DOE/NV/11718--998

Nevada
Environmental
Restoration
Project

Completion Report for Well Cluster ER-5-4

February 2005

Environmental Restoration
Division

U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office

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Completion Report for Well Cluster ER-5-4

Prepared for:
U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office
Las Vegas, Nevada

Prepared by:
Bechtel Nevada
Geotechnical Sciences
Las Vegas, Nevada

February 2005

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DOE/NV/11718--998

COMPLETION REPORT FOR WELL CLUSTER ER-5-4

Approved by: Robert M. Bangerter Jr. Date: 3/8/05
Robert M. Bangerter, Project Manager
Underground Test Area Project

Approved by: Robert M. Bangerter Jr. Date: 3/8/05
for Janet L. Appenzeller-Wing, Acting Director
Environmental Restoration Division

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Completion Report for Well Cluster ER-5-4
DOE/NV/11718--998

ABSTRACT

Well Cluster ER-5-4 was drilled for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, in support of the Nevada Environmental Restoration Project at the Nevada Test Site, Nye County, Nevada. The cluster consists of two wells, positioned about 30 meters apart on the same drill pad, constructed as part of a hydrogeologic investigation program for Frenchman Flat at the Nevada Test Site.

At Well ER-5-4, constructed in early 2001, a 66.0-centimeter surface hole was drilled and cased off to a depth of 279.1 meters below the surface. The hole diameter was then decreased to 44.5 centimeters and cased off to a depth of 510.0 meters. The borehole size was further decreased to 31.1 centimeters for drilling to a total depth of 1,115.6 meters. At Well ER-5-4#2, constructed in mid-2002, a 66.0-centimeter surface hole was drilled and cased off to a depth of 266.5 meters. The hole diameter was decreased and the borehole cased off twice more, with the final casing set at the depth of 1,477.9 meters. Borehole size was decreased again to 22.2 centimeters for drilling to a total depth of 2,133.6 meters. Severe problems with borehole instability were encountered during drilling of both holes, which required use of bentonite drill fluid, the use of lost-circulation materials, and cementing and redrilling parts of the holes.

At Well ER-5-4, a 7.3-centimeter piezometer string with one slotted interval was installed in the annulus of the surface casing. A 14.0-centimeter completion string with 2 isolated slotted intervals was also installed in the well. All 3 completions are open to the alluvial aquifer. A preliminary composite, static water level was measured at the depth of 221.3 meters.

At Well ER-5-4#2, a string of 14.0-centimeter stainless-steel casing hangs from a liner hanger set at 1,437.1 meters within 24.4-centimeter carbon-steel intermediate casing. The bottom of the completion string is at the depth of 2,030.0 meters, and the casing is slotted in the interval 1,976.9 to 2,029.3 meters, open to the tuff confining unit. No gravel-pack or cement was utilized.

Detailed lithologic descriptions with preliminary stratigraphic assignments for the well cluster are included in this report. These are based on composite drill cuttings collected every 3 meters, and 156 sidewall samples taken at various depths below 192 meters in both boreholes, supplemented by geophysical log data. Detailed petrographic, chemical, and mineralogical studies of rock samples were conducted on 122 samples. Well ER-5-4 penetrated approximately 1,120 meters of Quaternary and Tertiary alluvium before reaching total depth in Tertiary volcanic rocks at 1,137.5 meters. The deeper Well ER-5-4#2 penetrated 1,120.4 meters of alluvial sediments, and was terminated within Tertiary volcanic rocks at a depth of 2,133.6 meters, indicating that Paleozoic rocks are deeper than expected at this site.

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List of Acronyms and Abbreviations

3-D	three-dimensional
BHA	bottom-hole assembly
BN	Bechtel Nevada
C	Celsius
cc	cubic centimeters
cm	centimeter(s)
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DRI	Desert Research Institute
EC	Electrical conductivity
F	Fahrenheit
FMP	Fluid Management Plan
ft	foot (feet)
gal	gallon(s)
GBEC	Great Basin Exploration Consultants, Inc.
gpm	gallons per minute
in.	inch(es)
IT	IT Corporation
km	kilometer(s)
LANL	Los Alamos National Laboratory
LCM	lost circulation material
LiBr	lithium bromide
lpm	liters per minute
m	meter(s)
Ma	million years ago
mi	mile(s)
NAD	North American Datum
NNSA/NSO	National Nuclear Security Administration Nevada Site Office
NTS	Nevada Test Site
pCi/L	picoCuries per liter
RWMS	Radioactive Waste Management Site
TD	total depth
TFM	Thermal Flow Meter
TWG	Technical Working Group
UGTA	Underground Test Area
UDI	United Drilling, Inc.
USGS	United States Geological Survey

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1.0 Introduction

1.1 Project Description

Well Cluster ER-5-4 was drilled for the U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Site Office (NNSA/NSO; formerly Nevada Operations Office, DOE/NV) in support of the Nevada Environmental Restoration Project at the Nevada Test Site (NTS), Nye County, Nevada. These two wells were constructed as part of the hydrogeologic investigation well program for Frenchman Flat. This program is part of the NNSA/NSO Environmental Restoration Division's Underground Test Area (UGTA) project at the NTS. The goals of the UGTA project include evaluating the nature and extent of contamination in groundwater due to underground nuclear testing, and establishing a long-term groundwater monitoring network. As part of the UGTA project, scientists are developing computer models to predict groundwater flow and contaminant migration within and near the NTS. To build and test these models, it is necessary to collect geologic, geophysical, and hydrologic data from new and existing wells to define groundwater quality, migration pathways, and migration rates.

The goal of constructing, sampling, and hydrologic testing at Well Cluster ER-5-4 is to collect subsurface geologic and hydrologic data in a poorly characterized area near a group of underground nuclear test locations in Frenchman Flat. Data from these wells will allow for more accurate modeling of groundwater flow and radionuclide migration in the region. One of the wells may also function as a long-term monitoring well.

Well Cluster ER-5-4 is located in central Area 5 of the NTS (Figure 1-1), approximately 1.6 kilometers (km) (1.0 miles [mi]) northwest of the Frenchman Lake playa. The cluster consists of two boreholes drilled 30.5 meters (m) (100 feet [ft]) apart on the same drill pad (Figure 1-2). The elevation of the dirt-fill drill pad at the wellheads is 954.5 m (3,131.7 ft) above mean sea level. The Nevada State plane coordinates and elevation at both wellheads are listed in Table 1-1, along with additional site summary and survey information.

IT Corporation (IT) was the principal environmental contractor for the project, and IT personnel collected geologic and hydrologic data during drilling. The drilling company was United Drilling, Incorporated (UDI), a subcontractor to Bechtel Nevada (BN). Site supervision, engineering, construction, inspection, and geologic support were provided by BN. The roles and responsibilities

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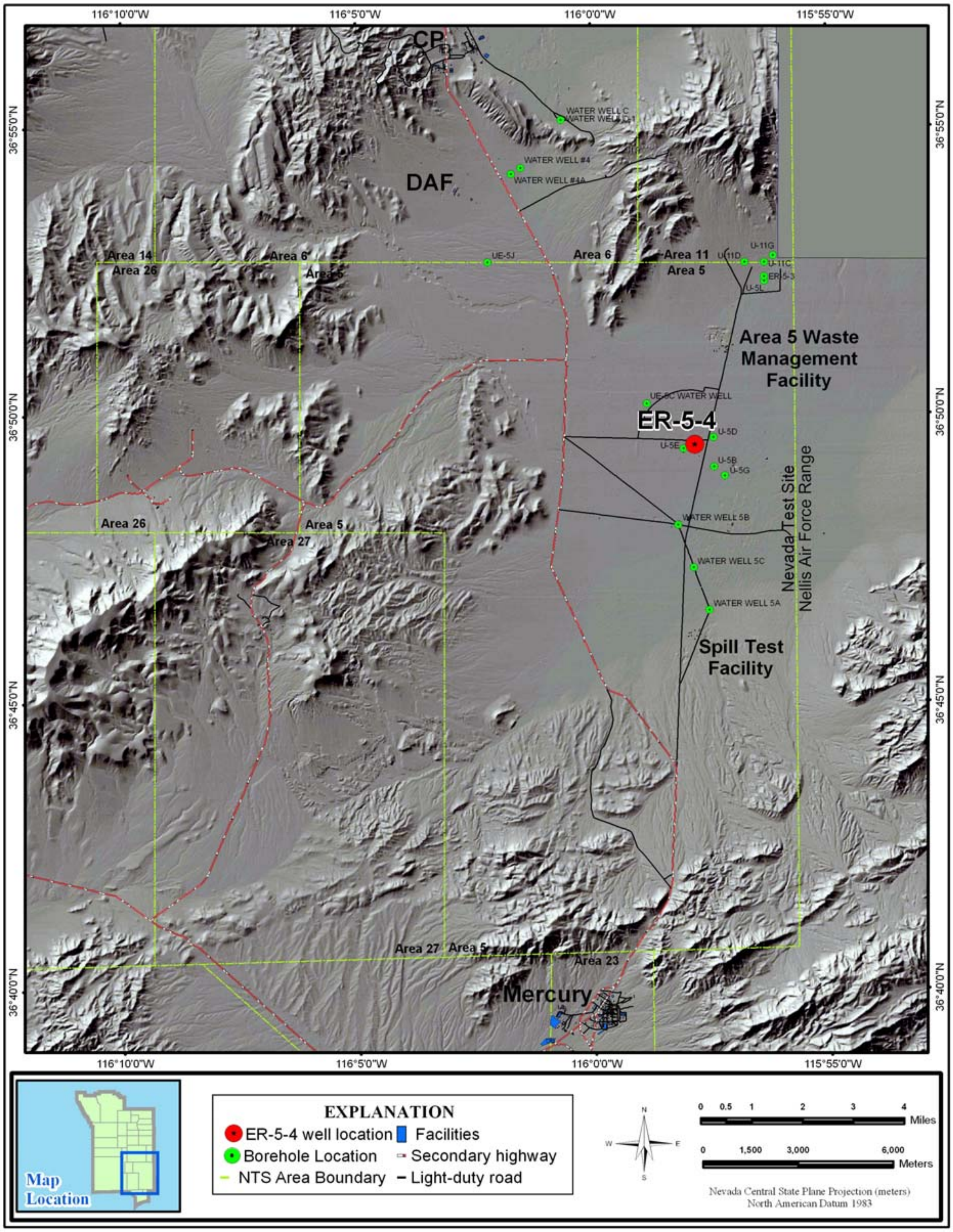

Figure 1-1
Reference Map Showing Location of Well Cluster ER-5-4

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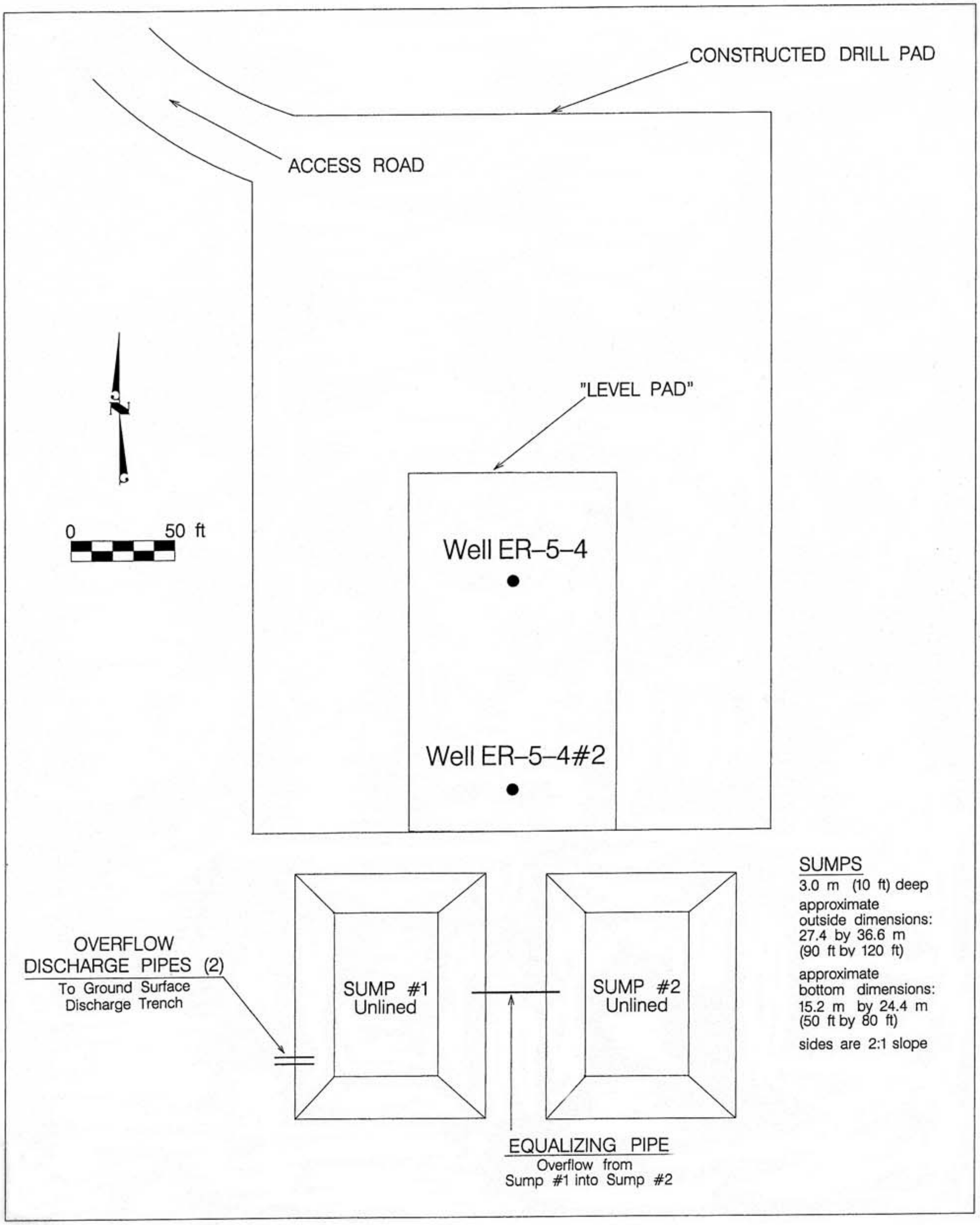

Figure 1-2
Drill Site Configuration for Well Cluster ER-5-4

Table 1-1
Well Cluster ER-5-4 Site Data Summary

Well Designation (Date TD reached)		**ER-5-4** (March 18, 2001)	**ER-5-4#2** (September 11, 2002)
Site Coordinates [a]	Nevada State Plane (central zone) (NAD 83) meters	N 6,230,353.7 E 562,655.5	N 6,230,323.2 E 562,655.4
	Nevada State Plane (central zone) (NAD 83) feet	N 20,440,752.2 E 1,845,978.9	N 20,440,652.0 E 1,845,978.6
	Nevada State Plane (central zone) (NAD 27) feet	N 755,751.3 E 705,819.9	N 755,651.2 E 705,819.6
	Universal Transverse Mercator (Zone 11) (NAD 83) meters	N 4,075,874.5 E 592,364.5	N 4,075,844.0 E 592,364.5
Surface Elevation [b]		954.5 m (3,131.7 ft)	954.5 m (3,131.7 ft)
Drilled Depth		1,137.5 m (3,732 ft)	2,133.6 m (7,000 ft)
Preliminary Fluid-Level Depth [c]		221.3 m (726.0 ft)	215.7 m (707.6 ft)
Fluid-Level Elevation		733.6 m (2,405.7 ft)	732.8 m (2,404.1 ft)

a Measurement made by BN Survey. 1983 or 1927 North American Datum (NAD).
b Measurement made by BN Survey. Elevation at top of construction pad. 1929 National Geodetic Vertical Datum.
c Well ER-5-4: determined on February 16, 2001, prior to introduction of bentonite mud (IT, 2001b).
Well ER-5-4 #2: determined on September 18, 2002 (IT, 2003).

of these and other contractors involved in the project are described in Contract Number DE-RP-08-95NV11808, and in BN Field Activity Work Plans Number D-002-001.01 and Number D-006-001.02 (BN, 2001, 2002). The UGTA Technical Working Group (TWG), a committee of scientists and engineers comprising NNSA/NSO, Lawrence Livermore National Laboratory, Los Alamos National Laboratory (LANL), and contractor personnel, provided additional technical advice during drilling, design, and construction of the well. See *Frenchman Flat Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 2000) and an addendum to that document (IT, 2001a) for descriptions of the general plan and goals of the Well Cluster ER-5-4 project, as well as specific goals for both wells.

General guidelines for managing fluids used and generated during drilling, completion, and testing of UGTA wells are provided in the UGTA Fluid Management Plan (FMP) (DOE/NV, 1999), an attachment to the UGTA Waste Management Plan (DOE/NV, 1996). Estimates of production of fluid and drill cuttings for these holes are given in Appendix C of the drilling and completion criteria document for the Frenchman Flat drilling project (IT, 2000), along with sampling requirements and contingency plans for management of any hazardous waste produced. All activities were conducted according to the Nevada Environmental Restoration Project Health and Safety Plan (DOE/NV, 1998), and the UGTA Health and Safety Plan (BN, 2001).

This report presents construction data and summarizes scientific data gathered during drilling and installation of the completion strings in Wells ER-5-4 and ER-5-4#2. Well data reports prepared by IT (IT, 2001b, 2003) contain additional information on fluid management, waste management, and environmental compliance. Information on well development, aquifer testing, and groundwater analytical sampling will be compiled and disseminated separately.

1.2 Objectives

The primary purpose of constructing Well Cluster ER-5-4 was to obtain information that will help characterize the hydrogeology of this part of Frenchman Flat. The primary scientific objectives for these wells, as discussed in the drilling criteria documents (IT, 2000, 2001a), include the following:

- Validate the current hydrogeologic framework model for this part of Frenchman Flat, with special interest in the base of the alluvium and the top of the lower carbonate aquifer.
- Verify the presence of the tuff confining unit and obtain data on its geologic and hydrologic properties.
- Document any differences in the physical nature of the alluvial aquifer with depth.
- Obtain velocity data and geologic control to aid interpretation of the recently conducted 3-dimensional (3-D) seismic survey.
- Obtain geologic samples for detailed mineralogical analyses.
- Obtain water level data to refine knowledge of the local water table.
- Obtain data to determine vertical head distribution/vertical hydraulic gradient at various locations within the alluvial aquifer and between the various hydrogeologic units.

- Obtain vertical and horizontal conductivity measurements.

- Obtain data to address potential contaminant transport processes such as a hydrologic "short cut" from contaminant sources in the alluvium to the lower carbonate aquifer via a fault. The deeper well in this cluster was expected to intercept a geophysically inferred fault.

- Serve as a multi-level observation well during full-scale aquifer tests.

- Provide long-term monitoring point(s) for the evaluation of temporal changes in water levels and groundwater chemistry.

Some of these objectives will not be met until additional work, outside the scope of this report, is completed, including installing pumps and conducting hydraulic testing, and analyzing geologic and hydrologic data from these wells and other data for the Frenchman Flat area. Objectives for individual wells of the cluster are listed in the well-specific portions of this report.

1.3 Project Summary

This section summarizes construction operations at Well Cluster ER-5-4; the details are provided in Sections 2.0 through 8.0.

1.3.1 Well ER-5-4

The surface conductor hole was constructed by augering a 121.9-centimeter (cm) (48-inch [in.]) diameter hole to a depth of 37.2 m (122 ft) and installing a string of 30-in. casing. Drilling of the main hole with a 17½-in. rotary bit, using an air-water-foam-polymer fluid in conventional circulation, began on February 10, 2001, and continued to the depth of 312.1 m (1,024 ft). At that depth circulation was lost and drilling was suspended for geophysical logging and installation of the surface casing. The diameter of the hole was increased to 66.0 cm (26 in.) by reaming, to allow installation of a string of 20-in. surface casing. The 20-in. casing was set on February 24, 2001, at the depth of 279.1 m (915.5 ft). Drilling resumed with bentonite mud and a 17½-in. bit to the depth of 510.5 m (1,675 ft). At this point, drilling was again suspended for geophysical logging, and then the 13d-in. intermediate casing string was landed at 510.0 m (1,673.3 ft). Drilling continued with a 12¼-in. bit to a total depth (TD) of 1,137.5 m (3,732 ft), which was reached on March 18, 2001. Several attempts at geophysical logging made during the week after TD was reached were hampered by blockages due to accumulations of fill in the borehole. The entire drilling operation was hampered by borehole sloughing and loss of drill fluid to the formation. Efforts to overcome these problems included the use of bentonite in the drill fluid, the use of lost-circulation material, and cementing and redrilling parts of the hole.

Water production was first noted at the depth of approximately 223.1 m (732 ft), and reached a maximum of approximately 2,271 liters per minute (lpm) (600 gallons per minute (gpm) at the depth of about 310 m (2,000 ft). A preliminary composite fluid-level tag was made at the depth of 221.3 m (726 ft). Radionuclide levels above background were encountered in only two short intervals, and the maximum tritium activity of 5,028 picoCuries per liter (pCi/L) was measured in a sample of drill fluid from the depth of 298.7 m (980 ft) (IT, 2001b).

Composite drill cuttings were collected every 3 m (10 ft) from 36.6 m (120 ft) to TD, and 154 sidewall core samples were taken at various depths below 192.0 m (630 ft). Open-hole geophysical logging of the well was conducted to help verify the geology and characterize the hydrology of the rocks; some logs also aided in the construction of the well by indicating borehole volume and condition, and cement location. The well penetrated Quaternary and Tertiary alluvium from the surface to 1,118.6 m (3,670 ft) and Tertiary volcanic rocks from 1,118.6 m (3,670 ft) to TD. No recognizable faults were encountered.

The as-built completion design for Well ER-5-4 provides access to the alluvial aquifer at 3 depths. A bull-nosed piezometer string of 2 f -in. stainless-steel tubing is set in the annulus of the 20-in. casing at a depth of 247.8 m (812.8 ft). The piezometer string is slotted in the depth interval 220.2 to 247.4 m (722.6 to 811.7 ft). A string of 5½-in. stainless-steel casing was landed at the depth of 1,048.0 m (3,438.3 ft). The bull-nosed string has 2 slotted intervals, at 955.9 to 1,021.1 m (3,136.3 to 3,350.1 ft) and at 539.5 to 644.2 m (1,770.0 to 2,113.4 ft). The 5½-in. casing hangs from a string of 7 e -in. carbon-steel production casing that extends to the ground surface. The completion string was gravel-packed across the slotted intervals and the remaining annular space was filled with gravel, sand, and cement to the depth of 499.9 m (1,640 ft) on March 31, 2001. No pump was installed at the time of completion, but will be inserted as needed for hydrologic testing and sampling activities.

1.3.2 Well ER-5-4#2

The surface conductor hole for Well ER-5-4#2 was constructed immediately after that for Well ER-5-4 by augering a 121.9-cm (48-in.) diameter hole to a depth of 35.1 m (115 ft) and installing a string of 30-in. casing. Drilling of the main hole with a 17½-in. rotary bit, using an air-water-foam-polymer fluid in conventional circulation, began 17 months later, on July 15, 2002.

Based on experience during drilling of Well ER-5-4, measures were taken to try to minimize borehole instability. However, lost circulation and borehole sloughing were ongoing problems during drilling to the depth of 371.9 m (1,220 ft). At that depth, on July 22, 2002, a crack opened at the surface, with drilling fluid flowing out of it, and extending for a distance of 15.2 to 21.3 m (50 to 70 ft) from the well collar on two sides of the hole. The crack was observed via down-hole camera, to extend across the borehole from the base of the conductor casing at 33.8 m (111 ft) to a depth of 71.6 m (235 ft). To seal off the crack and to control sloughing of the borehole, the hole was opened to 66.0 cm (26 in.) in diameter to accommodate a string of 20-in. surface casing.

The 20-in. casing was run in the hole to the top of fill at 266.5 m (874.5 ft), and the bottom was cemented. Borehole sloughing and lost circulation persisted, and the bottom of the surface hole was cemented and re-drilled 4 times, before drilling resumed at the original depth of the 44.5-cm (17½-in.) surface hole at 371.9 m (1,220 ft) on August 8, 2002. Additional problems with borehole instability were again encountered below the depth of 923.5 m (3,030 ft). The 13d-in. intermediate casing was set at the depth of 965.9 m (3,169.0 ft) on August 16, 2002, after the depth of 1,052.5 m (3,453 ft) was reached. The hole was advanced with a 12¼-in. bit to 1,573.7 m (5,163 ft) on August 24, 2002, despite continued borehole instability. Geophysical logging was conducted, and then a string of 9e-in. casing was set at the depth of 1,477.9 m (4,848.8 ft). Drilling resumed with a 8¾-in. bit with few problems to the TD of 2,133.6 m (7,000 ft), reached on September 11, 2002.

The drillers repeatedly encountered severe sloughing of the borehole, large accumulations of fill, and loss of large quantities of drill fluid to the formation, despite efforts to overcome these problems, which included the use of bentonite in the drill fluid, the use of lost-circulation material, and cementing and redrilling parts of the hole.

Water production was first noted at the depth of approximately 221.6 m (727 ft), and reached a maximum of approximately 2,157 lpm (570 gpm) at the depth of about 1,996 m (6,550 ft). A preliminary composite fluid level was measured soon after completion at the depth of 215.7 m (707.6 ft). Radionuclide levels above background were encountered in two intervals, and the maximum tritium activity of 1,792 pCi/L was measured in a sample of drill fluid from the depth of 1,576.1 m (5,171 ft).

Composite drill cuttings were collected every 3 m (10 ft) from 35.1 m (115 ft) to TD, and 2 partial sidewall core samples were obtained. Open-hole geophysical logging of the well was conducted to help verify the geology and characterize the hydrology of the rocks; some logs also aided in the construction of the well by indicating borehole volume and condition, and cement location. The borehole penetrated Quaternary and Tertiary alluvium from the surface to the depth of 1,120.4 m (3,676 ft), and Tertiary volcanic rocks from that depth to the TD. Paleozoic sedimentary rocks were not encountered in Well ER-5-4#2. No recognizable faults were encountered.

A single completion zone was constructed within Tertiary volcanic rocks. The completion string consists of 169.7 m (556.9 ft) of 5½-in. stainless-steel casing, hung from a liner hanger set at 1,437.1 m (4,715.0 ft) within the 9e-in. carbon-steel intermediate casing. The bottom of the 5½-in. casing terminates in a bull-nose at the depth of 2,030.0 m (6,660.0 ft). The casing is slotted in the interval 1,976.9 to 2,029.3 m (6,486.0 to 6,657.7 ft). No gravel-pack or cement were utilized in the completion. The slotted interval coincides with a fractured interval that produced water during drilling.

1.4 Project Manager

Inquiries concerning Well Cluster ER-5-4 should be directed to the UGTA Project Manager at:

U.S. Department of Energy
National Nuclear Security Administration
Nevada Site Office
Environmental Restoration Division
Post Office Box 98518
Las Vegas, Nevada 89193-8518

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2.0 Well ER-5-4

This section contains detailed descriptions of the drilling process and fluid management issues, geologic data collection, and completion information for Well ER-5-4. Subsequent hydrologic sampling and testing are beyond the scope of this report.

2.1 Well-Specific Objectives

The scientific objectives for Well ER-5-4 include those listed for the well cluster in Section 1.2. However, the specific goal of this first well in the cluster was to penetrate the alluvial section and install completions within 3 zones of interest in the saturated alluvium. Well ER-5-4 was planned to reach TD in the top of the underlying volcanic rocks.

2.2 Drilling Summary

This section contains detailed descriptions of the drilling process and fluid management issues.

2.2.1 Introduction

The general drilling requirements for Well ER-5-4 were provided in *Frenchman Flat Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 2000) and an addendum to that document (IT, 2001a). Specific requirements for Well ER-5-4 were outlined in Field Activity Work Plan Number D-002-001.01 (BN, 2001). A summary of drilling statistics for the well is given in Table 2-1. Figure 2-1 is a chart of the drilling and completion history for Well ER-5-4. The following information was compiled primarily from BN daily drilling reports.

2.2.2 Drilling History

Field operations at Well ER-5-4 began on January 24, 2001, when a BN crew began dry-augering a 121.9-cm (48-in.) diameter conductor hole. The conductor hole was completed the next day to a depth of 37.2 m (122 ft), and a string of 30-in. conductor casing was set at 36.3 m (119 ft). The bottom of the casing was cemented into place with neat type II cement, and the annulus was cemented to ground level. A short hiatus in the construction of Well ER-5-4 followed, during which the BN crew augered the "rat hole," "mouse hole," and anchor holes for Well ER-5-4, and drilled the conductor hole for the nearby planned Well ER-5-4#2.

The UDI crew rigged up the Wilson Mogul 42B rig from on February 7 to 10, 2001, and tagged cement at the depth of 34.7 m (114 ft). Drilling resumed with a center-punch assembly consisting of a

Table 2-1
Abridged Drill Hole Statistics for Well ER-5-4

LOCATION DATA:

Coordinates:	Nevada State Plane (central zone):	NAD 83:	N 6,230,353.7 m	E 562,655.5 m
		NAD 27:	N 755,751.3 ft	E 705,819.9 ft
	Universal Transverse Mercator:	NAD 83:	N 4,075,874.5 m	E 592,364.5 m
Surface Elevation [a]:	954.5 m (3,131.7 ft)			

DRILLING DATA:

Spud Date:	2/11/2001 (main hole drilling with Wilson Mogul 42B rig)
Total Depth (TD):	1,137.5 m (3,732 ft)
Date TD Reached:	3/18/2001
Date Well Completed [b]:	3/31/2001
Hole Diameter:	121.9 cm (48 in.) from surface to 37.2 m (122 ft.); 66.0 cm (26 in.) from 36.6 to 289.9 m (120 to 951 ft); 44.5 cm (17.5 in.) from 289.9 to 510.5 m (951 to 1,675 ft); 31.1 cm (12.25 in.) from 510.5 m (1,675 ft) to TD of 1,137.5 m (3,732 ft).
Drilling Techniques:	Dry auger from surface to 37.2 m (122 ft); center-punch with a 17½-in. rotary bit mounted below a 26-in. hole opener to 39.6 m (130 ft); rotary drill with a 17½-in. bit and air-foam/ polymer in direct circulation from 39.6 to 312.1 m (130 to 1,024 ft). Rest of hole drilled using bentonite gel/polymer fluid in direct circulation. Ream with a 17½-in. bit mounted below a 26-in. hole-opener from 37.2 to 280.7 m (122 to 921 ft); clean out fill with 26-in. mill-tooth bit from 280.7 to 290.9 m (921 to 951 ft); clean out fill with a 17½-in. bit to 309.7 m (1,016 ft). Plug back hole with cement and re-drill with 17½-in. bit to 510.5 m (1,675 ft); rotary drill with 12¼-in. bit from 510.5 m to TD of 1,137.5 m (1,675 to 3,732 ft).

CASING DATA: 30-in. conductor casing, surface to 36.3 m (119 ft); 20-in. surface casing, surface to 279.1 m (915.5 ft); 13 d-in. intermediate casing, surface to 509.9 m (1,673.3 ft).

WELL COMPLETION DATA:

The completion string consists of 7 e-in. carbon-steel casing with an internal epoxy coating, connected to 5½-in. stainless-steel casing via an internally coated carbon-steel cross-over sub. The carbon-steel casing extends through the unsaturated zone approximately 279 m (915 ft) into the top of the saturated zone. The 14.13-cm (5.563-in.) outside-diameter (od) stainless-steel casing has a 12.82-cm (5.047-in.) inside diameter (id), is bull-nosed, and has two slotted intervals (listed below). A piezometer string of 6.2-cm (2.441-in.) id stainless-steel tubing (od of 7.303 cm [2.875 in.]), was installed in the annulus of the 20-in. casing and left unpacked. The slotted interval in the piezometer string is given below. Detailed data for the completion intervals are provided in Section 2.6 of this report.

Total Depth:	1,048.0 m (3,438.3 ft)	
Depth of Slotted Sections in 5½-in. Production Casing:	539.5 to 644.2 m (1,770.0 to 2,113.4 ft)	955.9 to 1,021.1 m (3,136.3 to 3,350.1 ft)
Depth of Sand Packs [c]:	522.7 to 545.0 m (1,715 to 1,788 ft)	918.7 to 930.9 m (3,014 to 3,054 ft)
Depth of Gravel Packs [c]:	545.0 to 650.1 m (1,788 to 2,133 ft)	930.9 to 1,095.8 m (3,054 to 3,595 ft)
Depth of Slotted Section in 2 f-in. Piezometer String [c]:	220.2 to 247.4 m (722.6 to 811.7 ft)	
Depth of Pump:	Not installed at time of completion.	
Water Depth [d]:	221.3 m (726 ft)	

DRILLING CONTRACTOR: United Drilling, Inc.

GEOPHYSICAL LOGS BY: Schlumberger, Colog, Inc., Desert Research Institute, Gyrodata, Inc.

SURVEYING CONTRACTOR: Bechtel Nevada

a Elevation of ground level at wellhead. 1929 National Geodetic Vertical Datum.
b Date completion string was cemented. Pump will be installed as needed for pumping or sampling.
c Gravel and sand adjacent to slotted intervals of 5½-inch casing only. Includes fill at 930.9 to 933.9 m (3,054 to 3,064 ft). Additional gravel layers were used as stemming outside blank casing sections. Piezometer string was not gravel-packed. See Table 2-5.
d Determined from gamma ray log run on February 16, 2001, prior to introduction of bentonite mud in the borehole (IT, 2001b).

WELL ER-5-4 SUMMARY

Activity	Date
Begin drilling conductor hole:	1/24/2001
Conductor hole completed and 30-in. casing set to 36.3 m (119 ft):	1/25/2001
Begin drilling 17 1/2-in. surface hole:	2/11/2001
Begin opening surface hole to 26-in.:	2/18/2001
20-in. casing set at 279.0 m (915.5 ft):	2/24/2001
13 3/8-in. surface casing set at 510.0 m (1,673.3 ft):	3/11/2001
Begin drilling 12 1/4-in. hole:	3/12/2001
Reach total drilled depth of 1,137.5 m (3,732 ft):	3/18/2001
Well completed:	3/31/2001

LEGEND

bbl	Barrels
BHA	Bottom hole assembly
BN	Bechtel Nevada
ft	foot (feet)
GL	ground level
in.	inch(es)
LCM	Lost-circulation material
m	Meter(s)
TD	Total depth
TIH	Trip into hole
TOC	Top of cement
TOH	Trip out of hole
WOC	Wait on cement

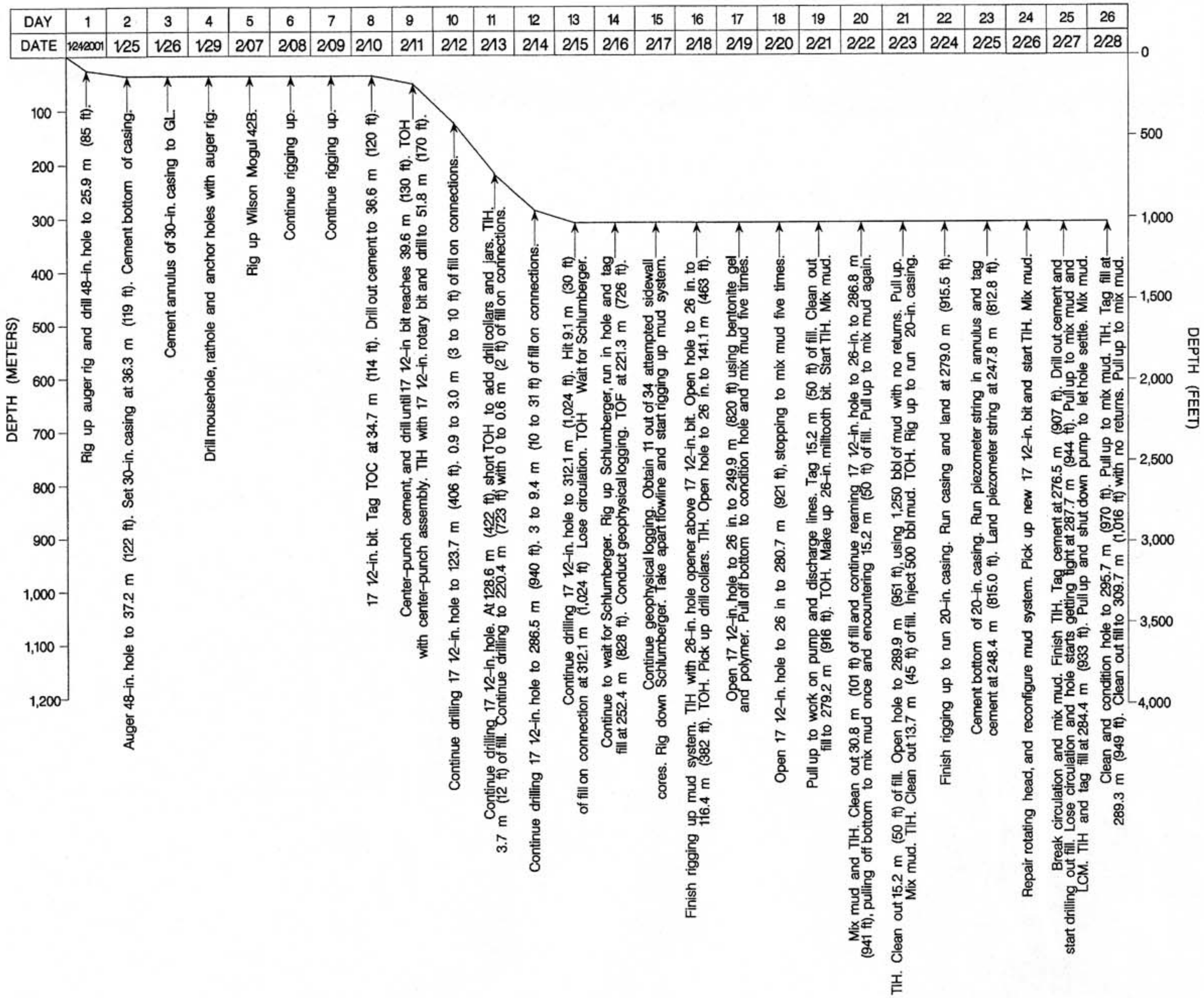


FIGURE 2-1
WELL ER-5-4
DRILLING AND COMPLETION HISTORY
SHEET 1 OF 2

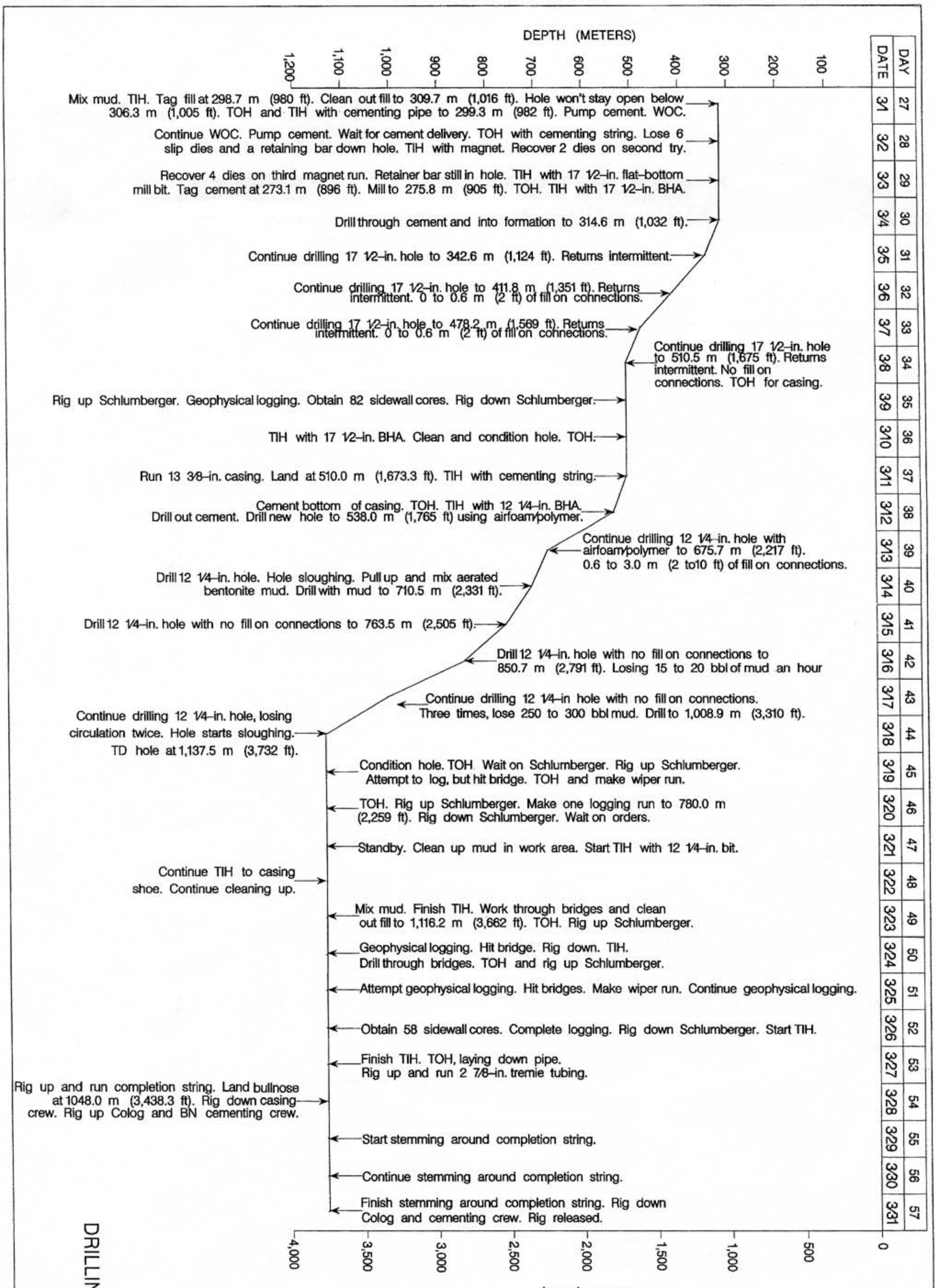


FIGURE 2-1
WELL ER-5-4
DRILLING AND COMPLETION
HISTORY
SHEET 2 OF 2

17½-in. rotary bit mounted below a 26-in. hole opener. When the hole opener had cleared the bottom of the conductor casing (hole depth at 39.6 m [130 ft]) , the center-punch assembly was replaced with a 17½-in. bottom-hole assembly (BHA), and drilling continued. The drilling fluid was a mix of air, water, and foam ("air-foam") in conventional circulation, with a polymer additive. As the hole deepened, as much as 3.7 m (12 ft) of fill material, sloughed from the borehole wall, was encountered whenever drilling was stopped to add drill pipe ("make a connection"). Below the static water level at approximately 221.3 m (726 ft), sloughing increased dramatically, with 3.0 to 9.4 m (10 to 31 ft) of fill encountered on each connection. In an effort to minimize sloughing and maintain circulation, additional foam and polymer were added to the drill-fluid mix, and another compressor was added. Drilling of the 44.5-cm (17½-in.) hole continued to a depth of 312.1 m (1,024 ft) on February 15, 2001, when circulation was lost. At that point drilling was stopped for geophysical logging, which was conducted February 16 to 17, 2001. Fill was tagged by loggers at 252.4 m (828 ft). The decision was made to install the surface casing to protect the upper part of the hole from additional erosion, and the NNSA/NSO project manager approved the use of bentonite mud (a heavier drill fluid) in an effort to stabilize the borehole.

After the new system for circulating the heavier mud was set up, drillers put together a BHA with a 26-in. hole-opener mounted above a 17½-in. rotary bit, and the next 4 days were spent cleaning out fill and opening the hole to allow installation of the 20-in. surface casing. Bentonite mud was used for reaming below the depth of 141.1 m (463 ft). Progress in opening the hole was slow due to difficulty in mixing enough mud to keep up with fluid loss to the formation. On February 21, 2001, when the hole had been opened to a depth of 280.7 m (921 ft), the BHA was replaced with a 26-in. mill-tooth bit. Reaming of the hole continued to 289.9 m (951 ft) with considerable difficulty due to sloughing of the borehole and the need to mix large amounts of bentonite mud to keep up with fluid loss.

A casing subcontractor set a string of 20-in. casing at 279.1 m (915.5 ft) on February 24, 2001. To cement the bottom of the casing, drill pipe was stabbed into the casing shoe, the seal was checked, and neat type II cement was pumped down the drill pipe. Water was then pumped down the pipe to displace the cement into the casing annulus. The top of cement in the annulus was later tagged at the depth of approximately 248.4 m (815 ft). No baskets were installed on the 20-in. casing, and the upper part of the annulus remains uncemented. A string of slotted 2 **f** -in. tubing was installed adjacent to the borehole wall in the annulus of the 20-in. casing, and landed at 247.8 m (812.8 ft), to serve as a piezometer (see Section 2.6).

The mud circulation system was modified to route cuttings to a shaker tray to aid in removing the thick bentonite mud from the cuttings. Drilling resumed on February 27, 2001, with bentonite mud and a new 17½-in. bit. Cement was drilled from inside the bottom of the casing from 276.5 to 279.2 m (907 to 916 ft), and drilling continued into fill. Progress was slowed by borehole sloughing and loss of circulation while drilling out fill. No fluid was returned during drilling from 283.5 to 309.7 m (930 to 1,016 ft). Lost-circulation material (LCM) consisting of cedar fiber and a commercial cellulose-based sealant was mixed into the mud to try to seal the borehole walls, but after reaching the depth of 309.7 m (1,016 ft) the drillers could not keep the borehole open. The decision was made to cement (or "plug back") and then re-drill the lower portion of the hole, so on March 1, 2001, the BHA was removed and open-ended drill pipe was installed to serve as a cementing string. The hole was cemented in 2 stages, with 16.1 cubic meters (570 cubic feet) of neat type II cement emplaced on the top of fill tagged at the depth of 308.5 m (1,012 ft). While the cement string was being tripped out, 6 slip dies and a retaining bar were lost in the hole. After 3 runs with a magnet, all 6 dies were recovered, but the retaining bar remained in the hole, so a 17½-in. flat-bottom mill bit was lowered into the hole, tagging the top of cement at 273.1 m (896 ft). After the retaining bar and cement were milled out to 275.8 m (905 ft), the mill bit was replaced with the standard 17½-in. BHA.

Drilling resumed through the cement plug, but alluvium found mixed with the cuttings indicates that the hole may have partially sidetracked the cement at 295.0 m (968 ft). On March 4, 2001, drilling reached the original hole depth of 312.1 m (1,024 ft), and over the next 4 days the hole was advanced with a 17½-in. bit to 510.5 m (1,675 ft), with little or no fill encountered on connections. A compressor was used to aerate drilling mud, and LCM was added to the mud, but returns of cuttings and mud were intermittent due to frequent loss of fluid to the formation.

The decision was made to stop drilling and set the intermediate casing at 510.5 m (1,675 ft), so drillers pulled the drill string up, waited for 30 minutes, and tripped back in to check for fill. None was found, so the drill string was removed and geophysical logging and sidewall sampling were conducted on March 9, 2001 (sidewall cores taken at the depths 290.8 and 296.9 m [954 and 972 ft] recovered only cement). After drillers made a "wiper run," the casing subcontractor landed a string of 13d-in. casing at the depth of 510.0 m (1,673.3 ft). Drill pipe was stabbed into the casing shoe, the seal was checked, and neat type II cement was pumped down the drill pipe to seal the bottom of the casing. The top of the cement in the annulus of the 13d-in. casing was later estimated with the aid of geophysical logs to be at 442.6 m (1,452 ft). No cement baskets were installed on the 13d-in. casing, and the top of the casing remains uncemented.

Drilling resumed on March 12, 2001, with a 12¼-in. bit and air-foam with polymer, but problems with borehole sloughing necessitated a return to the use of aerated bentonite mud below the depth of 694.0 m (2,277 ft). Drilling continued with intermittent loss of circulation, but little or no fill on connections. Drillers encountered increasing amounts of fill on connections below the depth of 1,115.6 m (3,660 ft), until reaching the TD of 1,137.5 m (3,732 ft) on March 18, 2001.

Immediately after reaching TD, the drillers circulated fluid for 3½ hours to clean and condition the hole. The drill string was pulled up, and after 30 minutes tripped back in to check for fill. An accumulation of 15.2 m (50 ft) of fill was found, but the third phase of geophysical logging was initiated. The logging crew could not work their tool past a bridge of fill material at 651.4 m (2,137 ft), so they rigged down and the drillers made a wiper run with the 12¼-in. bit. On the second logging attempt, it was possible to log to the depth of 780.0 m (2,559 ft), but at this time work was suspended because the amount of mud on the drill pad was causing a hazardous situation.

Crews spent the next 38 hours standing by while a plan was made to address the situation and cleaning up mud from the area during daylight hours. On March 23, 2001, drillers resumed reaming and cleaning out the hole in preparation for another attempt at geophysical logging. When logging was attempted the next day, loggers tagged fill at 1,100.0 m (3,609 ft), and successfully made one logging run; however, attempts to obtain other logs that day failed due to an obstruction in the hole at 553.5 m (1,816 ft). Once again, drillers cleaned out the hole, washing, reaming, and drilling through bridges. After more attempts at geophysical logging failed the next day, drillers made another wiper run. Loggers tagged fill at 1,095.8 m (3,595 ft) and successfully completed logging March 26, 2001. Installation of the completion string began on March 27, 2001. Demobilization from the Well ER-5-4 site began after gravel-packing and cementing were completed on March 31, 2001.

The directional survey run in the well on May 10, 2001, indicates that at the lowest surveyed depth of 951.6 m (3,122 ft) the hole had drifted 9.8 m (32 ft) to the southwest of the collar location, and that the hole is relatively straight (no “dog-legs”).

A graphical depiction of drilling parameters including penetration rate, revolutions per minute, pump pressure, and weight on the bit is presented in Appendix A-1. See Appendix A-2 for a listing of tubing and casing materials. Drilling fluids and cements used in Well ER-5-4 are listed in Appendix A-3.

2.2.3 Drilling Problems

Significant drilling problems associated with borehole instability were encountered at Well ER-5-4. Sloughing of material from the borehole wall produced large "washouts" and frequently produced up to 15.2 m (50 ft) of fill on connections, especially below the static water level. Loss of fluid circulation was also a problem. Significant amounts of drilling fluid were lost to the formation, and drilling progress was frequently slowed for mixing additional fluid. It was necessary to use bentonite mud and LCM in an effort to stabilize the borehole and maintain circulation. Because of poor drilling conditions, the interval from 279.2 to 308.5 m (916 to 1,012 ft) was cemented and re-drilled. However, similar difficulties persisted to the termination of drilling. Drilling continued 70.7 m (232 ft) below the originally planned depth of 1,066.8 m (3,500 ft) in an effort to tag the top of the volcanic rocks which were encountered at approximately 1,118.6 m (3,670 ft).

2.2.4 Fluid Management

This section provides a summary of fluid management activities during drilling operations at Well ER-5-4. Much of the information presented is from IT (2001b) where additional fluid management information is available. Fluids and drill cuttings produced during drilling operations at Well ER-5-4 were managed according to the methods prescribed in the UGTA FMP (DOE/NV, 1999) and associated state-approved waivers (Liebendorfer, 2000).

To manage the anticipated water production, 2 sumps (infiltration basins) were constructed prior to drilling (Figure 1-2). Each sump has a capacity of 2,029.6 cubic meters (71,675 cubic feet) or 536,322 gallons at a 3.0-m (10-ft) fluid level. No contaminants were expected during drilling at this site, so neither sump was lined prior to drilling. Two overflow pipes were installed in the western-most sump (Sump #1), but no overflow pipes were installed in Sump #2.

The drill fluid was circulated down the inside of the drill string and back up the hole through the annulus (conventional or direct circulation) and then discharged into a sump. Return fluids were piped to Sump #1 until bentonite mud was added to the fluid mix; returns were then diverted to Sump #2. Overflow fluids from Sump #1 were discharged to a trench that connects to the "Cambric ditch" which ultimately conveys fluids to the Frenchman Flat playa. When the shaker tray was installed for removal of mud from the cuttings, a trench was constructed to allow the excess mud to flow to Sump #2.

Water used to prepare drilling fluids came from fill stands located at the Radioactive Waste Management Site (RWMS) in Area 5 and in Mercury, in Area 23. Water from various NTS water wells on the site water well system feeds these fill stands; the stands typically may contain a mix of waters from Water Well 4, Water Well 4a, or the Army Well. Lithium bromide (LiBr) was added to the drill fluid as a tracer to provide a means of estimating groundwater production. The rate of water inflow was estimated from the dilution of the tracer in the drill fluid returns. However, loss of circulation and use of bentonite mud prevented monitoring of LiBr dilution in several intervals.

Samples of drilling effluent were tested onsite hourly for the presence of tritium, and every 8 hours for lead. The onsite monitoring results indicate that lead was undetectable (less than 50 parts per billion) during the entire drilling operation, and tritium remained at background levels (IT, 2001b). However, slightly elevated tritium levels (up to 5,028 pCi/L) were detected in the depth interval 274.3 to 312.4 m (900 to 1,025 ft).

Before fluids are discharged from a sump through the overflow pipe, the UGTA FMP requires that a sample be collected from the sump and analyzed offsite to verify onsite monitoring data and demonstrate compliance with the FMP. Duplicate samples were collected from Sump #1 on February 14, 2001, before the sump filled to the level of the overflow pipes, but the analytical results were not available before it was necessary to divert fluids from Sump #1 to Sump #2. A leaking (closed) valve released approximately 881 liters (200 gallons) to the ground surface at this time. While the sample was being analyzed, the bottom of the surface hole was reached and geophysical logging was begun. The analytical results obtained on February 16, 2001, showed that the sump fluids were within the parameters of the FMP criteria, and discharge of fluid from Sump #1 was approved by NNSA/NSO. A sample was collected from Sump #2 before approval was given by NNSA/NSO to transfer fluids from Sump #2 to a borrow pit on the east side of the drill site. The results of this analysis indicated that the sample was within the parameters of the FMP criteria. Samples from both sumps were also collected and analyzed at the end of drilling operations. Water-quality data for all 5 sump samples are provided in Appendix B.

The results of analyses of samples of drilling fluid collected at Well ER-5-4 during drilling operations indicate that all fluid quality objectives were met, as shown on the fluid management reporting form dated September 25, 2001 (Appendix B). The form lists volumes of solids (drill cuttings) and fluids produced during well-construction operations, Stages I and II (i.e., vadose- and saturated-zone drilling only; well development and aquifer testing will be conducted as a separate initiative). The volume of solids produced was calculated using the diameter of the borehole (from caliper logs) and the depth drilled, and includes added volume attributed to a rock bulking factor. The volumes of fluids listed on the report are estimates of total fluid production, and do not account for any infiltration or evaporation of fluids from the sumps.

2.3 Geologic Data Collection

This section describes the sources of geologic data obtained from Well ER-5-4 and the methods of data collection. Improving the understanding of variations within the alluvial section and gaining information on the volcanic rocks beneath the alluvium in this part of the Frenchman Flat basin were among the primary objectives of Well ER-5-4, so the proper collection of geologic and hydrogeologic data from Well ER-5-4 was considered fundamental to successful completion of the project. The geology of this site is presented in Section 4.0.

Geologic data collected at Well ER-5-4 consist of drill cuttings, sidewall core samples, and geophysical logs. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures.

2.3.1 Collection of Drill Cuttings

Composite drill cuttings samples were collected from Well ER-5-4 at 3-m (10-ft) intervals as drilling progressed from the depth of 36.6 m (120 ft) to the TD of the well at 1,137 m (3,732 ft). Cuttings samples were collected from 301 intervals. The effort was made to obtain enough material for triplicate samples, each consisting of approximately 550 cubic centimeters (cc) (1 pint) of drill cuttings, in each 3-m (10-ft) sample interval. However, in the lower portion of the hole the volume of cuttings was low, and some samples are composites of materials from intervals as great as 9.1 to 21.3 m (30 to 70 ft). Also, no samples were collected in several intervals where drill fluid was not returned to the surface. The drill cuttings samples are stored under secure, environmentally controlled conditions at the U.S. Geological Survey (USGS) Geologic Data Center and Core Library in Mercury, Nevada. One of these sample sets was sealed with custody tape at the rig site and remains sealed as an archive sample; one set was left unsealed in the original sample containers; and the third set was washed and stored according to standard USGS Core Library procedures. The washed set was used by BN to construct the detailed lithologic log presented in Appendix C-1.

The IT field representative collected an additional 2 sets of reference drill cuttings samples (approximately 15 cc) from each of the sample intervals. One set was examined at the drill site for use in preparing field lithologic descriptions, and remains in the custody of IT (now Stoller-Navarro, IT and Shaw's successor and the current environmental contractor for NNSA/NSO). The other set was sent to R. G. Warren at LANL for petrographic, mineralogic, and chemical analyses, where it remains.

2.3.2 Sidewall Core Samples

A Schlumberger percussion gun tool was used to collect sidewall core samples from 154 locations in Well ER-5-4. These samples were collected primarily to support a study by project scientists to characterize the distribution of reactive minerals within the alluvium in Frenchman Flat. The sidewall samples were also very valuable as sources of geologic data to supplement the generally poor cuttings samples. Sample locations were selected by the IT Field Representative on the basis of field lithologic logs (with consideration of borehole conditions determined from caliper logs). Eleven sidewall cores were obtained in the upper 231.6 m (760 ft) of the borehole on February 17, 2001, prior to installation of the surface casing. Prior to installation of the intermediate casing, Schlumberger collected 83 sidewall cores from the interval 290.8 to 506.0 m (954 to 1,660 ft). The final 60 sidewall samples were obtained from the lower part of the borehole before the completion string was installed. Table 2-2 1ists the core length recovered for each sample depth.

2.3.3 Sample Analysis

Nine samples of drill cuttings and 154 sidewall core samples from various depths in Well ER-5-4 were submitted to the LANL Earth and Environmental Sciences Division - Geology and Geochemistry laboratories for petrographic, mineralogic, and chemical analyses. Table 2-3 lists sample depth and type, and the analyses performed on each sample. Analytical results and interpretations were incorporated into the detailed lithologic log for Well ER-5-4 presented in Appendix C of this report, and in the discussion of the geology of the well presented in Section 4.0. More detailed information on the analytical results and interpretations is provided in Warren et al. (2002).

2.3.4 Geophysical Data

Geophysical logs were run in the borehole to further characterize the lithology, structure, and water content of the rocks encountered. In addition, logs were run to evaluate borehole conditions, to determine the fluid levels during the course of drilling, and to monitor completion progress. Geophysical logging was conducted during 3 stages of drilling and completion: prior to setting surface casing, prior to installing the completion well casing, and during well installation (annulus investigation log). Some logs were run in both the saturated and unsaturated zones of the borehole, while others (e.g., thermal flow log, chemistry log, ultrasonic borehole imager log, etc.) were run only in the saturated interval. A complete listing of the logs, dates run, depths, and service companies is provided in Table 2-4. The logs are available from BN in Mercury, Nevada, and copies are on file at the Stoller-Navarro office in Las Vegas, Nevada. Preliminary geophysical data from the logs are reproduced in Appendix D.

Table 2-2
Percussion Gun Sidewall Core Samples from Well ER-5-4
(Page 1 of 2)

Core Depth meters (feet)	**Length Recovered** cm (in.)
192.0 (630)	4.06 (1.6)
196.9 (646)	0.51 (0.2)
202.4 (664)	0.25 (0.1)
204.8 (672)	5.08 (2.0)
210.3 (690)	5.08 (2.0)
211.8 (695)	1.02 (0.4)
214.0 (702)	1.52 (0.6)
226.2 (742)	2.54 (1.0)
227.7 (747)	2.03 (0.8)
229.2 (752)	0.51 (0.2)
231.6 (760)	2.54 (1.0)
290.8 (954)	2.54 (1.0)
296.3 (972)	2.54 (1.0)
315.5 (1,035)	3.18 (1.25)
316.1 (1,037)	2.54 (1.0)
317.0 (1,040)	1.27 (0.5)
318.5 (1,045)	3.18 (1.25)
320.0 (1,050)	3.18 (1.25)
321.9 (1,056)	3.81 (1.5)
322.5 (1,058)	1.27 (0.5)
323.1 (1,060)	2.54 (1.0)
324.6 (1,065)	1.27 (0.5)
326.1 (1,070)	3.18 (1.25)
326.4 (1,071)	5.08 (2.0)
326.7 (1,072)	3.81 (1.5)
327.1 (1,073)	5.08 (2.0)
327.4 (1,074)	5.08 (2.0)
327.7 (1,075)	5.08 (2.0)

Core Depth meters (feet)	**Length Recovered** cm (in.)
328.0 (1,076)	3.18 (1.25)
328.6 (1,078)	5.08 (2.0)
329.2 (1,080)	4.45 (1.75)
330.7 (1,085)	5.08 (2.0)
332.2 (1,090)	1.91 (0.75)
333.5 (1,094)	2.54 (1.0)
333.8 (1,095)	1.91 (0.75)
338.9 (1,112)	2.54 (1.0)
339.5 (1,114)	5.08 (2.0)
342.3 (1,123)	3.18 (1.25)
352.0 (1,155)	1.27 (0.5)
356.6 (1,170)	3.81 (1.5)
359.7 (1,180)	2.54 (1.0)
361.5 (1,186)	5.08 (2.0)
367.0 (1,204)	.05 (.02)
368.2 (1,208)	4.45 (1.75)
368.8 (1,210)	5.08 (2.0)
369.7 (1,213)	3.18 (1.25)
374.9 (1,230)	3.81 (1.5)
377.3 (1,238)	3.18 (1.25)
385.9 (1,266)	1.27 (0.5)
387.1 (1,270)	1.91 (0.75)
390.4 (1,281)	1.27 (0.5)
395.3 (1,297)	5.08 (2.0)
396.2 (1,300)	3.81 (1.5)
400.8 (1,315)	1.27 (0.5)
406.6 (1,334)	3.81 (1.5)
411.5 (1,350)	3.18 (1.25)

Core Depth meters (feet)	**Length Recovered** cm (in.)
413.0 (1,355)	1.91 (0.75)
414.5 (1,360)	3.18 (1.25)
415.4 (1,363)	4.45 (1.75)
415.7 (1,364)	1.91 (0.75)
416.1 (1,365)	2.54 (1.0)
416.4 (1,366)	2.54 (1.0)
416.7 (1,367)	1.91 (0.75)
417.6 (1,370)	3.18 (1.25)
418.8 (1,374)	4.45 (1.75)
420.6 (1,380)	5.08 (2.0)
422.1 (1,385)	1.27 (0.5)
423.7 (1,390)	2.54 (1.0)
425.2 (1,395)	1.27 (0.5)
427.9 (1,404)	1.91 (0.75)
428.2 (1,405)	2.54 (1.0)
432.8 (1,420)	5.08 (2.0)
434.0 (1,424)	5.08 (2.0)
435.9 (1,430)	0.64 (0.25)
437.4 (1,435)	2.54 (1.0)
448.1 (1,470)	5.08 (2.0)
451.1 (1,480)	3.18 (1.25)
452.3 (1,484)	4.45 (1.75)
457.2 (1,500)	5.08 (2.0)
457.8 (1,502)	4.45 (1.75)
460.2 (1,510)	5.08 (2.0)
467.9 (1,535)	1.91 (0.75)
469.4 (1,540)	5.08 (2.0)
472.4 (1,550)	3.18 (1.25)

Table 2-2
Percussion Gun Sidewall Core Samples from Well ER-5-4
(Page 2 of 2)

Core Depth meters (feet)	Length Recovered cm (in.)
475.5 (1,560)	1.91 (0.75)
477.9 (1,568)	3.18 (1.25)
483.1 (1,585)	2.54 (1.0)
484.6 (1,590)	5.08 (2.0)
487.7 (1,600)	2.54 (1.0)
488.9 (1,604)	1.27 (0.5)
493.8 (1,620)	5.08 (2.0)
496.2 (1,628)	1.91 (0.75)
502.9 (1,650)	5.08 (2.0)
506.0 (1,660)	3.18 (1.25)
614.5 (2,016)	4.45 (1.75)
623.9 (2,047)	4.45 (1.75)
641.6 (2,105)	5.08 (2.0)
654.1 (2,146)	5.08 (2.0)
673.6 (2,210)	5.08 (2.0)
686.4 (2,252)	5.08 (2.0)
707.1 (2,320)	5.08 (2.0)
714.5 (2,344)	5.08 (2.0)
730.9 (2,398)	4.45 (1.75)
737.9 (2,421)	4.45 (1.75)
748.0 (2,454)	3.81 (1.5)
762.6 (2,502)	5.08 (2.0)
768.7 (2,522)	3.18 (1.25)
773.0 (2,536)	5.08 (2.0)
776.0 (2,546)	3.56 (1.4)
780.0 (2,559)	4.06 (1.6)
792.8 (2,601)	5.08 (2.0)
801.0 (2,628)	5.08 (2.0)
809.9 (2,657)	4.45 (1.75)
816.9 (2,680)	5.08 (2.0)
821.1 (2,694)	5.08 (2.0)
824.2 (2,704)	4.06 (1.6)
831.5 (2,728)	5.08 (2.0)
835.2 (2,740)	5.08 (2.0)
846.7 (2,778)	5.08 (2.0)
851.0 (2,792)	5.08 (2.0)
856.5 (2,810)	5.08 (2.0)
859.5 (2,820)	5.08 (2.0)
862.6 (2,830)	5.08 (2.0)
871.7 (2,860)	4.45 (1.75)
877.8 (2,880	4.45 (1.75)
887.0 (2,910)	5.08 (2.0)
902.2 (2,960)	3.81 (1.5)
914.4 (3,000)	3.18 (1.25)
922.3 (3,026)	5.08 (2.0)
928.7 (3,047)	4.06 (1.6)
937.9 (3,077)	4.45 (1.75)
949.5 (3,115)	4.06 (1.6)
960.4 (3,151)	5.08 (2.0)
971.1 (3,186)	0.05 (0..2)
979.6 (3,214)	4.45 (1.75)
990.6 (3,250)	5.08 (2)
999.7 (3,280)	3.81 (1.5)
1,006.4 (3,302)	4.32 (1.7)
1,013.5 (3,325)	5.08 (2.0)
1,024.4 (3,361)	1.91 (0.75)
1,031.4 (3,384)	3.81 (1.5)
1,036.3 (3,400)	5.08 (2.0)
1,041.5 (3,417)	5.08 (2.0)
1,044.9 (3,428)	0.51 (0.2)
1,051.6 (3,450)	4.45 (1.75)
1,058.3 (3,472)	3.81 (1.5)
1,060.7 (3,480)	3.56 (1.4)
1,064.4 (3,492)	3.18 (1.25)
1,067.4 (3,502)	3.81 (1.5)
1,075.9 (3,530)	5.08 (2.0)
1,081.1 (3,547)	2.54 (1.0)
1,083.3 (3,554)	5.08 (2.0)
1,086.9 (3,566)	3.18 (1.25)
1,091.2 (3,580)	5.08 (2.0)

All samples are Quaternary or Tertiary alluvium.

Table 2-3
Status of Rock Sample Analyses for Well ER-5-4

Depth meters (feet) [a]	Sample Type [b]	Analyses Performed [c]					
		Petrographic		Mineralogic		Chemical	
		PTS	SEM	MP	XRD	XRF	Fe^{2+}/Fe^{3+}
48.8 (160)	DC	C	--	--	--	--	--
192.0 (630)	SWC	C	--	--	C	C	C
204.8 (672)	SWC	--	--	--	C	C	C
231.6 (760)	SWC	C	C	C	C	--	--
286.5 (940)	DC	C	--	--	--	--	--
315.5 (1,035)	SWC	--	C	--	C	--	--
317.0 (1,040)	SWC	--	C	--	C	--	--
318.5 (1,045)	SWC	--	C	--	C	--	--
320.0 (1,050)	SWC	--	C	--	C	--	--
321.9 (1,056)	SWC	--	C	--	C	--	--
323.1 (1,060)	SWC	C	C	C	C	--	--
324.6 (1,065)	SWC	--	C	--	C	--	--
326.1 (1,071)	SWC	--	C	--	C	--	--
326.7 (1,072)	SWC	C	C	C	C	--	--
327.1 (1,073)	SWC	--	C	--	C	--	--
327.4 (1,074)	SWC	--	X	--	C	--	--
327.7 (1,075)	SWC	--	C	--	C	--	--
328.0 (1,076)	SWC	C	C	C	C	--	--
328.6 (1.078)	SWC	--	C	--	C	--	--
329.2 (1,080)	SWC	C	C	C	C	--	--
330.7 (1,085)	SWC	--	C	--	C	--	--
332.2 (1,090)	SWC	--	C	--	C	--	--
333.8 (1,095)	SWC	--	C	--	C	--	--
339.5 (1,114)	SWC	--	C	--	C	--	--
352.0 (1,155)	SWC	C	C	C	C	--	--
359.7 (1,180)	SWC	--	C	--	C	--	--
368.8 (1,210)	SWC	C	C	C	C	--	--

Table 2-3
Status of Rock Sample Analyses for Well ER-5-4 (continued)

Depth meters (feet) [a]	**Sample Type** [b]	**Analyses Performed** [c]					
		Petrographic		**Mineralogic**		**Chemical**	
		PTS	**SEM**	**MP**	**XRD**	**XRF**	**Fe^{2+}/Fe^{3+}**
377.3 (1,238)	SWC	--	C	--	C	--	--
387.1 (1,270)	SWC	--	C	--	C	--	--
396.2 (1,300)	SWC	--	C	--	C	--	--
406.6 (1,334)	SWC	C	C	C	C	--	--
411.5 (1,350)	SWC	--	C	--	C	--	--
413.0 (1,355)	SWC	--	C	--	C	--	--
414.5 (1,360)	SWC	--	C	--	C	--	--
415.4 (1,363)	SWC	--	C	--	C	--	--
415.7 (1,364)	SWC	--	C	--	C	--	--
416.1 (1,365)	SWC	--	X	--	C	--	--
416.4 (1,366)	SWC	C	C	--	C	--	--
416.7 (1,367)	SWC	--	X	--	C	--	--
417.6 (1,370)	SWC	--	C	--	C	--	--
418.8 (1,374)	SWC	--	C	--	C	--	--
420.6 (1,380)	SWC	--	X	--	C	--	--
422.1 (1,385)	SWC	--	X	--	C	--	--
423.7 (1,390)	SWC	--	C	--	C	--	--
425.2 (1,395)	SWC	C	C	C	C	--	--
427.9 (1,404)	SWC	C	C	C	C	--	--
428.2 (1,405)	SWC	--	C	--	C	--	--
432.8 (1,420)	SWC	C	C	C	C	--	--
437.4 (1,435)	SWC	C	--	--	C	C	C
451.1 (1,480)	SWC	C	C	--	C	--	--
457.2 (1,500)	SWC	--	C	--	C	--	--
469.4 (1,540)	SWC	--	--	--	C	C	C
477.9 (1,568)	SWC	--	--	--	C	C	C
487.7 (1,600)	SWC	C	C	C	C	--	--
493.8 (1,620)	SWC	--	--	--	C	C	C

Table 2-3
Status of Rock Sample Analyses for Well ER-5-4 (continued)

Depth meters (feet) [a]	**Sample Type** [b]	**Analyses Performed** [c]					
		Petrographic		**Mineralogic**		**Chemical**	
		PTS	**SEM**	**MP**	**XRD**	**XRF**	**Fe^{2+}/Fe^{3+}**
502.9 (1,650)	SWC	--	--	--	C	C	C
521.2 (1,710)	DC	--	--	--	C	C	C
536.4 (1,760)	DC	--	--	--	C	C	C
570.0 (1,870)	DC	--	--	--	C	C	C
609.6 (2,000)	DC	--	--	--	C	C	C
614.5 (2,016)	SWC	C	C	C	C	--	--
623.9 (2,047)	SWC	--	--	--	C	C	C
641.6 (2,105)	SWC	C	X	C	C	--	--
654.1 (2,146)	SWC	--	--	--	C	C	C
673.6 (2,210)	SWC	C	C	C	C	--	--
686.4 (2,252)	SWC	--	--	--	C	C	C
707.1 (2,320)	SWC	--	C	--	C	--	--
730.9 (2,398)	SWC	C	C	--	C	--	--
748.0 (2,454)	SWC	C	--	--	C	C	C
762.6 (2,502)	SWC	C	C	--	C	--	--
776.0 (2,546)	SWC	--	--	--	C	C	C
792.8 (2,601)	SWC	C	C	C	C	--	--
809.9 (2,657)	SWC	C	--	--	C	C	C
821.1 (2,694)	SWC	--	C	--	C	--	--
824.2 (2,704)	SWC	C	--	--	C	C	C
835.2 (2,740)	SWC	--	--	--	C	C	C
856.5 (2,810)	SWC	--	C	--	C	--	--
871.7 (2,860)	SWC	--	--	--	C	C	C
887.0 (2,910)	SWC	C	C	--	C	--	--
902.2 (2,960)	SWC	--	--	--	C	C	C
914.4 (3,000)	SWC	--	C	--	C	--	--
928.7 (3,047)	SWC	C	--	--	C	C	C
949.5 (3,115)	SWC	--	C	--	C	--	--

Table 2-3
Status of Rock Sample Analyses for Well ER-5-4 (continued)

Depth meters (feet) [a]	Sample Type [b]	Analyses Performed [c]					
		Petrographic		Mineralogic		Chemical	
		PTS	SEM	MP	XRD	XRF	Fe^{2+}/Fe^{3+}
960.4 (3,151)	SWC	--	--	--	C	C	C
979.6 (3,214)	SWC	C	C	C	C	--	--
990.6 (3,250)	SWC	--	--	--	C	C	C
1,006.4 (3,302)	SWC	C	C	C	C	--	--
1,024.4 (3,361)	SWC	C	--	--	C	C	C
1,036.3 (3,400)	SWC	--	C	--	C	--	--
1,051.6 (3,450)	SWC	--	--	--	C	C	C
1,067.4 (3,502)	SWC	C	C	C	C	--	--
1,083.3 (3,554)	SWC	C	--	--	C	C	C
1,091.2 (3,580)	SWC	--	--	--	C	C	C
1,103.4 (3,620)	DC	--	--	--	C	C	C
1,118.6 (3,670)	DC	--	--	--	C	C	C
1,133.9 (3,720)	DC	C	--	--	C	C	C

a Depth represents base of 3-m (10-ft) interval for drill cuttings.

b **DC** = drill cuttings sample; **SWC** = sidewall core sample.

c Status of analyses: **C** = analysis complete; **X** = SEM results were not obtained or were poor, due to surface charging; **--** = analysis not performed. Analysis type: **PTS** = polished thin section; **SEM** = scanning electron microscopy; **MP** = electron microprobe; **XRD** = x-ray diffraction; **XRF** = x-ray fluorescence; Fe^{2+}/Fe^{3+} = wet chemical analysis for iron.

Table 2-4
Well ER-5-4 Geophysical Log Summary
(Page 1 of 2)

Geophysical Log Type [a]	Log Purpose	Logging Service	Date Logged	Run Number	Bottom of Logged Interval [b] meters (feet)	Top of Logged Interval [b] meters (feet)
* Natural Gamma Ray Spectroscopy	Stratigraphic correlation, mineralogy, natural and man-made radiation, lithologic determination, fracture identification	Schlumberger	02/17/2001 03/09/2001 03/25/2001	SGR-1 SGR-2 SGR-3	243.2 (798) 496.8 (1,630) 1,090.6 (3,578)	36.3 (199) 194.5 (638) 460.2 (1,510)
* Four Arm Caliper/ Gamma Ray	Borehole conditions, cement volume calculation, fracture identification	Schlumberger	02/16/2001 03/09/2001 03/19/2001 03/20/2001 03/24/2001	CA4-1/GR-1 CA4-2/SGR-2 CA4-3/GR-4 CA4-4/GR-5 CA4-5/GR-6	252.1 (827) 508.7 (1,669) 651.1 (2,136) 779.7 (2,558) 1,099.7 (3,608)	36.3 (119) 194.5 (638) 493.8 (1,620) 491.6 (1,613) 492.6 (1,616)
*Array Induction Log/Spontaneous Potential	Lithologic determination, stratigraphic correlation	Schlumberger	02/16/2001 03/09/2001	AIT-1/SP-1/GR-2 AIT-2/ SP-2/GR-3	250.0 (820) 505.4 (1,658)	36.3 (119) 235.3 (772)
* Epithermal Neutron/ Density	Total water content, rock porosity, stratigraphic correlation, lithologic determination	Schlumberger	02/16/2001 03/09/2001 03/25/2001	ENP-1/CDL-1/GR-2 ENP-2/CDL-2/GR-3 ENP-3/CDL-3/GR-7	246.9 (810) 502.3 (1,648) 1,090.3 (3,577)	36.6 (119) 235.3 (772) 395.6 (1,298)
* Dual Laterolog/ Spontaneous Potential	Water saturation, stratigraphic correlation, lithologic determination	Schlumberger	03/25/2001	DLL-1/ SP-3/GR-7	1,093.3 (3,587)	509.9 (1,673)
Digital Array Sonic - wave-form and variable density	Fracture identification	Schlumberger	03/25/2001	AC-1/ SGR-3	1,090.6 (3,578)	460.3 (1,510)
*Digital Array Sonic - porosity and travel time	Rock porosity, seismic properties	Schlumberger	03/25/2001	AC-1/ SGR-3	1,090.6 (3,578)	460.3 (1,510)
Ultrasonic Borehole Imager	Lithologic characterization, structural analysis, fracture identification	Schlumberger	03/26/2001	BHTV-1	1,082.0 (3,550)	509.9 (1,673)
Temperature	Groundwater temperature, open fracture identification	Schlumberger	03/19/2001 03/20/2001 03/24/2001 03/26/2001	TL-1/GR-4 TL-2/GR-5 TL-3/GR-6 TL-4/GR-8	638.3 (2,094) 765.1 (2,510) 1,087.8 (3,569) 1,091.0 (3,579)	480.1 (1,575) 482.2 (1,582) 486.5 (1,596) 487.8 (1,600)

Table 2-4
Well ER-5-4 Geophysical Log Summary
(Page 2 of 2)

Geophysical Log Type [a]	Log Purpose	Logging Service	Date Logged	Run Number	Bottom of Logged Interval [b] meters (feet)	Top of Logged Interval [b] meters (feet)
Percussion Sidewall Coring Tool	Geologic Samples	Schlumberger	02/17/2001 03/09/2001 03/26/2001	SGUN-1 SGUN-3, 4, 5 SGUN-6, 7	231.7 (760) 506.0 (1,660) 1,091.2 (3,580)	184.7 (606) 290.8 (954) 614.5 (2,016)
Thermal Flow Log	Rate and direction of groundwater flow in borehole	Desert Research Institute	07/13/2001	TFM-1	1,025.7 (3,365)	518.2 (1,700)
Chemistry/Temperature Log	Groundwater chemistry and temperature, formation transmissivity	Desert Research Institute	07/13/2001	Chem-1/TL-5	1,046.4 (3,433)	221.6 (727)
Nuclear Annulus Investigation Log	Well construction monitoring	Colog	03/28-31 2001	AIN-1	1,047.9 (3,438)	495.3 (1,625)
Gyroscopic Directional Survey	Bottom hole location, true vertical depth	Gyrodata	05/10/2001	GDS-1	951.6 (3,122)	0

a Logs presented in geophysical log summary, Appendix D, are indicated by *.

b Depth below ground surface.

2.4 Hydrology of Well ER-5-4

Well ER-5-4 is located in central Frenchman Flat near the southernmost of two areas of underground nuclear test locations. Hydrologic data in this area are concentrated along a north-south band in the center of the valley, but various workers have developed potentiometric maps and hydrologic interpretations for the area from these previously existing data. These interpretations were used to estimate the expected water level at Well ER-5-4 and to plan for handling water production, as described in IT (2000, 2001a). The two closest wells to Well Cluster ER-5-4 are Wells RNM-1 and RNM-2, located 295.7 m (970 ft) west-southwest.

2.4.1 Preliminary Water-Level Information

The elevation of the water table at Well ER-5-4 was projected to be approximately 733.7 m (2,407 ft), as derived from sparse hydrologic data for this region (IT, 2000). Based on the pre-construction estimate of surface elevation at the site, depth to water was expected at approximately 219.4 m (720 ft) (IT, 2000). Fluid depths between 185.9 and 221.3 m (610 and 726 ft) were obtained from various geophysical logs run on February 16 and 19, 2001, and March 25 and 26, 2001, before the completion string was installed. The most reliable of these measurements, made before the introduction of heavy bentonite mud into the borehole, was 221.3 m (726 ft) obtained on February 16, 2001, when the borehole was at the depth of 312.1 m (1,024 ft) (IT, 2001b). Based on this preliminary fluid depth and the as-built surface elevation of 954.5 m (3,131.7 ft), the fluid level elevation at Well ER-5-4 is 733.3 m (2,405.7 ft). This is approximately 0.4 m (1.3 ft) below the predicted elevation of 734 m (2,407 ft). A transducer for monitoring of the water level was not installed at the time of completion.

2.4.2 Water Production

Water production was estimated during drilling of Well ER-5-4 on the basis of LiBr dilution data as measured by IT field personnel. Measurable water production (approximately 19 lpm [5 gpm]) began when the borehole had reached the depth of about 223.1 m (732 ft). The production rate increased rapidly to about 1,514 lpm (400 gpm) at the depth of about 305 m (1,000 ft). Fluid circulation was lost at the depth of 312.1 m (1,024 ft). Because of borehole instability problems, the hole was cased to the depth of 279.0 m (915.5 ft), and then finally cemented up to the depth of 273.1 m (896 ft) and re-drilled, then cased again to the depth of 510.0 m (1,673.3 ft). Water production was not measured during these operations. When drilling resumed, water production could be measured, and increased to approximately 2,271 lpm (600 gpm) at the depth of about 310 m (2,000 ft). Below that depth, most of the drill fluid was lost to the formation, and no water was produced from the borehole. All measurable water production was from the alluvial aquifer. Estimated water production rates are presented graphically in Appendix A-1.

2.4.3 Preliminary Flow Meter and Chemistry Log Data

Flow meter data, along with temperature, electrical conductivity (EC), and pH measurements, can be used to characterize borehole fluid variability, which may indicate inflow and outflow zones. Typically, these measurements are made before the completion string is installed, and the data are consulted during planning of zones to be completed. At Well ER-5-4, these data were collected approximately 3½ months after the completion string was installed, following partial development of the well by pumping (these pumping operations will be described in a separate report). Desert Research Institute (DRI) personnel made measurements inside the Well ER-5-4 completion string with their thermal flow meter (TFM) and chemistry tools on July 13, 2001.

DRI personnel obtained TFM measurements at 7 locations between the depths of 541.0 and 1,019.6 m (1,775 and 3,345 ft). Preliminary analysis of these data indicates a downward flow of water within the borehole at all 7 stations.

In addition, DRI ran a chemistry log, which included measurements of temperature, EC, and pH, from 221.6 to 1,046.4 m (727 to 3,433 ft). Groundwater temperature gradually increased from the minimum reading of 23.2 degrees Celsius (C) (73.8 degrees Fahrenheit [F]) at the top of the fluid column to the deepest logged depth near the bottom of the completion string. The maximum temperature of 33.6 degrees C (92.5 degrees F) was measured at 1,046.1 m (3,432 ft). A slight perturbation in the temperature curve was noted near the top of the uppermost cement section around the 5½-in. production casing.

2.4.4 Preliminary Groundwater Characterization Samples

No preliminary groundwater characterization samples were collected from Well ER-5-4 after drilling, because of the residual bentonite mud in the borehole, and because it was expected that samples would soon be collected during upcoming development and testing operations.

2.5 Precompletion and Open-Hole Development

No precompletion development was conducted in Well ER-5-4 due to borehole instability problems that persisted through geophysical logging operations and installation of the completion string.

2.6 Well Completion

Well completion refers to the installation in a borehole of a string of pipe (casing or tubing) that is slotted or screened at one or more locations along its length. The completion process also typically includes emplacement of backfill materials around the casing, with coarse fill such as gravel adjacent to the open intervals and impervious materials such as cement between the open intervals to isolate them. The casing serves as a conduit for insertion of a pump in the well, for inserting devices for measuring fluid level, and for sampling, so that accurate potentiometric and water chemistry data can be collected from known portions of the borehole.

Installation of the completion string and packing materials at Well ER-5-4 took place on March 27 to 31, 2001 (a pump was installed later to support hydrologic testing, which is documented elsewhere). Figure 2-2 is a schematic of the final well-completion design for Well ER-5-4, Figure 2-3 shows a plan view and profile of the wellhead surface completion, and Table 2-5 is a construction summary for the well. Data for this section were obtained from daily operations and activity reports, casing records, and cementing records provided by the BN Drilling Department. Information from IT's well data report (IT, 2001b) was also consulted for preparation of this section.

2.6.1 Well Completion Design

The final completion design differs slightly from the proposed design, as described in the following paragraphs.

2.6.1.1 Proposed Completion Design

The proposed completion design (IT, 2001a) was based on the assumption that Well ER-5-4 would penetrate a thick alluvial aquifer and reach TD in older Tertiary volcanic and volcaniclastic rocks of the tuff confining unit. The well was planned to be constructed with 2 completion zones, one near the base of the alluvial section, and the other in the middle of the saturated portion of the alluvium, with a piezometer installed just below the static water level. A string of 5½-in. stainless-steel casing with 2 slotted intervals would be installed to provide access to the lower and middle saturated alluvium. A string of 2 f -in. tubing would be installed outside the production casing, just below the static water level, to serve as a piezometer. The primary goal was to obtain separate completion zones within the top, middle, and bottom of the saturated alluvial aquifer.

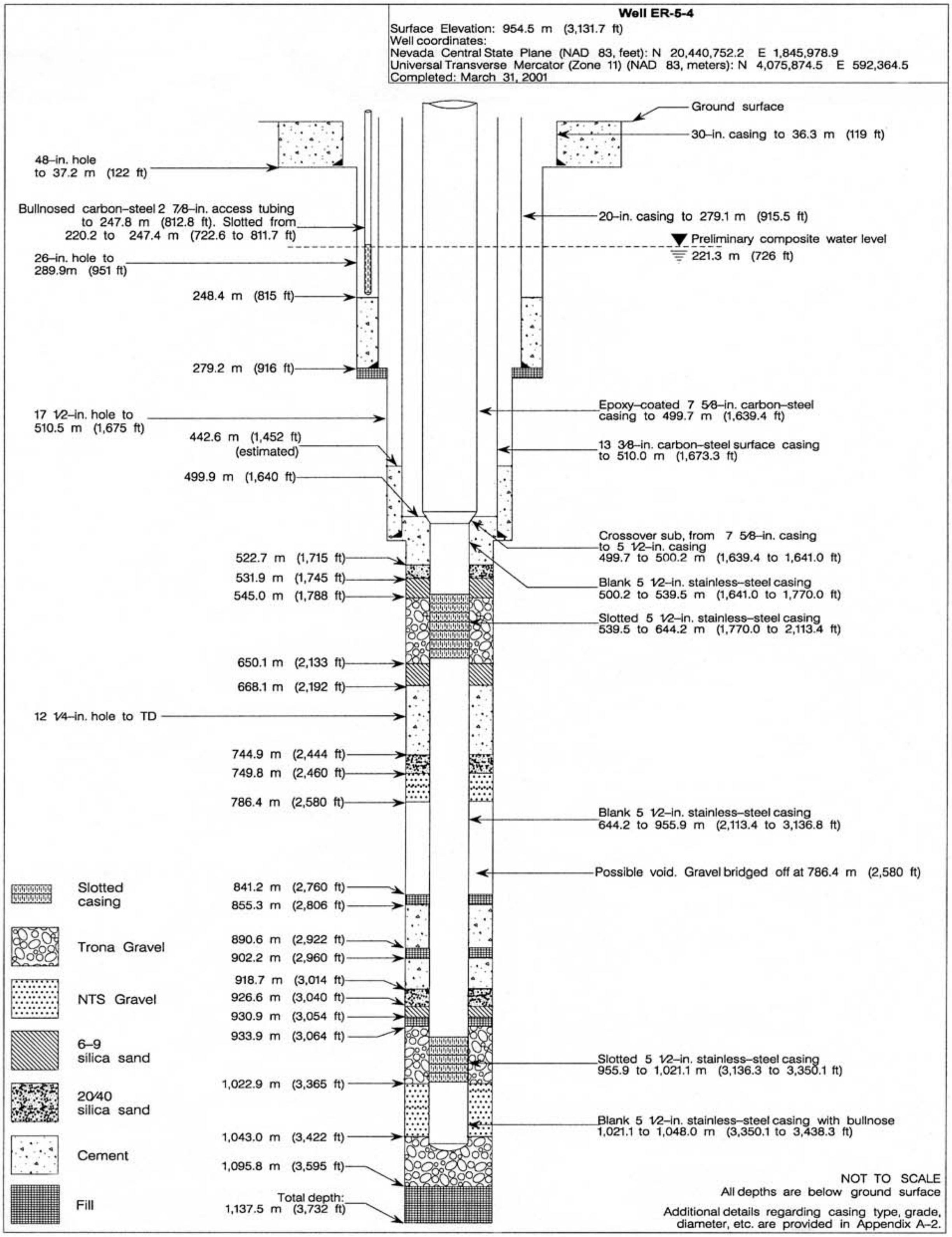


Figure 2-2
As-Built Completion Schematic for Well ER-5-4

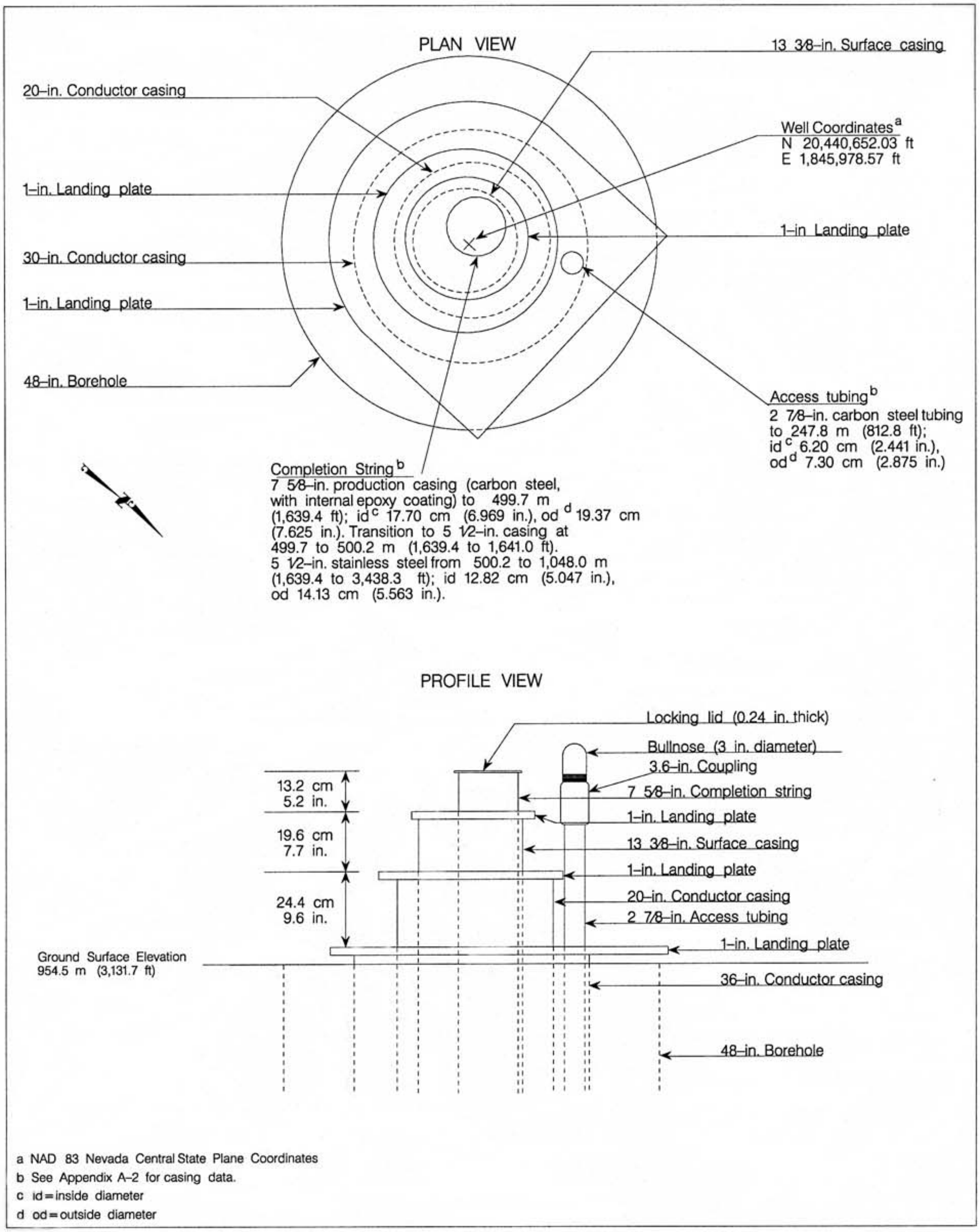


Figure 2-3
Wellhead Diagram for Well ER-5-4

Table 2-5
Completion String Construction Summary for Well ER-5-4

Casing and Tubing Types	Configuration meters (feet)		Cement	Sand/Gravel
2 f -in. stainless-steel tubing (piezometer)	0 to 247.7 (0 to 812.8)	Blank	None	None
		Slotted joints 220.2 to 247.4 (722.6 to 811.7)		
		Blank and bull-nosed 247.4 to 247.7 (811.7 to 812.8)		
7 e -in. carbon-steel production casing with internal epoxy coating	0 to 499.7 (0 to 1,639.4)	Blank	None	None
7 e -in. to 5½-in. cross-over sub, carbon-steel, with stainless-steel double pin	499.7 to 500.2 (1,639.4 to 1,641.0)		Type II 499.9 to 500.2 (1,640 to 1,641)	
5½-in. stainless-steel production casing	500.2 to 1,048.0 (1,641.0 to 3,438.3)	Blank 500.2 to 539.5 (1,641.0 to 1,770.0)	Type II 500.2 to 522.7 (1,641 to 1,715) Type II 668.1 to 744.9 (2,192 to 2,444) *Fill* *890.6 to 902.2* *(2,922 to 2,960)* Type II 902.2 to 918.7 (2,960 to 3,014)	20/40 Sand 522.7 to 531.9 (1,715 to 1,745) 744.9 to 749.8 (2,444 to 2,460) 918.7 to 926.6 (3,014 to 3,040) 6-9 Sand 531.9 to 545.0 (1,745 to 1,788) 650.1 to 668.1 (2,133 to 2,192) 926.6 to 930.9 (3,040 to 3,054) 3/8-in. x 4 Gravel [a] 545.0 to 650.1 (1,788 to 2,133) Possible Void [b] 786.4 to 841.2 (2,580 to 2,760) *Fill* *841.2 to 855.3* *(2,760 to 2,806)* *930.9 to 933.9* *3,054 to 3,064)* 3/8-in. x 4 Gravel [a] 933.9 to 1,095.8 (3,064 to 3,595)
		8 consecutive slotted joints 539.5 to 644.2 (1,770.0 to 2,113.4)		
		Blank 644.1 to 955.9 (2,113.4 to 3,136.3)		
		5 consecutive slotted joints 955.9 to 1,021.1 (3,136.3 to 3,350.1)		
		Blank and bull-nosed 1,021.1 to 1,048.0 (3,350.1 to 3,438.3)		

a Trona gravel except 2 sections of NTS gravel not adjacent to slotted intervals, at 749.8 to 786.4 m (2,460 to 2,580 ft) and 1,022.9 to 1,043.0 m (3,356 to 3,422 ft).
b Gravel bridge at 786.4 m (2,580 ft).

2.6.1.2 As-Built Completion Design

The design of the Well ER-5-4 completion was determined through consultation with members of the UGTA TWG, on the basis of onsite evaluation of data such as lithology and water production, drilling data (lost circulation, etc.), and data from various geophysical logs.

The as-built completion design for Well 5-4 provides access to the alluvial aquifer at 3 depths (Figure 2-2). The composition of the string summarized here is detailed on Table 2-5, and the casing materials are listed in Appendix A-2. The lower section of the completion string, from 500.2 to 1,048.0 m (1,641.0 to 3,438.3 ft), is stainless-steel 5½-in. casing. The top of the 5½-in. casing is approximately 279 m (915 ft) below the static fluid level. The bottom 26.9 m (88.2 ft) of the string is blank and terminates in a bull-nose to serve as a sediment sump. Above the 5½-in. casing, a 0.49-m (1.6-ft) long cross-over sub serves as the transition to the upper part of the string, which is 7 e -in. carbon-steel production casing with an internal epoxy coating. A bull-nosed piezometer string of stainless-steel 2 f -in. tubing is set in the annulus of the 20-in. casing at a depth of 247.7 m (812.8 ft).

The lowest slotted interval, 955.9 to 1,021.1 m (3,136.3 to 3,350.1 ft), is open to sandy, Tertiary-age alluvium. This casing interval consists of 5 consecutive slotted joints. The upper slotted interval of the 5½-in. casing, 539.5 to 644.2 m (1,770.0 to 2,113.4 ft), consists of 8 consecutive slotted joints. It is open to sandy Quaternary or Tertiary alluvium. The piezometer string placed between the borehole wall and the 20-in. casing contains 3 consecutive slotted joints in the depth interval 220.2 to 247.4 m (722.6 to 811.7 ft). This completion zone is open to the upper alluvial aquifer at the top of the saturated zone and is not gravel packed (the annulus is open).

The openings in each slotted casing joint are 0.198 cm (0.078 in.) wide and 6.35 to 7.62 cm (2.5 to 3.0 in.) long, cut in rings of 18 slots (spaced 20 degrees apart around the joint). The rings are spaced 15.2 cm (6 in.) apart, and the longitudinal centers of the slots in each ring are staggered 10 degrees from the slot centers in the next ring. No slots are cut within 0.6 m (2 ft) of the ends of the slotted joints to assure that the strength of the pipe near the connections is not degraded.

The openings in the 2 f -in. piezometer tube are 5.715 cm (2.25 in.) long, and 0.030 cm (0.012 in.) wide, placed on staggered 15.2-cm (6-in.) centers.

2.6.1.3 Rationale for Differences between Actual and Proposed Well Design

The proposed well design was based on the expectation that the Well ER-5-4 borehole would penetrate the entire alluvial section and enter the underlying volcanic tuffs. The original plan to construct 3 completions in the lower, middle, and upper saturated alluvial sections was accomplished.

2.6.2 Well Completion Method

A "tremie" line and the completion string were landed after a brief period of circulation and conditioning of the hole. The 2 completion zones of the 5½-in. string were gravel-packed and isolated from each other with sand and cement barriers. One additional gravel layer (instead of cement) was placed adjacent to a blank interval (Figure 2-2; Table 2-5) to save time waiting for cement deliveries. Caliper logs were used to calculate the volumes of stemming materials needed during well completion. Well-construction materials were inspected according to relevant procedures; standard decontamination procedures were employed to prevent the introduction of contaminants into the well.

The filter pack around each open interval consists of 0.95-cm (**d**-in.) by 4-mesh washed pea gravel or "Trona" gravel. However, due to lack of availability of enough Trona gravel, gravel from the NTS batch plant was substituted in some of the blank intervals (see Table 2-5 and following paragraph). The gravel-packed sections of the lower 2 completion zones are topped with 6-9 Colorado silica sand directly above the gravel, and 20/40 sand on top of the 6-9 sand. In this stemming design, developed by the UGTA program at the NTS, the layer of 20/40 sand serves as a barrier to any fluids that might seep from the cement above, preventing cement fluids from contaminating the groundwater (fluids from the cement would have the effect of drastically raising the pH of the groundwater). The underlying layer of 6-9 sand prevents the 20/40 sand from infiltrating the gravel-packed interval. All cement used in stemming the completion string was type II Portland cement with no additives. A clear-water pre-flush and back-flush were made at each stage of emplacement. Gravel, sand, and cement were emplaced through a 2 **f**-in. Hydril® tremie line that was withdrawn as the completion process progressed. A nuclear annulus investigation log ("NAIL log") was used to monitor the emplacement of stemming materials. As-built positions of the well materials are shown on Figure 2-2 and listed in Table 2-5.

Stemming of the hole began with the first stage of Trona gravel emplaced from 1,095.8 to 1,043.0 m (3,595 to 3,422 ft) on top of 41.8 m (137 ft) of fill at the bottom of the hole. This layer of gravel is topped by a 20.1-m (66-ft) interval of NTS gravel, to the depth of 1,022.9 m (3,356 ft). Trona gravel was placed above the NTS gravel, adjacent to the lowest slotted interval. This gravel pack is topped by a 3-m (10-ft) interval of fill which sloughed from the borehole wall before sand could be added. The sand barrier extends from the top of the fill at 930.9 m (3,054 ft) to the depth of 918.7 m (3,014 ft), and is followed by cement, poured in 2 stages up to 855.3 m (2,806 ft). Between these 2 stages of cement, the NAIL log indicates that the borehole again sloughed, creating another layer of fill between 902.2 and 890.6 m (2,960 and 2,922 ft). The NAIL log indicates that after the second stage of cement had been poured, 14.0 m (46 ft) of fill was present on top of the cement. Stemming continued with a second layer of NTS gravel, but during emplacement the gravel "bridged off" in the hole, leaving a void space adjacent to the blank 5½-in. casing, between the top of the fill at 841.2 m (2,760 ft) and 786.4 m (2,580 ft). The borehole annulus is filled with gravel above this void to the depth of 749.8 m (2,460 ft). This gravel was topped with 20/40 sand to the depth of 744.9 m (2,444 ft), and cement, poured in 2 stages, to the depth of 668.1 m (2,192 ft). An interval of 6-9 sand was emplaced above the cement to a depth of 650.1 m (2,133 ft). The uppermost gravel section, located adjacent to the upper slotted interval of the 5½-in. casing, consists of Trona gravel, between the depths of 650.1 and 545.0 m (2,133 and 1,788 ft). This gravel pack is capped with sand to a depth of 522.7 m (1,715 ft). The final cemented section, poured in 3 stages, extends to the depth of 499.9 m (1,640 ft). The upper part of the hole containing the piezometer string was left open.

The drill rig was released after cementing was completed. Hydrologic testing was planned as a separate effort, so a pump was not installed in the well and no well development or pumping tests were conducted immediately after completion.

2.7 Actual versus Planned Costs and Scheduling

The original BN cost model developed for Well ER-5-4 was based on drilling to the planned TD of 1,066.8 m (3,500 ft). The drilling program baseline projected that it would require 30 days to drill and complete the well. However, the actual conditions encountered during drilling of the well (severe borehole instability; deeper than planned TD) were measurably different from predicted conditions so the baseline was changed during drilling.

The new cost model is based on the actual TD of 1,137.5 m (3,732 ft). It took 50 days to accomplish drilling of the surface and main holes, logging, and completion of the well, after construction of the conductor hole by BN. Drilling of the surface hole and installation of the 20-in. surface casing proceeded as expected. However, drilling of the production hole and installation of the completion casing took longer than predicted, and required installation of an intermediate casing string. A graphical comparison, by day, of planned and actual well-construction activities is presented in Figure 2-4.

The cost analysis for Well ER-5-4 begins with the movement of the UDI drill rig to the Well ER-5-4 site from the site of Well Cluster ER-5-3. The cost of building roads, the drill pad, and sumps is not included, and the cost of well-site support by IT is not included. The total construction cost for Well ER-5-4 includes all drilling costs: charges by the drilling subcontractor; charges by other support subcontractors (including compressor services, drilling fluids, bits, casing services, down-hole tools, and geophysical logging); and charges by BN for mobilization and demobilization of equipment, construction of the conductor hole, cementing services, completion materials, radiation technicians, inspection services, and geotechnical consultation.

The total planned cost for constructing Well ER-5-4, based on the new baseline developed because the actual conditions differed greatly from the expected conditions, was $3,286,909. The actual cost was $2,973,290, or 9.5 percent less than the planned cost. Figure 2-5 presents a comparison of the planned (new baseline) and actual costs, by day, for drilling and completing Well ER-5-4.

2.8 Summary, Recommendations, and Lessons Learned

2.8.1 Summary for Well ER-5-4

Subcontractor activities at Well Cluster ER-5-4 commenced on February 7, 2001, with the drilling of Well ER-5-4. Drilling of Well ER-5-4 concluded on March 18, 2001, when the TD of 1,137.5 m (3,732 ft) was reached. After geophysical logging, the completion string and piezometer were installed and the well was gravel-packed and stemmed to the depth of 499.9 m (1,640 ft) on March 27-31, 2001. Crews worked on a 7-days-per-week, 24-hours-per-day schedule for most of the operation. Fifty working days were expended to drill the surface and main holes, conduct geophysical logging, and install the completion string. Severe sloughing of the borehole wall during drilling, geophysical logging, and well-installation operations prolonged the construction of Well ER-5-4.

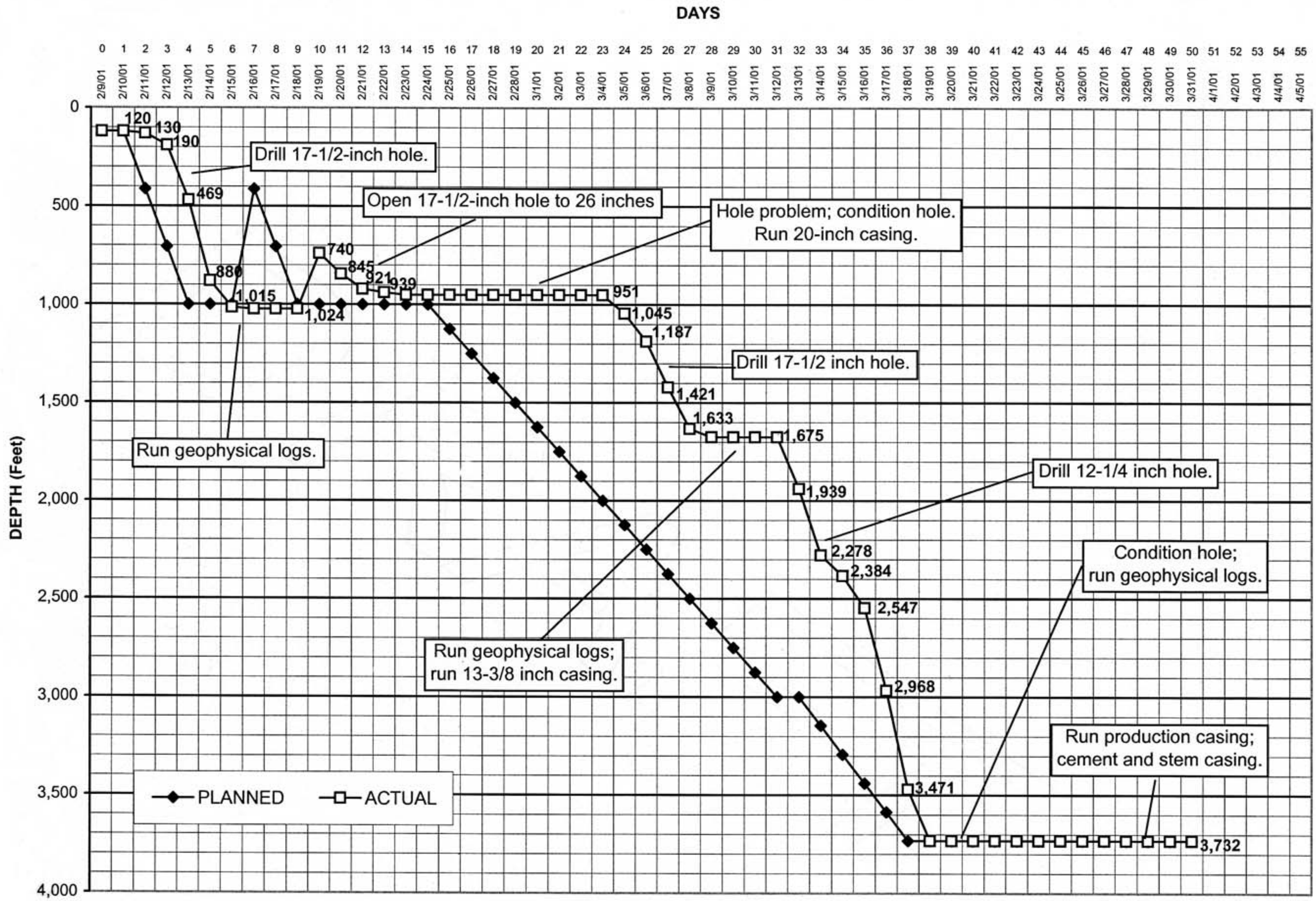


Figure 2-4
Planned versus Actual Construction Progress for Well ER-5-4

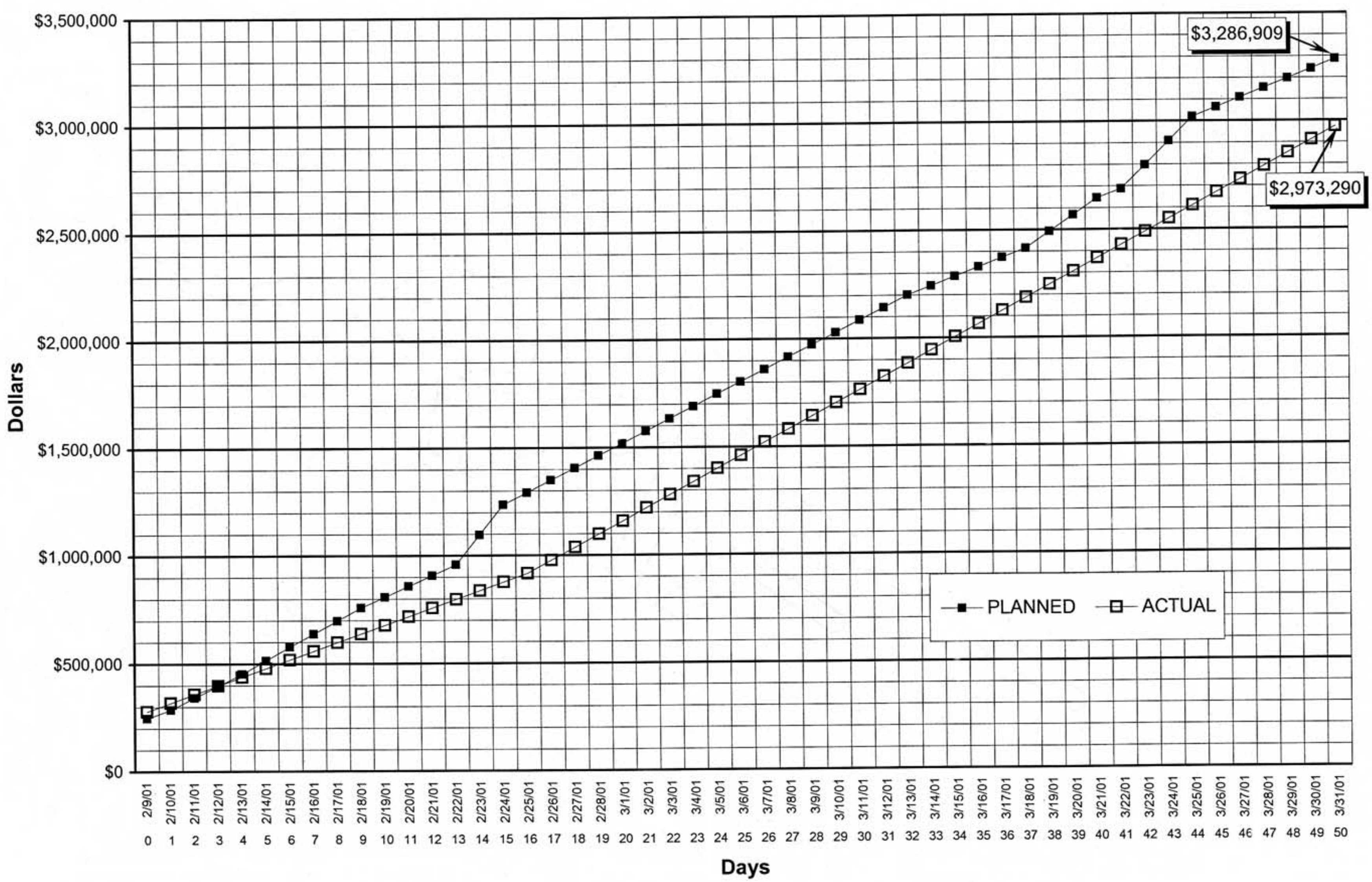


Figure 2-5
Planned versus Actual Cost for Constructing Well ER-5-4

No radionuclides above background were encountered in the groundwater produced during drilling of Well ER-5-4, except in the interval 274.3 to 312.4 m (900 to 1,025 ft), where slightly elevated tritium levels up to 5,028 pCi/L were measured. Preliminary (field-monitoring) data indicated no lead above permitted levels for dissolved lead in the drilling effluent.

A completion string with 2 gravel-packed, slotted intervals was installed in the lower portion of Well ER-5-4, and a piezometer string was installed in the upper, open portion of the hole. A string of 5½-in. stainless-steel casing installed below the water table is suspended from 7 e -in. carbon-steel casing that extends to the surface. The open intervals in the 5½-in. casing are centered within the gravel-packed intervals that are located at 933.0 to 1,095.8 m (3,054 to 3,595 ft) and 545.0 to 650.1 m (1,788 to 2,133 ft). The stainless-steel, 2 f -in. piezometer tube installed in the annulus of the 20-in. casing is open to the formation (saturated alluvium). A preliminary fluid depth was measured at 221.3 m (726.6 ft) before the addition of bentonite mud.

2.8.2 Recommendations

The planned pump installation, well development, groundwater sampling, and hydrologic testing must be conducted at Well ER-5-4 to accomplish the remaining objectives for this well-construction effort. In addition, after Well ER-5-4#2 is drilled, geologic, and hydrologic data must be evaluated and interpretations of the area hydrogeology updated and inserted into the UGTA hydrologic model. This process, in conjunction with interpretation of the 3-D seismic reflection survey conducted in this area, and followed by analysis of the updated model, will allow more precise characterization of groundwater flow direction and velocity in the Frenchman Flat CAU.

2.8.3 Lessons Learned from Well ER-5-4

Significant problems associated with borehole instability can occur while drilling alluvium in the central portions of Frenchman Flat. Severe sloughing and erosion of the borehole wall can occur even when drilling with bentonite mud, especially below the water table. The complete loss of circulation fluid, which is typically associated with fractured intervals in harder and more brittle units, can also occur while drilling alluvium in the central portions of Frenchman Flat. Additional casing strings and the use of cement plugs may be necessary to successfully drill through the alluvial section in Frenchman Flat.

3.0 Well ER-5-4#2

3.1 Well-Specific Objectives

The scientific objectives for Well ER-5-4#2 include those listed in Section 1.2. However, the specific goal of Well ER-5-4#2 was to penetrate through the volcanic rock section and into the underlying Paleozoic-age sedimentary rocks that at this location are thought to comprise the lower carbonate aquifer. Two completion zones were to be installed, one in the middle of the volcanic rock section which was expected to be a tuff confining unit, and the other in the upper part of the lower carbonate aquifer. The planned TD of the well was 1,889.8 m (6,200 ft), which was expected to place the bottom of the well approximately 61.0 m (200 ft) into the lower carbonate aquifer.

3.2 Drilling Summary

This section contains detailed description of the drilling process and fluid management issues.

3.2.1 Introduction

The general drilling requirements for Well ER-5-4#2 were provided in *Frenchman Flat Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 2000) and an addendum to that document (IT, 2001a). Specific requirements for Well ER-5-4#2 were outlined in Field Activity Work Plan Number D-006-001.02 (BN, 2002). A summary of drilling statistics for the well is given in Table 3-1. Figure 3-1 is a chart of the drilling and completion history for Well ER-5-4#2. The following information was compiled primarily from BN daily drilling reports.

3.2.2 Drilling History

Field operations at Well ER-5-4#2 began on January 25, 2001, when a BN crew began dry-augering a 121.9-cm (48-in.) diameter conductor hole. The conductor hole was completed on the next day to a depth of 35.1 m (115 ft), and on January 30, 2001, a string of 30-in. conductor casing was set at 33.8 m (111 ft). The bottom of the casing was cemented into place and the annulus of the conductor casing was cemented to ground level with neat type II cement. A hiatus of 17 months occurred between the construction of the conductor hole by BN and the beginning of work on the main hole by the drilling subcontractor, UDI.

Table 3-1
Abridged Drill Hole Statistics for Well ER-5-4#2

LOCATION DATA:

Coordinates:	Nevada State Plane (central zone):	NAD 83:	N 6,230,323.2 m	E 562,655.4 m
		NAD 27:	N 755,651.2 ft	E 705,819.6 ft
	Universal Transverse Mercator:	NAD 83:	N 4,075,844.0 m	E 592,364.5 m
Surface Elevation [a]:	954.5 m (3,131.7 ft)			

DRILLING DATA:

Spud Date:	07/16/2002 (main hole drilling with Wilson Mogul 42B rig)
Total Depth (TD):	2,133.6 m (7,000 ft)
Date TD Reached:	09/11/2002
Date Well Completed [b]:	09/18/2002
Hole Diameter:	121.9 cm (48 in.) from surface to 35.1 m (115 ft.); 66.0 cm (26 in.) from 35.1 m (115 ft.) to 311.8 m (1,023 ft.); 44.5 cm (17.5 in.) from 311.8 m (1,023 ft.) to 1,052.8 m (3,454 ft); 31.1 cm (12.25 in.) from 1,052.8 m (3,454 ft) to 1,573.7 m (5,163 ft); 22.2 cm (8.75 in.) from 1,573.7 m (5,163 ft) to 2,133.6 m (7,000 ft).
Drilling Techniques:	Dry-hole auger from surface to 35.1 m (115 ft); center-punch with 17½-in. rotary bit mounted below a 26-in. hole opener to 38.1 m (125 ft); rotary drilling with 17½-in. bit using an aerated mud/polymer/ soap mix and occasional LCM in direct circulation from 38.1 to 371.9 m (125 to 1,220 ft); open 44.5-cm (17.5-in.) diameter hole to 66.0 cm (26 in.) using a 26-in. hole opener mounted above a 17½-in. rotary bit, with aerated mud/polymer/soap in direct circulation from 35.1 to 371.9 m (115 to 1,220 ft); rotary drilling with 17½-in. bit using mud in direct circulation from 371.9 to 1,052.8 m (1,220 to 3,454 ft); rotary drilling with a 12¼-in. bit with mud in direct circulation from 1,052.8 1 to 573.7 m (3,454 to 5,163 ft); rotary drilling with 8¾-in. bit and mud in direct circulation from 1,573.7 m (5,163 ft) to TD of 2,133.6 m (7,000 ft).

CASING DATA: 30-in. conductor casing from surface to 33.8 m (111 ft); 20-in. surface casing from surface to 266.1 m (873.0 ft); 13**d**-in. intermediate casing from surface to 965.9 m (3,169.0 ft); 9 **e**-in. intermediate casing from surface to 1,477.9 m (4,848.8 ft).

WELL COMPLETION DATA:

The completion string consists of approximately 592.8 m (1,945 ft) of 14.1-cm (5½-in.) stainless steel casing hung from within the 24.4-cm (9**e**-in.) intermediate casing using a liner hanger positioned at 1,437.1 m (4,715 ft). The stainless steel casing has an outside diameter of 14.13-cm (5.563-in.) and an inside diameter of 12.8-cm (5.047 in.), is bull-nosed, and has a single slotted interval from 1,976.9 to 2,029.3 m (6,486 .0 to 6,657.7 ft) consisting of consecutive slotted joints. No sand or gravel packs were installed, and the casing was not cemented. No pumps were installed at time of completion.

Total Depth:	2,030.0 m (6,660 ft)
Depth of Slotted Sections in 5½-in. Production Casing:	1,976.9 to 2,029.3 m (6,486.0 to 6,657.7 ft)
Depth of Sand Packs:	None
Depth of Gravel Packs:	None
Depth of Pump:	Not installed at time of completion
Water Depth [c]:	215.7 m (707.6 ft)

DRILLING CONTRACTOR: United Drilling, Inc.

GEOPHYSICAL LOGS BY: Halliburton Energy Services, Desert Research Institute, Baker Hughes Inteq

SURVEYING CONTRACTOR: Bechtel Nevada

a Elevation of ground level at wellhead. 1929 National Geodetic Vertical Datum.
b Date completion string was cemented. Pump will be installed at a later date as needed.
c Measured on September 18, 2002 (IT, 2003).

WELL ER-5-4#2 SUMMARY

Activity	Date
Begin drilling conductor hole:	1/25/2001
Conductor hole completed and 30-in. casing set to 33.8 m (111.0 ft):	1/30/2002
Begin drilling 17 1/2-in. surface hole:	7/16/2002
Begin opening 17 1/2-in. hole to 26-in.:	7/24/2002
20-in. casing set at 266.1 m (873.0 ft):	7/29/2002
13 3/8-in. surface casing set at 965.9 m (3,169.0 ft):	8/18/2002
Begin drilling 12 1/4-in. hole:	8/20/2002
Reach total drilled depth of 2,133.6 m (7,000 ft):	9/11/2002
Well completed:	9/18/2002

LEGEND

BHA	Bottom hole assembly
DP	Drill pipe
DRI	Desert Research Institute
ft	foot (feet)
GL	Ground level
gpm	Gallons per minute
hr	hour(s)
HO	Hole opener
in.	inch(es)
LCM	Lost circulation material
lpm	Liters per minute
m	meter (meters)
ROP	Rate of penetration
SWC	Sidewall core
TD	Total depth
TIH	Trip into hole
TOC	Top of cement
TOH	Trip out of hole
UDI	United Drilling Inc.
WOC	Wait on cement

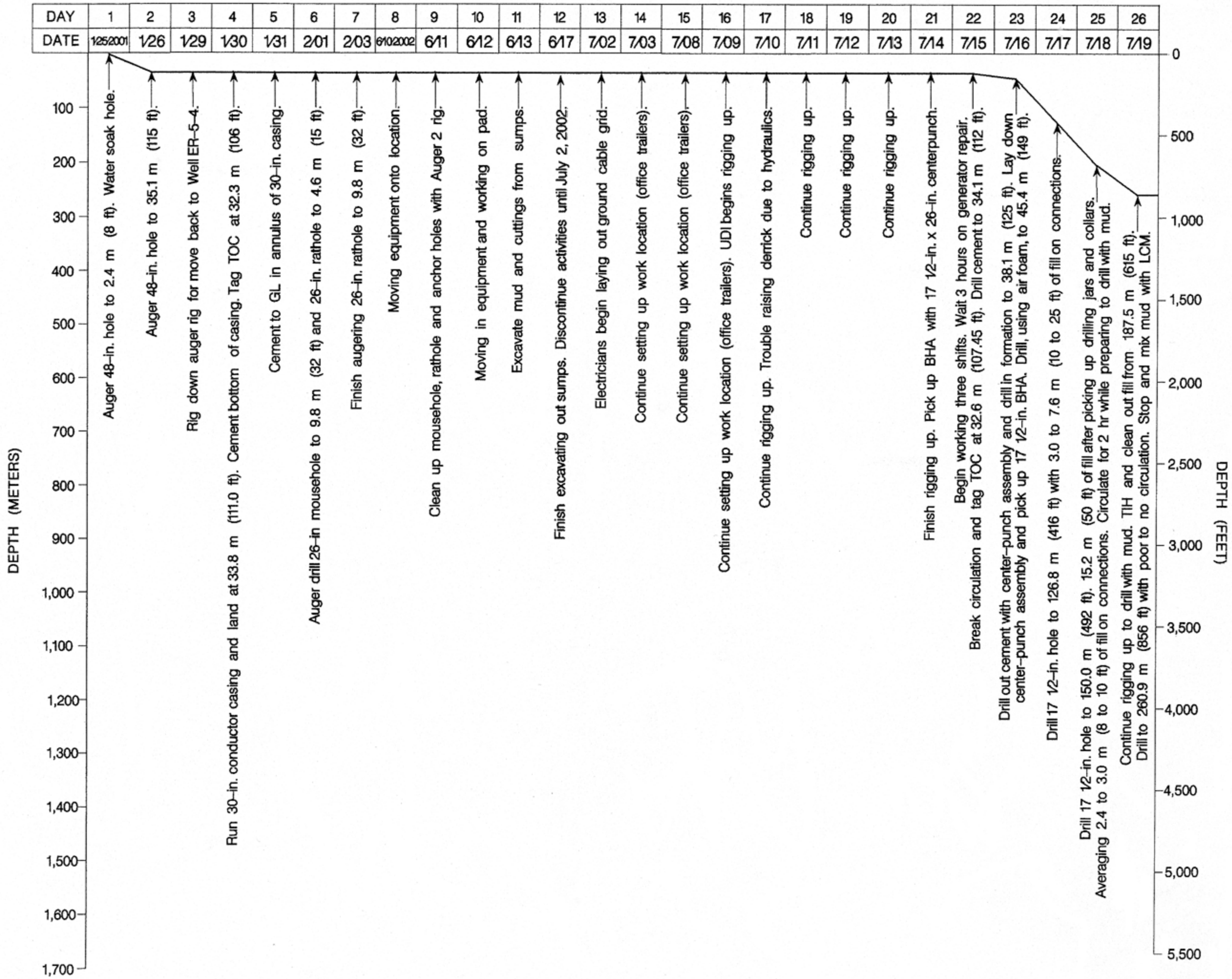


FIGURE 3-1
WELL ER-5-4#2
DRILLING AND COMPLETION
HISTORY
SHEET 1 OF 3

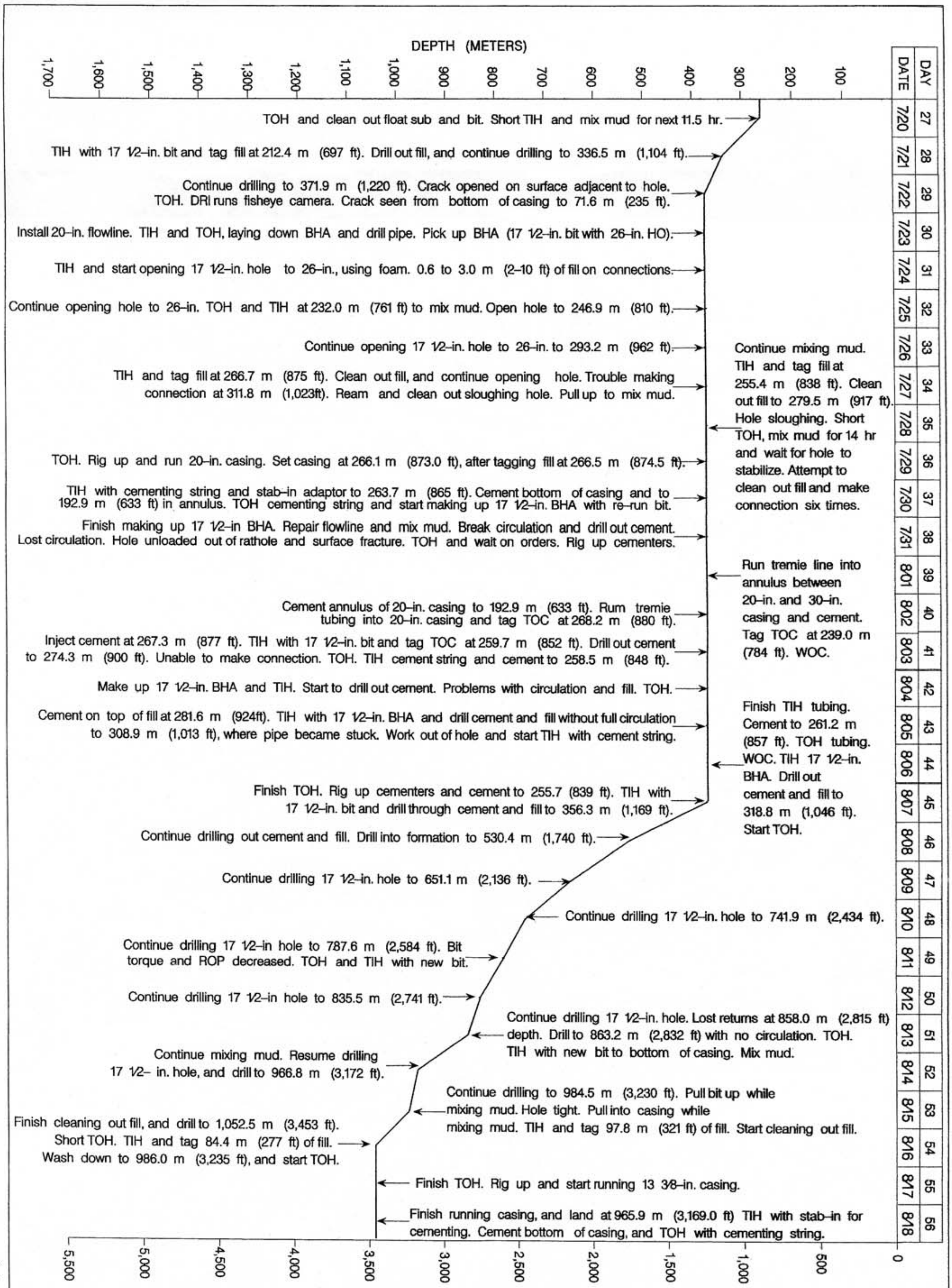


FIGURE 3-1
WELL ER-5-4#2
DRILLING AND
COMPLETION
HISTORY
SHEET 2 OF 3

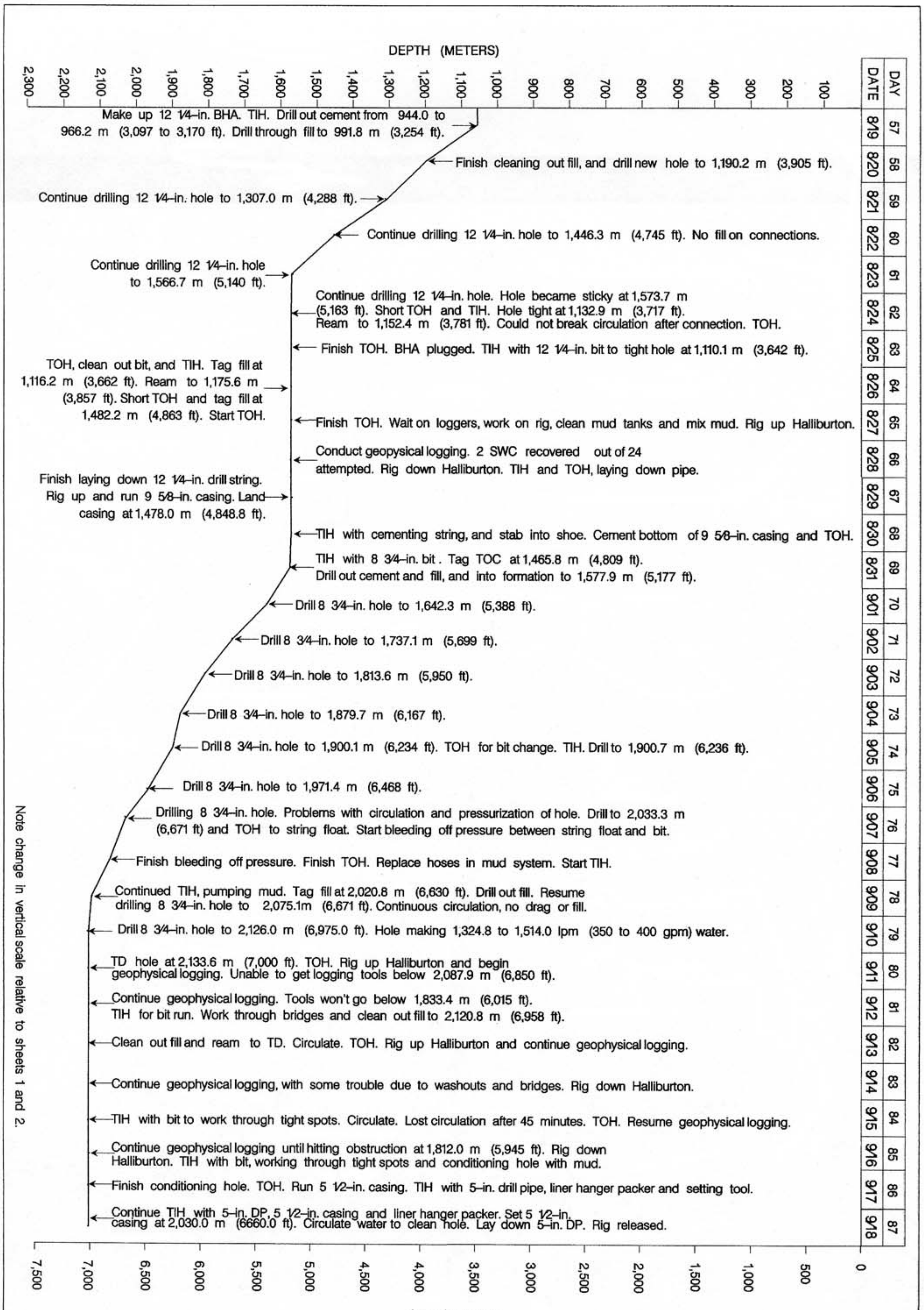


FIGURE 3-1
WELL ER-5-4#2
DRILLING AND
COMPLETION
HISTORY
SHEET 3 OF 3

The UDI crew rigged up the Wilson Mogul 42B drill rig July 9 to 15, 2002. They tagged the top of cement in the conductor hole at 32.6 m (107 ft) with a center-punch assembly consisting of a 17½-in. rotary bit mounted below a 26-in. hole opener. When the hole opener had cleared the bottom of the conductor casing (hole depth at 38.1 m [125 ft]), the center-punch assembly was replaced with a 17½-in. BHA and drilling continued. The drilling fluid was air-foam in conventional circulation. Drilling continued to 205.4 m (674 ft) with 3.0 to 7.6 m (10 to 25 ft) of fill encountered after most connections. At that depth the fluid was changed to an aerated mix of bentonite mud, polymer, and gel. This mix was expected to help minimize borehole instability, particularly near the water table (expected at the depth of approximately 221.3 m [726 ft]), where severe borehole sloughing had been experienced during drilling of Well ER-5-4 (Section 2.1).

When drilling resumed, loss of drill fluid to the formation prompted the addition of LCM to the mud to help control the lost circulation. Drilling continued to the depth of 260.9 m (856 ft) with 4.6 to 6.1 m (15 to 20 ft) of fill on connections. Fluid returns became intermittent, and additional mud with gel, polymer, and LCM was pumped down hole in an effort to regain and maintain fluid circulation. The bit became plugged, so the drillers pulled the drill string from the hole and cleaned out the bit and float sub. No drilling was accomplished while additional mud was mixed for the next 11.5 hours, then the 17½-in. BHA was lowered back into the hole and drilling resumed to 276.8 m (908 ft), stopping occasionally to mix more mud.

Drilling had reached the depth of 371.9 m (1,220 ft) on July 22, 2002, when a crack opened at the surface with drilling fluid flowing out of it. The crack was oriented approximately north-south; it extended through the borehole and for a distance of 15.2 to 21.3 m (50 to 70 ft) each side of the hole. Drilling was halted and the drill string removed from the hole, so that a camera could be run in the borehole. The camera was run by DRI to the top of foam in the hole at 129.5 m (425 ft). The crack was observed to extend across the borehole from the base of the conductor casing at 33.8 m (111 ft) to a depth of 71.6 m (235 ft). The decision was made to open the hole to 66.0 cm (26 in.) in diameter so that a string of 20-in. surface casing could be installed to seal off the crack and to control sloughing of the borehole.

Over the next 5 days, while attempting to open the 44.4-cm (17.5-in.) diameter hole to 66.0 cm (26 in.), the drillers repeatedly encountered severe sloughing of the borehole, large accumulations of fill, and loss of large quantities of drill fluid to the formation. The crew repeatedly worked their way through tight spots, reaming and cleaning the hole, and stopping for as much as 10 to 12 hours at a time to mix more drilling mud. Finally, these efforts were halted at the depth of 371.9 m (1,220 ft), and on July 29, 2002, the drill string was removed from the borehole in preparation for running the surface casing.

As the casing crew began running the 20-in. casing into the hole, the wireline parted and allowed some of the rigging to fall on top of the casing tongs. After a 4-hour suspension of work to re-rig the tongs and inspect the rigging, work resumed. The 20-in. casing was run in the hole and landed at 266.1 m (873.0 ft) after the top of fill was tagged at 266.5 m (874.5 ft). A string of 5-in. drill pipe with a stab-in adaptor was run inside the casing and stabbed into the casing guide shoe. Neat type II cement was pumped down the drill pipe to cement the bottom of the casing.

After the bottom of the casing was cemented, a BHA with a 17½-in. bit was made up and lowered into the hole. The casing guide shoe and cement were drilled out to 266.1 m (873 ft), at which point circulation was lost. After reaming and cleaning out fill and trying to regain circulation, the crew made a connection at 266.1 m (873 ft), but fluid was forced from the annulus between the 20-in. and 30-in. casings, and from the rathole and the surface crack. This indicated that the bottom of the 20-in. casing was not completely cemented, and the annular space between the 20-in. casing and the borehole wall was not sealed off. After removing the drill pipe from the hole, drillers ran a "tremie" tubing line down the annulus between the 20-in. casing and the borehole wall so that cement could be placed directly within the annulus. The annulus was cemented through the tubing in 8 stages with neat type II cement, and it was later determined that the top of cement within the annulus was at the depth of 192.9 m (633 ft). The tremie line was then pulled out and placed inside the 20-in. casing to pump additional cement at the bottom of the casing.

When drilling resumed with the 17½-in. bit, the top of cement in the 20-in. casing was tagged at the depth of 259.7 m (852 ft). Cement and fill were drilled out to a depth of 274.3 m (900 ft), but circulation was lost at 263.7 m (865 ft) and the connection at 274.3 m (900 ft) could not be made due to the accumulation of fill. The drill string was removed and a tremie line lowered inside the 20-in. casing to place a cement plug at the bottom of the hole to help stabilize the borehole and reduce sloughing and lost circulation. After the cement job, the top of cement was tagged at 258.5 m (848 ft), and cement and fill were drilled out to a depth of 289.6 m (950 ft). Continuous sloughing and lost circulation were again encountered, necessitating the placement of additional cement in the hole. After this cement job the top of cement was tagged at 260.0 m (853 ft). Cement was drilled out to 284.1 m (932 ft), and fill to 308.8 m (1,013 ft) with 3.0 to 4.6 m (10 to 15 ft) of fill encountered on connections and circulation lost at 266.1 m (873 ft). At the depth of 308.8 m (1,013 ft) the pipe became stuck, and after the drillers worked it free they removed the drill string and cemented the bottom of the hole again, up to the depth of 261.2 m (857 ft). Cement was drilled out to the depth of 293.2 m (962 ft), followed by fill material to 318.8 m (1,046 ft); 3.0 to 6.1 m (10 to 20 ft) of fill was encountered on connections. An additional load of cement was placed at the bottom of the hole to a depth of 255.7 m (839 ft), and the cement and fill were again drilled out to the original depth of the 17½-in hole at 371.9 m (1,220 ft) on August 8, 2002.

Drilling then continued more smoothly, reaching the depth of 787.6 m (2,584 ft) on August 11, 2002, at which time the drill bit was replaced with a new 17½-in. bit. Drilling then continued to 863.2 m (2,832 ft), on August 13, 2002, when the drillers pulled the pipe from the hole and found that the drill bit had a loose cone and a missing seal. As drilling proceeded with a new 17½-in. bit, water production increased and 6.1 m (20 ft) of fill was encountered at connections below 923.5 m (3,030 ft). At the depth of 984.5 m (3,230 ft) tight hole conditions were encountered while pulling the drill bit off bottom to mix mud. The crew worked the drill bit through the tight spots and pulled the bit up into the 20-in. casing while more mud was mixed. When the drill pipe was lowered again, the bit tagged the top of fill at 886.7 m (2,909 ft), indicating that 97.8 m (321 ft) of fill had accumulated. The fill was cleaned out and the 44.4-cm (17½-in.) hole advanced to 1,052.8 m (3,454 ft) on August 16, 2002, with 9.1 m (30 ft) of fill encountered at connections. The drillers added high viscosity mud to the hole to control sloughing, and pulled up the bit to wait for the hole to stabilize. After 2 hours, they tagged the top of 84.4 m (277 ft) of fill at 968.0 m (3,176 ft). They cleaned out the fill to 986.0 m (3,235 ft), at which point the drill pipe was pulled from the hole in preparation for installing an intermediate casing.

The 13**d**-in. intermediate casing was run in the hole by a casing subcontractor on August 17, 2002. After working through an obstruction at 285.9 m (938 ft), the casing tagged top of fill at 950.4 m (3,118 ft). The crew washed the casing down through the fill and landed it at the depth of 965.9 m (3,169.0 ft). A string of 5-in. drill pipe was run inside the casing and stabbed into the float shoe to cement the bottom of the casing.

On August 19, 2002, the crew made up a BHA with a 12¼-in. bit and lowered it into the hole. The top of cement was tagged at 944.0 m (3,097 ft), and 22.3 m (73 ft) of cement was drilled to 966.2 m (3,170 ft). Fill was cleaned out to 1,052.8 m (3,454 ft), and the hole was advanced to 1,573.7 m (5,163 ft) on August 24, 2002, averaging 3 m (10 ft) of fill on most connections. Tight hole conditions and intermittent fluid returns were encountered below 1457.9 m (4,783 ft), and at 1,573.7 m (5,163 ft) the hole became tight and the bit would not rotate except when extra mud was pumped to unload cuttings from the hole. As the crew pulled the drill pipe up into the 13**d**-in. casing, the bit began to stick again through the interval

1,493.5 to 1,406.7 m (4,900 to 4,615 ft). When the drill pipe was lowered, a tight spot was encountered at 1,132.9 m (3,717 ft), requiring reaming of a 37.8-m (124-ft) length of hole past this spot.

Circulation could not be broken after the connection at 1,152.4 m (3,781 ft). When the crew removed the drill pipe from the hole they found that the bit was plugged with pieces of rubber from the inner liner of a 2-in. hose running from the mud pump to the suction pit. After the bit was unplugged and the source of the rubber determined, the crew cleaned out the mud pits and pumps, mixed more mud, and lowered the 12¼-in. bit back into the hole. The bit could not be advanced through a tight spot at 1,110.1 m (3,642 ft), so the drill pipe was again removed and the bit inspected. The drillers cleaned clay and fine sand that were blocking a jet on the bit, and lowered the drill pipe back into the hole, tagging fill at 1,116.2 m (3,662 ft). The drillers reamed and conditioned the hole, then pulled the drill pipe up a short distance to mix more mud. When they lowered the bit it tagged fill at 1,482.2 m (4,863 ft). The crew then removed the drill string from the hole in preparation for geophysical logging operations and installation of a string of 9e-in. casing to seal off the sloughing section of the hole.

Geophysical logging was conducted on August 27 and 28, 2002, and then a casing subcontractor ran a string of 9e-in. casing, landing it at the depth of 1,477.9 m (4,848.8 ft). The bottom of the casing was cemented with neat type II cement from inside the 9e-in. casing using the drill pipe with a stab-in adaptor. After this cement job, the drillers attached an 8¾-in. bit and lowered the BHA into the hole to the top of the cement at (4,809 ft). The crew drilled cement from 1,465.8 to 1,478.3 m (4,809 to 4,850 ft) and cleaned out fill to the depth of 1,573.7 m (5,163 ft). On September 5, 2002, the hole had advanced to 1,900.1 m (6,234 ft) with no fill on connections, and after a bit change, no fill was encountered when the BHA was lowered back into the hole.

Drilling reached the depth of 2,005.0 m (6,578 ft) on September 7, 2002, at which point the hole began to pressure up. As the hole was advanced to the depth of 2,033.3 m (6,671 ft) it began to take as much as 1 to 2 hours to break circulation after making a connection, and the hole was estimated to be producing water at a rate of about 1,892 lpm (500 gpm). Efforts were made to relieve the fluid pressure, and finally the crew removed the drill string to check the bit, but found that it was not plugged and was operating properly. When the crew lowered the drill string back into the hole on September 9, 2002, they encountered fill at 2,020.8 m (6,630 ft), but after this was removed, drilling of the 22.2-cm (8.75-in.) hole continued to the TD of 2,133.6 m (7,000 ft), reached on September 11, 2002.

The directional survey run inside the 9e-in. casing on December 7, 2002, indicates that at the lowest surveyed depth of 2,017.9 m (6,617 ft) the hole had drifted 57.9 m (190 ft) to the west of the collar location, and that the hole is relatively straight (no “dog-legs”).

A graphical depiction of drilling parameters including penetration rate, revolutions per minute, pump pressure, and weight on the bit is presented in Appendix A-1. See Appendix A-2 for a listing of tubing and casing materials. Drilling fluids and cements used in Well ER-5-4#2 are listed in Appendix A-3.

3.2.3 Drilling Problems

The primary drilling problem on Well ER-5-4#2 was borehole instability, especially below the water table at the depth of about 221.3 m (726 ft), despite the use of a bentonite mud mix. Moderate to large amounts of material that had sloughed from the borehole wall were encountered on most connections and at other times when drilling was halted (bit changes, mud-mixing, etc.). In addition, several intervals of the borehole were cemented and then re-drilled in the effort to create stable hole conditions. This resulted in additional drilling delays, complicated the collection of cuttings samples, and created zones in the borehole for which no representative geophysical log data could be collected. Borehole instability also necessitated the installation of additional casing strings to isolate unstable portions of the borehole and create better drilling conditions.

Large amounts of drill fluid were lost to the formation, especially from the depth of about 265 m (870 ft), and at other locations. This caused delays in drilling while mud was mixed, and it severely impeded collection of representative drill cuttings samples.

3.2.4 Fluid Management

This section provides a summary of fluid management activities during drilling operations at Well ER-5-4#2. Much of the information presented is from IT (2003) where additional fluid management information is available. Fluids and drill cuttings produced during drilling operations at Well ER-5-4#2 were managed according to the UGTA FMP (DOE/NV, 1999) and associated state-approved waivers (Liebendorfer, 2000).

To manage the drilling fluids and anticipated water production, 2 sumps (infiltration basins) were constructed prior to drilling of Well ER-5-4, as described in Section 2.2.4 (see also Figure 1-2). No modifications were made to the sump system for drilling of Well ER-5-4#2. No contaminants were expected during drilling at this site, so neither sump was lined.

Water used to prepare drilling fluids came from a fill stand at the RWMS in Area 5 and Water Well 5B at the Hazardous Materials Spill Center, also in Area 5. Water from various NTS water wells on the site water well system feeds the RWMS fill stand, which may contain a variable mix of waters from Water Well 4 or Water Well 4a. Lithium bromide was added to the drill fluid as a tracer to provide a means of estimating groundwater production. The rate of water inflow was estimated from the dilution of the tracer in the drill fluid returns. However, loss of circulation and use of bentonite mud prevented monitoring of LiBr dilution in several intervals.

Drilling effluent was monitored according to the methods prescribed in the UGTA FMP (DOE/NV, 1999). Samples of drilling effluent were tested onsite hourly for the presence of tritium, and every 8 hours for lead. Onsite monitoring results indicate that tritium remained at or below background levels, ranging from 0 to 1,792 pCi/L (IT, 2003). No lead was detected above the detection limit of 50 parts per billion.

The fluid management reporting form for Well ER-5-4 #2 is provided in Appendix B. The form lists volumes of solids (drill cuttings) and fluids produced during well-construction operations (vadose- and saturated-zone drilling only; well development and aquifer testing will be conducted as a separate initiative). The volume of solids produced was calculated using the diameter of the borehole (from caliper logs) and the depth drilled, and includes added volume attributed to a rock bulking factor. The volumes of fluids listed on the report are estimates of total fluid production, and do not account for any infiltration or evaporation of fluids from the sumps.

3.3 Geologic Data Collection

This section describes the sources of geologic data obtained from Well ER-5-4#2 and the methods of data collection. Geologic data collected at Well ER-5-4#2 consist of drill cuttings, sidewall core samples, and geophysical logs. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures.

3.3.1 Collection of Drill Cuttings

Composite drill cuttings were collected from Well ER-4-5#2 at 3-m (10-ft) intervals as drilling progressed from the bottom of the conductor hole at 35.1 m (115 ft) to the TD of the well at 2,133.6 m (7,000 ft). Triplicate samples, each consisting of approximately 550 cc of material, were collected from 614 intervals. However, in some portions of the hole the volume of cuttings was low, and some samples are composites of materials from intervals greater than 3 m (10 ft). No samples were collected in 75 intervals where drill fluid was not returned to the surface due to lost circulation. The drill cuttings samples are stored under secure, environmentally controlled conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada. One of these sample sets was sealed with custody tape at the rig site and remains sealed as an archive sample; one set was left unsealed in the original sample containers; and the third set was washed and stored according to standard USGS Core Library procedures. The washed set was used by BN to construct the detailed lithologic log presented in Appendix C. The IT field representative collected an additional 2 sets of reference drill cuttings samples (approximately 15 cc each) from each of the cuttings intervals. One set was examined at the drill site for use in preparing field lithologic descriptions, and remains in the custody of Stoller-Navarro. The other set was sent to Giday WoldeGabriel at LANL for petrographic, mineralogic, and chemical analyses where it remains (see Section 3.3.3).

3.3.2 Sidewall Core Samples

The objective of the sampling operation was to acquire geologic samples to supplement very poor quality drill cuttings samples in Well ER-5-4. Sample locations were selected by the IT field representative on the basis of field lithologic logs (with consideration of borehole conditions determined from caliper logs). Table 3-2 lists the recovery and stratigraphic assignment for the two samples recovered. Twenty-four sidewall core samples were attempted by Halliburton Energy Services using a percussion gun tool in the interval 1,306.1 to 1,475.2 m (4,285 to 4,840 ft). The operation was mostly unsuccessful, resulting in only 2 partial cores of rock recovered. Eleven attempts resulted in misfires and ten core barrels were lost in the hole.

Table 3-2
Percussion Gun Sidewall Core samples from Well ER-5-4#2

Core Depth meters (feet)	**Length Recovered** centimeters (inches)	**Stratigraphic Unit**
1,366.4 (4,483)	2.0 (0.8)	Wahmonie Formation
1,414.0 (4,639)	3.5 (1.4)	

3.3.3 Sample Analysis

Twenty-six samples of drill cuttings from various depths in Well ER-5-4#2 were submitted to the LANL Earth and Environmental Sciences Division - Geology and Geochemistry laboratories for petrographic, mineralogic, and chemical analyses to aid in stratigraphic identification and for characterization of mineral alteration (WoldeGrabriel et al., 2003). The status of the analyses is listed in Table 3-3. Information from the analyses was incorporated into the detailed lithologic logs presented in Appendix C and the geologic discussions in Section 4.0.

3.3.4 Geophysical Data

Geophysical logs were run in the borehole to further characterize the lithology, structure, and water content of the rocks encountered, and to evaluate borehole conditions. Geophysical logging was conducted in 2 stages during drilling: prior to setting 9⅝-in. intermediate casing and prior to setting the 5½-in. completion string. No logs were run above approximately 914.4 m (3,000 ft) in Well ER-5-4#2 because log data had previously been acquired from this interval in nearby Well ER-5-4. A complete listing of the logs, dates run, depths, and service companies is provided in Table 3-4. The logs are available from BN in Mercury, Nevada, and copies are on file at the Stoller-Navarro office in Las Vegas, Nevada. Preliminary geophysical data from the logs are reproduced in Appendix D.

3.4 Hydrology of Well ER-5-4#2

3.4.1 Preliminary Water-Level Information

The elevation of the water table at Well ER-5-4#2 was projected to be the same as that for Well ER-5-4, approximately 734 m (2,407 ft). This corresponds to an expected depth to water at approximately 220 m (720 ft) (IT, 2000). Fluid levels in the well varied considerably during drilling, and the last measurement made during drilling and completion activities found fluid at the depth of 215.7 m (707.6 ft) (IT, 2003). This measurement was made a week after the completion strings were installed and drilling mud was air-lifted from the well, and probably does not represent the actual stabilized water level at this location. Hydrologic studies planned for this well cluster will likely provide a more accurate water level for this site.

3.4.2 Water Production

Water production was estimated during drilling of Well ER-5-4#2 on the basis of LiBr dilution data as measured by IT field personnel. Measurable water production of less than 95 lpm (25 gpm) was first noted at a depth of 221.6 m (727 ft). Water production ranged from approximately 76 to 1,135 lpm

Table 3-3
Status of Rock Sample Analyses for Well ER-5-4#2

Depth [a] meters (feet)	Analyses Performed [b]					
	Petrographic		Mineralogic		Chemical	
	PTS	SEM	MP	XRD	XRF	Fe^{2+}/Fe^{3+}
435.9 (1,430)	C	--	C	--	--	--
771.1 (2,530)	--	--	--	--	--	--
859.5 (2,820)	--	--	--	--	--	--
1,100.3 (3,610)	C	--	--	--	--	--
1,140.0 (3,740)	C	--	--	C	C	C
1,176.5 (3,860)	C	--	C	C	C	C
1,197.9 (3,930)	C	--	--	C	C	C
1,222.2 (4,010)	C	--	--	C	C	C
1,268.0 (4,160)	C	--	--	C	C	C
1,332.0 (4,370)	C	--	--	C	C	C
1,380.7 (4,530)	C	--	--	C	C	C
1,517.9 (4,980)	C	--	--	--	--	--
1,612.4 (5,290)	C	--	C	C	C	C
1,673.4 (5,490)	C	--	--	C	C	C
1,694.7 (5,560)	C	--	--	C	C	C
1,740.4 (5,710)	C	--	--	C	C	C
1,764.8 (5,790)	C	--	--	C	C	C
1,813.6 (5,950)	C	--	--	C	C	C
1,841.0 (6,040)	C	--	--	C	C	C
1,902.0 (6,240)	C	--	C	C	C	C
1,935.5 (6,350)	C	--	--	C	C	C
1,953.8 (6,410)	C	--	C	C	C	C
1,999.5 (6,560)	C	--	--	C	C	C
2,069.6 (6,790)	C	--	--	C	C	C
2,100.1 (6,890)	C	--	--	C	C	C
2,133.6 (7,000)	C	--	--	C	C	C

a All samples are from drill cuttings. Depth represents base of 3-m (10-ft) sample interval for drill cuttings.

b Analyses performed by the research laboratory of the Hydrology, Geochemistry, and Geology Group of the Earth and Environmental Sciences Division at LANL. **C** = analysis complete; **--** = analysis not planned. Analysis type: **PTS** = polished thin section; **SEM** = scanning electron microscopy; **MP** = electron microprobe; **XRD** = x-ray diffraction; **XRF** = x-ray fluorescence; **Fe^{2+}/Fe^{3+}** = wet chemical analysis for iron.

Table 3-4
Well ER-5-4#2 Geophysical Log Summary

Geophysical Log Type [a]	Log Purpose	Logging Service [b]	Date Logged	Run Number	Bottom of Logged Interval [c] meters (feet)	Top of Logged Interval [c] meters (feet)
*Natural Gamma Ray Spectroscopy	Stratigraphic correlation, lithologic determination, mineralogy, natural and man-made radiation, fracture identification	HES	09/13/2002 09/14/2002 09/15/2002 09/15/2002	SGR-1/GR-8 SGR-2/GR-9 SGR-3/GR-10 SGR-4/GR-11	1,852.6 (6,078) 2,035.1 (6,677) 2,132.1 (6,995) 2,125.4 (6,973)	1,452.7 (4,766) 1,219.2 (4,000) 1,447.8 (4,750) 1,447.8 (4,750)
*Six Arm Caliper/Gamma Ray	Borehole conditions, cement volume calculation, fracture identification	HES	08/28/2002 09/13/2002	CA6-1/GR-1 CA6-2/GR-7	1,477.8 (4,848) 2,128.4 (6,983)	923.5 (3,030) 1,356.2 (4,450)
*Epithermal Neutron/ Density	Total water content, rock porosity, stratigraphic correlation, lithologic determination	HES	08/28/2002 09/14/2002 09/15/2002	DSEN-1/ SDL-1/GR-2 DSEN-2/ SDL-2/GR-10 DSEN-3/SDL-3 /GR-11	1,479.5 (4,854) 2,035.8 (6,679) 2,131.8 (6,994)	838.2 (2,750) 1,219.2 (4,000) 1,447.8 (4,750)
*Dual Laterolog/ Spontaneous Potential	Lithologic determination, water saturation, stratigraphic correlation	HES	08/28/2002 09/14/2002	DLL-1/ SP-1/GR-3 DLL-2/ SP-2	1,477.1 (4,846) 2,126.9 (6,978)	944.9 (3,100) 1,447.8 (4,750)
Full Wave Sonic - Waveform	Fracture identification	HES	08/28/2002 09/14/2002	FWS-1/GR-4 FWS-2	1,465.5 (4,808) 2,117.8 (6,948)	941.8 (3,090) 1,447.8 (4,750)
*Full Wave Sonic - Delta-T	Porosity, seismic properties	HES	08/28/2002 09/14/2002	FWS-1/GR-4 FWS-2	1,465.5 (4,808) 2,117.8 (6,948)	941.8 (3,090) 1,447.8 (4,750)
Temperature	Groundwater temperature, open fracture identification	HES	09/11/2002 09/13/2002	TL-1/GR-5 TL-2/GR-6	2,084.8 (6,840) 2,114.1 (6,936)	1,341.1 (4,400) 1,402.1 (4,600)
Percussion Gun Sidewall Coring Tool	Geologic Samples	HES	08/28/2002	SWC-1	1,475.2 (4,840)	1,306.1 (4,285)
Electro-Micro Imager	Lithologic characterization, structural analysis, fracture and void analysis	HES	09/14/2002	EMI-3/GR-9	2,029.1 (6,657)	1,486.8 (4,878)
Thermal Flow Meter	Rate and direction of groundwater flow in borehole	DRI	12/05/2002	TFM-1	2,011.7 (6,600)	304.8 (1,000)
Chemistry/ Temperature Log	Groundwater chemistry and temperature, formation transmissivity	DRI	12/04/2002 12/04/2002	Chem-1/TL-4 Chem-2/TL-5	1,819.7 (5,970) 2,023.9 (6,640)	224.9 (738) 224.9 (738)
North Seeker Earth-Rate Gyro	Bottom hole location, true vertical depth	BHI	12/06/2002	DRG-1	2,016.6 (6,617)	Surface

a Logs presented in geophysical log summary, Appendix D, are indicated by *****.

b **HES** = Halliburton Energy Services; **DRI** = Desert Research Institute; **BHI** = Baker Hughes Inteq

c Depth below ground surface.

(20 to 300 gpm), but was generally less than 379 lpm (100 gpm) from 221.6 m (727 ft) to a depth of approximately 1,104.9 m (3,625 ft). At approximately 1,104.9 m (3,625 ft), water production increased abruptly to about 568 lpm (150 gpm), and then further increased to1,893 lpm (500 gpm) at approximately 1,325.9 m (4,350 ft), within the welded Rainier Mesa Tuff. Below 1,325.9 m (4,350 ft), production remained generally between 1,136 and 1,514 lpm (300 and 400 gpm) to a depth of about 1,562.1 m (5,125 ft). When drilling resumed at 1,573.7 m (5,163 ft) after setting of the intermediate casing at 1,477.9 m (4,848.8 ft), water production dropped precipitously to 38 lpm (10 gpm) and remained at this level to a depth of approximately 1,966.0 m (6,450 ft). At 1,966.0 m (6,450 ft) production began to increase rapidly to a maximum rate of 2,158 lpm (570 gpm) at approximately 1,996.4 m (6,550 ft). Geophysical logs and lost circulation during drilling at this depth indicate that the increased water production around 1,996.4 m (6,550 ft) is likely due to the presence of open fractures within zeolitic nonwelded tuff of the Bullfrog Tuff in this depth interval. Below 2,034.5 m (6,675 ft) production decreased to approximately 1,136 lpm (300 gpm) and then rose steadily to approximately 1,325 lpm (350 gpm) near the TD of the well at 2,133.6 m (7,000 ft).

Estimated water production rates are presented graphically in Appendix A-1.

3.4.3 Preliminary Flow Meter Data

Flow meter data, along with temperature, EC, and pH measurements, can be used to characterize borehole fluid variability, which may indicate inflow and outflow zones. Typically, these measurements are made before the completion string is installed and the data are consulted during planning of zones to be completed. At Well ER-5-4#2, these data were collected approximately 2½ months after the completion string was installed, following partial development of the well by pumping (these pumping operations will be described in a separate report). DRI personnel made measurements inside the Well ER-5-4#2 completion string with their TFM and chemistry tools on December 4 and 5, 2002.

DRI personnel obtained TFM measurements at 10 locations between the depths of 304.8 and 2,011.7 m (1,000 and 6,600 ft). Preliminary analysis of these data indicates an upward flow of water within the borehole at the 8 highest stations located between 304.8 and 1,981.2 m (1,000 to 6,500 ft). The 2 deepest stations, at 1,996.4 and 2,011.7 m (6,550 and 6,600 ft), both recorded downward flow. These 2 stations are located opposite large fractures that produced water during drilling.

DRI also ran a chemistry log, which included measurements of temperature, EC, and pH. Two runs of the tool had to be made due to the failure on the first run of the pH sensor at 1,738.0 m (5,702 ft) and the subsequent failure of all sensors due to the implosion of the pH sensor at 1,819.7 m (5,970 ft). After the tool was repaired, the second run was made from 224.9 to 2,023.9 m (738 to 6,640 ft) recording only temperature and EC. Groundwater temperature gradually increased from the minimum reading of 30.3 degrees C (86.5 degrees F) at the top of the fluid column to the deepest logged depth near the bottom of the completion string. The maximum temperature of 48.7 degrees C (119.7 degrees F) was measured at 2,025.1 m (6,644 ft). A slight perturbation in the temperature curve was noted near 1,074.4 m (3,525 ft), within the 9 e -in. intermediate casing, approximately 22.9 m (75 ft) below the bottom of the 44.5-cm (17½-in.) diameter portion of the borehole. Changes in the pH and EC are most notable from 1,432.6 to 1,524.0 m (4,700 to 5,000 ft) near the top of the 5½-in. production casing.

3.4.4 Preliminary Groundwater Characterization Samples

No preliminary groundwater characterization samples were collected from Well ER-5-4#2 after drilling because of the residual bentonite mud in the borehole, and because it was expected that samples would soon be collected during upcoming development and testing operations.

3.5 Precompletion and Open-Hole Development

No precompletion development was conducted in Well ER-5-4#2 due to borehole instability problems that persisted through geophysical logging operations and installation of the completion string.

3.6 Well Completion

Installation of the completion string at Well ER-5-4#2 took place on September 17 and 18, 2002. Figure 3-2 is a schematic of the final well-completion design for Well ER-5-4#2, Figure 3-3 shows a plan view and profile of the wellhead surface completion, and Table 3-4 summarizes construction specifications of the completion string. Data for this section were obtained from daily activity reports and casing records provided by the BN Drilling Department. Information from IT's well data report (IT, 2003) was also consulted for preparation of this section.

3.6.1 Well Completion Design

The final completion design differs from the proposed design, as described in the following paragraphs. The departure of the final completion design from that proposed is mainly due to significant differences in the geology encountered at Well ER-5-4#2 from that predicted prior to drilling (see Section 4.3).

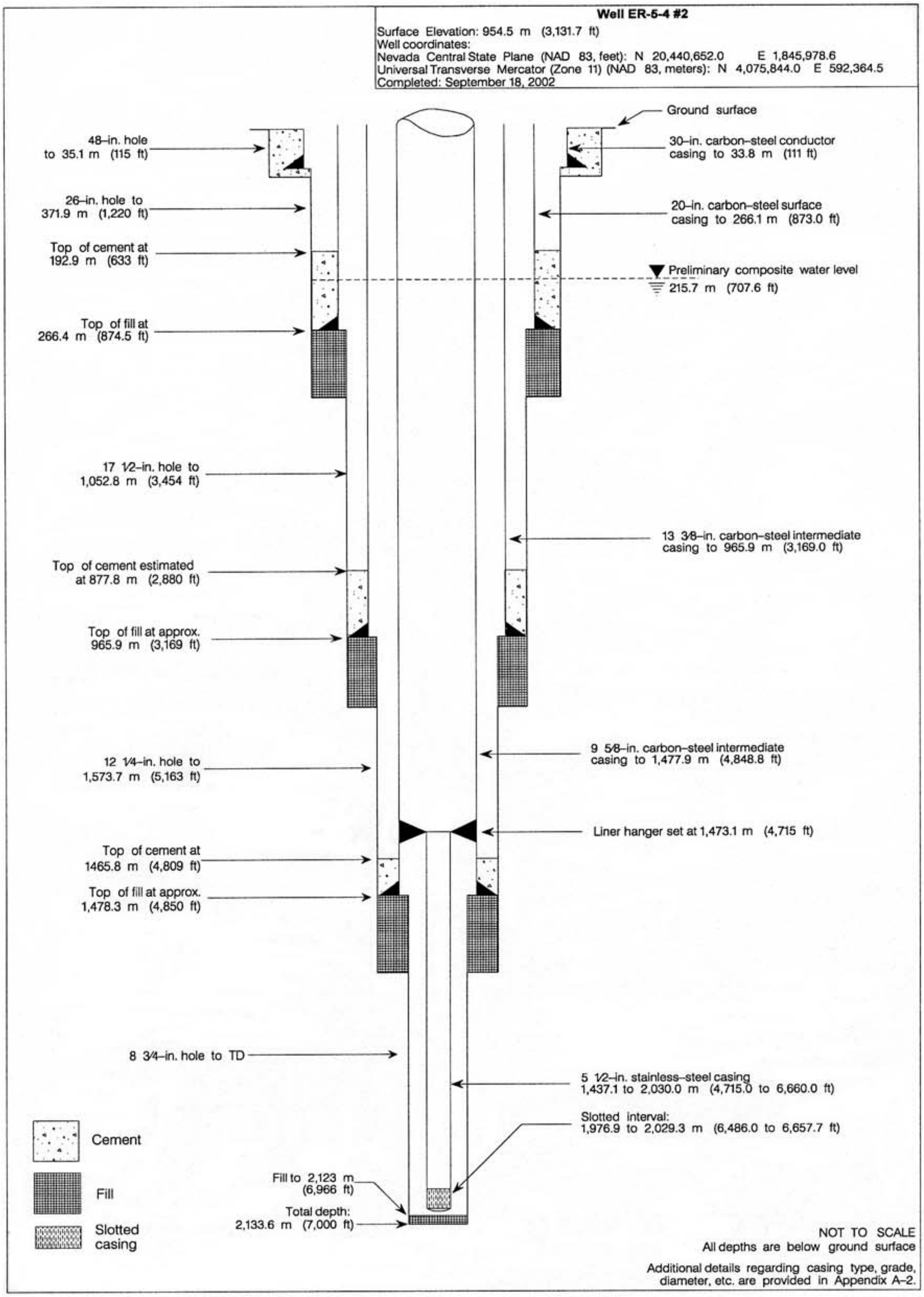
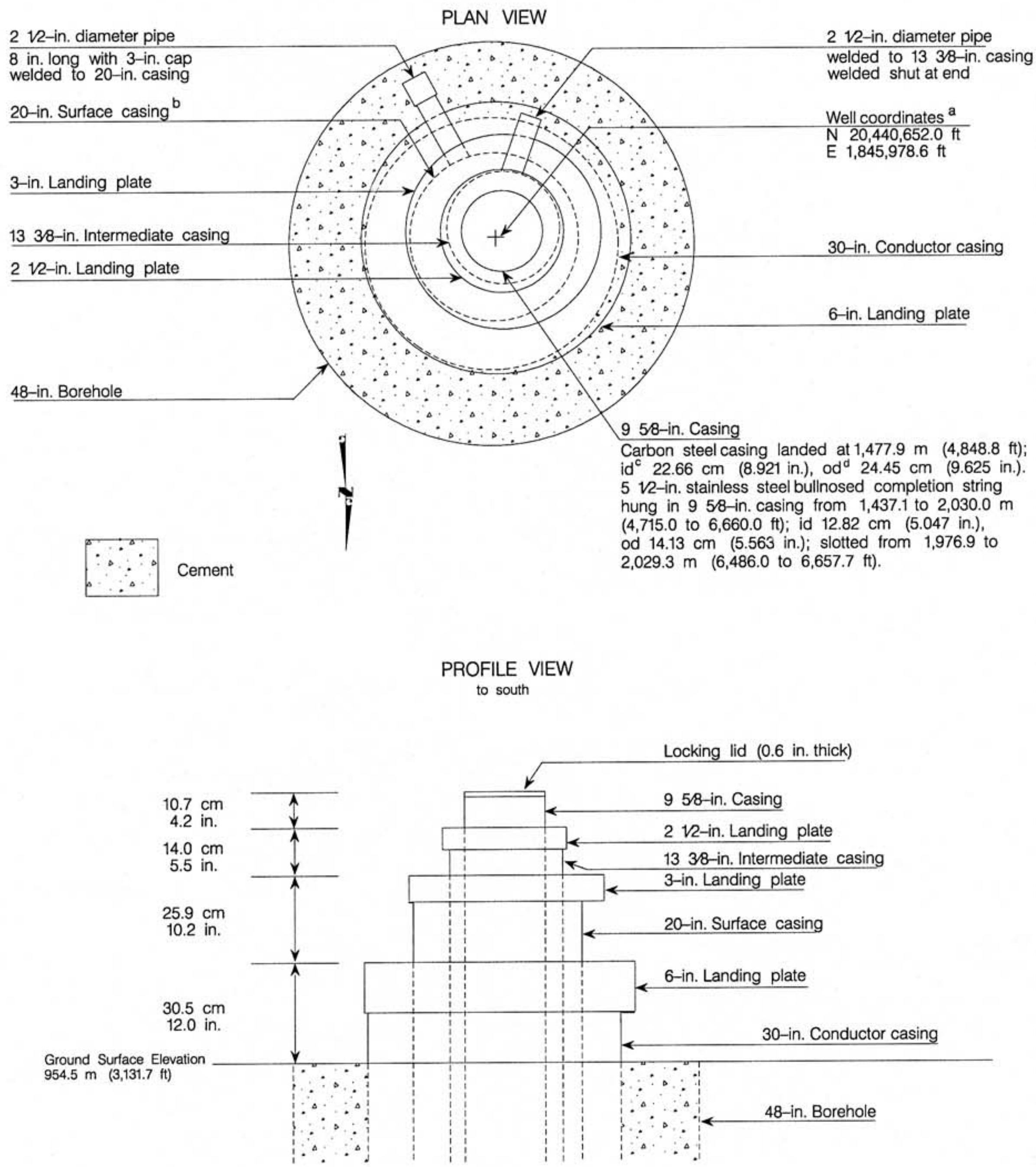


Figure 3-2
As-Built Completion Schematic for Well ER-5-4#2



a NAD 83 Nevada Central State Plane Coordinates
b See Appendix A-2 for casing data.
c id = inside diameter
d od = outside diameter

Figure 3-3
Wellhead Diagram for Well ER-5-4#2

Table 3-5
Completion String Construction Summary for Well ER-5-4#2

Casing Type	Configuration meters (feet)		Cement	Sand/Gravel
5½-in. Stainless-steel production casing [a]	1,437.1 to 2,030 (4,715 to 6,660)	Blank 1,437.1 to 1,976.9 (4,715.0 to 6,486.0)	None	None
		4 consecutive slotted joints 1,976.9 to 2,029.3 (6,486.0 to 6,657.7)		
		Bull nose 2,029.3 to 2,030) (6,657.7 to 6,660.0)		

a Top of 5½-in. casing is suspended from a liner hanger set at 1,437.1 m (4,715 ft) within the 9 e -in. carbon-steel intermediate casing.

3.6.1.1 Proposed Completion Design

The proposed completion design (IT, 2001a) was based on the assumption that the well would penetrate completely through the volcanic rocks, which form a thick tuff confining unit, and reach TD at 1,889.8 m (6,200 ft) within the underlying Paleozoic-age carbonate rocks, which compose the lower carbonate aquifer. The well was planned to be constructed with 2 completion zones, one in the middle portion of the tuff confining unit, and the other at the top of the lower carbonate aquifer. A string of 5½-in. stainless-steel casing (suspended from carbon-steel 7 e -in. casing) with a slotted interval at 1,828.8 to 1,886.7 m (6,000 to 6,190 ft) was planned to provide hydrologic access to the lower carbonate aquifer. A string of 2 f -in. tubing with a 30-m (100-ft) slotted interval was planned to be installed (outside the production casing) in the middle of the tuff confining unit.

3.6.1.2 As-Built Completion Design

The design of the Well ER-5-4#2 completion was determined through consultation with members of the UGTA TWG, on the basis of onsite evaluation of data such as lithology and water production, drilling data (lost circulation, etc.), and data from various geophysical logs.

Drilling at Well ER-5-4#2 was terminated at 2,133.6 m (7,000 ft) (243.8 m [800 ft] below the planned TD) while still in the tuff confining unit. A single completion zone was placed within the tuff confining unit (Figure 3-2, see also Figure 4-3). The composition of the completion string summarized here is also provided in Table 3-5, and the casing materials are listed in Appendix A-2. The string consists of 169.7 m (556.9 ft) of stainless-steel 5½-in. casing. The top of the string hangs from a liner hanger set at 1,437.1 m (4,715.0 ft) within the 9e-in. carbon-steel intermediate casing. The bottom of the casing terminates in a bull nose at 2,030.0 m (6,660.0 ft).

The slotted interval consists of 4 consecutive slotted joints placed at 1,976.9 to 2,029.3 m (6,486 to 6,657.7 ft). The openings in each slotted casing joint are 0.198 to 0.203 cm (0.078 to 0.080 in.) wide and 5.08 cm (2 in.) long, cut in rings of 18 slots (spaced 20 degrees apart around the joint). The rings are spaced 15.2 cm (6 in.) apart, and the longitudinal centers of the slots in each ring are staggered 10 degrees from the slot centers in the next ring. No gravel-pack or cement was utilized in the completion to isolate the slotted interval because only a single hydrogeologic unit, the tuff confining unit, was encountered below the base of the 9e-in. intermediate casing. However, the slotted interval does coincide with a fractured interval within the tuff confining unit that appeared to produce water during drilling (see Sections 4.2.1 and 4.4).

3.6.1.3 Rationale for Differences between Actual and Proposed Well Design

The proposed well design was based on the expectation that the Well ER-5-4#2 borehole would penetrate completely through the tuff confining unit and terminate within the lower carbonate aquifer. Because the well did not penetrate through the tuff confining unit as expected, a completion zone within the lower carbonate aquifer was not possible. A single completion zone was placed within the tuff confining unit as generally planned.

3.6.2 Well Completion Method

Well construction materials were inspected according to relevant procedures; standard decontamination procedures were employed to prevent the introduction of contaminants into the well. The 5½-in. casing and liner hanger were lowered into the hole on 5-in. drill pipe. After the liner hanger was set at 1,473.1 m (4,715 ft), the 5-in. drill pipe was detached from the liner hanger. The hole was then unloaded by pumping clear water down the 5-in. drill pipe. When clear water was observed at the discharge line, unloading was terminated and the 5-in. drill pipe was removed from the hole. No gravel pack or cement was used in the completion.

The drill rig was released after the completion string was installed. Hydrologic testing was planned as a separate effort, so a pump was not installed in the well and no well development or pumping tests were conducted immediately after completion.

3.7 *Actual versus Planned Costs and Scheduling*

The original BN cost model developed for Well ER-5-4#2 was based on drilling to the planned TD of 1,889.8 m (6,200 ft). The drilling program baseline projected that it would require 53 days to drill and complete the well. However, as with Well ER-5-4, the actual conditions encountered during drilling of the well (severe borehole instability; deeper than planned TD) were measurably different from predicted conditions so the baseline was changed during drilling.

The new cost model is based on the actual TD of 2,133.6 m (7,000 ft). It took 69 days to accomplish drilling of the surface and main holes, logging, and completion of the well, after construction of the conductor hole by BN. Drilling of the surface hole and installation of the 20-in. surface casing proceeded as expected. However, drilling of the production hole and installation of the completion casing took longer than predicted, and required additional cementing and re-drilling of segments of the borehole, and installation of an intermediate casing string. A graphical comparison, by day, of planned and actual well-construction activities is presented in Figure 3-4.

The cost analysis for Well ER-5-4#2 begins with the repositioning of the UDI drill rig on the Well Cluster ER-5-4 pad after drilling of Well ER-5-4. The cost of building roads, the drill pad, and sumps is not included, and the cost of well-site support by IT is not included. The total construction cost for Well ER-5-4#2 includes all drilling costs: charges by the drilling subcontractor; charges by other support subcontractors (including compressor services, drilling fluids, bits, casing services, down-hole tools, and geophysical logging); and charges by BN for mobilization and demobilization of equipment, construction of the conductor hole, cementing services, completion materials, radiation technicians, inspection services, and geotechnical consultation.

The total planned cost for constructing Well ER-5-4#2, based on the new baseline developed because the actual conditions differed greatly from the expected conditions, was $5,607,398. The actual cost was $5,357,674, or 4.5 percent less than the planned cost. Figure 3-5 presents a comparison of the planned (new baseline) and actual costs, by day, for drilling and completing Well ER-5-4#2.

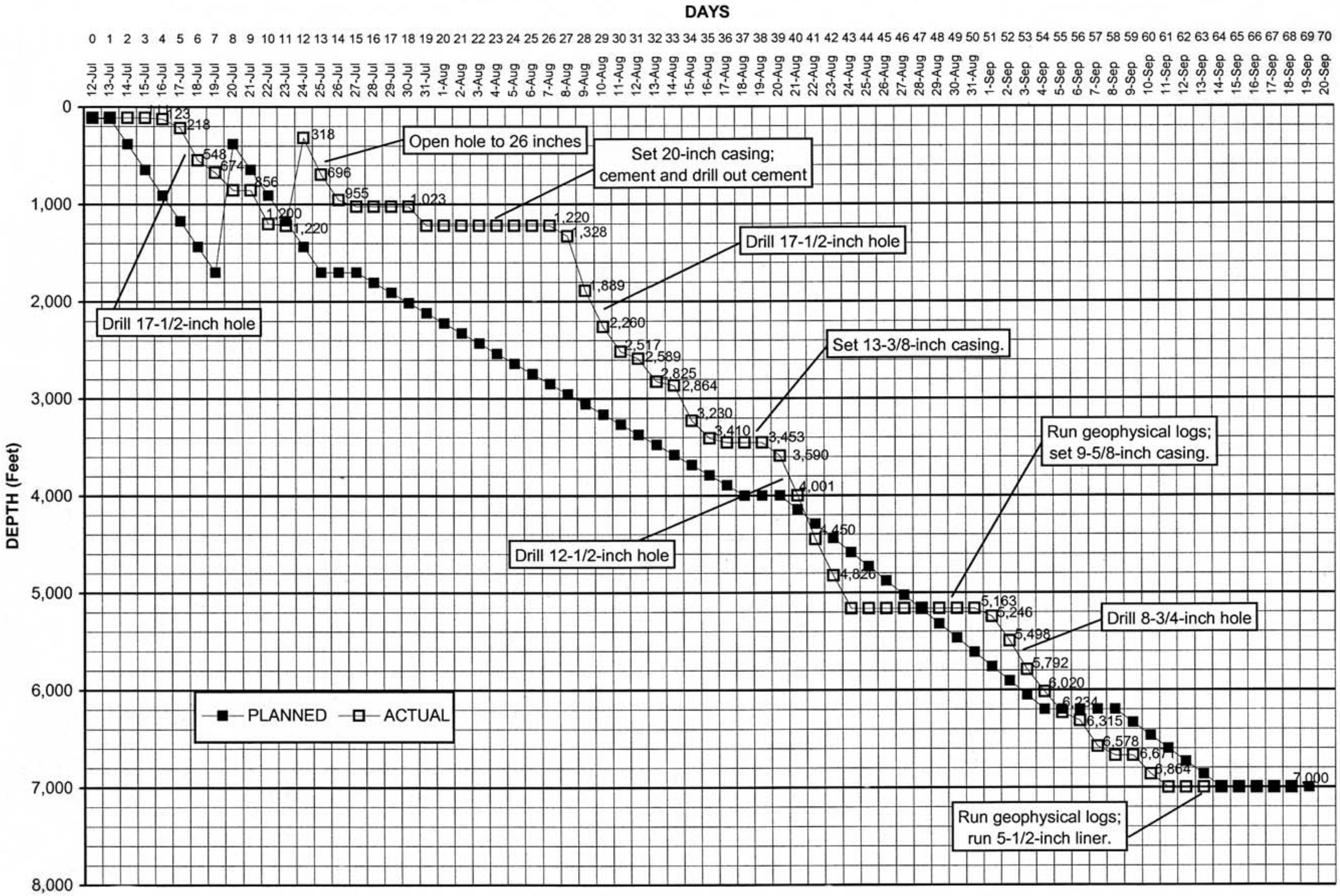


Figure 3-4
Planned versus Actual Construction Progress for Well ER-5-4#2

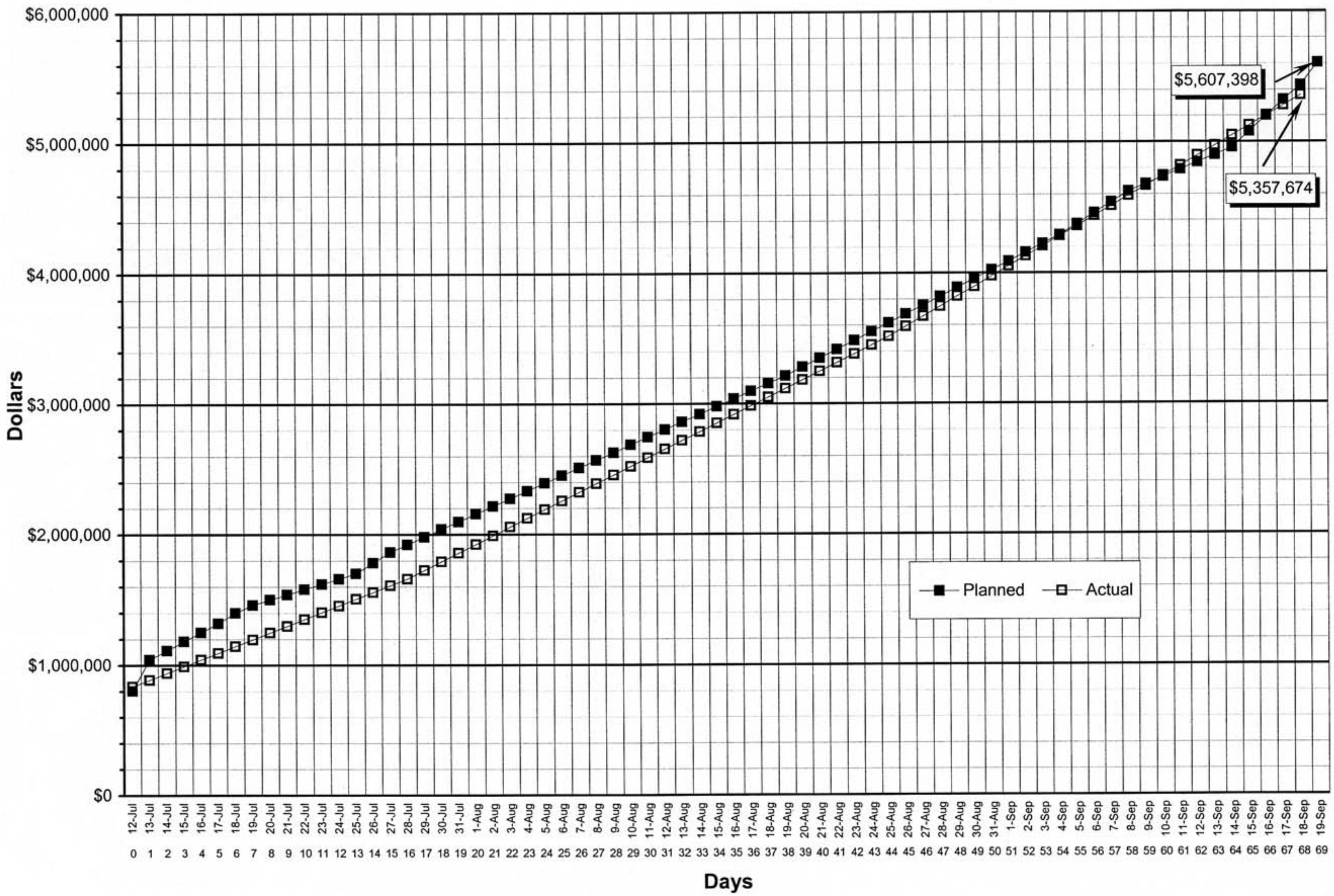


Figure 3-5
Planned versus Actual Cost for Constructing Well ER-5-4#2

3.8 Summary, Recommendations, and Lessons Learned

3.8.1 Summary for Well ER-5-4#2

Main hole drilling at Well ER-5-4 #2 commenced on July 16, 2002, and concluded on September 11, 2002, at a total drilled depth of 2,133.6 m (7,000 ft). Sloughing of the borehole wall, particularly in the upper portions of the hole, resulted in difficult drilling conditions and necessitated numerous borehole cleaning and conditioning efforts, placing of cement plugs and re-drilling portions of the hole, setting of 2 additional strings of casing, and required the use of bentonite-based mud as a circulating fluid. A single completion string consisting of 5 ½-in. stainless steel casing, slotted from 1,976.9 to 2,020.3 m (6,486 to 6,657.7 ft), was installed in the hole.

Geologic data collected during drilling include composite drill cuttings samples collected every 3 m (10 ft) from 35.1 m (115 ft) to TD, and 2 partial sidewall core samples. Geophysical logging was conducted in 2 stages during drilling: prior to setting 9e-in. intermediate casing and prior to setting the 5½-in. completion string. No logs were run above approximately 914.4 m (3,000 ft) in Well ER-5-4#2 because log data had previously been acquired from the equivalent stratigraphic interval in nearby Well ER-5-4.

Well ER-5-4 #2 is collared in young alluvial deposits, and penetrated 1,120.4 m (3,676 ft) of Quaternary and Tertiary alluvium before encountering 242.6 m (796 ft) of Tertiary volcanic rocks that consist mainly of unaltered, nonwelded to moderately welded ash-flow tuff. Below the interval of ash-flow tuff the well penetrated an additional 770.5 m (2,528 ft) of Tertiary volcanic rocks consisting mainly of zeolitic nonwelded tuff. Paleozoic rocks were not encountered and drilling was terminated within volcanic rocks at a depth of 2,133.6 m (7,000 ft). Tritium levels in the drilling fluid ranged from 0 to 1,792 picocuries per liter during drilling, which is at or below background levels. No other radionuclides above background were encountered in the drilling fluids from Well ER-5-4#2, and lead was not detected above the detection limit of 50 parts per billion. A preliminary fluid-level was measured at 215.7 m (707.6 ft) on September 18, 2002, after the completion string was installed.

3.8.2 Recommendations

Results from well development and testing activities should be evaluated to better understand the potential for groundwater flow through fractures within the tuff confining unit. All the geologic and hydrologic data from Well ER-5-4#2 should be integrated with other Frenchman Flat data to refine the Frenchman Flat hydrostratigraphic framework model (IT, 1998).

3.8.3 Lessons Learned from Well ER-5-4#2

Borehole instability can cause severe problems when drilling alluvium in the central portion of Frenchman Flat, even when bentonite-based mud is used as a drilling fluid.

Increased down-hole pressures related to the use of bentonite mud as a drilling fluid can cause near-surface fracturing of poorly consolidated units such as alluvium. These drilling-induced borehole fractures can propagate to the surface and create pathways for drilling fluids to flow out of the borehole and onto the ground surface.

4.0 Geology and Hydrogeology

4.1 Introduction

This section summarizes the geology and hydrogeology of Well Cluster ER-5-4. The detailed lithologic logs for both wells are presented in Appendix C. These lithologic descriptions were developed using drill cuttings and sidewall core samples, geophysical logs, and drilling parameters. The Hydrology, Geochemistry, and Geology Group of the Earth and Environmental Sciences Division at LANL performed petrographic, mineralogic, and chemical analyses of select lithologic samples from both wells of the cluster (WoldeGabriel et al., 2003). Results from these analyses were incorporated into the lithologic logs. Regional (i.e., basin-wide) geologic interpretations and analyses provided in this section integrate the well information with surface geology and geophysical data, including gravity (Phelps and Graham, 2002), aeromagnetic (Grauch and Hudson, 1995), and 3-D seismic reflection (Prothro, 2002).

4.2 Geology

This section is subdivided into 3 discussions relating to the geology of Well Cluster ER-5-4. Section 4.2.1 describes the geologic setting of Frenchman Flat and the well cluster. The stratigraphic and lithologic units penetrated at the well cluster are discussed in Section 4.2.2. Because of the significant influence some alteration products have on the hydraulic properties of certain rocks, alteration of the rocks encountered at the well cluster is discussed separately in Section 4.2.3. More detailed descriptions of the stratigraphy, lithology, and alteration of the rocks encountered are provided in Appendix C.

4.2.1 Geologic Setting

Well Cluster ER-5-4 lies on a very gently southeast-sloping surface composed of young alluvium (Figure 4-1) in the central portion of Frenchman Flat. Frenchman Flat is a hydrologically closed, Cenozoic-age basin formed in response to basin-and-range extension. Topographically, the basin is oval-shaped, elongated in a northeast direction, and contains the Frenchman Lake playa that marks the topographic low point of the basin. The well cluster is located approximately 1.6 km (1 mi) northwest of the Frenchman Lake playa ("Qp" on Figure 4-1).

Rocks exposed in the highlands around the margins of Frenchman Flat consist of Tertiary-age volcanic and tuffaceous sedimentary rocks that overlie complexly folded and faulted Paleozoic-age sedimentary rocks (Hinrichs and McKay, 1965; Poole, 1965; Poole et al., 1965; Hinrichs, 1968; McKeown et al., 1976;

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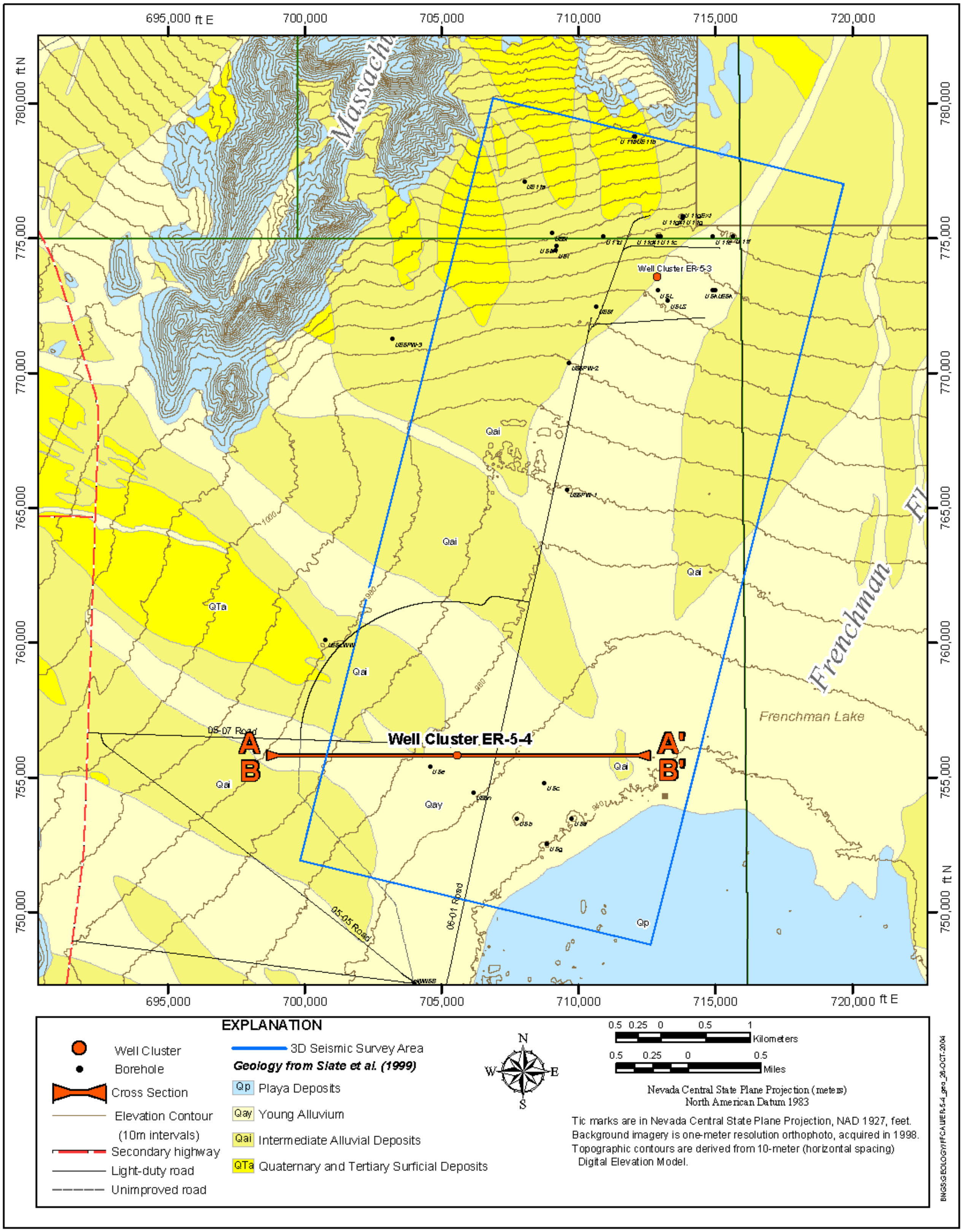

Figure 4-1
Surface Geologic Map of the Well Cluster ER-5-4 Site

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Barnes et al., 1982). Volcanic rocks exposed in the highlands around Frenchman Flat are mostly Miocene-age tuffs of generally rhyolitic composition erupted from large calderas located 40 km (25 mi) northwest of Frenchman Flat, and intermediate-composition tuffs, lavas, and debris flows from the Wahmonie volcanic center located adjacent to Frenchman Flat on the west. Tuffaceous sedimentary rocks appear to occur within a rather narrow, linear, northeast-trending depositional area that generally corresponds to the topographic axis of the basin (Prothro and Drellack, 1997). These rocks are exposed along the southern margin of the basin where they consist of a diverse assemblage of fluvial and lacustrine sandstone and mudrocks, freshwater limestone, conglomerate, and volcanic tuff. The tuffaceous sedimentary rocks appear to be partly coeval with the older volcanic rocks and thus likely interfinger with the volcanic rocks beneath Frenchman Flat. Paleozoic-age sedimentary rocks are exposed along the south and east sides of Frenchman Flat and consist mostly of carbonate rocks ranging in age from Cambrian to Mississippian. Drilling and geophysical data from Frenchman Flat indicate that many of the formations exposed along the margins of the basin are present beneath Frenchman Flat and have been buried by thick aprons of alluvial debris shed from the exposed highlands during basin development. Alluvial deposits obtain a thickness of 1,676.4 m (5,500 ft) in the central portion of Frenchman Flat based on interpretation of seismic data (Prothro, 2002).

Modeling of surface gravity data shows the basin to be a northeast-trending, roughly oval, bowl-shaped depression (Grauch and Hudson, 1995; Phelps and Graham, 2002). Using the gravity inversion method, Phelps and Graham (2002) estimated the maximum depth to Paleozoic rocks beneath the Frenchman Flat basin at 2,400 m (8,000 ft). Recently acquired 3-D seismic reflection data from a 36.3-square-kilometer (14-square-mile) area of northern and central Frenchman Flat (Figure 4-1) indicate a maximum depth of about 3,017.5 m (9,900 ft) within the seismic survey area corresponding to the central portion of the basin (Great Basin Exploration Consultants [GBEC], 2002).

Although the gravity data do not indicate any major horst-and-graben structures beneath the basin, analysis of aeromagnetic data from Frenchman Flat reveals magnetic boundaries beneath Frenchman Flat that have been interpreted to represent buried faults. Integrating the geophysical data with regional structural analyses, Grauch and Hudson (1995) developed a conceptual structural model for Frenchman Flat. This model indicates that in a broad sense Frenchman Flat is probably best described structurally as an east-tilted half-graben with one or more major basin-forming faults along its eastern margin. The main faults beneath the basin are likely north-trending, down-to-the-west normal faults that merge southward into the east-northeast striking Rock Valley strike-slip fault system.

In summary, geological and geophysical data suggest that Frenchman Flat is an oval, bowl-shaped depression elongated in a northeast direction. The basin can be characterized as a large east-tilted half-graben bounded along its eastern margin by a west-dipping normal fault(s) that likely merges into the Rock Valley strike-slip fault system beneath the southern portion of the basin. In its deepest portions, Frenchman Flat basin probably contains from 2,400 to 3,017.5 m (8,000 to 9,900 ft) of mostly Tertiary-age alluvium, volcanic rocks, and tuffaceous sedimentary rocks overlying complexly deformed Paleozoic-age sedimentary rocks.

4.2.2 Stratigraphy and Lithology

This section describes the stratigraphic and lithologic units encountered in Wells ER-5-4 and ER-5-4#2. The descriptions are based on the detailed lithologic logs provided in Appendix C. The stratigraphic and lithologic units penetrated at Well Cluster ER-5-4 are illustrated in Figure 4-2.

4.2.2.1 Well ER-5-4

Well ER-5-4 penetrated 1,118.6 m (3,670 ft) of Tertiary- and Quaternary-age alluvium consisting mostly of silty to gravelly sand associated with alluvial fan deposition. Beds of finer-grained sediments (silt and clay), possibly associated with an earlier period of playa lake deposition, were penetrated from 704.7 to 896.1 m (2,312 to 2,940 ft). A layer of volcanic ash is present from 823.6 to 825.1 m (2,702 to 2,707 ft) within the interval of silt and clay beds. The source of the ash layer was probably the Black Mountain volcanic center (Warren et al., 2002) located approximately 80 km (50 mi) northwest of Frenchman Flat. Volcanic rocks associated with the Black Mountain caldera have been determined to be about 9.4 million years old (Sawyer et al., 1994). Detailed chemical, mineralogic, and micrographic analyses of sidewall core samples from Well ER-5-4 indicate that the alluvium penetrated by the well has not been significantly altered since deposition (Warren et al., 2002).

Volcanic rocks consisting of vitric to devitrified, nonwelded to partially welded ash-flow tuff were encountered at approximately 1,118.6 m (3,670 ft) in Well ER-5-4. These rocks are assigned to the Ammonia Tanks Tuff based on the abundance of felsic phenocrysts of feldspar and quartz, moderate amounts of biotite, and especially the presence of sphene and adularescent sanidine, both of which are highly diagnostic of the Ammonia Tanks Tuff. The Ammonia Tanks Tuff was erupted 11.45 million years ago (Ma) (Sawyer et al., 1994) from the Timber Mountain caldera complex located approximately

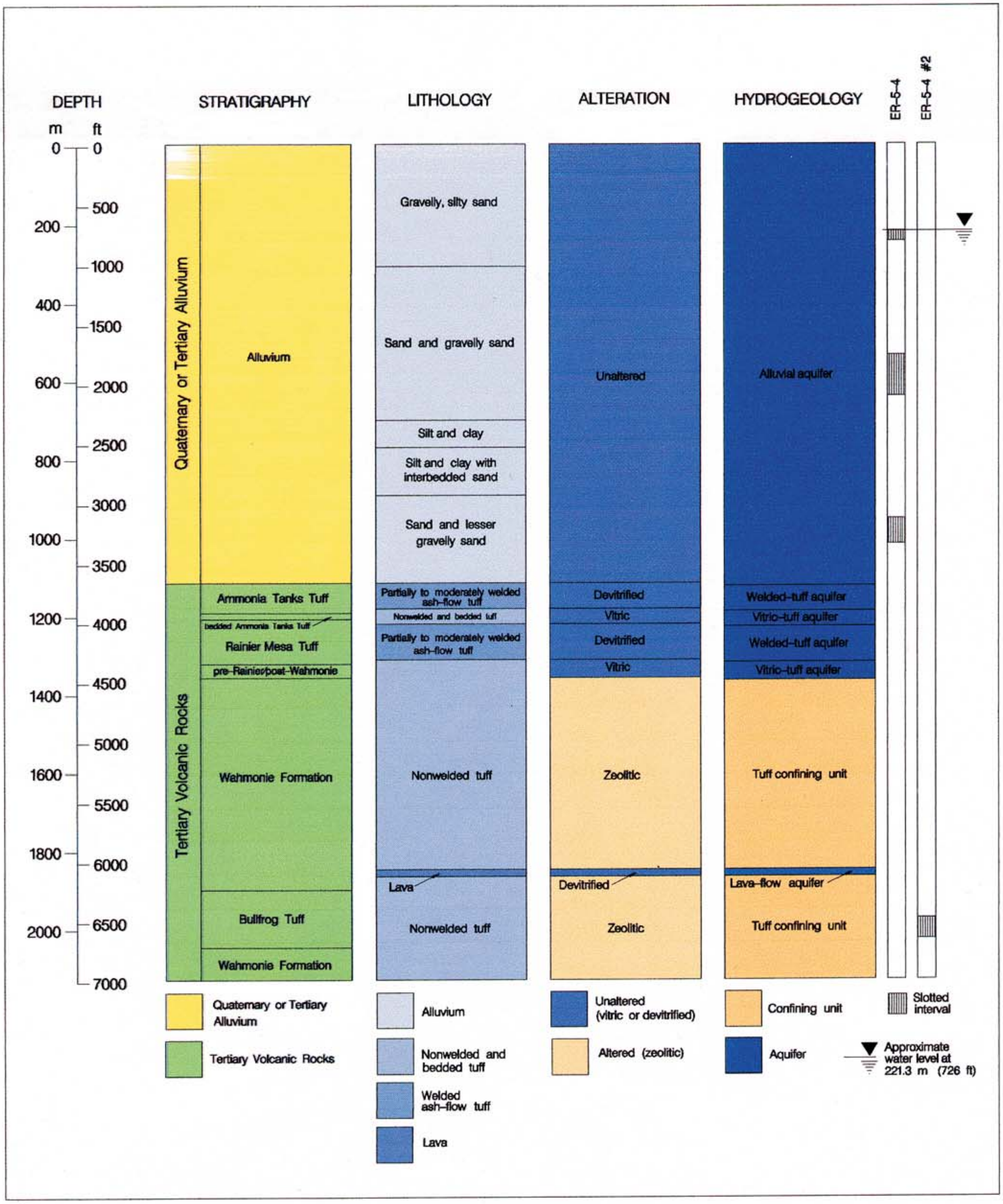

Figure 4-2
Geology and Hydrogeology of Well Cluster ER-5-4

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40 km (25 mi) northwest of Frenchman Flat. Well ER-5-4 reached TD at 1,137.5 m (3,732 ft) within the Ammonia Tanks Tuff after penetrating approximately 18.8 m (62 ft) of the formation.

4.2.2.2 Well ER-5-4#2

Well ER-5-4#2 penetrated through the alluvium and reached TD within Tertiary volcanic rocks at a depth of 2,133.6 m (7,000 ft). Because only drill cuttings were collected during the drilling of the alluvial section at Well ER-5-4#2 (no geophysical log data or sidewall cores were collected), detailed descriptions of the alluvium like those developed for Well ER-5-4 (Appendix C-1) are not possible. However, the close proximity of the 2 holes and an examination of the alluvium drill cuttings samples from Well ER-5-4#2 indicate that the alluvial section penetrated by this well is very similar to that penetrated by Well ER-5-4, 30.5 m (100 ft) to the north.

Well ER-5-4#2 encountered volcanic rocks at a depth of 1,120.4 m (3,676 ft). The first volcanic unit encountered is the Ammonia Tanks Tuff, consisting of 76.8 m (252 ft) of mostly devitrified, partially to moderately welded ash-flow tuff (this unit was identified on the basis of mineralogy, as described in section 4.2.2.1). Below the welded Ammonia Tanks Tuff the borehole penetrated 15.8 m (52 ft) of vitric bedded tuff assigned to the bedded Ammonia Tanks Tuff. The stratigraphic assignment is based on the lithologic character of the interval and its stratigraphic position between the ash-flow tuffs of the Ammonia Tanks Tuff and Rainier Mesa Tuff.

The borehole encountered the Rainier Mesa Tuff directly beneath the bedded Ammonia Tanks Tuff, at a depth of 1,213.1 m (3,980 ft). At Well ER-5-4#2, the Rainier Mesa Tuff consists of 114.6 m (376 ft) of vitric to devitrified nonwelded to moderately welded ash-flow tuff. The stratigraphic assignment of Rainier Mesa Tuff to the rocks penetrated from 1,213.1 to 1,327.7 m (3,980 to 4,356 ft) is based on the ash-flow tuff lithology, stratigraphic position below the Ammonia Tanks Tuff, and the primary mineralogy, which consists of moderate amounts of quartz, feldspar, and biotite, only rare volcanic lithic fragments, and no sphene. The Rainier Mesa Tuff was erupted 11.6 Ma (Sawyer et. al., 1994) from the Timber Mountain caldera complex.

Many of the drill cuttings samples collected below the Rainier Mesa Tuff are of poor quality, with many samples containing substantial amounts of material caved from higher intervals. In addition, caving of the borehole wall, along with large borehole wash-outs and zones of lost circulation, disrupted the circulating fluid in the borehole and caused considerable mixing of the drill cuttings suspended in the fluid column, further degrading the quality of the samples. Although of poor quality, the samples do provide general information on the rocks encountered by the well. Incorporating additional information from sidewall core samples, geophysical logs, laboratory analyses, surrounding geologic exposures, and regional stratigraphic concepts allows for reasonably confident stratigraphic determinations and lithologic descriptions of the units penetrated by the well.

Below the Rainier Mesa Tuff, the well appears to have penetrated 35.4 m (116 ft) of nonwelded and bedded tuffs in the depth interval 1,327.7 to 1,363.1 m (4,356 to 4,472 ft). Because of the very poor quality of the drill cuttings samples from this interval, the rocks are assigned as an informal grouping referred to as pre-Rainier Mesa Tuff / post-Wahmonie Formation, undifferentiated. This interval is likely to include formations such as the tuff of Holmes Road, Topopah Spring Tuff, and Calico Hills Formation. Although difficult to determine due to the poor quality of the samples, the interval appears to be unaltered (i.e., vitric), based on a comparison of resistivity values from the interval with those from overlying vitric intervals and underlying zeolitic intervals (see Appendix D for geophysical log plots). The base of the interval is constrained by a sidewall core taken at 1,366.4 m (4,483 ft) that was identified as Wahmonie Formation, and is picked at an abrupt decrease in natural gamma radiation of the rock observed on the gamma ray log at 1,363.1 m (4,472 ft).

Below the depth of 1,363.1 m (4,472 ft), the well penetrated 540.7 m (1,774 ft) of mostly zeolitic nonwelded tuff assigned to the Wahmonie Formation. Drill cuttings samples are of very poor quality above 1,554.5 m (5,100 ft) due to severe contamination by material caving in from higher intervals. Below 1,554.5 m (5,100 ft) the quality of the samples improves due to a significant reduction of caved material as a result of casing being set at 1,477.9 m (4,848.8 ft) prior to drilling below 1,573.7 m (5,163 ft), and thus eliminating the sources of post-Wahmonie Formation contamination. The assignment of these rocks to the Wahmonie Formation is based mainly on the high abundance of mafic minerals (particularly orthopyroxene), the absence of quartz observed in the drilling cuttings samples below 1,554.5 m (5,100 ft), and interpretation of two sidewall cores obtained from the depths of 1,366.4 and 1,413 m (4,483 and 4,639 ft). The abundance of orthopyroxene is characteristic of the upper portions of the Wahmonie Formation. Drill cuttings from the sample interval 1,514.9 to 1,517.9 m (4,970 to 4,980 ft) were tentatively identified by mineralogical analysis as Calico Hills Formation (WoldeGabriel et al., 2003). The samples may represent material caved from higher intervals, or indicate that the Calico Hills Formation is intercalated with the upper portions of the Wahmonie Formation. The relatively low resistivity of the formation as observed on the dual laterolog (Appendix D) is characteristic of zeolitic, poorly welded tuffs, and is consistent with the lithology of the two sidewall core samples taken from the interval and the majority of the samples below 1,554.5 m (5,100 ft). An interval of lava was tentatively identified in the

Wahmonie Formation, in the interval 1,850.7 to 1,869.6 m (6,072 to 6,134 ft), based mainly on a conspicuous abrupt increase in resistivity and density through this interval. Rocks of the Wahmonie Formation were erupted 13.0 Ma (Sawyer et. al., 1994) from the Wahmonie volcano, the remnants of which form the highlands that border Frenchman Flat on the west.

The Bullfrog Tuff was encountered below the Wahmonie Formation, from 1,903.8 to 2,051.3 m (6,246 to 6,730 ft). The unit consists of 147.5 m (484 ft) of zeolitic nonwelded tuff. The assignment of this interval to the Bullfrog Tuff is based mainly on the presence of moderate amounts of felsic phenocrysts (including quartz), and biotite. Drill cuttings from the sample interval 1,898.9 to 1,902.0 m (6,230 to 6,240 ft) were identified by petrographic and microprobe analyses as the genetically related Prow Pass Tuff (WoldeGabriel et al., 2003), indicating that the Prow Pass Tuff occurs at the top of the interval. The Bullfrog Tuff was erupted 13.25 Ma (Sawyer et. al., 1994) from the Silent Canyon caldera complex located approximately 56 km (35 mi) northwest of Frenchman Flat.

The natural gamma ray spectroscopy log (Appendix D) indicates possible fractures within the Bullfrog Tuff at 1,932.1, 1,953.8, 1,970.2, and 1,980.9 m (6,339, 6,410, 6,464, and 6,499 ft). However, the lack of corresponding breakouts on the caliper log and no increase in water production or lost circulation while drilling at these depths suggest that the fractures are probably healed. Conspicuous breakouts are observed on the caliper log between the depths of 1,998.0 and 2,024.5 m (6,555 to 6,642 ft). An increase in water production and lost circulation occurred during drilling of this interval, suggesting that these fractures are open. Preliminary analysis of the field print of the Electric-Micro Imager® log indicates that these fractures strike almost due north and dip more than 70 degrees to both the west and east.

Another interval of Wahmonie Formation was penetrated below the Bullfrog Tuff from the depth of 2,051.3 m (6,730 ft) to the TD of the well at 2,133.6 m (7,000 ft). This interval of Wahmonie also appears to consist mainly of zeolitic nonwelded tuff. However, no orthopyroxene was observed, which suggests the interval is part of the lower portion of the Wahmonie, possibly the Salyer Member which has only rare orthopyroxene. The occurrence of Wahmonie Formation stratigraphically above and below the Bullfrog Tuff indicates that the 2 formations, originating from different sources, interfinger beneath Frenchman Flat, and that the lower portions of the Wahmonie Formation are older than 13.25 Ma.

4.2.3 Alteration

Although the alluvium contains volcanic clasts that are altered (i.e., zeolitic) the alluvial matrix is primarily vitric, indicating that the alluvium has undergone very little in situ alteration since deposition (Warren et al., 2002).

The volcanic rocks above the Wahmonie Formation (depth interval 1,120.4 to 1,363.1 m [3,676 to 4,472 ft]), including the Ammonia Tanks and Rainier Mesa Tuffs, are also primarily unaltered. The nonwelded and bedded tuffs are vitric, while the more welded ash-flow tuffs are devitrified (Figure 4-2).

The rocks assigned to the Wahmonie Formation and Bullfrog Tuff are pervasively zeolitic. Quantitative mineralogic analysis shows that the degree of alteration increases with depth (WoldeGabriel et al., 2003), as summarized here and illustrated on Figure 4-2. However, the absence of analcime, the fresh unaltered appearance of the biotite, and the lack of any apparent alteration of feldspar phenocrysts suggest that this alteration is typical zeolitization and not the more advanced quartzo-feldspathic alteration present in volcanic rocks near the bottom of the Tertiary section in Yucca Flat and at the base of the Bullfrog Tuff immediately above the top of the Paleozoic rocks in Well ER-5-3#2 in northern Frenchman Flat. This may indicate that the base of the Tertiary volcanic rock section (i.e., top of Paleozoic sedimentary rocks) in Well ER-5-4#2 is still some distance below the TD of the well.

In summary, rocks from the surface to 1,363.1 m (4,472 ft) at Well Cluster ER-5-4 are primarily unaltered, while rocks from 1,363.1 to 2,133.6 m (4,472 to 7,000 ft) show pervasive zeolitic alteration, with the degree of alteration increasing with depth.

4.3 Predicted Versus Actual Geology

Figure 4-3 provides a comparison of the geology predicted to be encountered by the two wells of the cluster prior to drilling with the geology actually encountered by the wells. Originally, Well ER-5-4 was planned to be drilled completely through the alluvium and reach a TD of 1,066.8 m (3,500 ft) in the underlying volcanic rocks. However, drilling was terminated due to severe borehole instability while apparently still in alluvium, at a depth of 1,137.5 m (3,732 ft). Later detailed examination of the cuttings and comparison of data from Well ER-5-4#2 indicated that the top of the volcanic rocks was encountered at approximately 1,118.6 m (3,670 ft) in Well ER-5-4. The predicted depth to the top of the volcanic rocks was 1,005.8 m (3,300 ft), indicating that the alluvium is 112.8 m (370 ft) thicker than originally predicted.

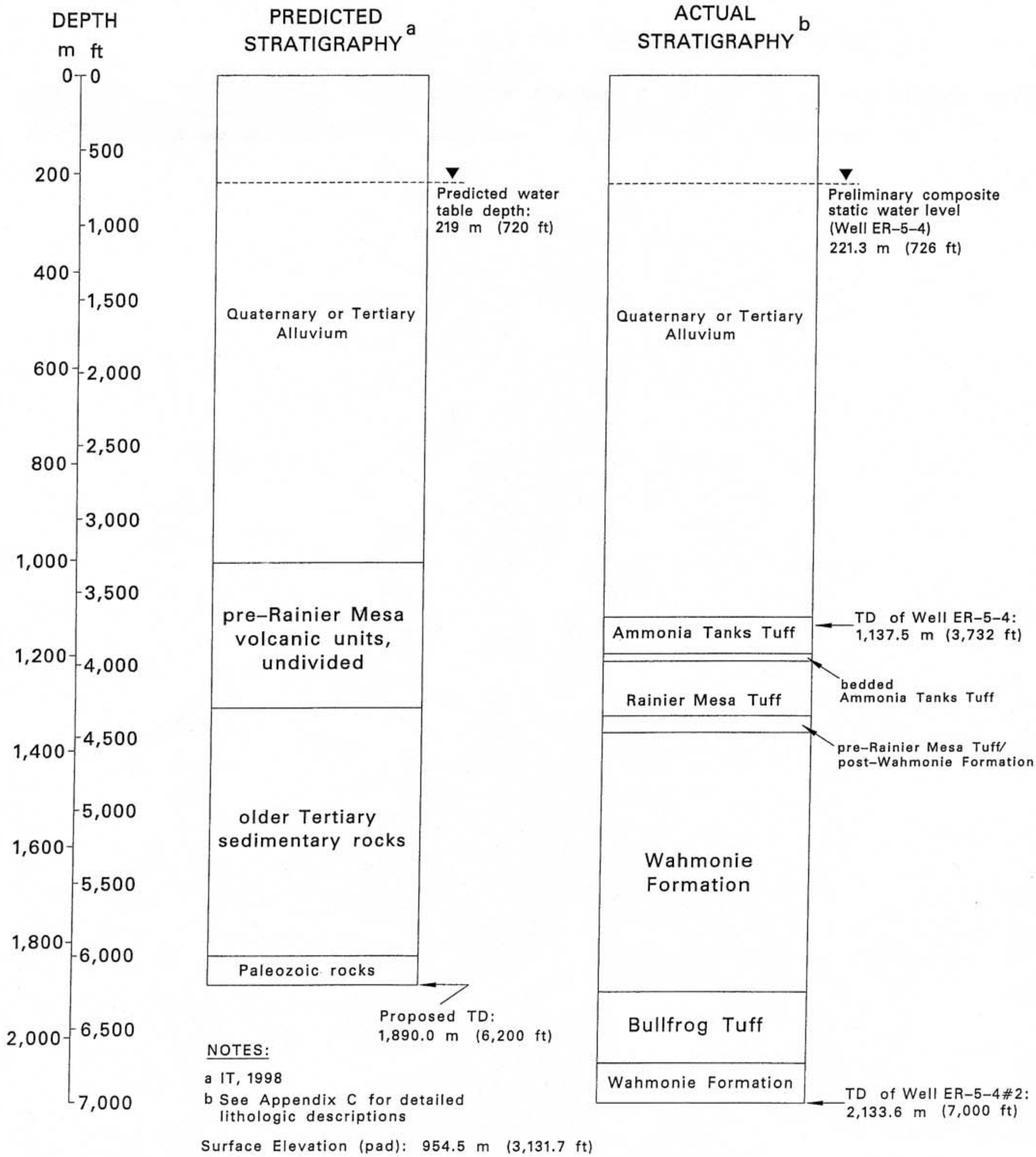

Figure 4-3
Predicted and Actual Stratigraphy at Well Cluster ER-5-4

Well ER-5-4#2 was drilled 30.5 m (100 ft) south of Well ER-5-4. It encountered the top of the volcanic rocks at a more precisely determined depth of 1,120.4 m (3,676 ft) which is 114.6 m (376 ft) lower than the pre-drill prediction for the top of volcanic rocks. It was predicted that the first volcanic rocks encountered would be poorly welded, zeolitic tuffs older than the Rainier Mesa Tuff. However, after penetrating the alluvium, the well encountered 207.3 m (680 ft) of mostly welded ash-flow tuff assigned to the Rainier Mesa and younger Ammonia Tanks Tuffs, indicating that the ash-flow tuffs of the Timber Mountain Group extend farther south beneath Frenchman Flat than previously modeled (IT, 1998). The rocks were also primarily unaltered (vitric and devitrified), which indicates that the top of pervasive zeolitic alteration is deeper than predicted. The well was predicted to penetrate approximately 304.8 m (1,000 ft) of pre-Rainier Mesa Tuff units consisting of zeolitic, nonwelded and bedded tuffs, then cut approximately 518.2 m (1,700 ft) of older Tertiary sedimentary rocks, before encountering Paleozoic rocks at 1,828.8 m (6,000 ft). At the depth of 2,133.6 m (7,000 ft) Well ER-5-4#2 was still in pre-Rainier Mesa volcanic rocks after penetrating 805.9 m (2,644 ft) of these rocks. This indicates that these rocks are more than 501.1m (1,644 ft) thicker than predicted. The well reached TD in Wahmonie Formation and thus did not reach the older Tertiary sedimentary rocks or Paleozoic rocks.

Analysis of seismic data in combination with information from the well cluster indicates that the top of the Paleozoic rocks is probably no shallower than 2,377.4 m (7,800 ft) (Prothro, 2002), and thus at least 548.6 m (1,800 ft) deeper at the well cluster site than originally predicted.

Cross sections constructed through the well site prior to drilling show a series of down-to-the-west normal faults located both east and west of the site (IT, 2001a). These faults were interpreted to be major basin-forming faults, forming a series of north-trending, east-tilted half-grabens. The locations of the faults were based primarily on interpretation of aeromagnetic data (Grauch and Hudson, 1995). However re-interpretation of the gravity data (Phelps and Graham, 2002) and recently acquired and interpreted 3-D seismic reflection data indicate that no major faults are present in the vicinity of the well cluster site, as shown on the west-east seismic profile in Figure 4-4. Figure 4-5, a west-east geologic cross section through the well site, also shows no major faults in this area. The cross section incorporates information from the wells and from an interpretation of the 3-D seismic reflection data (Prothro, 2002).

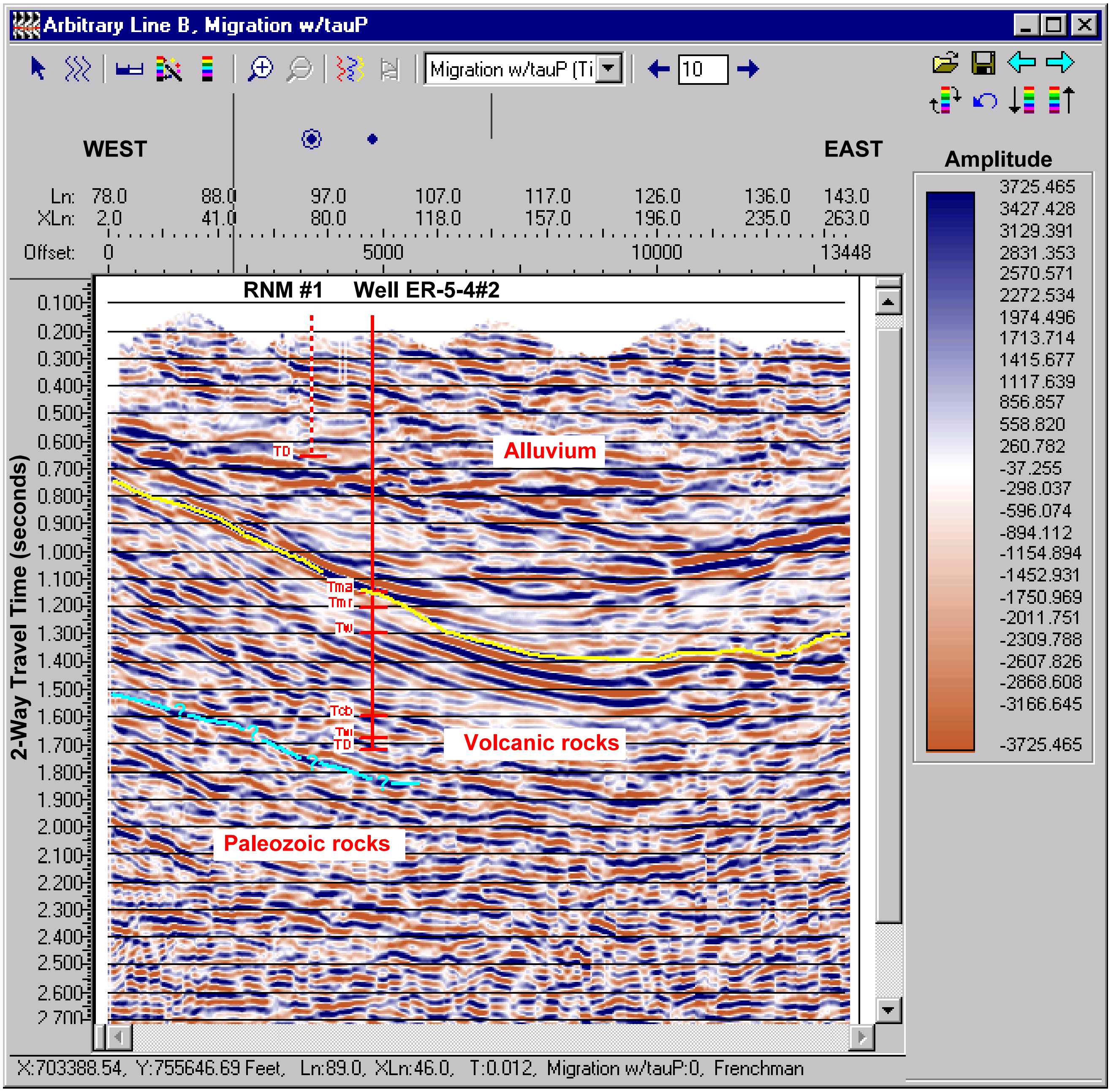

Figure 4-4
West-East Seismic Profile through Well ER-5-4#2

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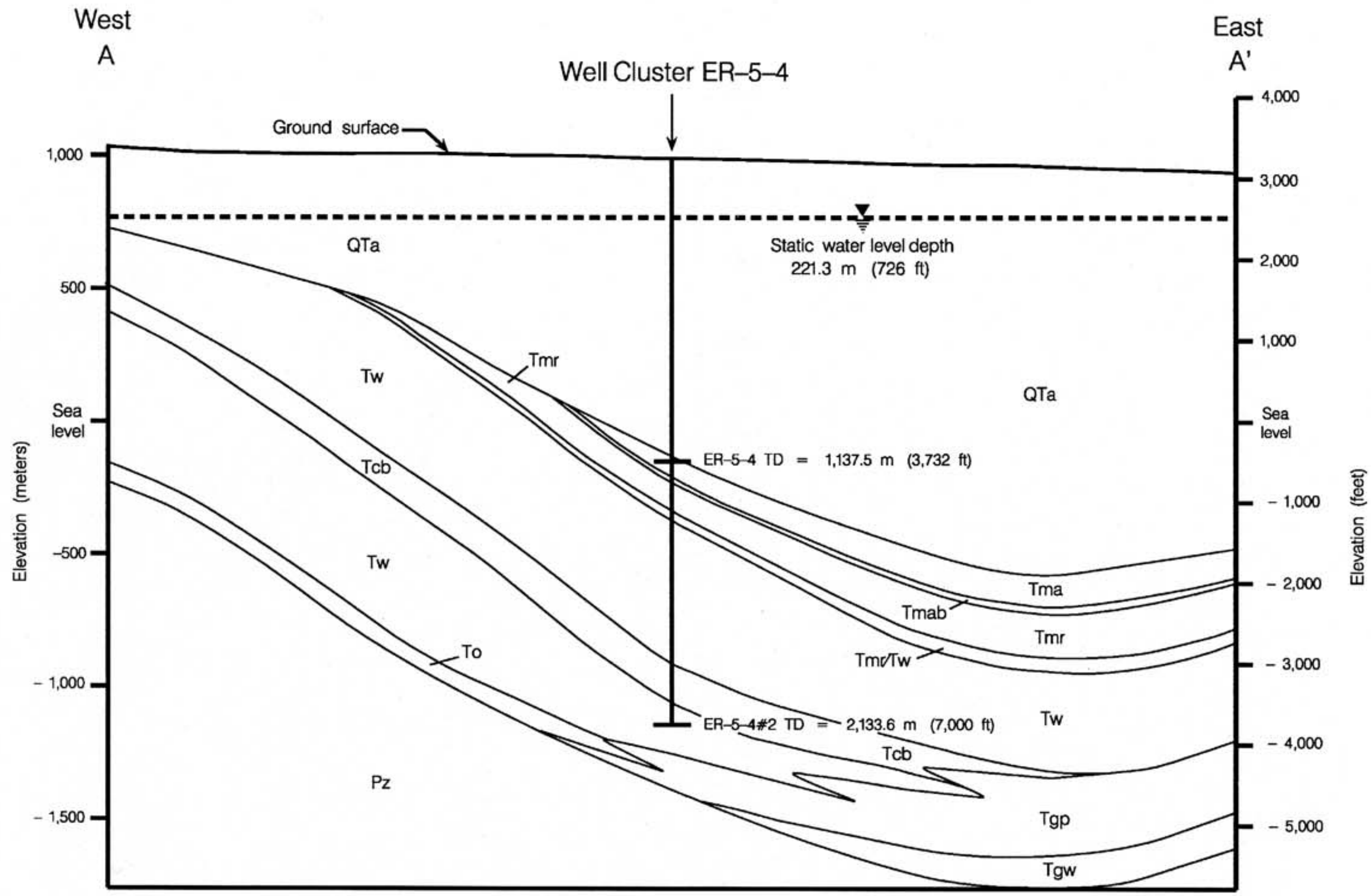

No vertical exaggeration

Cross section location shown on Figure 4–1

QTa	Quaternary or Tertiary Alluvium, undivided
Tma	Ammonia Tanks Tuff
Tmab	bedded Ammonia Tanks Tuff
Tmr	Rainier Mesa Tuff
Tmr/Tw	pre–Rainier Mesa Tuff/ post–Wahmonie Formation, undifferentiated
Tcb	Bullfrog Tuff
Tw	Wahmonie Formation
To	older tuffs, undifferentiated
Tgp	Rocks of Pavits Springs
Tgw	Rocks of Winapi Wash
Pz	Paleozoic rocks, undifferentiated
TD	Total Depth

Figure 4-5
Geologic Cross Section A - A' through Well Cluster ER-5-4

4.4 Hydrogeology

Figure 4-6 shows a west-east cross sectional view of the distribution of hydrogeologic units encountered at the well cluster. The poorly consolidated and unaltered alluvium encountered in both wells forms an alluvial aquifer (Figure 4-2), which is 1,120 m (3,676 ft) thick in Well ER-5-4#2. The preliminary composite, static water levels measured in both wells soon after completion are within the alluvial aquifer. Finer grained sediments that may represent playa deposits, encountered from 704.7 to 896.1 m (2,312 to 2,940 ft) in Well ER-5-4, are likely less porous and permeable than the more typical alluvial deposits, forming an interval within the alluvial aquifer that may actually behave hydrologically more like a confining unit.

Below the alluvial aquifer, the 2 intervals of partially to moderately welded ash-flow tuff assigned to the Ammonia Tanks and Rainier Mesa Tuffs form welded-tuff aquifers. The unaltered, bedded Ammonia Tanks Tuff present between the 2 welded tuff aquifers forms a thin (18.1 m [52 ft]) interval of vitric-tuff aquifer that, at least locally, separates the 2 welded-tuff aquifers. The vitric, nonwelded base of the Rainier Mesa Tuff and the nonwelded and bedded tuffs present between the Rainier Mesa Tuff and the Wahmonie Formation form another interval of vitric-tuff aquifer that is 46.3 m (152 ft) thick.

The top of pervasive zeolitization that appears to correspond generally to the top of the Wahmonie Formation forms the upper contact of a very thick section of tuff confining unit. This confining unit is present in the interval from 1,363.1 m (4,472 ft) to the TD of Well ER-5-4#2 at 2,133.6 m (7,000 ft), and consists of zeolitic, nonwelded tuffs of the Wahmonie Formation and Bullfrog Tuff. Only a relatively thin (18.9 m [62 ft]) interval of lava that forms a lava-flow aquifer breaks up this thick monotonous sequence of tuff confining unit. These rocks are considered to be a confining unit based on lithology and alteration, which was generally confirmed by the lack of significant water production during drilling. However, fractures encountered within the Bullfrog Tuff in the interval 1998.0 to 2,024.5 m (6,555 to 6,642 ft) appear to have produced significant amounts water during drilling (see Section 3.4.2). Although it is not unusual for tuff confining units to have open fractures that produce water, production is usually short-lived because the fractures typically are poorly developed and do not form systematic, interconnecting networks that can sustain water production. Well development and testing activities at Well ER-5-4#2 will provide additional information on the productivity of these fractures.

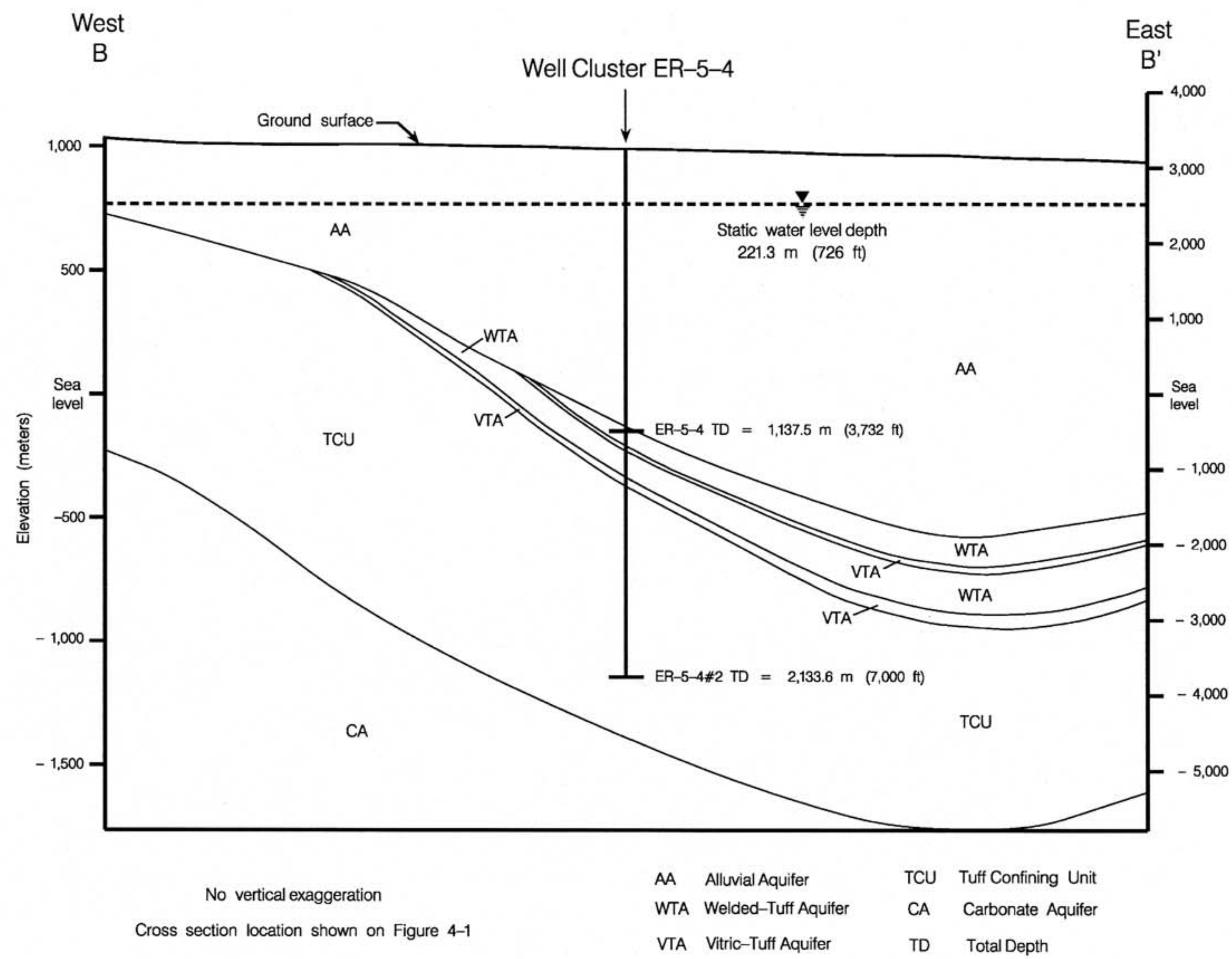

Figure 4-6
Hydrogeologic Cross Section B - B' through Well Cluster ER-5-4

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5.0 Summary, Recommendations, and Lessons Learned

5.1 Summary

Well Cluster ER-5-4 consists of two wells, ER-5-4 and ER-5-4 #2, drilled 30.5 m (100 ft) apart in the central portion of Frenchman Flat of the NTS. The wells were drilled as part of the hydrogeologic investigation well program for Frenchman Flat. The primary purpose of constructing Well Cluster ER-5-4 was to obtain information that will help characterize the hydrogeology near a group of underground nuclear test locations in this part of Frenchman Flat. Data from these wells will allow for more accurate modeling of groundwater flow and radionuclide migration in the region.

Drilling operations at Well Cluster ER-5-4 were hampered by persistent problems related to borehole instability and lost circulation that resulted in numerous delays and required additional equipment and engineering designs to mitigate and resolve. Drilling of Well ER-5-4, the first well of the cluster, commenced on February 11, 2001, and concluded on March 18, 2001, at a depth of 1,137.5 m (3,732 ft). The completion design of the well allows for access to groundwater in the alluvial aquifer at three discrete locations within the well bore. A piezometer tube slotted from 220.2 to 247.4 m (722.6 to 811.7 ft) was installed at the water level depth, and a string of 5½-in. stainless-steel casing was installed with slotted intervals from 539.5 to 644.2 m (1,770.0 to 2,113.4 ft) and 955.9 to 1,021.1 m (3,136.6 to 3,350.1 ft).

Drilling at Well ER-5-4#2 began on July 16, 2002, and concluded on September 11, 2002, at a depth of 2,133.6 m (7,000 ft). The well completion consists of a string of 5½-in. stainless-steel casing slotted from 1,976.9 to 2,029.3 m (6,486.0 to 6,657.7 ft), open to the tuff confining unit, with no gravel or cement.

Geologic data collected at Well Cluster ER-5-4 consist of drill cuttings collected every 3 m (10 ft) from below the conductor casing to total depth in both wells. In addition, a total of 156 sidewall core samples was collected from both holes. Numerous geophysical logs were also run in each hole to verify the geology, determine hydrologic characteristics, and aid in well construction.

The geology encountered at the well cluster consists, in descending order, of 1,120.4 m (3,676 ft) of Quaternary and Tertiary alluvium, 242.6 m (796 ft) of generally unaltered nonwelded and welded ash-flow tuff of Tertiary age, and 770.5 m (2,528 ft) of mostly zeolitic nonwelded tuff, also of Tertiary age. The preliminary, composite water level in Well ER-5-4 is approximately 221.3 m (726 ft) below ground surface. No radionuclides above background were encountered in the groundwater produced from either well. Preliminary (field-monitoring) data indicated no lead above permitted levels for dissolved lead in the drilling effluent.

5.2 Recommendations

All geologic, geophysical, and hydrologic information, including results from well development activities, from Well Cluster ER-5-4 should be used to refine hydrogeologic models of Frenchman Flat.

5.3 Lessons Learned

The alluvium in the central portion of Frenchman Flat can be difficult to drill through due to the poorly consolidated nature of the unit that can cause significant problems associated with borehole wall instability. Sloughing and washout of the borehole wall and loss of fluid circulation can severely hamper drilling operations. The use of bentonite drilling mud and lost circulation material can help alleviate some of these problems but may not be sufficient to successfully drill through the alluvial section. Additional drilling methods such as extra casing strings and cement plugs may be necessary for successful drilling of this unit.

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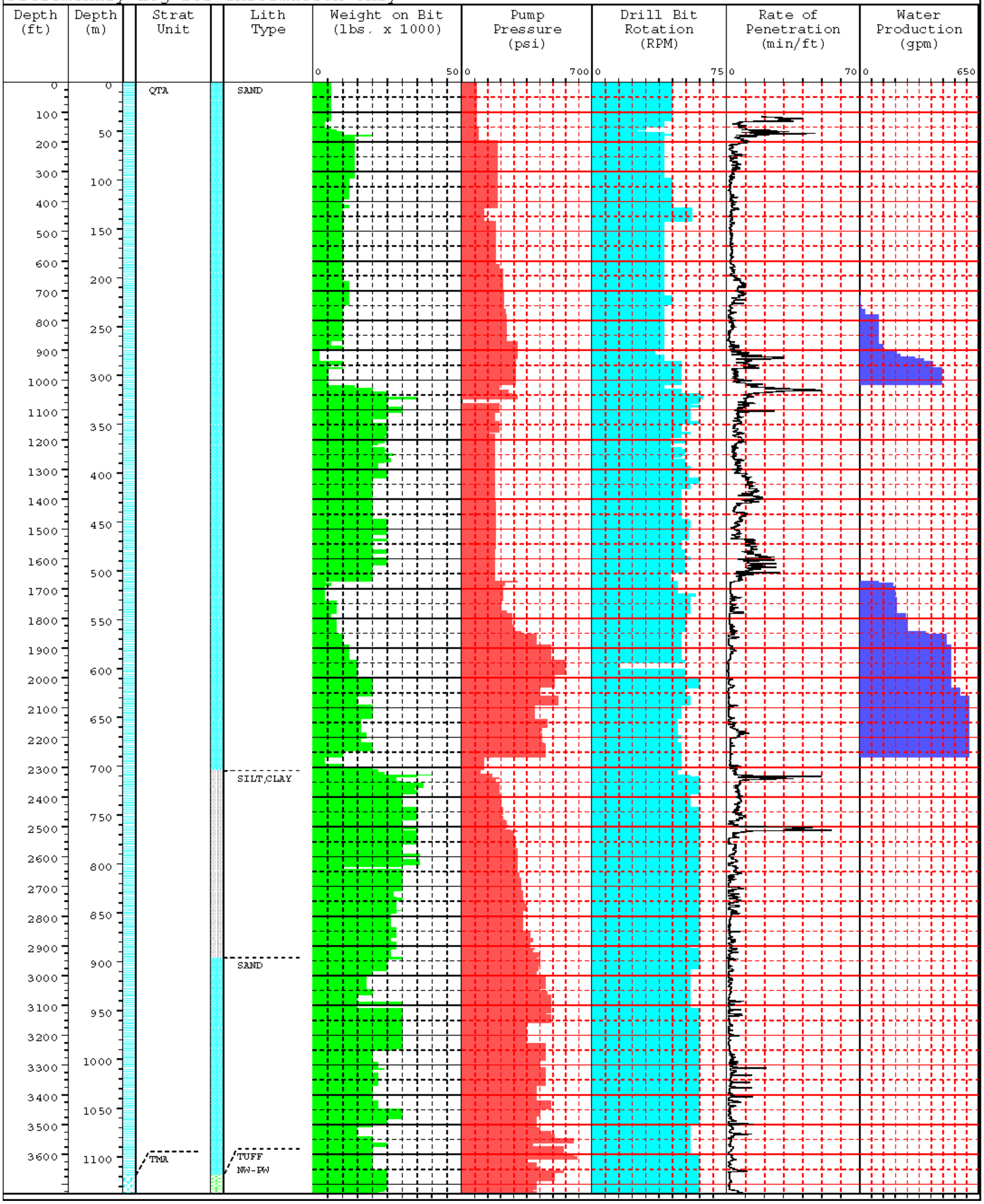
Appendix A
Drilling Data

Appendix A-1
Drilling Parameter Logs for Well Cluster ER-5-4

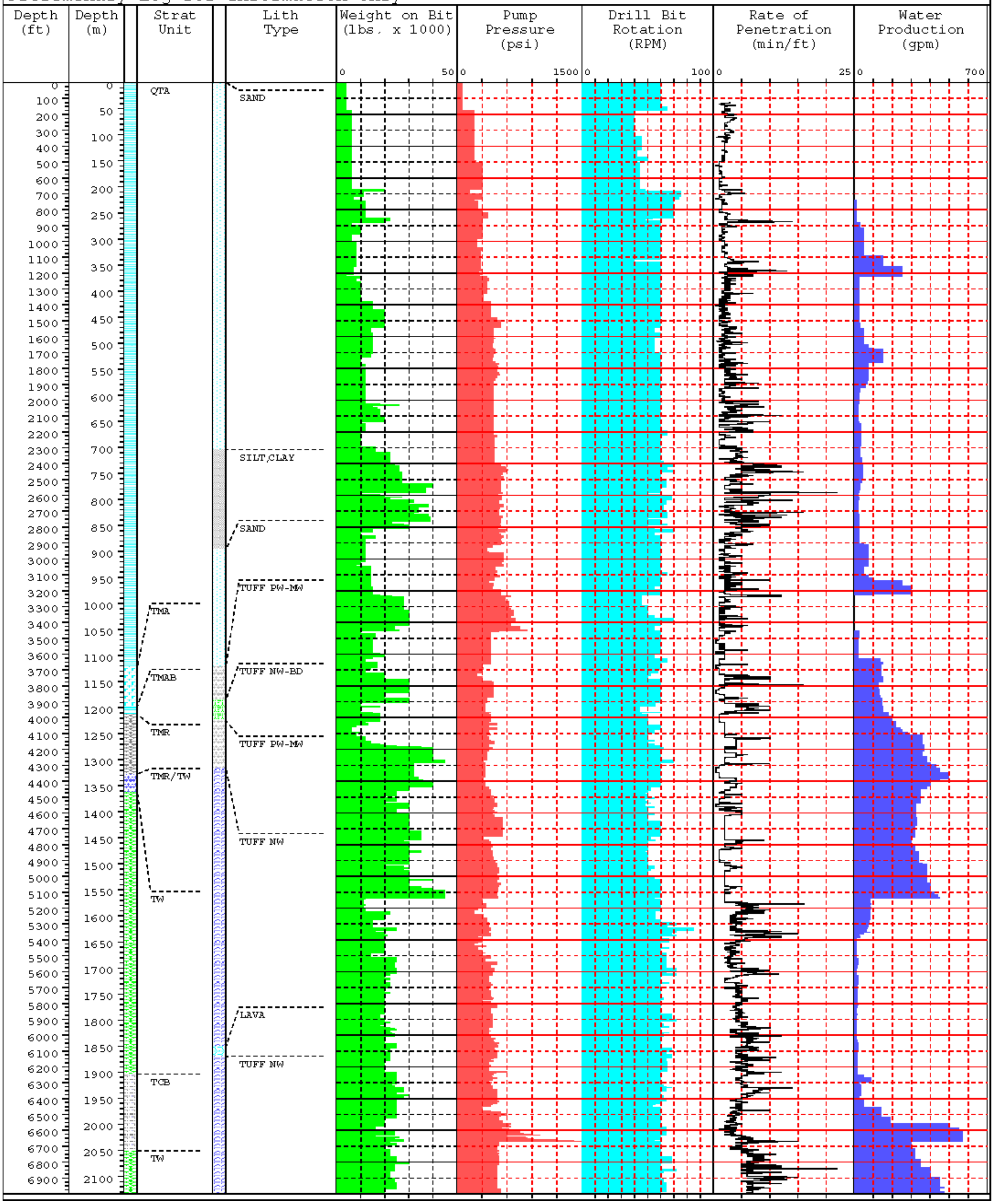
Well Name: ER-5-4	Frenchman Flat Drilling Program		Northing:4075874.5 m
Date: 08/26/03	Start Date: 02/10/01	Stop Date: 03/31/01	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No: 799416.01010095	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Drilled Depth: 3732 ft

Preliminary Log for Information Only



Well Name: ER-5-4 #2	Frenchman Flat Drilling Program		Northing:4075844.0 m
Date: 08/26/03	Start Date: 07/15/02	Stop Date: 09/18/02	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No: 799416.01010095	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air-Mud	Geol: J. Wurtz	Drilled Depth: 7000 ft

Preliminary Log for Information Only



Appendix A-2
Casing and Tubing Data for Well Cluster ER-5-4

Table A-2-1
Casing and Tubing Data for Well ER-5-4

Casing	**Depth Interval** meters (feet)	**Type**	**Grade**	**Outside Diameter** centimeters (inches)	**Inside Diameter** centimeters (inches)	**Wall Thickness** centimeters (inches)	**Weight per foot** (pounds)
Conductor Casing	0 to 36.3 (0 to 119.0)	Carbon Steel PE Weld	N/A	76.2 (30)	74.295 (29.250)	0.953 (0.375)	118.65
Surface Casing	0 to 279.1 (0 to 915.5)	Carbon Steel	K55	50.80 (20)	48.575 (19.124)	1.113 (0.438)	94.0
Intermediate Casing	0 to 63.9 (0 to 209.6)	Carbon Steel	K55	33.97 (13.375)	31.788 (12.515)	1.092 (0.430)	61.0
	63.9 to 510.0 (209.6 to 1,673.3)	Carbon Steel	K55	33.97 (13.375)	32.042 (12.615)	0.965 (0.380)	54.5
Piezometer String	0 to 248.1 (1 to 813.9)	Stainless Steel	P110	7.303 (2.875)	6.200 (2.441)	0.551 (0.217)	6.5
Completion Casing (with cross-over)	0 to 500.2 (0 to 1,641.0)	Carbon Steel with internal epoxy coating	N80	19.37 (7.625)	17.701 (6.969)	0.833 (0.328)	26.4
Completion Casing	500.2 to 1,048.0 (1,641.0 to 3,438.3)	Stainless Steel	SSTP304	14.13 (5.563)	12.819 (5.047)	0.655 (0.258)	14.6

Table A-2-2
Casing and Tubing Data for Well ER-5-4#2

<table>
<tr><th>Casing</th><th>Depth Interval
meters
(feet)</th><th>Type</th><th>Grade</th><th>Outside Diameter
centimeters
(inches)</th><th>Inside Diameter
centimeters
(inches)</th><th>Wall Thickness
centimeters
(inches)</th><th>Weight per foot
pounds</th></tr>
<tr><td>Conductor Casing</td><td>0 to 33.8
(0 to 111)</td><td>Carbon Steel PE Weld</td><td>N/A</td><td>76.2
(30)</td><td>74.3
(29.250)</td><td>0.9
(0.375)</td><td>118.65</td></tr>
<tr><td>Surface Casing</td><td>0 to 266.1
(0 to 873)</td><td rowspan="4">Carbon Steel</td><td rowspan="4">K55</td><td>50.8
(20)</td><td>48.6
(19.124)</td><td>2.2
(0.876)</td><td>94</td></tr>
<tr><td rowspan="3">Intermediate Casing</td><td>0 to 280.2
(0 to 919.2)</td><td>34.0
(13.375)</td><td>31.8
(12.515)</td><td>2.2
(0.865)</td><td>61</td></tr>
<tr><td>280.2 to 965.9
(919.2 to 3,169)</td><td>34.0
(13.375)</td><td>32.0
(12.615)</td><td>1.9
(0.760)</td><td>54.5</td></tr>
<tr><td>0 to 1,477.9
(0 to 4,848.8)</td><td>24.4
(9.625)</td><td>22.7
(8.921)</td><td>1.8
(0.704)</td><td>36</td></tr>
<tr><td>Completion Casing</td><td>1,437.1 - 2,030.0
(4,715 - 6,660)</td><td>Stainless Steel</td><td>SSTP304</td><td>14.1
(5.563)</td><td>12.8
(5.047)</td><td>1.3
(0.516)</td><td>14.6</td></tr>
</table>

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Appendix A-3
Well Cluster ER-5-4 Drilling Fluids and Cement Composition

Table A-3-1
Well ER-5-4 Drilling Fluids

Typical Air-Foam/Polymer Mix	Typical Bentonite Mud Mix
26.5 liters (7 gallons) Geofoam® [a] 7.6 liters (2 gallons) LP-701® [a] per 7,949 liters (50 barrels) water	50 viscosity Geo Gel® [a] and LP-701® mixture Walnut hulls, cotton seed pellets, and Prima Seal® [a] as lost circulation material added periodically

a Geofoam® foaming agent, LP-701® polymer additive, Geo Gel® bentonite mud and Prima Seal® lost circulation material are products of Geo Drilling Fluids, Inc.

NOTES:
1. All water used to mix drilling fluids for Well ER-5-4 came from a fill stands at the Radioactive Waste Management Site in Area 5 and Mercury, Nevada in Area 23.
2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of approximately 15 to 20 milligrams per liter.

Table A-3-2
Well ER-5-4#2 Drilling Fluids

Typical Air-Foam/Polymer Mix	Typical Bentonite Mud Mix
22.7 to 30.3 liters (6 to 8 gallons) Geofoam® [a] 7.6 liters (2 gallons) LP-701® [a] per 7,949 liters (50 barrels) water	50 to 60 viscosity Geo Gel® [a] and LP-701 ® mixture Cedar fiber and Prima Seal® as lost circulation material added periodically above 1,039.4 m (3,410 ft)

a Geofoam® foaming agent, LP-701® polymer additive, Geo Gel® bentonite mud and Prima Seal® lost circulation material are products of Geo Drilling Fluids, Inc.

NOTES:
1. All water used to mix drilling fluids for Well ER-5-4 #2 came from a fill stand at the Radioactive Waste Management Site and Water Well 5B, both located in Area 5.
2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of approximately 20 milligrams per liter.

Table A-3-3
Well ER-5-4 Cement Composition

Cement Composition	Cemented Interval (depth below ground surface)			
	30-inch Conductor Casing	20-inch Surface Casing	13 d -inch Intermediate Casing	5½-inch Completion String
Type II neat	0 - 37.2 m [a] (0 - 122 ft [b])	248.4 - 277.4 m (815 - 910 ft)	442.6 - 510.5 m (1,452 [c] - 1,675 ft)	499.9 - 522.7 m (1,640 - 1,715 ft) 668.1 - 744.9 m (2,192 - 2,444 ft) 855.3 - 890.6 m (2,806 - 2,922 ft) 902.2 - 918.7 m (2,960 - 3,014 ft)

a meter(s) b foot (feet) c estimated

Table A-3-4
Well ER-5-4#2 Cement Composition

Cement Composition	Cemented Interval (depth below ground surface)				
	30-inch Conductor Casing	20-inch Surface Casing	13 d -inch Intermediate Casing	9 e -inch Intermediate Casing	5½-inch Completion String
Type II neat	0 - 35.1 m [a] (0 - 115 ft [b])	192.9 to 266.4 m (633 - 874 ft)	944.0 - 966.2 m (3,097 [c] - 3,170 ft)	1,465.8 - 1,478.3 m (4,809 [c] - 4,850 ft)	Not used

a meter(s) b foot (feet) c estimated

Appendix B

Well Cluster ER-5-4 Fluid Management Data

Table 3-2

Well ER-5-4 Fluid Disposition Reporting Form

Site Identification: ER-5-4

Site Location: Nevada Test Site

Site Coordinates: N: 4,075,696 ft E: 592,450 ft

Well Classification: ER Hydrogeologic Investigation Well

Project Number: 779416-01010095

Report Date: 09/21/01

DOE/NV Project Manager: Bob Bangerter

IT Project Manager: Janet Wille

IT Site Representative: Jeff Wurtz

IT Waste Coordinator: Patty Gallo

Well Activity	Activity Duration		#Ops Days[a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes (m^3)		Infiltration Area (m^3)[c]	Other[d] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids[b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	2/10/01	2/14/01	4	221.3	577.9	98.5	400.2	NA	NA	NA	NA	Yes
Phase I: Saturated-Zone Drilling	2/14/01	3/18/01	32	1,137.8	5,693.3	61.6	537.4	90.0	1,592.6	6,338.4	NA	Yes
Phase II: Initial Well Development	Pending	Pending	-	-	-	-	-	-	-	-	-	-
Phase II: Aquifer Testing	Pending	Pending	-	-	-	-	-	-	-	-	-	-
Phase II: Final Development	Pending	Pending	-	-	-	-	-	-	-	-	-	-
Cumulative Production Totals to Date:			36	1,359.1	6,271.2	160.1	937.6	90.0	1,592.6	6,338.4	NA	Yes

[a]Operational days refer to the number of days that fluids were produced during at least part (>3 hours) of one shift.
[b]Solids volume estimates include calculated added volume attributed to rock bulking factor.
[c]Ground surface discharge and infiltration within the unlined sump.
[d]Other refers to fluid conveyance to other fluid management locations or facilities away from the well site, such as vacuum truck transport to another well site.

NA = Not applicable m = Meters m^3 = Cubic meters

Total Facility Capacities (at an 8.5 ft fluid level): Sump #1 = 1,595.5 m^3 Sump #2 = 1,595.5 m^3
Infiltration Area (assuming very low/no infiltration) = NA m^3

Remaining Facility Capacity (Approximate) as of 3/31/01 : Sump #1 = 1,124.3 m^3 (67%) Sump #2 = 52.8 m^3 (3%)

Current Average Tritium = (Natural Background) pCi/L

IT Authorizing Signature/Date [signature] 9-25-01

Preliminary Analytical Results for Fluid Management Samples from Well ER-5-4

Sample Number	Date & Time Collected	Comment		*Resource Conservation Recovery Act* Metals (mg/L) [a]								Gross Alpha (pCi/L) [b]	Gross Beta (pCi/L)	Tritium (pCi/L)
				Arsenic	Barium	Cadmium	Chromium	Lead	Selenium	Silver	Mercury			
ER-5-4-02141-1	02/14/2001 08:50	Sample taken from unlined Sump #1	Total	0.016	0.38	0.00052 (B) [c]	0.017	0.0077	0.0044 (B)	0.01 (U) [d]	0.0002 (U)			
			Dissolved	0.0065 (B)	0.032 (B)	0.005 (U)	0.013	0.003	0.0029 (B)	0.00052 (B)	0.0002 (U)	5.2 E [e] =2.9	10.4 E=3.2	150 E=180 (U)
ER-5-4-02141-2	02/14/2001 09:00	Duplicate sample taken from unlined Sump #1	Total	0.0091 (B)	0.16	0.005 (U)	0.013	0.0013 (B)	0.0067	0.01 (U)	0.0002 (U)			
			Dissolved	0.0071 (B)	0.03 (B)	0.005 (U)	0.012	0.003 (U)	0.0044 (B)	0.01 (U)	0.0002 (U)	8.5 E=3.1	12.2 E=3.4	20 E=170 (U)
ER-5-4-03171-1	03/17/2001 13:00	Sample taken from unlined Sump #2	Total	0.037	0.62	0.005 (U)	0.033	0.1	0.01	0.01 (U)	7.7e-05 (B)			
			Dissolved	0.018	0.017 (B)	0.00027 (B)	0.014	0.0029 (B)	0.0067	0.0016 (B)	0.0002 (U)	9.7 E=2.5	5.3 E=1.8	1,460 E=270
ER-5-4-03191-1	03/19/2001 12:05	Sample taken from unlined Sump #1	Total	0.044	0.042 (B)	0.005 (U)	0.0046 (B)	0.003 (U)	0.005 (U)	0.0012 (B)	0.0002 (U)			
			Dissolved	0.045	0.016 (B)	0.005 (U)	0.0054 (B)	0.00097 (B)	0.005 (U)	0.0015 (B)	0.0002 (U)	7.6 E=1.8	7.2 E=1.5	250 E=170 (U)
ER-5-4-03191-2	03/19/2001 12:20	Sample taken from unlined Sump #2	Total	0.032	0.38	0.005 (U)	0.022	0.044	0.0058	0.01 (U)	9.9e-05 (B)			
			Dissolved	0.016	0.056 (B)	0.005 (U)	0.0082 (B)	0.014	0.0047 (B)	0.00065 (B)	0.0002 (U)	11.3 E=2.7	7.5 E=2.1	540 E=190
Contract-Required Detection Limit				0.01	0.1	0.005	0.01	0.003	0.005	0.01	0.0002	N/A [f]	N/A	N/A
Nevada Drinking Water Standard (NDWS)				0.05	2.0	0.005	0.1	0.015	0.05	0.1	0.002	15	50	20,000
5 Times NDWS				0.25	10	0.025	0.5	0.075	0.25	0.5	0.01	75	250	100,000

Data provided by IT (IT, 2001)

All analyses by Paragon Analytics, Inc.

a mg/L = milligrams per liter

b pCi/L = picocuries per liter

c B = Result less than Contract-Required Detection Limit, but greater than the Instrument Detection Limit

d U = Result less the Instrument Detection Limit or the Minimum Detectable Concentration

e E = Error

f N/A = Not applicable

Table 3-1
Well ER-5-4 #2 Fluid Disposition Reporting Form

Site Identification: ER-5-4 #2
Site Location: Nevada Test Site
Approximate Site Coordinates: N: 4,075,665 m E: 592,450 m
Well Classification: ER Hydrogeologic Investigation Well
Project Number: 840223.03010060

Report Date: 09/18/02
DOE/NV Project Manager: Bob Bangerter
IT Project Manager: Janet Wille
IT Site Representative: Jeff Wurtz
IT Waste Coordinator: Patty Gallo

Well Activity	Activity Duration		#Ops Days[a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes (m^3)		Infiltration Area (m^3)[c]	Other[d] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids[b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	7/15/2002	7/18/2002	4	215.68	739.3	92.8	166.0	0	71.1	0	NA	Yes
Phase I: Saturated-Zone Drilling	7/19/2002	9/18/2002	48	1,917.92	9,831.8	0	1,336.6	313.8	1,494.1	11,821.3	NA	Yes
Phase II: Initial Well Development	Pending	Pending	-	-	-	-	-	-	-	-	-	-
Phase II: Aquifer Testing	Pending	Pending	-	-	-	-	-	-	-	-	-	-
Phase II: Final Development	Pending	Pending	-	-	-	-	-	-	-	-	-	-
Cumulative Production Totals to Date:			52	2,133.60	10,571.1	92.8	1,502.6	313.8	1,565.2	11,821.3	NA	Yes

[a]Operational days refer to the number of days that fluids were produced during at least part (>3 hours) of one shift.
[b]Solids volume estimates include rock bulking factor of 1.5.
[c]Ground surface discharge and infiltration within the unlined sump.
[d]Other refers to fluid conveyance to other fluid management locations or facilities away from the well site, such as vacuum truck transport to another well site.
NA = Not Applicable m = Meters m^3 = Cubic Meters

Total Facility Capacities (at 10 ft fluid level): Sump #1 = 2,029.6 m^3 Sump #2 = 2,029.6 m^3
Infiltration Area (assuming very low/no infiltration) = ground surface trench conveys to Cambric Ditch m^3

Remaining Facility Capacity (Approximate) as of 9/18/02 : Sump #1 = 434.2 m^3 (21%) Sump #2 = 150.6 m^3 (7%)

Current Average Tritium = 0 pCi/L

IT Authorizing Signature/Date [signature] 2-26-03

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Appendix C

Lithologic Logs for Well Cluster ER-5-4

Appendix C-1

Detailed Lithologic Log for Well ER-5-4

Detailed Lithologic Log for Well ER-5-4

Logged by Heather Huckins-Gang, Bechtel Nevada
December, 2001

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type**[1]	**Laboratory Analyses**[2]	**Lithologic Description**[3]	**Stratigraphic Unit**
0 - 310.9 (0 -1,020)	310.9 (1,020)	DB1, SC	PTS, SEM, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Gravelly and Silty Sand:** Poorly sorted, poorly indurated gravelly sand or sand. Sand is tuffaceous, moderate-yellowish-brown (10YR5/4), moderately to highly calcareous, very coarse to very fine and silty. Thin, discontinuous carbonate coats are typically seen on up to 50 percent of clasts in cuttings. Most coated (i.e. unbroken) clasts are subangular to subrounded fine pebbles. Gravel clasts are almost entirely volcanic but contain rare Paleozoic argillite, probably Eleana Formation transported from the northeast, and very rare Paleozoic carbonate and quartzite. Lithology of volcanic clasts in cuttings gradually changes with depth from predominantly lighter colored ash-flow tuffs of the Timber Mountain Group, transported from the north or northeast, to predominantly darker lava of the Wahmonie Formation transported from the east. A moderate brown (5YR4/4) slightly silty and/or clayey, highly calcareous sand seen in a sidewall core at 210.3 m (690 ft) possibly indicates a buried soil.	Quaternary or Tertiary alluvium
310.9 - 704.7 (1020-2312)	393.8 (1,292)	DB1, SC	PTS, SEM, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Sand and Gravelly Sand:** Poorly indurated, moderately sorted sand with little silt or clay. Lesser interbeds of poorly sorted silty sand. Moderate-yellowish-brown (10YR 5/4); moderate-yellowish-brown (10YR 5/4) to dark-yellowish-brown (10YR4/2) below approximately 324.6 m (1,065 ft); noncalcareous to highly calcareous. Gravel clasts in cuttings are predominantly dark lava of the Wahmonie Formation with very rare Paleozoic quartzite. Clayey, calcareous sand in sidewall core at 425.2 m (1,395 ft). A density increase is seen on logs at 348.7 m (1,144 ft). Below 512.1 m (1,680 ft), sandy matrix of alluvium is seen in cuttings as fragments and coatings on clasts.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type**[1]	**Laboratory Analyses**[2]	**Lithologic Description**[3]	**Stratigraphic Unit**
704.7 - 774.2 (2,312- 2,540)	69.5 (228)	DB2, SC	PTS, SEM, XRD, XRF, Fe^{2+}/Fe^{3+}	**Silt and Clay:** Moderately indurated, highly calcareous, bedded silt, clay, and clayey silt; some beds sandy; biotite flakes vary from rare to common. Moderate yellowish brown (10YR5/4) with lesser beds of grayish-orange-pink (5YR7/2), grayish-orange (10YR7/4), and dark-yellowish-orange (10YR6/6).	Quaternary or Tertiary alluvium
774.2 - 896.1 (2,540 - 2,940)	121.9 (400)	DB1, SC	PTS, SEM, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Silt and Clay with interbedded Sand**: Silt and clay are moderately indurated, highly calcareous, bedded clay, silt and clayey silt; some beds are sandy. Grayish-orange (10YR7/4) to moderate-yellowish-brown (10YR5/4). Sandy beds are typically moderately sorted with little silt or clay, poorly indurated, calcareous, dark-yellowish-brown (10YR4/2), occasionally containing concentrations of magnetite or other heavy minerals. Most clasts are volcanic lithologies of the Wahmonie Formation. Cuttings contain common argillite clasts, and few rounded white quartzite clasts. Between 823.6 and 825.1 m (2,702 and 2,707 ft), interval contains a pale-brown (5YR5/2), highly calcareous, fine-grained ash with rare sand-sized vitric pumice. Abundant black biotite and felsic phenocrysts ranging from rare to common in poorly defined beds. This ash has been tentatively identified as an ash-fall of the 9.4 Ma Pahute Mesa Tuff [4]. A bed of dusky-yellowish-brown (10YR2/2) silty sand was noted in sidewall core at 776.0 m (2,546 ft). A pumice-rich bed of silty and/or clayey fine sand, probably a marginal playa deposit, was noted in sidewall core at 831.5 m (2,728 ft).	Quaternary or Tertiary alluvium

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type**[1]	**Laboratory Analyses**[2]	**Lithologic Description**[3]	**Stratigraphic Unit**
896.1 - 1,118.6 (2,940 - 3,670)	222.5 (730)	DB1, SC	PTS, SEM, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Sand and lesser Gravelly Sand**: Poorly to moderately indurated, calcareous to highly calcareous, typically dark-yellowish-brown (10YR4/2). Beds with little silt or clay alternate with silty beds and beds with possibly zeolitic matrix. Below 920.5 m (3,020 ft) Wahmonie Formation clasts in cuttings start to decrease and clasts of Timber Mountain Tuff start to increase. Logs show a density increase at 989.4 m (3,246 ft), possibly indicating an increase in zeolitic and opaline alteration of matrix.	Quaternary or Tertiary alluvium
1,118.6 - 1,137.5 (3,670 - 3,732) TD	18.9 (62)	DB1	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded to Partially Welded Ash-Flow Tuff**: Pale-brown (5YR 5/2); vitric to devitrified; common white (N9) pumice; minor to common felsic phenocrysts of quartz and feldspar including adularescent sanidine; minor biotite, trace of sphene; minor lithic fragments.	Ammonia Tanks Tuff

1 **DB1** = drill cuttings enriched in hard components; **DB2** = cuttings from interval different than that drilled; **SC** = sidewall core.

2 **PTS** = polished thin section; **SEM** = scanning electron microscopy; **MP** = electron microprobe; **XRD** = x-ray diffraction; **XRF** = x-ray fluorescence; **Fe^{2+}/Fe^{3+}** = wet chemical analysis for iron. See Table 2-3 of this report for additional information.

3 Descriptions are based mainly on visual examination of lithologic samples using a 10x- to 40x-zoom binocular microscope, and incorporating observations from geophysical logs. Colors describe wet sample color.

Abundances for felsic phenocrysts, pumice fragments, and lithic fragments: **trace** = only one or two individuals observed; **rare** = $\leq$ 1%; **minor** = 5%; **common** = 10%; **abundant** = 15%; **very abundant** = $\geq$ 20%.

Abundances for mafic minerals: **trace** = only one or two individuals observed; **rare** = $\leq$ 0.05%; **minor** = 0.2%; **common** = 0.5%; **abundant** = 1%; **very abundant** = $\geq$ 2%.

4 Warren, R. G., F. C. Benedict Jr., T. P. Rose, D. K. Smith, S. J. Chipera, E. C. Kluk, and K. M. Raven, 2002. "Alluvial Layering and Distribution of Reactive Phases within Drill Holes ER5/4 and UE5n of Frenchman Flat. Los Alamos National Laboratory Report LA-UR-02-6206. Los Alamos, NM.

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Appendix C-2

Detailed Lithologic Log for Well ER-5-4#2

Detailed Lithologic Log for Well ER-5-4#2

Logged by Lance Prothro, Bechtel Nevada

October, 2002

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [1]	**Laboratory Analyses** [2]	**Lithologic Description** [3]	**Stratigraphic Unit**
0 - 1,120.4 (0 - 3,676)	1,120.4 (3,676)	DB1	PTS, MP	**Alluvium:** Not described. See detailed descriptions from Well ER-5-4 in Appendix C-1.	Quaternary or Tertiary alluvium
1,120.4 - 1,136.9 (3,676 - 3,730)	16.5 (54)	DA	None	**Partially Welded Ash-Flow Tuff:** Pale-brown (5YR 5/2); devitrified, partially vitric in upper part; common white (N9) and lesser moderate-brown (5YR 3/4) pumice; common felsic phenocrysts of feldspar and slightly less quartz, some feldspar phenocrysts exhibit labradorescence; minor mafic minerals of biotite and trace of clinopyroxene; trace of sphene; minor volcanic lithic fragments.	Ammonia Tanks Tuff
1,136.9 - 1,167.4 (3,730 - 3,830)	30.5 (100)	DA	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Grayish-brown (5YR 3/2) in upper part, becoming pale-brown (5YR 5/2) lower; devitrified; common pale-brown (5YR 5/2) pumice; common to abundant felsic phenocrysts of feldspar and quartz; minor mafic minerals of biotite and lesser clinopyroxene; trace of sphene; rare volcanic lithic fragments.	
1,167.4 - 1,185.7 (3,830 - 3,890)	18.3 (60)	DA	PTS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Partially Welded Ash-Flow Tuff:** Yellowish-gray (5Y 8/1) and light-brownish-gray (5YR 6/1); devitrified; rare medium-light-gray (N6) pumice; minor felsic phenocrysts of quartz and feldspar, some feldspar phenocrysts exhibit labradorescence; minor mafic minerals of biotite and much less clinopyroxene; trace of sphene; rare volcanic lithic fragments.	
1,185.7 - 1,197.3 (3,890 - 3,928)	11.6 (38)	DA	None	**Nonwelded Ash-Flow Tuff:** Dark-yellowish-orange (10YR 6/6); vitric; minor very-pale-orange (10YR 8/2) pumice; minor to common felsic phenocrysts of feldspar and quartz; rare to minor biotite; minor volcanic lithic fragments; very abundant and conspicuous orange cuspate glass shards.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [1]	**Laboratory Analyses** [2]	**Lithologic Description** [3]	**Stratigraphic Unit**
1,197.3 - 1,213.1 (3,928 - 3,980)	15.8 (52)	DB1	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Bedded Tuff:** Drill cuttings samples consist mainly of a varied mixture of lava and welded tuff fragments from various, and probably older, stratigraphic units. Many fragments have thin coatings of fine-sand-size, vitric, tuffaceous material that is weakly calcareous and has a composition similar to that of Ammonia Tanks Tuff. Most of the fragments likely represent hard lithic fragments liberated from poorly consolidated bedded tuffs during the drilling process.	bedded, Ammonia Tanks Tuff
1,213.1 - 1,225.3 (3,980 - 4,020)	12.2 (40)	DA	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Ash-Flow Tuff:** Pale-reddish-brown (10R 5/4); mostly vitric, partially devitrified; common white (N9) pumice; minor to common felsic phenocrysts of feldspar and quartz; common biotite; rare volcanic lithic fragments.	Rainier Mesa Tuff
1,225.3 - 1,250.3 (4,020 - 4,102)	25.0 (82)	DA	None	**Partially Welded Ash-Flow Tuff:** Light-brownish-gray (5YR 6/1); devitrified; common brownish-gray (5YR 4/1) pumice; common felsic phenocrysts of feldspar and quartz; minor to common biotite; rare volcanic lithic fragments.	
1,250.3 - 1,312.5 (4,102 - 4,306)	62.2 (204)	DA	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Medium-gray (N5) to brownish-gray (5YR 4/1); devitrified; minor brownish-gray (5YR 4/1) pumice; minor felsic phenocrysts of feldspar and lesser quartz; minor to common biotite; rare volcanic lithic fragments. Geophysical logs indicate degree of welding increases with depth.	
1,312.5 - 1,316.7 (4,306 - 4,320)	4.3 (14)	DA	None	**Partially Welded Ash-Flow Tuff:** Indicated by geophysical logs.	
1,316.7 - 1,327.7 (4,320 - 4,356)	11.0 (36)	DA	None	**Nonwelded Ash-Flow Tuff:** Moderate-brown (5YR 4/4); vitric; common grayish-orange-pink (5YR 7/2) pumice; common felsic phenocrysts of feldspar and quartz; rare biotite; rare volcanic lithic fragments; common cuspate glass shards.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [1]	**Laboratory Analyses** [2]	**Lithologic Description** [3]	**Stratigraphic Unit**
1,327.7 - 1,363.1 (4,356 - 4,472)	35.4 (116)	DB2, DB4	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded and Bedded Tuff:** A detailed lithologic description is not possible due to the poor quality of drill cuttings samples, which consist of highly varied mixtures of volcanic rock fragments generally less than 3 mm in size. Approximately 25% or more of the fragments in samples are moderately welded, devitrified, Rainier Mesa Tuff from the interval 1,250.3 - 1,312.5 m (4,102 - 4,306 ft), indicating considerable contamination of the samples from higher lithologic intervals. Lithologic and stratigraphic determinations are based on information from regional geology, lithologic and stratigraphic assignments of over- and underlying intervals, and geophysical logs.	pre-Rainier Mesa Tuff/ Post-Wahmonie Formation

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [1]	**Laboratory Analyses** [2]	**Lithologic Description** [3]	**Stratigraphic Unit**
1,363.1 - 1,553.3 (4,472 - 5,096)	190.2 (624)	DB2, DB4, SC	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Tuff:** Olive-gray (5Y 4/1) and dusky-yellow-green (5GY 5/2); zeolitic; rare to minor pumice; common to abundant feldspar phenocrysts; very abundant mafic minerals of orthopyroxene and lesser biotite; common to very abundant volcanic lithic fragments. This description is based on small (< 2 cm in diameter) fragments of sidewall core samples obtained from the 1,366.4 m (4,483 ft) and 1,414.0 m (4,639 ft) depths, and thus appropriate uncertainties should be considered when applying the description to the entire interval. Drill cuttings samples throughout interval are of very poor quality and are not representative of the rocks of the interval. Drill cuttings samples appear to consist mainly of material caved from higher intervals. This is indicated by the observation that approximately 25% or more of the fragments in samples above 1,432.6 m (4,700 ft) are moderately welded, devitrified, Rainier Mesa Tuff from the interval 1,250.3 - 1,312.5 m (4,102 - 4,306 ft). The zeolitic, nonwelded, nature of the interval is indicated by the relatively low resistivity of the interval as measured by the dual laterolog. The upper contact corresponds to an abrupt decrease in natural gamma radiation as observed on gamma ray logs. The lower contact is near the bottom of the 12¼-in. hole and is based partly on the general depth where drill cuttings samples change from being highly mixed and severely contaminated by higher, pre-Wahmonie units to highly mixed samples that are dominated by mafic-rich fragments representative of the upper portions of the Wahmonie Formation. This change is due to casing being set at 1,477.9 m (4,848.8 ft), which eliminates post-Wahmonie sources of contamination.	Wahmonie Formation

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [1]	**Laboratory Analyses** [2]	**Lithologic Description** [3]	**Stratigraphic Unit**
1,553.3 - 1,850.7 (5,096 - 6,072)	297.5 (976)	DB4	PTS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded and Bedded Tuff:** Greenish-gray (5G 6/1), light-greenish-gray (5G 8/1), light-brownish-gray (5YR 6/1), and light-brown (5YR 5/6); zeolitic; rare to minor pumice; common to abundant feldspar phenocrysts; abundant to very abundant mafic minerals of biotite and lesser orthopyroxene; minor to abundant volcanic lithic fragments consisting mostly of very dense welded tuff and lava. Drill cuttings samples are of poor quality. They consist of a varied mixture of various volcanic rock fragments generally less than 3 mm in size, and are likely mixed and contaminated with material from various horizons. The representative lithology in most samples from the interval appears to be poorly welded, mafic-rich, zeolitic tuff as described above. The relatively low resistivity throughout the interval as measured on the dual laterolog is consistent with poorly-welded, zeolitic tuff. Several intervals of samples mostly contain fragments of moderately- to densely-welded tuff and dense lava, and may represent more lithic-rich intervals. Slightly higher density values from geophysical logs correspond to these sample depths.	Wahmonie Formation
1,850.7 - 1,869.6 (6,072 - 6,134)	18.9 (62)	DB4	None	**Lava:** Grayish-brown (5YR 3/2), with a mottled appearance; devitrified, with sucrose texture that may indicate silicic alteration; common feldspar phenocrysts; rare to minor, very small, unaltered to partially altered biotite; common to abundant unknown moderate-green (5G 5/6) pseudomorphs after biotite(?). No pumice or lithic fragments observed. Drill cuttings samples are of poor quality. They consist of a varied mixture of volcanic rock fragments generally less than 3 mm in size, and are likely mixed and contaminated with material from various horizons. Recognition of interval is based mainly on a conspicuous, abrupt increase in density and resistivity as observed on geophysical logs. The abrupt contacts are more indicative of a lava than a welded ash-flow tuff.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [1]	**Laboratory Analyses** [2]	**Lithologic Description** [3]	**Stratigraphic Unit**
1,869.6 - 1,903.8 (6,134 - 6,246)	34.1 (112)	DB4	PTS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Tuff:** Light-brownish-gray (5YR 6/1); zeolitic; common white (N9) pumice; common to abundant feldspar phenocrysts; very abundant mafic minerals of mostly biotite and lesser partially altered orthopyroxene(?); minor to common volcanic lithic fragments. Drill cuttings samples are of poor quality, They consist of a varied mixture of volcanic rock fragments generally less than 3 mm in size, and are likely mixed and contaminated with material from various horizons.	Wahmonie Formation
1,903.8 - 1,922.1 (6,246 - 6,306)	18.3 (60)	DA	None	**Nonwelded Tuff:** Moderate-yellow (5Y 7/6) at top of interval, becoming moderate-reddish-brown (10R 4/6) lower; zeolitic; common pumice; minor felsic phenocrysts feldspar and quartz; rare to minor biotite; rare volcanic lithic fragments.	Bullfrog Tuff
1,922.1 - 2,051.3 (6,306 - 6,730)	129.2 (424)	DA, DB4	PTS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Tuff:** Grayish-orange (10YR 7/4) at top of interval, becoming grayish-red (10R 4/2) lower and moderate-yellowish-brown (10YR 5/4) at base of interval; zeolitic; minor to common pumice; minor felsic phenocrysts of feldspar and quartz; minor to common biotite; minor volcanic lithic fragments. The spectral gamma ray log indicates fractures at 1,932.1 m (6,339 ft), 1,953.8 m (6,410 ft), 1,970.2 m (6,464 ft), and 1,980.9 m (6,499 ft). The lack of an increase in water production during drilling of these depths, and absence of borehole breakouts on the caliper log suggest fractures are closed/healed. An interval of large open fractures from 1,998.0 - 2,024.5 m (6,555 - 6,642 ft) is indicated by the caliper log and by an increase in water production during drilling of this depth interval. Missing samples at 2,005.6 - 2,011.7 m (6,580 - 6,600 ft), 2,014.7 - 2,020.8 m (6,610 - 6,630 ft), and 2,023.9 - 2,033.0 m (6,640 - 6,670 ft) due to lost circulation during drilling at these depths is also indicative of open fractures. Although the drill cuttings samples degrade in quality below 1,996.4 m (6,550 ft), becoming varied mixtures of volcanic units, geophysical logs suggest the lithology is generally consistent throughout interval.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [1]	**Laboratory Analyses** [2]	**Lithologic Description** [3]	**Stratigraphic Unit**
2,051.3 - 2,133.6 (6,730 - 7,000)	82.3 (270)	DB4	PTS, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Tuff:** Medium-dark-gray (N4) and light-olive-gray (5Y 6/1); zeolitic; minor pumice; common to very abundant feldspar phenocrysts; very abundant biotite; common to abundant lithic fragments. Fragments of grayish-brown (5YR 3/2) tuffaceous siltstone compose less than 25% by volume in samples below approximately 2,072.6 m (6,800 ft). Drill cuttings samples throughout interval are of poor quality. They consist of a varied mixture of volcanic rock units, and may not be representative of the rocks comprising the interval. However, the dominance of tuffaceous fragments, particularly fragments of poorly welded tuff, and the low resistivity of the interval suggest the interval is composed of poorly welded, zeolitic tuff. The biotite-rich, quartz-poor character of most fragments is characteristic of the Wahmonie Formation and may indicate that the lower portion of the Wahmonie Formation is older than the Bullfrog Tuff.	Wahmonie Formation

1 **DA** = drill cuttings that represent lithologic character of interval; **DB1** = drill cuttings enriched in hard components; **DB2** = cuttings from interval different than that drilled; **DB4** = cuttings that are intimate mixtures of units; **SC** = sidewall core.

2 **PTS** = polished thin section; **MP** = electron microprobe; **XRD** = x-ray diffraction; **XRF** = x-ray fluorescence; **Fe^{2+}/Fe^{3+}** = wet chemical analysis for iron. See Table 3-3 of this report for additional information.

3 Descriptions are based mainly on visual examination of lithologic samples using a 10x- to 40x-zoom binocular microscope, and incorporating observations from geophysical logs and results of laboratory analyses. Colors describe wet sample color.

Abundances for felsic phenocrysts, pumice fragments, and lithic fragments: **trace** = only one or two individuals observed; **rare** = $\leq$ 1%; **minor** = 5%; **common** = 10%; **abundant** = 15%; **very abundant** $\geq$ 20%.

Abundances for mafic minerals: **trace** = only one or two individuals observed; **rare** = $\leq$ 0.05%; **minor** = 0.2%; **common** = 0.5%; **abundant** = 1%; **very abundant** = $\geq$ 2%.

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Appendix D
Geophysical Logs Run at Well Cluster ER5-4

D-1 Geophysical Logs Run in Well ER-5-4

D-2 Geophysical Logs Run in Well ER-5-4#2

Appendix D-1

Geophysical Logs Run in Well ER5-4

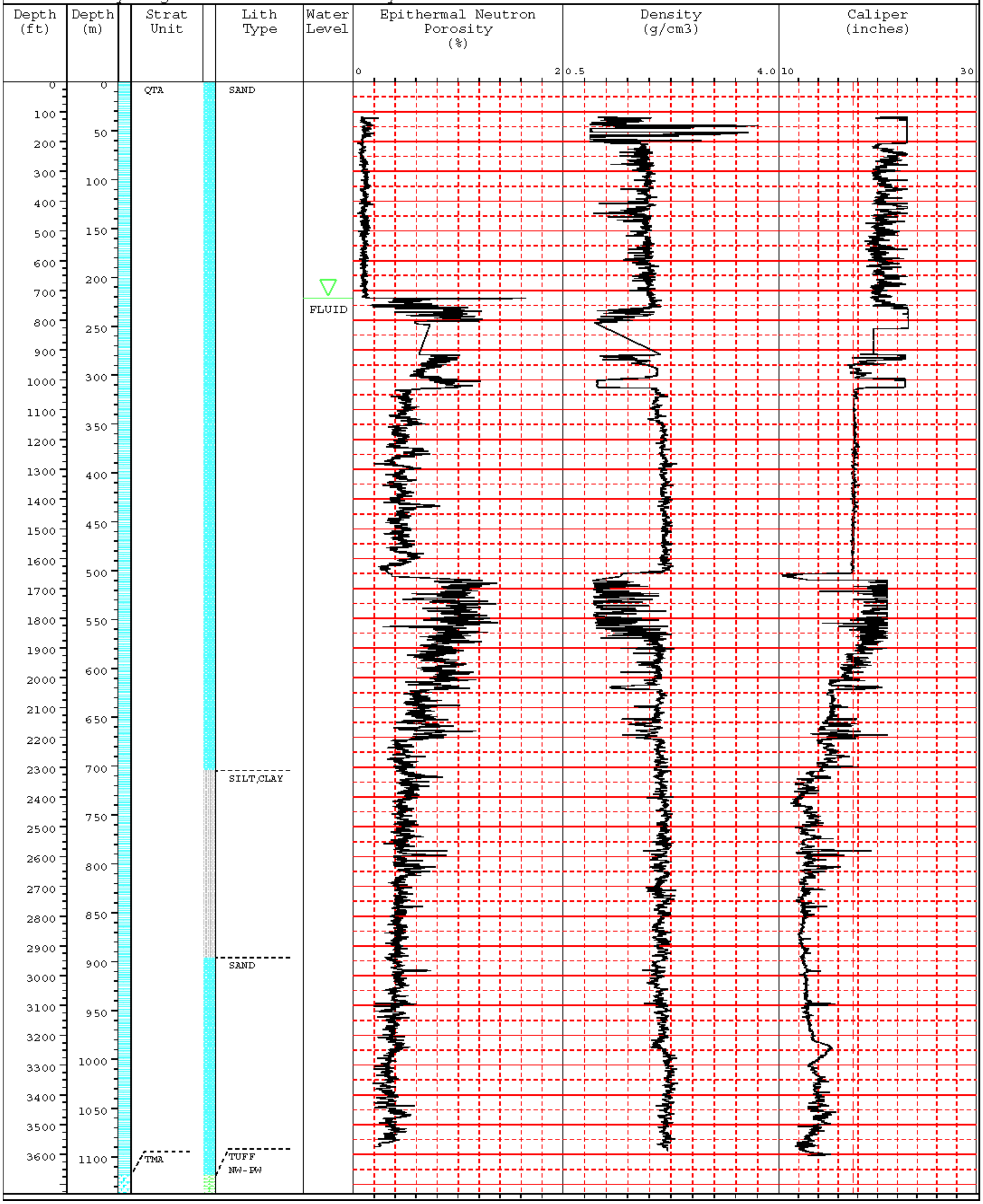
Appendix D-1 contains unprocessed data presentations of selected geophysical logs run in Well ER-5-4. Table D-1-1 summarizes the logs presented for Well ER-5-4. See Table 2-4 for more information.

Table D-1-1
Well ER-5-4 Geophysical Logs Presented

Log Type	Run Number	Date	Log Interval meters	feet
Caliper	CA4-1 CA4-2 CA4-5	02/16/2001 03/09/2001 03/24/2001	36.3 - 252.1 194.5 - 508.7 492.6 - 1,099.7	119 - 827 638 - 1,669 1,616 - 3,608
Epithermal Neutron (porosity)	ENP-1 ENP-2 ENP-3	02/16/2001 03/09/2001 03/25/2001	36.6 - 246.9 235.3 - 502.3 395.6 - 1,090.3	119 - 810 772 - 1,648 1,298 - 3,577
Density	CDL-1 CDL-2 CDL-3	02/16/2001 03/09/2001 03/25/2001	36.6 - 246.9 235.3 - 502.3 395.6 - 1,090.3	119 - 810 772 - 1,648 1,298 - 3,577
Array Induction and Dual Laterolog (resistivity)	AIT-1 AIT-2 DLL-1	02/16/2001 03/09/2001 03/25/2001	36.3 - 250.0 235.3 - 505.4 509.9 - 1,093.3	118 - 820 772 - 1,658 1,673 - 3,587
Spontaneous Potential	SP-1 SP-2 SP-3	02/16/2001 03/09/2001 03/25/2001	36.3 - 250.0 235.3 - 505.4 396.2 - 1,510.3	118 - 820 772 - 1,648 1,300 - 4,955
Gamma Ray	GR-1 GR-3 GR-7	02/16/2001 03/09/2001 03/25/2001	36.3 - 252.1 235.3 - 505.4 395.6 - 1,090.3	119 - 827 772 - 1,658 1,298 - 3,577
Digital Array Sonic (delta T and sonic porosity)	AC-1	03/25/2001	460.3 - 1,090.6	1,510 - 3,578
Spectral Gamma Ray (potassium, thorium, uranium)	SGR-1 SGR-2 SGR-3	02/17/2001 03/09/2001 03/25/2001	36.3 - 243.2 194.5 - 496.8 460.2 - 1,090.6	199 - 798 638 - 1,630 1,510 - 3,578

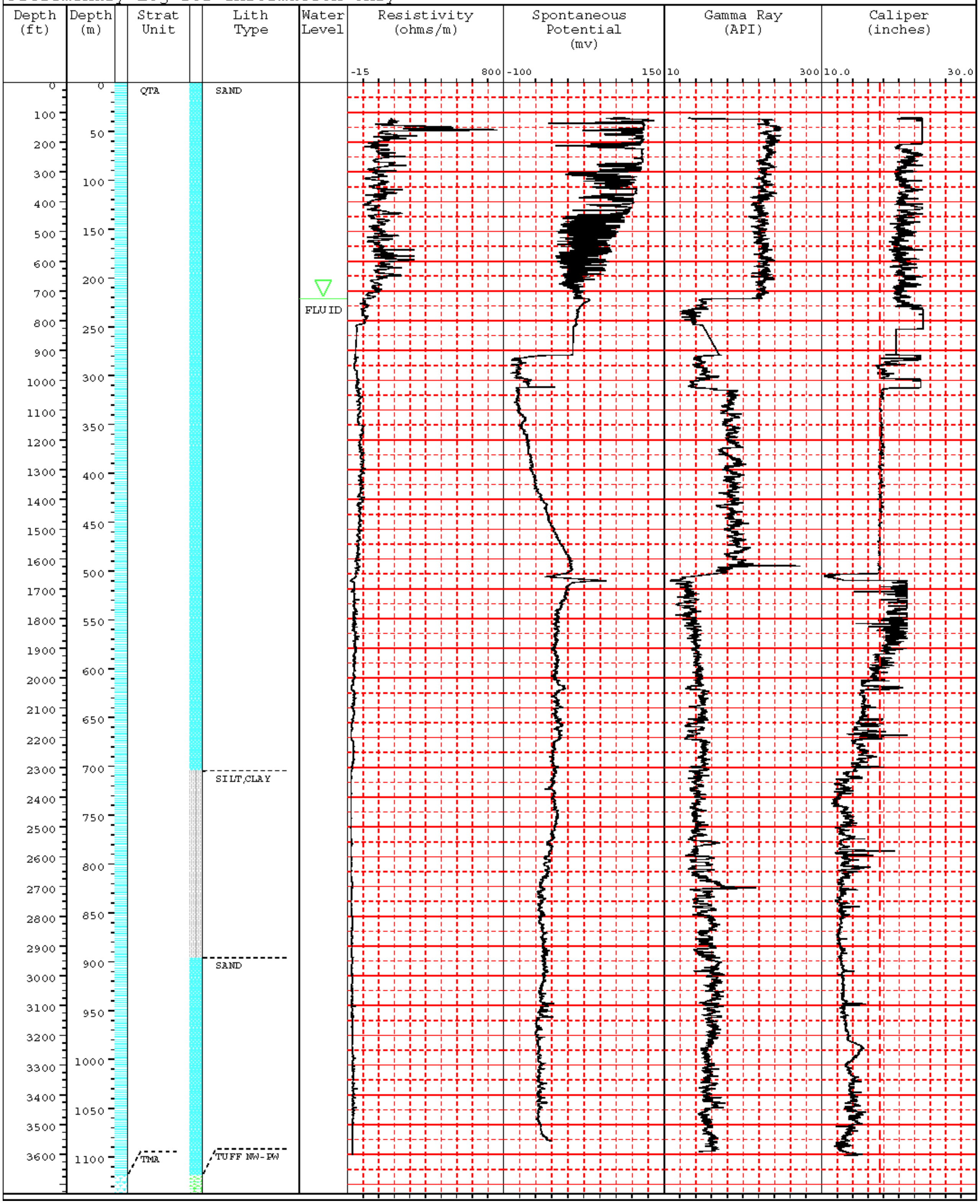
Well Name: ER-5-4	Frenchman Flat Drilling Program		Northing:4075874.5 m
Date: 08/26/03	Start Date: 02/10/01	Stop Date: 03/31/01	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No: 799416.01010095	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Drilled Depth: 3732 ft

Preliminary Log for Information Only



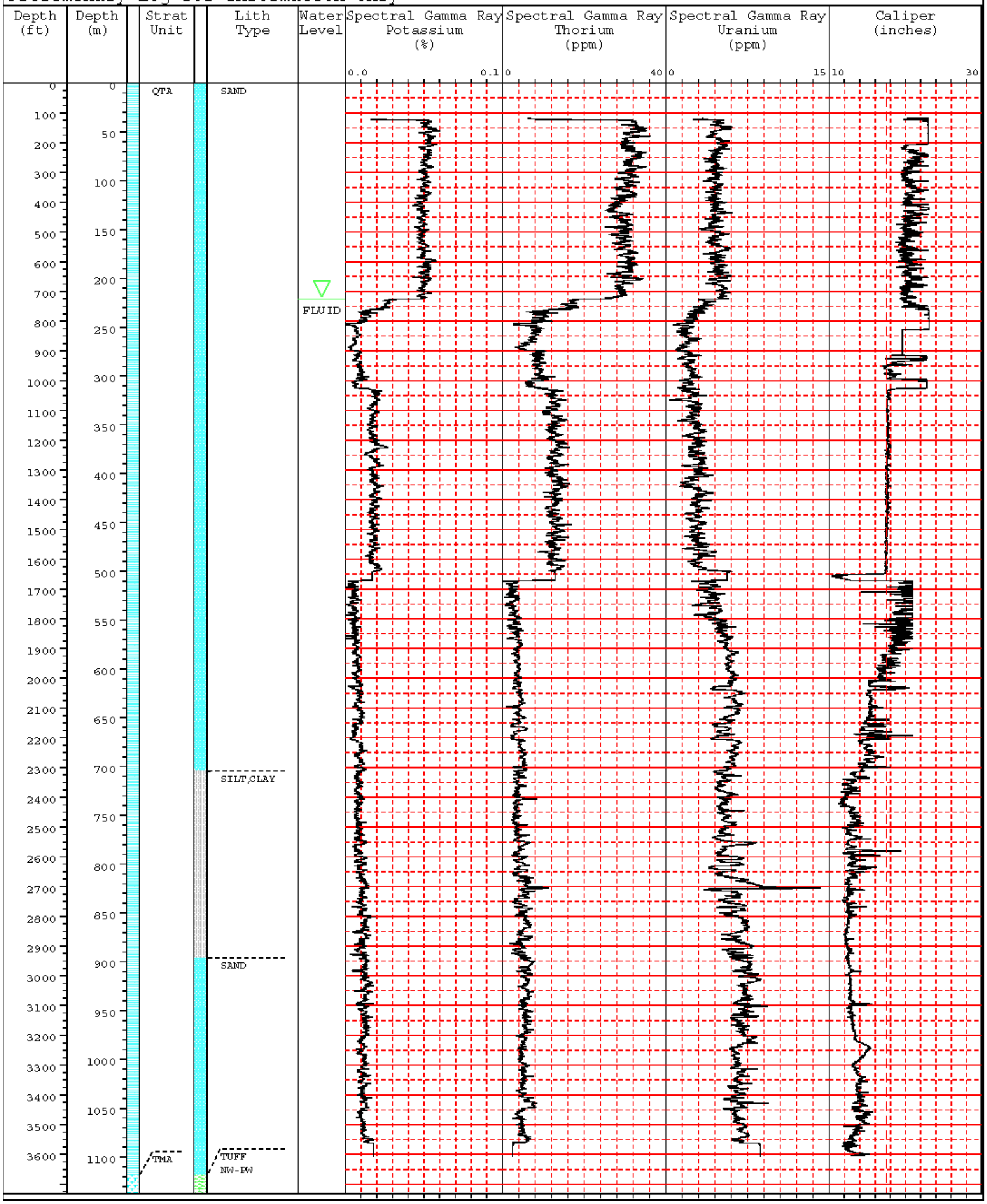
Well Name: ER-5-4	Frenchman Flat Drilling Program		Northing:4075874.5 m
Date: 08/26/2003	Start Date: 02/10/01	Stop Date: 03/31/01	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No: 799416.01010095	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Drilled Depth: 3732 ft

Preliminary Log for Information Only



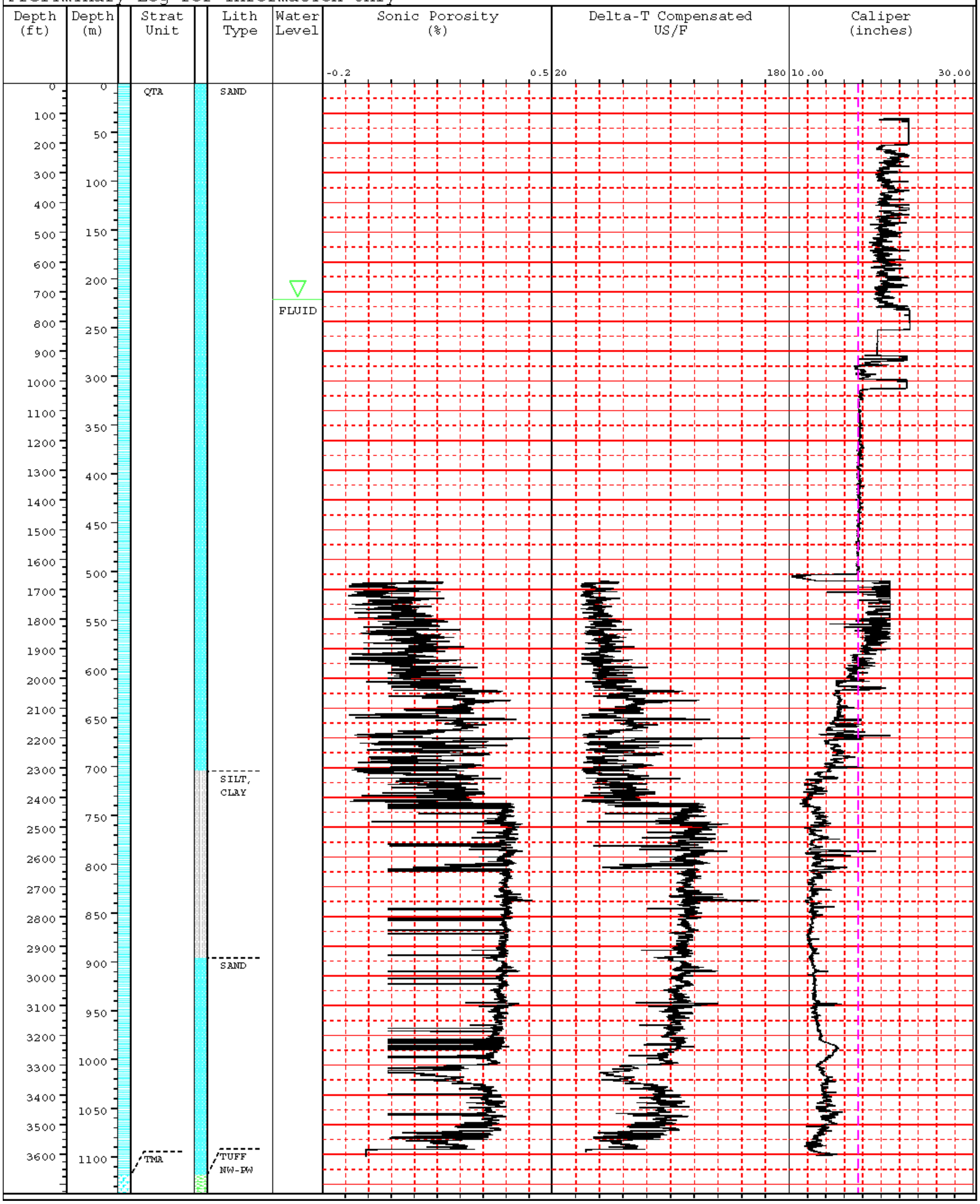
Well Name: ER-5-4	Frenchman Flat Drilling Program		Northing:4075874.5 m
Date: 08/26/03	Start Date: 02/10/01	Stop Date: 03/31/01	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No: 799416.01010095	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Drilled Depth: 3732 ft

Preliminary Log for Information Only



Well Name: ER-5-4	Frenchman Flat Drilling Program		Northing: 4075874.5 m
Date: 08/26/03	Start Date: 02/10/01	Stop Date: 03/31/01	Easting: 592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No: 799416.01010095	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Drilled Depth: 3732 ft

Preliminary Log for Information Only



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Appendix D-2
Geophysical Logs Run in Well ER5-4#2

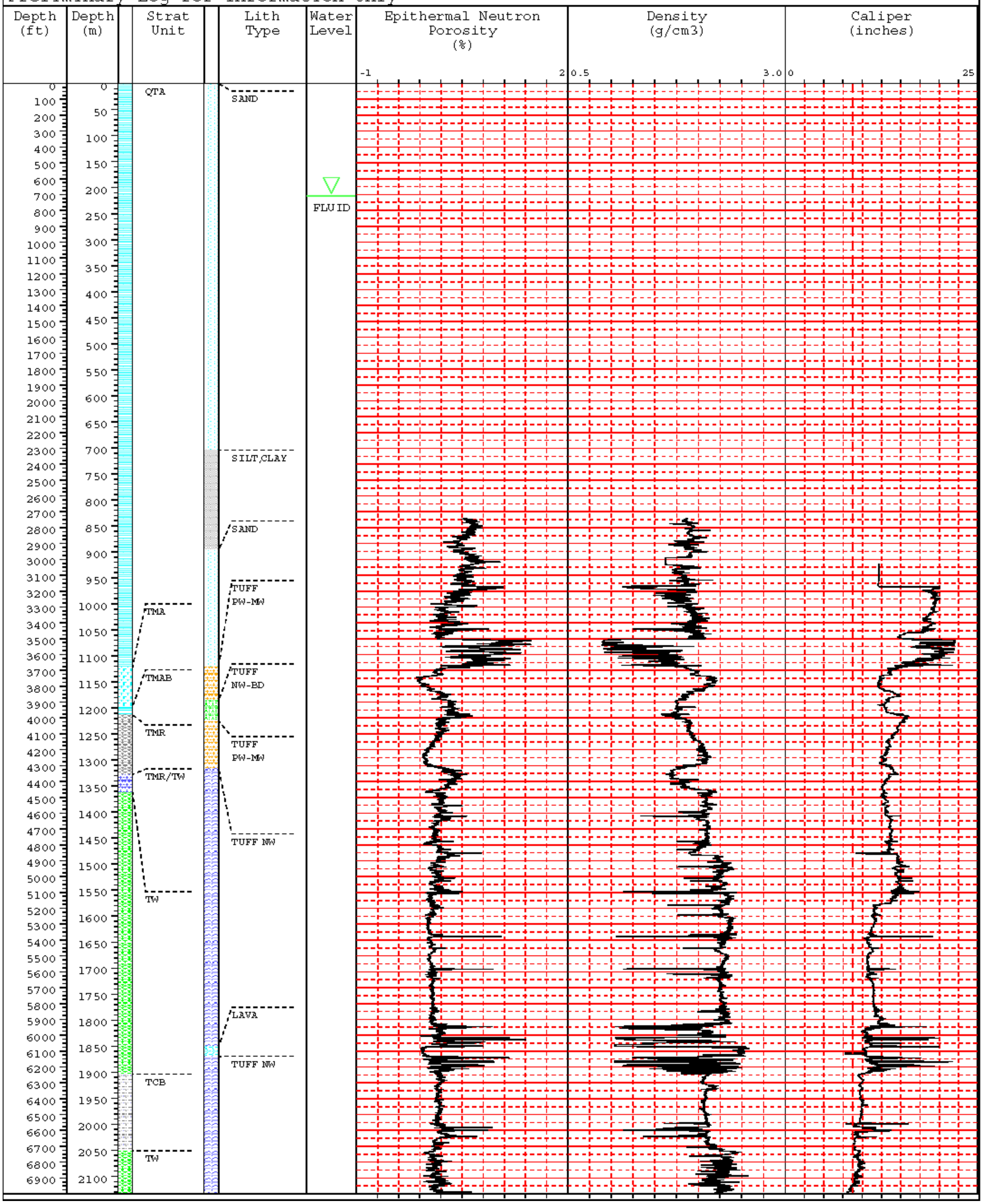
Appendix D-2 contains unprocessed data presentations of selected geophysical logs run in Well ER-5-4#2. Table D-2-1 summarizes the logs presented for Well ER-5-4#2. See Table 3-4 for more information.

Table D-2-1
Well ER-5-4#2 Geophysical Logs Presented

Log Type	Run Number	Date	Log Interval meters	Log Interval feet
Caliper	CA6-1 CA6-2	08/28/2002 09/13/2002	923.5 - 1,477.8 1,356.2 - 2,128.4	3,030 - 4,848 4,450 - 6,983
Epithermal Neutron (porosity)	DSEN-1 DSEN-3	08/28/2002 09/15/2002	838.2 - 1,479.5 1,447.8 - 2,131.8	2,750 - 4,854 4,750 - 6,994
Density	CDL-1 CDL-3	08/28/2002 09/15/2002	838.2 - 1,479.5 1,447.8 - 2,131.8	2,750 - 4,854 4,750 - 6,994
Dual Laterolog (resistivity)	DLL-1 DLL-2	08/28/2002 09/14/2002	944.9 - 1,477.1 1,447.8 - 2,126.9	3,100 - 4,846 4,750 - 6,978
Spontaneous Potential	SP-1 SP-2	08/28/2002 09/14/2002	944.9 - 1,477.1 1,447.8 - 2,126.9	3,100 - 4,846 4,750 - 6,978
Gamma Ray	GR-1 GR-11	08/28/2002 09/15/2002	923.5 - 1,477.8 1,447.8 - 2,125.4	3,030 - 4,848 4,750 - 6,973
Digital Array Sonic (delta T and sonic porosity)	FWS-1 FWS-2	08/28/2002 09/14/2002	941.8 - 1,465.5 1,447.8 - 2,117.8	3,090 - 4,808 4,750 - 6,948
Spectral Gamma Ray (potassium, thorium, uranium)	SGR-2	09/14/2002	1,219.2 - 2,035.1	4,000 - 6,677

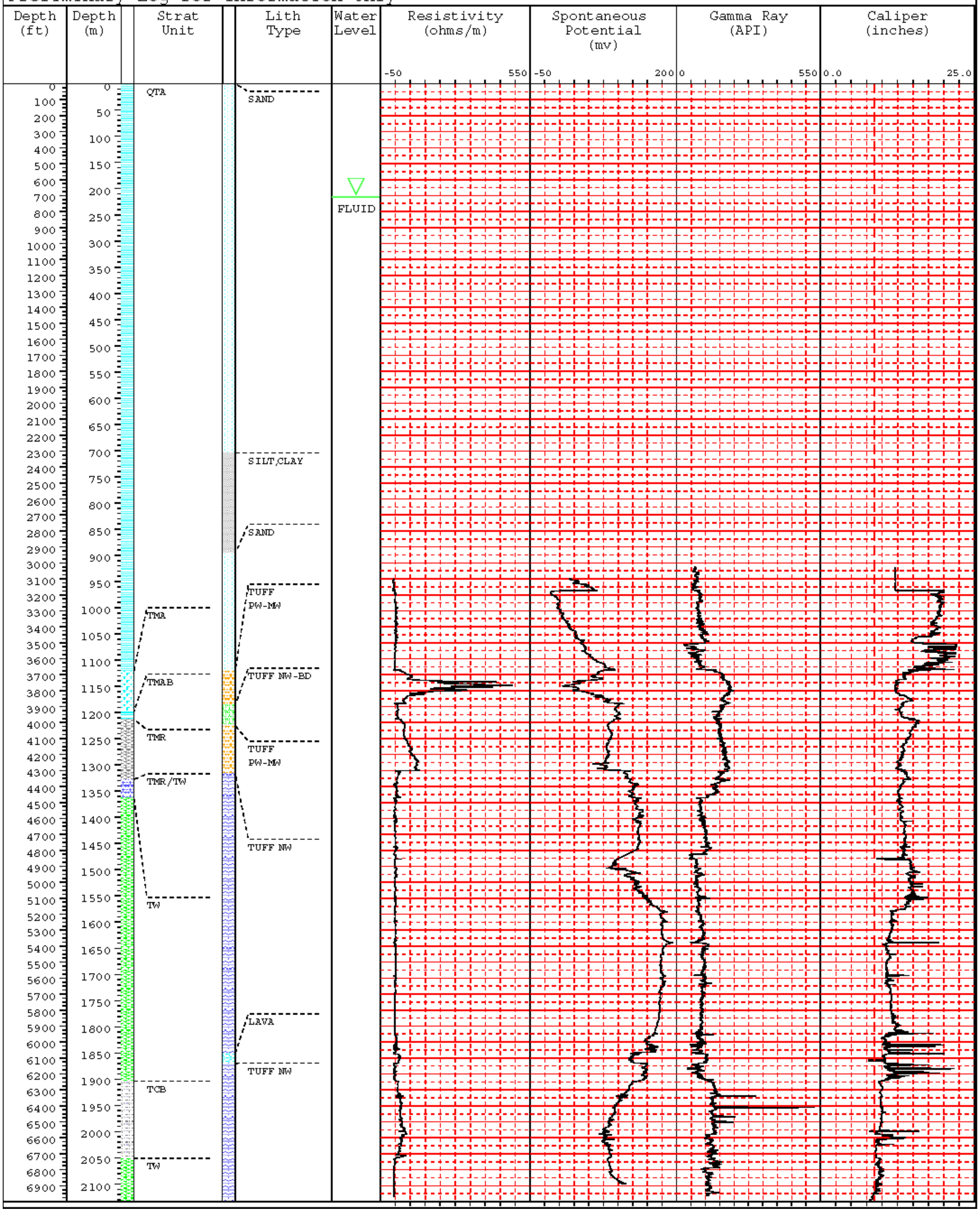
Well Name: ER-5-4 #2	Frenchman Flat Drilling Program		Northing:4075844.0 m
Date: 08/26/03	Start Date: 07/15/02	Stop Date: 09/18/02	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No. 831840-02010085	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air-Mud	Geol: J. Wurtz	Drilled Depth: 7000 ft

Preliminary Log for Information Only



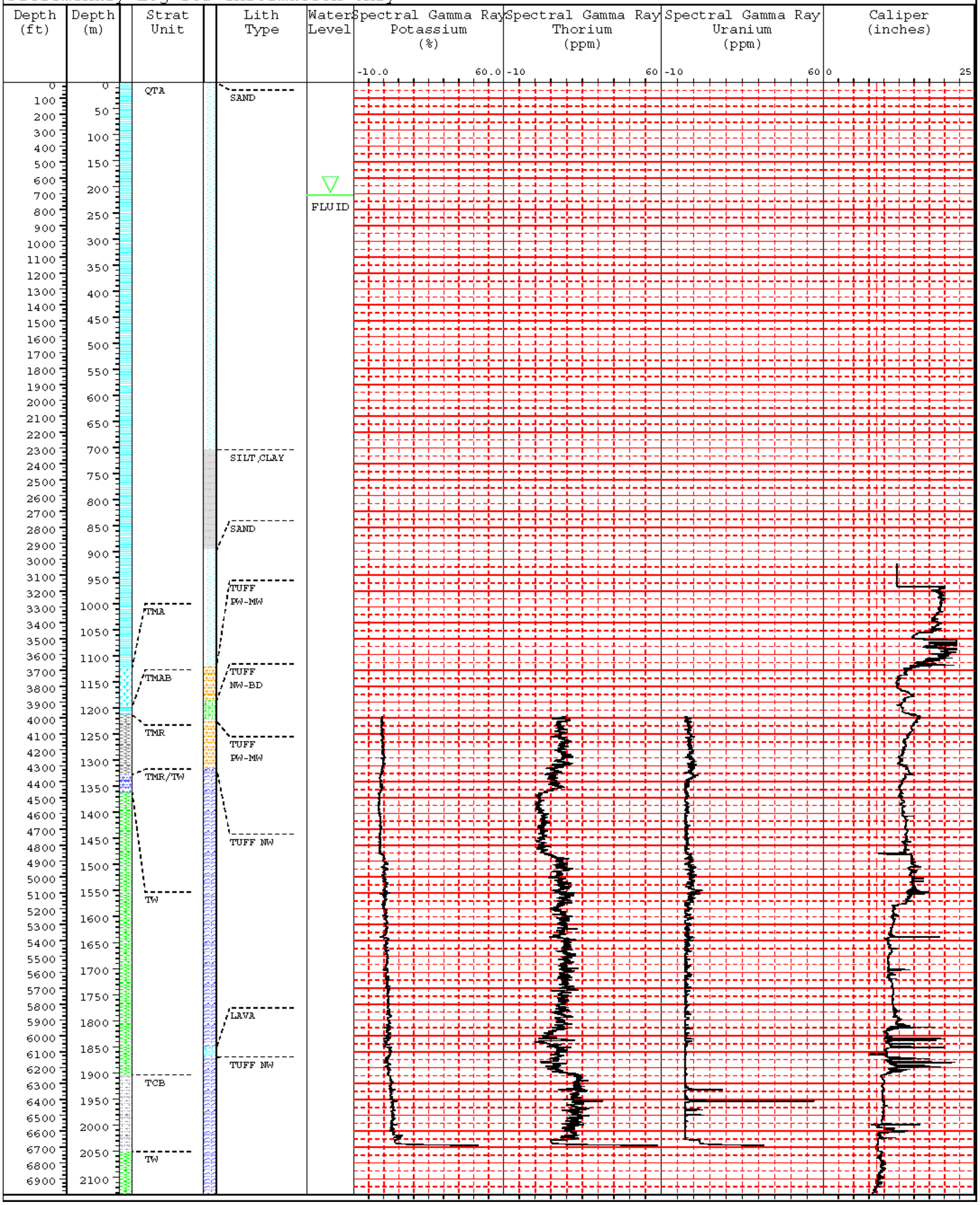
Well Name: ER-5-4 #2	Frenchman Flat Drilling Program		Northing:4075844.0 m
Date: 08/26/03	Start Date: 07/15/02	Stop Date: 09/18/02	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj. No. 831840-02010085	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air-Mud	Geol: J. Wurtz	Drilled Depth: 7000 ft

Preliminary Log for Information Only



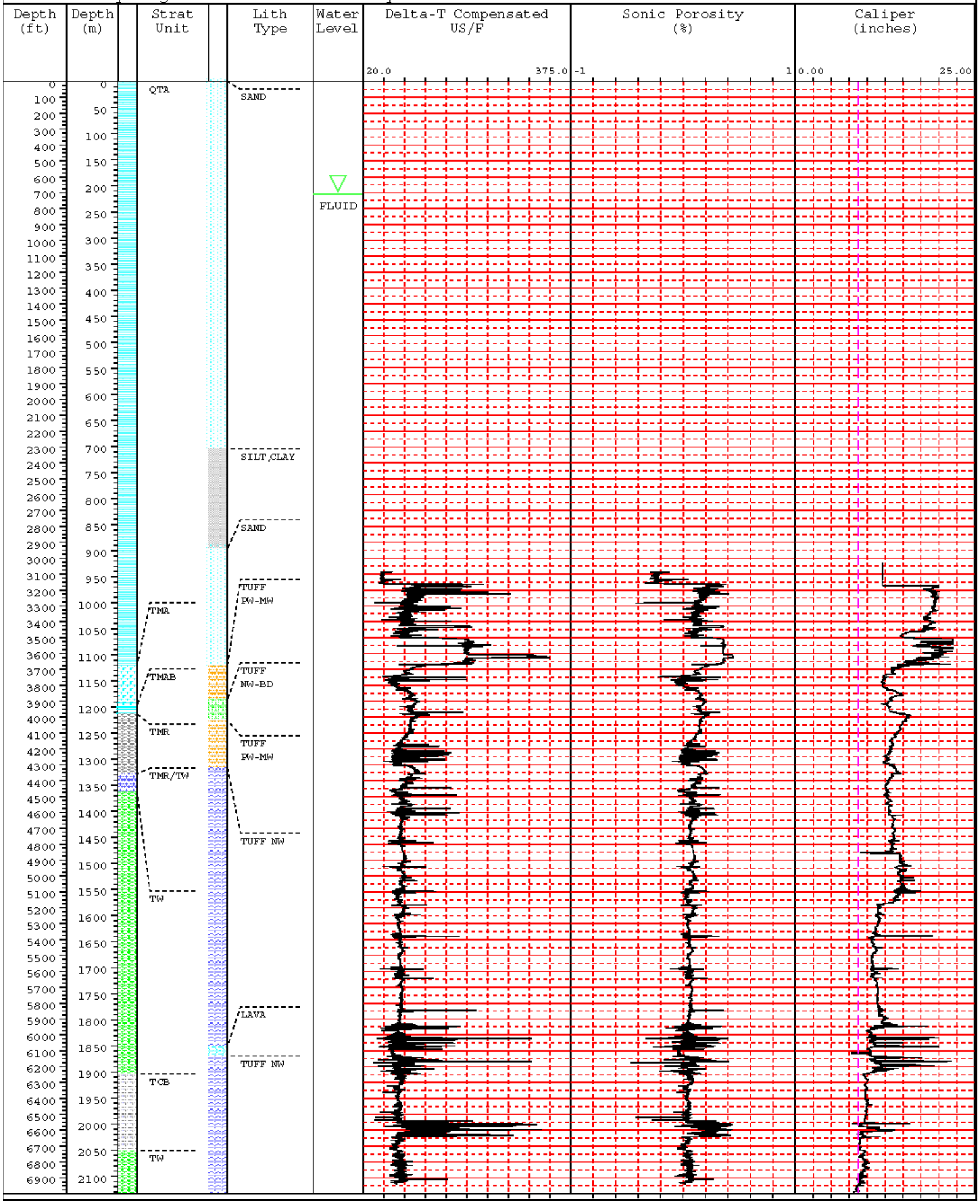
Well Name: ER-5-4 #2	Frenchman Flat Drilling Program		Northing:4075844.0 m
Date: 08/26/03	Start Date: 07/15/02	Stop Date: 09/18/02	Easting:592364.5 m
Environmental Contractor: UGTA/Shaw		Proj. No. 831840-02010085	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air-Mud	Geol: J. Wurtz	Drilled Depth: 7000 ft

Preliminary Log for Information Only



Well Name: ER-5-4 #2	Frenchman Flat Drilling Program		Northing: 4075844.0 m
Date: 08/26/03	Start Date: 07/15/02	Stop Date: 09/18/02	Easting: 592364.5 m
Environmental Contractor: UGTA/Shaw		Proj No. 831840-02010085	Surface Elevation:3131.7 ft
Drilling Contractor: United	Drilling Method: Air-Mud	Geol: J. Wurtz	Drilled Depth: 7000 ft

Preliminary Log for Information Only



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