DOE/NV/11718--397

Nevada
Environmental
Restoration
Project

Completion Report for Well ER-EC-4

September 2000

Environmental Restoration
Division

U.S. Department of Energy
Nevada Operations Office

DISCLAIMER STATEMENT

AVAILABILITY STATEMENT

Available to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA, 22161-0002
Telephone: 800-553-6847 or 703-605-6000
Fax: 703-605-6900
E-mail: orders@ntis.fedworld.gov
Online ordering: http://www.ntis.gov/ordering.htm

Available electronically at http://www/doe.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN, 37831-0062
Telephone: 865-576-8401
Fax: 865-576-5728
E-mail: reports@adonis.osti.gov

DOE/NV/11718--397

Completion Report for Well ER-EC-4

Prepared for:
U.S. Department of Energy
Nevada Operations Office
Las Vegas, Nevada

Prepared by:
Bechtel Nevada
Geological and Hydrological Services
Las Vegas, Nevada

September 2000

Work performed under Contract No. DE-AC08-96NV11718

This page intentionally left blank.

COMPLETION REPORT FOR WELL ER-EC-4

Approved by: Robert M. Bangerter Jr. Date: 9/7/00

Robert M. Bangerter, Project Manager,
Underground Test Area Project

Approved by: Date: 9/7/00

for Runore C. Wycoff, Director,
Environmental Restoration Division

This page intentionally left blank.

Completion Report for Well ER-EC-4
DOE/NV/11718--397

ABSTRACT

Well ER-EC-4 was drilled for the U.S. Department of Energy, Nevada Operations Office in support of the Nevada Environmental Restoration Project at the Nevada Test Site, Nye County, Nevada. This well was drilled in the summer of 1999 as part of the U.S Department of Energy's hydrogeologic investigation well program in the Western Pahute Mesa - Oasis Valley region just west of the Test Site. A 44.5-centimeter surface hole was drilled and cased off to a depth of 263.7 meters below the surface. The hole diameter was then decreased to 31.1 centimeters for drilling to a total depth of 1,062.8 meters.

One completion string with three isolated slotted intervals was installed in the well. A preliminary composite, static, water level was measured at the depth of 228.3 meters, two months after installation of the completion string.

Detailed lithologic descriptions with preliminary stratigraphic assignments are included in the report. These are based on composite drill cuttings collected every 3 meters, and 35 sidewall samples taken at various depths below 286.5 meters, supplemented by geophysical log data. Detailed chemical and mineralogical studies of rock samples are in progress. The well was collared in basalt and penetrated Tertiary-age lava and tuff of the Thirsty Canyon Group, the Volcanics of Fortymile Canyon, and the Timber Mountain Group. The preliminary geologic interpretation of data from this well helps pinpoint the location of the western margin of the Timber Mountain caldera complex in the southern Nevada volcanic field.

This page intentionally left blank.

Table of Contents

Table of Contents *(Continued)*

List of Figures

Number	Title	Page

List of Tables

Number ***Title*** ***Page***

List of Acronyms and Abbreviations

BHA	bottom-hole assembly
BN	Bechtel Nevada
C	(degrees) Celsius
cm	centimeter(s)
DOE/NV	U. S. Department of Energy, Nevada Operations Office
DRI	Desert Research Institute
EC	Electrical Conductivity
F	(degrees) Fahrenheit`
FMP	Fluid Management Plan
ft	foot (feet)
gpm	gallons per minute
in.	inch(es)
IT	IT Corporation
km	kilometer(s)
lpm	liters per minute
LANL	Los Alamos National Laboratory
LiBr	lithium bromide
m	meter(s)
Ma	million years ago
mi	mile(s)
NAD	North American Datum
NTS	Nevada Test Site
ppb	parts per billion
TD	total depth
TFM	Thermal Flow Meter
TWG	Technical Working Group
UDI	United Drilling, Inc.
UGTA	Underground Test Area
USGS	United States Geological Survey
WPM-OV	Western Pahute Mesa - Oasis Valley

This page intentionally left blank.

1.0 Introduction

1.1 Project Description

Well ER-EC-4 was drilled for the U.S. Department of Energy, Nevada Operations Office (DOE/NV) in support of the Nevada Environmental Restoration Project at the Nevada Test Site (NTS), Nye County, Nevada. Well ER-EC-4 is the fourth in a series of wells drilled as part of the hydrogeologic investigation well program in the Western Pahute Mesa - Oasis Valley (WPM-OV) region of Nye County, Nevada. This program is part of the DOE/NV 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 develop and test these models it is necessary to collect geologic, geophysical, and hydrologic data from new and existing wells to define groundwater migration pathways, migration rates, and quality.

The goal of the WPM-OV program is to collect subsurface geologic and hydrologic data in a large, poorly characterized area down-gradient from Pahute Mesa where underground nuclear tests were conducted, and up-gradient from groundwater discharge and withdrawal sites in Oasis Valley northeast of Beatty, Nevada (Figure 1-1). Data from these wells will allow for more accurate modeling of groundwater flow and radionuclide migration in the region. Some of the wells may also function as long-term monitoring wells.

Well ER-EC-4 is located within the Nellis Air Force Range complex, approximately 14 kilometers (km) (9.0 miles [mi]) southwest of the Area 20 underground nuclear test area (Figure 1-1) and on the east flank of Thirsty Mountain, just west of a geophysically inferred north-northeast striking structure (Thirsty Canyon lineament). The elevation of the dirt-fill drill pad at the wellhead is 1,450.7 meters (m) (4,759.6 feet [ft]) above sea level. The Nevada State Planar coordinates (North American Datum [NAD] 1983) at the wellhead are North (N) 6,267,250.6 and East (E) 503,083.2 m (N 20,541,410.7 and E 1,650,474.7 ft). Additional site data are listed in Table 1-1.

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, Inc. (UDI), a subcontractor to Bechtel Nevada (BN). Site supervision, engineering,

This page intentionally left blank.

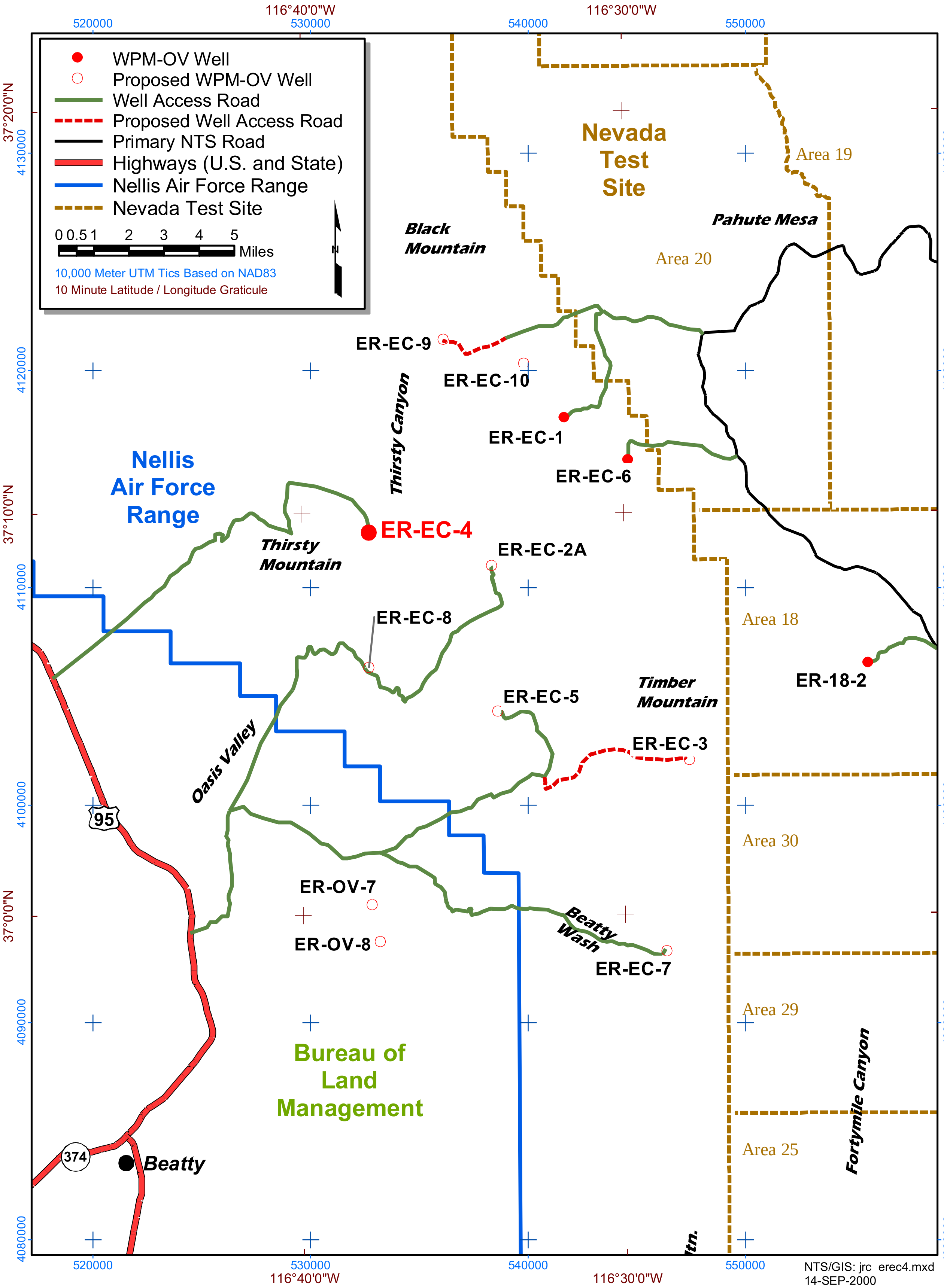


Figure 1-1
Reference Map Showing Location of Well ER-EC-4
(Proposed wells not drilled at time Well ER-EC-4 was drilled.)

This page intentionally left blank.

Table 1-1
Well ER-EC-4 Site Data Summary

Well Designation	ER-EC-4
Site Coordinates [a]	Central Nevada State Planar (NAD 83): N 6,267,250.6 m (N 20,561,804.6 ft) E 503,083.2 m (E 1,650,532.1 ft) Central Nevada State Planar (NAD 27): N 8 76,803.5 ft E 510,376.5 ft Universal Transverse Mercator (Zone 11)(NAD 83): N 4,112,552.8 m E 532,679.2 m
Surface Elevation [b]	1,450.7 m (4,759.6 ft)
Drilled Depth	1,062.8 m (3,487 ft)
Fluid-Level Depth [c]	228.3 m (748.9 ft)
Fluid-Level Elevation	1,222.4 m (4,010.7 ft)

a Measurement made by BN Survey. NAD 1983 and 1927.
b Measurement made by BN Survey. Elevation at top of construction pad. 1929 North American Vertical Datum.
c Measured by IT on August 19, 1999, approximately two months after completion string was installed.

construction, inspection, and geologic support were provided by BN. The roles and responsibilities of these and other contractors involved in the project are described in Contract Number DE-RP-08-95NV11808, and in BN Drilling Work Plan Number D-005-002.99 (BN, 1999b). The UGTA Technical Working Group (TWG), a committee of scientists and engineers comprising DOE, 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 *FY99 Western Pahute Mesa-Oasis Valley Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 1998) for descriptions of the general plan and goals of the WPM-OV project, as well as specific goals for each planned well.

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, 1996a), an attachment to the UGTA Waste Management Plan (DOE, 1996b). Estimates of fluid and cuttings production for the WPM-OV holes are given in Appendix N of the drilling and completion criteria document for the WPM-OV project (IT, 1998), along with sampling requirements and contingency plans for management of any hazardous waste produced. All activities were conducted in accordance with the Nevada Environmental Restoration Project Health and Safety Plan (DOE, 1998), and the Site-Specific Health and Safety Plan for WPM-OV Investigation Wells (BN, 1999a).

This report presents construction data and summarizes scientific data gathered during drilling and installation of the completion string. Some of the information in this report is preliminary and unprocessed, but is being released so that drilling, geologic, and completion data can be rapidly disseminated. A preliminary well data report prepared by IT (written communication, 1999) contains additional information on fluid management, waste management, and environmental compliance. Information on well development, aquifer testing, and groundwater analytical sampling will be disseminated after any such work is performed.

1.2 Objectives

The primary purpose of Well ER-EC-4 was to obtain information about hydrostratigraphic units, geologic structures, and bulk hydraulic properties in this part of the WPM-OV area. Well-specific scientific objectives, as discussed in Appendix D of the drilling criteria document (IT, 1998), include the following:

- Characterize the hydrogeology west of a geophysically inferred, north-northeast striking structure informally known as the Thirsty Canyon lineament (Grauch et al., 1997) (see hydrogeology discussion in Section 4 of this report).

- Better define the potentiometric surface along the inferred northwestern edge of the local groundwater flow system.

Some of these objectives will not be met until additional work is completed, including installing a pump and conducting hydraulic testing, and analyzing geology and hydrology data from this and other planned wells in the WPM-OV area.

1.3 Project Summary

This section summarizes Well ER-EC-4 construction operations; the details are provided in sections 2 through 8 of this report.

The surface conductor hole was constructed by augering a 91.4-centimeter (cm) (36-inch [in.]) hole to a depth of 5.3 m (17.5 ft) and installing a string of 36-in. casing. Drilling continued using a 30-in. hammer bit to 7.5 m (24.5 ft) and a 26-in. rotary bit to penetrate the hard basalt surface rock to the depth of 11.6 m (38 ft). A string of 20-in. conductor casing was set at 11.0 m (36 ft) below ground level and cemented on May 26, 1999.

Drilling of the main hole with a 17½-in. rotary bit, using air-foam and polymer in conventional circulation, began on May 27, 1999. A suitable depth to set casing was reached at 268.8 m (882 ft). At this point, drilling was suspended for geophysical logging, and then 13d-in. surface casing was landed at 263.7 m (865 ft) on June 3, 1999, approximately 35 m (116 ft) below the static water level. Drilling continued with a 12¼-in. bit to a total depth (TD) of 1,062.8 m (3,487 ft), which was reached on June 13, 1999.

Water production was first noted at the depth of approximately 213 m (700 ft), and reached a maximum of approximately 3,785 liters per minute (lpm) (1,000 gallons per minute [gpm]) near the bottom of the hole. Two months after installation of the completion string, the fluid level was tagged by IT at the depth of 228.3 m (748.9 ft). No radionuclides above background levels were encountered during drilling of Well ER-EC-4.

Composite drill cuttings were collected every 3.0 m (10 ft) from 9.1 m (30 ft) to TD, and 35 sidewall core samples were taken at various depths below 286.5 m (940 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 Tertiary-age lava and tuff of the Thirsty Canyon Group, Volcanics of Fortymile Canyon, and Timber Mountain Group.

A single completion string was installed in Well ER-EC-4 on June 17, 1999. Stainless steel, 5½-in. production casing was landed at 1,050.6 m (3,447.0 ft). The bull-nosed string has three slotted intervals, at 945.9 m to 1,037.8 m (3,103.3 to 3,404.8 ft), 582.2 m to 686.7 m (1,910.0 to 2,253.0 ft), and 301.5 m to 372.1 m (989.1 to 1,220.9 ft). Internally epoxy-coated, 7e-in. carbon-steel casing extends (via crossover subs) from the top of the 5½-in. casing at 289.2 m (948.7 ft) 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 165.2 m (542 ft) on June 20, 1999. No pump was installed at the time of completion.

1.4 Project Manager

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

Environmental Restoration Division
DOE/Nevada Operations Office
Post Office Box 98518
Las Vegas, Nevada 89193-8518

2.0 Drilling Summary

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

2.1 Introduction

The general drilling requirements for all WPM-OV wells were provided in *FY99 Western Pahute Mesa-Oasis Valley Hydrogeologic Investigation Wells Drilling and Completion Criteria* (IT, 1998). Specific requirements for Well ER-EC-4 were outlined in Drilling Work Plan Number D-005-002.99 (BN, 1999b). The following information was compiled primarily from BN daily drilling reports. Figure 2-1 shows the layout of the drill site. Figure 2-2 is a chart of the drilling and completion history for Well ER-EC-4. A summary of construction data for the well is given in Table 2-1. Fluid management information (Section 2.4) was obtained primarily from IT's preliminary well data report (written communication, 1999)

2.2 Drilling History

Field operations at Well ER-EC-4 began with the augering of a 91.4-cm (36-in.) surface hole to 5.3 m (17.5 ft). A section of 36-in. casing was set at 5.3 m (17.5 ft) on the same day, and the annulus was packed with native material. The "CP" 750 rig was moved in on May 20, 1999, and a BN crew drilled with a 30-in. hammer bit to a depth of 7.5 m (24.5 ft). The next day, the "CP" rig was moved off, as UDI equipment started arriving from Well ER-18-2. The UDI crews rigged up the Wilson Mogul 42B rig on May 22 and 23, 1999, and tagged fill at the depth of 6.1 m (20 ft). Drilling resumed with a 30-in. hammer bit on May 24, 1999, using water and polymer in conventional circulation, but only progressed to 7.5 m (24.5 ft) due to problems with the hammer. Drilling resumed the next day with a 26-in. milltooth bit and continued to 11.6 m (38 ft), using air, water, and polymer. While pulling the 26-in. bit out of the hole, a 0.3-m (1-ft) length of 2.5-cm (1-in.) chain fell downhole and several hours were spent unsuccessfully trying to retrieve it. The 20-in. conductor casing was then set at 11.0 m (36 ft), and the bottom was cemented in place with Type II cement. Cementing of the casing annulus to the surface was completed the next day. While waiting for cement deliveries the UDI crew worked on the casing surface construction (installing gussets and the flow line) and drilled and cased the rat hole. The top of cement in the casing was then tagged at 9.1 m (30 ft), and cement was drilled out with a 17½-in. rotary button bit to 11.6 m (38 ft). The drill cuttings were inspected for metal fragments from the lost chain, and after the hole was cleaned out and conditioned, a magnet was run in the hole in another unsuccessful attempt to retrieve the chain.

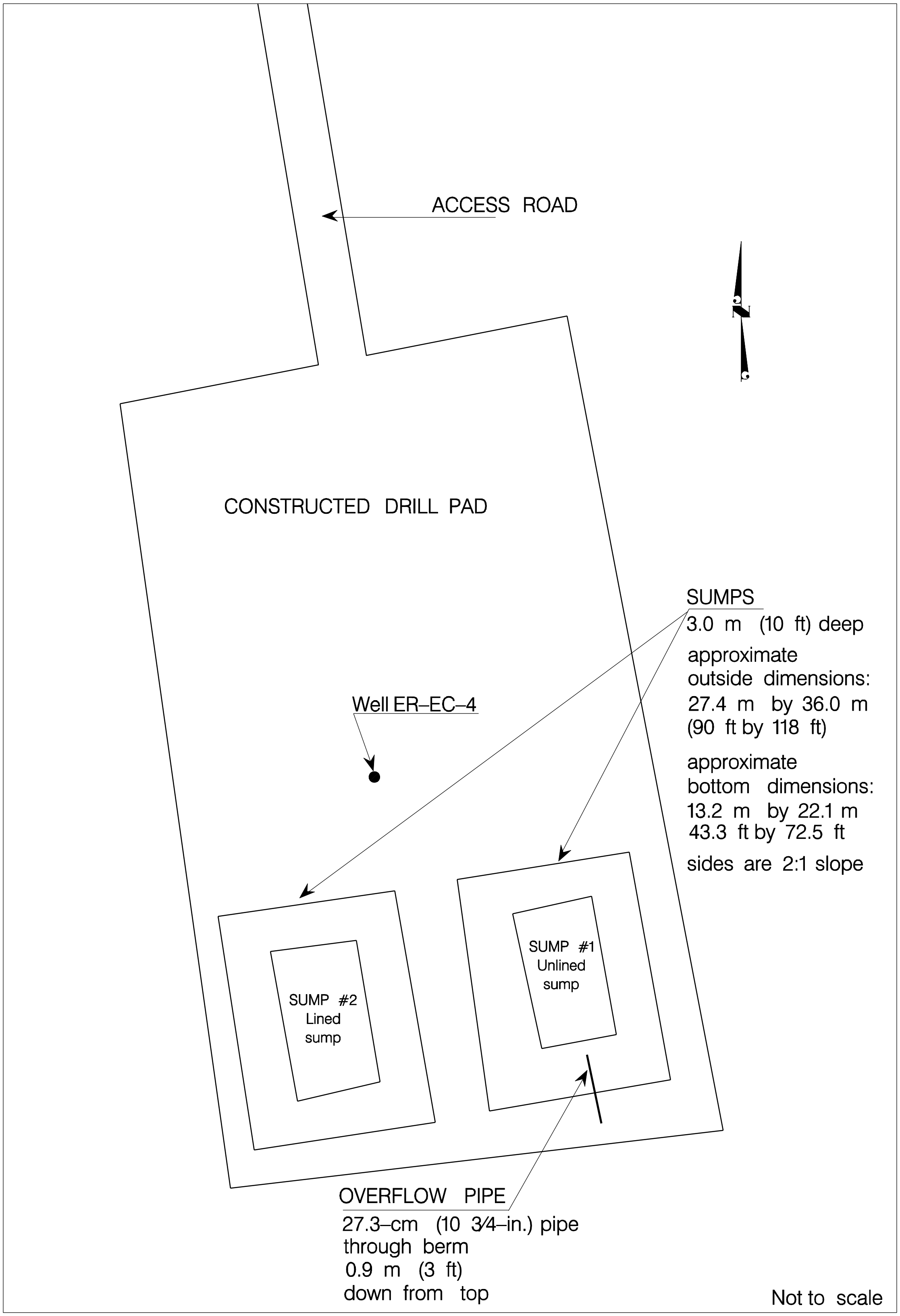
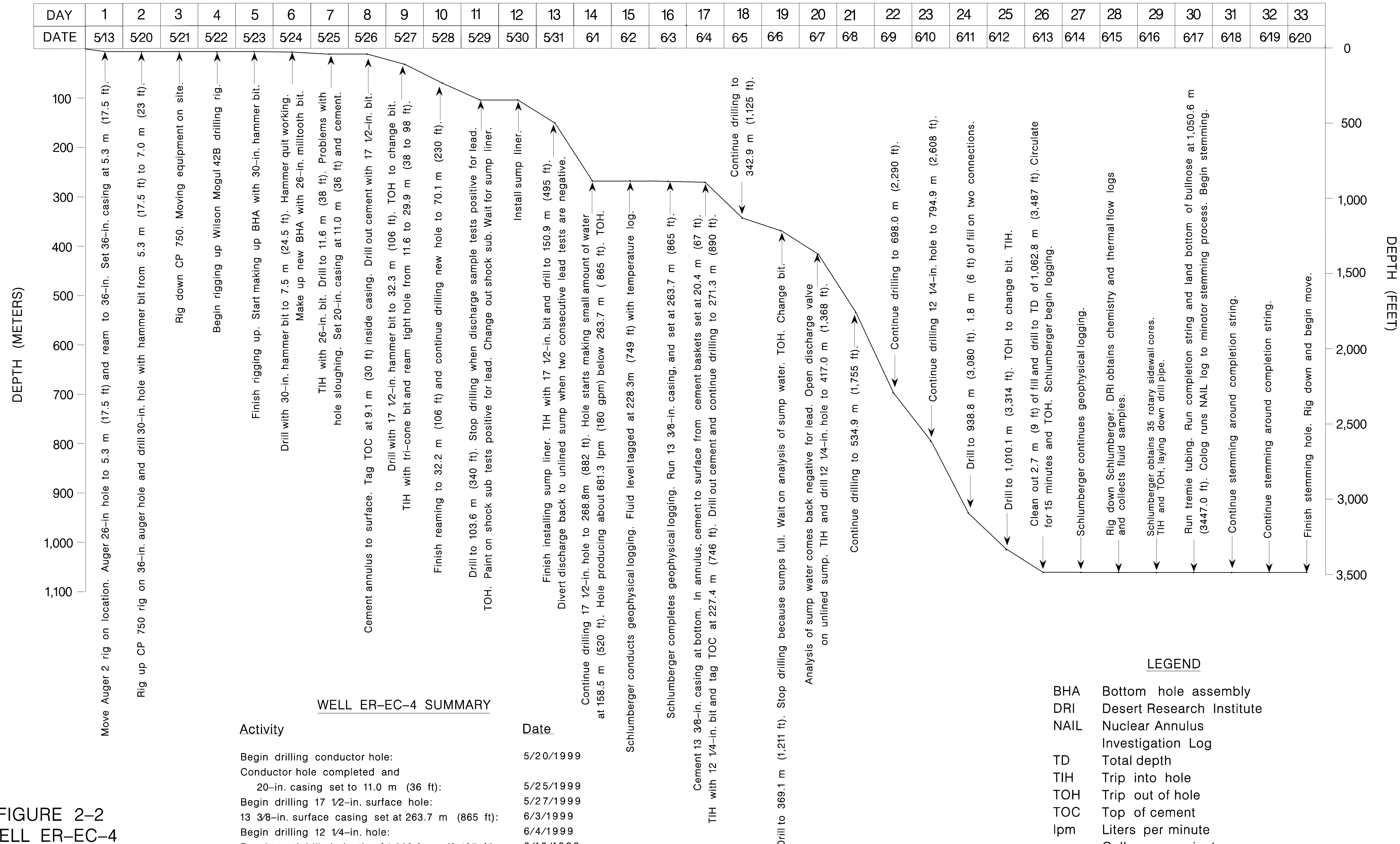


Figure 2-1
Drill-Site Configuration for Well ER-EC-4



WELL ER-EC-4 SUMMARY

Activity	Date
Begin drilling conductor hole:	5/20/1999
Conductor hole completed and 20-in. casing set to 11.0 m (36 ft):	5/25/1999
Begin drilling 17 1/2-in. surface hole:	5/27/1999
13 3/8-in. surface casing set at 263.7 m (865 ft):	6/3/1999
Begin drilling 12 1/4-in. hole:	6/4/1999
Reach total drilled depth of 1,062.8 m (3,487 ft):	6/13/1999
Well completed:	6/20/1999

LEGEND

BHA	Bottom hole assembly
DRI	Desert Research Institute
NAIL	Nuclear Annulus Investigation Log
TD	Total depth
TIH	Trip into hole
TOH	Trip out of hole
TOC	Top of cement
lpm	Liters per minute
gpm	Gallons per minute

FIGURE 2-2
WELL ER-EC-4
DRILLING AND COMPLETION HISTORY

This page intentionally left blank.

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

LOCATION DATA:

Coordinates:	Central Nevada State Planar:	NAD 83:	N 6,267,250.6 m E 503,083.2 m
		NAD 27:	N 876,803,5 ft E 510,376.5 ft
	Universal Transverse Mercator:	NAD 83:	N 4,112,552.8 m E 532,679.2 m
Surface Elevation [a]:	1,450.7 m (4,759.6 ft)		

DRILLING DATA:

Spud Date:	5/24/1999 (main hole drilled with Wilson Mogul 42B rig)
Total Depth (TD):	1,062.8 m (3,487 ft)
Date TD Reached:	6/13/1999
Date Well Completed [b]:	6/20/1999
Hole Diameter:	91.4 cm (36 in.) from surface to 5.3 m (17.5 ft.); 76.2 cm (30.0 in.) from 5.3 to 7.5 m (17.5 to 24.5 ft.); 66.0 cm (26.0 in.) from 7.5 to 11.6 m (24.5 to 38 ft); 44.5 cm (17.5 in.) from 11.6 to 268.8 m (38 to 882 ft); 31.1 cm (12.25 in.) from 268.8 m (882 ft) to TD of 1,062.8 m (3,487 ft).
Drilling Techniques:	Dry-hole auger from surface to 5.3 m (17.5 ft.); drill with 30-in. hammer bit from 5.3 to 7.5 m (17.5 to 24.5 ft); rotary drilling with 26-in. mill-tooth bit from 7.5 to 11.6 m (24.5 to 38 ft); drill with 17½-in. hammer bit using air-foam from 11.6 to 32.2 m (38 to 106 ft); rotary drilling with 17½-in. bit using air-foam/polymer in direct circulation from 32.2 to 268.8 m (106 to 882 ft); drill with 12¼-in. rotary bit using air-foam/polymer to TD of 1,062.8 m (3,487 ft).

CASING DATA: 36-in. conductor casing, surface to 5.3 m (17.5 ft); 20-in. conductor casing, surface to 11.0 m (36 ft); 13d-in. surface casing, surface to 263.7 m (865 ft).

WELL COMPLETION DATA:

The completion string consists of 7e-in. carbon-steel casing with an internal epoxy coating, connected to 5½-in. stainless-steel casing via an internally coated carbon-steel crossover sub. The carbon-steel casing extends through the unsaturated zone approximately 61 m (200 ft) into the top of the saturated zone. The 14.0-cm (5.5-in.) outside-diameter casing has a 12.83-cm (5.05-in.) inside diameter, is bull-nosed, and has three slotted intervals (listed below) that each consist of alternating blank and slotted joints. Detailed data for the completion intervals are provided in Section 7 of this report.

Total Depth:	1,050.6 m (3,447.0 ft)		
Depth of Slotted Sections:	289.2 to 372.1 m (948.7 to 1,220.9 ft)	582.2 to 686.7 m (1,910.0 to 2,253.0 ft)	945.9 to 1,037.8 m (3,103.3 to 3,404.8 ft)
Depth of Sand Packs[c]:	290.2 to 294.1 m (952 to 965 ft)	559.9 to 571.2 m (1,837 to 1,874 ft)	923.8 to 937.0 m (3,031 to 3,074 ft)
Depth of Gravel Packs[c]:	294.1 to 378.0 m (965 to 1,240 ft)	571.2 to 699.8 m (1,874 to 2,296 ft)	937.0 to 1,057.0 m (3,074 to 3,468 ft)
Depth of Pump:	None installed at time of completion.		
Water Depth[d]:	228.3 m (748.9 ft)		

DRILLING CONTRACTOR: United Drilling, Inc.

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

SURVEYING CONTRACTOR: Bechtel Nevada

a Elevation of ground level at wellhead. 1929 North American Vertical Datum.
b Date completion string was cemented. Pump will be installed at a later date.
c Gravel and sand adjacent to slotted intervals only. Additional gravel layers were used as stemming outside blank casing sections. See Table 7-1.
d Measured by IT on August 19, 1999, approximately two months after completion string was installed (IT, written communication, 1999).

Drilling of the main hole with a 17½-in. hammer bit and air-foam began May 27, 1999. At a depth of 32.3 m (106 ft), the hammer bit was replaced with a 17½-in. rotary button bit. This bit was slightly larger, so it was necessary to ream from 11.6 m (38 ft) back down to 32.3 m (106 ft). Drilling continued with the 17½-in. button bit, using air-foam with a polymer additive. On May 29, 1999, at a depth of 103.6 m (340 ft), drilling was suspended due to a positive (>200 parts per billion [ppb]) test result for lead in the discharge fluid. Drilling was halted for approximately 56 hours while BN crews installed a liner in one of the sumps. Paint on the shock sub (part of the bottom-hole assembly [BHA]) tested positive for lead, and was presumed to be the source of the lead in the fluid. The shock sub was replaced and drilling resumed on May 31, 1999, with fluid discharge routed into the lined sump. Later that day the DOE/NV representative approved rerouting of discharge to the unlined sump after two consecutive negative (<50 ppb) lead tests (see paragraph 2.4). The first water production was noted by IT personnel at a depth of approximately 213 m (700 ft) (IT, written communication, 1999).

As a precaution against sloughing of the upper section of unsaturated volcanic rocks, it was decided to install surface casing when a competent formation for supporting the casing was reached. The decision was made to stop and set casing on June 1, 1999, at a depth of 268.8 m (882 ft). At this depth the hole was producing water at a rate of approximately 681 to 757 lpm (180 to 200 gpm). The drillers circulated fluid to clean and condition the hole, pulled the drill string off the bottom, and waited about 30 minutes before tagging bottom again. No fill was found, and the drillers tripped the drill string out of the hole. Geophysical logging was conducted on June 2 and 3, 1999, prior to installation of casing.

A casing subcontractor landed 13d-in. casing with centralizers installed above the float shoe, at the middle and top of the first joint, and at the top of the second joint. Two metal-petal cement baskets are located at 20.4 m (67 ft) below ground level. The casing was landed at a depth of 263.7 m (865 ft) on June 3, 1999, and after a stab-in sub was seated in the float shoe, the seal was checked by pumping air down the drill pipe. Pre-flush clear water was pumped down the casing and the annulus prior to cementing. Type II cement was pumped inside the casing through the stab-in sub, followed by water to displace the cement into the annulus. The top of cement in the annulus was later determined by geophysical logs to be at the depth of approximately 146.9 m (482 ft). After the drill pipe was tripped out of the hole, cement with sand was dropped on the cement baskets and allowed to harden before the remaining annulus was cemented to ground level. Cementing of the surface casing was completed on June 4, 1999. The top of cement inside the casing was tagged at 227.4 m (746 ft) when the BHA was tripped back into the hole.

Cement was drilled out with a 12¼-in. bit, and drilling continued into formation, using air-foam with a polymer additive. On June 6, 1999, at a depth of 369.1 m (1,211 ft), it was noted that the sumps were full, so drilling was stopped until the sump water could be analyzed for contaminants to determine whether it would be permissible to allow sump water to be discharged to the ground surface. During this 27-hour drilling hiatus, the drillers tripped the BHA out of the hole to check it and replaced the bit. Analyses of sump water for lead were found to be negative, so the discharge valve from the unlined sump was opened, and drilling continued on June 7, 1999. The drill bit was replaced once more at the depth of 1,010.1 m (3,314 ft), and drilling continued uninterrupted to the TD of 1,062.8 m (3,487 ft), reached on June 13, 1999.

Fill encountered (due to sloughing of the borehole wall) during drilling was minimal: no fill was found on most connections, though up to 2.7 m (9 ft) of fill was encountered on a few connections, and also typically after pauses in drilling (bit changes, for example). The amounts of polymer and foaming agent in the drilling fluid and the fluid injection rate were adjusted as necessary during drilling to maintain superior circulation and penetration rate, and to minimize borehole sloughing.

The TD was reached approximately 4 m (13 ft) short of the planned TD of 1,066.8 m (3,500 ft), after geologists verified that the hole had penetrated through the Rainier Mesa welded-tuff aquifer and entered pre-Rainier Mesa bedded tuff. Immediately after reaching TD, the drillers circulated fluid to condition the hole before the second phase of geophysical logging, which took place on June 13-16, 1999. Installation of the completion string began on June 17, 1999. Demobilization from the Well ER-EC-4 site began after gravel-packing and cementing were completed on June 20, 1999.

The directional survey run in the well on October 21, 1999, indicates that at the lowest surveyed depth of 1,040.9 m (3,415 ft) the hole had drifted 4.6 m (15.1 ft) to the northwest 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 casing materials. Drilling fluids and cements used in Well ER-EC-4 are listed in Appendix A-3.

2.3 Drilling Problems

No significant drilling problems were encountered at Well ER-EC-4. Fill of generally less than 3.0 m (10 ft) was encountered periodically throughout drilling. This sloughing did not result in significant drilling delays, though approximately 5.8 m (19 ft) of fill remained in the bottom of the hole prior to installation of the completion string. The only significant delays encountered were the result of fluid-management issues, discussed in paragraph 2.4.

2.4 Fluid Management

Drilling effluent was monitored in accordance with the methods prescribed in the UGTA FMP (DOE, 1996a). The air-foam/polymer drill fluid was circulated down the inside of the drill string and back up the hole through the annulus ("conventional circulation") and then discharged into a sump. Water used to prepare drilling fluids came from the spring-fed pond located on Boiling Pot Road, just outside the Nellis Air Force Range. Lithium bromide (LiBr) was added to the drill fluid as a tracer to provide a means of estimating groundwater production.

To manage the expected high water production, two sumps were constructed prior to drilling (Figure 2-1). No contaminants were expected during drilling at this site, so neither sump was lined prior to drilling. Samples of drilling effluent were tested on-site hourly for the presence of tritium, and every eight hours for lead. The on-site monitoring results indicate that tritium remained at background levels during the entire drilling operation. However, the presence of lead at a level above that permitted by the FMP for discharge to an infiltration basin (150 ppb) was detected on May 29, 1999, when drilling had reached the depth of 103.6 m (340 ft). Drilling was immediately halted, the DOE/NV representative notified the Nevada Division of Environmental Protection as required, and preparations for installing a liner in the unused sump (#2) were begun. Drilling resumed after the liner was installed, with effluent routed to the lined sump in case off-site analysis confirmed the presence of elevated levels of lead.

The FMP requires that if on-site analysis of drilling effluent indicates the presence of a contaminant above permitted levels, a confirmatory sample is collected from the sump and analyzed more precisely by an off-site laboratory. The final results of the off-site analysis indicated that at 121 ppb, the dissolved lead level was below the FMP criteria for discharge to an infiltration basin. Difficulties were encountered in filtering the high-viscosity sample (thickened by the foam drilling additive). Thus, it is believed that the source of lead in the original on-site analyses was suspended solids (presumably paint from the BHA; see paragraph 2.2) due to incomplete filtering of the sample. The FMP requirements apply only to dissolved (not total) constituents.

The DOE/NV representative approved discharge into the unlined sump on May 31, 1999, shortly after drilling resumed. A sample taken at that time from the unlined sump (#1) indicated lead levels below the allowable FMP discharge levels. Fluid samples were collected from both sumps during the remainder of the drilling operation and after drilling. Water-quality data from all seven sump samples are given in Appendix B.

The results of analyses of samples of drilling fluid collected at Well ER-EC-4 during drilling operations indicate that all fluid quality objectives were met, as shown on the fluid management reporting form dated November 23, 1999 (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; well development and aquifer testing will be conducted at a later date). 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.

This page intentionally left blank.

3.0 Geologic Data Collection

This section describes the sources of geologic data obtained from Well ER-EC-4 and the methods of data collection. Improving the understanding of the subsurface structure, stratigraphy, and hydrogeology in the area southwest of Pahute Mesa was among the primary objectives of Well ER-EC-4, so the proper collection of geologic and hydrogeologic data from Well ER-EC-4 was considered fundamental to successful completion of the project.

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

3.1 Collection of Drill Cuttings

Composite drill cuttings were collected from Well ER-EC-4 at 3.05-m (10-ft) intervals as drilling progressed from the depth of 9.1 m (30 ft) to the TD of the well at 1,062.8 m (3,487 ft). Triplicate samples were collected from 346 intervals and, in addition, the IT field representative collected two sets of reference samples 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 IT. The other set was sent to R. G. Warren (LANL) where it remains. All other samples (i.e., three sets of 346 samples) are stored under 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 in accordance with standard USGS Core Library procedures.

3.2 Sidewall Core Samples

Sidewall core samples were collected from Well ER-EC-4 immediately prior to installation of the completion string to verify the stratigraphy and lithology at selected locations. No attempt was made to obtain sidewall cores from the upper 286.5 m (940 ft) of the borehole prior to installing surface casing. 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) to obtain adequate representation of the rocks encountered below 286.5 m (940 ft). Schlumberger attempted to collect sidewall samples with a percussion-gun tool on June 15, 1999, but the tool malfunctioned, and only two partial cores were retrieved. On June 16, 1999, Schlumberger successfully collected 35 sidewall core samples from Well ER-EC-4 using a rotary sidewall coring tool. Five of the samples were re-samples at depths from which poor recovery was obtained on the first attempt. Table 3-1 1ists the recovery and stratigraphic assignment for each sample.

3.3 Sample Analysis

Three sidewall samples and 31 samples of drill cuttings from various depths in Well ER-EC-4 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. At the time of this report none of the planned analyses has been completed.

3.4 Geophysical Data

Geophysical logs were run 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 three 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 3-3. The logs are available from BN in Mercury, Nevada, and copies are on file at the IT office in Las Vegas, Nevada.

The overall quality of the geophysical data collected was good. Preliminary geophysical data from the logs are reproduced in Appendix D.

Table 3-1
Sidewall Core Samples from Well ER-EC-4

Core Depth meters (feet)	Tool Used [a]	Length Recovered cm (in.)	Stratigraphic Unit [b]
286.5 (940.0)	MSCT	3.81 (1.5)	Ttr
291.1 (955.0)	MSCT	3.18 (1.25)	Ttc
331.0 (1,086.0)	MSCT	5.08 (2.0)	Ttc
346.3 (1,136.0)	MSCT	3.81 (1.5)	Ttc
395.6 (1,298.0)	MSCT	4.45 (1.75)	Ttc
478.5 (1,570.0)	MSCT	3.18 (1.25)	Ttc
510.5 (1,675.0)	MSCT	3.18 (1.25)	Tfbr
518.2 (1,700.0)	MSCT	0.64 (0.25)	Tfbr
518.2 (1,700.0)	MSCT	3.18 (1.25)	Tfbr
538.0 (1,765.0)	MSCT	4.45 (1.75)	Tfbr
580.6 (1,905.0)	MSCT	5.08 (2.0)	Tfbw
587.0 (1,926.0)	MSCT	4.45 (1.75)	Tmay
594.4 (1,950.0)	MSCT	2.54 (1.0)	Tmap
606.6 (1,990.0)	MSCT	2.54 (1.0)	Tmap
635.5 (2,085.0)	MSCT	3.18 (1.25)	Tmap
694.9 (2,280.0)	MSCT	3.18 (1.25)	Tmap
734.6 (2,410.0)	MSCT	1.91 (0.75)	Tmap
786.4 (2,580.0)	MSCT	1.91 (0.75)	Tmap
786.4 (2,580.0)	MSCT	1.91 (0.75)	Tmap
821.7 (2,696.0)	MSCT	3.81 (1.5)	Tmap
844.9 (2,772.0)	MSCT	3.81 (1.5)	Tmap
874.8 (2,870.0)	MSCT	1.27 (0.5)	Tmap
888.5 (2,915.0)	MSCT	2.54 (1.0)	Tmab
919.0 (3,015.0)	MSCT	4.45 (1.75)	Tmrb
926.6 (3,040.0)	MSCT	3.81 (1.5)	Tmrb
947.9 (3,110.0)	MSCT	2.54 (1.0)	Tmrp
947.9 (3,110.0)	MSCT	4.45 (1.75)	Tmrp
963.2 (3,160.0)	MSCT	1.27 (0.5)	Tmrp
963.2 (3,160.0)	MSCT	3.18 (1.25)	Tmrp
996.0 (3,267.8)	SWC	0.64 (0.25)	Tmrp
1,005.8 (3,300.0)	MSCT	2.54 (1.0)	Tmrp
1,027.2 (3,370.0)	MSCT	4.45 (1.75)	Tmrp
1,040.8 (3,414.6)	SWC	0.64 (0.25)	Tmrp
1,047.0 (3,435.0)	MSCT	3.18 (1.25)	pre-Tmr
1,054.0 (3,458.0)	MSCT	3.81 (1.5)	pre-Tmr
1,054.3 (3,459.0)	MSCT	0.64 (0.25)	pre-Tmr
1,054.3 (3,459.0)	MSCT	3.18 (1.25)	pre-Tmr

a SWC = Percussion sidewall gun operated by Schlumberger; MSCT = rotary mechanical sidewall coring tool operated by Schlumberger.

b Preliminary assignments: **Ttr** = Rocket Wash Tuff; **Ttc** = trachyte of Ribbon Cliff; **Tfbr** = rhyolite of Chukar Canyon; **Tfbw** = rhyolite of Beatty Wash; **Tmay** = trachyte of East Cat Canyon; **Tmap** = mafic-poor Ammonia Tanks Tuff; **Tmab** = bedded Ammonia Tanks Tuff; **Tmrb** = bedded Rainier Mesa Tuff; **Tmrp** = mafic-poor Rainier Mesa Tuff; **pre-Tm**r = pre-Rainier Mesa Tuff volcanic rocks. See Appendix C for more information about the stratigraphy and lithology of Well ER-EC-4.

Table 3-2
Rock Samples from Well ER-EC-4 Submitted for Analysis [a]

Depth [b] meters (feet)	Sample Type [c]
27.4 (90)	DA
39.6 (130)	DA
54.9 (180)	DA
61.0 (200)	DA
76.2 (250)	DA
97.5 (320)	DA
128.0 (420)	DA
155.4 (510)	DA
210.3 (690)	DA
240.8 (790)	DA
274.3 (900)	DA
310.9 (1,020)	DA
323.1 (1,060)	DA
335.3 (1,100)	DA
417.6 (1,370)	DA
466.3 (1,530)	DA
499.9 (1,640)	DA

Depth [b] meters (feet)	Sample Type [c]
512.1 (1,680)	DA
548.6 (1,800)	DA
585.2 (1,920)	DA
588.3 (1,930)	DA
594.4 (1,950)	DA
652.3 (2,140)	DA
731.5 (2,400)	DA
792.5 (2,600)	DA
844.3 (2,770)	DA
902.2 (2,960)	DA
929.6 (3,050)	DA
993.6 (3,260)	DA
1,042.4 (3,420)	DA
1,047.0 (3,435)	SC
1,054.0 (3,458)	SC
1,054.3 (3,459)	SC
1,060.7 (3,480)	DA

a All analyses are pending at this time. The following analyses are planned:
Petrographic: polished thin sections. **Mineralogic**: electron microprobe; x-ray diffraction.
Chemical: X-ray fluorescence; wet chemical analysis for iron.

b Depth represents base of 3.0-m (10-ft) sample interval for drill cuttings.

c **DA** = drill cuttings that represent lithologic character of interval; **SC** = Rotary sidewall core.

Table 3-3
Well ER-EC-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)
Temperature/Gamma Ray	Saturated zone: groundwater temperature/stratigraphic correlation	Schlumberger	06/02/1999 06/13/1999	TL-1/SGR-1 TL-2/GR-3	249.9 (820) 1,050.3 (3,446)	0 141.1 (463)
* Natural Gamma Ray Spectroscopy	Stratigraphic correlation, mineralogy, natural and man-made radiation	Schlumberger	06/02/1999 06/14/1999	SGR-1 SGR-2	253.0 (830) 1,045.8 (3,431)	0.0 (0) 216.4 (710)
* Four Arm Caliper/Gamma Ray	Borehole conditions, cement volume calculation/ stratigraphic correlation	Schlumberger	06/02/1999 06/13-14/1999	CA4-1/SGR-1 CA4-2/GR-3	268.2 (880) 1,061.0 (3,481)	0.6 (2) 207.3 (680)
* Array Induction Log/ Caliper/Gamma Ray	Rock porosity/ borehole conditions/ lithologic determination, stratigraphic correlation	Schlumberger	06/03/1999	IND-1/GR-1/CAL-1	266.1 (873)	11.0 (36)
* Epithermal Neutron/Density/ Gamma Ray/ Caliper	Total water content/lithologic determination/stratigraphic correlation/borehole conditions	Schlumberger	06/03/1999 06/14/1999	ENP-1/CDL-1/ GR-2/CAL-2 ENP-2/CDL-2/ GR-4/CAL-3	267.9 (879) 1,058.9 (3,474)	11.0 (36) 131.1 (430)
* Dual Laterolog/ *Spontaneous Potential/Gamma Ray	Saturated zone: water saturation/ stratigraphic correlation	Schlumberger	06/14/1999	DLL-1/ SP-1 [c] /GR-5	1,057.7 (3,470)	263.3 (864)
Gamma Ray/Digital Array Sonic A. Wave-form and variable density presentations * B. Sonic porosity and travel time (STC) computations	Saturated zone: A. Porosity, lithologic determination B. Fracture identification	Schlumberger	06/14/1999	AC-1/GR-5	A. 1,050.0 (3,445) B. 1,047.0 (3,435)	228.6 (750)
Ultrasonic Borehole Imager	Saturated zone: lithologic characterization, fracture and void analysis.	Schlumberger	06/14/1999	BHTV-1	1,045.8 (3,431)	216.4 (710)
Mechanical Sidewall Coring Tool/Gamma Ray	Geologic Samples	Schlumberger	06/16/1999	MSCT-1/GR-2	1,054.3 (3,459)	286.5 (940)
* Thermal Flow Log	Rate and direction of groundwater flow in borehole	Desert Research Institute	06/15/1999	1	1,053.1 (3,455)	304.8 (1,000)

Table 3-3
Well ER-EC-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)
* Chemistry/Temperature Log	Groundwater chemistry and temperature, formation transmissivity	Desert Research Institute	06/15/1999	1	1,060.7 (3,480)	230.1 (755)
Nuclear Annulus Investigation Log	Well construction monitoring	Colog	06/17-20/1999	AIN-1	1,050.5 (3,446.5)	12.2 (40)
Gyroscopic Directional Survey	Borehole deviation	Gyrodata	10/21/1999	1	1,040.9 (3,415)	0

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

b Depth below ground surface.

c Run number not recorded on header of printed log.

4.0 Geology and Hydrogeology

This section summarizes the geology and hydrogeology of Well ER-EC-4. The data and interpretations presented in this section and in the detailed lithologic log are preliminary, pending results of laboratory analyses on the samples listed in Table 3-2. Bechtel Nevada geologists prepared the detailed lithologic log presented in Appendix C, incorporating information from field lithologic descriptions by IT well-site geologists and from geophysical logs.

Well ER-EC-4 was drilled just west of a geophysically inferred, north-northeast-trending feature known as the Thirsty Canyon lineament. This feature may represent a buried structural zone that is coincident with the western margins of the Timber Mountain and Silent Canyon caldera complexes (Grauch et al., 1997; Hildenbrand et al., 1999; Mankinen et al., 1999; Figure 4-1). Such a feature could provide a direct groundwater flow path from Pahute Mesa to discharge sites in Oasis Valley (Grauch et al., 1997; Hildenbrand et al., 1999; Mankinen et al., 1999), so it is important that this zone be characterized. Geologic and hydrologic data from Well ER-EC-4, in conjunction with data from holes drilled east of the Thirsty Canyon lineament (Well ER-EC-2a and Well ER-EC-8), will provide critical information about the geologic and hydrologic significance of this feature. The geologic interpretations of these wells will be updated if necessary after all drilling is complete and data have been analyzed in the context of the regional geologic setting.

4.1 Geology

Well ER-EC-4 is located on the eastern flank of Thirsty Mountain (Figure 4-1), a shield volcano composed of multiple flows of Pliocene basalt (Wahl et al., 1997; Figure 4-2). At Well ER-EC-4, the Thirsty Mountain basalt is approximately 15.2 m (50 ft) thick, and below the basalt, the well penetrated 1,047.6 m (3,437 ft) of volcanic rocks erupted from calderas located north and east of the well (Figure 4-1); these lower volcanic rocks are discussed in the following paragraphs.

Immediately below the basalt, the well encountered 272.8 m (895 ft) of nonwelded to moderately welded ash-flow tuff and bedded tuff assigned to four units of the Thirsty Canyon Group: the Gold Flat, Trail Ridge, Pahute Mesa, and Rocket Wash Tuffs (Figure 4-3). (The Rocket Wash Tuff is included in the Pahute Mesa Tuff in Wahl et al. [1997].) These units, which are exposed extensively at the surface just east of the well, were erupted approximately 9.4 million years ago

This page intentionally left blank.

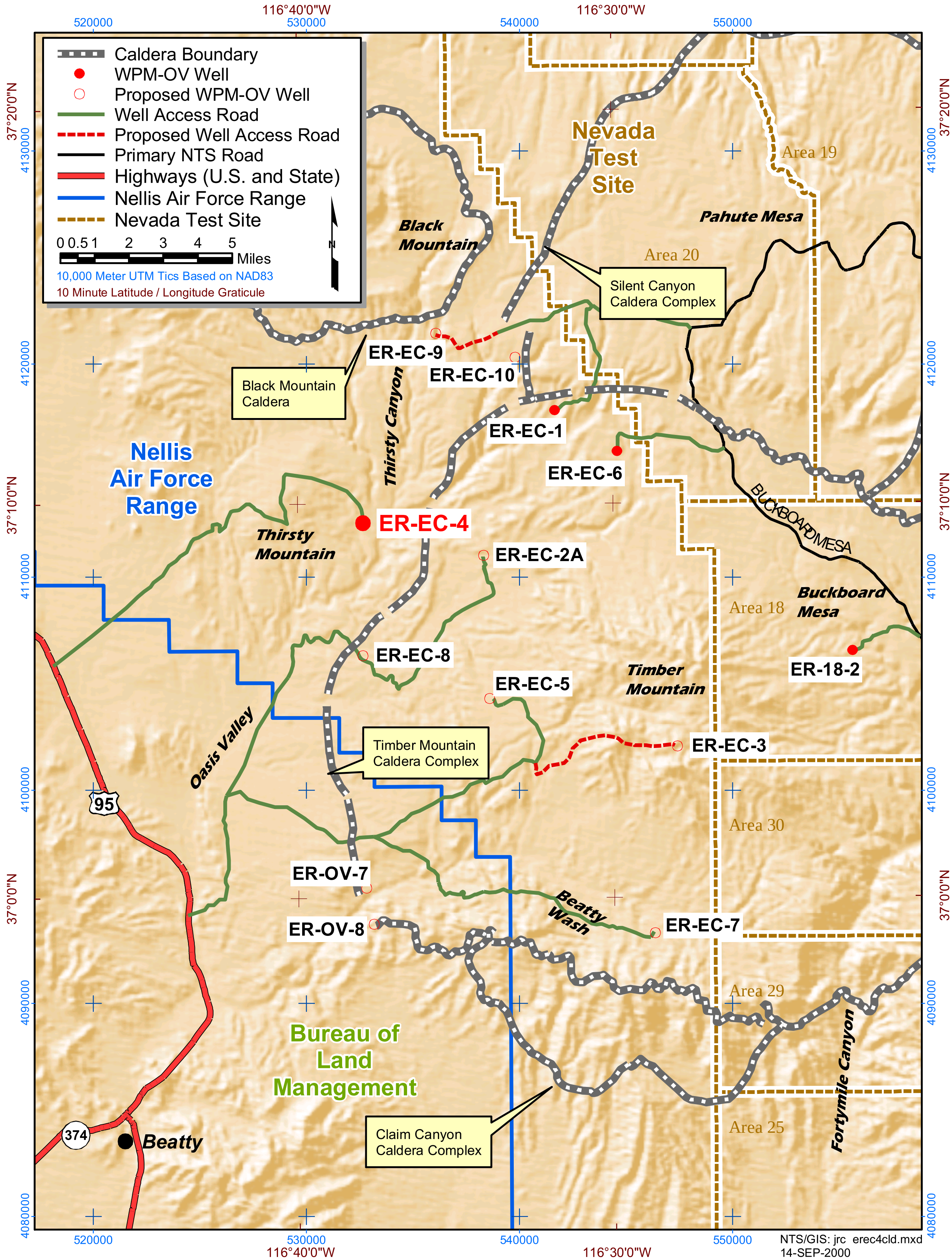
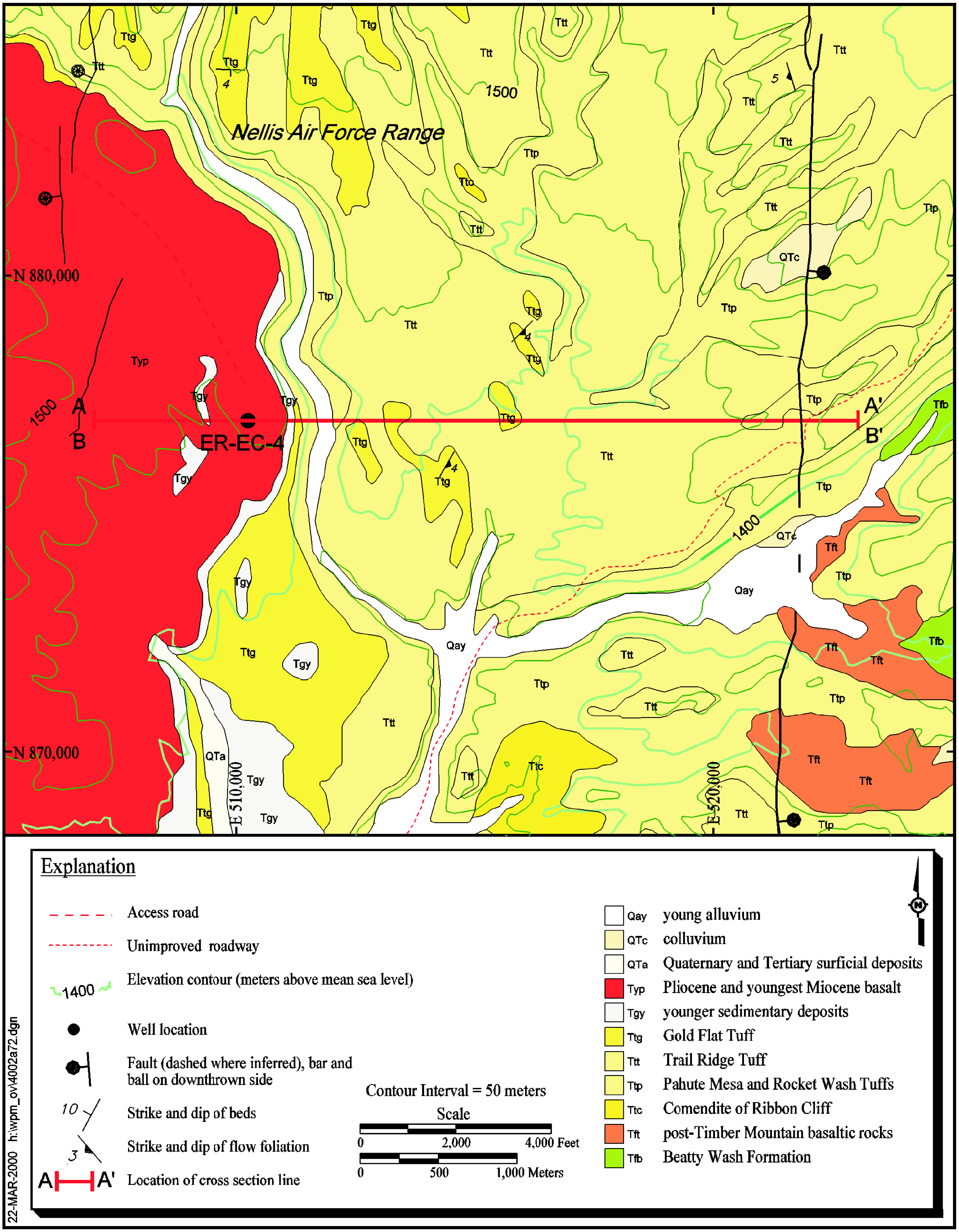


Figure 4-1
Map of Western Pahute Mesa - Oasis Valley Area Showing Theorized Locations of Caldera Boundaries (after Wahl, et. al., 1997)

This page intentionally left blank.



Source: Wahl et al., 1997

Figure 4-2
Surface Geologic Map of the Well ER-EC-4 Site

This page intentionally left blank.

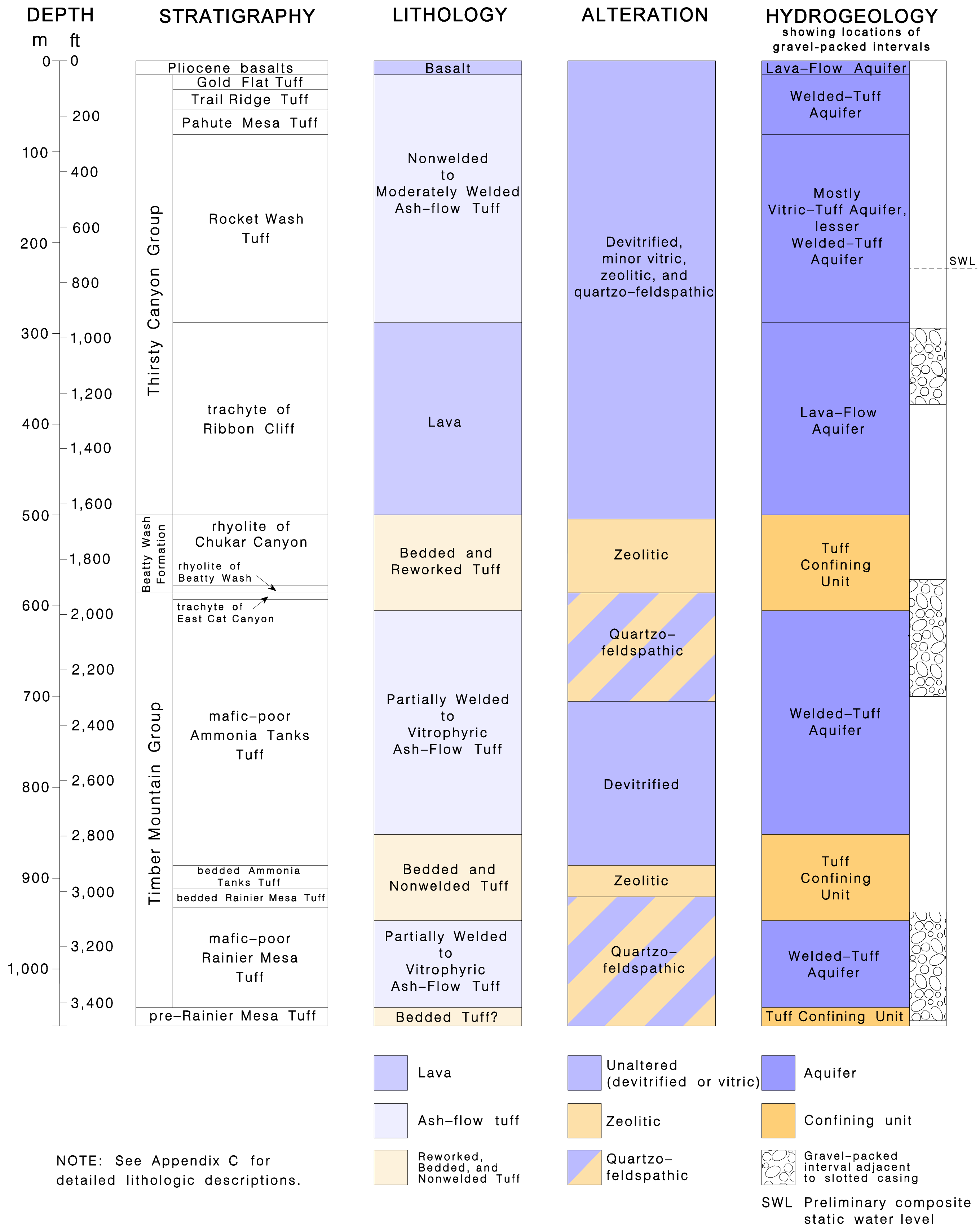


Figure 4-3
Preliminary Geology and Hydrogeology of Well ER-EC-4

This page intentionally left blank.

(Ma) from the Black Mountain caldera (Sawyer et al., 1994) located approximately 10 km (6.2 mi) north of Well ER-EC-4.

The Thirsty Canyon Group tuffs overlie 211.8 m (695 ft) of lava assigned to the trachyte of Ribbon Cliff (Ferguson et al., 1994; unit referred to as comendite of Ribbon Cliff in Wahl et al., 1997), also a unit of the Thirsty Canyon Group (Figure 4-3). In Well ER-EC-4, this interval of lava consists of more than ten individual flows of trachytic, comenditic, or basaltic lava, each less than 30 m (100 ft) thick, and representing fluid lava that probably flowed south from the vicinity of the Black Mountain caldera, during magma emplacement and uplift, but prior to caldera formation. Extensive exposures of Ribbon Cliff lava occur south and east of the Black Mountain caldera (Wahl et al., 1997), and small, isolated exposures of Ribbon Cliff lava occur approximately 2.4 km (1.5 mi) northeast and southeast of Well ER-EC-4. The rocks of the Thirsty Canyon Group are peralkaline in character (Wahl et al., 1997), so the stratigraphic assignment of Thirsty Canyon Group to the rocks encountered between the depths of 15.2 and 499.9 m (50 and 1,640 ft) in Well ER-EC-4 is based largely on the presence of olivine and absence of biotite (mineralogical characteristics typical of peralkaline rocks) as well as the absence of quartz, also a characteristic of the Thirsty Canyon Group.

Below the Ribbon Cliff lava, the well penetrated 86.0 m (282 ft) of bedded and reworked tuff assigned to the rhyolite of Chukar Canyon and rhyolite of Beatty Wash, both subunits of the Beatty Wash Formation in the stratigraphic group, Volcanics of Fortymile Canyon (Figure 4-3). These assignments are based mainly on mineralogical characteristics, including the presence of common to abundant mafic minerals such as biotite, hornblende, clinopyroxene, and sphene, and generally scarce quartz. Units of the Beatty Wash Formation are mostly buried by younger rocks in the vicinity of Well ER-EC-4, however, rhyolitic lava assigned to the Beatty Wash Formation is exposed at the surface approximately 4.3 km (2.7 mi) east of the well (Wahl et al., 1997). The Beatty Wash Formation was erupted about 11.2 to 11.4 Ma from vents in the vicinity of the older Timber Mountain caldera complex shortly after the formation of the Ammonia Tanks caldera (Sawyer et al., 1994). The Timber Mountain caldera complex consists of the nested Ammonia Tanks and Rainier Mesa calderas (Byers et al., 1976) and is located approximately 3.2 km (2 mi) east of Well ER-EC-4. The Beatty Wash Formation appears to partially fill the Timber Mountain caldera complex, typically having a thickness of greater than 152.4 m (500 ft) within the complex. Thus, a thickness of only 86.0 m (282 ft) of Beatty Wash Formation in Well ER-EC-4 suggests that the well is located outside of the Timber Mountain caldera complex.

Below the Beatty Wash Formation the well penetrated a thin (7.3-m [24-ft]) interval of trachytic or basaltic lava and associated bedded tuff tentatively assigned to the trachyte of East Cat Canyon, a formation of the Timber Mountain Group, based on its occurrence directly above Ammonia Tanks Tuff, also a formation of the Timber Mountain Group (Figure 4-3). However, the lava and tuff may instead be part of the Volcanics of Fortymile Canyon, considering the presence of outcrops of basaltic lava assigned to the Fortymile Canyon Group approximately 3.2 km (2.0 mi) southeast of the well (Wahl et al., 1997). However, this surface exposure of Fortymile Canyon lava appears to overlie rhyolitic lava assigned to the Beatty Wash Formation; this is stratigraphic evidence that the Well ER-EC-4 beds likely belong to the Timber Mountain Group. Data from laboratory analyses currently in progress are expected to clarify these stratigraphic assignments.

The thin interval of East Cat Canyon lava and tuff in Well ER-EC-4 overlies 292.9 m (961 ft) of ash-flow tuff assigned to the mafic-poor member of the Ammonia Tanks Tuff (Figure 4-3). The Ammonia Tanks Tuff, which is not exposed in the vicinity of the well due to its burial by younger rocks, was erupted 11.45 Ma, resulting in the formation of the Ammonia Tanks caldera (Sawyer et al., 1994). The stratigraphic assignment of mafic-poor Ammonia Tanks Tuff for this interval of ash-flow tuff in Well ER-EC-4 is based on the presence of biotite, clinopyroxene, sphene, chatoyant sanidine, and quartz, and the thick, welded ash-flow tuff lithology. The ash-flow tuff is nonwelded to partially welded in the upper and lower portions, and moderately welded to vitrophyric in the interior of the flow, a typical welding profile for extracaldera Ammonia Tanks Tuff. Although 292.9 m (961 ft) seems unusually thick for extracaldera Ammonia Tanks Tuff, this unit is still probably too thin to indicate deposition within the caldera.

The unusual thickness of extracaldera mafic-poor Ammonia Tanks Tuff in Well ER-EC-4 may indicate that a structural low had formed west of the Timber Mountain caldera complex prior to the eruption of the Ammonia Tanks Tuff. This is consistent with interpretations by Fridrich (C. J. Fridrich, USGS: Personal Communication, 1999) that indicate a north-trending structural low or basin extending from the Black Mountain caldera to south of Oasis Valley.

Mafic-poor Ammonia Tanks Tuff in Well ER-EC-4 overlies 46.0 m (151 ft) of bedded and reworked tuff (Figure 4-3). The upper 25.6 m (84 ft) of this interval is assigned to the bedded Ammonia Tanks Tuff based on its occurrence directly below mafic-poor Ammonia Tanks Tuff, and a similar phenocryst content to the Ammonia Tanks Tuff, including the presence of sphene. The lower 20.4 m (67 ft) of the interval is assigned to the bedded Rainier Mesa Tuff based on the absence of sphene, and the occurrence of the tuff directly above Rainier Mesa ash-flow tuff. The bedded Ammonia Tanks and Rainier Mesa Tuffs represent minor eruptions of tephra between the major caldera-forming eruptions of the Ammonia Tanks and Rainier Mesa volcanoes.

Bedded Rainier Mesa Tuff in Well ER-EC-4 overlies at least 110.3 m (362 ft) of ash-flow tuff assigned to the mafic-poor member of the Rainier Mesa Tuff, a formation of the Timber Mountain Group (Figure 4-3). The Rainier Mesa Tuff was erupted 11.6 Ma, forming the Rainier Mesa caldera (Sawyer et al., 1994). The assignment of mafic-poor Rainier Mesa Tuff is based on the presence of common felsic phenocrysts of quartz and feldspar, minor amounts of biotite, very scarce lithic fragments, the absence of sphene, and the ash-flow tuff lithology. The mafic-poor Rainier Mesa Tuff encountered in Well ER-EC-4 consists of nonwelded to vitrophyric ash-flow tuff that grades from nonwelded and partially welded in the upper portion to moderately to densely welded and vitrophyric in the lower portion. Two thin intervals of vitrophyre are present, with the base of the lowermost interval at the depth of 1,042.4 m (3,420 ft).

The base of the mafic-poor Rainier Mesa Tuff is poorly constrained in Well ER-EC-4. Samples of drill cuttings from 1,042.2 m (3,420 ft) to the bottom of the hole at 1,062.8 m (3,487 ft) are a confusing mixture of volcanic lithologies, making lithologic and stratigraphic assignments very difficult and uncertain. However, only two vitrophyres typically are found in the Rainier Mesa Tuff, the lower vitrophyre occurring near the base of the unit (Warren et al., 1989). This suggests that Well ER-EC-4 penetrated through most or all of the Rainier Mesa Tuff. Due to uncertainties in characterizing the stratigraphy in this portion of the hole, the base of the Rainier Mesa Tuff is tentatively placed at the base of the lower vitrophyre, at the depth of 1,042.4 m (3,420 ft). This constrains the minimum thickness of the Rainier Mesa Tuff to 110.3 m (362 ft). Based on the lithologic sequence observed, compared with “typical” Rainier Mesa Tuff, it is unlikely that Rainier Mesa Tuff extends more than about 46 m (150 ft) below the lower vitrophyre, which suggests a maximum thickness of about 152 m (500 ft). Sidewall core samples from the lower portion of the borehole are being analyzed to verify their mineralogical and chemical composition; these data are expected to provide more definitive stratigraphic information for this section.

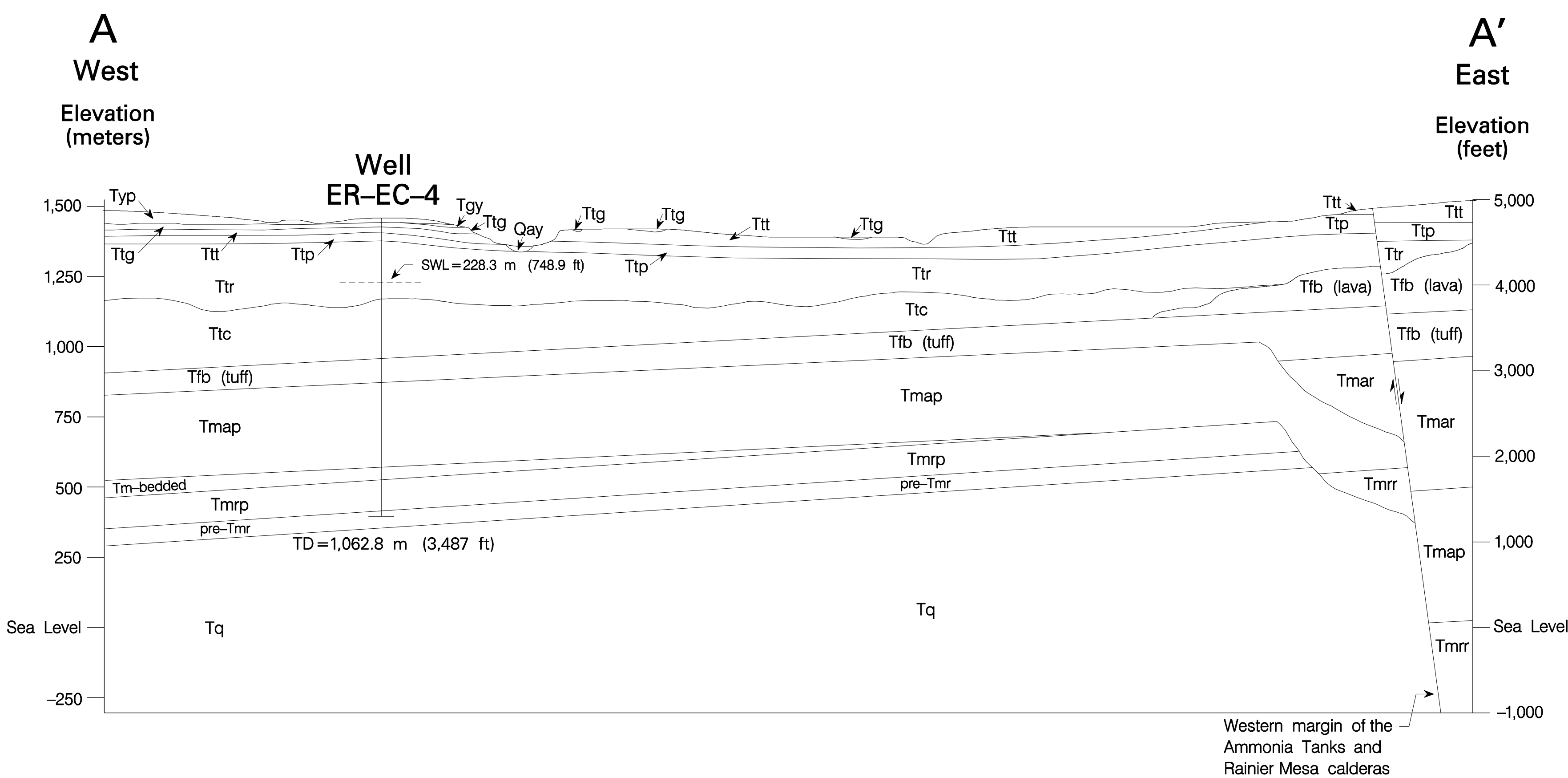
The presence of a relatively thin deposit of Rainier Mesa Tuff indicates that the well is outside the Rainier Mesa caldera, and that the caldera boundary must be to the east of the well. This interpretation represents a significant difference from some previous interpretations of the Timber Mountain caldera complex, in which the western boundary of the Rainier Mesa caldera extends more than 5 km (3.1 mi) west of the Well ER-EC-4 location (Noble et al., 1991 and Warren, 1994).

The location of the western margin of the Timber Mountain caldera complex as shown on the preliminary geologic cross section in Figure 4-4 is generally consistent with that of Wahl et al. (1997). Although the western margin of the caldera complex is depicted on the cross section as coinciding with the western boundaries of both the Ammonia Tanks and Rainier Mesa calderas, the nature of this zone is unknown. Future drilling of Well ER-EC-2a east of Well ER-EC-4 is expected to provide data that will better characterize and constrain the western margins of the Timber Mountain caldera complex and its associated calderas. The location of the caldera margin shown in Figure 4-4 is also generally coincident with the location of the Thirsty Canyon lineament at the surface (Grauch et al., 1997; Hildenbrand et al., 1999; Mankinen et al., 1999). This suggests that the Thirsty Canyon lineament may indeed reflect the western margin of the caldera complex.

The predominant type of mineralogic alteration observed in each stratigraphic unit encountered in Well ER-EC-4 is illustrated on Figure 4-3. Alteration has a significant effect on both the general hydraulic character of tuff and on how radionuclides migrate through tuffs. The tuffs and lavas of the Thirsty Canyon Group encountered above the depth of 499.9 m (1,640 ft) are mostly devitrified, but with some vitric (unaltered), zeolitic, and higher temperature quartzo-feldspathic alteration also present. The bedded and reworked tuffs of the underlying Beatty Wash Formation are zeolitic. Below this interval of zeolitic alteration is a zone of higher temperature quartzo-feldspathic alteration that includes the trachyte of East Cat Canyon and the upper 112.2 m (368 ft) of the mafic-poor Ammonia Tanks Tuff. The lower 180.7 m (593 ft) of mafic-poor Ammonia Tanks Tuff is mostly devitrified, but with some vitric and some silicic alteration also present. The bedded Ammonia Tanks Tuff and upper portion of the bedded Rainier Mesa Tuff are silicic, zeolitic, and argillic. Another zone of quartzo-feldspathic alteration occurs below 920.5 m (3,020 ft) and includes all the rocks from the lower portion of the bedded Rainier Mesa Tuff to the bottom of the well, except for the intervals of vitrophyre within the mafic-poor Rainier Mesa Tuff which are vitric to devitrified.

4.2 Predicted Versus Actual Geology

The predicted geology for Well ER-EC-4 was based partly on the locations of caldera margins as interpreted by Warren (1994), which placed the western margin of the Rainier Mesa caldera west of Thirsty Mountain as described by Noble et al. (1991). Consequently, geologists anticipated



SWL	Preliminary composite static water level	Qay	Young Alluvium	Tfb	Beatty Wash Formation
TD	Total depth	Typ	Pliocene basalts	Tmar	mafic–rich Ammonia Tanks Tuff
	Fault showing relative sense of movement	Tgy	Younger sedimentary deposits	Tmap	mafic–poor Ammonia Tanks Tuff
		Ttg	Gold Flat Tuff	Tm–bedded	Ammonia Tanks and Rainier Mesa bedded tuffs
		Ttt	Trail Ridge Tuff	Tmrr	mafic–rich Rainier Mesa Tuff
		Ttp	Pahute Mesa Tuff	Tmrp	mafic–poor Rainier Mesa Tuff
		Ttr	Rocket Wash Tuff	pre–Tmr	pre–Rainier Mesa Tuff volcanic rocks
		Ttc	trachyte of Ribbon Cliff	Tq	Volcanics of Quartz Mountain

Scale

0 2,000 4,000 Feet

0 500 1,000 Meters

No vertical exaggeration

Figure 4-4
Preliminary Geologic Cross Section A-A' Through Well ER-EC-4

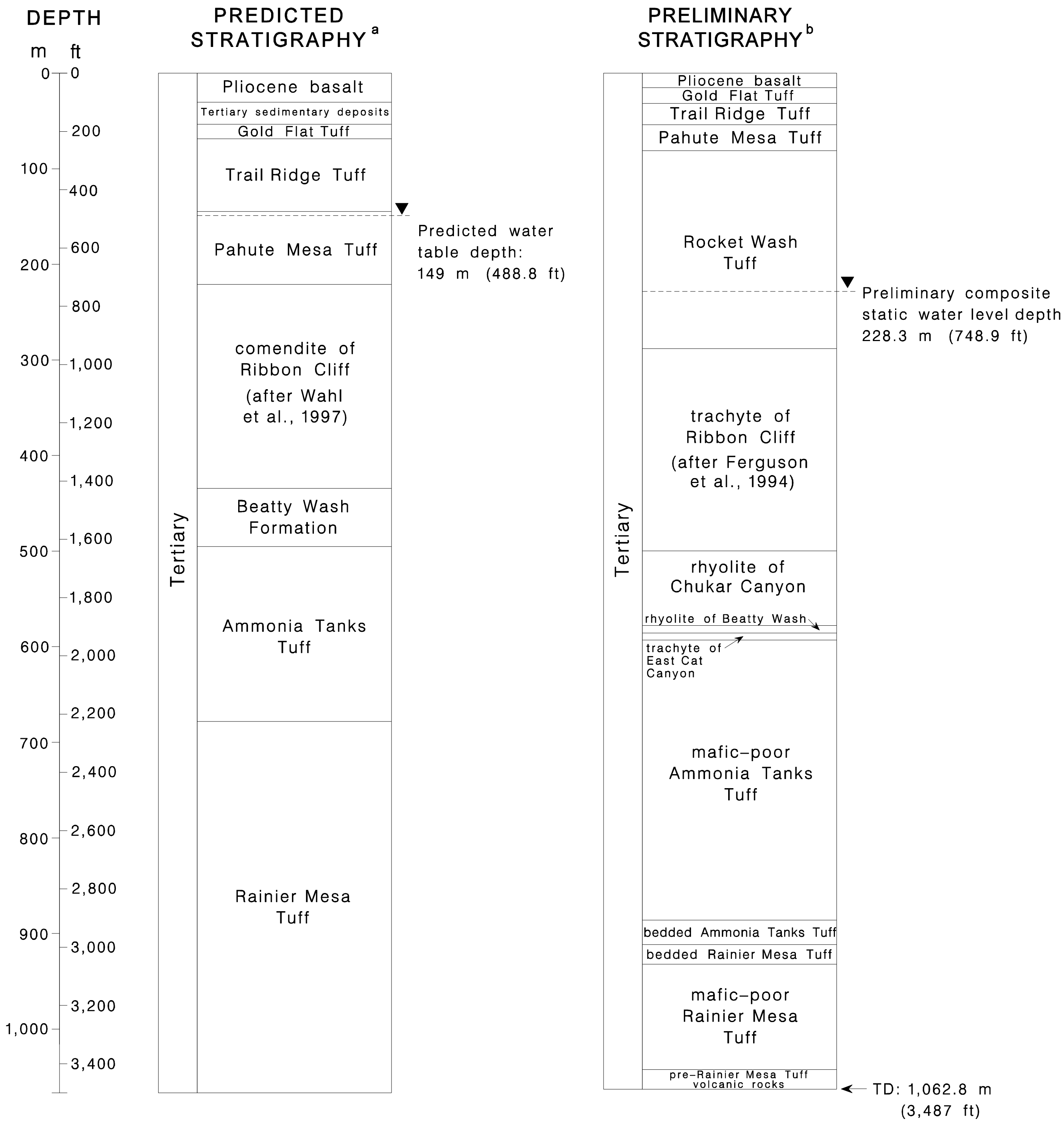
that a considerable thickness of intracaldera Rainier Mesa Tuff would be encountered in the well. As discussed in Section 4.1, the likelihood that less than about 152 m (500 ft) of Rainier Mesa Tuff is present at Well ER-EC-4 constrains the western margin of the caldera to a position east of the well. See Figure 4-1 for an illustration of WPM-OV area caldera boundary locations (according to Wahl et al., 1997), and Figure 4-5 for a comparison of predicted versus actual (preliminary) stratigraphy for Well ER-EC-4.

Although it was anticipated prior to drilling that extracaldera Ammonia Tanks Tuff would be encountered, the actual thickness penetrated was considerably greater than anticipated (Figure 4-5). This, along with greater than anticipated thicknesses for younger rocks (particularly the Thirsty Canyon Group), may indicate, as mentioned in Section 4.1, a pre-Ammonia Tanks/post-Rainier Mesa Tuff structural low in the vicinity of Well ER-EC-4 (Figure 4-4). The timing of the development of this structural low is generally the same as that for the structural bench first described by Warren (1994) and more accurately constrained and defined by data from wells ER-EC-6 and ER-EC-1 (DOE, 2000a; 2000b). Together, these two structural features suggest that significant structural adjustments occurred just beyond the margins of the Rainier Mesa caldera shortly after the caldera was formed.

4.3 Hydrogeology

Well ER-EC-4 penetrated three separate intervals of rocks that likely behave as aquifers (Figure 4-3). The tuffs and lavas of the Thirsty Canyon Group probably have hydraulic properties consistent with those of welded-tuff and lava-flow aquifers due to the likelihood that these dense, brittle rocks are fractured. However, many of the tuffs appear to be only slightly welded and thus are probably poorly fractured, resulting in hydraulic properties that may be similar to those of vitric-tuff aquifers, in which more groundwater is thought to flow through the rock matrix (interstitial flow) and less through fractures. The welded portions of the Ammonia Tanks and Rainier Mesa Tuffs are also assumed to behave as welded-tuff aquifers due to the presence of fractures.

Rocks that likely behave as tuff confining units occur between the aquifer-like rocks (Figure 4-3). The zeolitic and quartzo-feldspathic bedded and reworked tuffs of the Beatty Wash Formation likely behave as tuff confining units, thus separating the welded-tuff and lava-flow aquifers of the overlying Thirsty Canyon Group from the welded-tuff aquifer of the Ammonia Tanks Tuff. Similarly, the bedded and reworked tuffs of the bedded Ammonia Tanks and bedded Rainier Mesa Tuffs and adjacent, nonwelded portions of the mafic-poor Ammonia Tanks



NOTES:

a IT, 1998

b See Appendix C for detailed lithologic descriptions.

Surface Elevation (pad): 1,450.7 m (4,759.6 ft)
Nevada Coordinates (NAD 1983): N 20,561,804.6 ft; E 1,650,532.1 ft
Well Completed: 6/20/1999

Figure 4-5
Predicted and Preliminary Actual Stratigraphy at Well ER-EC-4

and mafic-poor Rainier Mesa Tuffs are also zeolitic and quartzo-feldspathic, and separate the welded-tuff aquifer of the Ammonia Tanks Tuff from the welded-tuff aquifer of the Rainier Mesa Tuff. If the rocks below the base of the Rainier Mesa Tuff are bedded or nonwelded tuffs, then they likely form an additional tuff confining unit below the welded-tuff aquifer of the Rainier Mesa Tuff.

Figure 4-6 is a preliminary hydrogeologic cross section through the Well ER-EC-4 vicinity. Due to the limited and preliminary nature of data in the Well ER-EC-4 vicinity, and the difficulty in predicting the lateral continuity of hydraulic properties of volcanic rocks, the cross section is rather conjectural. However, it does illustrate the complexities associated with the distribution of hydrogeologic units in caldera settings such as at Well ER-EC-4. See the discussion of general hydraulic properties of expected WPM-OV units in IT (1998), Section D.6.2 and Table D.6-1. Proposed hydrologic testing in the well will verify the actual hydraulic character of these units.

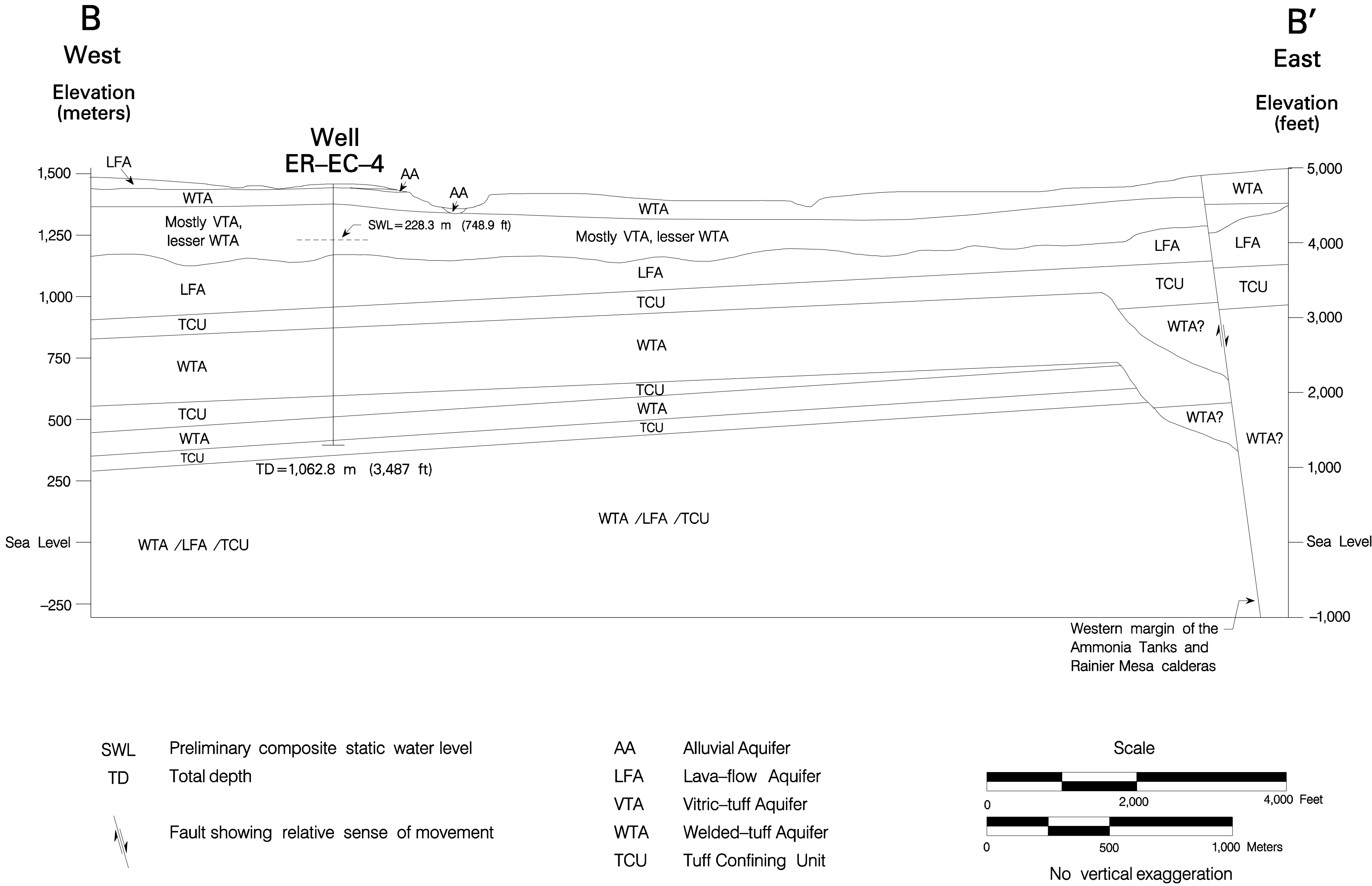


Figure 4-6
Preliminary Hydrogeologic Cross Section B-B' Through Well ER-EC-4

This page intentionally left blank.

5.0 Hydrology

5.1 Preliminary Water-level Information

The elevation of the water table at Well ER-EC-4 was projected to be approximately 1,293 m (4,241 ft), as derived from sparse hydrologic data for this region (IT, 1998). Based on the pre-construction estimate of surface elevation at the site, depth to water was expected at approximately 149 m (489 ft) (IT, 1998). During drilling, the fluid level consistently stabilized at a depth of approximately 228.3 m (749 ft), and fluid-level depths between 228.0 and 228.3 m (748 and 749 ft) were obtained from various geophysical logs run June 14-19, 1999, before the completion string was installed. Two months after the completion string was set, on August 19, 1999, IT obtained a fluid-level depth in the well of 228.3 m (748.9 ft) (IT, written communication, 1999). Based on this composite fluid-level depth and the as-built surface elevation of 1,450.7 m (4,759.6 ft), the fluid-level elevation at Well ER-EC-4 is 1,222.4 m (4,010.7 ft). This is approximately 70 m (230 ft) below the predicted elevation of 1,293 m (4,241 ft). A transducer was not installed for monitoring of the water level at the time of completion.

5.2 Water Production

Water production was estimated on the basis of LiBr dilution data as measured by IT field personnel. As expected, the welded and vitrophyric ash-flow tuffs of the Ammonia Tanks Tuff and Rainier Mesa Tuff formations were the primary water-producing units at this location. Measurable water production (approximately 190 lpm [50 gpm]) began at the depth of approximately 213 m (700 ft) within bedded Rocket Wash Tuff. The production rate averaged about 1,515 to 1,890 lpm (400 to 500 gpm) to the depth of about 686 m (2,250 ft) where it increased to about 3,030 lpm (800 gpm) within Ammonia Tanks ash-flow tuff. Production varied between about 1,515 and 3,405 lpm (400 and 900 gpm) to the depth of about 853 m (2,800 ft) where the borehole penetrated a tuff confining unit (nonwelded ash-flow tuff of the Ammonia Tanks Tuff). At that point, water production decreased to a relatively steady 760 to 945 lpm (200 to 250 gpm) to the depth of about 1,006 m (3,300 ft) where it again increased as the borehole penetrated the densely welded Rainier Mesa Tuff. The maximum production rate of more than 3,785 lpm (1,000 gpm) was measured at the depth of 1,036 m (3,400 ft). Estimated water production rates are presented graphically in Appendix A-1.

5.3 Preliminary Thermal Flow Meter Data

Thermal flow meter (TFM) data, along with temperature, electrical conductivity (EC), and pH measurements can characterize borehole fluid variability, which may indicate inflow and outflow zones. The design of the completion string for Well ER-EC-4 was based in part on these data. Desert Research Institute (DRI) personnel made TFM measurements at seven locations between the depths of 243.8 and 1,053.1 m (800 and 3,455 ft) in Well ER-EC-4 before the completion string was installed. In addition, DRI ran a chemistry log, including temperature, EC, and pH, from 230.1 to 1,060.7 m (755 to 3,480 ft). Groundwater temperature gradually increased from 39.71 degrees Celsius (C) (103.5 degrees Fahrenheit [F]) at the top of the fluid column to 64.13 degrees C (147.4 degrees F) at the depth of 1,060.7 m (3,480 ft).

Preliminary analysis of a plot of the discrete TFM data points indicates a steady downward flow of water within the borehole between the depths of 274.3 and 1,048.5 m (900 and 3,440 ft). Plots of the TFM and chemistry log data are reproduced in Appendix D.

5.4 Preliminary Groundwater Characterization Samples

Following geophysical logging, DRI collected preliminary groundwater characterization samples at two locations within the open borehole. Four samples were collected at the depth of 515.1 m (1,690 ft), and two were collected at the depth of 1,054.7 m (3,460 ft). Analytical data from these initial samples, collected before formal well development, will provide a basis for comparison with future groundwater chemistry data.

6.0 Precompletion and Open-Hole Development

The only precompletion development conducted in Well ER-EC-4 consisted of circulating fluid for 15 minutes to clean the borehole. This process was conducted immediately after TD was reached and prior to geophysical logging.

This page intentionally left blank.

7.0 Well Completion

7.1 Introduction

Well completion refers to the installation in a borehole of a string of pipe or casing 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 the fluid level, and for sampling, so that accurate potentiometric and water chemistry data can be obtained from a known portion of the borehole.

Completion activities at Well ER-EC-4 took place on June 17-20, 1999, though the submersible pump will be installed at a later date. Figure 7-1 is a schematic of the final well-completion design for Well ER-EC-4; Table 7-1 is a construction summary for the well; and Figure 7-2 shows a plan view and profile of the wellhead surface completion. 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, written communication, 1999) was also consulted for preparation of this section.

7.2 Well Completion Design

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

7.2.1 Proposed Completion Design

The original completion design (IT, 1998) was based on the assumption that Well ER-EC-4 would penetrate thick welded-tuff aquifers of the Ammonia Tanks and Rainier Mesa Tuffs. The well was planned to be completed with a single casing string consisting of 5½-in. stainless steel casing, with every other joint slotted, suspended on carbon-steel 7e-in. casing. The primary goal was to obtain satisfactory completion within these welded-tuff aquifers, but the proposed completion design also called for the isolation (using non-slotted casing) of low transmissivity zones within the completion interval, if such zones could be identified.

7.2.2 As-Built Completion Design

The design of the Well ER-EC-4 completion was determined through consultation with members of the UGTA TWG, on the basis of on-site evaluation of data such as lithology and water

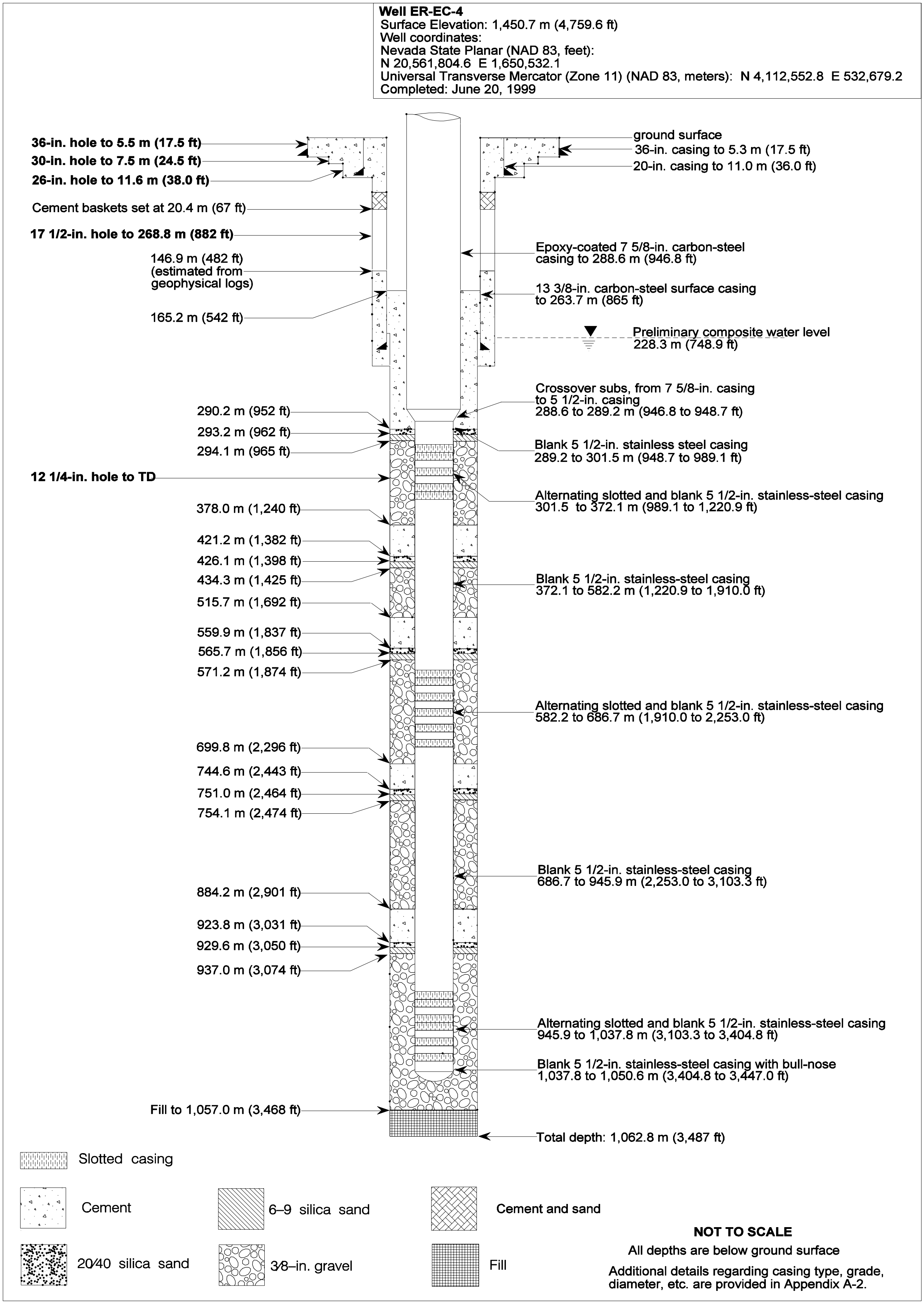


Figure 7-1
As-built Completion Schematic for Well ER-EC-4

Table 7-1
Well ER-EC-4 Completion String Construction Summary

<table>
<tr><th>Casing Type</th><th colspan="2">Configuration
meters (feet)</th><th>Cement
meters (feet)</th><th>Sand/Gravel
meters (feet)</th></tr>
<tr><td>7 e-in. carbon-steel production casing with internal epoxy coating</td><td>0 to 288.6
(0 to 946.8)</td><td>Blank</td><td rowspan="2">Type II

165.2 to 290.2
(542 to 952)</td><td rowspan="2">None</td></tr>
<tr><td>7 e-in. to 5½-in. cross-over sub, carbon-steel, with stainless-steel double pin</td><td>288.6 to 289.2
(946.8 to 948.7)</td><td>Blank</td></tr>
<tr><td rowspan="7">5½-in.
Stainless-steel production casing</td><td rowspan="7">289.2 to 1,050.6
(948.7.4 to 3,447.0)</td><td>Blank
289.2 to 301.5
(948.7 to 989.1)</td><td rowspan="7">Type II

378.0 to 421.2
(1,240 to 1,382)

515.7 to 559.9
(1,692 to 1,837)

699.8 to 744.6
(2,296 to 2,443)

884.2 to 923.8
(2,901 to 3,031)</td><td rowspan="7">20/40 Sand

290.2 to 293.2
(952 to 962)

421.2 to 426.1
(1,382 to 1,398)

559.9 to 565.7
(1,837 to 1,856)

744.6 to 751.0
(2,443 to 2,464)

923.8 to 929.6
(3,031 to 3,050)

6-9 Sand

293.2 to 294.1
(962 to 965)

426.1 to 434.3
(1,398 to 1,425)

751.0 to 754.1
(2,464 to 2,474)

929.6 to 937.0
(3,050 to 3,074)

3/8-in. x 4 Gravel

294.1 to 378.0
(965 to 1,240

434.3 to 515.7 [a]
(1,425 to 1,692)

571.2 to 699.8
(1,874 to 2,296)

754.1 to 884.2 [a]
(2,474 to 2,901

937.0 to 1,057.0
(3,074 to 3,468)</td></tr>
<tr><td>2 slotted joints above and below 2 blank joints, with one slotted joint in center
301.5 to 372.1
(989.1 to 1,220.9)</td></tr>
<tr><td>Blank
372.1 to 582.2
(1,220.9 to 1,910.0)</td></tr>
<tr><td>3 slotted joints alternating with 4 blank joints, overlain by 2 consecutive slotted joints
582.2 to 686.7
(1,910.0 to 2,253.0)</td></tr>
<tr><td>Blank
686.7 to 945.9
(2,253.0 to 3,103.3)</td></tr>
<tr><td>2 pairs slotted joints separated by 1 blank joint above 2 blank joints alternating with 2 slotted joints
945.9 to 1,037.8
(3,103.3 to 3,404.8)</td></tr>
<tr><td>Blank and bull-nosed
1,037.8 to 1,050.6
(3,404.8 to 3,447.0)</td></tr>
</table>

a Gravel sections not adjacent to slotted intervals.

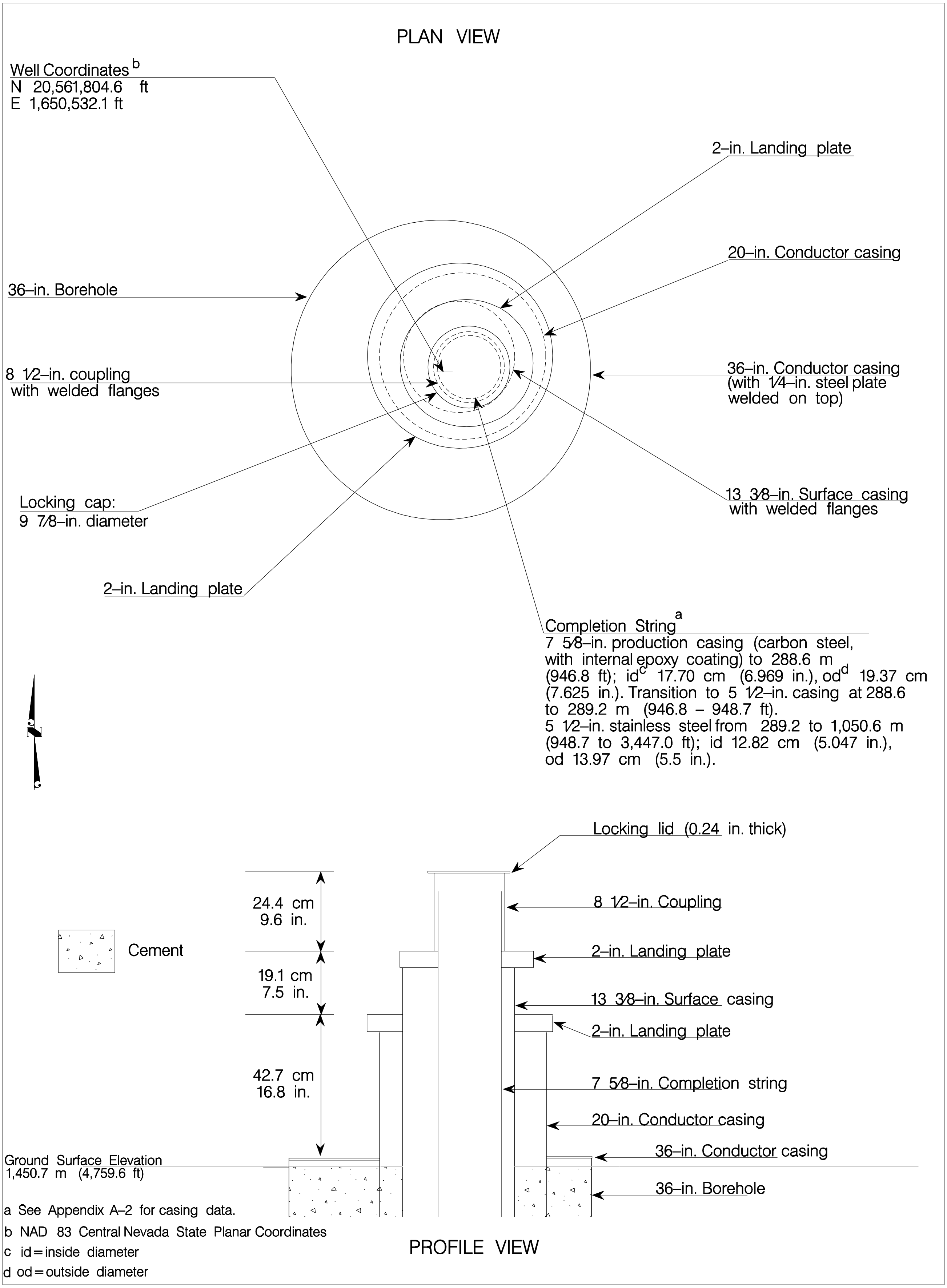


Figure 7-2
Wellhead Diagram for Well ER-EC-4

production, drilling data (lost circulation, etc.), data from various geophysical logs, and from thermal-flow and water chemistry logs.

The as-built completion design for Well ER-EC-4 provides access to three aquifers (Figure 7-1). The composition of the string summarized here is detailed on Table 7-1, and the casing materials are listed in Appendix A-2. The lower section of the completion string, from 1,050.6 to 289.2 m (3,447.0 to 948.7 ft), is type T304L stainless-steel casing with an outside diameter of 13.97 cm (5.5 in.) and an inside diameter of 12.82 cm (5.047 in.). The top of the 5½-in. casing is approximately 61 m (200 ft) below the static fluid level. The bottom 0.5-m (1.7-ft) joint is a blank bull-nose to serve as a sediment sump. Above the 5½-in. casing, a 0.6-m (1.9-ft) long crossover sub serves as the transition to the upper part of the string, which is 7e-in. carbon-steel production casing with an internal epoxy coating.

The lowest screened interval, 945.9 to 1,037.8 m (3,103.3 to 3,404.8 ft), is open to welded-tuff aquifer lithologies of the Rainier Mesa Tuff (See Figure 4-3 for an illustration of gravel-pack locations relative to hydrogeologic units.). This casing interval consists of two pairs of slotted joints separated by one blank joint, placed above two blank joints alternating with two slotted joints. The second slotted interval, 582.2 to 686.7 m (1,910.0 to 2,253.0 ft) is open to a welded-tuff aquifer of the Ammonia Tanks Tuff, and consists of three slotted joints alternating with four blank joints, overlain by two consecutive slotted joints. The uppermost slotted interval, 301.5 to 372.1 m (989.1 to 1,220.9 ft), consists of two slotted joints above and below two blank joints, with one slotted joint in the center, and is open to the lava-flow aquifer of the trachyte of Ribbon Cliff.

The openings in each slotted casing joint are 0.198 cm (0.078 in.) wide and 5.1 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 slots are cut within 0.6 m (2 ft) of the ends of the slotted joints to assure that the strength of the connections is not degraded.

7.2.3 Rationale for Differences between Actual and Proposed Well Design

In addition to the expected welded-tuff aquifers of the Ammonia Tanks and Rainier Mesa Tuffs, a thick lava-flow aquifer assigned to the trachyte of Ribbon Cliff was encountered near the top of the saturated section. The completion design was modified to include a completion zone in this aquifer, and tuff confining units encountered above the Ammonia Tanks Tuff and above the

Rainier Mesa Tuff were isolated by blank sections. However, the basic plan of installing a single string consisting of larger diameter carbon-steel casing above the water table and smaller diameter stainless-steel casing in the saturated zone was accomplished.

7.3 Well Completion Method

A "tremie" line and the completion string were landed after a brief period of circulation and conditioning of the hole. The three completion zones were gravel-packed and isolated from each other with sand and cement barriers. Two additional gravel layers (instead of cement) were placed adjacent to blank intervals (Figure 7-1; Table 7-1) 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 in accordance with 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 gravel, with 6-9 Colorado silica sand directly above the gravel, and 20/40 silica 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 was Type II Portland cement with no additives. A clear-water pre-flush and back-flush were made at each stage of cement 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 was used to monitor the emplacement of stemming materials. As-built positions of the well materials are shown on Figure 7-1 and listed in Table 7-1.

Stemming of the hole began with the first stage of gravel emplaced from 1,057.0 to 937.0 m (3,468 to 3,074 ft) on top of 5.8 m (19 ft) of fill at the bottom of the hole, and adjacent to the lowest slotted interval. This gravel pack is topped by a sand barrier to the depth of 923.8 m (3,031 ft), followed by cement, poured in two stages up to 884.2 m (2,901 ft). A second layer of gravel was placed between the depths of 884.2 and 754.1 m (2,901 and 2,474 ft), adjacent to a blank casing interval; this gravel was topped with sand to the depth of 744.6 m (2,443 ft), and cement to the depth of 699.8 m (2,296 ft). The next gravel pack, adjacent to the middle slotted interval, is located between 699.8 and 571.2 m (2,296 and 1,874 ft), and is capped with a sand barrier to the depth of 559.9 m (1,837 ft) and cement to 515.7 m (1,692 ft). Another gravel layer was placed around a blank casing interval between the depths of 515.7 and 434.3 m (1,692 and 1,425 ft). This gravel layer was topped with sand to the depth of 426.2 m (1,398 ft) and cement to the depth of 378.0 m (1,240 ft). The last gravel-packed zone was placed outside the uppermost slotted interval between the depths of 378.0 and 294.1 m (1,240 and 965 ft), and was capped with sand to the depth of 290.2 m (952 ft). The final cemented section extends to the depth of 165.2 m (542 ft).

The drill rig was released after cementing was completed. Because a pump was not installed in the well, no well-development or pumping tests have been conducted to date.

This page intentionally left blank.

8.0 Actual versus Planned Costs and Scheduling

The BN cost model developed for Well ER-EC-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 29 days to accomplish drilling of the surface and main holes, logging, and completion for the well, assuming the conductor hole would already have been constructed by BN. The actual time spent to finish the conductor hole, drill the main and surface holes, and install the completion string in Well ER-EC-4 was 27 days. A graphical comparison, by day, of planned and actual well-construction activities is presented in Figure 8-1.

The cost analysis for Well ER-EC-4 begins with construction of the conductor hole by BN and the cost of the move of the UDI drill rig from Well ER-18-2 to the Well ER-EC-4 site. 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-EC-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, and geophysical logging); and charges by BN for mobilization and demobilization of equipment, partial construction of the conductor hole, cementing services, completion materials, radiation technicians, inspection services, and geotechnical consultation.

The total planned cost for Well ER-EC-4 was $1,458,363. The actual cost was $1,692,163, or 16 percent more than the planned cost. Figure 8-2 is a comparison of the planned (“baseline”) and actual costs, by day, for drilling and completing Well ER-EC-4 (the chart shows the original drilling schedule in July, following the planned schedules for the three previous wells in the program). Even though the well was constructed in two fewer days than estimated, the unexpected requirement to stop drilling and construct a liner in one of the sumps contributed to the higher than planned construction cost for Well ER-EC-4.

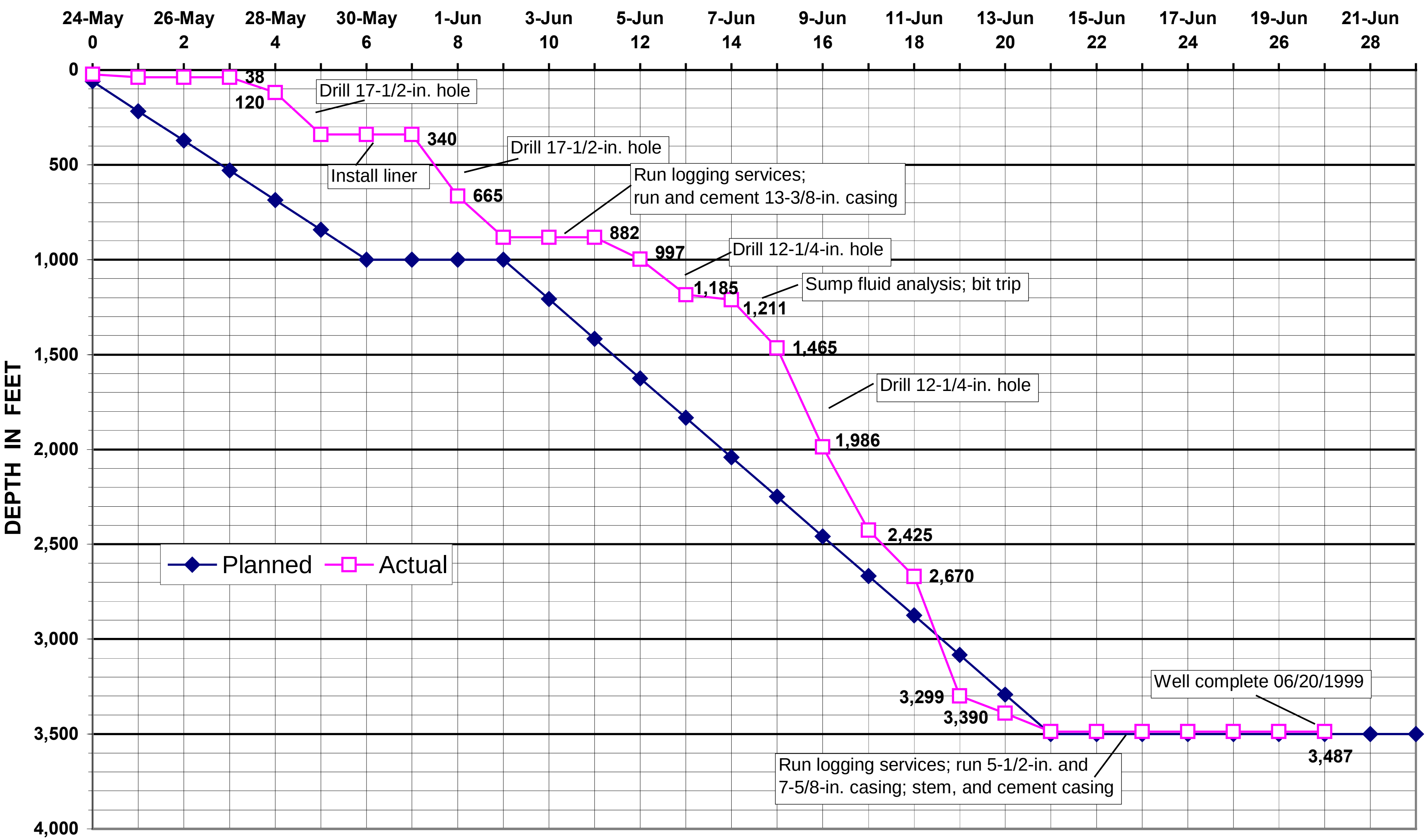


Figure 8-1
Planned versus Actual Drilling Progress for Well ER-EC-4

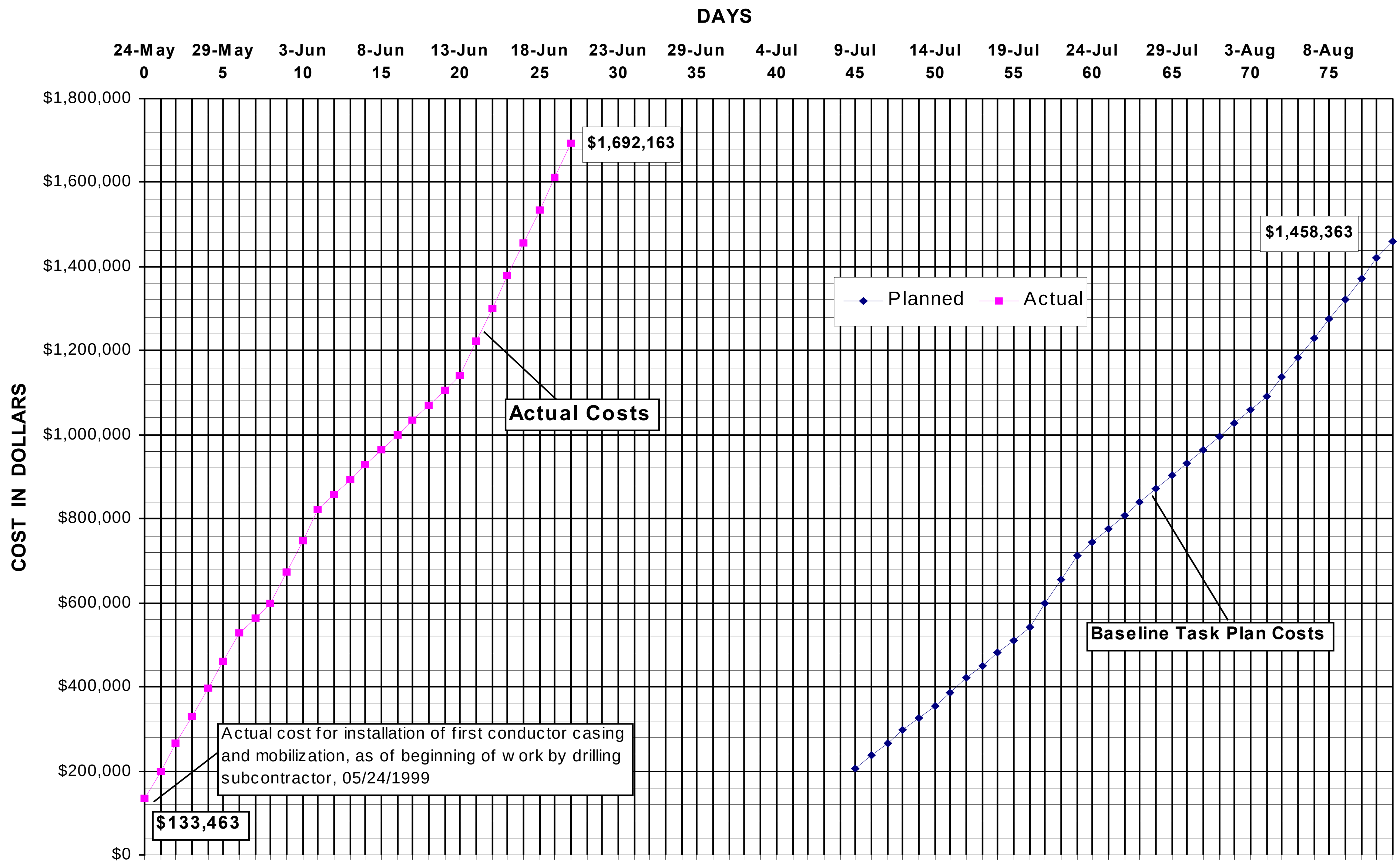


Figure 8-2
Planned versus Actual Costs for Drilling Well ER-EC-4

This page intentionally left blank.

9.0 Summary, Recommendations, and Lessons Learned

9.1 Summary

Subcontractor activities at Well ER-EC-4 commenced on May 24, 1999, and concluded on June 20, 1999. The TD of 1,062.8 m (3,487 ft) was reached on June 13, 1999, and after geophysical logging, the completion string was installed and gravel-packed, and the hole was stemmed to the depth of 165.2 m (542 ft) on June 17-20, 1999. Crews worked on a 7-days-per-week, 24-hours-per-day schedule for most of the operation. Twenty-seven working days were expended to finish the conductor hole, drill the surface and main holes, conduct geophysical logging, and install the completion string. The only problem encountered during construction of Well ER-EC-4 was a delay during drilling due to a fluid-management issue.

No radionuclides above background were encountered in the groundwater produced from Well ER-EC-4. Preliminary (field-monitoring) data indicated lead above permitted levels for dissolved lead in the drilling effluent, but laboratory testing indicated that the high lead reading was probably due to solids in the fluid rather than dissolved lead. A two-day delay was incurred while a sump was lined for disposal of potentially contaminated fluids.

IT personnel obtained a fluid level of 228.3 m (748.9 ft) on August 19, 1999, two months after the completion string was installed.

Composite drill cuttings were collected every 3 m (10 ft) from 9.1 m (30 ft) to TD. Thirty-five sidewall core samples were collected in the interval 286.5 to 1,054.3 m (940 to 3,459 ft). Geophysical logging was conducted in the upper part of the hole before installation of the surface casing, and in the lower part of the hole before installation of the completion string. Some of these logs were used to aid in construction of the well, while others help to verify the geology and determine the hydrologic characteristics of the rocks.

A single completion string with three gravel-packed, slotted intervals, was installed in Well ER-EC-4. A string of 5½-in. stainless-steel casing installed below the water table is suspended from 7e-in. carbon-steel casing (with an internal epoxy coating) which extends to the surface. The open intervals in the 5½-in. casing are centered within the gravel-pack intervals that are located at 294.1 to 378.0 m (965 to 1,240 ft); 571.2 to 699.8 m (1,874 to 2,296 ft); and 936.6

to 1,057.0 m (3,074 to 3,468 ft). These intervals are open to the lava-flow aquifer of the trachyte of Ribbon Cliff and welded-tuff aquifers of Ammonia Tanks and Rainier Mesa Tuffs.

9.2 Recommendations

The planned pump installation, well development, groundwater sampling, and hydrologic testing must be conducted at Well ER-EC-4 to accomplish the remaining objectives for this well-construction effort. Mineralogical and chemical analyses of rock samples, which are currently in progress, must be completed and evaluated for preparation of the final interpretation of the well geology. In addition, after all the planned WPM-OV wells are drilled, geologic and hydrologic data must be evaluated and interpretations of the area hydrogeology updated for insertion into the UGTA hydrologic model. This process, followed by analysis of the updated model, will allow more precise characterization of groundwater flow direction and velocity in the region between the nuclear testing areas of Pahute Mesa and the Oasis Valley discharge area.

9.3 Lessons Learned

The efficiency of drilling and constructing wells to obtain hydrogeologic data in support of the UGTA project continues to improve as experience is gained with each new well. Yet each new well produces some “lessons learned” that can be applied to improve future well-construction projects. The paragraphs below describe two primary lessons learned during construction of Well ER-EC-4.

- Estimation of water production rates is typically based on evaluation of several parameters (dilution of the LiBr tracer, visual estimates of flow-line discharge, fluid injection rates, etc.) However, field technicians responsible for reporting water production during drilling of Well ER-EC-4 were inconsistent in their means of estimating production rates. All estimates presented in this report are based on tracer dilution, but in the future, technical leads will incorporate other types of data and be more consistent in estimates.

- It was suspected that preliminary field monitoring for lead in the drilling effluent gave a positive reading because particulate lead was not removed by filtering before the analysis (permitted levels for lead are defined for dissolved lead, not total lead content in the sample). Adequate time must be allowed for filtering, especially within intervals of low water production when the effluent is thickened by foam and polymer additives.

10.0 References

Bechtel Nevada. 1999a. *Western Pahute Mesa/Oasis Valley (WPM-OV) Investigation Wells Site-Specific Health and Safety Plan (SSHASP)*. February 1999. Las Vegas, NV.

Bechtel Nevada. 1999b. Drilling Program for Underground Test Area (UGTA) Western Pahute Mesa/Oasis Valley (WPM-OV) Investigation Well ER-EC-4 - Original. Drilling Work Plan Number D-005-002.99. May 25, 1999. Las Vegas, NV.

BN, see Bechtel Nevada.

Byers, F. M., Jr., W. J. Carr, R. L. Christiansen, P. W. Lipman, P. P. Orkild, and W. D. Quinlivan. 1976. "Geologic Map of the Timber Mountain Caldera Area, Nye County, Nevada." U. S. Geological Survey Miscellaneous Investigations Map I-891, scale. Denver, CO.

DOE, see U.S. Department of Energy.

Ferguson, J. F., A. H. Cogbill, and R. G. Warren. 1994. "A Geophysical-Geologic Transect of the Silent Canyon Caldera Complex, Pahute Mesa, Nevada." In *Journal of Geophysical Research,* v. 99, n. 33, pp. 4,323-4,339.

Fridrich, C. J., U.S. Geological Survey. 1999. Personal communication to L. B. Prothro, Bechtel Nevada, concerning geologic structures in Oasis Valley, Nevada.

Grauch, V. J. S., D. A. Sawyer, C. J. Fridrich, and M. R. Hudson. 1997. *Geophysical Interpretations West of and Within the Northwestern Part of the Nevada Test Site.* U. S. Geological Survey Open-File Report 97-476. Denver, CO.

Hildenbrand, T. G., V. E. Langenheim, E. A. Mankinen, and E. H. McKee. 1999. *Inversion of Gravity Data to Define the Pre-Tertiary Surface and Regional Structures Possibly Influencing Ground-Water Flow in the Pahute Mesa - Oasis Valley Region, Nye County, Nevada*. U. S. Geological Survey Open-File Report 99-49. Menlo Park, CA.

IT, see IT Corporation.

IT Corporation. 1998. *Western Pahute Mesa - Oasis Valley Hydrogeologic Investigation Wells Drilling and Completion Criteria*, ITLV/13052-049. Prepared for DOE/NV. Las Vegas, NV.

IT Corporation, 1999. Written communication prepared for DOE/NV. Subject: "Western Pahute Mesa - Oasis Valley ER-EC-4 Well Data Report." September. Las Vegas, NV.

Mankinen, E. A., T. G. Hildenbrand, G. L. Dixon, E. H. McKee, C. J. Fridrich, and R. J. Laczniak. 1999. *Gravity and Magnetic Study of the Pahute Mesa and Oasis Valley Region, Nye County, Nevada*, U. S. Geological Survey Open-File Report 99-303. Menlo Park, CA.

Noble, D. C., S. I. Weiss, and E. H. McKee. 1991. "Magmatic and Hydrothermal Activity, Caldera Geology, and Regional Extension in the Western Part of the Southwestern Nevada Volcanic Field." In Raines, G. L., R. E. Lisle, R. W. Schaefer, and W. H. Wilkinson, eds., *Geology and Ore Deposits of the Great Basin: Symposium Proceedings*, Geological Society of Nevada, pp. 913-934. Reno, NV.

Sawyer, D. A., J. J. Fleck, M. A. Lanphere, R. G. Warren, and D. E. Broxton. 1994. "Episodic Caldera Volcanism in the Miocene Southwest Nevada Volcanic Field: Revised Stratigraphic Caldera Framework, $^{40}Ar/^{39}Ar$ Geochronology, and Implications for Magmatism and Extension." *Geological Society of America Bulletin*, v. 67, n. 10, pp. 1,304-1,318.

U.S. Department of Energy. 1996a. Attachment 1, "Fluid Management Plan for the Underground Test Area Subproject." In *Underground Test Area Subproject Waste Management Plan,* Revision 1, DOE/NV--343. Las Vegas, NV.

U.S. Department of Energy. 1996b. *Underground Test Area Subproject Waste Management Plan,* Rev. 1, DOE/NV--343. Las Vegas, NV.

U.S. Department of Energy. 1998. *Nevada Environmental Restoration Project Health and Safety Plan*, Revision 3, February 1998. Las Vegas, NV.

U.S. Department of Energy. 2000a. *Completion Report for Well ER-EC-6*, DOE/NV/11718--360. Las Vegas, NV.

U.S. Department of Energy. 2000b. *Completion Report for Well ER-EC-1*, DOE/NV/11718--381. Las Vegas, NV.

Wahl, R. R., D. A. Sawyer, M. D. Carr, S. A. Minor, J. C. Cole, WC Swadley, R. J. Laczniak, R. G. Warren, K. S. Green, and C. M. Engle. 1997. Digital Geologic Map of the Nevada Test Site Area, Nevada. U. S. Geological Survey Open-File Report 97-140, scale, 1:120,000. Denver, CO.

Warren, R. G. 1994. Written communication to Ed Price, GeoTrans, Las Vegas, NV. Subject: "Structural Elements and Hydrogeologic Units of the Southwestern Nevada Volcanic Field," Attachment to Los Alamos National Laboratory letter, May 1994. 19 pp., 4 figures, structural block model map, 2 cross sections.

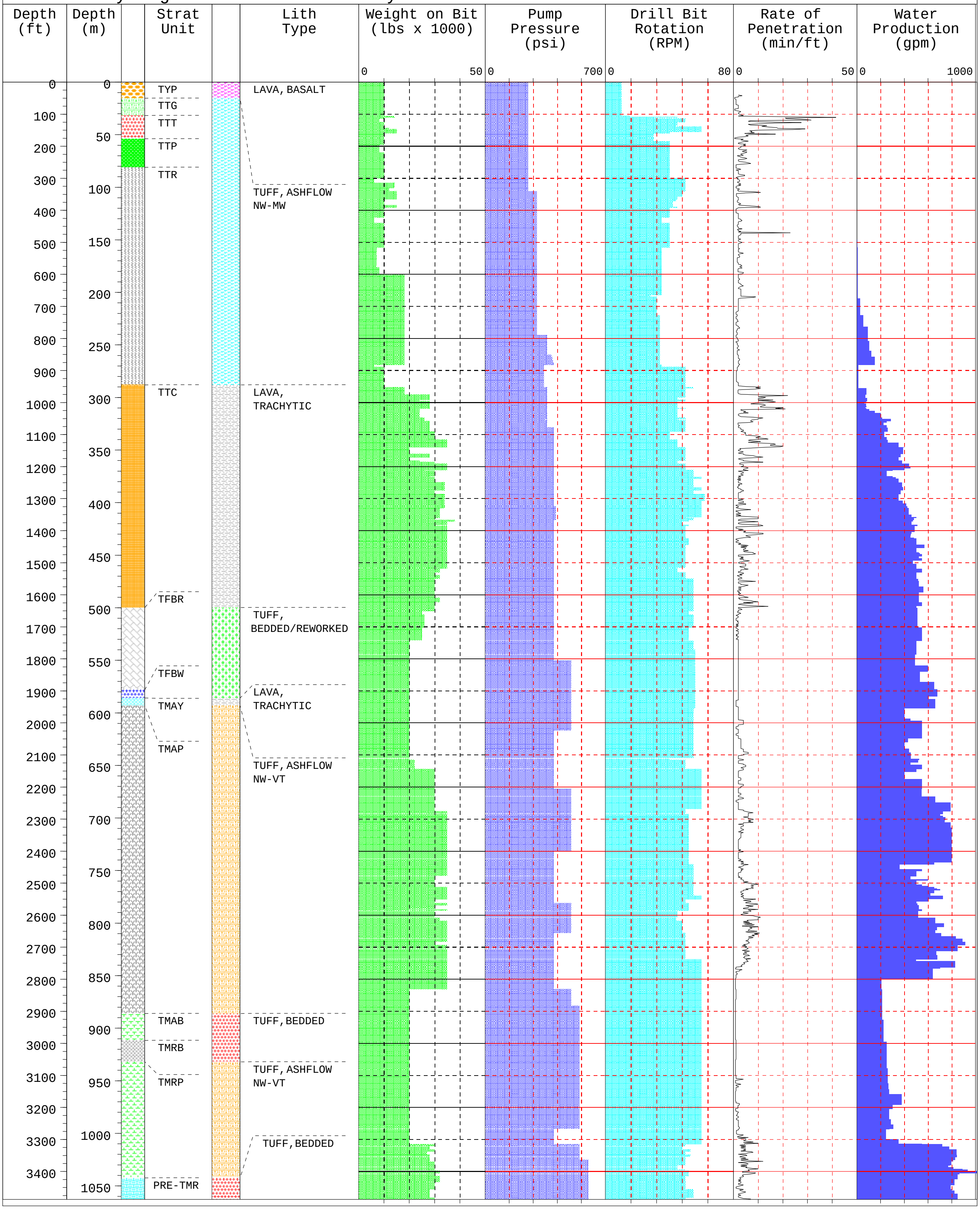
Warren, R. G., F. M. Byers, Jr., D. E. Broxton, S. H. Freeman, and R. C. Hagan. 1989. "Phenocryst Abundances and Glass and Phenocryst Compositions as Indicators of Magmatic Environments of Large-Volume Ash Flow Sheets in Southwestern Nevada." *Journal of Geophysical Research*, v. 94, n. B5, pp. 5,987-6,020.

Appendix A
Drilling Data

Appendix A-1
Drilling Parameter Logs for Well ER-EC-4

Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program	Northing: 4112552.8
Date: 11/23/99	Start Date: 5/26/99 / Stop Date: 6/20/99	Easting: 532679.2
Environmental Contractor: UGTA/IT	Proj No: 776706.02.08.05.02	Surface Elevation: 4759.6
Drilling Contractor: United	Drilling Method: Air Foam / Geol: J. Wurtz	Depth: 3487 ft.

Preliminary Log for Information Only



This page intentionally left blank.

Appendix A-2
Casing Data for Well ER-EC-4

Casing Data for Well ER-EC-4

Casing	**Depth Interval** meters (feet)	Type	Grade	**Outside Diameter** centimeters (inches)	**Inside Diameter** centimeters (inches)	**Wall Thickness** centimeters (inches)	**Weight per foot** (pounds)
36-inch Conductor Casing	0 to 5.3 (0 to 17.5)	Carbon Steel PE Weld	N/A	91.44 (36)	88.9 (35.0)	1.27 (0.500)	190
20-inch Conductor Casing	0 to 11.0 (0 to 36.0)	Carbon Steel	K55	50.80 (20)	48.575 19.124	1.113 (0.438)	94
Surface Casing	0 to 263.7 (0 to 865.0)	Carbon Steel	K5	33.97 (13.375)	32.042 (12.615)	0.965 (0.380)	54.5
Completion Casing (with cross-over)	0 to 289.2 (0 to 948.7)	Carbon Steel with internal epoxy coating	N80	19.37 (7.625)	17.701 (6.969)	0.833 (0.328)	26.4
Completion Casing	289.2 to 1,050.6 (948.7 to 3,447.0)	Stainless Steel	T304L	13.97 (5.5)	12.819 (5.047)	0.577 (0.227)	14.6

This page intentionally left blank.

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

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

Typical Air-Foam/Polymer Mix [a]
8 to 28 liters (2 - 7 gallons) Acrylafoam®[b] and 4 to 11 liters (1 - 3 gallons) Acrylavis ®[b] per 7,949 liters (50 barrels) water

a Air and water with polymer additive was used to drill the conductor hole from the depth of approximately 7.0 to 11.6 meters (23 to 38 feet). During air-foam drilling below approximately 11.6 meters (38 feet), various proportions of polymer were added to suit conditions.

b Acrylafoam® foaming agent and Acrylavis® polymer additive are products of Enterprise Drilling Fluids, Inc.

NOTES:
1. All water used to mix drilling fluids for Well ER-EC-4 came from the spring-fed pond located on Boiling Pot Road just outside the Nellis Air Force Range.
2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of 17 to 27 milligrams per liter.

Table A-3-2
Well ER-EC-4 Cement Composition

Cement Composition	36-in.[a] Conductor Casing	20-in. Conductor Casing	13 d -in. Surface Casing	Completion
Native material	0 to 5.3 m [b] (0 to 17.5 ft [c])	Not used	Not used	Not used
Type II plus 25 percent sand	Not used	Not used	Above cement baskets 19.2 to 20.4 m (63 to 67 ft)	Not used
Type II neat	Not used	0 to 11.0 (0 to 36)	0 to 19.2 m (0 to 63 ft) 146.9 [d] to 268.8 m (482 [d] to 882 ft)	165.2 to 290.2 m (542 to 952 ft) 378.0 to 421.2 m (1,240 to 1,382 ft) 515.7 to 559.9 m (1,692 to 1,837 ft) 699.8 to 744.6 m (2,296 to 2,443 ft) 884.2 to 923.8 (2,901 to 3,031)

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

This page intentionally left blank.

Appendix B
Well ER-EC-4 Fluid Management Data

Fluid Disposition Reporting Form for ER-EC-4

Site Identification: ER-EC-4
Site Location: Nellis Air Force Range
Site Coordinates: N: 4,112,561.3; E: 532,683.1 (UTM, Zone 11, NAD 83, meters)
Well Classification: ER Hydrogeologic Investigation Well
Project Number: 776706.02.08.05

Report Date: 11/23/1999
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	5/25/99	6/01/99	5.5	228.3	496	43.8	149.6	9.3	48.3		NA	YES
Phase I: Saturated-Zone Drilling	6/01/99	6/20/99	18.5	1063.1	1231	81.3	960.3	23.4	1,445.6	14,568	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:			24		1,727	125.1	1,109.9	32.7	1493.9	14,568	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 from 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: Sump #1 = 1,653 m^3 Sump #2 = 1,571 m^3
Infiltration Area (assuming very low/no infiltration) = NA m^3

Remaining Facility Capacity (Approximate) as of 6/20/99: Sump #1 = 587 m^3 (36%) Sump #2 = 1,269 m^3 (81%)
Current Average Tritium = (Natural Background) pCi/L

IT Authorizing Signature/Date: [signature] 11-23-99

Preliminary Analytical Results for Fluid Management Samples: Well ER-EC-4

Sample Number	Date & Time Collected	Comment		RCRA Metals (mg/L)								Gross Alpha (pCi/L)	Gross Beta (pCi/L)	Tritium (pCi/L)
				Arsenic	Barium	Cadmium	Chromium	Lead	Selenium	Silver	Mercury			
EC-4-06019-1	06/01/1999 11:45	Sample taken from unlined Sump #1	Total [a]	0.0641	B 0.0616	U 0.0002	0.0166	0.486	0.0125	U 0.0005	U 0.00002	N/Anl	N/Anl	N/Anl
			Dissolved [b]	0.0244	B 0.0121	U 0.0002	B 0.0072	0.121	0.0152	U 0.0005	U 0.00002	25.2	12.7	U 169
EC-4-06049-1	06/06/1999 16:05	Sample taken from unlined Sump #1	Total	0.03	B 0.0368	U 0.0002	0.0107	0.198	0.0113	U 0.0005	U 0.00002	N/Anl	N/Anl	N/Anl
			Dissolved	0.0122	B 0.004	U 0.0002	B 0.005	0.0173	0.023	U 0.0005	U 0.00002	N/Anl	N/Anl	N/Anl
EC-4-06069-1	06/06/1999 01:00	Sample taken from unlined Sump #1	Total	B 0.0049	B 0.032	U 0.0002	B 0.0015	U 0.0009	U 0.002	U 0.0005	U 0.00002	N/Anl	N/Anl	N/Anl
			Dissolved	B 0.0023	B 0.0029	U 0.0002	U 0.0004	U 0.0009	0.013	U 0.0005	U 0.00002	7.05	8.31	U -5.85
EC-4-06069-2	06/06/1999 03:15	Sample taken from unlined Sump #1	Total	B 0.0078	B 0.0392	U 0.0002	B 0.0019	U 0.0009	0.0083	U 0.0005	U 0.00002	N/Anl	N/Anl	N/Anl
			Dissolved	B 0.0059	B 0.0041	U 0.0002	B 0.0004	U 0.0009	0.0138	U 0.0005	U 0.00002	14.8	16.5	U 170
EC-4-06079-1	06/07/1999 09:20	Sample taken from unlined Sump #2	Total	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl
			Dissolved	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	N/Anl	7.32	15.1	U -9.9
EC-4-06139-1	06/18/1999 15:10	Sample taken from unlined Sump #1	Total	0.0183	B 0.0157	U 0.0002	B 0.0052	0.0036	U 0.0002	U 0.0005	U 0.00002	N/Anl	N/Anl	N/Anl
			Dissolved	0.0188	0.166	U 0.0002	B 0.0014	U 0.0009	B 0.0024	U 0.0005	U 0.00002	9.41	5.43	U 255
EC-4-06189-1	06/18/1999 09:10	Sample taken from unlined Sump #2	Total	B 0.0082	B 0.0586	U 0.0002	0.0168	B 0.0018	U 0.002	U 0.0005	U 0.00002	N/Anl	N/Anl	N/Anl
			Dissolved	B 0.0053	0.221	U 0.0002	0.0161	U 0.0009	U 0.002	U 0.0005	U 0.00002	6.57	8.50	U -49.8
Contract-Required Detection Limit				0.01	0.1	0.005	0.01	0.003	0.005	0.01	0.0002	N/A	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

a Initial analysis for total RCRA metals.
b Analysis of dissolved RCRA metals on a resubmitted sample fraction, filtered by Paragon Analytics.

Data provided by IT (written communication, 1999)

Analysis of metals by Paragon Analytics, Inc.; analysis of radionuclides by Bechtel Nevada

RCRA = Resource Conservation and Recovery Act of 1976
N/Anl = not analyzed   N/A = Not applicable
mg/L = milligrams per liter   pCi/L = picocuries per liter
B = Result less than CRDL, but greater than the IDL
U = Result less the IDL
CRDL = Contract-Required Detection Limit
IDL = Instrument Detection Limit

Appendix C
Preliminary Detailed Lithologic Log for Well ER-EC-4

Preliminary Detailed Lithologic Log for Well ER-EC-4
Logged by Lance Prothro, Bechtel Nevada
October 20, 1999

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
0 - 15.2 (0 - 50)	15.2 (50)	DA (No samples above 9.1 m [30 ft])	None	**Basalt:** Grayish-black (N2); aphanitic; very abundant felsic crystals; abundant moderate-yellow (5Y 7/6) and dark yellowish-orange (10YR 6/6) olivine crystals.	Pliocene basalts
15.2 - 25.9 (50 - 85)	10.7 (35)	DA	None	**Moderately Welded Ash-Flow Tuff:** Light olive-gray (5Y 5/2); devitrified; minor pale reddish-brown (10R 5/4) and grayish-orange-pink (5YR 7/2) pumice; common feldspar phenocrysts; common mafic minerals of dark pyroxene and olivine; rare lithic fragments.	Gold Flat Tuff
25.9 - 31.7 (85 - 104)	5.8 (19)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Bedded Tuff:** Dark yellowish-orange (10YR 6/6) and pale yellowish-orange (10YR 8/6); vitric; very abundant pale yellowish-orange (10YR 8/6) pumice; rare feldspar phenocrysts; rare to minor mafic minerals of olivine and dark pyroxene; rare lithic fragments.	
31.7 - 50.3 (104 - 165)	18.6 (61)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Dusky brown (5YR 2/2), becoming mottled grayish brown (5YR 3/2) and dusky yellowish-brown (10YR 2/2) at base of interval; devitrified, becoming partially vitric at base of interval; minor dusky yellowish-brown (10YR 2/2) scoriaceous pumice; common feldspar phenocrysts; rare dark olivine; no lithic fragments.	Trail Ridge Tuff
50.3 - 53.9 (165 - 177)	3.7 (12)	DA	None	**Bedded Tuff:** Very pale orange (10YR 8/2); vitric; very abundant very-pale-orange (10YR 8/2) pumice; rare feldspar phenocrysts; rare mafic minerals of biotite and clinopyroxene.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
53.9 - 67.4 (177 - 221)	13.4 (44)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Partially Welded Ash-Flow Tuff:** Dusky yellowish-brown (10YR 2/2); devitrified, with strong vapor-phase mineralization; minor dusky-brown (5YR 2/2) scoriaceous pumice; abundant feldspar phenocrysts; rare olivine; rare lithic fragments.	Pahute Mesa Tuff
67.4 - 81.1 (221 - 266)	13.7 (45)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Dusky yellowish brown (10YR 2/2); devitrified; minor brownish-black (5YR 2/1) scoriaceous pumice; common feldspar phenocrysts; minor mafic minerals of clinopyroxene and olivine; rare lithic fragments; calcite fills some open spaces.	
81.1 - 103.6 (266 - 340)	22.6 (74)	DB1	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Ash-Flow Tuff:** Dark yellowish-brown (10YR 4/2); mostly devitrified, with moderate vapor-phase mineralization; partially vitric; minor light-brown (5YR 5/6) pumice; minor feldspar phenocrysts; rare olivine; common medium-dark-gray (N4) lithic fragments of lava.	Rocket Wash Tuff
103.6 - 125.6 (340 - 412)	21.9 (72)	DB1	None	**Bedded and Nonwelded Tuff:** Moderate brown (5YR 4/4); devitrified, with moderate to strong vapor-phase mineralization; common feldspar phenocrysts including chatoyant sanidine; rare olivine; common to abundant medium-dark-gray (N4) lithic fragments of lava.	
125.6 - 142.6 (412 - 468)	17.1 (56)	DB1	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded to Partially Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4); devitrified, with weak to moderate vapor-phase mineralization; minor light-brown (5YR 5/6) pumice; common feldspar phenocrysts, including chatoyant sanidine; minor olivine; abundant medium-dark-gray (N4) lithic fragments of devitrified and silicic lava.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
142.6 - 153.0 (468 - 502)	10.4 (34)	DA	None	**Partially Welded to Moderately Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4); devitrified, with weak to moderate vapor-phase mineralization; minor light-brown (5YR 5/6) pumice; common feldspar phenocrysts, including chatoyant sanidine; minor olivine; abundant medium-dark-gray (N4) lithic fragments of devitrified and silicic lava.	Rocket Wash Tuff
153.0 - 187.5 (502 - 615)	34.4 (113)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Ash-Flow Tuff:** Pale yellowish-brown (10YR 6/2); devitrified, with moderate vapor-phase mineralization; minor moderate-brown (5YR 3/4) pumice; common feldspar phenocrysts; minor mafic minerals of olivine and dark pyroxene; abundant lithic fragments of medium-dark-gray (N4) to dark-gray (N3) lava containing rare feldspar phenocrysts and rare biotite.	
187.5 - 200.6 (615 - 658)	13.1 (43)	DA	None	**Partially Welded Ash-Flow Tuff:** Pale yellowish-brown (10YR 6/2); devitrified, with moderate vapor-phase mineralization; minor moderate-brown (5YR 3/4) pumice; common feldspar phenocrysts; minor mafic minerals of olivine and dark pyroxene; abundant lithic fragments of medium-dark-gray (N4) to dark-gray (N3) lava containing rare feldspar phenocrysts and rare biotite.	
200.6 - 207.3 (658 - 680)	6.7 (22)	DA	None	**Moderately Welded Ash-Flow Tuff:** Pale yellowish-brown (10YR 6/2); devitrified, with moderate vapor-phase mineralization; minor moderate-brown (5YR 3/4) pumice; common feldspar phenocrysts; minor mafic minerals of olivine and dark pyroxene; abundant grayish-red (10R 4/2) and very dusky-red (10R 2/2) lithic fragments.	
207.3 - 213.4 (680 - 700)	6.1 (20)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Partially to Moderately Welded Ash-Flow Tuff:** Moderate brown (5YR 3/4); devitrified; common moderate-reddish-brown (10R 4/6) pumice; common feldspar phenocrysts; minor olivine; minor lithic fragments.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
213.4 - 228.6 (700 - 750)	15.2 (50)	DA	None	**Bedded Tuff:** Mostly moderate brown (5YR 4/4), lesser moderate reddish brown (10R 4/6) and olive gray (5Y 4/1); devitrified, with weak to moderate vapor-phase mineralization; minor to common pumice; rare to common feldspar phenocrysts; minor mafic minerals of olivine and lesser dark pyroxene; rare to minor lithic fragments.	Rocket Wash Tuff
228.6 - 234.7 (750 - 770)	6.1 (20)	DA	None	**Partially Welded Ash-Flow Tuff:** Dark yellowish-brown (10YR 4/2); devitrified, with strong vapor-phase mineralization; rare light-brown (5YR 5/6) pumice; rare feldspar phenocrysts, trace of quartz; rare mafic minerals of olivine, pseudomorphs after clinopyroxene, and a trace of biotite; rare lithic fragments.	
234.7 - 240.8 (770 - 790)	6.1 (20)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Dark yellowish-brown (10YR 4/2); devitrified, with strong vapor-phase mineralization; rare light-brown (5YR 5/6) pumice; rare feldspar phenocrysts, trace of quartz; rare mafic minerals of olivine, pseudomorphs after clinopyroxene, and a trace of biotite; rare lithic fragments.	
240.8 - 245.4 (790 - 805)	4.6 (15)	DA	None	**Nonwelded Ash-Flow Tuff:** Pale yellowish-brown (10YR 6/2); devitrified, with strong vapor-phase mineralization; minor dark-yellowish-orange (10YR 6/6) pumice; rare to minor feldspar phenocrysts; rare olivine and pseudomorphs after clinopyroxene; minor pale-red (10R 6/2) lithic fragments.	
245.4 - 262.1 (805 - 860)	16.8 (55)	DA	None	**Nonwelded Ash-Flow Tuff:** Moderate brown (5YR 4/4); devitrified, with moderate vapor-phase mineralization; common moderate-brown (5YR 3/4) pumice; abundant feldspar phenocrysts; rare olivine, trace biotite; common mostly grayish-red (5R 4/2) lithic fragments.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type [a]	Laboratory Analyses [b]	Lithologic Description [c]	Stratigraphic Unit
262.1 - 285.0 (860 - 935)	22.9 (75)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Partially Welded Ash-Flow Tuff:** Moderate yellowish-brown (10YR 5/4); mostly devitrified, partially vitric; abundant moderate-yellowish-brown (10YR 5/4) mostly recrystallized pumice; minor feldspar phenocrysts; minor mafic minerals of olivine and lesser pseudomorphs after clinopyroxene; common mostly grayish-brown (5YR 3/2) lithic fragments.	Rocket Wash Tuff
285.0 - 288.0 (935 - 945)	3.0 (10)	DA, SC	None	**Colluvium:** Dusky-brown (5YR 2/2) clasts of dense, devitrified, vesicular, trachytic(?) lava in a moderate-yellowish-brown (10YR 5/4), tuffaceous, sandy matrix.	
288.0 - 311.5 (945 - 1,022)	23.5 (77)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Lava (Trachytic?):** Brownish-black (5YR 2/1) vesicular lava at top of interval, grading to black (N1) massive lava lower; devitrified; porphyritic; very abundant felsic crystals as tiny lath-shaped plagioclase and large (up to 5 mm) phenocrysts of sanidine and plagioclase; mafic minerals include common olivine and a trace of biotite; vesicles are partially to completely filled with mostly massive and crystalline zeolite and lesser calcite.	trachyte of Ribbon Cliff
311.5 - 324.9 (1,022 - 1,066)	13.4 (44)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Lava (Trachytic?):** Dusky-brown (5YR 2/2) and dark-yellowish-orange (10YR 4/2) vesicular lava at top of interval, grading to mostly brownish-black (5YR 2/1) and lesser very-dusky-red (10R 2/2) massive lava lower; devitrified; mostly aphanitic, weakly porphyritic; very rare feldspar phenocrysts (predominantly sanidine); minor to common mafic minerals of olivine and dark pyroxene.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type [a]	Laboratory Analyses [b]	Lithologic Description [c]	Stratigraphic Unit
324.9 - 348.1 (1,066 - 1,142)	23.2 (76)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Lava (Trachytic?):** Dusky brown (5YR 2/2) and moderate-brown (5YR 3/4) vesicular lava at top of interval, grading to mostly brownish-black (5YR 2/1) and lesser grayish-brown (5YR 3/2) massive lava lower; devitrified; mostly aphanitic, weakly to moderately porphyritic; abundant felsic crystals including tiny lath-shaped plagioclase and rare to minor phenocrysts of mostly sanidine and lesser plagioclase; common mafic minerals of olivine, clinopyroxene, and much less biotite; tiny prismatic to lath-shaped, moderate-yellowish-brown (10YR 5/4) crystals are conspicuously present throughout, including open spaces, suggesting a diagenetic/hydrothermal origin. Vesicles are partially to completely filled with mostly zeolite, including massive noncrystalline chalky material, white (N9) tufts of radiating acicular crystals, and soft transparent tabular crystals; and lesser calcite and quartz. Also present in vesicles and associated with the chalky massive zeolite are prismatic to lath-shaped crystals described above and small grayish-orange (10YR 7/4), translucent platy crystals resembling mica.	trachyte of Ribbon Cliff
348.1 - 362.7 (1,142 - 1,190)	14.6 (48)	DA	None	**Lava (Trachytic?):** Brownish-black (5YR 2/1) vesicular lava at top of interval, grading to very-dusky-red (10R 2/2) and brownish-black (5YR 2/1) massive lava lower; devitrified; mostly aphanitic, very weakly porphyritic; abundant tiny feldspar crystals and very rare felsic phenocrysts of sanidine and lath-shaped plagioclase; minor mafic minerals of olivine and lesser clinopyroxene; pervasive iron-oxide staining; vesicles are partially to completely filled white (N9) massive zeolite and thin platy crystals resembling mica. A thin veneer of light-brown (5YR 5/6) reworked tuff containing quartz and substantial biotite appears to overlie the lava. Geophysical logs indicate that the lower 4.9 m (16 ft) of this interval is probably a separate flow.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
362.7 - 366.4 (1,190 - 1,202)	3.7 (12)	DA	None	**Paleocolluvium:** Very abundant, angular clasts of trachytic(?) lava in a moderate-yellowish-brown (10YR 5/4) to dark-yellowish-brown (10YR 4/2), zeolitic matrix containing common tiny felsic crystals and minor biotite.	trachyte of Ribbon Cliff
366.4 - 393.2 (1,202 - 1,290)	26.8 (88)	DA	None	**Lava (Trachytic?):** Mostly dusky-brown (5YR 2/2) vesicular lava above 387.1 m (1,270 ft), becoming brownish-black (5YR 2/1) massive lava below; devitrified; mostly aphanitc, weakly porphyritic; very abundant felsic crystals including tiny lath-shaped plagioclase, very rare feldspar phenocrysts; rare black (N1) olivine and lesser moderate-brown (5YR 3/4) altered pyroxene; white (N9) zeolite fills most vesicles. Geophysical logs indicate interval is probably composed of several individual flows.	
393.2 - 401.7 (1,290 - 1,318)	8.5 (28)	DA, SC	None	**Lava (Trachytic?):** Dusky-brown (5YR 2/2) vesicular lava above 398.1 m (1,306 ft), becoming greenish-black (5GY 2/1) massive lava below 398.1 m (1,306 ft); quartzo-feldspathic above 398.1 m (1,306 ft), devitrified below; porphyritic; rare to minor felsic phenocrysts of sanidine and plagioclase; minor olivine; vesicles filled with white (N9) zeolite. Approximately 1.2 m (4 ft) of grayish-orange (10YR 7/4) partially vitric, partially zeolitic bedded tuff containing quartz and biotite overlies the lava.	
401.7 - 407.8 (1,318 - 1,338)	6.1 (20)	DA	None	**Lava (Trachytic?):** Brownish-black (5YR 2/1); devitrified; massive; very abundant felsic crystals; minor olivine and pyroxene. Approximately 0.9 m (3 ft) of moderate-reddish-brown (10R 4/6) and moderate-reddish-orange (10 6/6) bedded tuff overlies the lava.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
407.8 - 434.6 (1,338 - 1,426)	26.8 (88)	DA	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Lava (Trachytic?):** Mostly black (N1) to greenish-black (5G 2/1), lesser dark reddish-brown (10R 3/4); mostly massive, vesicular from 407.8 to 412.7 m (1,338 to 1,354 ft), weakly vesicular from 418.8 to 420.0 m (1,374 to 1,380 ft) and from 423.1 to 426.1 m (1,388 to 1,398 ft); devitrified; mostly aphanitic, weakly porphyritic; very abundant tiny felsic crystals including lath-shaped plagioclase; rare feldspar phenocrysts; minor olivine, trace dark pyroxene. Vesicular intervals probably represent tops of individual flows.	trachyte of Ribbon Cliff
434.6 - 449.9 (1,426 - 1,476)	15.2 (50)	DA	None	**Lava (Trachytic?):** Brownish-black (5YR 2/1) vesicular lava at top of interval, grading to very-dusky-red (10R 2/2) iron-oxide stained and black (N1) massive lava lower; devitrified; aphanitic; abundant tiny felsic crystals including lath-shaped plagioclase; minor biotite; vesicles partially to completely filled with quartz, calcite, and zeolite.	
449.9 - 499.9 (1,476 - 1,640)	50.0 (164)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Lava (Trachytic?):** Very dusky-red (10R 2/2) and black (N1), lesser dark-reddish-brown (10R 3/4); devitrified and quartzo-feldspathic; mostly vesicular, lesser massive; mostly aphanitic, very weakly porphyritic; abundant tiny felsic crystals, including lath-shaped plagioclase and pseudomorphs after plagioclase phenocrysts; minor to common olivine, trace of biotite; vesicles partially to completely filled with quartz, calcite, and zeolite. Interval is probably composed of several individual flows.	
499.9 - 504.4 (1,640 - 1,655)	4.6 (15)	DA	None	**Reworked Tuff:** Moderate brown (5YR 4/4) to moderate yellowish-brown (10YR 5/4); quartzo-feldspathic, with substantial zeolite; medium-grained; moderately sorted; moderately indurated; composed of felsic crystals including quartz, volcanic lithic fragments, pumice fragments, biotite flakes, and fine ash.	rhyolite of Chukar Canyon

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
504.4 - 518.8 (1,655 - 1,702)	14.3 (47)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Bedded Tuff:** Moderate yellowish-brown (10YR 5/4), lesser pale yellowish-green (10Y 8/2); mostly zeolitic, partially vitric in upper portion, becoming completely zeolitic lower; common to abundant very-pale-orange (10YR 8/2) and moderate-greenish-yellow (10Y 7/4) pumice; minor to common felsic phenocrysts of feldspar and much less quartz; abundant mafic minerals of biotite, hornblende, and lesser clinopyroxene, no sphene observed; rare lithic fragments in upper portion, becoming more lithic-rich lower. Interval includes some reworked tuffs.	rhyolite of Chukar Canyon
518.8 - 577.9 (1,702 - 1,896)	59.1 (194)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Reworked Tuff:** Mostly moderate yellowish-brown (10YR 5/4), lesser moderate brown (5YR 4/4); zeolitic, weakly calcareous; medium grained; moderately sorted; minor to common very-pale-orange (10YR 8/2) pumice; common felsic phenocrysts of frosted feldspar and quartz; common to abundant mafic minerals of biotite, lesser hornblende and clinopyroxene; common lithic fragments.	
577.9 - 585.8 (1,896 - 1,922)	7.9 (26)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Bedded Tuff:** Pale yellowish-brown (10YR 6/2), very pale orange (10YR 8/2), and grayish-yellow (5Y 8/4); strongly zeolitic; rare to common pumice; minor feldspar phenocrysts; common to abundant mafic minerals of biotite, lesser hornblende, and conspicuous sphene.	rhyolite of Beatty Wash
585.8 - 589.5 (1,922 -1,934)	3.7 (12)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Lava (Trachytic?):** Dusky yellowish-brown (10YR 2/2); devitrified; porphyritic; vesicular; abundant tiny felsic crystals include lath-shaped plagioclase; rare feldspar phenocrysts; minor olivine; vesicles filled with white (N9) and moderate-yellow (5Y 7/6) zeolite.	trachyte of East Cat Canyon

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
589.5 - 593.1 (1,934 - 1,946)	3.7 (12)	DA	None	**Bedded Tuff:** Moderate brown (5YR 4/4); quartzo-feldspathic with substantial zeolite; well indurated; minor to common very-pale-orange (10YR 8/2) and pale-greenish-yellow (10Y 8/2) pumice; abundant felsic phenocrysts of feldspar and much less quartz; very abundant mafic minerals of biotite and clinopyroxene; minor lithic fragments.	trachyte of East Cat Canyon
593.1 - 605.3 (1,946 - 1,986)	12.2 (40)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Nonwelded Ash-Flow Tuff:** Moderate brown (5YR 3/4); quartzo-feldspathic; weakly scoriaceous; minor to common dark-reddish-brown (10R 3/4) scoriaceous and pale-yellowish-orange (10YR 8/6) pumice; abundant felsic phenocrysts of quartz and feldspar, including weakly to moderately altered plagioclase; very abundant biotite; trace lithic fragments.	mafic-poor Ammonia Tanks Tuff
605.3 - 611.4 (1,986 - 2,006)	6.1 (20)	DA, SC	None	**Partially Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4); quartzo-feldspathic; common dark-reddish-brown (10R 3/4) scoriaceous and very-pale-orange (10YR 8/2) pumice; common felsic phenocrysts of quartz and feldspar, including chatoyant sanidine and partially altered plagioclase; common mafic minerals of biotite, including many with a bronze color, and lesser partially altered clinopyroxene; rare lithic fragments.	
611.4 - 624.2 (2,006 - 2,048)	12.8 (42)	DA	None	**Moderately Welded Ash-Flow Tuff:** Light brownish-gray (5YR 6/1); quartzo-feldspathic; pumice difficult to discern due to alteration but appears to be minor to common in abundance and very light gray (N8) in color; common felsic phenocrysts of quartz and feldspar, including chatoyant sanidine and strongly altered plagioclase; minor bronze-colored biotite; rare lithic fragments.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
624.2 - 671.8 (2,048 - 2,204)	47.5 (156)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Brownish gray (5YR 4/1); quartzo-feldspathic with substantial silicification from 634.0 to 638.3 m (2,080 to 2,094 ft); pumice difficult to discern due to alteration but appears to be minor in abundance and white (N9) in color; common felsic phenocrysts of quartz and feldspar, including chatoyant sanidine and strongly altered plagioclase; minor bronze-colored biotite, sphene is present; rare lithic fragments; slickensided fragments present in samples at approximately 640.1 m (2,100 ft).	mafic-poor Ammonia Tanks Tuff
671.8 - 680.9 (2,204 - 2,234)	9.1 (30)	DA	None	**Moderately Welded Ash-Flow Tuff:** Grayish-red (10R 4/2); quartzo-feldspathic; common very-light-gray (N8) pumice; minor felsic phenocrysts of quartz and feldspar, including partially altered plagioclase; minor bronze-colored biotite and pseudomorphs after biotite; rare lithic fragments; slickensided fragments are present in samples throughout interval.	
680.9 - 705.3 (2,234 - 2,314)	24.4 (80)	DA, SC	None	**Moderately Welded Ash-Flow Tuff:** Pale brown (5YR 5/2) in upper portion, becoming grayish-brown (5YR 3/2) lower; quartzo-feldspathic with substantial silicification below 691.1 m (2,270 ft); pumice not discernable due to alteration; common felsic phenocrysts of quartz and feldspar including partially altered plagioclase; minor strongly altered biotite and pseudomorphs after biotite, lesser bronze-colored biotite; rare lithic fragments.	
705.3 - 778.8 (2,314 - 2,555)	73.5 (241)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4) to dark yellowish-brown (10YR 4/2); mostly devitrified, partially silicic from 737.6 to 749.8 m (2,420 to 2,460 ft), strongly silicic from 762.6 to 766.9 m (2,502 to 2,516 ft); abundant dark-yellowish-orange (10YR 6/6), very-light-gray (N8), and pale-yellowish-brown (10YR 6/2) pumice; common felsic phenocrysts of quartz and feldspar, including chatoyant sanidine; minor biotite, trace of clinopyroxene, sphene is present; minor lithic fragments.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
778.8 - 793.7 (2,555 - 2,604)	14.9 (49)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Densely Welded to Vitrophyric Ash-Flow Tuff:** Brownish-black (5YR 2/1) to black (N1); mostly devitrified, partially vitric to 789.4 m (2,590 ft), becoming mostly vitric, partially devitrified below 789.4 m (2,590 ft); common felsic phenocrysts of quartz and feldspar, including chatoyant sanidine; minor mafic minerals of biotite and much less clinopyroxene and sphene; rare lithic fragments.	mafic-poor Ammonia Tanks Tuff
793.7 - 823.0 (2,604 - 2,700)	29.3 (96)	DA, SC	None	**Moderately Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4), becoming dark yellowish-brown (10YR 4/2) near base of interval; mostly devitrified, weakly silicic above approximately 813.8 m (2,670 ft), becoming moderately silicic below; minor pale red (10R 6/2) devitrified pumice and moderate-brown (5YR 3/4) and grayish-brown (5YR 3/2) silicic strongly flattened pumice; abundant felsic phenocrysts of quartz and feldspar, including chatoyant sanidine; common mafic minerals of biotite and lesser clinopyroxene and sphene; rare to minor lithic fragments.	
823.0 - 829.1 (2,700 - 2,720)	6.1 (20)	DA	None	**Densely Welded to Vitrophyric Ash-Flow Tuff:** Brownish-black (5YR 3/4); devitrified; common felsic phenocrysts of quartz and feldspar, including chatoyant sanidine; common mafic minerals of biotite and lesser clinopyroxene and sphene; rare lithic fragments.	
829.1 - 841.6 (2,720 - 2,761)	12.5 (41)	DA	None	**Moderately Welded Ash-Flow Tuff:** Moderate brown (5YR 3/4) in upper portion, becoming brownish-gray (5YR 4/1) lower; mostly devitrified, partially silicic; minor to common moderate-brown (5YR 3/4), grayish-orange (10YR 7/4), and dark-gray (N3) pumice; common felsic phenocrysts of quartz and feldspar; common mafic minerals of biotite and lesser clinopyroxene (clinopyroxene is more conspicuous than in overlying intervals) and sphene; rare lithic fragments.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
841.6 - 851.6 (2,761 - 2,794)	10.1 (33)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Partially Welded Ash-Flow Tuff:** Moderate yellowish-brown (10YR 5/4) to dark yellowish-brown (10YR 4/2); devitrified; common pale-brown (5YR 5/2) and very-pale-orange (10YR 8/2) pumice; minor felsic phenocrysts of feldspar and quartz; common mafic minerals of biotite and lesser clinopyroxene and sphene; rare lithic fragments.	mafic-poor Ammonia Tanks Tuff
851.6 - 886.1 (2,794 - 2,907)	34.4 (113)	DA, SC	None	**Nonwelded Ash-Flow Tuff:** Light brownish-gray (5YR 6/1); mostly devitrified, partially silicic; common medium-dark-gray (N4) silicic pumice; minor felsic phenocrysts of feldspar and quartz; minor mafic minerals of biotite and lesser clinopyroxene and sphene; rare to minor lithic fragments.	
886.1 - 911.7 (2,907 - 2,991)	25.6 (84)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Bedded Tuff:** Grayish-red (10R 4/2), yellowish-gray (5Y 7/2), and light olive-gray (5Y 6/1); mostly silicic, partially zeolitic at base of interval; minor to common silicic pumice; common felsic phenocrysts of quartz and feldspar; common biotite, sphene is present; minor lithic fragments.	bedded Ammonia Tanks Tuff
911.7 - 920.5 (2,991 - 3,020)	8.8 (29)	DA, SC	None	**Reworked Tuff:** Dark yellowish-brown (10YR 4/2) and very dusky-red (10R 2/2); fine- to medium-grained, sandy texture; moderately sorted; moderately indurated; zeolitic and argillic, weakly calcareous; composed of felsic crystals of feldspar and quartz, tuffaceous lithic fragments, pumice fragments, and flakes of biotite.	bedded Rainier Mesa Tuff
920.5 - 932.1 (3,020 - 3,058)	11.6 (38)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Bedded Tuff:** Moderate brown (5YR 4/4) to moderate reddish-brown (10R 4/6); quartzo-feldspathic, with only minor zeolite, minor opal; rare dark-reddish-brown (10R 3/4) pumice; minor felsic phenocrysts of quartz and feldspar; minor to common biotite; rare lithic fragments.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
932.1 - 946.7 (3,058 - 3,106)	14.6 (48)	DA	None	**Nonwelded Ash-Flow Tuff:** Grayish-red (10R 4/2) and pale brown (5YR 5/2); quartzo-feldspathic, with substantial silicification, minor opal; pumice difficult to discern due to alteration, but appears to be minor in abundance and recrystallized to microcrystalline quartz and lesser opal; common felsic phenocrysts of quartz and feldspar, including sanidine and partially altered plagioclase and pseudomorphs after plagioclase; minor biotite; trace lithic fragments.	mafic-poor Rainier Mesa Tuff
946.7 - 988.8 (3,106 - 3,244)	42.1 (138)	DA, SC	None	**Partially Welded Ash-Flow Tuff:** Pale red (10R 6/2) to grayish-red (10R 4/2); quartzo-feldspathic, with substantial silicification, minor opal; common grayish-orange-pink (10R 8/2) and very-pale-orange (10YR 8/2) pumice, some replaced by microcrystalline quartz and opal; common felsic phenocrysts of quartz and feldspar, including sanidine and partially altered plagioclase and pseudomorphs after plagioclase; minor biotite; trace lithic fragments.	
988.8 - 1,011.9 (3,244 - 3,320)	23.2 (76)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Moderately Welded Ash-Flow Tuff:** Grayish-red (5R 4/2); quartzo-feldspathic; common white (N9) to pale red (5R 6/2) pumice; common felsic phenocrysts of quartz and feldspar, including sanidine and altered plagioclase; minor biotite; trace lithic fragments.	
1,011.9 - 1,018.0 (3,320 - 3,340)	6.1 (20)	DA	None	**Vitrophyric Ash-Flow Tuff:** Mottled black (N1) and moderate brown (5YR 3/4); mostly vitric, partially devitrified; weakly perlitic; abundant felsic phenocrysts of quartz and feldspar; minor biotite.	
1,018.0 - 1,038.1 (3,340 - 3,406)	20.1 (66)	DA, SC	None	**Densely Welded Ash-Flow Tuff:** Dark reddish-brown (10R 3/4) to moderate reddish-brown (10R 4/6); quartzo-feldspathic, with substantial silicification, minor opal and agate; shows flow texture and brecciation; common felsic phenocrysts of quartz and feldspar; rare biotite.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Laboratory Analyses** [b]	**Lithologic Description** [c]	**Stratigraphic Unit**
1,038.1 - 1,042.4 (3,406 - 3,420)	4.3 (14)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Vitrophyric Ash-Flow Tuff:** Black (N1) and dark gray (N3); mostly vitric, partially devitrified; perlitic; common felsic phenocrysts of feldspar and quartz; rare biotite. Geophysical logs show degree of welding decreases abruptly at base of interval.	mafic-poor Rainier Mesa Tuff
1,042.4 - 1,062.8 (3,420 - 3,487) Total Depth	20.4 (67)	DA, SC	TS, MP, XRD, XRF, Fe^{2+}/Fe^{3+}	**Bedded Tuff (?):** Each 3.0 m (10 ft) sample through this interval varies considerably in composition from adjacent samples, and each sample consists of a mixture of volcanic lithologies. Samples at 1,048.5 m (3,440 ft) and 1,060.7 m (3,480 ft) are dominated by very-pale-orange (10YR 8/2) and yellowish-gray (5Y 8/1), mostly zeolitic, lesser silicic nonwelded tuff containing rare to common felsic phenocrysts of feldspar and quartz, and rare to minor biotite. Samples at 1,057.7 m (3,470 ft) and 1,062.8 m (3,487 ft) are dominated by denser and darker-colored fragments that appear more like welded tuff or lava. Because these fragments are angular and have no matrix coatings, they do not appear to be lithic fragments from a tuff. The fragments are quartzo-feldspathic with pervasive silicification, and contain rare to minor felsic phenocrysts of feldspar and quartz, and rare biotite. Drill cuttings sample from 1,051.6 m (3,450 ft) depth contains fragments of moderate-reddish-brown (10R 4/6), quartzo-feldspathic, nonwelded tuff with tiny felsic crystals and biotite. These fragments resemble tuff of Holmes Road.	pre-Rainier Mesa Tuff volcanic rocks

a **DA** = drill cuttings that represent lithologic character of interval; **DB1** = drill cuttings enriched in hard components; **SC** = sidewall core.

b All analyses pending. **TS** = 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 3-2 of this report for additional information.

c 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** = ≤ 1%; **minor** = 5%; **common** = 10%; **abundant** = 15%; **very abundant** = ≥ 20%. Abundances for mafic minerals: **trace** = only one or two individuals observed; **rare** = ≤ 0.05%; **minor** = 0.2%; **common** = 0.5%; **abundant** = 1%; **very abundant** = ≥ 2%.

This page intentionally left blank.

Appendix D
Geophysical Logs Run in Well ER-EC-4

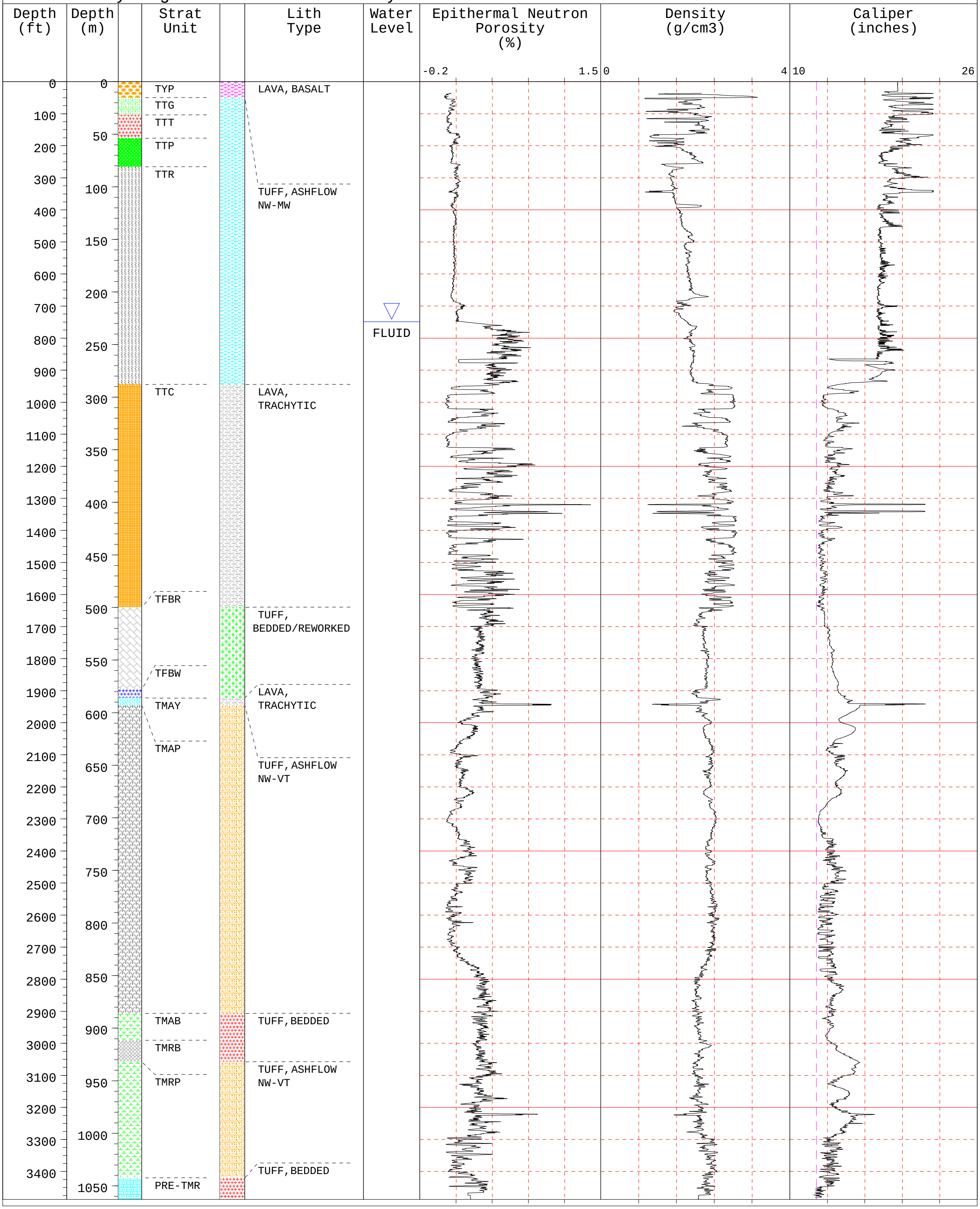
Appendix D contains unprocessed data presentations of selected geophysical logs run in Well ER-EC-4. Table D-1 summarizes the logs presented. See Table 3-3 for more information.

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

Log Type	Run Number	Date	Log Interval meters	feet
Epithermal Neutron	ENP-1 ENP-2	06/03/1999 06/14/1999	11.0 - 267.9 131.1 - 1,058.9	36 - 879 430 - 3,474
Density	CDL-1 CDL-2	06/30/1999 06/14/1999	11.0 - 267.9 131.1 - 1,058.9	36 - 879 430 - 3,474
Array Induction and Dual Laterolog (resistivity)	IND-1 DLL-1	06/03/1999 06/14/1999	11.0 - 266.1 263.3 - 1,057.6	36 - 873 864 - 3,470
Spontaneous Potential	SP-1	06/14/1999	263.3 - 1,057.6	864 - 3,470
Gamma Ray	SGR-1 GR-3	06/02/1999 06/13/1999	0.6 - 268.2 207.3 - 1,061.0	2 - 880 680 - 3,481
Digital Array Sonic (delta T and sonic porosity)	AC-1	06/14/1999	228.6 - 1,047.0	750 - 3,435
Spectral Gamma Ray (potassium, thorium, uranium)	SGR-1 SGR-2	06/02/1999 06/14/1999	0 - 253.0 216.4 - 1,045.8	0 - 830 710 - 3,431
Thermal Flow	1	06/15/1999	304.8 - 1,053.1	1,000 - 3,455
Chemistry (temperature, pH, electrical conductivity)	1	06/15/1999	230.1 - 1,060.7	755 - 3,480

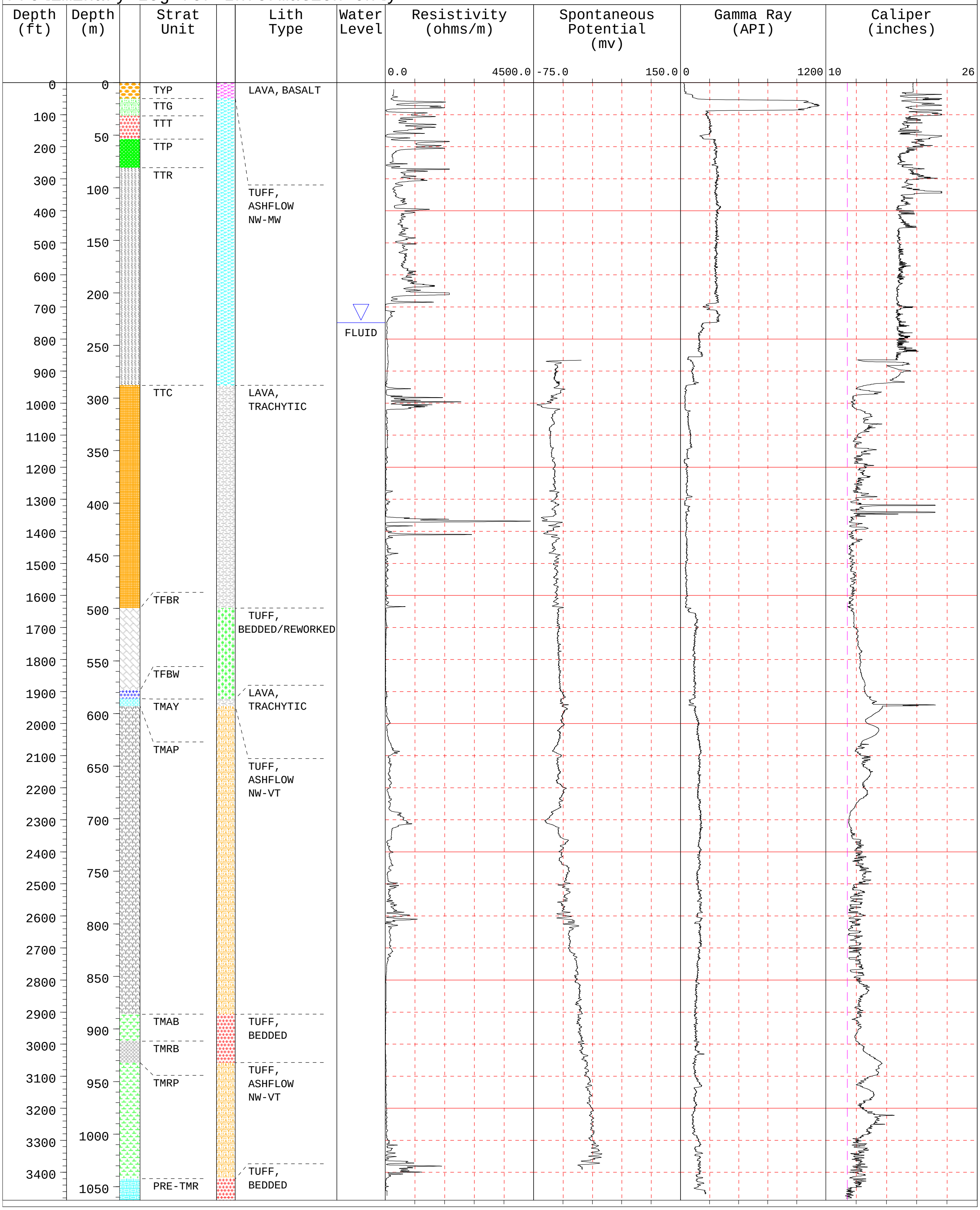
Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program		Northing: 4112552.8
Date: 11/23/99	Start Date: 5/26/99	Stop Date: 6/20/99	Easting: 532679.2
Environmental Contractor: UGTA/IT		Proj No: 776706.02.08.05.02	Surface Elevation: 4759.6
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Depth: 3487 ft.

Preliminary Log for Information Only



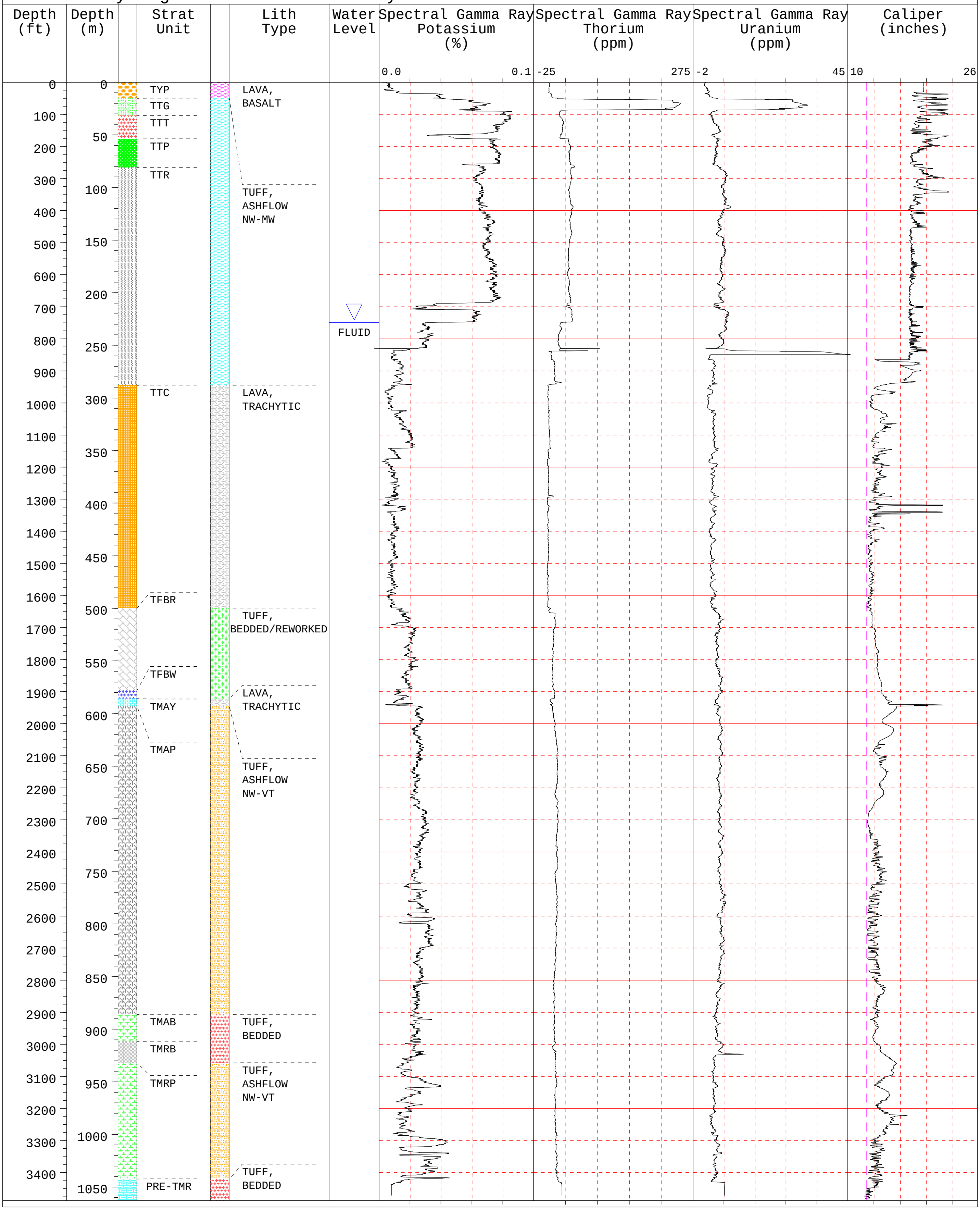
Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program		Northing: 4112552.8
Date: 11/23/99	Start Date: 5/26/99	Stop Date: 6/20/99	Easting: 532679.2
Environmental Contractor: UGTA/IT		Proj No: 776706.02.08.05.02	Surface Elevation: 4759.6
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Depth: 3487 ft.

Preliminary Log for Information Only



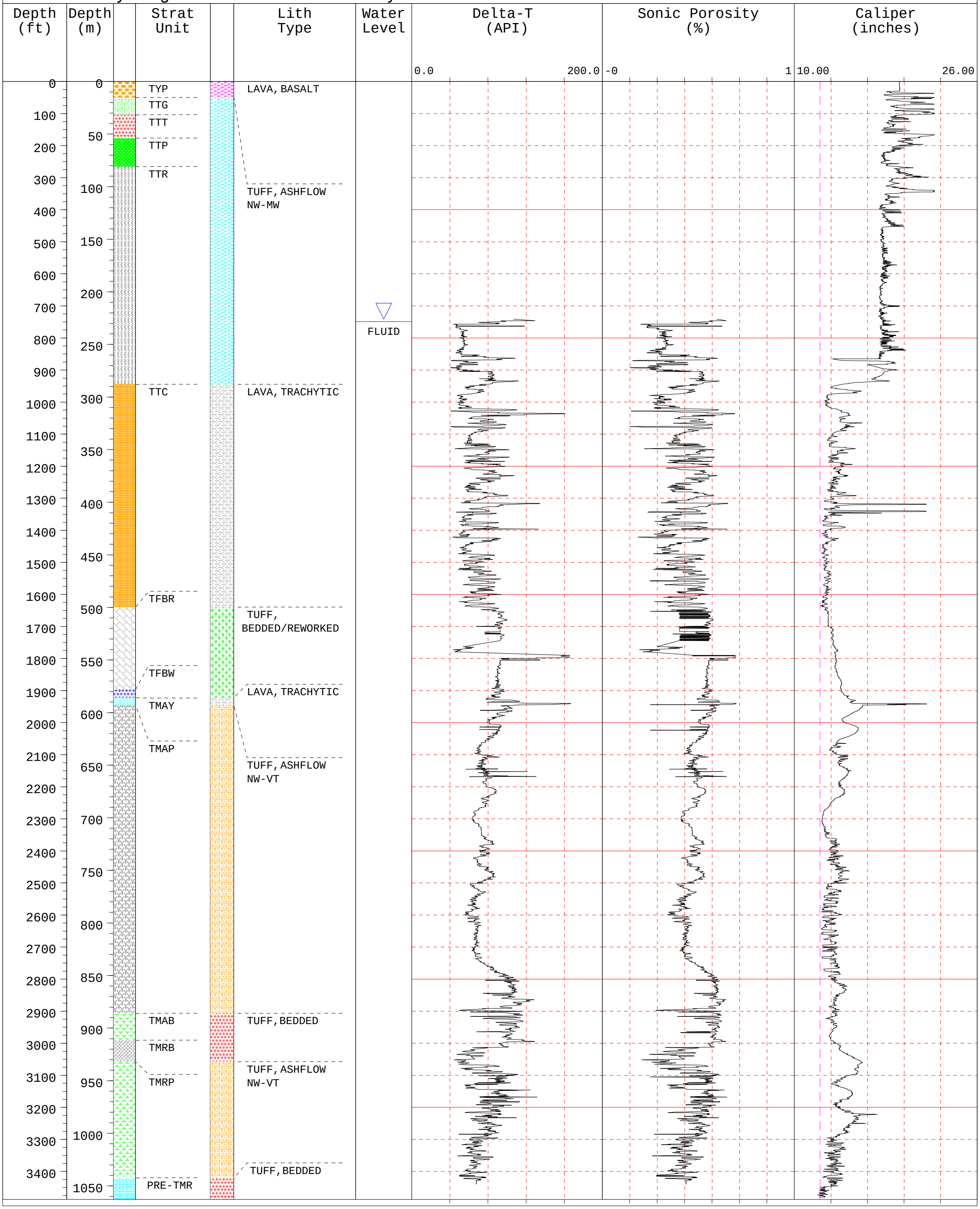
Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program		Northing: 4112552.8
Date: 11/23/99	Start Date: 5/26/99	Stop Date: 6/20/99	Easting: 532679.2
Environmental Contractor: UGTA/IT		Proj No: 776706.02.08.05.02	Surface Elevation: 4759.6
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Depth: 3487 ft.

Preliminary Log for Information Only



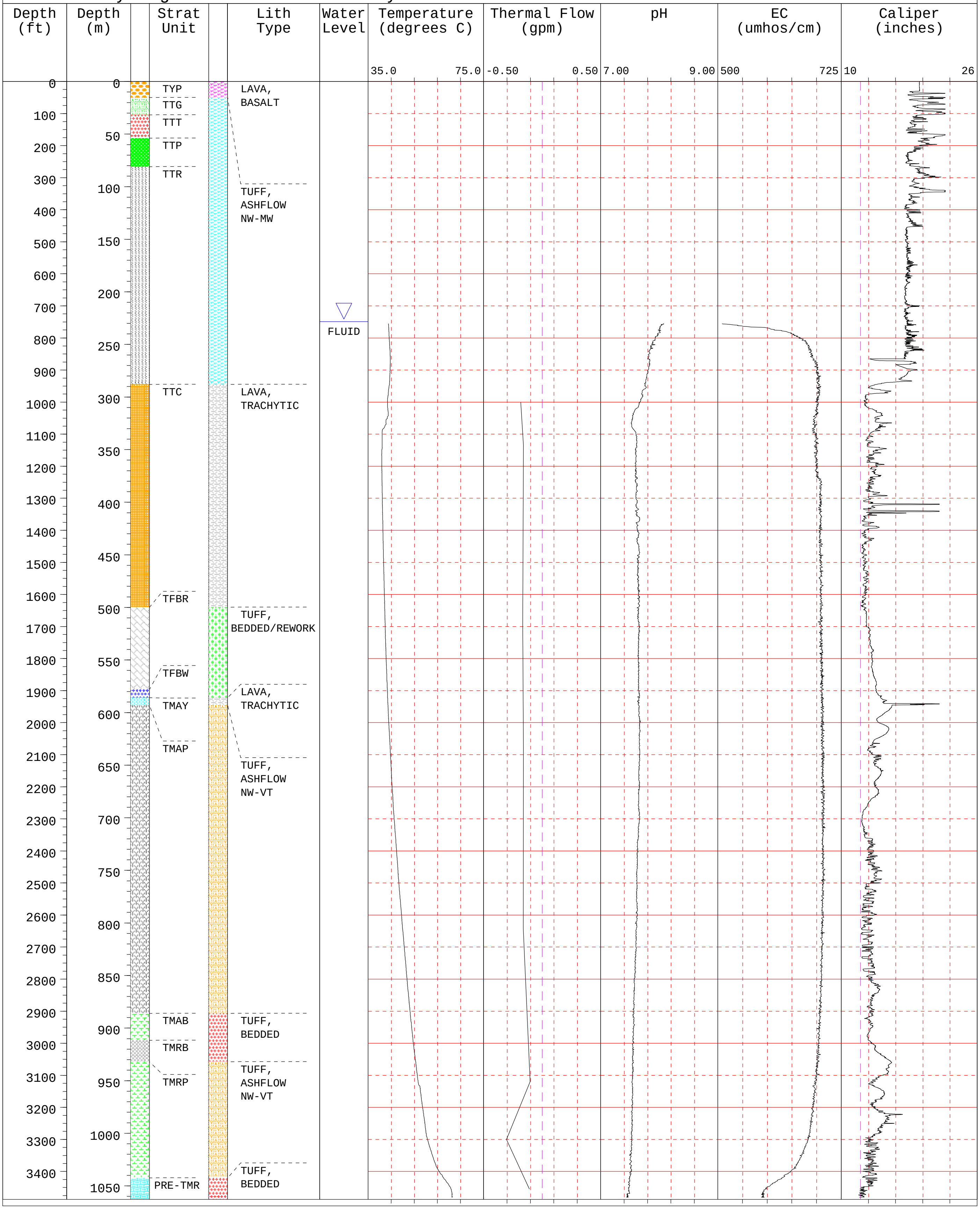
Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program		Northing: 4112552.8
Date: 11/23/99	Start Date: 5/26/99	Stop Date: 6/20/99	Easting: 532679.2
Environmental Contractor: UGTA/IT		Proj No: 776706.02.08.05.02	Surface Elevation: 4759.6
Drilling Contractor: United	Drilling Method: Air Foam	Geol: J. Wurtz	Depth: 3487 ft.

Preliminary Log for Information Only



Well Name: ER-EC-4	Western Pahute Mesa - Oasis Valley Drilling Program		Northing: 4112552.8
Date: 11/23/99	Start Date: 5/26/99	Stop Date: 6/20/99	Easting: 532679.2
Environmental Contractor: UGTA/IT		Proj No: 776706.02.08.05.02	Surface Elevation:4759.6
Drilling Contractor: United	Drilling Meth: Air Foam	Geol: J. Wurtz	Depth: 3487 ft.

Preliminary Log for Information Only



Distribution List

	Copies
R. M. Bangerter Environmental Restoration Division DOE Nevada Operations Office P.O. Box 98518, M/S 505 Las Vegas, NV 89193-8518	2
DOE Nevada Operations Office Technical Information Resource Center P.O. Box 98518, M/S 505 Las Vegas, NV 89193-8518	1
DOE Nevada Operations Office Public Reading Facility P.O. Box 98518, M/S 505 Las Vegas, NV 89193-8518	1
U.S. Department of Energy Office of Scientific and Technical Information 175 Oak Ridge Turnpike Post Office Box 62 Oak Ridge, Tennessee 37831-0062	2
K. A. Hoar, Director Environment, Safety, and Health Division DOE Nevada Operations Office P.O. Box 98518, M/S 505 Las Vegas, NV 89193-8518	1
P. K. Ortego Bechtel Nevada P.O. Box 98521, MS NLV082 Las Vegas, NV 89193-8521	1
Janet Wille IT Corporation P.O. Box 93838, MS 439 Las Vegas, NV 89193-3838	1
IT Library IT Corporation P.O. Box 93838, MS 439 Las Vegas, NV 89193-3838	1
W. L. Hawkins Los Alamos National Laboratory P. O. Box 1663 Los Alamos, NM 87545-1663	1

Distribution List (continued)

	Copies
G. A. Pawloski Lawrence Livermore National Laboratory P. O. Box 808 Livermore, CA 94551-9234	1
D. K. Smith Lawrence Livermore National Laboratory P. O. Box 808 Livermore, CA 94551-9234	1
B. K. Thompson DOE/USGS Cooperative Program Manager U.S. Geological Survey Water Resources Division 6770 South Paradise Road Las Vegas, NV 89119-3721	1
C. E. Russell Desert Research Institute 755 East Flamingo Road P.O. Box 19040 Las Vegas, NV 89119-7363	1