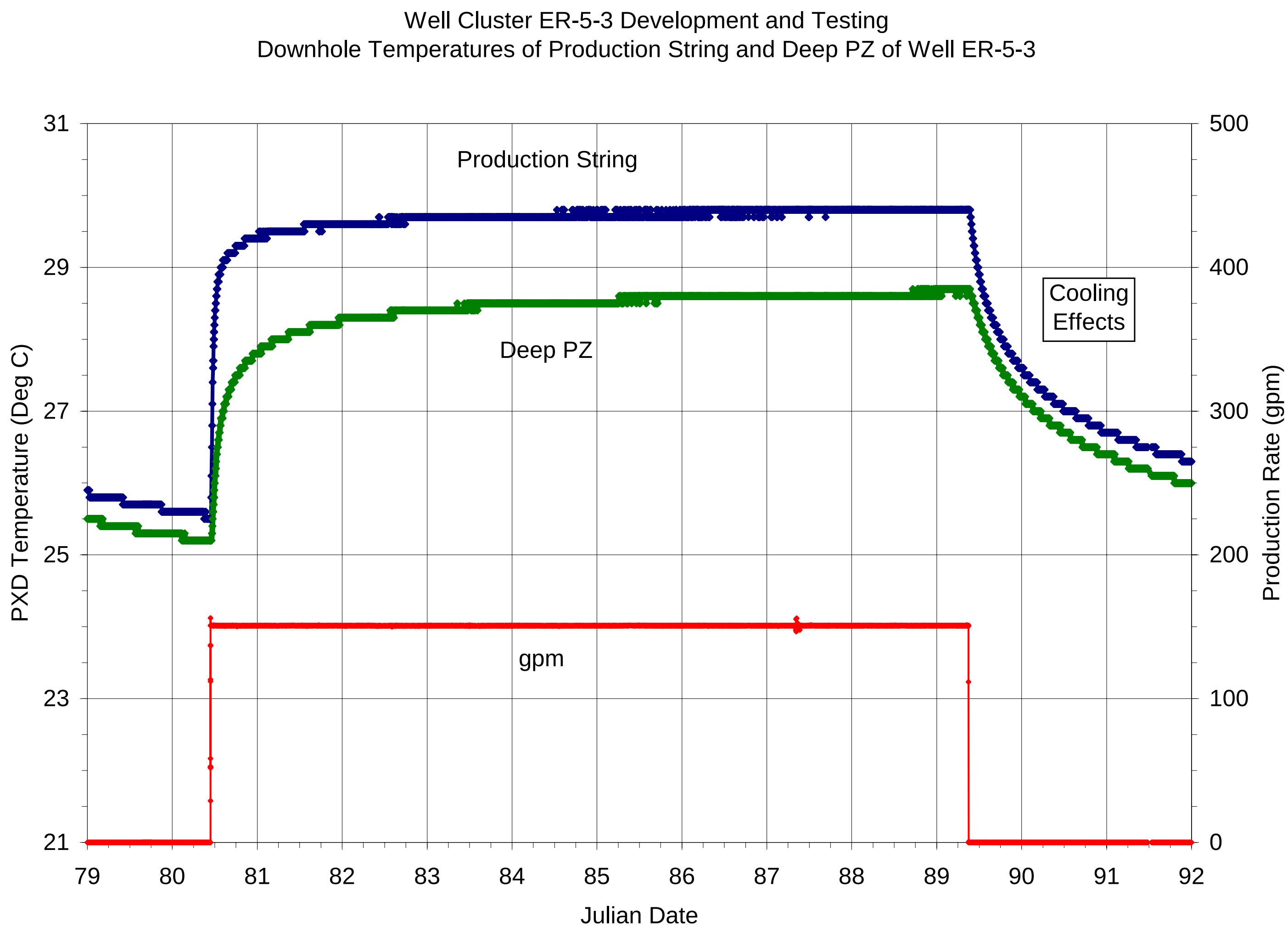


Figure 2-15
Barometric Pressure and PXD Pressure in Well ER-5-3#3 During the ER-5-3 Constant-Rate Test



PXD - Pressure transducer
PZ - Piezometer

Deg C - Degrees Celsius
gpm - Gallons per minute

Figure 2-16
PXD Temperature in ER-5-3 and the Deep PZ of ER-5-3 During the ER-5-3 Constant-Rate Test

through the early part of the test, with temperature increases exponentially diminishing over time. The downhole temperatures in the production string, in particular, display a range of about 4.5°C between static (pretest) values and values recorded after several days of production.

2.5 Step-Drawdown Tests in ER-5-3#2

Two step-drawdown tests were completed at Well ER-5-3#2 to assess the progress of development and to provide additional data for quantifying the efficiency of the well. The tests consisted of five steps, with each step approximately 1-hr in duration. The steps (five progressively higher production rates) included production at 65, 90, 115, 140, and 165 gpm (Figure 2-17). Some preliminary results of the tests have been compiled (Table 2-4). The drawdown values provided in Table 2-4 were obtained 30 to 45 min after production at each step was initiated. Based on the results of the step-drawdown testing, the development efforts appear to have substantially improved the efficiency of the well. This may be especially recognized at higher production rates. Only the second step drawdown test will be analyzed for hydraulic parameters.

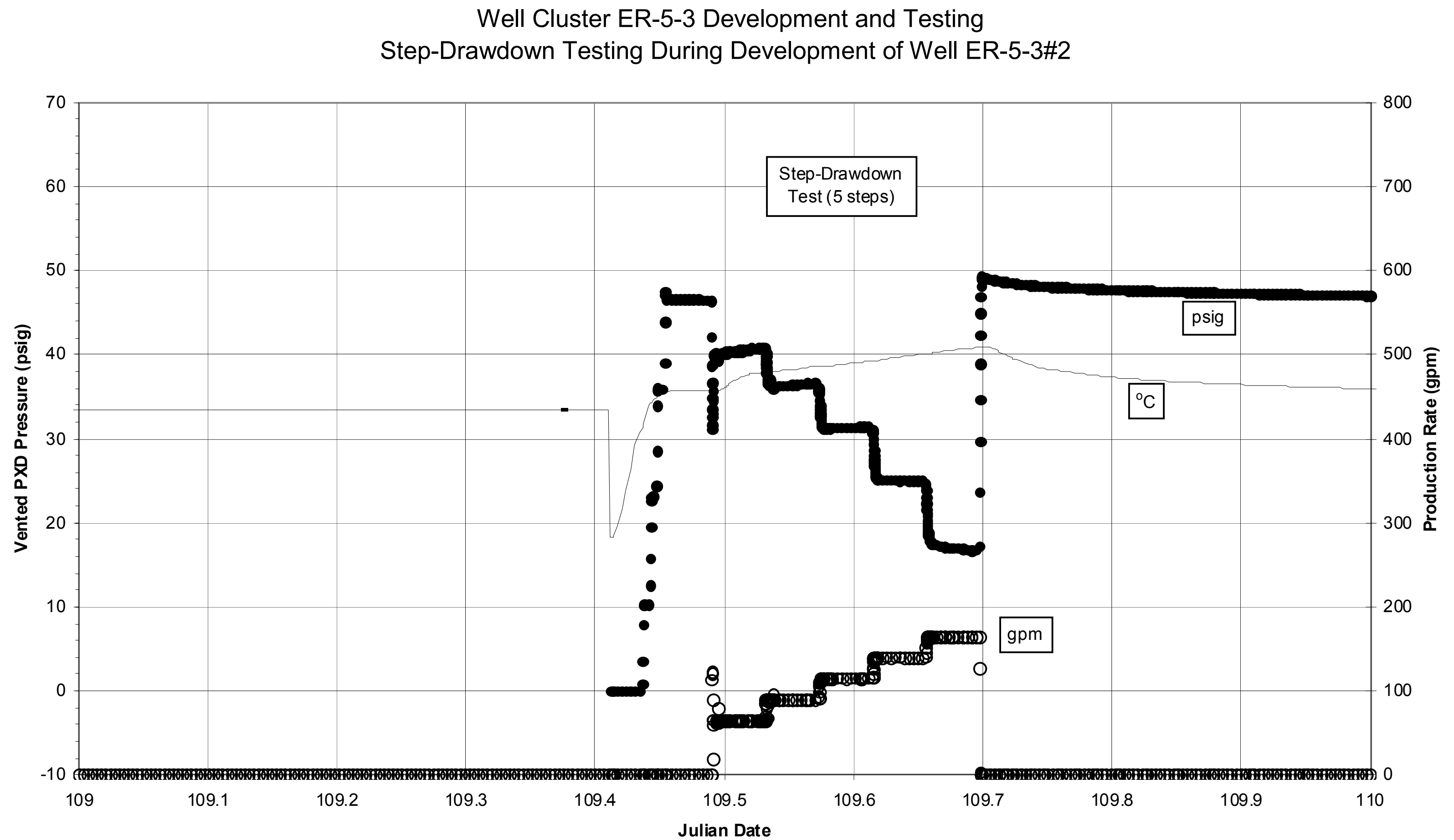
Water levels increased during the first three pumping steps (65, 90, and 115 gpm) because the effect of thermal volume expansion of heated formation groundwater entering the well was greater than the drawdown from pumping. Drawdown through the two final steps (140 and 165 gpm) decreased exponentially. The temperature increase was sufficiently low over the latter two steps (Figure 2-17) that thermal volume expansion was less than drawdown from pumping.

2.6 Stressed Flow Logging in ER-5-3#2

Stressed flow logging at Well ER-5-3#2 was conducted by DRI on April 17, 2001. Information on the distribution of water production from the single CZ of the well was obtained by completing the stressed flow logging at various production rates. Three of the rates used during the step-drawdown testing were chosen as the rates to be utilized during the flow logging (i.e., 65, 115, and 165 gpm). This ensures that the logging results can be directly compared with other observations.

A complete suite of logging runs was completed, including calibration under no production, stationary measurements, and trolling logs. A temperature log was also acquired in conjunction with the flow logs to facilitate the characterization of water production in the well. The trolling logs were conducted at four line speeds (i.e., 20, 40, 60, and 70 fpm) in upward and downward directions.

Except for minor differences in the noise of the flow log traces, the configurations of the logs at a particular production rate coincide well. Differences between logs at the different production rates are not considered significant. One example of the flow logging is presented in Figure 2-18 for a pumping rate of 115 gpm and a trolling speed of 20 fpm downward. A temperature trace has been included for comparison purposes.



PXD – Pressure Transducer
Psig – Pounds per square inch gauge
Gpm – Gallons per minute

Figure 2-17
Detail of Step-Drawdown Response in Well ER-5-3#2

Table 2-4
Step-Drawdown Results at Well ER-5-3#2
(Source: IT, 2001b)

Date	Drawdown at Different Pumping Rates (in feet)				
	65 gpm	90 gpm	115 gpm	140 gpm	165 gpm
4/08/2001	19.98	36.60	57.78	86.47	118.7
4/19/2001	13.77	23.61	35.39	50.50	69.60

Each step was approximately 1-hr in duration. Drawdown values were obtained 30 to 45 min after production at each step was initiated

Overall, the trolling logs indicate that most of the water (>90 percent) enters the well completion from the lower sections of the slotted casing, below a depth of about 1,440 m (4,725 ft) bgs, with the majority of the flow produced between the depths of 4,825 and 4,900 ft and an additional 5 percent produced at a depth of 4,725 ft. The temperature traces show two distinct deflections that correspond to the aforementioned production intervals.

The configurations of the flow log traces display anomalous noise and increases in measured flow rates through the upper sections of slotted casing. These sections of slotted casing immediately underlie the cement seal in the annulus. The various flow log traces in this section of the well completion indicate flow rates that actually exceed the production rate occurring during the respective logging runs. This suggests that these sections of slotted casing are constricted, with decreased effective diameters inside the casing. This likely results from some amount of residual cement within the slots.

After the completion of the stressed flow logging (and discrete bailer sampling), a check valve was installed in the pump string of Well ER-5-3#2. A PXD was also re-installed to monitor water-level recovery prior to the constant-rate pumping test (Figure 2-19). The recovery curve that developed prior to the constant-rate test shows the temperature effects recognized in the well. The curve suggests prolonged recovery with gradually decreasing head. However, the curve may not represent actual head decreases, but extended cooling of the water column in the vicinity of the PXD sensor. The effects are to be comprehensively evaluated during the data analysis task.

2.7 Constant-Rate Test in ER-5-3#2

A constant-rate pumping test was conducted following well development to, in part, capture hydraulic data for the derivation of aquifer parameters. Information obtained during the water-level monitoring before the test was used to establish baseline (pretest) conditions. The constant-rate test was adequately completed despite several impacts over the duration of the test.

A 0 to 50 psig PXD was installed in the production string access line on April 19, 2001, to monitor water levels throughout all phases of the test (i.e., pretest monitoring, production, and post-test water-level recovery).

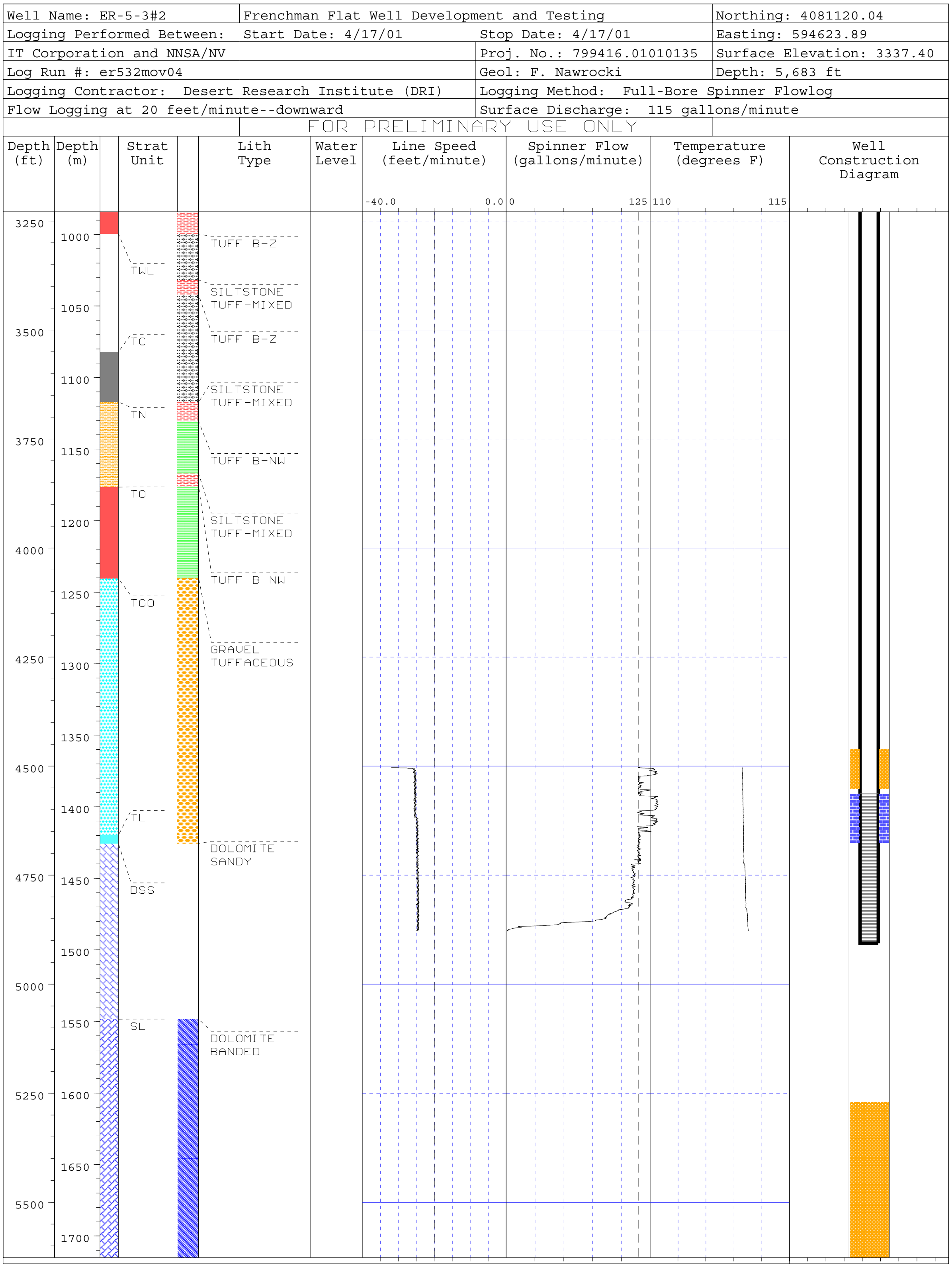
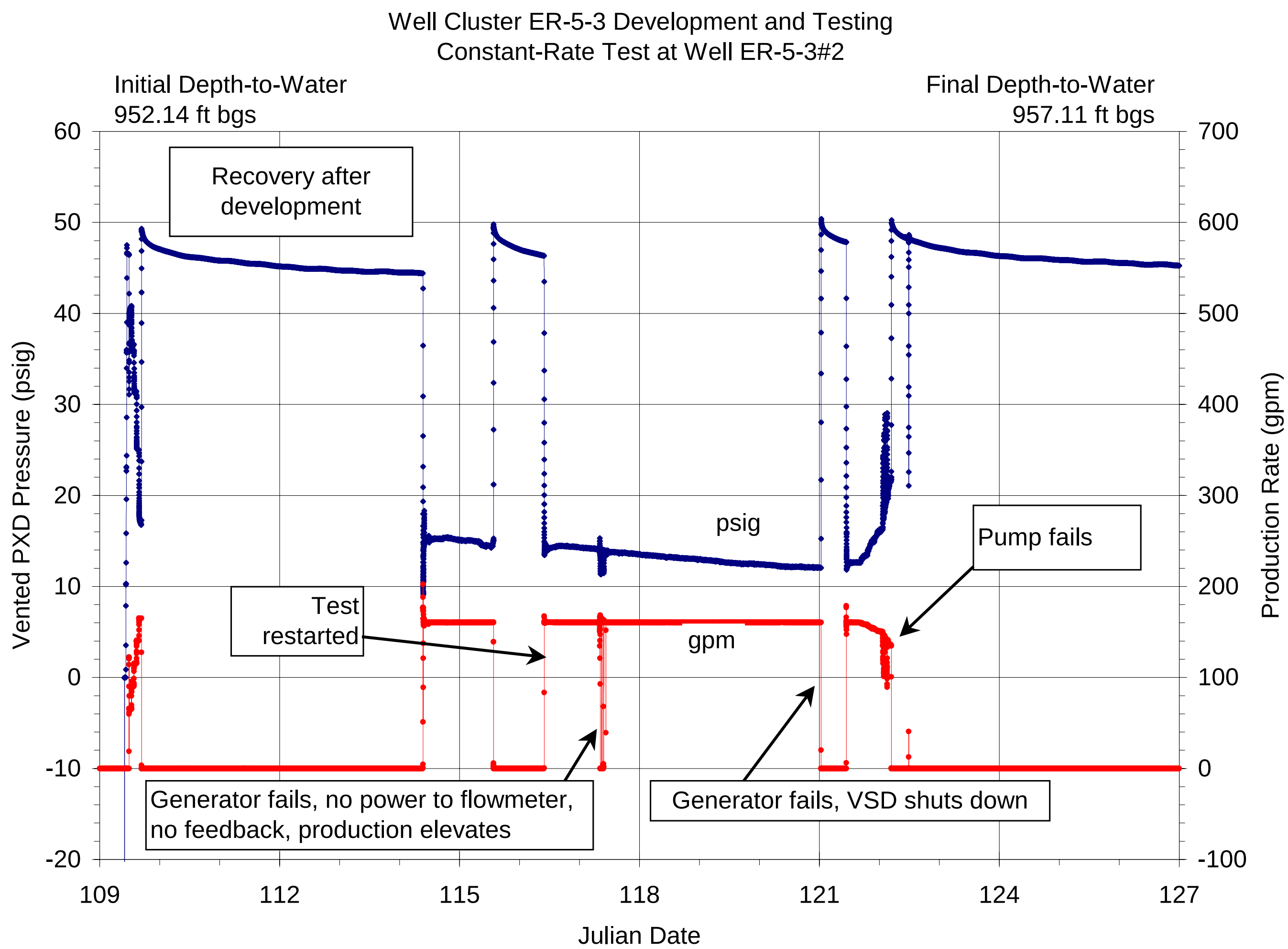


Figure 2-18
Stressed Flow Log (115 gpm and 20 fpm Downward) in Well ER-5-3#2



PXD - Pressure transducer
psig - Pounds per square inch gauge

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

Figure 2-19
Production Rates and PXD Pressure in Well ER-5-3#2 During the ER-5-3#2 Constant-Rate Test

Production for the test commenced on April 24, 2001, at 09:30. However, the two-wire feedback loop from the magnetic flow meter to the VSD was cut. This resulted in a poor start with an inadequate data record (i.e., elevated production rates and excessive drawdown). The test was restarted on April 26, 2001, at 09:55. Another impact to the test occurred on April 27, 2001, when the 100-kilowatt (kW) generator powering the ancillary equipment at the site failed. Power to the magnetic flowmeter and the control signal from the flowmeter to the VSD was lost. This resulted in the VSD increasing the operating frequency to its maximum (high-speed clamp), inducing elevated rates of production (180+ gpm). This problem was remedied fairly quickly at the site.

The test progressed well for four days. However, the Hall-Pittman generator, powering the VSD/pump, failed at 00:42 on May 1, 2001. The generator was repaired and the test was resumed the morning of May 1, 2001. After the test was resumed, the performance of the pump began to diminish, requiring more electrical power to maintain the constant production rate. Production rates eventually began to decline after the VSD proceeded to operate at the maximum frequency.

The pump failed on May 2, 2001, after production had steadily decreased to 135 gpm. Attempts to restart the VSD/pump were unsuccessful, the pump required replacement. The data records for the constant-rate test were evaluated by ITLV technical personnel. It was determined that sufficient data had been captured to achieve the scientific objectives of the test, and the test was considered complete. Monitoring for water-level recovery followed. Recovery was monitored for five days until May 7, 2001. Because of the pump failure, the collection of the composite wellhead samples for groundwater characterization had to be suspended. The samples were obtained on May 17, 2001, using the dedicated sampling pump.

2.7.1 Methodology

Continuous water-level records for each of the wells and piezometers at the well cluster were captured during the constant-rate test at Well ER-5-3#2. Additional data acquisition at Well ER-5-3#2 included production rates, barometric pressure, and in-line water-quality parameters. Field monitoring of other ancillary equipment was also continued, including performance checks of the VSD and generator(s). Grab sampling and analysis were also continued approximately every two hours during daylight shifts. With the exception of the initial cut in the production rate when the test was first initiated, the feedback loop (control signal) from the magnetic flowmeter to the VSD performed as intended. This ensured a consistent production rate as drawdown increased.

A production rate of 160 gpm was established for the test. This rate was slightly less than the maximum rate of 165 gpm used during the development of the well. The 0 to 50 psig PXD remained in the access line throughout all phases of the test. The PXDs and dataloggers associated with the monitoring of the strings at wells ER-5-3 and ER-5-3#3 also remained operative throughout the test.

2.7.2 Hydraulic Data Collection

A suitable data record was captured at Well ER-5-3#2 during all phases (i.e., pretest monitoring, production, and post-test water-level recovery) of the constant-rate test (Figure 2-19). Considerable effects from downhole temperature (density) changes continued to be recognized as the test progressed. Variations in barometric pressure were negligible relative to the magnitude of drawdown during the testing period (Figure 2-20).

An average production rate of 160.12 gpm was maintained over the final four days of the test, before the testing pump began to fail (Figure 2-20). Excluding the various equipment-related problems, the water-level (PXD pressure) record that was captured is suitable for more comprehensive evaluations. The noise in the PXD pressure record was minimal, with the sustained noise band remaining less than 0.5 psig. Considering the overall hydraulic response of approximately 32 psig (about 22.9 m [75 ft] of drawdown), such noise is considered negligible.

The last day of the test involved the gradual failure of the testing pump (Figure 2-21). The recovery curve that develops after the pump failed completely displays a fairly abrupt rise in water levels. The check valve that was installed prior to the test performed as intended, eliminating the occurrence of any u-tube effects. The apex of the PXD pressure record likely represents instantaneous head changes. This is followed by a recovery curve that develops as a prolonged record of decreasing PXD pressures. Such a configuration in a conventional recovery curve is anomalous. It is suspected that the configuration of the curve results from the cooling of the water column profile below the PXD to the equilibrium condition. More detailed discussions on the downhole density and temperature effects in the well are presented in Section 3.0. These effects will also be quantified as part of the data analysis efforts for the well. Additional discussion on the constant-rate test is presented in Section 3.0.

2.8 Multiple-Well Aquifer Test

The MWAT at Well Cluster ER-5-3 consisted of a constant-rate pumping test that included 63 days of groundwater production from the upper CZ of Well ER-5-3. Preproduction and postproduction monitoring of water levels were also integral elements of the MWAT. The MWAT was conducted after the completion of well-specific well development and testing (WDT) operations at wells ER-5-3 and ER-5-3#2. A bridge plug instrumented with integrated PXDs was installed in Well ER-5-3 prior to the test to isolate the upper and lower CZs from each other. The information and data acquired during the testing activities will be used to evaluate the hydrology of the Frenchman Flat basin and advance comprehensive characterization efforts for the northern part of the basin, including determinations of the hydraulic parameters of the local HSUs. Specific objectives of the MWAT at Well Cluster ER-5-3 included:

1. Acquiring data for quantifying the horizontal and vertical hydraulic conductivity, and storage coefficient, of the alluvial aquifer in northern Frenchman Flat

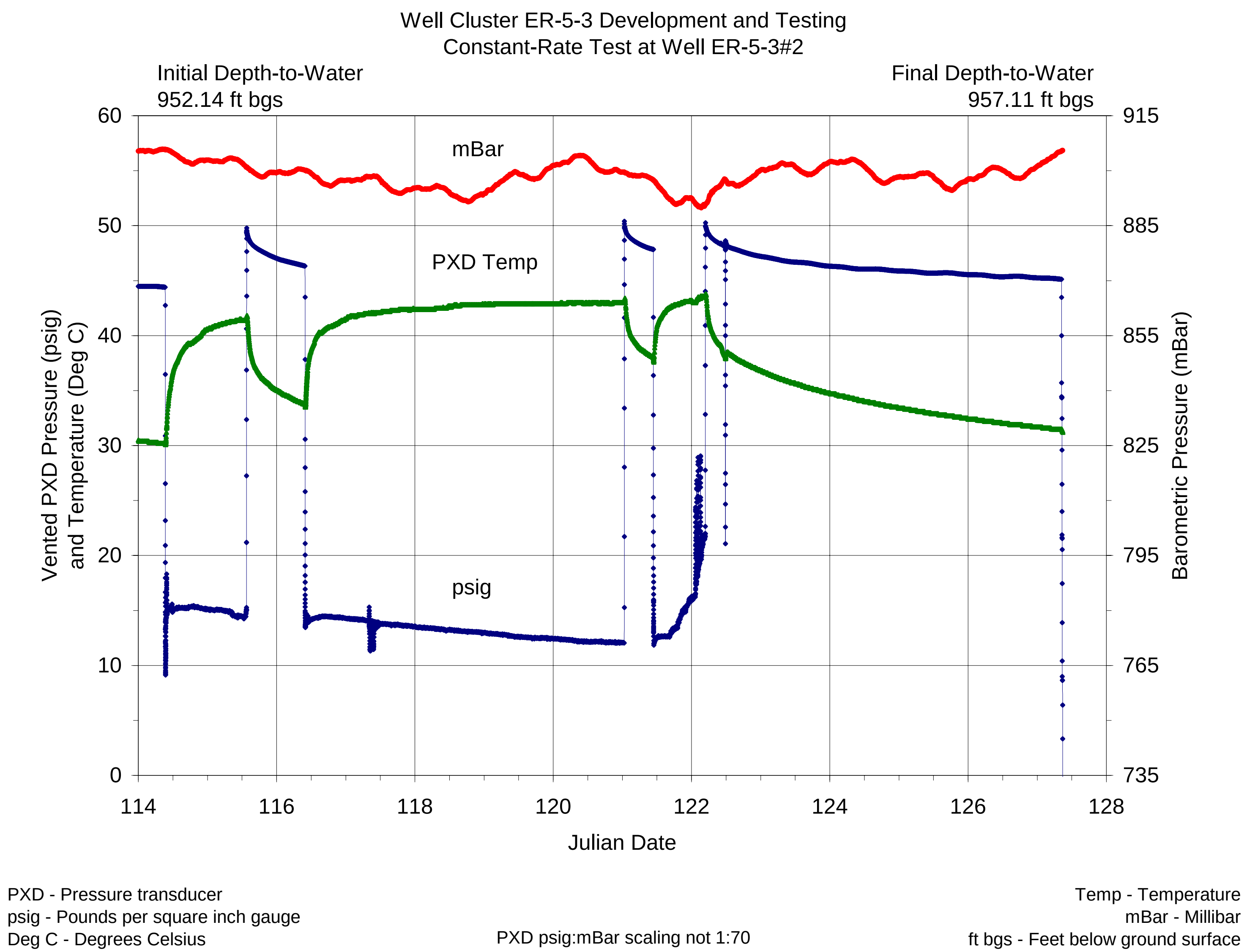
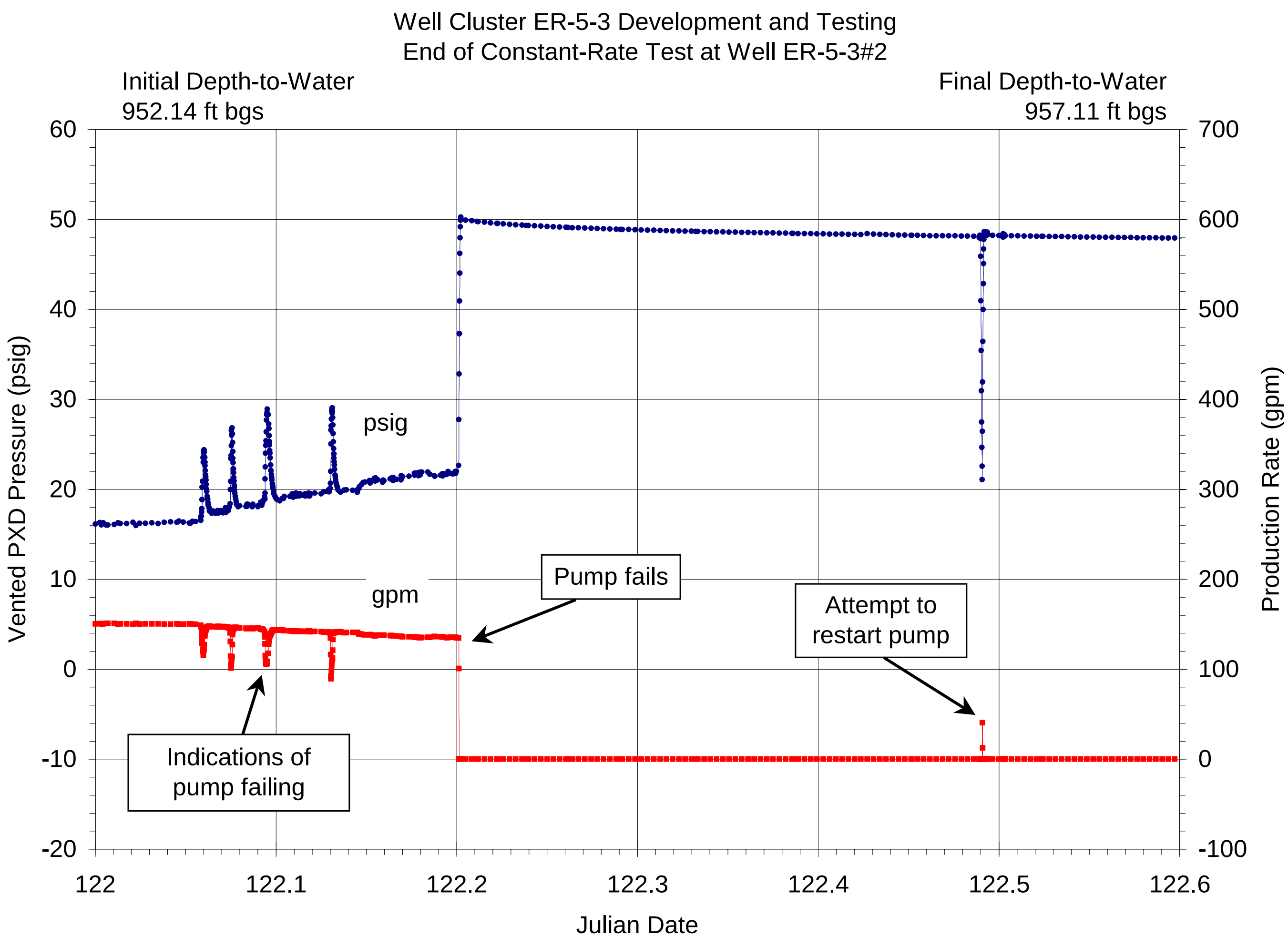


Figure 2-20
Barometric Pressure, PXD Pressure and Temperature in ER-5-3#2 During the ER-5-3#2 Constant-Rate Test



PXD - Pressure transducer
psig - Pounds per square inch gauge

ft bgs - Feet below ground surface
gpm - Gallons per minute
DTW - Depth to water

Figure 2-21
Detail PXD Pressure in ER-5-3#2 During Pump Failure at the End of the ER-5-3#2 Constant-Rate Test

2. Obtaining data for quantifying hydraulic parameters at a scale larger than can be achieved during typical single-well testing

3. Obtaining vertically and laterally discrete head data for the various HSUs/CZs at the well cluster

4. Collecting ancillary information to facilitate subsequent data analyses and interpretations

Water levels in the various HSUs accessed by the CZs of the wells and PZs at the well cluster were monitored as an integral element of the field operations during the test. Additional head data were acquired from wells distal to the well cluster. Water levels were monitored before (preproduction), during (drawdown), and after (postproduction/recovery) the production phase of the test.

The monitored HSUs included local OAA, BLFA, TMWTA containing minor intervals of TCU, and the LCA (Table 1-1).

2.8.1 Bridge-Plug Installation

The MWAT activities at the well cluster formally began on April 12, 2001, with the installation of the bridge plug in Well ER-5-3 by Baker-Atlas. The installation activities were supervised by ITLV technical personnel and a Bechtel Nevada (BN) geophysical logging engineer. No problems were encountered during the installation of the bridge-plug assembly. The bridge plug was installed at a depth of 1,890 ft bgs (*center element*) to isolate the upper CZ of Well ER-5-3 (OAA) from lower CZ (TMWTA) of the well. The installation of the bridge plug restricted production to the OAA only during the test. The requirements for setting the bridge plug included placing it in a location nominally halfway between the CZs. In addition, the plug was to be centrally located within a blank joint of 0.14 m (5.5-in.) production casing, with the joint adequately supported by stemmed cement in the annulus. The actual set-depth of the bridge plug, although somewhat different from the specified depth, fulfilled these requirements. The bridge plug remained in the well throughout all phases of the test.

The installation procedures employed by ITLV provide for in-well calibration of pressure versus head (e.g., temperature-dependent density) for use in interpreting the equilibrated head for the isolated CZ. The procedure for installing and retrieving the bridge plug included:

- Run gauge and basket below the bridge plug set-depth to verify that the bridge-plug assembly could be routed into the casing.

- Synchronize clock(s) of bridge-plug dataloggers to site clock.

- Acquire three or more pressure readings at the ground surface (Cal. Station-1).

- Measure composite water level with an E-tape to establish a reference head (head is assumed to be in equilibrium).

- Trip in bridge plug to point above SWL and collect three or more pressure readings (Cal. Station-2).
- Lower bridge plug to 15.24 m (50 ft) above the set-depth (minus 15.24 m [50 ft]) and collect three or more pressure readings (Cal. Station-3).
- Lower bridge plug to 15.24 m (50 ft) below the set-depth (plus 15.24 m [50 ft]) and collect three or more pressure readings (Cal. Station-4).
- Raise bridge plug to the set-depth, collect three or more pressure readings, then set bridge plug to isolate underlying CZ. Head change in the underlying CZ is monitored via the integrated PXDs/dataloggers.
- Measure water level, representative of upper CZ, with an e-tape to determine change in head after installation of the bridge plug (assumed to be stable).
- Install downhole equipment (e.g., pump and access line).
- Measure water level with an e-tape to establish a reference head for the upper CZ (assumed to be stable).
- Install wireline-set PXD in well to monitor head change in upper CZ.
- After adequate data acquisition, remove PXD from well.
- Measure water level with an e-tape to establish a final head for the upper CZ.
- Remove downhole equipment (e.g., pump and access line).
- Retrieve bridge plug, obtaining three or more pressure readings at same calibration stations used during installation, if possible.
- Acquire three or more pressure readings at the ground surface.
- Measure composite water level with an e-tape (assumed to be stable).
- Download bridge-plug datalogger(s) and determine drift in clock(s) of bridge-plug dataloggers.

Two dataloggers, each with a sealed 0 to 750 pounds per square inch absolute (psia) PXD, were integrated into the bridge-plug assembly. The sensing elements of the upper and lower PXDs were configured below the center element at 1,894 and 1,895.7 ft bgs. The dataloggers were programmed to acquire PXD pressure and temperature measurements, representative of the underlying HSUs accessed by the lower CZ, every 5 min throughout all phases of the MWAT. Calibration information (e.g., PXD pressure measurements at discrete stations) was obtained as part of the bridge plug installation and removal procedures. The data captured by the bridge-plug dataloggers could not be accessed remotely while the bridge plug remained downhole. The data were downloaded and reduced after the retrieval of the assembly on October 10, 2001.

2.8.2 Water-Level Measurements

Depth-to-water measurements were obtained in the wells and piezometers at Well Cluster ER-5-3 during the MWAT operations (Table 2-5). Water-level tags were integrated into the PXD installation and removal process, but additional tags were also completed when deemed appropriate. In general, the measurements appear to be consistent, with good repeatability. In particular, the consistency of the measurements obtained during the pre- and postproduction phases of the MWAT indicate that the water levels likely approximate equilibrium conditions.

2.8.3 Preproduction Monitoring

Preproduction, water-level monitoring was initiated subsequent to the installation of the PXDs in wells ER-5-3 (production string and two PZs) and ER-5-3#3. This monitoring period occurred over a period of 29 days and served, in part, to obtain baseline records prior to the production phase of the test. As previously mentioned, the water-level records from these four strings appear to be unaffected by the concurrent water production from Well ER-5-3#2. Therefore, the water levels are considered representative of natural fluctuations.

Adequate water-level and barometric pressure records were acquired as part of the preproduction activities of the MWAT field operations. Water-level records were obtained from the production and two piezometer strings at Well ER-5-3, and the single string of Well ER-5-3#3. These records were captured while well-specific operations were being conducted at Well ER-5-3#2. Since the operations were being conducted at the well throughout this phase of the MWAT, no preproduction record exists for Well ER-5-3#2. Barometric pressure was measured at 10-second intervals at wells ER-5-3, ER-5-3#2, and ER-5-3#3.

2.8.3.1 PXD Pressure Records

The earliest part of the preproduction PXD record for the production string of Well ER-5-3 clearly displays water-level recovery in the well after the second functionality test of the low-capacity testing pump (Figure 2-22). The 29-day record also defines water-level responses in the string as a direct result of variations in barometric pressure. Diurnal fluctuations induced a response of approximately 0.15 psia, with larger-scale variations also recognizable. Since the PXD in the string was sealed, PXD pressure responses are directly proportional to changes in barometric pressure.

An adequate preproduction record was obtained for the deep PZ of Well ER-5-3 (Figure 2-23). Although not developed, slug testing of the string on March 2, 2001, indicated that the string is well connected hydraulically to the adjacent HSUs, TMWTA +/- TCUs. Water-level responses to changes in barometric pressure can be clearly discerned, with PXD pressures fluctuating

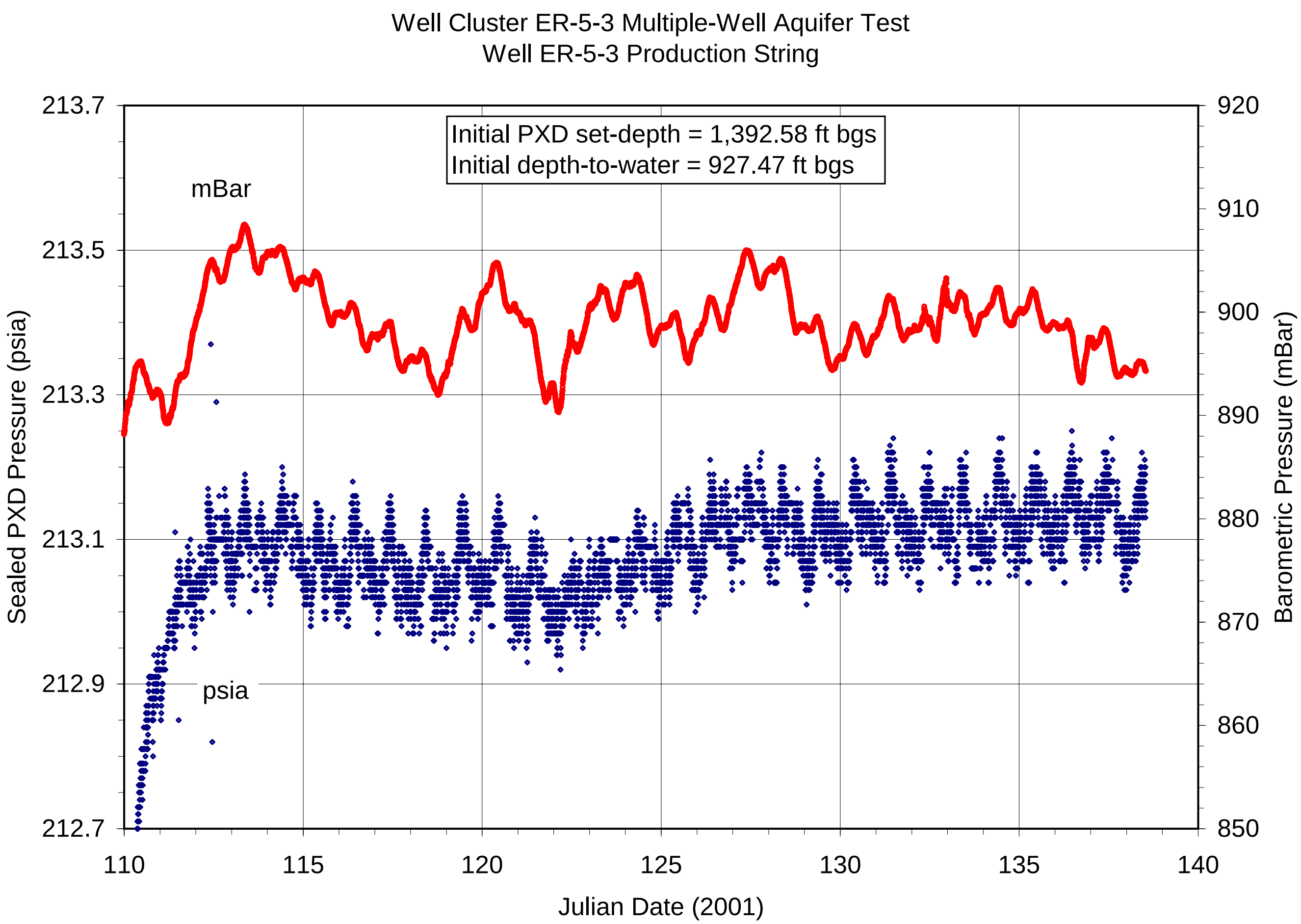
Table 2-5
Depth-to-Water Measurements
(Modified from IT, 2002)

Date	Time	Depth-to-Water (bgs)		Barometric Pressure (mBar)	Head[a]	
		Feet	Meters		Feet	Meters
Well ER-5-3 Production String (Composite Water Level)						
04/12/2001	08:25	927.99	282.85	902.50	2,409.41	734.39
10/11/2001[b]	07:09	927.92	282.83	903.2	2,409.48	734.41
Well ER-5-3 Production String (Upper CZ)						
04/12/2001[c]	18:00	927.76	282.78	901.19	2,409.64	734.46
04/13/2001[c]	13:51	927.72	282.77	899.7	2,409.68	734.47
04/18/2001[c]	11:21	927.47	282.69	897.25	2,409.93	734.55
05/23/2001[d]	14:40	1,225.74	373.61	898.50	2,111.66	643.63
09/06/2001[c]	10:54	927.47	282.69	898.85	2,409.93	734.55
10/09/2001[c]	14:39	927.84	282.81	899.5	2,409.56	734.43
10/15/2001[e]	09:52	928.81	283.10	906.2	2,408.59	734.14
Well ER-5-3 Deep Piezometer						
04/19/2001	12:25	927.86	282.81	892.80	2,409.54	734.43
09/06/2001	10:30	928.47	283.00	898.78	2,408.93	734.24
Well ER-5-3 Shallow Piezometer						
04/13/2001	14:38	927.54	282.71	899.7	2,409.86	734.53
04/19/2001	11:30	927.29	282.64	894.19	2,410.11	734.60
09/06/2001	09:14	927.52	282.71	898.67	2,409.88	734.53
Well ER-5-3#2						
05/18/2001	08:27	956.03	291.40	894.70	2,381.37	725.84
09/06/2001	13:17	961.63	293.10	896.95	2,375.77	724.14
Well ER-5-3#3						
05/11/2001	09:24	927.61	282.74	901.55	2,409.79	734.50
09/06/2001	12:39	927.51	282.71	897.44	2,409.89	734.53

[a]Reference datum: Meters/feet above mean sea level (AMSL), ground surface elevation 3,337.4 ft above mean sea level.
[b]Water-level measurement after removal of temporary bridge plug but before installation of permanent bridge plug
[c]Water-level measurement before removal of temporary bridge plug (upper CZ only)
[d]Nonequilibrium, water-level measurement during reinstallation of PXD due to electrical short in wireline
[e]Water-level measurement after installation of permanent bridge plug (upper CZ only)

1. Bridge plug set in Well ER-5-3 at depth of 1,890 ft bgs from 04/12/2001 (13:30) until fishing operations on 10/10/2001. Water-level measurements in production string of Well ER-5-3 during this period only representative of upper CZ (alluvium)
2. ITLV removes all PXDs on 09/06/2001

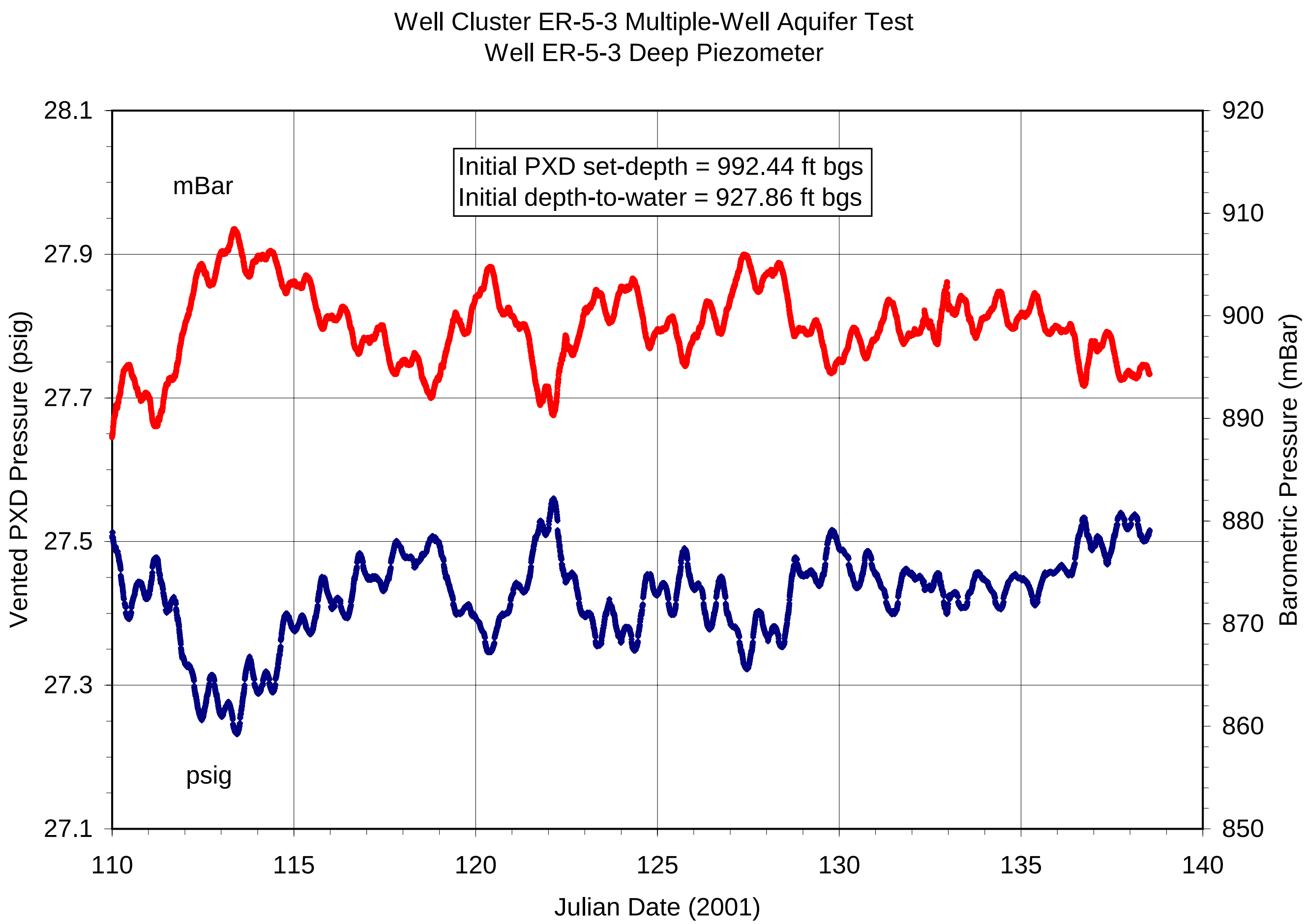
mBar - Millibars



PXD - Pressure transducer
ft bgs - Feet below ground surface

psia - Pounds per square inch absolute
mBar - Millibars

Figure 2-22
MWAT Preproduction Monitoring from ER-5-3



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-23
MWAT Preproduction Monitoring in the Deep PZ of ER-5-3

approximately 0.06 psig, diurnally. The PXD pressures also responded appropriately to larger-scale variations in barometric pressure.

The PXD record acquired from the shallow PZ of Well ER-5-3 during the preproduction monitoring displays a much smaller magnitude of water-level fluctuations in comparison to the other strings (Figure 2-24). Although the string has not been subjected to development, slug testing of the string on March 13, 2001, indicated that the string is well connected to the OAA and BLFA accessed by the single CZ of the string. Diurnal fluctuations are negligible (typically < 0.02 psig), even larger changes in barometric pressure failed to induce a significant response in PXD pressures. The PXD in the string was sealed, so PXD pressure responses, although minimal, are directly proportional to changes in barometric pressure.

The preproduction monitoring of Well ER-5-3#3 also resulted in a suitable ambient water-level record (Figure 2-25). Although never developed, slug testing of the string on February 23, 2001, indicated that the string is well connected to the local OAA. Both diurnal and larger-scale responses to changes in barometric pressure can be discerned, with diurnal responses occurring on the order of 0.08 psig.

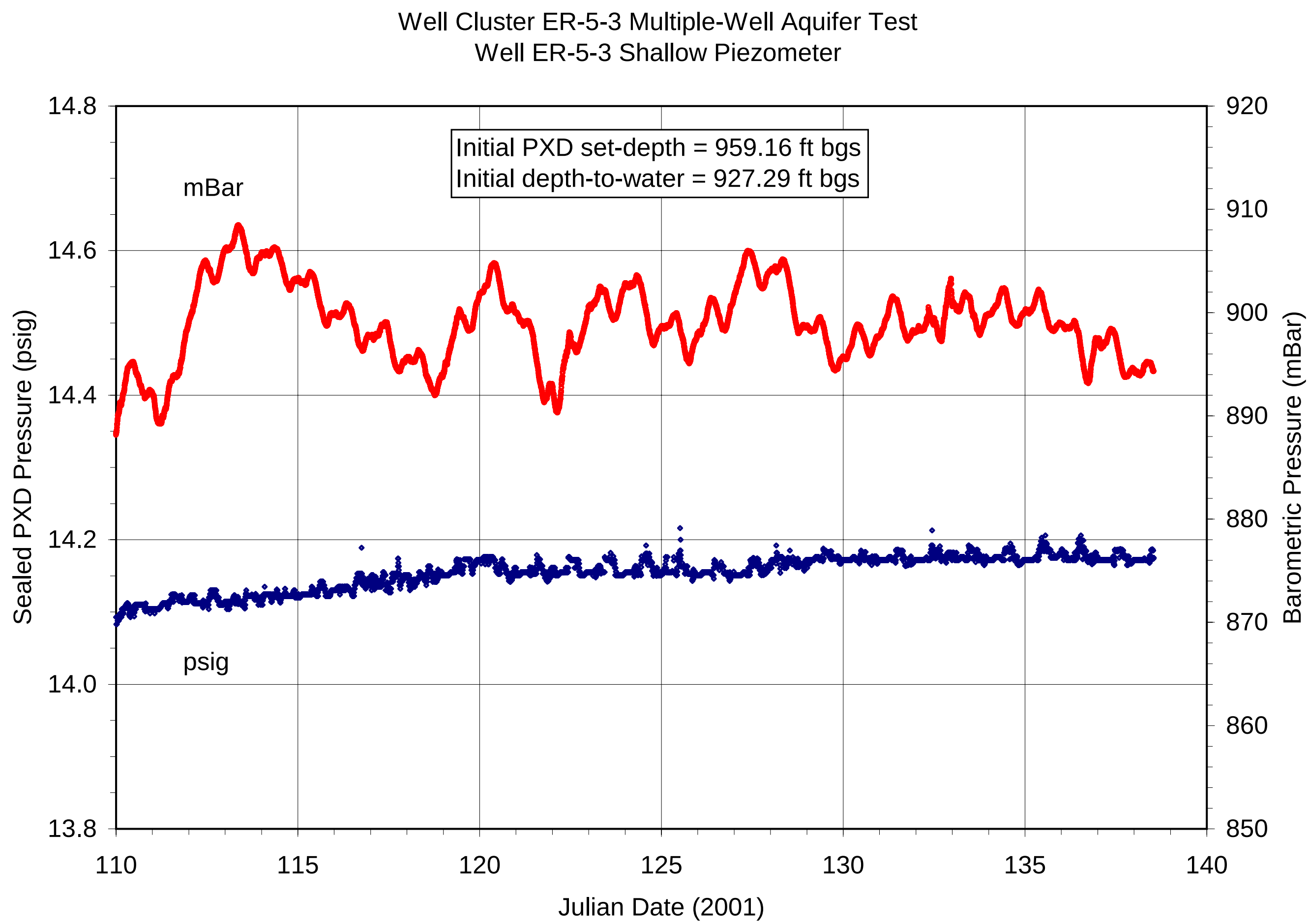
2.8.4 Production Phase

The production phase of the MWAT was initiated at 13:00 on May 18, 2001, JDate 138.542. ITLV staffed the well site overnight during the initial 24 hours of the test to ensure that all instrumentation was operating properly and that the sensors were adequate for monitoring hydraulic responses. Production continued until the failure of the site generator around 07:47 on June 15, 2001 (JDate 166). However, the problem was quickly remedied and production was reinitiated 66 min later. In addition, the site generators were placed on a preventative maintenance schedule where they were switched approximately every 10 days throughout the production phase. The VSD was shutdown at 13:27 on July 19, 2001 (JDate 200.560), to end the production phase of the test.

2.8.4.1 Data Acquisition

Continuous data records were captured during the production phase of the test. Data acquisition included PXD pressures (all strings), barometric pressure (at each wellhead), production rates, and downhole temperatures. Constant rates of production were maintained by the VSD via the control signal from the magnetic flowmeter. The production rate maintained during the test averaged 12.45 gallons per minute (gpm).

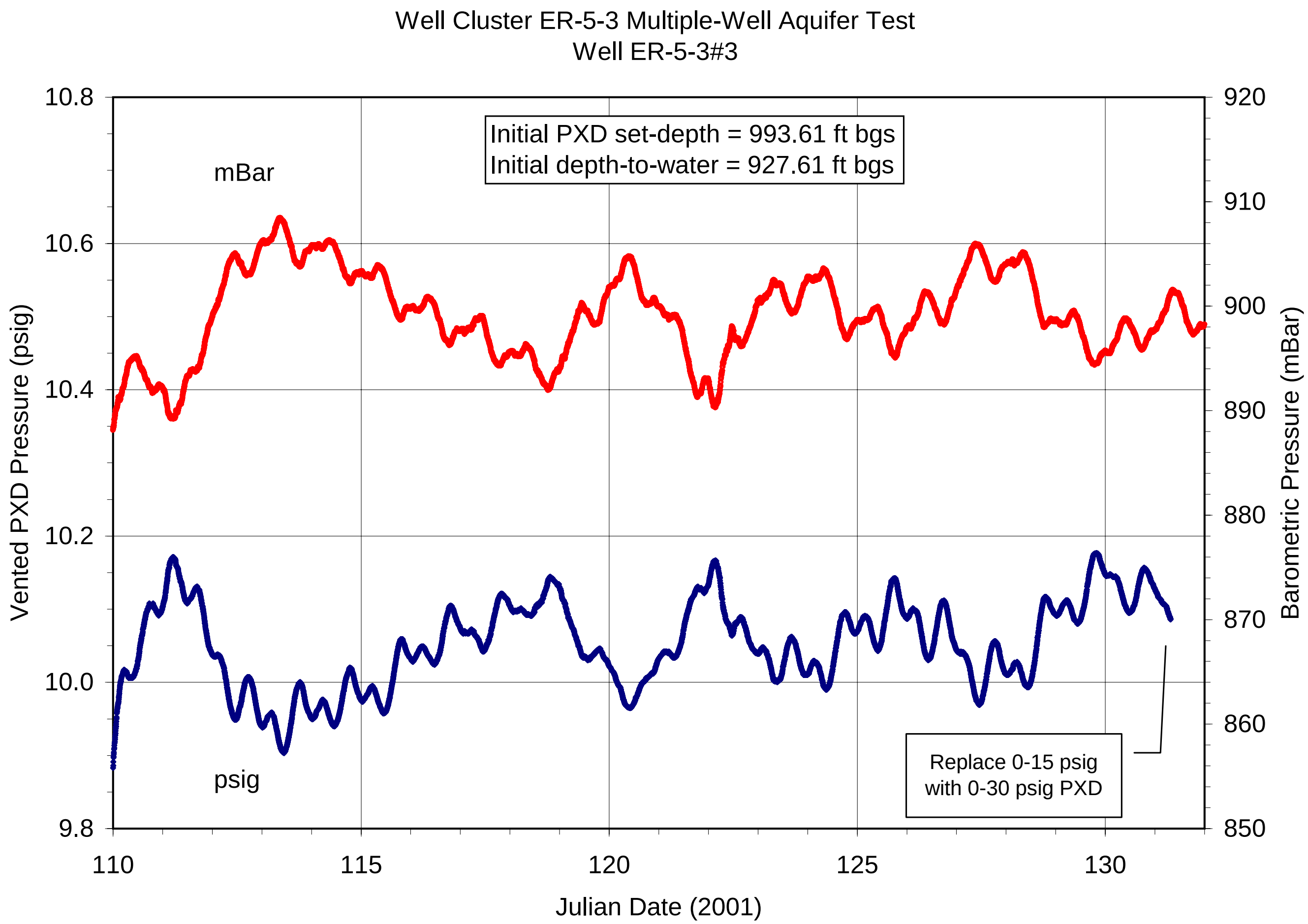
Water-level records acquired from each monitored string during the 63-day production phase of the MWAT have been compiled. The records provide information on the hydraulic responses in each string, along with coinciding production rates and barometric pressure.



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-24
MWAT Preproduction Monitoring in the Shallow PZ of ER-5-3



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-25
MWAT Preproduction Monitoring in Well ER-5-3#3

2.8.4.2 Production Record

For the most part, the production record acquired by the main datalogger at Well ER-5-3 is considered suitable for future data analyses (Figure 2-26). However, the record is clearly impacted during the early periods of production (e.g., JDates 138 through 159). It is suspected that the noise in the record results from the occurrence of elevated contents of entrained air in the discharged water. Detailed discussions on the effects and impacts from the elevated content of entrained air are presented in a later section. Additionally, the inadvertent shutdown of the site generator on JDate 166 is also exhibited in the record. The regular maintenance (switching) of the site generators approximately every 10 days can also be observed as brief periods (< 1 min) of no production.

2.8.5 Barometric Pressure Records

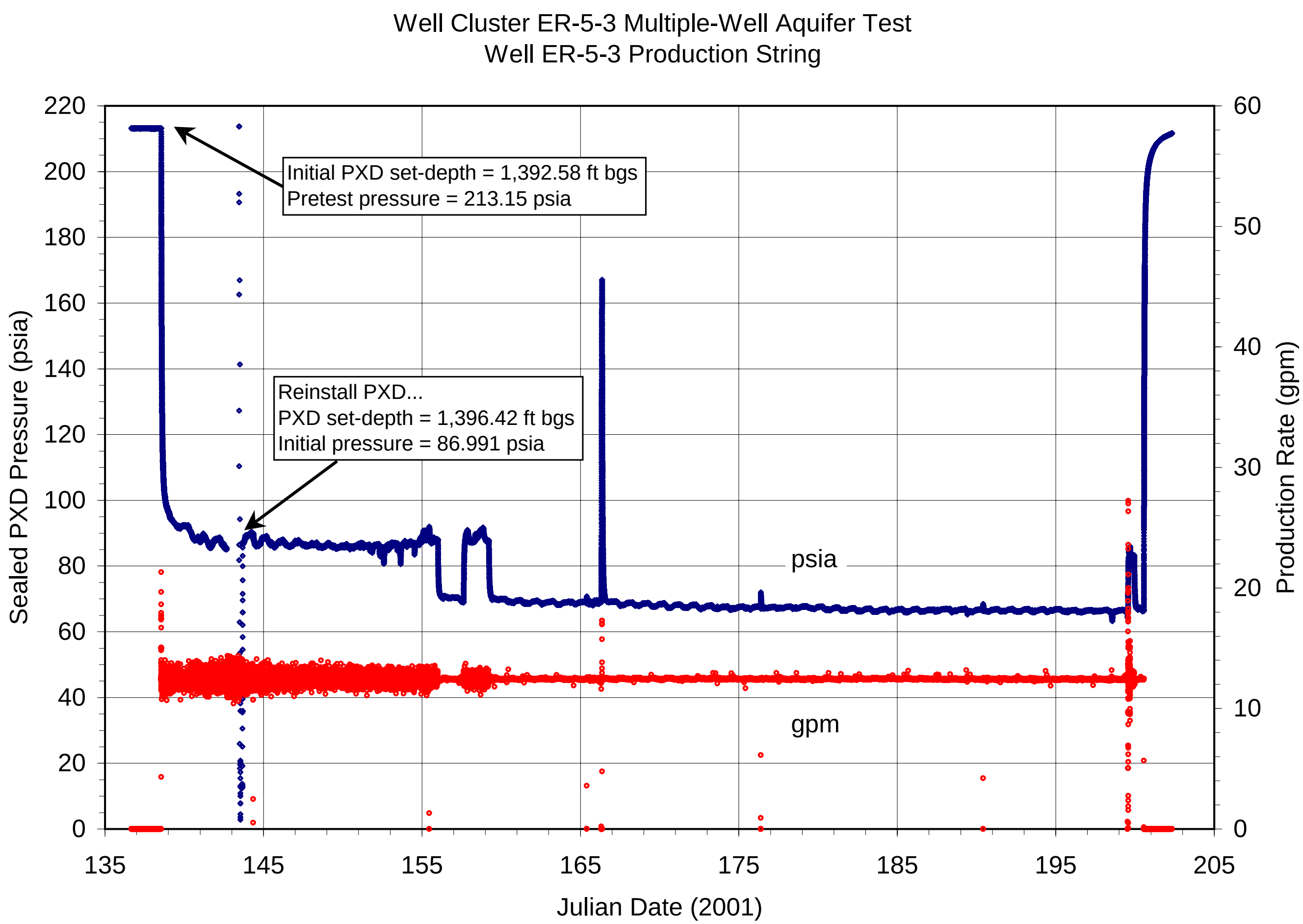
Appropriate records of barometric pressure were captured during the production phase of the MWAT. Monitoring for barometric pressure was accomplished via the use of the three barometers at each wellhead. The barometer at Well ER-5-3#3 continued to measure anomalous values periodically. Diurnal fluctuations in barometric pressure averaged approximately 4.0 mBar during the production phase of the test. Larger-scale changes in barometric pressure, on the order of 14 mBar, are recognizable in the data records.

2.8.6 PXD Pressure Records

It was anticipated that water levels in the production string of Well ER-5-3 would undergo the greatest stress and best respond to production from the upper CZ of the well. As expected, the record from this string most clearly displays hydraulic responses and anomalies while the upper CZ of Well ER-5-3 was under production (see Figure 2-26). The PXD pressure measured immediately before production was initiated was 213.15 psia. Once production was initiated, and drawdown was induced, PXD pressures rapidly decreased to approximately 88 psia. Because the PXD was installed while the well was under production, pertinent information on the reinstalled PXD had to be derived from information obtained during the removal of the sensor.

Not accounting for the impacts of entrained air and the loss of site power, prolonged decreases in PXD pressures as production continued can be discerned in the record. After water levels semi-stabilized around 70 psia on June 9, 2001 (JDate 160), PXD pressure values continued to decline to 66.4 psia (JDate 198). Diurnal fluctuations in barometric pressure induced a response of approximately 1.13 psia, as indicated by the latter part of the record (Figure 2-27). Water-level responses to larger-scale fluctuations in barometric pressure may also be discerned in the latter part of the record (e.g., JDates 178 and 195).

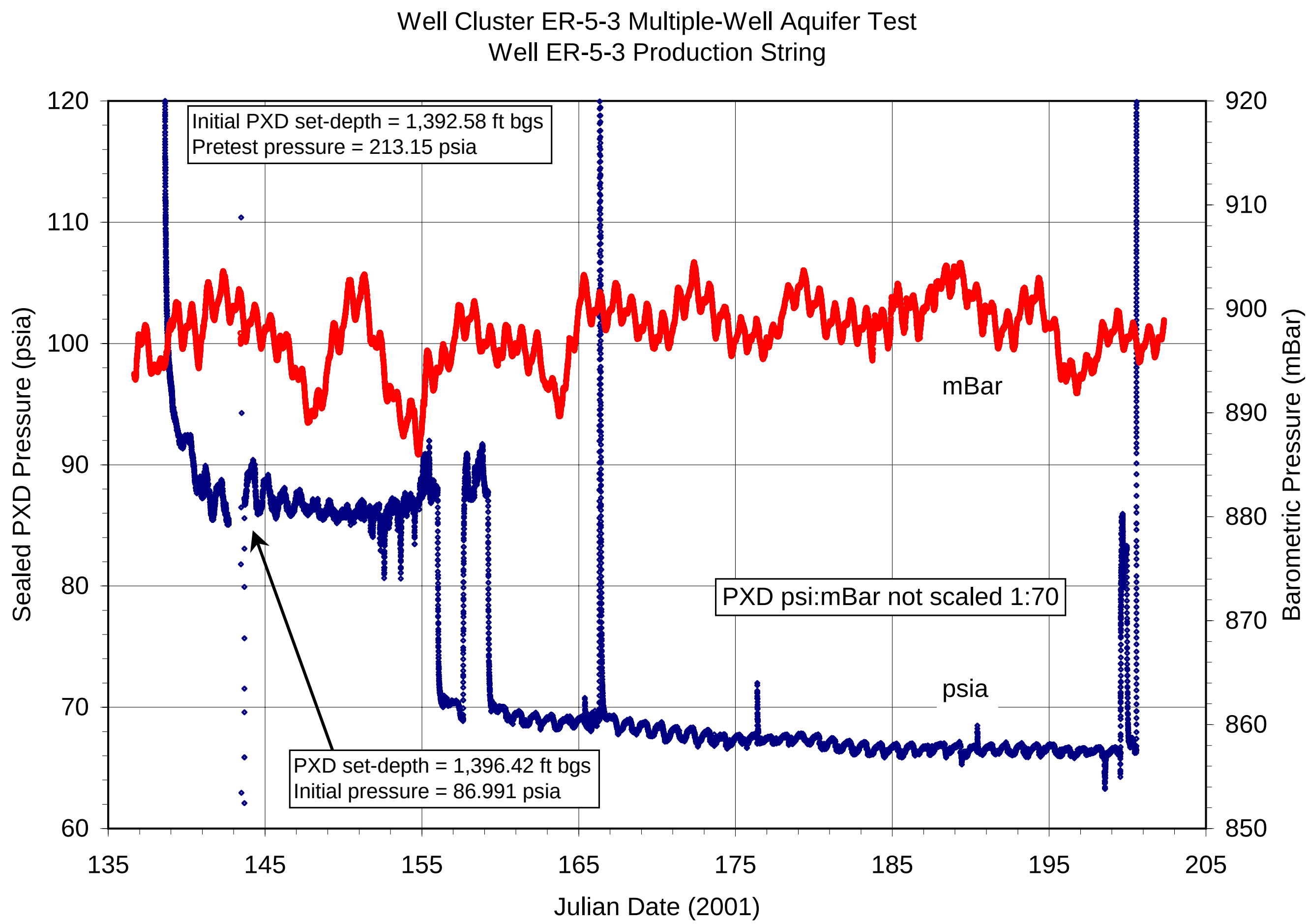
The record for the deep PZ of Well ER-5-3 indicates that the string was not impacted by the production from Well ER-5-3 (Figure 2-28). The lack of response is likely the combination of two factors. First, the OAA and underlying volcanic aquifer units (e.g., TMWTA) may not be well connected because of the



PXD - Pressure transducer
ft bgs - Feet below ground surface

psia - Pound per square inch absolute
gpm - Gallons per minute

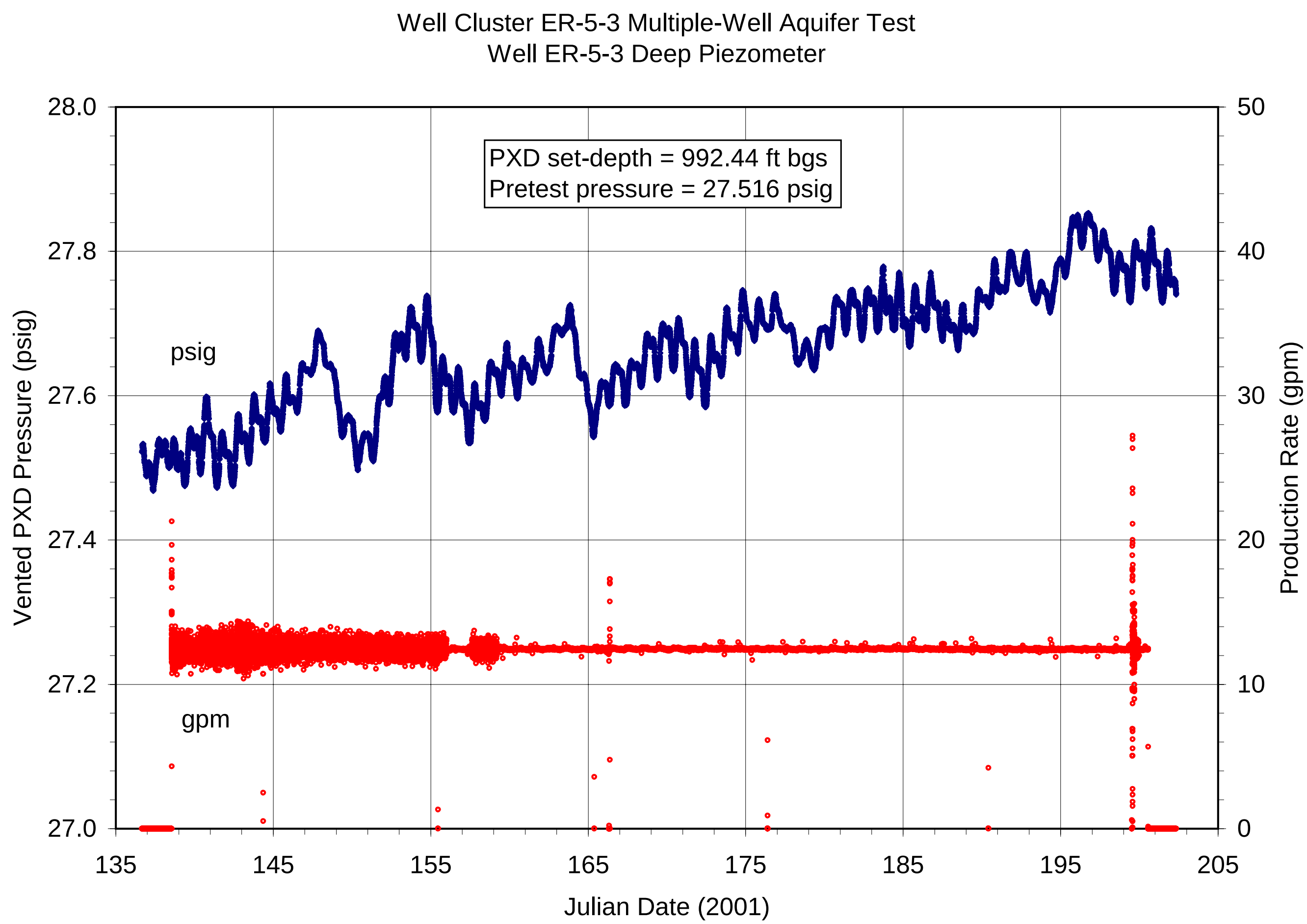
Figure 2-26
Production Rate and Drawdown Response in ER-5-3 During the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psia - Pound per square inch absolute
mBar - Millibars

Figure 2-27
Barometric Pressure and Drawdown Response in ER-5-3 During the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

Figure 2-28
Production Rate and PXD Pressure in the Deep PZ of ER-5-3 During the MWAT

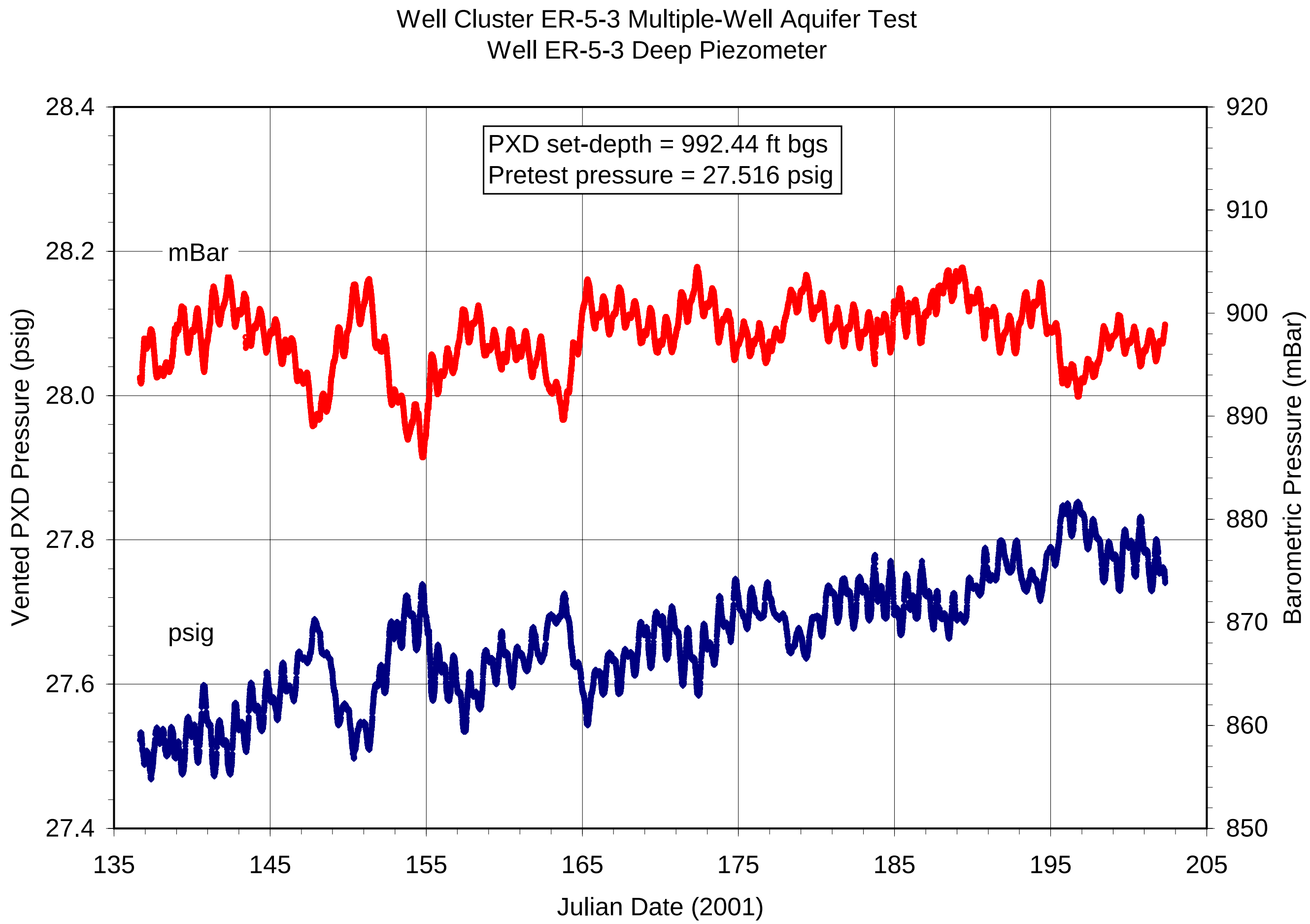
intervening TCUs in the TMWTA. Secondly, the hydraulic conductivity of the volcanic aquifer has been recognized as being significantly greater than the alluvium, which may result in a negligible response in the deep piezometer even if some amount of groundwater was being withdrawn from the underlying volcanic aquifer units from pumping of the lower main CZ.

The PXD pressure measured in the deep PZ of Well ER-5-3 immediately before production was initially recorded at 27.516 psig. No response is recognized in the data after production was initiated. Water levels in the string generally rose throughout the production phase of the test, with PXD pressures progressively increasing from 27.516 (on JDate 138) to 27.784 psig (on JDate 198). The PXD pressures fluctuated approximately 0.062 psig (Figure 2-29), diurnally. Periodic larger-scale changes can be recognized periodically in the record (e.g., JDates 151, 164, and 194). The downhole temperature record from the deep PZ suggests that thermal volume expansion of heated groundwater from the upper CZ of the well produced the rising trend in water levels in the string. The PXD data record indicates that the water column began to cool after production was ended. See Section 3.0 for details on downhole temperature effects on the PXD records captured during the test.

The record captured from the shallow PZ of Well ER-5-3 indicates that production from the upper CZ of Well ER-5-3 clearly induced a decrease in PXD pressures, although the magnitude of the response was small (Figure 2-30). Measured PXD pressures declined approximately 0.295 psig after production was initiated. A PXD pressure of 14.175 psig was recorded immediately before production was initiated. Drawdown gradually developed with PXD pressures decreasing to approximately 13.88 psig over a 27-day period. Diurnal fluctuations in PXD pressures were minimal, on the order of 0.015 psig (Figure 2-31). Large-scale changes in PXD pressures were also not significant, fluctuating on the order of 0.022 psig.

The PXD pressure record from Well ER-5-3#2 indicates that the LCA was not impacted by the production from the upper CZ of Well ER-5-3 (Figure 2-32). Water levels in Well ER-5-3#2 declined throughout the production phase of the MWAT. However, it is likely that the exponentially decreasing PXD pressures result from the prolonged cooling of the water column of the well after the well-specific operations, and do not represent any drawdown induced by the production from Well ER-5-3. A PXD pressure of 9.255 psig was measured immediately before production from Well ER-5-3 was initiated. Pressure values of about 6.9 psig were measured near the end of the production phase of the test. Diurnal fluctuations of approximately 0.06 psig, and larger-scale changes in upwards of 0.35 psig, may be discerned as being superimposed on the exponentially declining record (Figure 2-33).

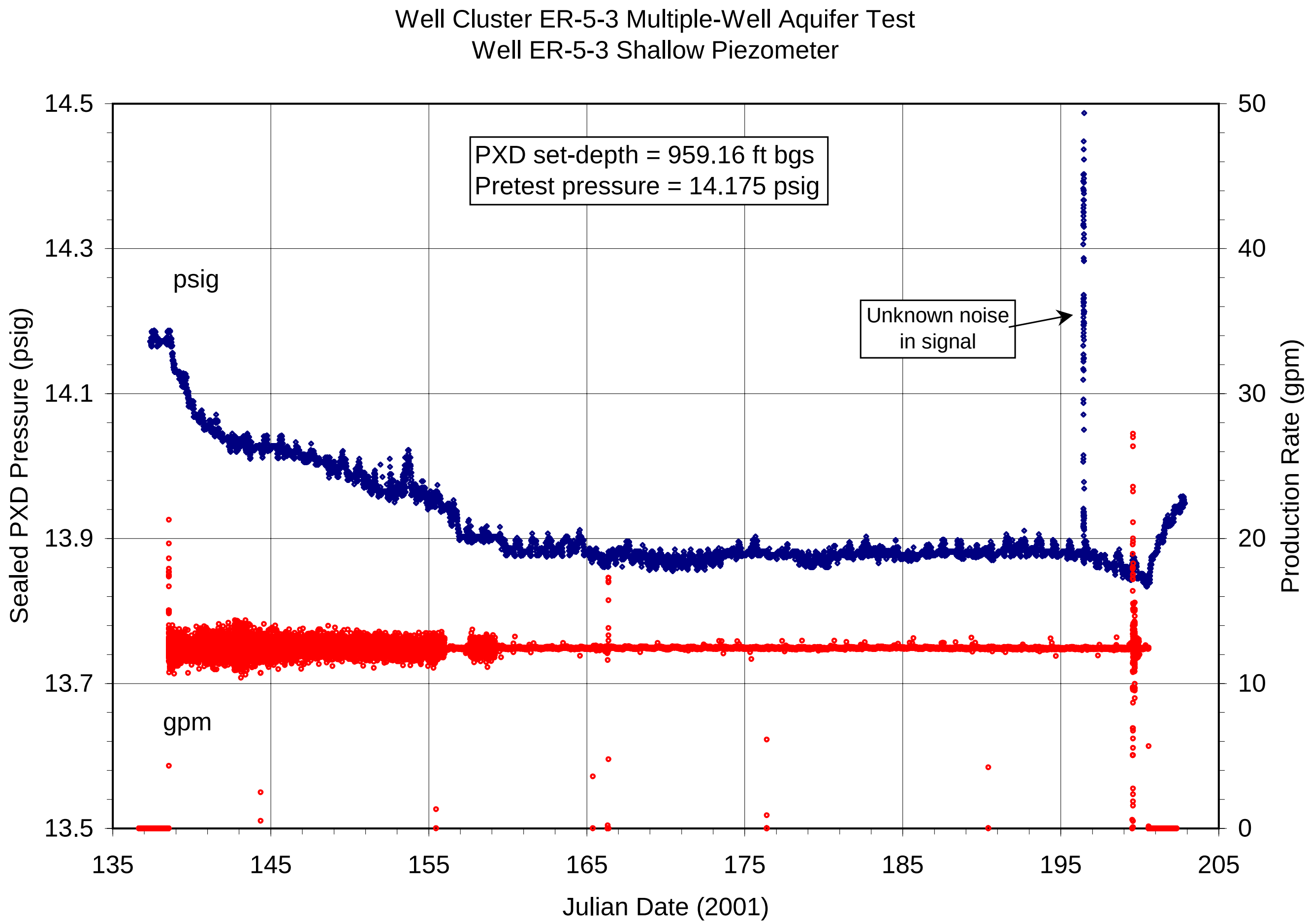
The record captured from Well ER-5-3#3 indicates that the CZ responded well and fairly rapidly to the production from the upper CZ of Well ER-5-3. Although attenuated, the responses in Well ER-5-3#3 tended to mimic the various responses of the production string of Well ER-5-3 (see Section 3.0). An appropriate drawdown curve developed, with the initial pressure of 28.052 psig decreasing to semi-stable values of approximately 21.7 psig about 10 days after production was



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

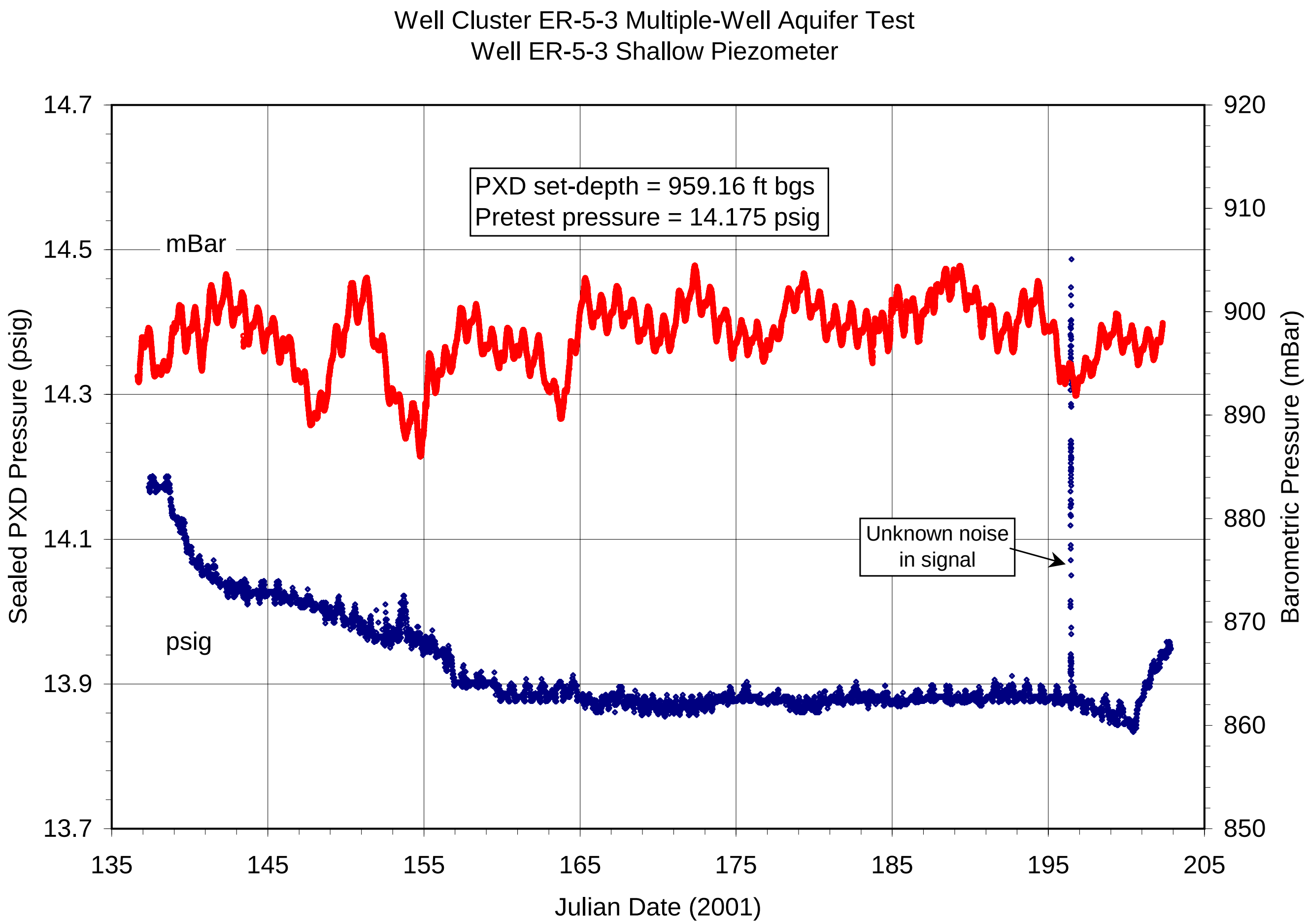
Figure 2-29
Barometric Pressure and PXD Pressure in the Deep PZ of ER-5-3 During the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

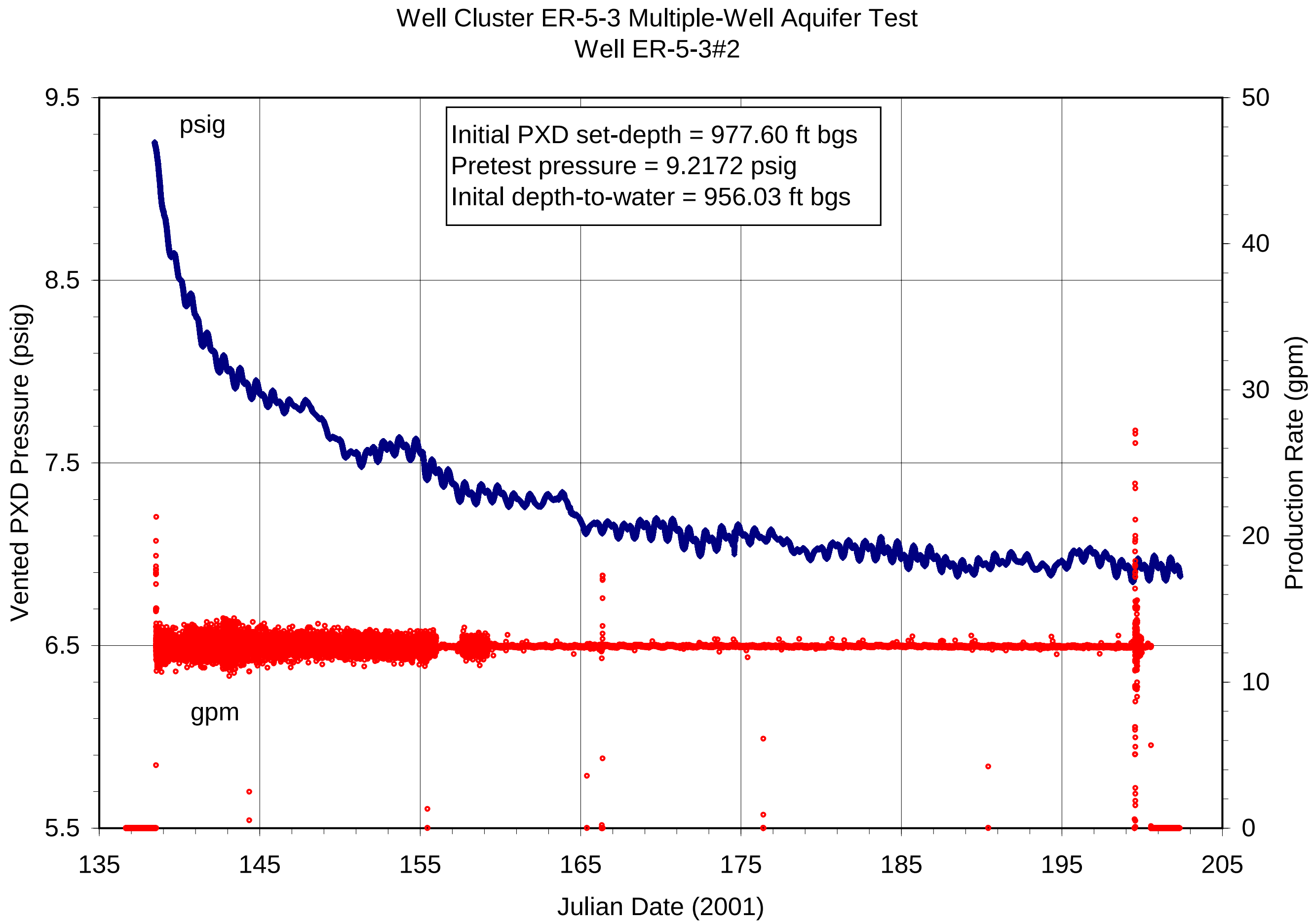
Figure 2-30
Production Rate and the PXD Pressure in the Shallow PZ of ER-5-3 During the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

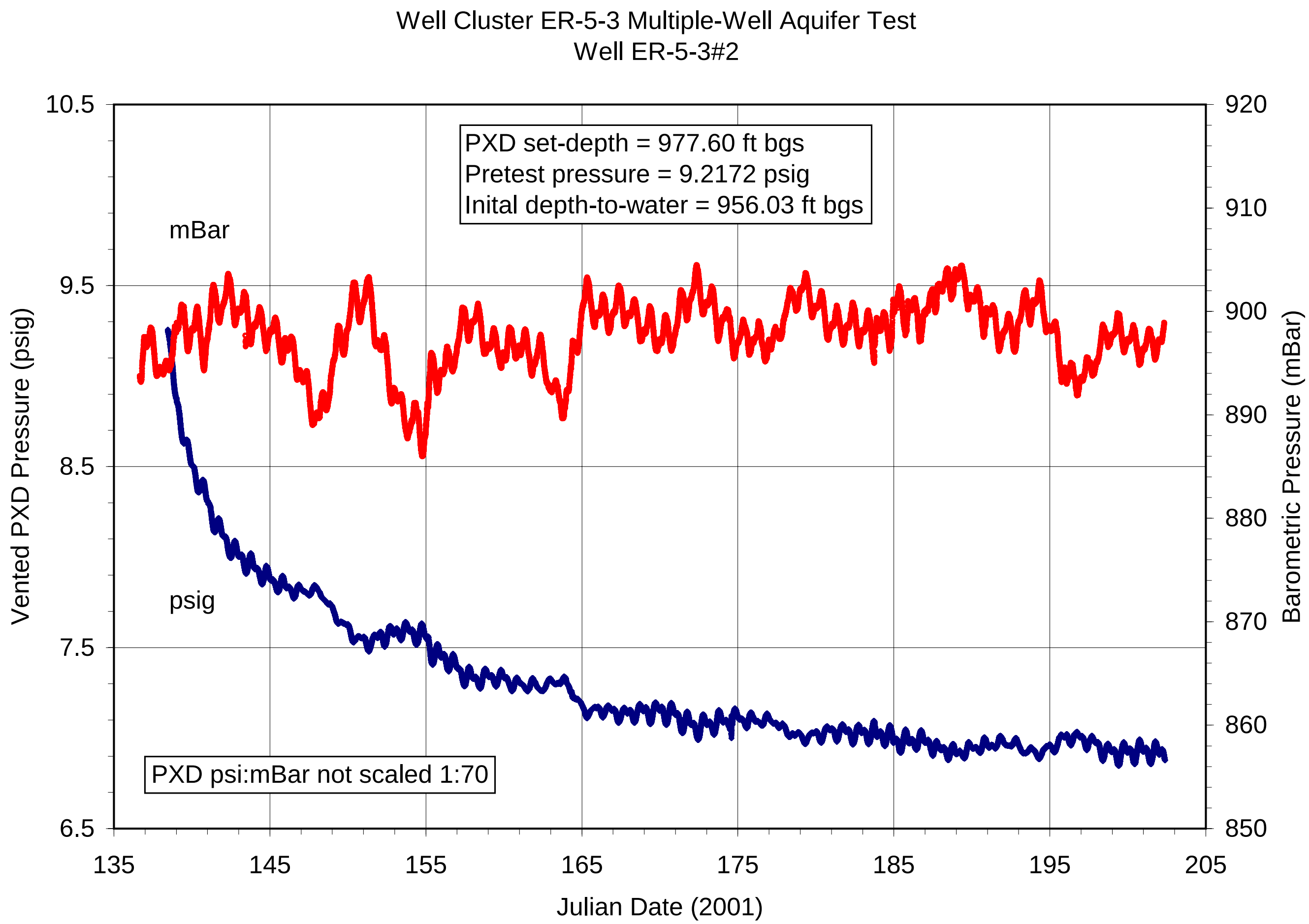
Figure 2-31
Barometric Pressure and PXD Pressure in the Shallow PZ of ER-5-3 During the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

Figure 2-32
Production Rate and PXD Pressure in ER-5-3#2 During the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-33
Barometric Pressure and PXD Pressure in ER-5-3#2 During the MWAT

initiated (Figure 2-34). The record from Well ER-5-3#3 shows the suspected decreased production from Well ER-5-3 while entrained air was impacting the monitoring/control systems from Jdates 138 to 159. Additionally, the impacts from the loss of site power on Jdate 166 can also be readily discerned in the record from this string. Diurnal and larger-scale fluctuations in PXD pressures ranged approximately 0.038 and 0.123 psig, respectively (Figure 2-35).

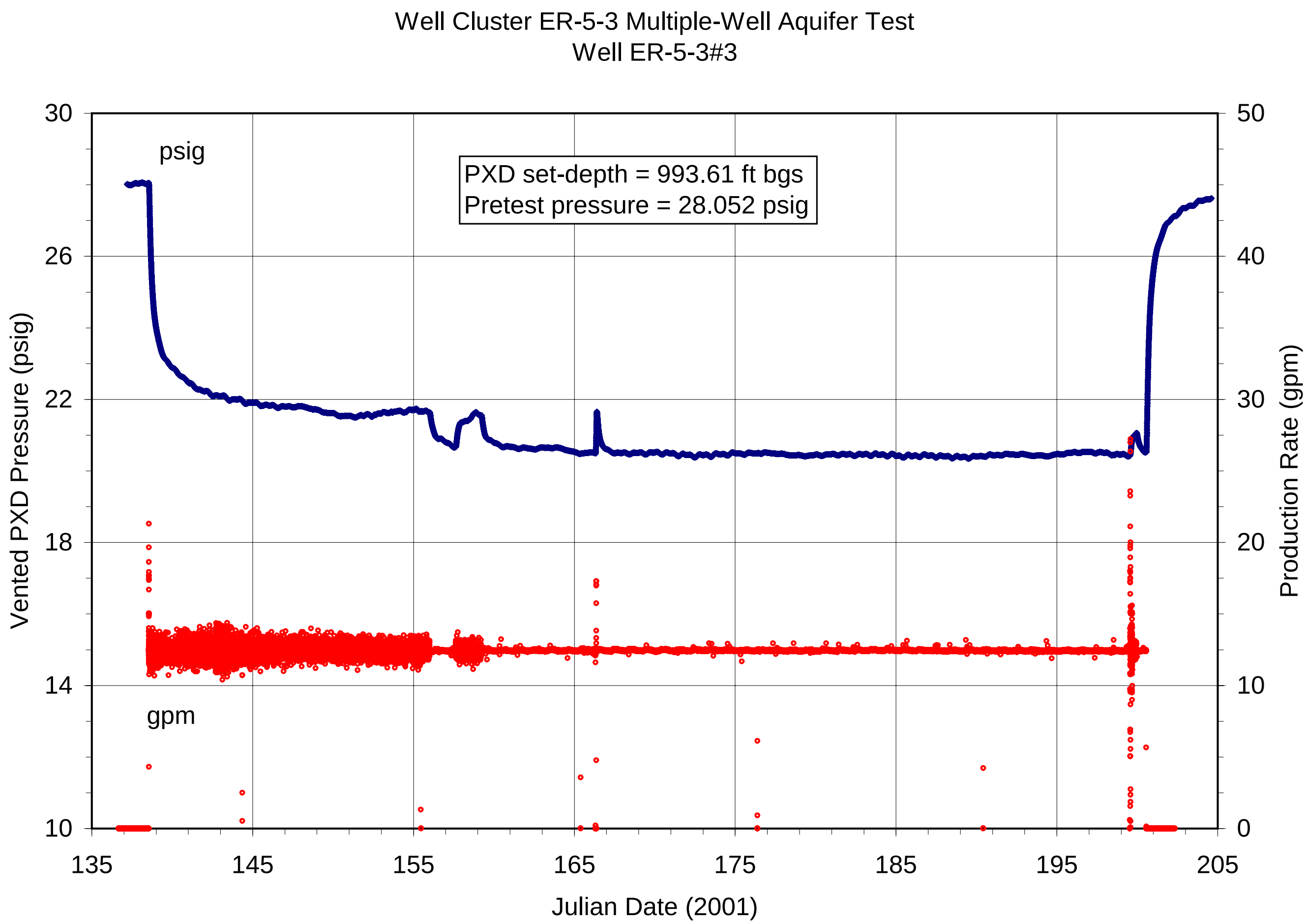
2.8.6.1 Entrained Air Testing

Observations and data acquired during the early periods of the production phase of the test suggested that entrained air was potentially inducing adverse effects on the monitoring/control systems in use at the well cluster (Figure 2-36). Therefore, on July 18, 2001 (JDate 199), ITLV personnel conducted entrained air tests near the end of the production phase of the MWAT in an attempt to characterize the potential effects.

The testing included instrumenting a mass flowmeter in the discharge line downstream from the magnetic flowmeter. Mass flowmeters are capable of measuring flow as a function of fluid density, which would reflect entrained air. ITLV field representatives also coupled an air source (compressor) to the ITLV wellhead assembly at Well ER-5-3, upstream from the discharge monitoring and control equipment. The compressor allowed field personnel to inject various volumes and rates of air into the discharge system. The testing consisted of injecting various volumes (rates) of air and monitoring the responses of the instrumentation. Information obtained by ITLV during the tests included:

- Qualitative assessments of air injected at the wellhead
- Exact-time production rates measured by the mass flowmeter, including fluid density/specific gravity
- Exact-time production rates measured by the magnetic flowmeter
- Five-second interval time-averaged production rates measured by the magnetic flowmeter and displayed on the field laptop computer (PC208W datalogger software)
- VSD operational parameters (e.g., hertz [Hz], Mode, and gpm)
- Frequent sampling and measurement of entrained air via the BOD-bottle procedure (measurement of sample volume after allowing the sample to degas)

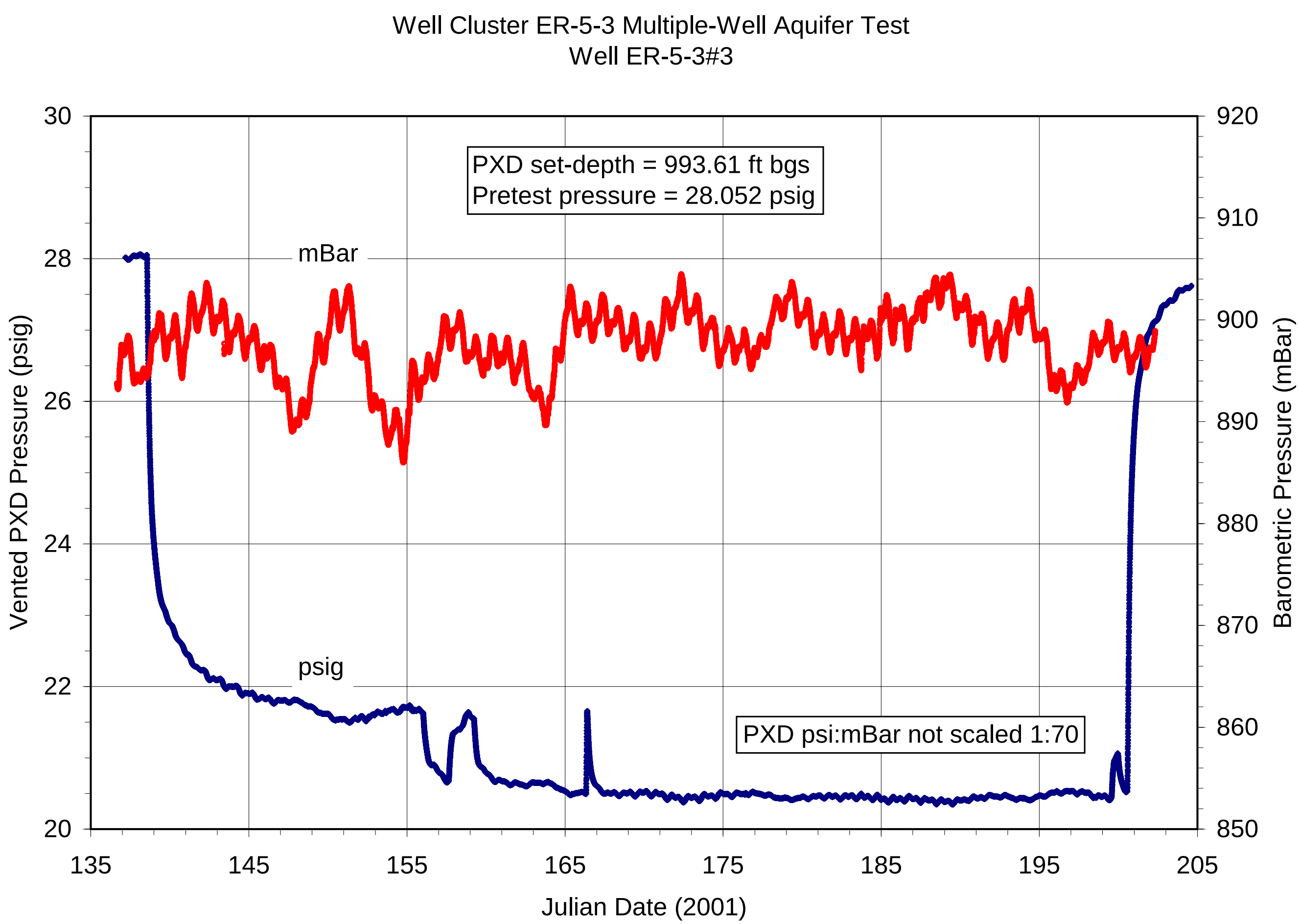
ITLV personnel conducted tests on July 18, 2001 (JDate 199), to assess the impacts of air entrained in the discharged fluids. The information and data obtained during the entrained air testing conducted on July 18, 2001, have been compiled and evaluated (Table 2-6). Some preliminary interpretations and insights are provided.



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
gpm - Gallons per minute

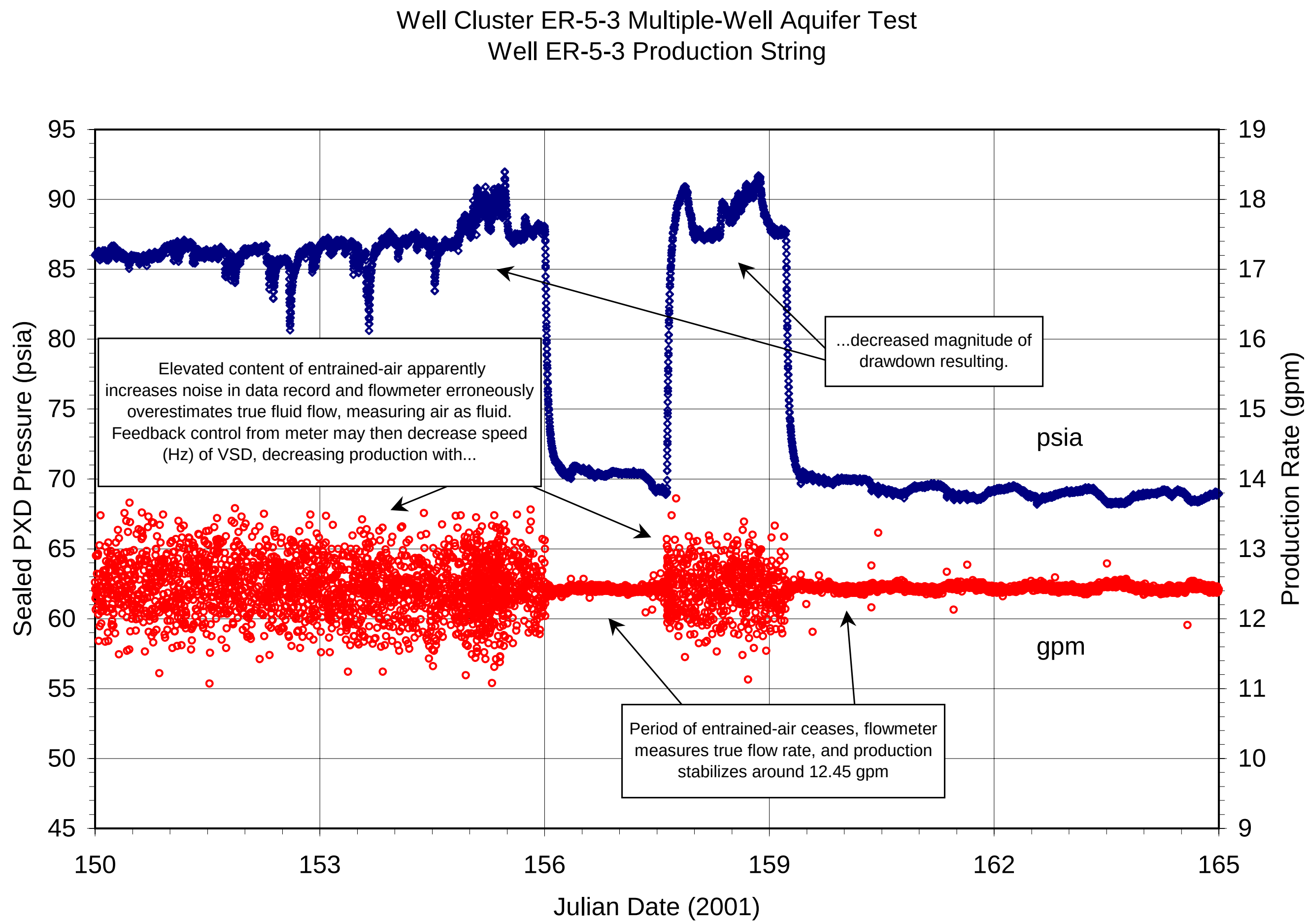
Figure 2-34
Production Rate and PXD Pressure in ER-5-3#3 During the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-35
Barometric Pressure and PXD Pressure in ER-5-3#3 During the MWAT



PXD - Pressure transducer

psia - Pounds per square inch absolute
gpm - Gallons per minute

Figure 2-36
Detail of Possible Entrained Air Effects on Discharge and Water Level in ER-5-3 During the MWAT

Table 2-6
Testing of Entrained Air Effects

Time	Air Injection[a]	Production Rate (gpm)				VSD		Mass Flowmeter		BOD Sampling (% air)
		PC208W[b]	Magnetic Flowmeter	Mass Flowmeter	VSD	Hz	Mode	Density (gr/cc)	SG (ρ/std water)	
199.552	----	----	----	----	----	----	----	----	----	0
199.554	----	----	12.59	15.039	----	----	2	0.993	0.99	----
199.556	----	----	12.57	14.923	----	----		0.993	0.99	----
199.557	----	----	12.65	14.865	----	----		0.993	0.99	----
199.560	low-mod	8.60	----	----	12-19	42.5		----	----	----
199.567	v. low (0)	10.76	12.64	13.535	13.0	40.5		0.987	0.99	----
199.567	----	----	----	----	----	----	----	----	----	0
199.572	low (0)	11.50	12.38	5.734	11.4	39.8	2	0.677	0.38	0
199.576	mod (0.5)	7.22	8.35	3.930	19.3	41.3		0.182	0.25	0
199.581	none	12.63	11.04	11.002	13.0	40.3		0.960	0.96	----
199.583	high (1.5)	27.22	17.44	16.299	3.9	35.9		0.084	0.08	No fluid
199.590	low (0)	12.53	11.50	1.730	13.5	40.2		0.883	0.88	0
199.597		12.37	13.21	6.010	12.7	39.9		0.939	0.94	0
199.604		12.74	13.15	1.409	12.0	39.9		0.891	0.89	0
199.611		12.90	14.76	10.676	14.2	39.8		0.884	0.88	1
199.618		13.77	12.27	0.440	14.2	39.5		0.860	0.86	0.33
199.625		12.37	13.78	1.756	12.3	40.2		0.895	0.89	0.33
199.635		12.03	12.90	13.183	12.9	40.1	1	0.987	0.98	0
199.642		12.22	11.85	13.532	11.9	40.2		0.979	0.97	0
199.649		12.93	13.20	13.634	12.2	40.2		0.968	0.97	0
199.656		13.22	12.91	10.407	13.7	40.1		0.943	0.93	0
199.667	none	13.07	12.79	11.157	12.2	40.2	2	0.986	0.98	0
199.670		----	12.19	14.217	----	----		0.989	0.98	----
199.674	v. low	12.55	12.98	12.266	12.4	40.2		0.974	0.97	----
199.677	v. low-low	12.22	13.97	12.266	11.9	39.6		0.974	0.97	0
199.681	low	12.55	11.81	1.995	13.9	40.2		0.898	0.89	----
199.684		12.57	11.85	3.867	16.3	39.4		0.606	0.60	----
199.688	low-mod	13.42	13.93	5.675	11.9	39.6		0.379	0.37	----

[a]The air-injection rates provided are *qualitative*, based on ITLV observations and gauge readings (provided in parentheses when applicable)
[b]Data displayed from datalogger software program

See information from the two functionality tests for stable values of operational parameters (e.g., VSD gpm and Hz).

gr/cc - Grams per cubic centimeter; SG - Specific gravity; ρ/std water - Measured density per standard unit of water; ---- - No information obtained

It is suspected that some air may have existed in the alluvium from anthropogenic sources subsequent to the drilling operations. The air was likely released from the alluvium once the head of the upper CZ declined during the initial days of production. Air entrained within the discharged fluids appears to impact the flow-rate monitoring and consequently the feedback control system.

The magnetic flowmeter appears to respond to entrained air erratically. According to information provided by Omega (2002), the manufacturer of the flowmeter, “The magmeter cannot distinguish entrained air from the process fluid; therefore, air bubbles will cause the magmeter to read high. If the trapped air is not homogeneously dispersed, but takes the form of air slugs or large air bubbles (the size of the electrode), this will make the output signal noisy or even disrupt it.” Thus, the flowmeter does not have the capacity to differentiate between air and water and measures the composite flow of both mediums as total discharge. This results in the overestimation of actual flow, that portion of the discharge that can be attributed to fluid only. As a result, production is reduced by the VSD based on the erroneous control signal from the magnetic flowmeter via the feedback loop.

Information on the volume and rates of air injected by the air-compressor at the wellhead could only be qualitatively assessed because the gauge on the compressor would not register pressures until an unreasonable amount of air was being applied. Additionally, the mass flowmeter could not be completely calibrated before the testing commenced. Therefore, the parameters acquired from the meter should only be regarded as qualitative. However, it is believed that the values obtained from the meter do provide a realistic sense of relative changes in fluid density.

2.8.7 Completion of the Production Phase of the MWAT

The VSD was shut down at 13:26 on July 19, 2001 (JDate 200.56), to end the production phase of the MWAT. Upon the termination of production from Well ER-5-3, recovery curves developed rapidly in the production string of Well ER-5-3 and in Well ER-5-3#3. There also appears to be a water-level response in the Shallow PZ after the VSD was shutdown, although the response was diminished. The data records from the deep PZ of Well ER-5-3 and from Well ER-5-3#2 do not indicate that these strings responded to the cessation of the production from Well ER-5-3.

2.8.8 Postproduction Monitoring

Postproduction water-level monitoring was conducted subsequent to the shutdown of the VSD on July 19, 2001. The postproduction monitoring occurred over a 50-day period, until September 6, 2001. During this period, the dataloggers were configured so they could be accessed and downloaded from the ER contractor office in Las Vegas. Most of the data records captured during this period provided information on water-level recovery (e.g., production string and shallow PZ of Well ER-5-3 and Well ER-5-3#3) and continued natural water-level fluctuations (e.g., deep PZ of Well ER-5-3 and Well ER-5-3#2).

Adequate barometric pressure records were obtained from the barometers at wells ER-5-3 and ER-5-3#2 during the postproduction monitoring period. Occasional anomalous values of barometric pressure, as transient noise or sensor drift, continued to be acquired by the datalogger system at Well ER-5-3#3. Diurnal fluctuations in barometric pressure averaged approximately 4.2 mBar during the postproduction period. Larger scale changes in barometric pressure, on the order of 10.2 mBar, can also be discerned in the record.

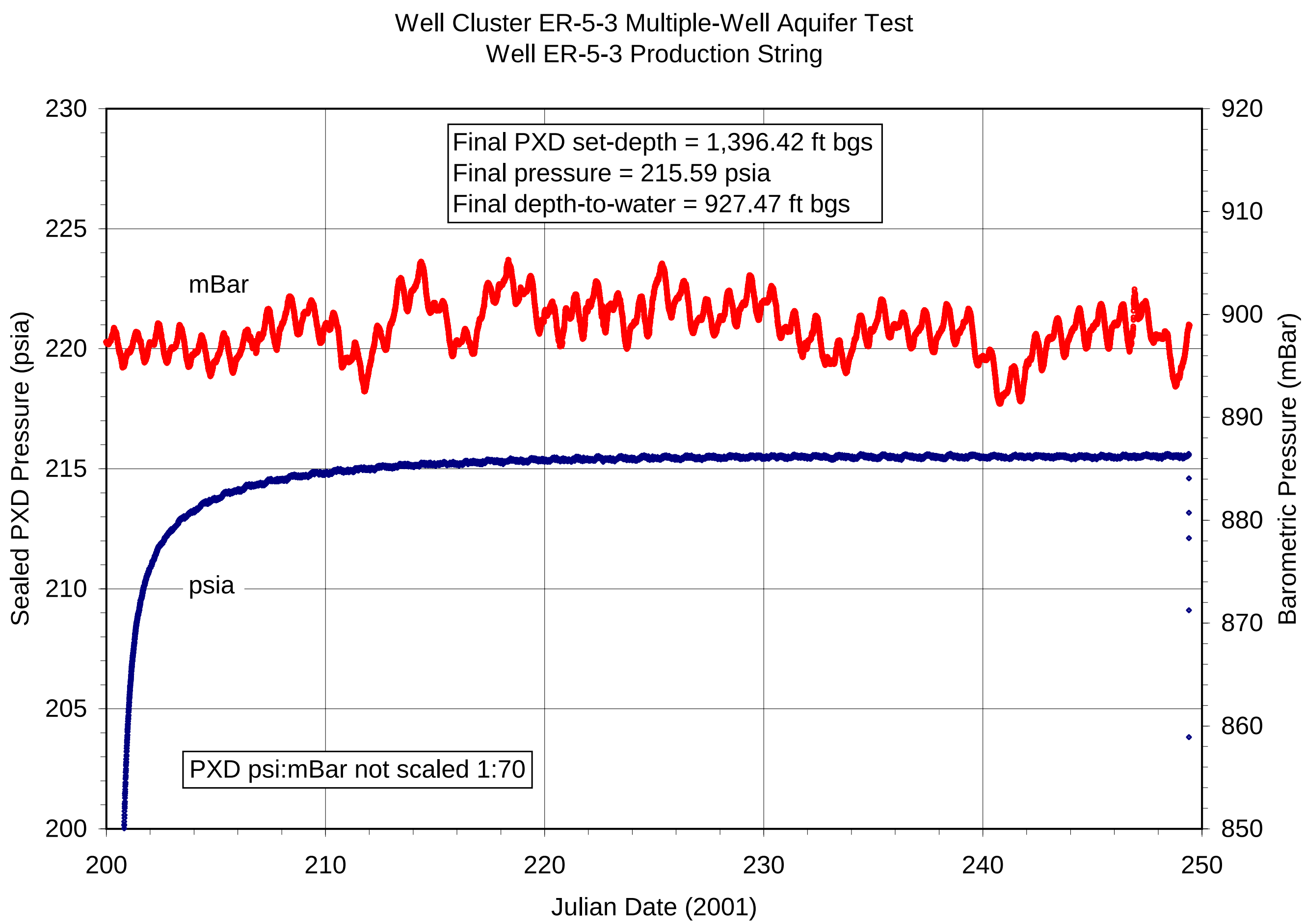
The PXD record from the production string of Well ER-5-3 resulted in the development of a suitable recovery curve after production ceased (Figure 2-26). The PXD pressures increased exponentially from an initial pressure of 66.5 to 215.3 psia over a 20-day period (Figure 2-37). Diurnal fluctuations in the PXD record, on the order of 0.19 psia, are apparent in the data record after approximately 6 days. Recovery appears to have been completed around August 21, 2001 (JDate 233). Subsequently, PXD pressures averaged approximately 215.47 psia while fluctuating approximately 0.18 psia due to diurnal fluctuations in barometric pressure.

The postproduction record for the deep PZ of Well ER-5-3 does not show any response attributable to recovery (Figure 2-28). The record generally displays water-level responses that appear to correlate with variations in barometric pressure (Figure 2-38). Diurnal fluctuations and larger-scale variations of approximately 0.07 and 0.16 psig, respectively, may be observed in the record.

The PXD record acquired from the shallow PZ of Well ER-5-3 during the postproduction period shows a distinct transition from production to recovery (Figure 2-30). Pressures increased from an initial value of 13.83 to approximately 14.03 psig over a 15-day period, with diurnal fluctuations on the order of 0.02 psig. Complete recovery in the string appears to have occurred approximately 33 days after the VSD was shutdown. The cause of the anomalous pressure measurements recorded on JDate 222 is not known, but transient electrical noise in the 4-20 milliamp (mA) signal is suspected.

The record captured for Well ER-5-3#2 indicates no hydraulic responses, as water-level recovery, after the cessation of production from the local AA (Figure 2-32). Water levels in the well appear to continue to fluctuate as a result of variations in barometric pressure, with some responses to earth tides also apparent (Figure 2-40). Diurnal fluctuations and larger-scale variations of approximately 0.10 and 0.25 psig, respectively, may be discerned in the record.

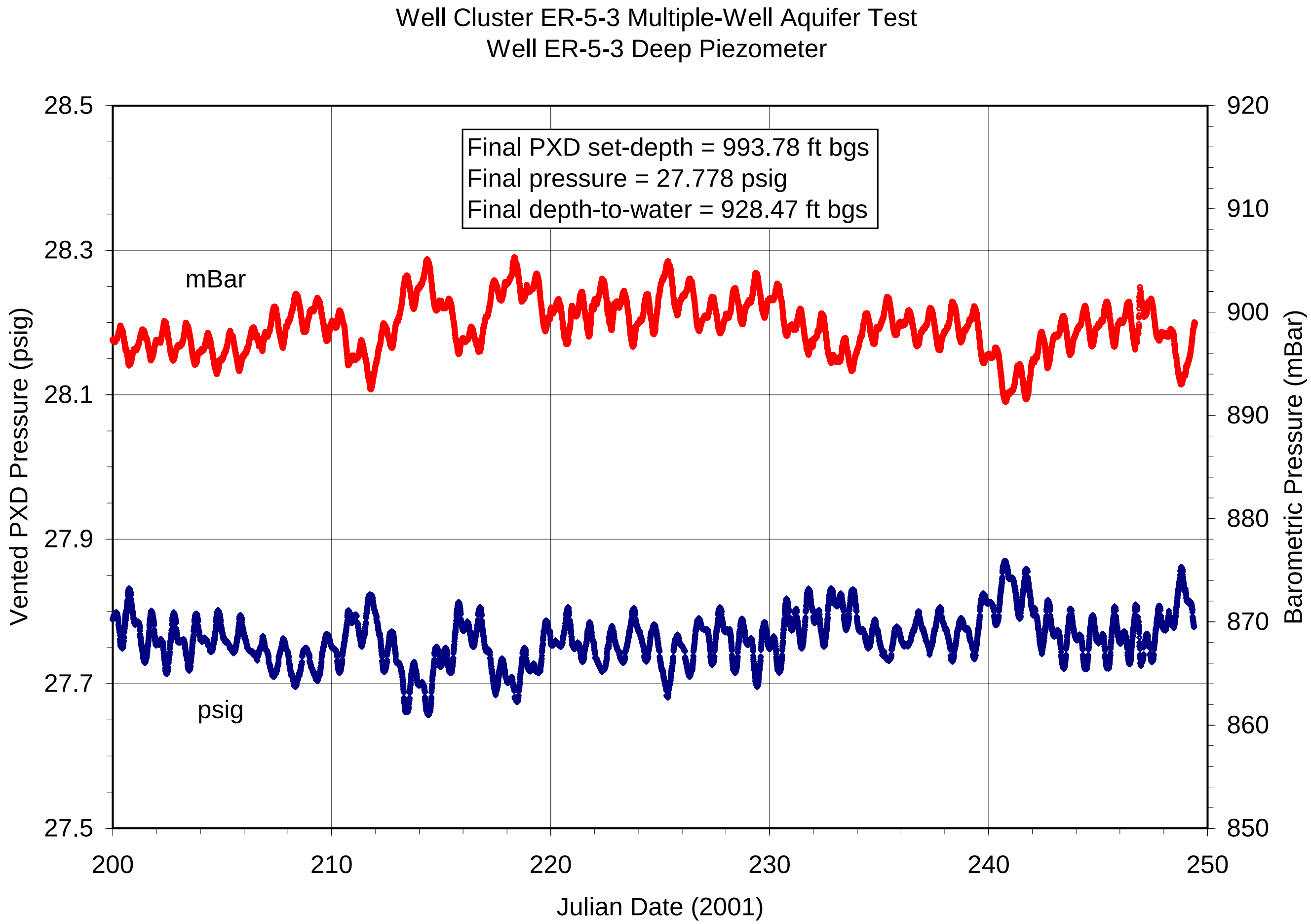
Recovery occurred in Well ER-5-3#3 after production from Well ER-5-3 was concluded (Figure 2-34). The PXD pressures exponentially increased approximately 7.5 psig over the first 20 days of recovery (Figure 2-41). Diurnal fluctuations in the PXD record, on the order of 0.06 psia, are apparent in the data record approximately 4 days after the VSD was shutdown. After JDate 220, PXD pressures averaged approximately 28.25 psig, with pressures continuing to fluctuate approximately 0.07 psig, diurnally. Complete recovery in the string appears to have occurred around JDate 233.



PXD - Pressure transducer
ft bgs - Feet below ground surface

psia - Pounds per square inch absolute
mBar - Millibars

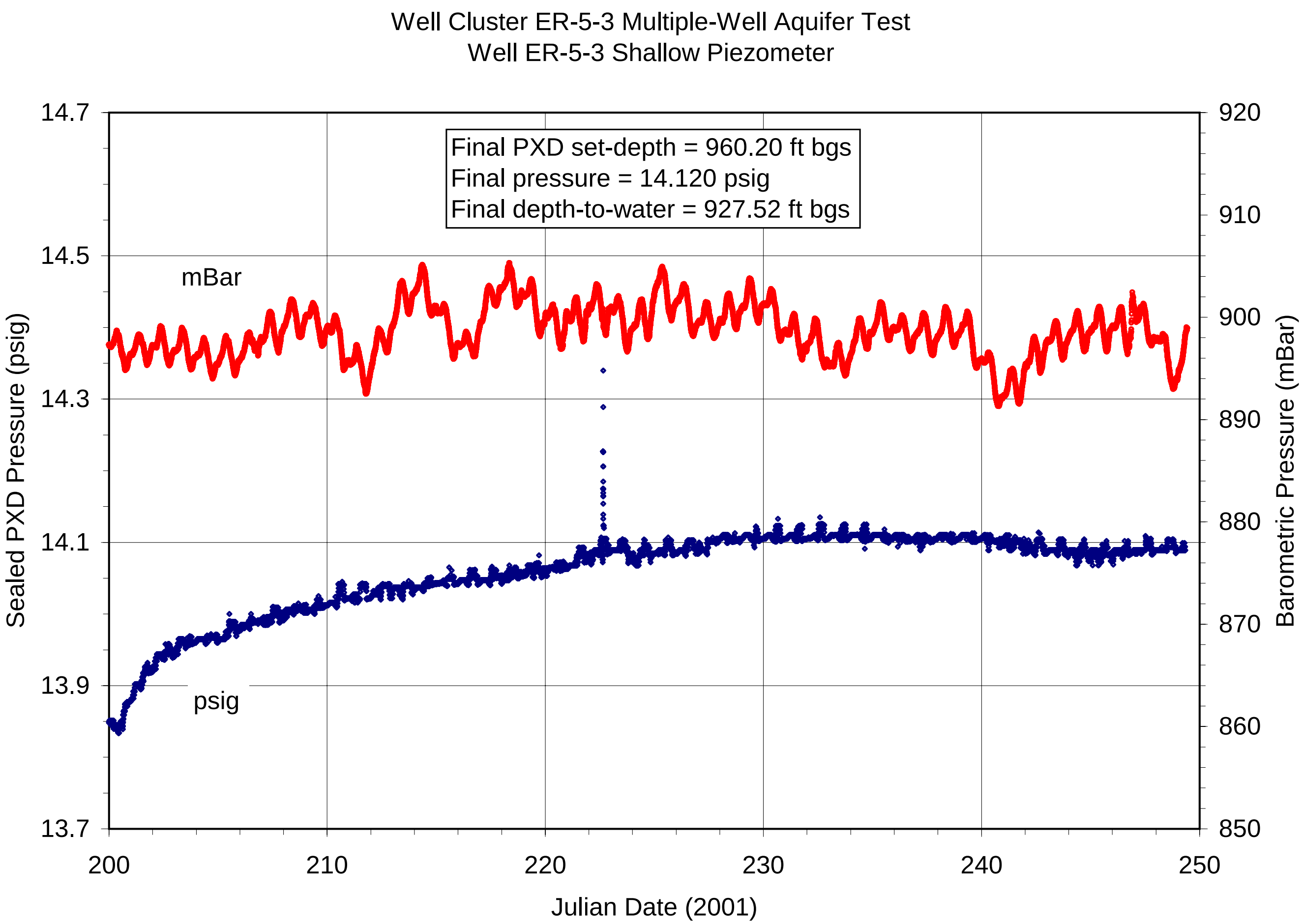
Figure 2-37
Barometric Pressure and PXD Pressure in ER-5-3 During the Recovery after the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

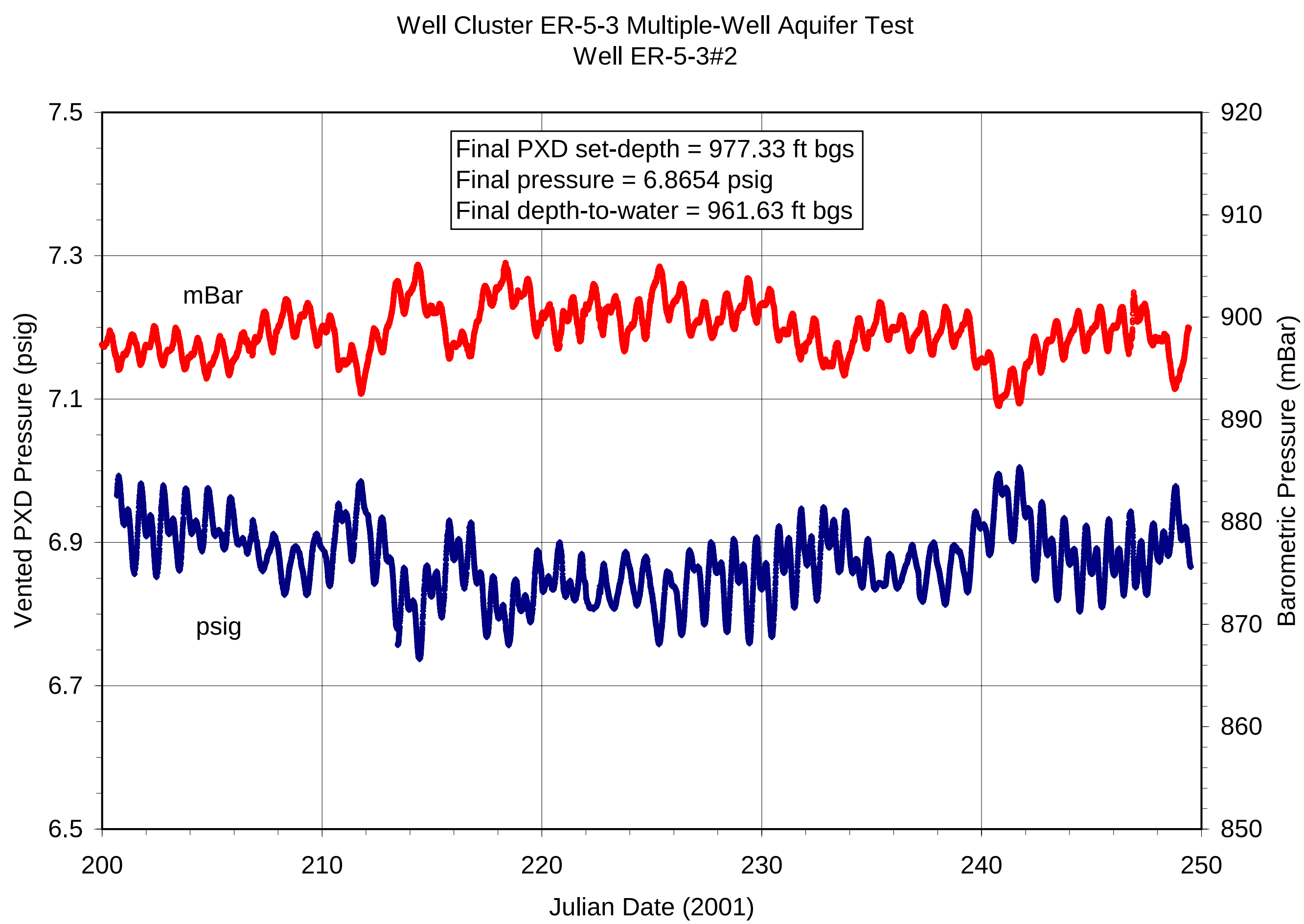
Figure 2-38
Barometric Pressure and PXD Pressure in the Deep PZ of ER-5-3 During Recovery after the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

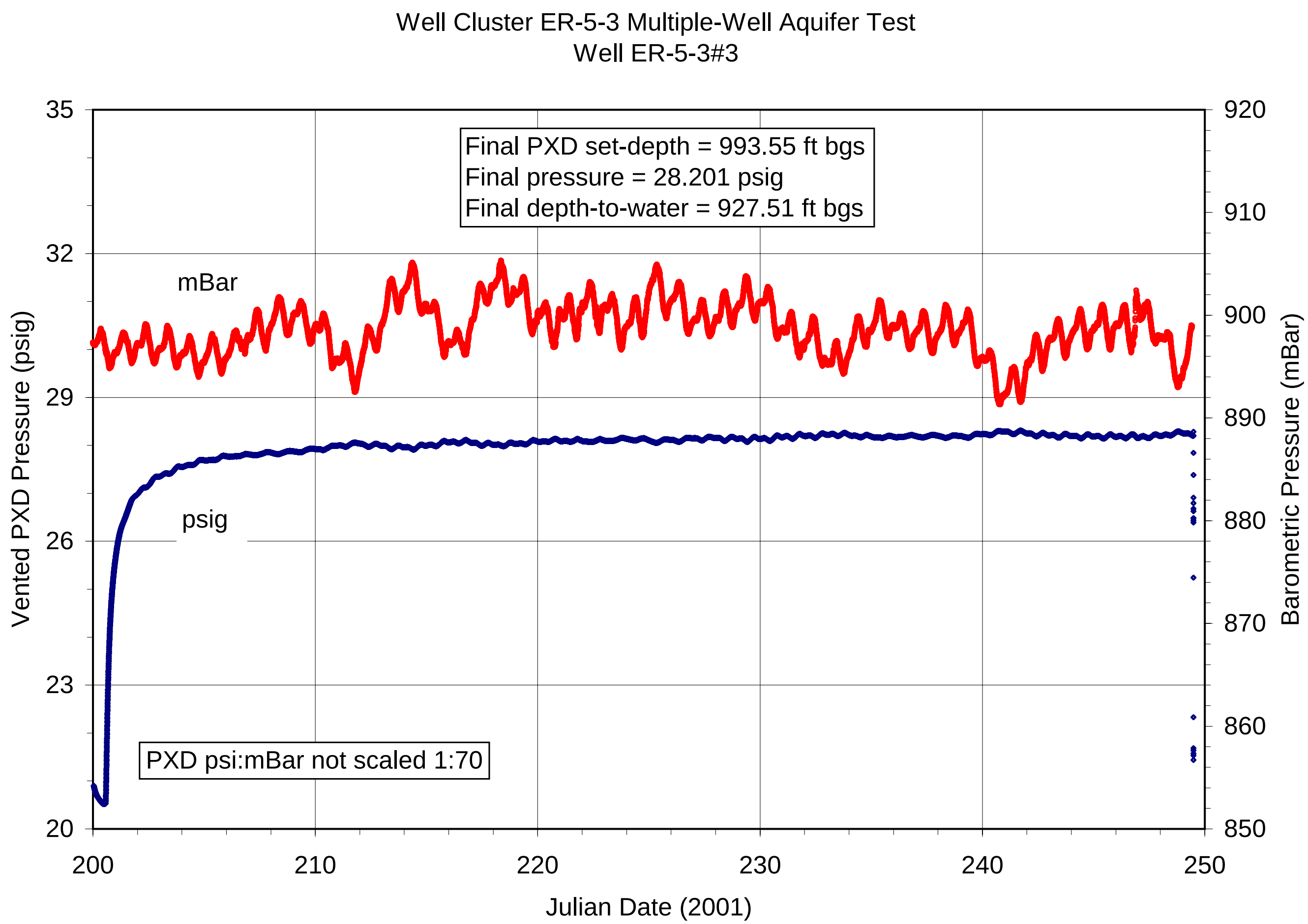
Figure 2-39
Barometric Pressure and PXD Pressure in the Shallow PZ of ER-5-3 During Recovery after the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-40
Barometric Pressure and PXD Pressure in ER-5-3#2 During Recovery after the MWAT



PXD - Pressure transducer
ft bgs - Feet below ground surface

psig - Pounds per square inch gauge
mBar - Millibars

Figure 2-41
Barometric Pressure and PXD Pressure in ER-5-3#3 During Recovery after the MWAT

2.8.9 Removal of PXDs

After reviews of the postproduction recovery records by members of the UGTA technical working group (TWG) on August 30, 2001, it was decided that recovery in the monitored strings was complete. Subsequently, the five PXDs at the well cluster were removed on September 6, 2001 (JDate 249). This work was the final element of the FY 2001 activities at the well cluster. As part of these field efforts, the clock of each datalogger was evaluated for drift against the clock of the main datalogger at Well ER-5-3. Each datalogger clock had been synchronized to the U.S. Naval Observatory Master Clock (atomic clock) before the production phase of the test was initiated. A maximum difference of 21 seconds (sec) was determined. The drift evaluation was as follows:

- Datalogger used to monitor the shallow PZ of Well ER-5-3 was 21 sec ahead of the main datalogger
- Datalogger used at Well ER-5-3#2 was 6 sec ahead of the main datalogger
- Datalogger at Well ER-5-3#3 was 19 sec ahead of the main datalogger.

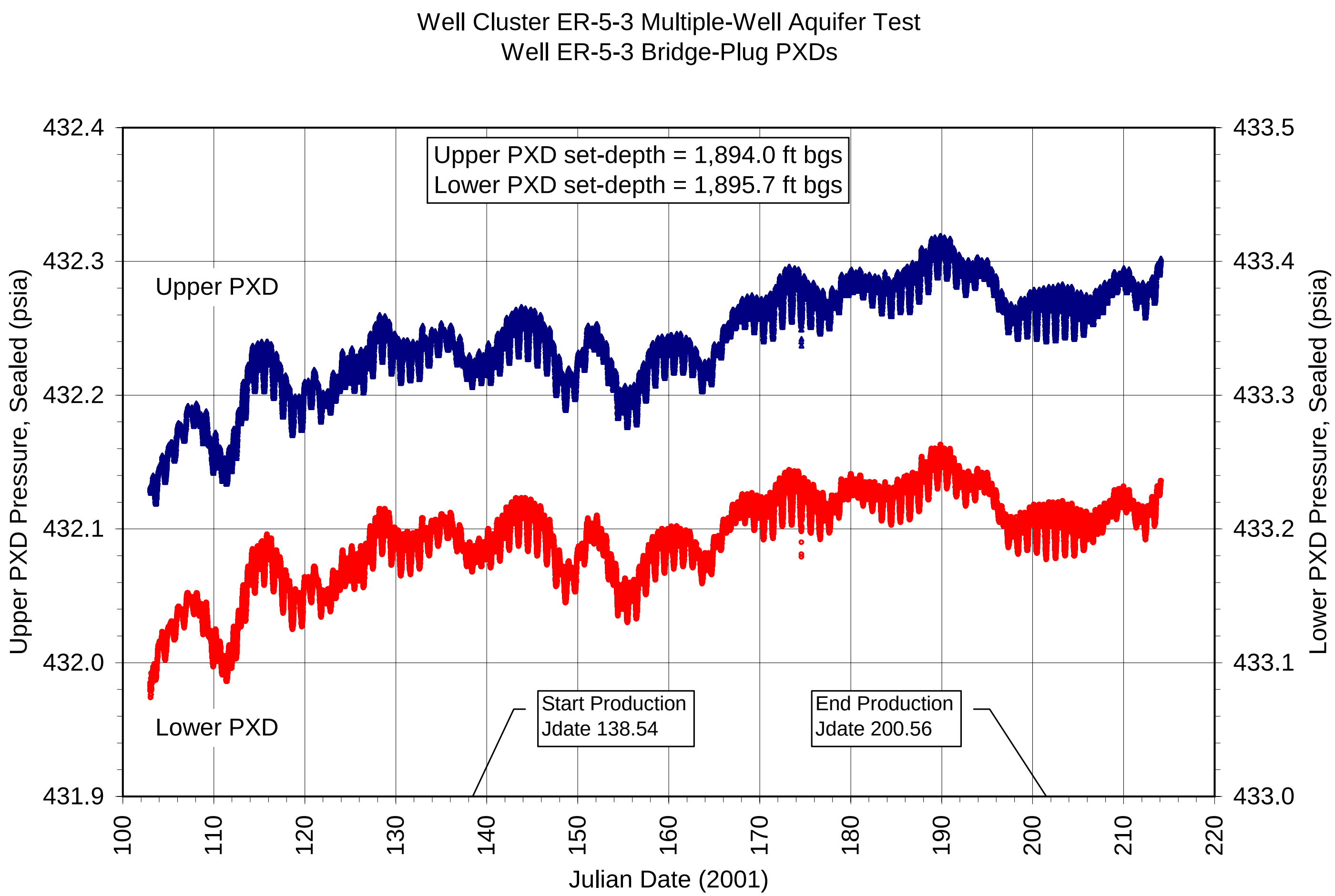
2.8.9.1 Bridge-Plug Data Records

Data from each bridge-plug datalogger were downloaded and field processed. Some discrepancies were noted. The data were subsequently forwarded to the manufacturer of the PXD/datalogger system (Spartek Systems of Alberta, Canada) for technical evaluations and additional processing. The resultant data record for the lower PXD indicated that the power to the unit failed at 09:05 on August 7, 2001 (JDate 219.3787). However, a data record was acquired from this sensor from 11:14 on April 12, 2001 (JDate 102.4685), until the power failure on August 7, 2001 (Figure 2-42). A complete data record was acquired by the upper PXD (Figure 2-42). The record for the upper PXD encompasses data that were obtained from 11:14 on April 12, 2001, to 16:20 on October 10, 2001 (JDates 102.4685 to 283.6809). The records for both PXDs are identical (e.g., magnitude of pressure changes); both sensors performed exceptionally well during their employment.

2.8.10 Observation Wells

Water levels in wells distal to Well Cluster ER-5-3 were monitored as observation wells by other project participants during the MWAT. These wells served as observation points for acquiring data on more areally-extensive head fluctuations in the basin from areas not expected to be impacted by the water production at Well Cluster ER-5-3.

Early in the FY 2001 WDT operations in Frenchman Flat, attempts were made to instrument additional wells as observation points (e.g., UE-5J AND UE-11A). However, these wells proved to be inadequate for various reasons (e.g., bridged casing or fill extending above the saturated zone). The observation wells that were



PXD - Pressure transducer
ft bgs - Feet below ground surface

psia - Pounds per square inch absolute
JDate - Julian date

Figure 2-42
PXD Pressure Beneath the Bridge Plug During the MWAT and Recovery

monitored included TW-3, located approximately 3.1 miles east of the Frenchman Flat playa, and the three pilot wells associated with the nearby Radioactive Waste Management Site (RWMS), located approximately 1.6 miles southwest of Well Cluster ER-5-3.

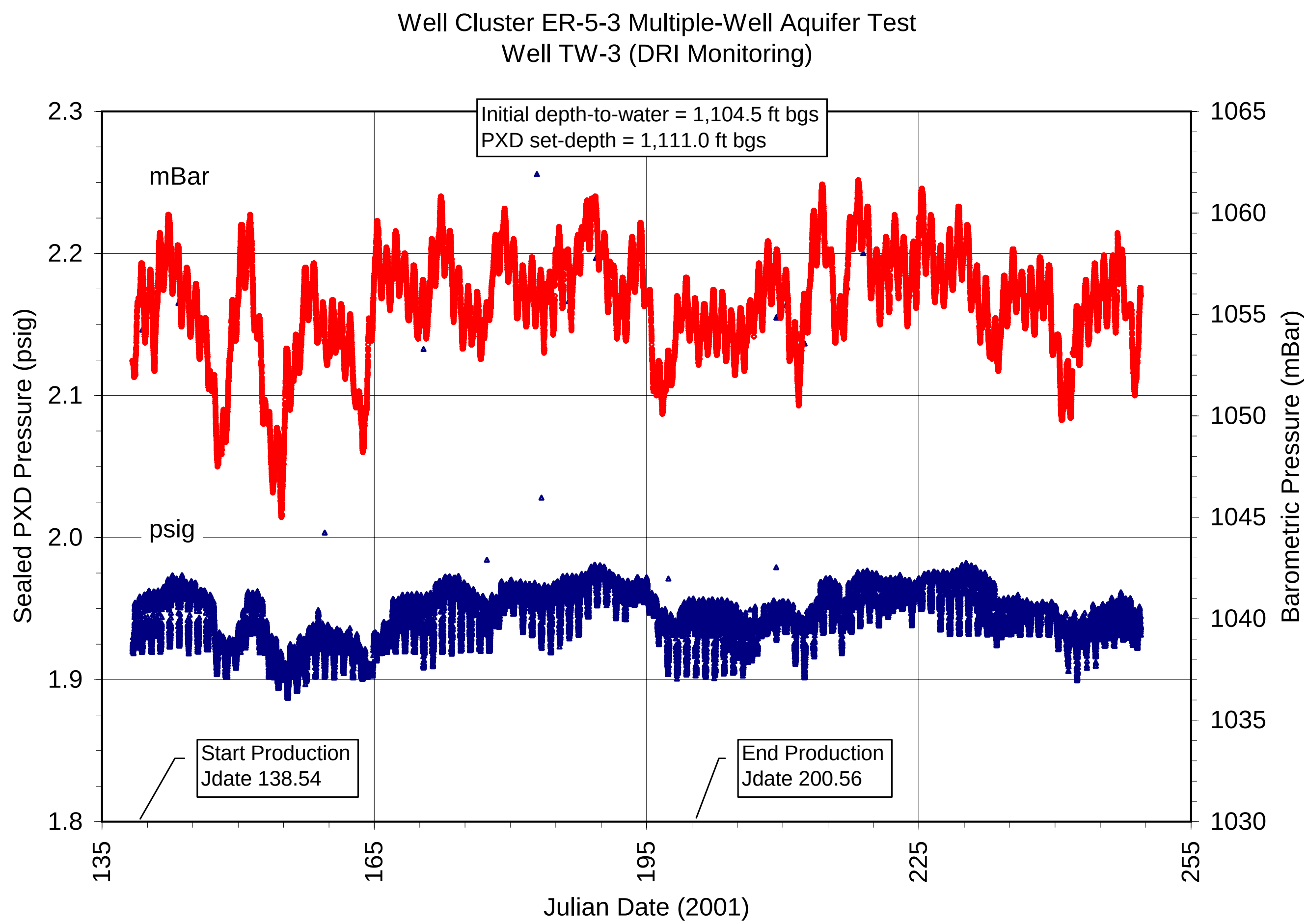
2.8.10.1 Well TW-3

Well TW-3, completed with a single CZ in the LCA, was instrumented with a downhole PXD, barometer, and datalogger by DRI. The well has not been subjected to development or production in recent years. Water levels in the well were monitored throughout the MWAT at Well Cluster ER-5-3. DRI initially installed a sealed vibrating-wire PXD in the well on March 20, 2001 (JDate 79), with a water-level tag of 1,104.2 ft bgs. However, the transmitted signals from the sensor were suspect, so it was replaced with another sealed vibrating-wire PXD on May 1, 2001 (JDate 121). On May 1, 2001, the water level in the well was tagged at 1,104.5 ft bgs with a barometric pressure of 1,053 mBar being recorded. A set-depth of 1,111 ft bgs has been provided for the second PXD.

Data records, from May 1, 2001 (JDate 121.5), through September 6, 2001 (JDate 249.48611), were obtained at the well (Figure 2-43), but some noise may be recognized in the data record. The PXD pressure record defines water-level responses in the well as a direct result of variations in barometric pressure. Diurnal fluctuations on the order of 3.2 mBar induced a response of approximately 0.04 psig. Larger-scale barometric variations of approximately 13 mBar induced responses of about 0.07 psig in the PXD measurements. Since the PXD in the string was sealed, measured PXD pressures are directly proportional to changes in barometric pressure.

2.8.10.2 Pilot Wells of the RWMS

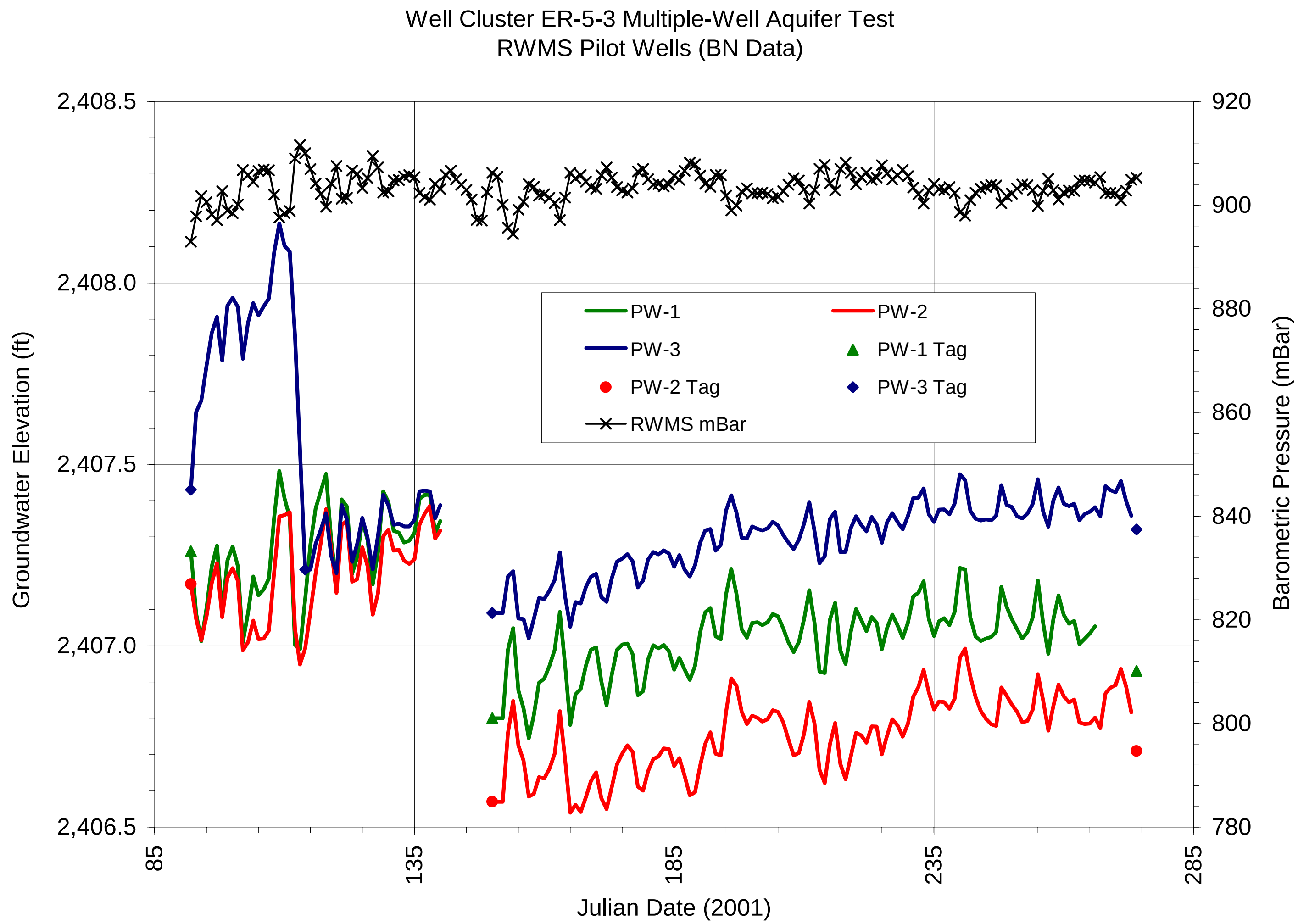
Bechtel Nevada is tasked with the monitoring and sampling of three pilot wells (PWs) associated with the RWMS. Water levels (e.g., PXD records and discrete water-level measurements) in the three wells were obtained from BN and have been evaluated (Figure 2-44). The PXDs used for water-level monitoring at the facility are removed for quarterly water-level measurements and semiannual sampling events. BN has indicated that the cables used to suspend the PXDs may be undergoing some amount of uncoiling over time. This may be recognized in the obtained records as prolonged, but limited, rises in the water levels over time. A PXD was installed in each of the three PWs on April 2, 2001. They were removed for a sampling event on May 20, 2001, with the subsequent reinstallation completed on May 30, 2001.



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

mBar - Millibars
JDate - Julian Date
DRI - Desert Research Institute

Figure 2-43
Barometric Pressure and PXD Pressure in TW-3 During the MWAT and Recovery



RWMS - Radioactive waste management site
BN - Bechtel Nevada
PW - Pilot well

ft - Feet
mBar - Millibars

Figure 2-44
Water Level Records from RWMS Pilot Wells

3.0 Interpretation of Hydraulic Testing

The methods of data collection and the hydraulic responses were presented in Section 2.0. The current section presents the quantitative interpretation of the hydraulic response.

3.1 Vertical Hydraulic Head Measurements

Wireline tags of water levels in Well ER-5-3, Well ER-5-3#2, Well ER-5-3#3, and the shallow and deep piezometers of Well ER-5-3 were presented in Table 2-5. Head values used for the estimation of vertical hydraulic gradients can be obtained in two different ways. Average heads can be compared, determined as the average value of all available data for each well or piezometer. Alternatively, measurements recorded on the same day (September 6, 2001) can be compared (Table 3-1).

Table 3-1
Water Levels in the Completion Zones of Well Cluster ER-5-3

Completion Interval	Average Water Level Elevation (m amsl)	Water Level Measured on 9/6/2001 (m amsl)
Shallow Piezometer ER-5-3	734.55	734.53
Upper Completion ER-5-3	734.43	734.55
Deep Piezometer ER-5-3	734.34	734.24
Lower Completion ER-5-3 (composite level)	734.40	no measurement
ER-5-3#3	734.52	734.53
ER-5-3#2	724.99	724.14

In Well ER-5-3, a bridge plug was installed to separate the two completion zones at two different periods of testing. Seven water-level measurements representative of the upper completion zone were recorded with the bridge plug installed. Two water-level measurements representative of the composite well head were recorded without the bridge plug installed. Borehole flowmeter logging in the well during testing indicated that more than 96 percent, and as much as 99 percent, of the water produced from the well came from the lower slotted interval. Therefore, it is reasonable to conclude that the composite water-level response is dominated by, and representative of, the lower completion interval head alone.

Observation of both the average and date-specific measurements show that there is a net downward vertical gradient within the alluvium, that extends into the underlying volcanic units. However, the hydraulic head differences used in the analysis are not always consistent. The head differences between the shallow piezometer and the upper ER-5-3 completion (both completed in the OAA) range between -0.02 and 0.12 m. On average, the head is higher in the piezometer than in the completion. The slightly lower head observed in the piezometer on September 6, 2001, is within measurement error. The hydraulic head difference between the shallow piezometer (OAA) and deep piezometer (TMWTA with TCU layers) varies between 0.24 and 0.29 m, with the shallow piezometer having the higher head in all cases. A comparison of the deep piezometer and the composite ER-5-3 completion head, assumed to represent the lower slotted casing interval (TMWTA with TCU layers), results in a head difference of -0.06 m on average, and indicates an upward gradient. Because the head difference is based on average values, the calculated upward gradient may not be representative. No composite head measurement was recorded on September 6, 2001, at ER-5-3.

The vertical hydraulic gradient in the alluvium and underlying volcanic aquifers at the Well ER-5-3 site appears to be downward, although this observation is not always consistent. The magnitude of the gradient is dependent upon the distance between measurement points. Relative to the center of each slotted casing interval, the vertical hydraulic gradient through the alluvium and shallow volcanics at Well ER-5-3 varies between 6.8×10^{-4} and 8.3×10^{-4}.

Data from three shallow wells (UE5PW-1, UE5PW-2, and UE5PW-3) near the Radioactive Waste Management Site in Area 5 indicate that the horizontal gradient at the water table is approximately 2.3×10^{-4}, or about 0.23 m per kilometer (Shott et al., 1998). The vertical gradients presented above are 2 to 3 times larger than the horizontal gradient. Underlying the shallow alluvium and volcanic strata is the LCA. The hydraulic head in the LCA, as measured at Well ER-5-3#2, averages at approximately 724.99 m above sea level. Compared with the hydraulic head in the shallower units (between 734.3 and 734.6 m), head in the LCA is 9.3 to 9.6 m lower. The vertical distance between the deepest head measurement in the volcanic units and the LCA is about 703 m, and leads to a vertical gradient across the volcanic confining units of 1.3×10^{-2}, a magnitude that is just over one order of magnitude greater than the vertical gradient measured across the alluvium and into the shallow volcanic aquifers.

In summary, the vertical hydraulic gradient in the alluvial aquifer and volcanic aquifer system is about 2 to 3 times larger than the horizontal hydraulic gradient near the water table. The direction of the vertical hydraulic gradient is downward, but the magnitude is small.

The vertical hydraulic gradient between the shallow alluvial system and the underlying LCA is much larger than any gradient observed in the alluvium. The direction of the gradient across the volcanic confining unit is downward. The large vertical hydraulic gradient inferred to exist across the volcanic confining unit indicates that the confining unit is an effective barrier to flow.

3.2 Slug Testing in Piezometer Strings

Slug tests were conducted in three piezometers, two adjacent to Well ER-5-3 and one adjacent to Well ER-5-3#3. The tests in each piezometer are presented and interpreted separately.

3.2.1 Slug Test in the Shallow Piezometer

The shallow piezometer adjacent to Well ER-5-3 was completed in the BLFA and the alluvium with a slotted interval from 289.4 to 313.4 m (949.4 to 1,028.1 ft) bgs (Figure 1-3). The water table is at about 282.5 m (927 ft) bgs, so the open interval is completely saturated. The gravel interval extends from 282.5 to 308.5 m (927 to 1,012 ft) bgs, and the overlying and underlying 20/40 and 6/9 sand, extends from 274.3 to 329.2 m (900 to 1,080 ft) bgs. The piezometer is constructed in the ER-5-3 annulus between the 0.47 m (18.5 in.) diameter borehole and the 0.34 m (13.375 in.) casing that extends past the depth of the piezometer to a depth of 381 m (1,250 ft).

To verify that the piezometer was in communication with the shallow aquifer, a slug of 0.0189 m^3 (5 gallons) of water was poured into the piezometer on March 13, 2001. The well response, as measured by a PXD in the well, is provided in Figure 2-4. The measured initial rise in the water level is 0.39 m (1.28 ft; 0.558 psi) with a pressure decline to ambient over a period of about 30 minutes. The analysis of the water level response was performed with the code AQTESOLV ™ (Version 2.13 - Professional edition). Table 3-2 contains specific parameters used in the analysis of the water-level response.

The majority of parameters are self explanatory, with the exception of the effective wellbore radius. The pipe inside diameter is 0.062 m (2.44 in.), so the 0.0189 m^3 (5 gallons) of water could have raised the water level in the pipe as much as 6.25 m (20.5 ft). The observed 0.39 m (1.28 ft) rise suggests that much of the slug of water exited the well screen and entered the gravel pack. This piezometer was placed in the annulus between a 0.34 m (13.375 in.) outside diameter (OD) casing and the 0.47 m (18.5 in.) borehole. The radius is as small as 0.033 m (0.1068 ft) if annulus between the 0.47 m (18.5 in.) borehole and the 0.34 m (13.375 in.) casing is assumed to be an effective borehole diameter. However, this is incorrect because the gravel pack surrounds the casing. If the area of the annulus is used, the effective diameter becomes 0.092 m (0.3005 ft). This effective diameter should have produced a 2.06 m (6.73 ft) rise in water level when 0.0189 m^3 (5 gallons) of water was added assuming 35 percent porosity of the gravel. This water-level rise is more than 5 times larger than the water-level rise observed. If the observed water-level rise of 0.39 m (1.28 ft) is used, the volume of water in the annulus and casing is only 0.0048 m^3 (1.26 gallons). The test required about 15 minutes for the water level to recover 90 percent of the original head, so it seems unlikely that 0.014 m^3 (3.7 gallons) of water was lost into the formation almost instantaneously when the water was added. Rather, it would appear that the area of the annulus is larger than calculated. If the borehole diameter was nominally 0.53 m (21 in.), instead of 0.47 (18.5 in.), the observed head rise of 0.39 m (1.28 ft) would be consistent with storage of water in the

Table 3-2
Parameters for the Interpretation of the Slug Test in the Shallow PZ of Well ER-5-3

Parameter Name	Parameter Value	Source of Parameter
Saturated Thickness	349 m (1,128 ft)	Depth of saturated alluvium 626.4 to 282.5 m (2,055 to 927 ft)
Length of Well Screen	19.1 m (62.6 ft)	Equal to the slotted interval from the top of screen to the bottom of the gravel; entire screen interval is 25.6 m (78.7 ft), with a portion in sand pack; the saturated gravel pack is 25.9 m (85 ft) thick, or 46.6 m (153 ft), if the sand pack is included
Depth of Penetration	25.9 m (85.0 ft)	Equal to distance from water table to the bottom of the gravel; 30.8 m (101.1 ft) if the bottom of screen is used, and 46.6 m (153 ft) if the bottom of the sand pack is used
Inside Radius of Well	0.031 m (0.1017 ft)	0.062-m (2.442-in.) inside diameter casing
Well Bore Radius (effective)	0.206 m (0.675 ft)	Based on the initial rise of water when 0.0189 m^3 (5 gallons) was added, assuming a porosity of 35 percent for the gravel.
Gravel Pack Porosity	35 percent	Professional Judgement
Initial Displacement	0.39 m (1.29 ft)	Measured from initial water level to the highest point

gravel with a porosity of 35 percent. It seems possible that the hole could have been slightly larger than the nominal diameter of 0.47 m (18.5 in.) in the vicinity of the water table. For the purposes of interpretation, the larger borehole diameter is used which leads to the effective radius of 0.206 m (0.675 ft).

The Bouwer and Rice method (Bouwer and Rice, 1976; Bouwer, 1989) was used to interpret the data. The solution applies to unconfined aquifers, partially penetrating wells, and anisotropy. Application of the Bouwer and Rice solution uses their recommendation that the casing radius be expanded to include the porosity of the gravel pack if it appears that the water storage in the gravel pack acts as if it were a portion of the well. This assumption appears valid because of the observed storage of the initial pulse of water outside of the piezometer casing. The well radius is recorded as 0.031 m (0.1017 ft), but the porosity of the wellbore is also included in the calculation of the effective casing radius. An example of the fit of the method to the data is given in Figure 3-1. An unknown in the application of the method is the effective screen length which can vary from 19.1 to 46.6 m (62.6 to 153 ft) depending on how much of the gravel and sand pack is included. Additionally, the correction proposed by Zlotnik (1994), as noted by Duffield (1998), for anisotropy (ratio of vertical to horizontal hydraulic conductivity) is also unknown. Values of anisotropy ranging from 1 to 0.01 were used to determine a range of values. Using the Bouwer and Rice method, with anisotropy and open interval varying, produced a range of hydraulic conductivity (K) values from 0.18 to 0.64 m/day (0.6 to 2.1 ft/day).

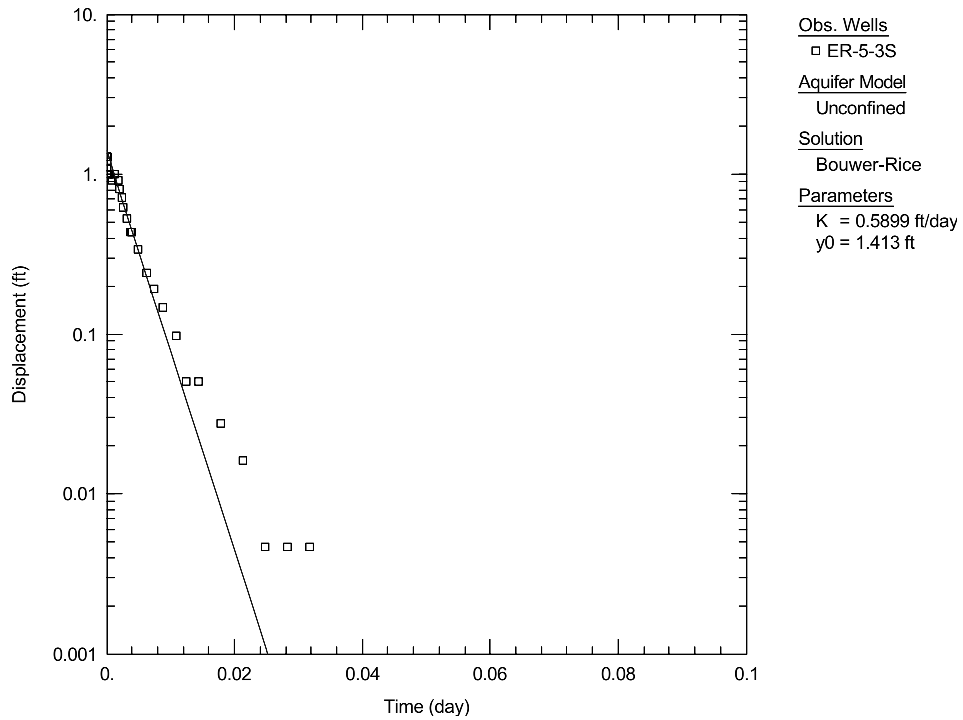


Figure 3-1
Fit of the Bouwer and Rice Solution to the Slug Test in the Shallow PZ adjacent to ER-5-3

In summary, the slug test on the shallow piezometer adjacent to Well ER-5-3 was performed to show a hydraulic connection between the piezometer and the aquifer. The fit of the Bouwer and Rice type curve to the hydraulic response data is shown in Figure 3-2. Analysis of the slug test data produced hydraulic conductivity values ranging from 0.18 to 0.64 m/day (0.6 to 2.1 ft/day). These values are in the same range as hydraulic conductivity values reported in IT (1999) for other measurements in the alluvium of Frenchman Flat. The reader should keep in mind that the purpose of this slug test was to demonstrate hydraulic connection and that a number of assumptions were made to complete the interpretation. These values should be considered approximate and may not be representative of large regions of the aquifer.

3.2.2 Slug Test in the Deep Piezometer of Well ER-5-3

On March 2, 2001, slug testing was performed in the deep piezometer adjacent to Well ER-5-3. This piezometer is set between the two main completion intervals of Well ER-5-3 (Figure 1-3) and is screened between depths of 637.0 to 667.5 m (2,090.0 and 2,189.9 ft). The piezometer is screened in the upper portion of the partially to densely welded TMWTA (Figure 1-3). This stratigraphic unit is

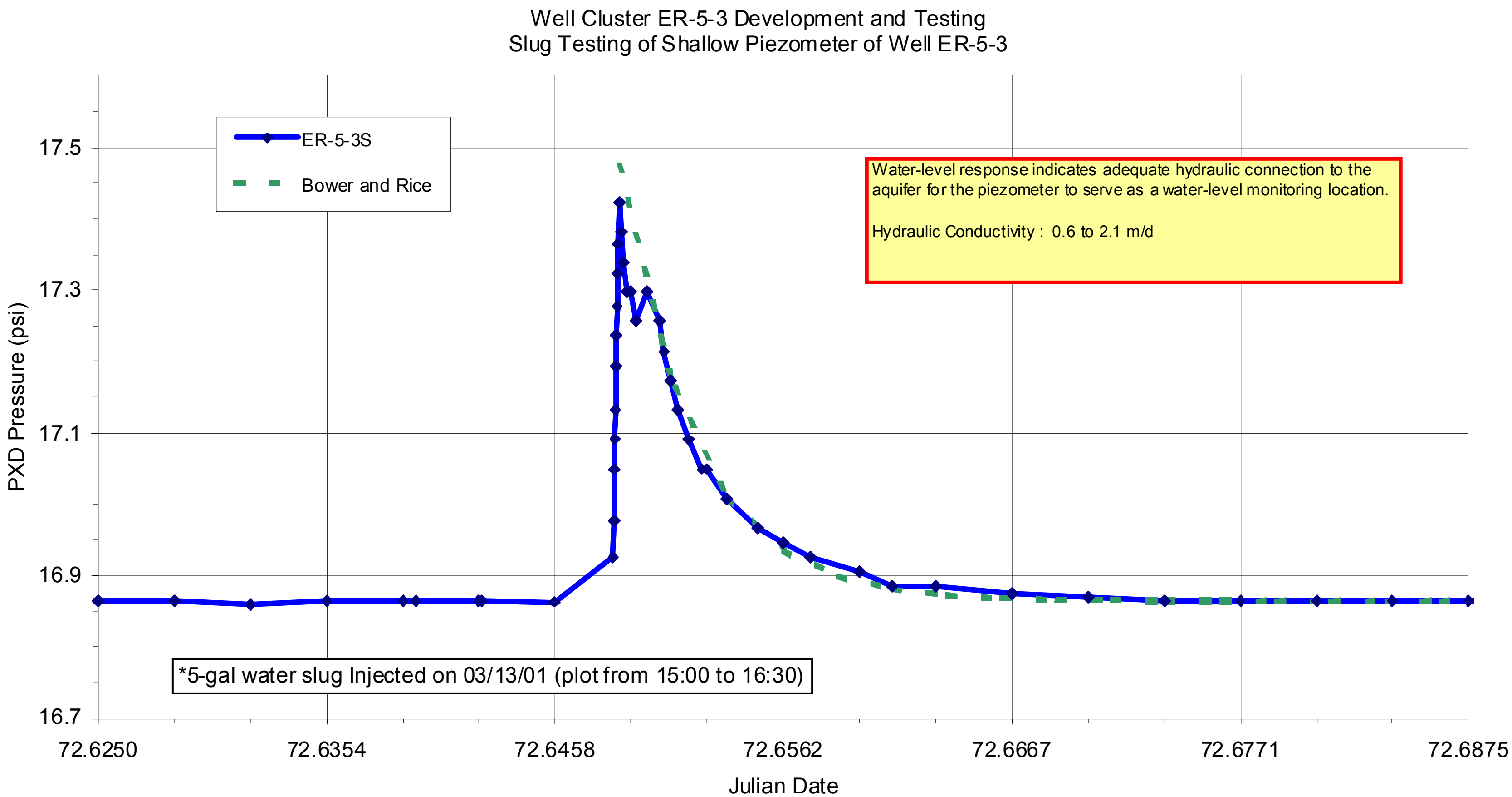


Figure 3-2
Comparison of Model Results and Measured Data from the Slug Test in the Shallow PZ of Well ER-5-3

located slightly below the base of the alluvial aquifer and above the bedded portion of the TCU, which is considered to be a confining unit.

The purpose of the slug testing in the deep piezometer adjacent to Well ER-5-3 was to verify that the piezometer was in hydraulic communication with the aquifer. Three slug tests were performed, two tests with inflow to the well (slug removal), and one with outflow (slug input). A cylinder, 0.045 m (1.79 in.) in diameter and 1.22 m (4 ft) long, was attached to the wireline about 0.97 m (38 in.) above the transducer. This slug displaces about 0.002 m^3 (0.0705 ft^3), or about 0.53 gallons. Therefore, this slug is much smaller that the one used in the shallow piezometer. The slug volume is sufficiently small that the formation may not have been tested. For example, a 0.53 gal slug would fill a 100-ft annulus (equal to the length of the deep piezometer slotted casing interval) that is only 0.023-in. thick. This assertion is addressed later in the text. The method of slugging the well is also different from that performed in the shallow piezometer. In the deep piezometer, the transducer and slug were lowered below the SWL and the water level allowed to equilibrate. Then, the slug was quickly removed, leaving the transducer beneath the water level. The recovery of the well back to the static position was recorded. Then the slug is dropped 2.13 m (7 ft) back into the water and the recovery to static was recorded. A third test, identical to the first was performed before the entire unit was removed from the well. All three of these tests are interpreted.

Table 3-3 provides the specific parameters for the interpretation of the slug tests.

Two methods of interpretation were applied to this situation, the Bouwer and Rice (1976) and Cooper et al. (1967) methods. Because of the small displacement, it is not clear how representative these interpretations will be for the TMWTA. Nonetheless, these interpretations provide insight into the range of values.

Several uncertainties are present in this analysis. The completion interval may be as small as the screened length of about 30.4 m (100 ft), or as large as the entire sand and gravel packed region of 73.2 m (240 ft). However, this uncertainty is deemed negligible by the small volume slug. A 0.53 gal slug would fill a 0.023-in.-thick open annulus of length 100 ft; therefore, the area tested is within the gravel pack regardless of the assumed length of the completion interval. Further, the anisotropy ratio is unknown. An estimate of 1.0 is used for the Bouwer and Rice analysis. The Cooper et al. method assumes horizontal flow, or a vertical hydraulic conductivity of zero; therefore, a comparison of results between the two methods addresses anisotropy uncertainty. A third uncertainty is the nature of the alluvial aquifer above the TMWTA. If it is assumed that the strata are hydraulically connected, the apparent aquifer thickness is much larger than if the TMWTA is isolated from the alluvium.

For the Bouwer and Rice interpretations, two different sets of interpretations were attempted, one with the aquifer thickness represented by only the TMWTA, and the other including the alluvium. The Bouwer and Rice interpretation assumes that the effective casing calculation is not necessary because the gravel pack is fully saturated. An example of the Bouwer and Rice fit to the data is given in Figure 3-3 which shows the fit to slug test #3.

Table 3-3
Parameters for the Interpretation of the Slug Tests in the Deep PZ of Well ER-5-3

Parameter Name	Parameter Value	Parameter Source
Saturated Thickness	77.7 m (255 ft)	Thickness of the TMWTA; if the Alluvium is included, the thickness becomes 422 m (1,383 ft)
Length of Well Screen	30.4 m (100 ft)	Slotted interval; the length of the gravel and sand packs is 73.2 m (240 ft); if the gravel pack up to the base of the alluvium is used, the thickness is 54.9 m (180 ft)
Depth of Penetration	41.1 m (134.9 ft)	Base of the alluvium to the bottom of the screen; 54.9 m (180 ft) if the bottom of the gravel is chosen; maximum is 422 m (1,383 ft) if the saturated thickness of the alluvium is included
Inside Radius of Well	0.031 m (0.1017 ft)	0.062 m (2.441 in.) inside diameter
Well Bore Radius (effective)	0.139 m (0.456 ft)	Based on the annual space between the 0.31 m (12.25 in.) borehole and the 0.14 m (5.5 in.) diameter casing of the main tubing string
Gravel Pack Porosity	35 percent	Professional Judgement
Initial Displacement	0.84 m (2.74 ft) slug #1; 0.90 m (2.94 ft) slug #2; 1.01 m (3.33 ft) slug #3	Measured as the greatest departure from the recovery curve to the initial value

For the Cooper et al. interpretation, which assumes a fully penetrating well in a confined aquifer, it is assumed that the screened open interval is the same as the aquifer thickness. Because the well-test interval is in actuality partially penetrating, there are likely vertical flow components that serve to increase the rate at which recovery occurs in the piezometer. This has the effect of overestimating the interval transmissivity; however, the resultant uncertainty is not assessed because more significant sources of uncertainty (reported above) dominate the effect of partial penetration. The fit to the data is provided in Figure 3-4.

Table 3-4 summarizes the hydraulic conductivity interpreted from the two analysis methods. Across the two methods, the range of values is quite small, from 0.04 to 0.23 m/day (0.13 to 0.75 ft/day). The result of the Cooper et al. (1967) analysis is typically about twice that of the Bouwer and Rice approach. Figure 3-5 is a plot showing the Cooper et al. (1967) fit to the data. The difference in aquifer thickness makes little difference in the calculated hydraulic conductivity. The reader is again cautioned that these measurements were performed with a small slug of water, about 0.002 m^3 (0.5 gallon) in a piezometer with at least 30.5 m (100 ft) of open interval. In addition, the well had minimal development prior to testing. It is highly probable that these parameter values represent the permeability of the disturbed zone around the wellbore and are not representative of the TMWTA aquifer at all.

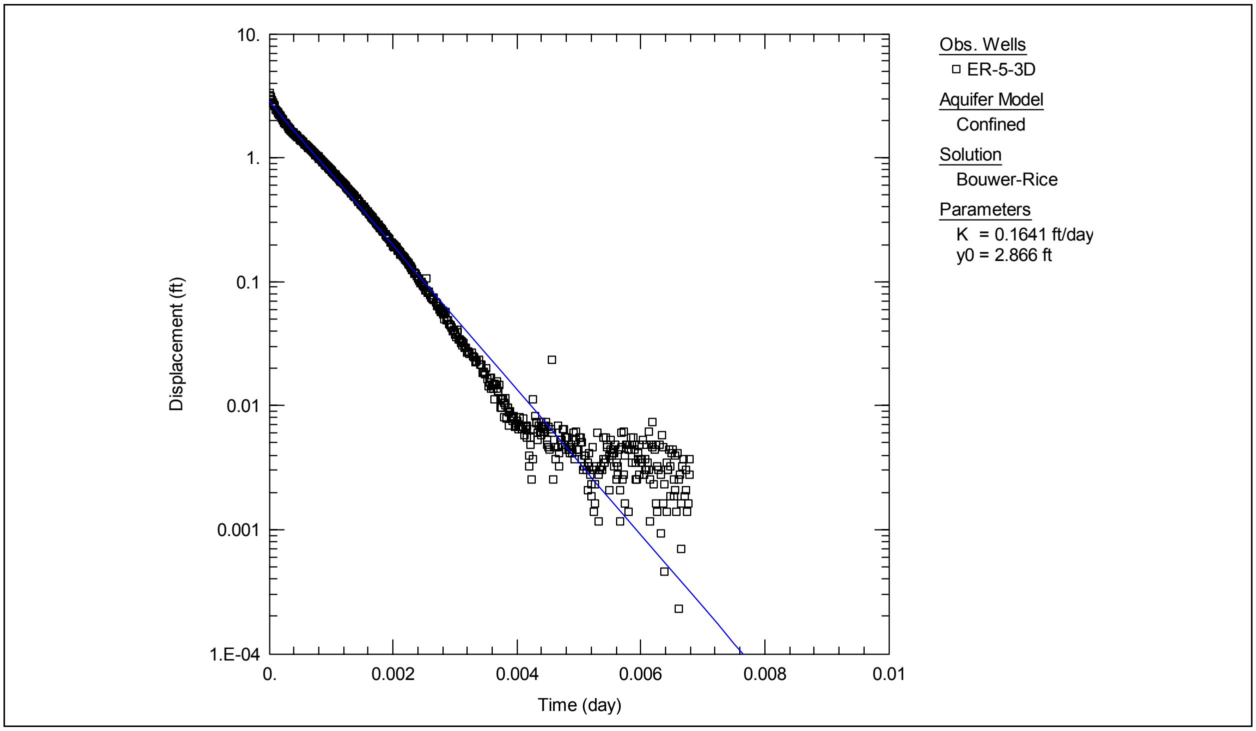


Figure 3-3
Fit for the Bouwer and Rice Solution to one of the Slug Tests in the Deep PZ of Well ER-5-3

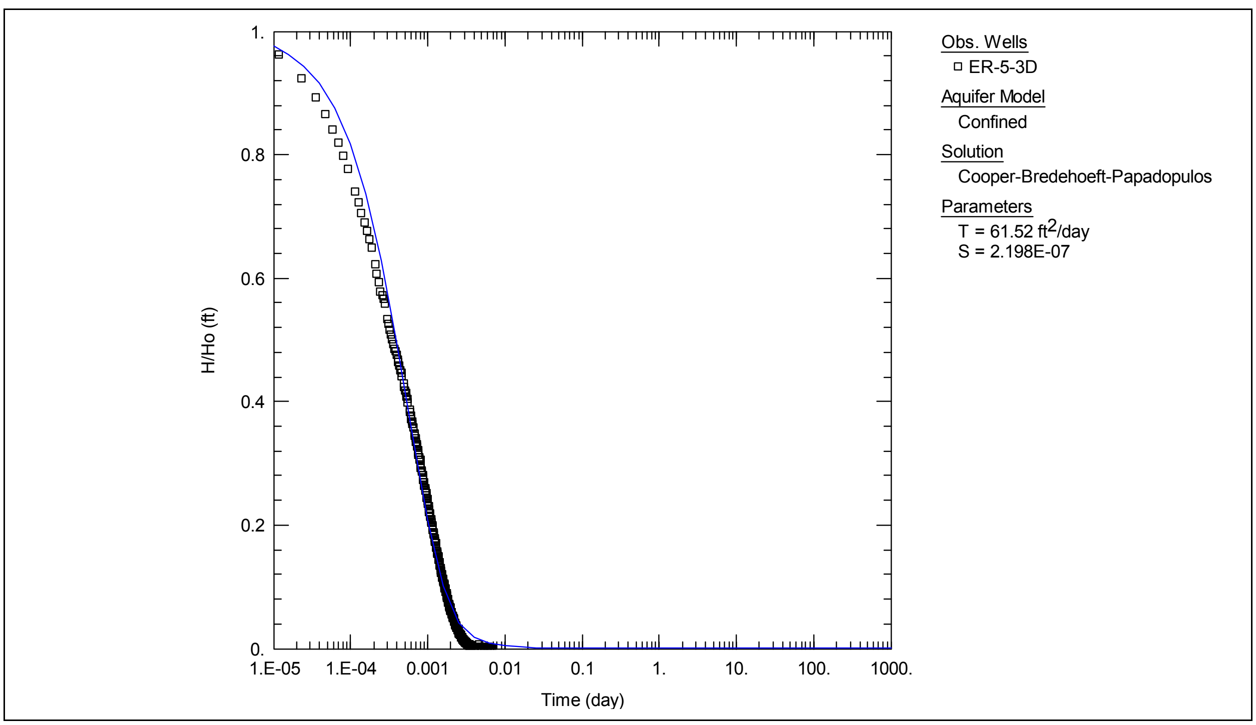


Figure 3-4
Fit of the Cooper et al. Solution to one of the Slug Tests in the Deep PZ of Well ER-5-3

Table 3-4
Calculated Hydraulic Conductivity Values from the Slug Tests in the Deep PZ of Well ER-5-3

Parameter Set	Slug Test #1 K (m/day)	Slug Test #2 K (m/day)	Slug Test #3 K (m/day)
Bouwer and Rice			
Thickness = 77.7 m (255 ft)			
Open interval = 30.4 m (100 ft)	0.098	0.11	0.12
Open interval = 73.2 m (240 ft)	0.04	0.05	0.05
Thickness = 422 m (1,383 ft)			
Open interval = 30.4 m (100 ft)	0.09	0.10	0.11
Open interval = 73.2 m (240 ft)	0.04	0.05	0.05
Cooper et al.			
Open interval = 30.4 m (100 ft)	0.20	0.23	0.19
Open interval = 73.2 m (240 ft)	0.08	0.09	0.08

3.2.3 Slug Tests in Well ER-5-3#3

The third well in the ER-5-3 cluster is #3, a piezometer completed across approximately the same depth interval in the OAA as the upper completion in the production string of Well ER-5-3. The 0.073 m (2 7/8 in.) OD string was installed in a 0.25 m (9 7/8 in.) borehole (Figure 1-5). The completion interval is gravel packed over 103 m (339 ft), with the open interval of the screen covering 77 m (252 ft). Table 3-5 contains the specific parameters for the interpretation of the slug tests in piezometer ER-5-3#3. The results of the slug test analyses on piezometer ER-5-3#3 are given in Table 3-5.

Figure 3-6 is an example of the fit to the data of the Bouwer and Rice (1967) method. Figure 3-7 is the fit using the Cooper et al. (1967) method. The results for the ER-5-3#3 slug tests are similar to each other and are about one order of magnitude smaller than the values from the shallow piezometer adjacent to Well ER-5-3. As with the analysis of the deep piezometer adjacent to Well ER-5-3, the slug of water actually moved during this test was 0.002 m^3 (approximately 0.5 gallon). The hydraulic response may be representative of the disturbed zone around the wellbore and may, therefore, not be representative of the formation as a whole. The reader is cautioned to be careful in extrapolating these results to large areas of the alluvial aquifer. Figure 3-8 is a plot of the first three slug tests with the corresponding Cooper et al. (1967) fit.

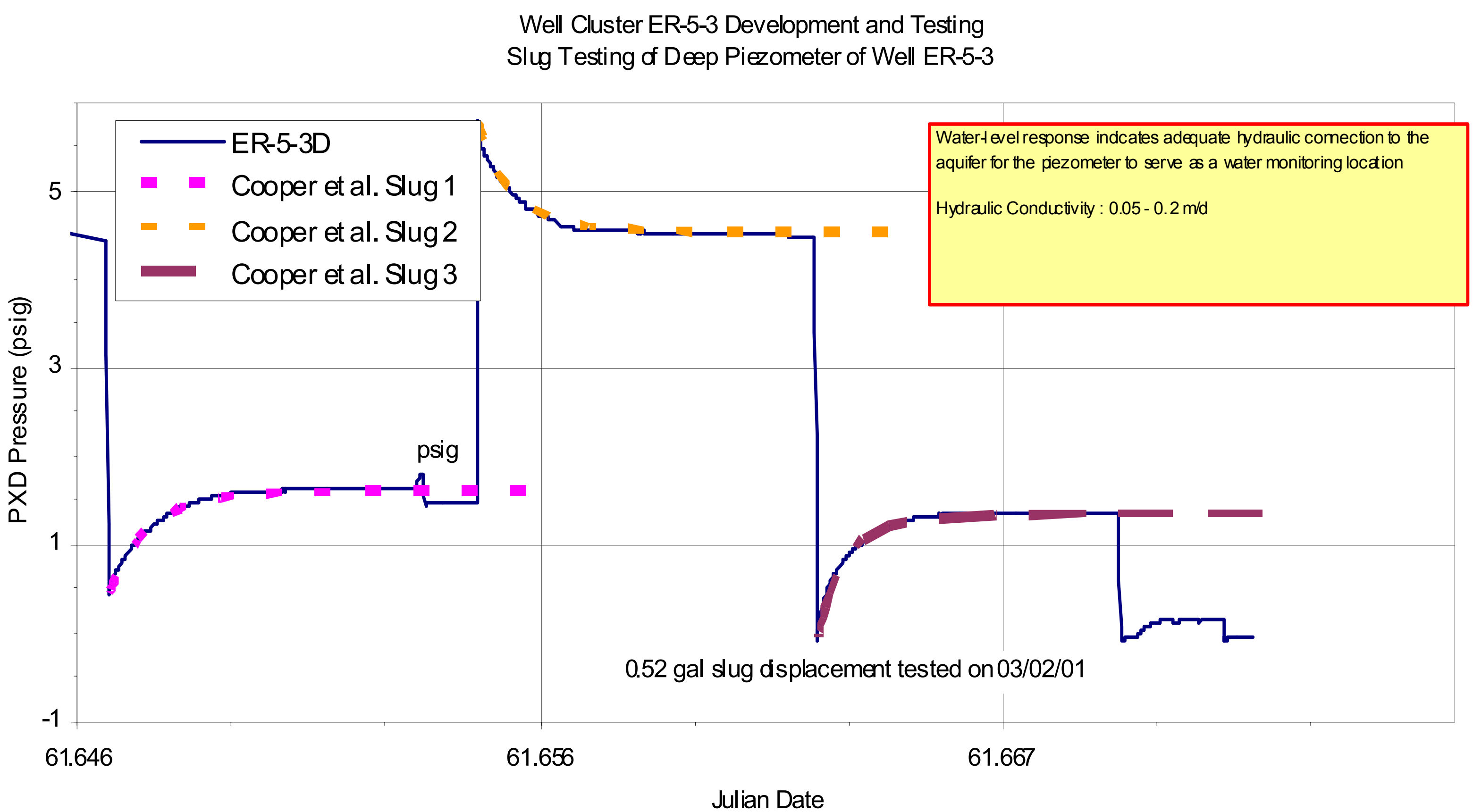


Figure 3-5
Comparison of Model Results and Measured Data from the Slug Tests in the Deep PZ Adjacent to Well ER-5-3

Table 3-5
Calculated Hydraulic Conductivity Values from the Slug Tests in Well ER-5-3#3

Parameter	Slug Test #1 K (m/day)	Slug Test #2 K (m/day)	Slug Test #3 K (m/day)	Slug Test #4 K (m/day)	Slug Test #5 K (m/day)
Bouwer and Rice					
Open Interval = 76.8 m (252 ft)	0.04	0.04	0.04	0.04	0.04
Open Interval = 116.7 m (383 ft)				0.02	0.03
Cooper et al					
Open Interval = 76.8 m (252 ft)	0.08	0.08	0.09	0.08	0.08
Open Interval = 116.7 m (383 ft)	0.05	0.05	0.06	0.05	0.05

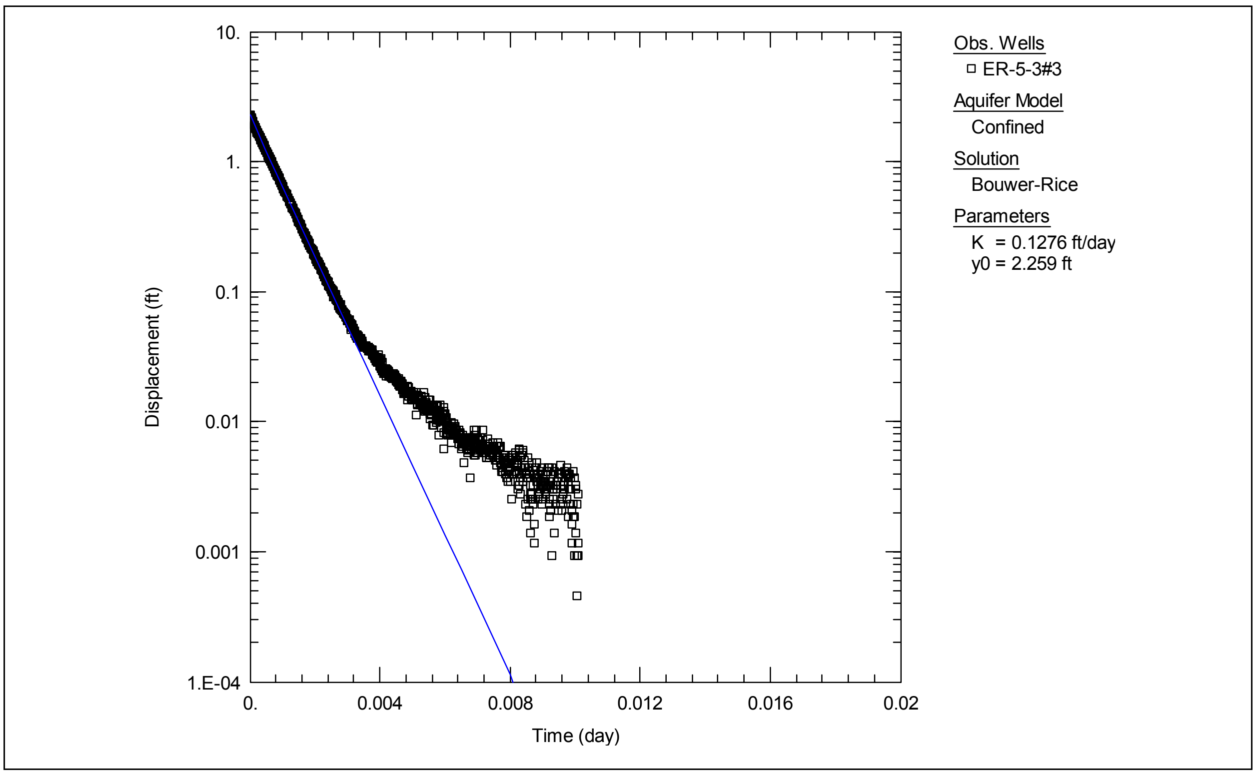


Figure 3-6
Fit of the Bouwer and Rice Solution to one of the Slug Tests in Well ER-5-3#3

3.3 Step-Drawdown Tests in ER-5-3

The step drawdown tests performed in Well ER-5-3 provide a measure of the efficiency of the well for pumping and provide estimates of K that are of larger scale than the slug tests which measure only the region immediately outside the well, if that. The step drawdown is performed by pumping at different discharge rates for a period of one hour for each rate. The pumping rate is increased each

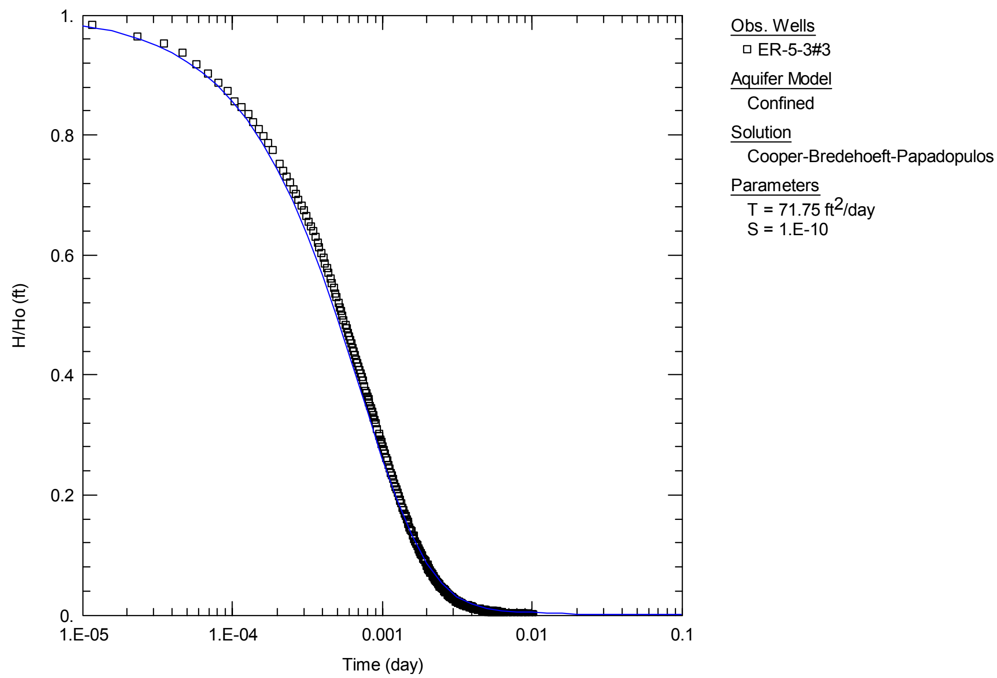


Figure 3-7
Fit of the Cooper et al. Solution to one of the Slug Tests in Well ER-5-3#3

time in a stepwise manner until the maximum discharge rate for the pump is reached. The results are interpreted using the Theis step test analysis option in AQTESOLV™. The primary output of the test is an estimate of the linear and nonlinear head loss components of the drawdown response. As has been observed, the drop in water level with increasing pumping is larger than would be expected from linear resistance to flow in the aquifer. Turbulent head losses, both in the well and the near well environment (e.g., the gravel pack and even near-well fractures) increase with the square of the pumping rate. Some researchers allow the exponent on the turbulent losses to be as large as 3. However, for this analysis, the exponent was fixed at 2.

During the testing of Well ER-5-3, both completion intervals were open and contributing water. Flow logging during pumping conducted by DRI indicates that 97 to 100 percent of the water produced by the well comes from the deeper completion in the TMWTA (see Section 3.4 below). Therefore, for the purposes of this analysis, the interpretation of the step-drawdown test in Well ER-5-3 is assumed to apply completely, and only to the Timber Mountain HSU. Two separate step-drawdown tests were performed, with each test consisting of four steps. The nominal pumping rates for both tests were 90, 120, 150, and 168 gpm. During each step, the drawdown generally stabilized at a constant value. As noted in Section 2.2, the two sets of step drawdown measurements produced nearly identical results. Both sets of curves were interpreted to provide estimates of the linear and turbulent well losses as well as to estimate the hydraulic conductivity of the Timber Mountain welded tuff.

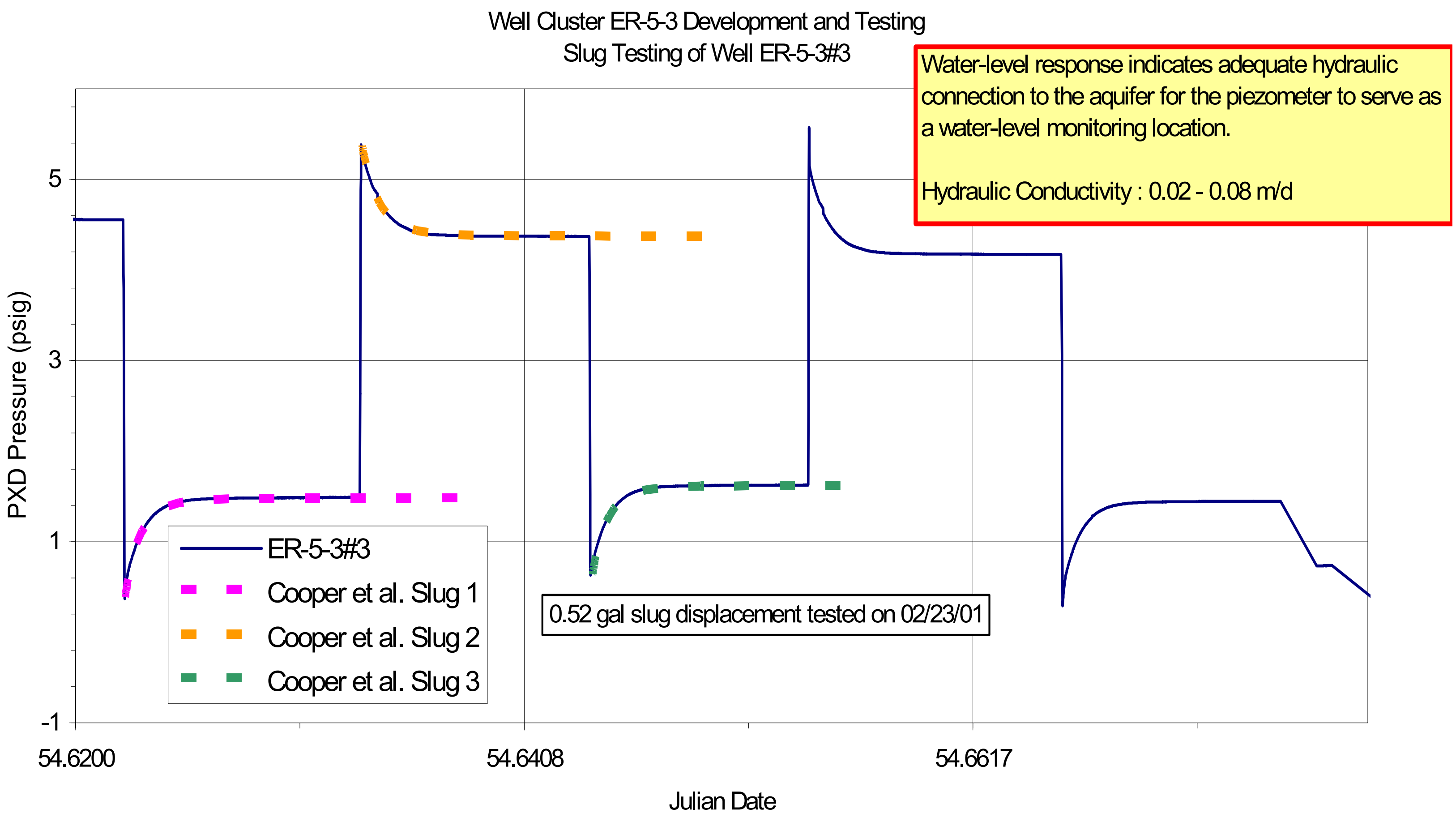


Figure 3-8
Comparison of Model Results and Measured Data for the Slug Tests in Well ER-5-3#3

The analysis was conducted in two steps. First, the drawdown for each pumping rate was recorded, and the specific capacity, defined as the drawdown divided by the pumping rate was determined for each rate. Then a regression was performed to determine the magnitude of the coefficient that describes turbulent losses.

The equation for drawdown with nonlinear well losses is given as:

$$S_W = BQ_n + CQ_n^2$$

where

S_w = The drawdown in the well
Q_n = The pumping rate of step n
B = The linear coefficient
C = The non-linear coefficient

Dividing both sides of the equation by Q_n produces a linear equation suitable for linear regression. Table 3-6 contains the data used to perform the regression.

Table 3-6
Drawdown and Pumpage for the Step Drawdown Test in Well ER-5-3

Sw (m)	Q (m³/day)	Sw / Q (day/m²)	B (day/m²)	C (day²/m⁵)
Step Test #1			0.00182	3.72e-06
1.78 (5.85 ft)	492 (90.1 gpm)	0.00362		
2.82 (9.27 ft)	655 (119.9 gpm)	0.00431		
4.00 (13.11 ft)	818 (149.7 gpm)	0.00488		
4.79 (15.71 ft)	920 (168.3 gpm)	0.00521		
Step Test #2			0.00196	3.17e-06
1.70 (5.57 ft)	492 (90.0 gpm)	0.00346		
2.62 (8.60 ft)	646 (118.2 gpm)	0.00406		
3.71 (12.18 ft)	804 (147.1 gpm)	0.00462		
4.39 (14.41 ft)	920 (168.3 gpm)	0.00478		

Both step drawdown tests yield similar parameter values. For the two step drawdown tests, the turbulent coefficient varied between 3.17×10^{-6} and 3.72×10^{-6} day²/m⁵. The linear coefficient is 0.00182 to 0.00120 day/m². Using these parameters, the drawdown attributable to the linear and nonlinear losses for each pumping rate can be calculated. Table 3-7 summarizes the linear and the turbulent components of the observed drawdown. The nonlinear losses are about the same as the linear losses at the low flow rates, but at the highest flow rate, the nonlinear losses are as much as twice as large as the linear losses. The large turbulent losses may be related to the length of the completion pipe, the relatively small completion interval in the TMWTA, and possibly flow in fractures immediately outside the well.

Table 3-7
Calculated Linear and Turbulent Well Losses in Well ER-5-3

Flowrate (m^3/day)	Calculated Drawdown from Linear Losses (m)	Calculated Drawdown from Nonlinear Losses (m)	Total Calculated Drawdown (m)	Measured Drawdown (m)
Step Test #1				
492 (90.1 gpm)	0.90 (2.94 ft)	0.90 (2.96 ft)	1.80 (5.90 ft)	1.78 (5.85 ft)
655 (199.9 gpm)	1.19 (3.92 ft)	1.60 (5.24 ft)	2.79 (9.16 ft)	2.83 (9.27 ft)
818 (149.7 gpm)	1.49 (4.89 ft)	2.49 (8.17 ft)	3.98 (13.06 ft)	4.00 (13.11 ft)
920 (168.3 gpm)	1.67 (5.49 ft)	3.14 (10.32 ft)	4.82 (15.81 ft)	4.79 (15.71 ft)
Step Test #2				
492 (90.0 gpm)	0.96 (3.16 ft)	0.77 (2.51 ft)	1.73 (5.67 ft)	1.70 (5.57 ft)
646 (118.2 gpm)	1.27 (4.15 ft)	1.32 (4.34 ft)	2.59 (8.49 ft)	2.62 (8.60 ft)
804 (147.1 gpm)	1.57 (5.17 ft)	2.05 (6.72 ft)	3.62 (11.89 ft)	3.71 (12.18 ft)
920 (168.3 gpm)	1.80 (5.91 ft)	2.68 (8.80 ft)	4.48 (14.71 ft)	4.39 (14.41 ft)

The interpretation of the step drawdown test for hydraulic conductivity required several assumptions. First, it is assumed that the aquifer thickness is restricted to the TMWTA. The upper TMWTA, above a distinct TCU stratum, is included based on the deep piezometer (Figure 3-9) which shows a response (about 0.1 psi) to pumping in the main string of Well ER-5-3. The much larger permeability of the TMWTA, compared with the overlying alluvium, and coupled with the relatively short duration of the step drawdown tests, suggests that only the highly permeable volcanics participated in the flow. The depth interval of the aquifer is 626.4 to 850.4 m (2,055 to 2,790 ft). The bottom of the alluvium (at 626.4 m) is the top of the aquifer. The bottom of the aquifer, 850.4 m, was determined from the bottom of the TMWTA in Well ER-5-3#2, minus 1.52 m (5 ft) to account for dip of the formation. The tested interval is the gravel packed portion, 733.3 to 777.0 m (2,406 to 2,549 ft). Therefore, the tested interval is considered partially penetrating, with an assigned depth below the top of aquifer as 107.0 to 150.6 m (351 to 494 ft).

Figure 3-10 and Figure 3-11 are the fitted Theis Step Drawdown solutions determined using AQTESOLV™. Several items to notice in the figures are: (1) the fits to the drawdown are very good for each of the four steps for each test, (2) the final water level does not return to static because the code does not remove the nonlinear loss component which is about 9 to 10 feet. Table 3-8 contains the transmissivity and hydraulic conductivity values obtained from the step drawdown analysis. The value of transmissivity is somewhat sensitive to the storage coefficient chosen. For this analysis a value of 1.0×10^{-5} is used. The automatic fitting function in AQTESOLV tries to pick a value as small as possible, 1.0×10^{-30}. If allowed to do that, AQTESOLV calculates a transmissivity that is nearly double the value calculated with storage in a more reasonable range. Another uncertainty is the aquifer thickness to choose to calculate the hydraulic conductivity. If the full volcanic aquifer thickness is chosen 224 m (735 ft), the hydraulic conductivity is about 5 times smaller than if the gravel packed interval 42.7 m (140 ft) is used.

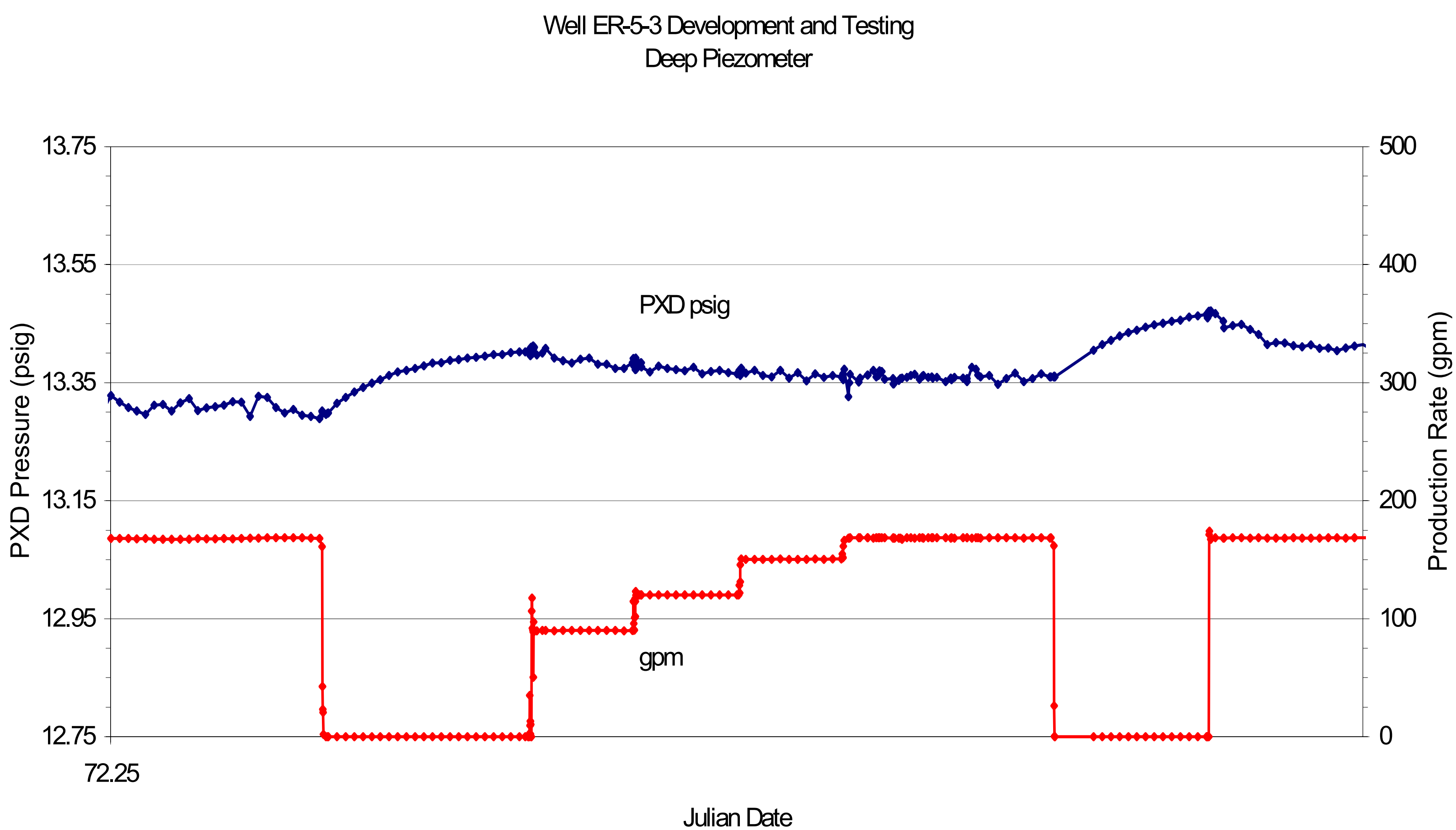


Figure 3-9
PXD Pressure in the Deep Piezometer of Well ER-5-3 During Pumping of Well ER-5-3

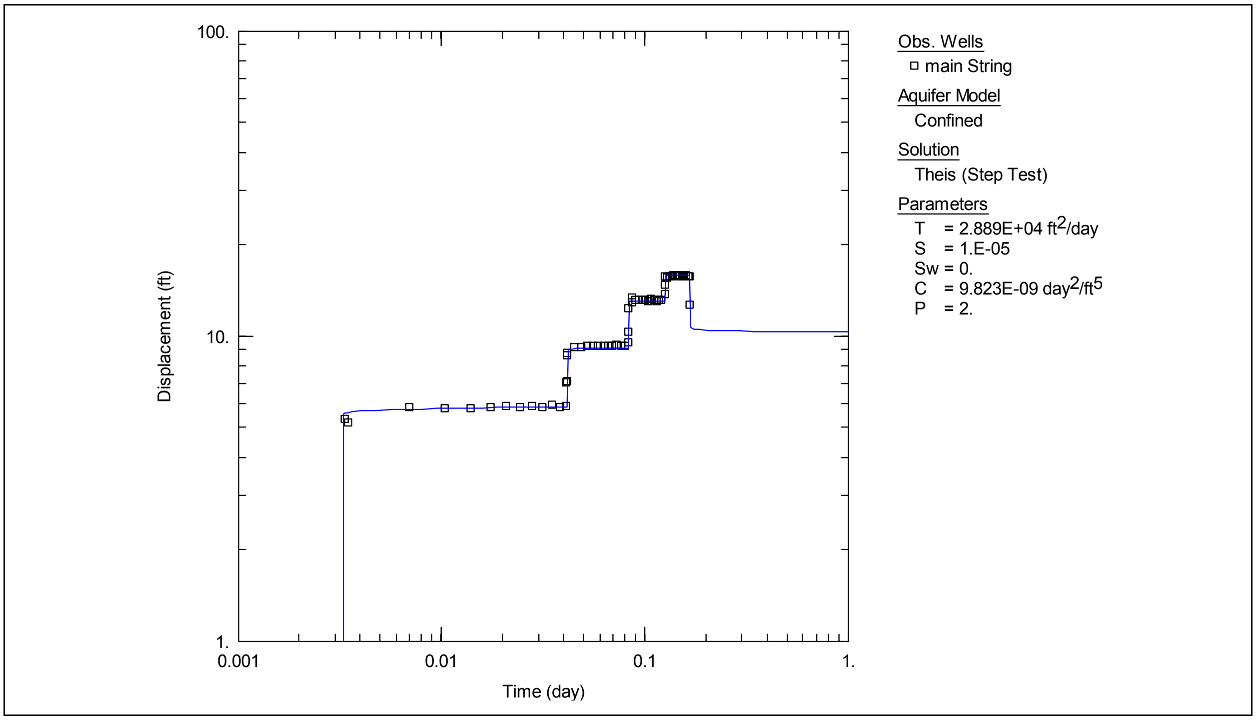


Figure 3-10
Fit of the Theis Step Drawdown Solution to the First Set of Step Drawdown Data From Well ER-5-3

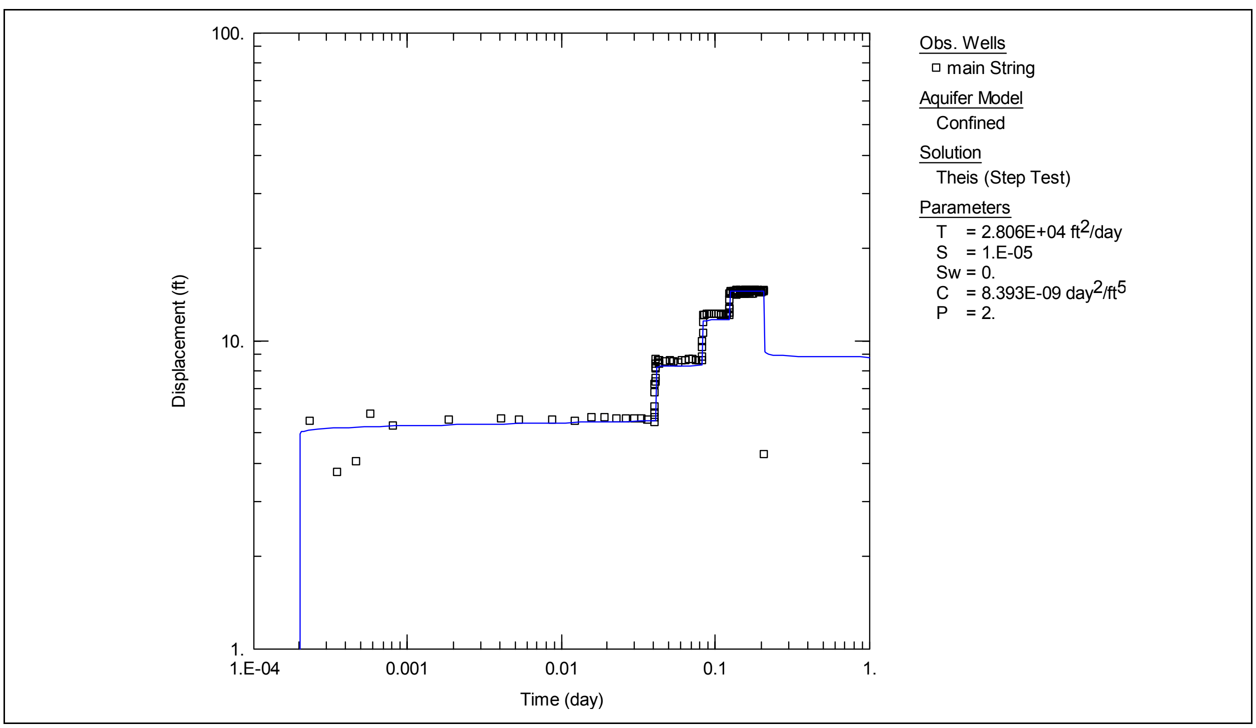


Figure 3-11
Fit of the Theis Step Drawdown Solution to the Second Set of Step Drawdown Data From Well ER-5-3

Both values are provided in Table 3-8. The hydraulic conductivity of the TMWTA is much larger than the alluvium. Figure 3-12 is a plot showing the modeled and measured data from step drawdown test #1.

Table 3-8
Hydraulic Parameters Obtained from the Interpretation of the Step Drawdown Test in Well ER-5-3

Test	Transmissivity (m^2/day)	Hydraulic Conductivity (m/day) (thickness 224 m)	Hydraulic Conductivity (m/day) (thickness 43.7 m)
Step #1	2,684 (28,890 ft^2/day)	12.0 (39.3 ft/day)	62.9 (206 ft/day)
Step #2	2,607 (28,060 ft^2/day)	11.6 (38.2 ft/day)	61.0 (200 ft/day)

3.4 Stressed and Ambient Flow Logging in ER-5-3

Stressed flow logging (logging while the well is under different rates of production) was conducted at the end of the development operations.

The resultant data provided valuable information on the distributions of wellbore flow under production rates of 90, 150, and 168 gpm.

The information from the stressed flow logging allows analysis of the hydraulic responses of different sections of the well including: inflow of water into the well, outflow of water from the well into the adjacent formation, and representativeness of the water-quality and groundwater characterization samples collected.

3.4.1 Optimal Flow Logging Run

The optimal configuration for stressed flow logging utilizing the full-bore spinner tool is considered the run conducted at trolled line-speed of 20 fpm in the downward direction. Based on field and data analysis experiences, this configuration maximizes sensitivity of the impeller while minimizing the effects of the line-speed on the natural flow within the well. This configuration is typically preferred for data analysis and hydraulic interpretations. Other configurations, such as 40 fpm-upward, are also useful for providing supplemental

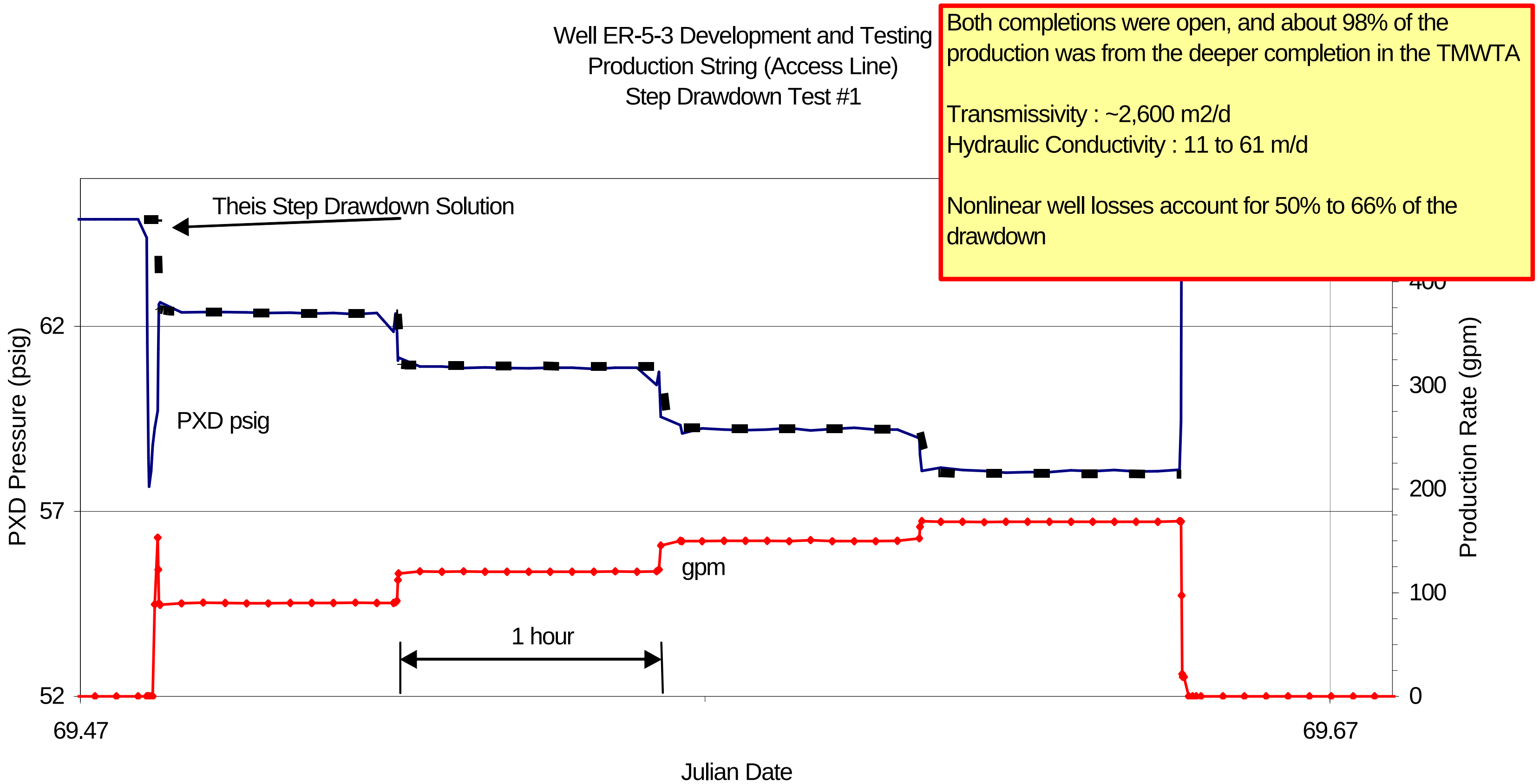


Figure 3-12
Comparison of Model Results and Measured Data from the First Step Drawdown Test in Well ER-5-3

data records. The mathematics behind the stressed flow logging with the spinner tool are 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 = The total rotation rate of the impeller at any depth
R_{ls} = The rotation rate of the impeller due to line speed
R_v = The rotation rate of the impeller due to natural 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 minimize the contribution of R_{ls} and maximize the response of R_v. This velocity is generally fast enough to overcome the stall speed of the full-bore spinner tool. The stall speed is the minimum velocity required to initiate impeller movement and prevent the impeller from stalling. At times the stall speed may be quite high if the spinner tool is moving with a strong opposing flow within the well. That is why the logging is performed at various line speeds and directions, so that the stall speed can be completely overcome in at least one of the logging runs.

3.4.2 Zones of Inflow

One of the stressed flow logs was presented in Figure 2-7. The remaining logs were very similar to Figure 2-7. The trolling logs indicate that 100 percent of the water production originated in the lower completion zone, 723 to 794 m (2,372 to 2,606 ft bgs), regardless of production rate. The stationary logs conducted while the well was under production varied slightly from the trolling logs. The stationary logs attributed 1.4 percent (at 168 gpm) to 3.1 percent (at 90 gpm) of the total flow to the upper completion zone. The conflict between the stationary and trolling logs is not significant, and these evaluations suggest that 97 to 100 percent of the total flow originates in the lower completion zone.

The logging data further indicate that of the flow originating from the lower completion zone, approximately 40 percent originates from the upper slotted section of this zone, 737.6 to 757.4 m (2,420 to 2,485 ft) bgs, while the remaining 60 percent originates from the lower slotted section, 757.4 to 777.2 m (2,485 to 2,550 ft) bgs. This spatial distribution is fairly consistent for the three production rates used during the stressed flow logging activities. The logs indicate that there is production throughout the lower interval, but that product is variable, reflecting heterogeneity in the formation.

A decrease in flow is notable in the entire upper screened interval (see Figure 2-7). The decreases range from approximately 8 gpm (at a production rate of 90 gpm) to about 16 gpm (at a production rate of 168 gpm). This represents between 8.9 and 9.5 percent of the total flow at these production rates, respectively. According to the stressed flow logs it appears that some amount of the upward flow is exiting the well and entering the gravel pack, then perhaps flowing parallel to the casing to finally reenter the well casing at the top of the screened interval. It is also possible that the changes in flow are not real, but simply an effect of turbulence or some other factor that is causing the spinner tool to give false readings through this section of the well.

3.4.3 Ambient Flow Logging

Flow logging under ambient conditions (no production) was conducted on April 10 and 11, 2001, after the recovery phase of the constant-rate test and before the bridge plug was set. Logging with the thermal flow meter (TFM) was only conducted in the upper part of the water column from 442 to 533 m (1,450 to 1,750 ft) due to electrical problems with the heat-pulse sensor. The five stations effectively overlapped the upper screened interval. The data record indicates no-flow above the upper screened interval, with slight downward flow (up to 0.25 gpm) from the top to the bottom of the upper slotted interval. TFM data from immediately below the upper screened interval shows slightly upward flow (0.21 gpm), suggesting flow from the lower completion zone into the upper completion zone. This indicates a potential water-loss zone in the lower part of the upper completion zone, with outflow from the well into the annulus or adjacent formation.

A full-bore spinner log was also conducted under ambient conditions (Figure 3-13). The data from the spinner log indicated downward flow from 283 to 436 m (930 to 1,430 ft) at somewhat substantial rates (2 to 5 gpm). The data further suggest slight downward flow between 451 and 527 m (1,480 and 1,730 ft). The spinner log data from this particular interval correlate quite well with the TFM data over the same interval. Much like the data from the TFM logging, the spinner log also indicates slight upward flow (<2 gpm) between 527 and 754 m (1,730 and 2,475 ft) (an interval separating the upper and lower completion zones). Overall, the data from the ambient spinner log substantiate the possible presence of a water-loss zone in the lower part of the upper completion zone. However, it is noted that the ambient flow log results are uncertain. Line speeds of approximately 30 ft/min were used to measured flow rates of 2 to 5 gpm; the measurement conditions were far from optimal.

The following conclusions can be drawn from the flow logging in ER-5-3:

1. Under ambient conditions a small amount of flow may occur from the upper interval screened in alluvium to the lower interval screened in volcanics.

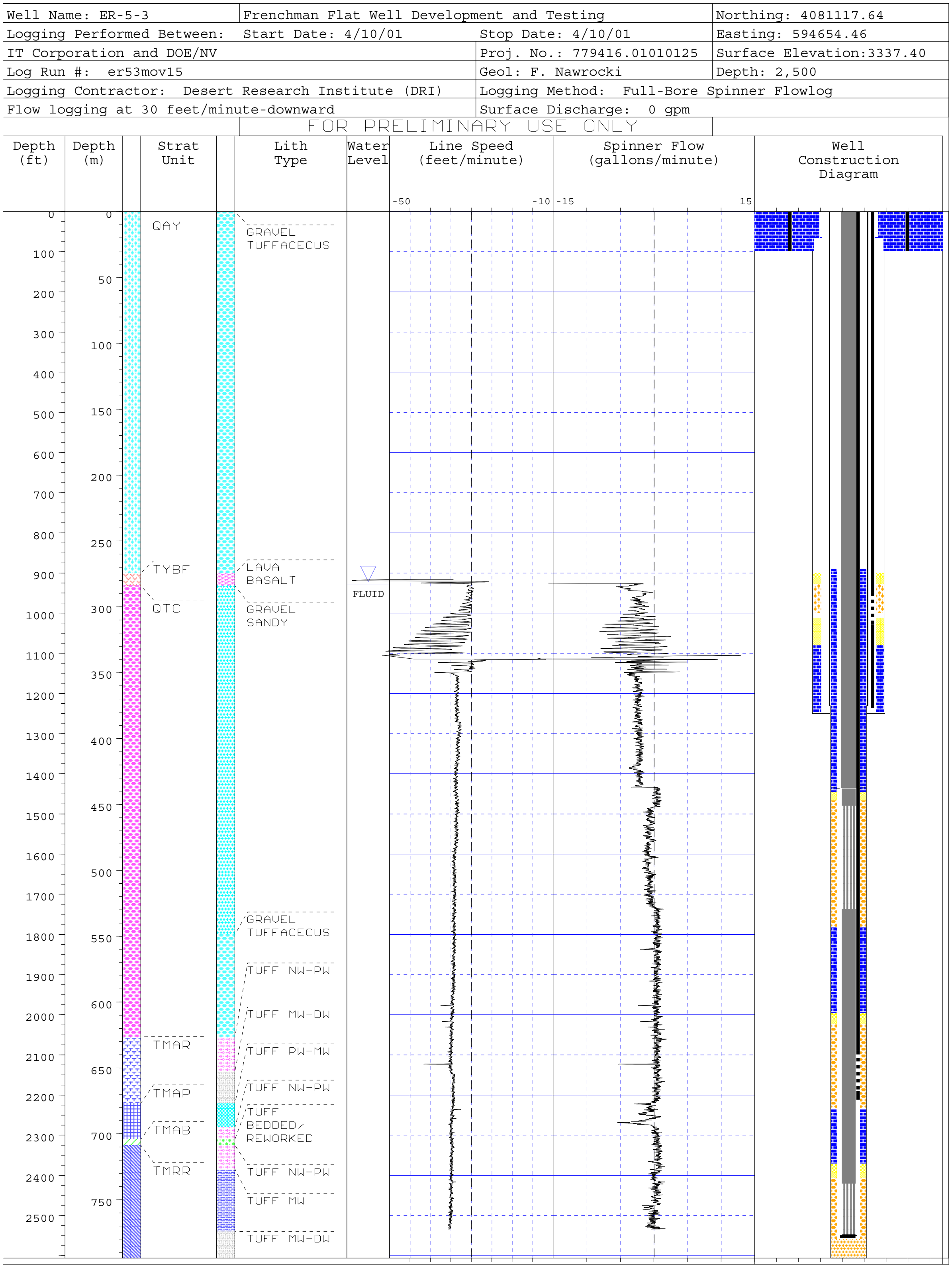


Figure 3-13
Spinner Flow Log in Well ER-5-3 under Ambient Flow Conditions

This is consistent with vertical hydraulic head measurements which indicate a small downward gradient.

2. Nearly all of the flow (greater than 97 percent) came from the lower completion. This indicates that the TMWTA is much more permeable than the Old Alluvial Aquifer at this location and is consistent with the analysis results of the ER-5-3 flow logs performed by Oberlander (2001).

3.5 Constant-Rate Test in ER-5-3

A ten-day constant-rate test was performed in well ER-5-3. Both intervals were open to pumping and water-level responses were observed in several observation wells including ER-5-3#3 and the deep piezometer in ER-5-3. The test was interpreted from two perspectives, each one treating the TMWTA and OAA as separate units. For the TMWTA, the deep piezometer serves as the observation well. The amount of pumpage from the TMWTA is measured at about 97.5 percent of the total. For the alluvium, ER-5-3#3 is the observation well and the discharge is only 2.5 percent of the total discharge based on flowmeter measurements.

3.5.1 ER-5-3 Deep Completion/Deep Piezometer

Water-level response to the 10-day pumping of Well ER-5-3 was recorded in the main string of ER-5-3 and in the deep piezometer. The data from the deep piezometer in response to pumping ER-5-3 may not be used for interpretation of hydraulic parameters. The deep piezometer is in the same borehole used to install ER-5-3. The bottom of the slotted interval of the deep piezometer is located 55.5 m (182.1 ft) above the top of the slotted casing interval of the ER-5-3 lower zone. In addition, a tuff confining unit of 4.6 m (15 ft) is shown (Figure 1-3) between the two slotted intervals and would serve to limit hydraulic communication. Furthermore, the piezometer data may not be reliable, based in part on examination of the recovery portion of the record. The piezometer did not recover from pumping as would be expected; the response included intermittent periods of drawdown and recovery following the end of production. The deep piezometer data is not reliable and should not be used for interpretation.

3.5.2 ER-5-3 Shallow Completion/ER-5-3#3

The drawdown in the main string associated with the shallow completion is the same as for the deep completion. To interpret this test, the discharge from the upper zone is assumed to be only 2.5 percent of the total discharge. Figure 3-14 is the fit of the Neuman (1974) solution to the response of observation Well ER-5-3#3. The parameters from this fit are 0.1 m/day for hydraulic conductivity, 0.22 for specific yield, and beta is 0.0186. This value of beta is unrealistic because it yields an anisotropy ratio of 1.8 for the vertical divided by horizontal hydraulic conductivity. In this alluvium, the anisotropy should be about

0.1, which would produce a beta value of 0.001 or less. Results are poor due to the uncertainty encountered in defining wellbore boundary conditions for the test. The upper slotted interval was tested, while the lower interval contributed at least 97.5 percent of well production. It is recommended that the hydraulic property estimation of the OAA be restricted to the MWAT analysis completed in Section 3.8.

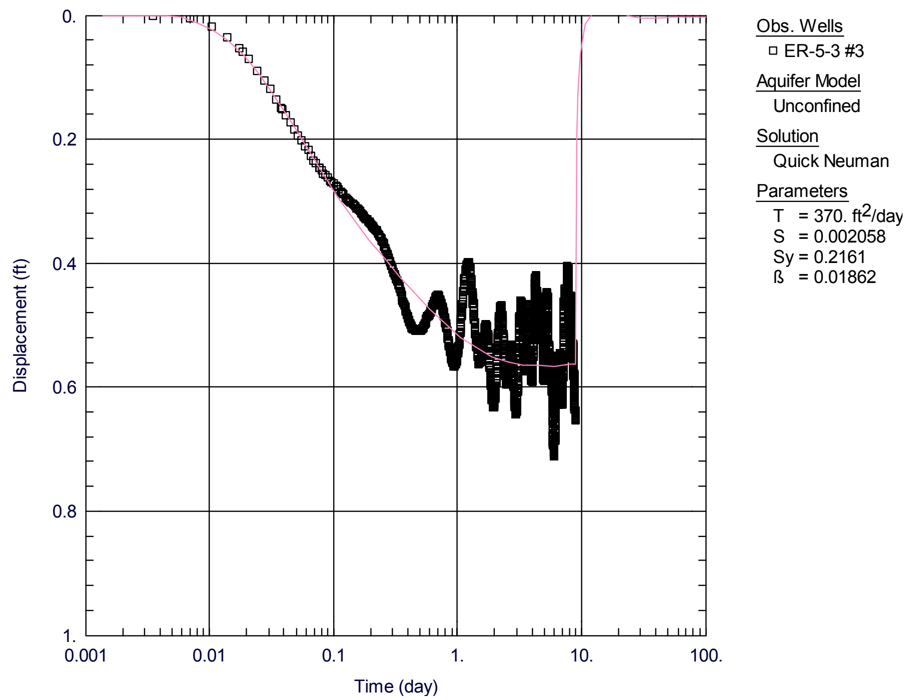


Figure 3-14
Fit of the Neuman Solution to the Drawdown in the Well ER-5-3#3 During the Constant-Rate Test in Well ER-5-3

3.6 Step Drawdown Test in ER-5-3#2

The five steps of the step drawdown test in Well ER-5-3#2 are shown in Figure 2-17 and Figure 3-15. Several interesting features are noticeable in this data. As shown in Figure 2-17, the well had been pumped for about one day, then was allowed to recover for one day prior to the beginning of the step drawdown testing. On Figure 3-15, it is apparent that water-level and temperature were stable for one hour prior to starting the pump. During the first three steps, after an initial water-level drop in response to pumping, the water-level rose throughout the step. Not until the last step did the water-level continue to decline during the duration of the step.

Fluctuations in pumping do not explain the unexpected water-level response. The temperature response, however, does explain the water-level response. The temperature is measured at the transducer, which is located a short distance below the water surface. ER-5-3#2 is a deep well with a long water column. Figure 3-16

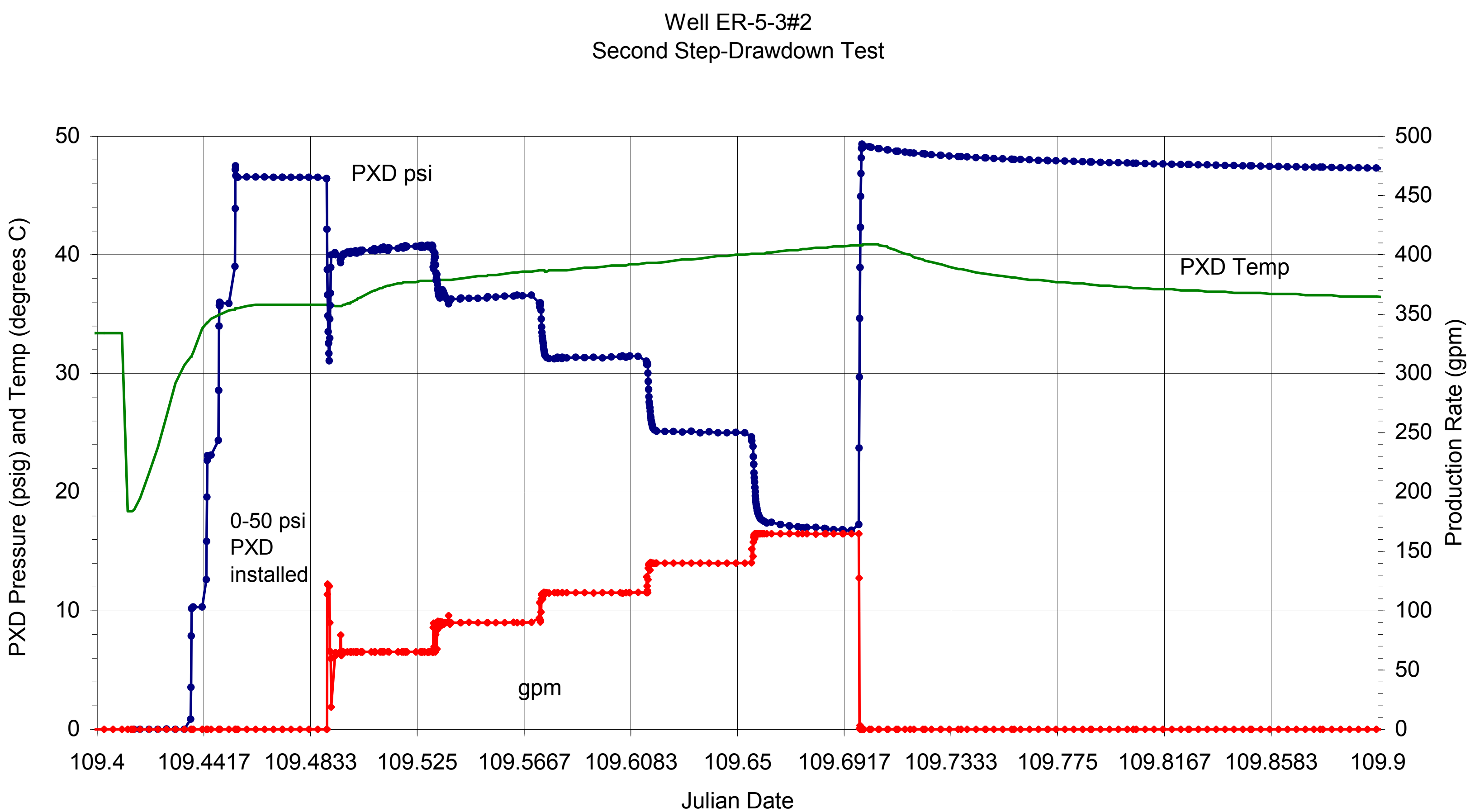


Figure 3-15
Production and PXD Pressure in Well ER-5-3#2 During Step Drawdown Tests in Well ER-5-3#2

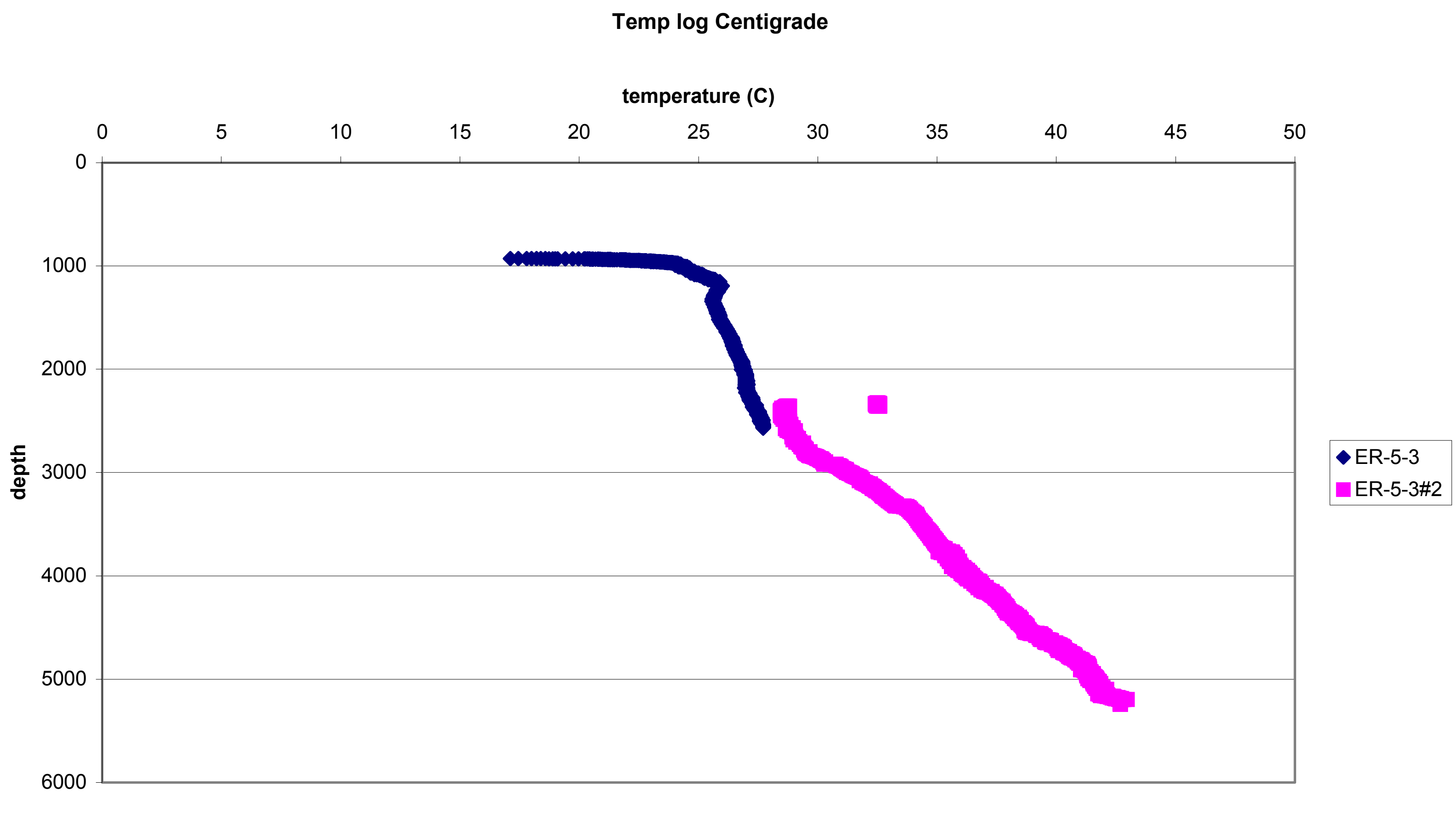


Figure 3-16
Composite Temperature Log Below the Water Table at the ER-5-3 Site

shows a plot of water temperature with depth for wells ER-5-3 and ER-5-3#2. The temperature of the water in the LCA is about 43°C, compared with about 25°C at the water table. The pump intake is set at a depth of 437 m (1,435 ft), but the top of the open portion of the screen is at about 1,425 m (4,675 ft). As water rises in the well, the heating of the nearly 1,000-meter water column causes thermal volume expansion throughout the column. Expansion below the PXD results in a higher measured water level than would be observed from the effects of production alone. Thermal expansion that occurred above the PXD would be invisible to the measurement; volume expansion is offset by the decrease in density in the PXD pressure measurement.

Ideally, all water levels in Well ER-5-3#2 should be corrected for water density in the column. Operationally, this cannot be done with the data available. There are no data to constrain the spatio-temporal heating of the profile through time. In addition, as the warmer water rises and displaces the existing fluid, conductive heating of the water outside the casing begins to occur. This process occurs over a longer duration and may explain the slow heating of the water column as documented in Figure 3-15. Any corrections for water density would be transient by necessity. Also, the precise temperature distribution downhole is not measured; it is recorded only at the transducer. Finally, when pumping ceases, the column rises and cools slowly back to ambient temperatures. This process has been observed to take more than 30 days to reach ambient. During development and testing, the pumping cycles occur over time scales much shorter than 30 days; therefore, residual temperature in the well complicates any calculation to correct water levels for density.

Some initial attempts to correct water levels for temperature caused water density variations proved unsuccessful because of the lack of downhole data and the large number of assumptions that were required to be made. As a result, the analysis presented here is based on hydraulic response uncorrected for density.

To estimate the hydraulic parameters from the step drawdown test, the pressure is converted to hydraulic head using a constant temperature of 38.5°C. This process ignores the transient nature of the temperature profile and will undoubtedly introduce errors in the results. Nonetheless, the analysis is useful for providing an approximate hydraulic conductivity value for the LCA. The pumping step, pumping rate, and drawdown, as shown in Figure 3-17 are summarized in Table 3-9. The linear regression through the data plotted as drawdown divided by discharge versus discharge produced linear and nonlinear component coefficients of 0.0977 day/m^2 (0.0907 day/ft^2) and 2.0×10^{-5} day^2/m^5 (5.23×10^{-8} day^2/ft^5), respectively. The calculated linear and nonlinear components of the drawdown are shown in Table 3-10. Figure 3-17 shows the fit of the Theis step drawdown analysis to the data from Well ER-5-3#2. The nonlinear component was set based on the linear regression. The resulting transmissivity is 313 m^2/day (3,364 ft^2/day). Using the thickness defined by the open interval (below the cement and above the fill, of 182 m (597 ft), the hydraulic conductivity is 1.7 m/day (5.6 ft/day).

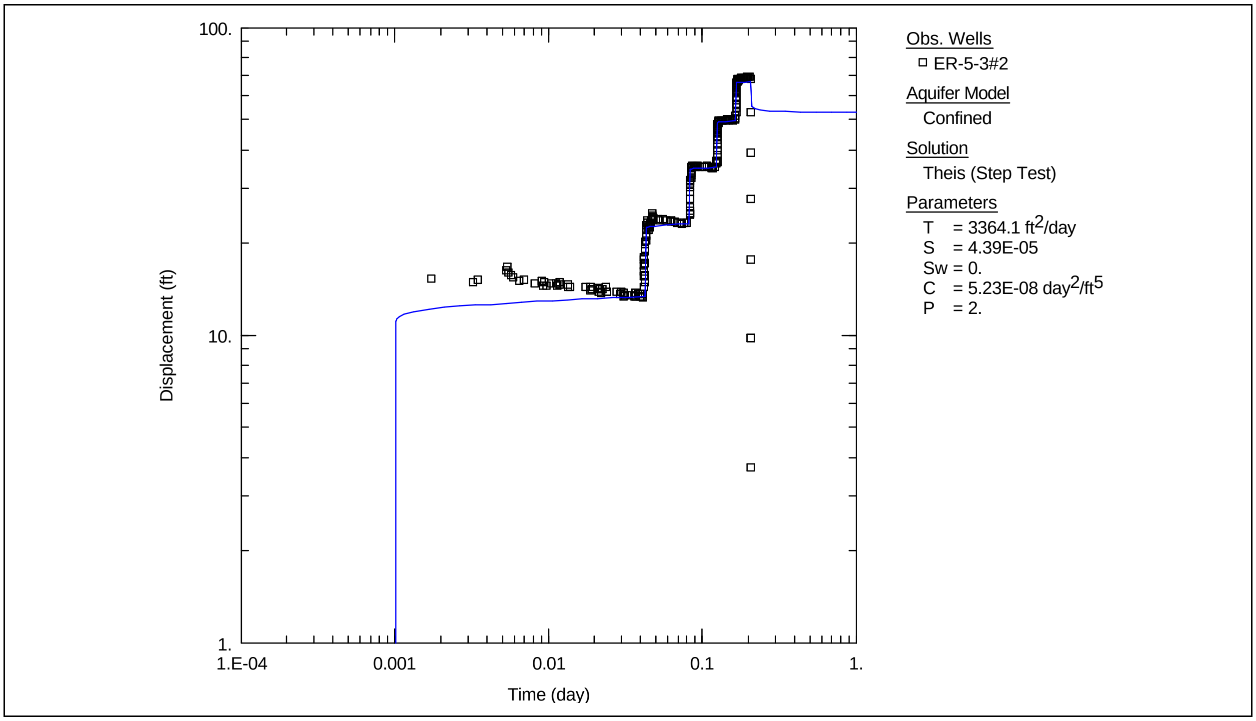


Figure 3-17
Fit of the Theis Step Drawdown Solution to the Step Drawdown Test Data from Well ER-5-3#2

Table 3-9
Measured Drawdown and Pumping from the Step Drawdown Test in Well ER-5-3#2

Step Number	Drawdown (m)	Pumping Rate (m^3/day)
1	4.5 (14.7 ft)	356 (65.3 gpm)
2	7.2 (23.6 ft)	491 (90.1 gpm)
3	10.8 (35.3 ft)	628 (115.2 gpm)
4	15.2 (50 ft)	764 (140.1 gpm)
5	21.1 (69.2 ft)	899 (165 gpm)

3.7 Constant-Rate Test in ER-5-3#2

A 10-day constant-rate test was planned for Well ER-5-3#2, completed in the LCA, following the step drawdown testing. As displayed in Figure 2-19, the well was allowed to equilibrate for about 5 days prior to starting the constant-rate test. By the start of the test on JDate 114, the temperature measured at the transducer had cooled to about 30°C (Figure 2-20). The pump was started and ran for slightly more than one day before being shut down because of equipment problems at the start of the test. The well equilibrated for about one day before restarting the pump. After restart, the test ran for about 4.5 days before a series of generator and pump failures terminated the test. On Figure 2-20, it is clear that temperature in

Table 3-10
Calculated Linear and Nonlinear Well Losses in Well ER-5-3#2

Discharge (m3/day)	Calculated Linear Component of Drawdown (m)	Calculated Nonlinear component of Drawdown (m)	Calculated Total Drawdown (m)	Observed Drawdown (m)
356 (65.3 gpm)	1.8 (5.9 ft)	2.5 (8.3 ft)	4.3 (14.2 ft)	4.5 (14.7 ft)
491 (90.1 gpm)	2.5 (8.2 ft)	4.8 (15.7 ft)	7.3 (23.9 ft)	7.2 (23.6 ft)
628 (115.2 gpm)	3.2 (10.5 ft)	7.8 (25.7 ft)	11.0 (36.2 ft)	10.8 (35.3 ft)
764 (140.1 gpm)	3.9 (12.7 ft)	11.6 (38.1 ft)	15.5 (50.8 ft)	15.2 (50 ft)
899 (165 gpm)	4.6 (15.0 ft)	16.1 (52.8 ft)	20.7 (67.8 ft)	21.1 (69.2 ft)

the well bore was fluctuating significantly prior to the restart. As the well pumped beginning the middle of JDate 116, the temperature at the transducer increased rapidly and the response of the water level was an increasing trend in the early part of JDate 117. The water level dropped immediately in response to pumping, then rose due to density changes as the water column heated. As the temperature stabilized, the water-level response followed an expected profile from JDate 118 to 122. Heating the water column increased water levels about 12 feet during the test. The only portion of this test that was deemed suitable for interpretation was the later portion of the restart drawdown curve (JDates 118 to 122).

Figure 3-18 is a plot of the Theis Step Drawdown solution applied to the 10-day constant-rate test. The weighting of the observation was reduced to 0.1 for time less than day 3.5, which corresponds to Julian Day less than 118. The nonlinear coefficient was fixed at the value from the step drawdown analysis of 2.0×10^{-5} day^2/m^5 (5.23×10^{-8} day^2/ft^5). The storage coefficient was fixed at 0.0074 based on a fit to the data using a standard Theis analysis. The thickness is taken as the open interval thickness of 182 m (597 ft). The transmissivity from this analysis is 89.5 m^2/day (963 ft^2/day). The corresponding hydraulic conductivity is 0.5 m/day (1.6 ft/day). This value is about a factor of 3.5 smaller than the value estimated from the step drawdown test.

3.8 Multiple-Well Aquifer Test

The multiple-well aquifer test involved pumping from the upper completion zone of ER-5-3. A bridge plug was installed between the upper and lower completion zones. As shown in Section 2.0, the MWAT at Well ER-5-3 in the alluvium encountered some difficulties but these do not prevent interpretation of the test. The apparent entrained air led to noisy discharge data (Figure 2-26) and lower true production. To interpret the early part of the breakthrough curves, the discharge was reduced to produce a match between observed drawdown. After Julian Day 159, the measured discharge was used. Type curves were fit to the observation well drawdown curves from Well ER-5-3#3 and the shallow piezometer of Well ER-5-3. The single-production well response in ER-5-3 was not analyzed. A Neuman (1974) delayed gravity drainage solution was fit to the data from the

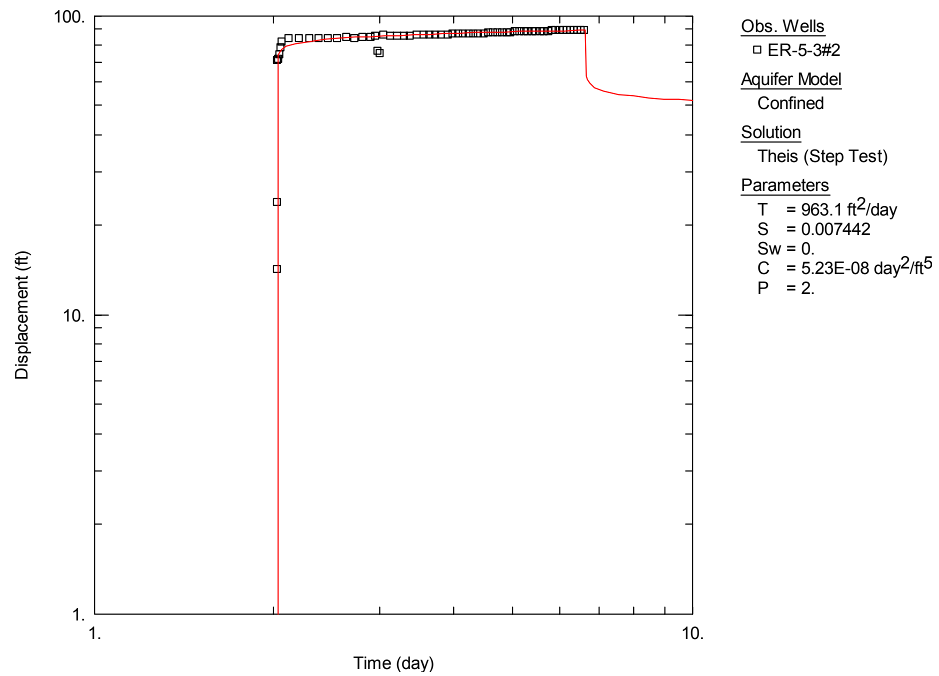


Figure 3-18
Fit of the Theis Solution to the Drawdown at ER-5-3#2
During the Constant-Rate Test at Well ER-5-3#2

two observation wells. The assumptions for Neuman's method are satisfied with the exception of a fully penetrating well through the unconfined aquifer thickness and the neglect of wellbore storage. As reported earlier in the document, partial penetration of the production well may induce a vertical component of formation flow near the well screen boundaries, thereby biasing high the transmissivity estimate. However, any vertical components of flow would be expected to have completely dissipated at the distance of the observation wells. The neglect, or ignoring, the effect of wellbore storage on the early period of the response record is acceptable because the observation well water level is assumed to be in constant equilibrium with the formation head directly adjacent to the well.

The drawdown records from both observation wells were corrected for barometric fluctuations. The calculated barometric efficiency for the shallow piezometer was 0.92 and for Well ER-5-3#3, 0.77.

The beginning of the aquifer test was assumed to begin on JDate 138.54. Changes in water level pressure in each monitoring well were determined by subtracting the observed pressure from the baseline value observed on JDate 138.54. The resultant change in pressure was then converted from psi to feet of head. The conversion factor incorporates groundwater density as a function of temperature and is derived from the average of the PXD installation and removal calibration groundwater densities. The conversion factors used for the Well ER-5-3 shallow piezometer and Well ER-5-3#3 were 2.2574 ft/psi and 2.3596 ft/psi, respectively.

Other relevant information used in the analysis is presented in Table 3-11 and Table 3-12.

Table 3-11
Parameters for Interpretation of the MWAT at Well Cluster ER-5-3

Well	Radius (m)	Top of Interval (depth below the water table m)	Bottom of Interval (depth below the water table m)
Shallow Piezometer of ER-5-3 Observation Well #1	0.3048 (1 ft)	0 (0 ft)	46.3 (152 ft)
ER-5-3#3 Observation Well #2	35.3 (115.7 ft)	147.5 (484 ft)	265.8 (872 ft)
ER-5-3 Pumped Well	0.0 (0.0 ft)	157.9 (518 ft)	260.3 (854 ft)

Table 3-12
Pumpage History During the MWAT at Well Cluster ER-5-3

Pumping Rate (m^3/day)	Elapsed Time (days)
60.0 (11 gpm)	0 to 17.468
67.9 (12.45 gpm)	17.468 to 19
60.0 (11 gpm)	19 to 20.7
67.9 (12.45 gpm)	20.7 to 27.786
0.0 (0 gpm)	27.786 to 27.832
67.9 (12.45 gpm)	27.832 to end of test

Figure 3-19 and Figure 3-20 show the Neuman delayed gravity drainage solution to Well ER-5-3#3 and the shallow piezometer of Well ER-5-3, respectively. With the exception of the first 0.3 days of Well ER-5-3#3, the fit to the data is quite good. Both drawdown curves were fit with similar aquifer parameters. The aquifer parameters are presented in Table 3-13.

Table 3-13
Hydraulic Parameters Determined from the MWAT at Well Cluster ER-5-3

Parameter	Parameter Value
Transmissivity	11.7 m^2/day (125.8 ft^2/day)
Hydraulic Conductivity (using aquifer thickness of 342.3 m (1,127 ft)	0.034 m/day (0.11 ft/day)
Storage Coefficient	0.000567
Specific Yield	0.118
Anisotropy Ratio (vertical/horizontal)	0.13

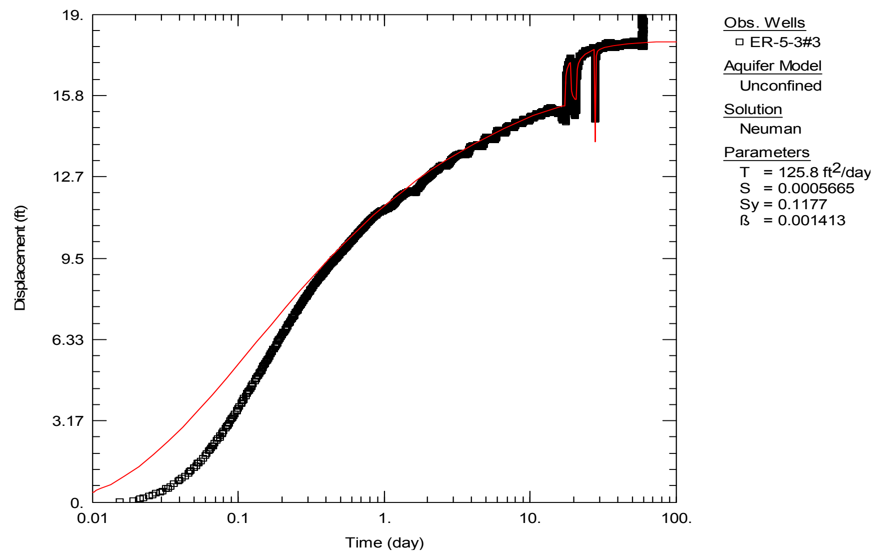


Figure 3-19
Fit of the Neuman Solution to the Drawdown at Well ER-5-3#3 During the MWAT at Well Cluster ER-5-3

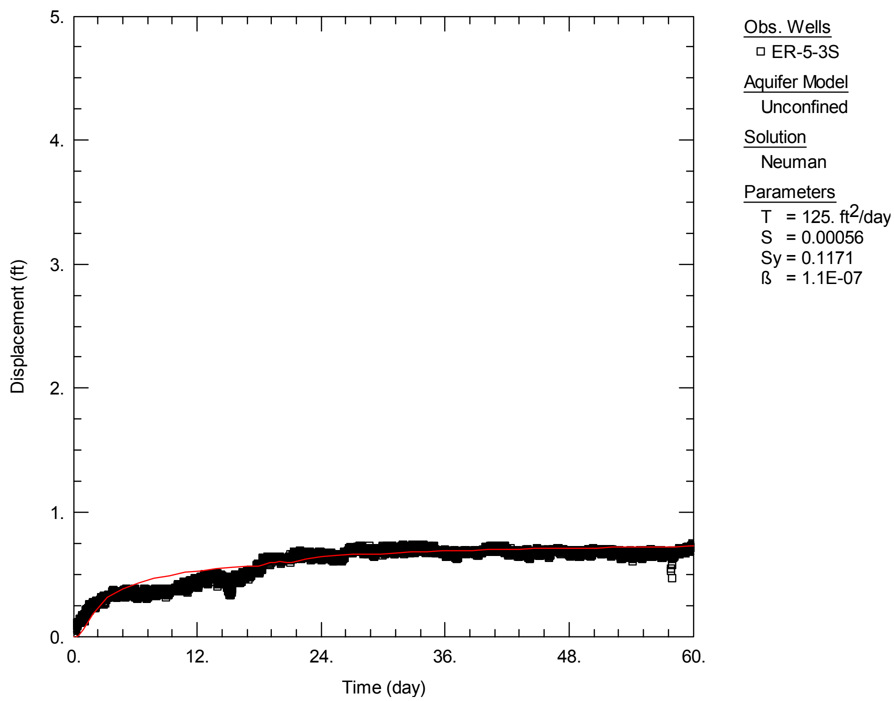


Figure 3-20
Fit of the Neuman Solution to the Drawdown at the Shallow Piezometer in Well ER-5-3 During the MWAT at Well Cluster ER-5-3

4.0 Summary of Hydraulic Test Results

A series of hydraulic tests were conducted at the ER-5-3 well cluster. This section summarizes the results derived from the hydraulic testing analyses presented in Section 3.0. Table 4-1 presents a composite list of the hydraulic properties interpreted.

The hydraulic conductivity of the OAA in the vicinity of Well ER-5-3 is relatively low. The analysis results presented are representative of the ER-5-3 shallow piezometer slug test and the MWAT; analysis results derived from other tests completed in the OAA are unsuitable for final presentation (Table 4-1). The MWAT provides the highest quality data (0.034 m/day). Although the slug test data from ER-5-3#3 provide physically realistic estimates (0.18 to 0.64 m/day), it is likely that the hydraulic properties derived from the test are more representative of the wellbore skin than of the alluvium. The primary purpose of all of the slug tests was to show the hydraulic connection between HSUs.

The MWAT estimate (0.034 m/day) is one to two orders of magnitude smaller than other estimates of hydraulic conductivity derived from testing of the alluvium in Frenchman Flat (IT, 1999). Based on results derived from the MWAT, the alluvium vertical hydraulic conductivity is nearly one order of magnitude smaller than the horizontal.

The hydraulic conductivity of the TMWTA, derived from two ER-5-3 step drawdown tests, is estimated at 61.0 and 62.9 m/day. The hydraulic properties estimated from testing of the TMWTA during the ER-5-3 deep piezometer slug test and ER-5-3 constant-rate test were too uncertain for inclusion into a final parameter set respective to the TMWTA. The high-valued estimates indicate that the TMWTA is the most permeable unit that was tested in the Frenchman Flat basin.

The LCA hydraulic conductivity is estimated at 0.5 m/day. The datum is similar to that derived from hydraulic testing of the LCA in FF wells Test Well F and Water Well C1 (IT, 1999), and appears to correspond well with other measurements in the vicinity. The LCA conductivity estimate derived from the step-drawdown test at Well ER-5-3#2 (1.7 m/day) was influenced by thermal effects in the measured drawdown data and is presented with prudence. Information was not available to correct the measured formation response for thermal volume expansion of the water column during step-drawdown production. Volume expansion results in the underestimation of measured drawdown, which would result in the overestimation of hydraulic conductivity. Therefore, the estimate of 1.7 m/day presented for the step drawdown test is biased high; the actual value would be closer to 0.5 m/day.

Table 4-1
Summary of Hydraulic Conductivity and Transmissivity Values

Production Well	Observation Well	Distance between Wells (m)	Interval Tested		HSU	Test Type	Analytical Method	K range (m day^{-1})	Transmissivity range (m^2 day^{-1})	Comments and Recommendation for Data Use
			Top (m bgs)	Bottom (m bgs)						
ER-5-3 Shallow PZ	ER-5-3 Shallow PZ	N/A	282.9	329.2	OAA	5 gal Slug Injection	Bouwer and Rice	0.18 - 0.64	8.33 - 29.63	Liquid slug; Purpose of the test was to show the hydraulic connection between the well and alluvium; Slug was sufficiently large to stress the alluvium through the gravel pack
ER-5-3 Deep PZ	ER-5-3 Deep PZ	N/A	637.0	667.4	TMWTA	0.53 gal Slug Injection	Bouwer and Rice, Cooper et al.	0.09 - 0.23	2.74 - 6.99	Purpose of the tests was to show the hydraulic connection between the well and aquifer; The slug was sufficiently small that the measured responses reflect the gravel pack and not the formation; The parameters are NOT recommended for further use
			608.1	681.2				0.04 - 0.09	2.92 - 6.58	
ER-5-3#3	ER-5-3#3	N/A	454.8	531.6	OAA	0.53 gal Slug	Bouwer and Rice, Cooper et al.	0.04 - 0.09	3.07 - 6.91	
			430.0	546.7				0.02 - 0.06	2.33 - 7.00	
ER-5-3	ER-5-3	N/A	733.3	776.9	TMWTA	2x Step Drawdown	Theis	61.0 - 62.9	2,659.6 - 2,742.4	The lower completion zone is tested (the upper completion zone contribution is assumed negligible); Two step drawdown tests show reproducible parameter estimates
ER-5-3	ER-5-3 Deep PZ	N/A	N/A	N/A	TMWTA	10-day Constant-rate	N/A	N/A		Data deemed unacceptable for interpretation and analysis (see Section 3.5.1)
	ER-5-3#3	35.27	440.7	543.2	OAA		Neuman (delayed gravity drainage)	0.1	10.3	Identification of well boundary conditions during the test are highly uncertain (see Section 3.5.2); The parameters are NOT recommended for further use
ER-5-3#2	ER-5-3#2	N/A	1425.9	1607.9	LCA	Step Drawdown	Theis	1.7	309.4	Significant temperature effects in measured drawdown result in high parameter estimate uncertainty (see Section 3.6); There are no data available to address the uncertainty; The parameters are NOT recommended for further use
ER-5-3#2	ER-5-3#2	N/A	1425.9	1607.9	LCA	Constant-rate	Theis	0.5	91.0	Temperature effects in measured drawdown (see cell above) are effectively removed through data weighting
MWAT: ER-5-3 Upper Completion Zone	ER-5-3#3	35.27	284.1	626.4	OAA	Constant-rate	Neuman (delayed gravity drainage)	0.034	11.64	Storage coefficient = 0.000567; Specific Yield = 0.118; Anisotropy ratio (vertical/horizontal) = 0.13
	Shallow PZ (~450 ft above)	N/A								

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