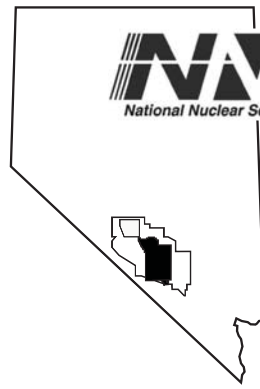
DOE/NV--1435

Nevada
Environmental
Restoration
Project



Completion Report for Well ER-EC-11

Corrective Action Units 101 and 102: Central and Western Pahute Mesa

December 2010

Environmental Restoration Project

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

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Completion Report for Well ER-EC-11

Corrective Action Units 101 and 102: Central and Western Pahute Mesa

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

Prepared by:
Underground Test Area and Boreholes Programs and Operations
National Security Technologies, LLC
Las Vegas, NV

December 2010

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Completion Report for Well ER-EC-11

Corrective Action Units 101 and 102: Central and Western Pahute Mesa

Approved by: Wilhelm R. Wilborn Date: 1/3/2011

Wilhelm R. Wilborn
Federal Sub-Project Director
Underground Test Area Project

Approved by: Robert F. Boehlecke Date: 1/3/11

Robert F. Boehlecke
Federal Project Director
Environmental Restoration Project

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Abstract

Well ER-EC-11 was drilled for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office, in support of the Nevada Environmental Restoration Project at the Nevada National Security Site (formerly Nevada Test Site), Nye County, Nevada. The well was drilled in September and October 2009 as part of the Pahute Mesa Phase II drilling program. A main objective was to investigate radionuclide migration down-gradient from Well Cluster ER-20-5 and Well ER-20-7 and across the northern Timber Mountain moat structural zone into the area referred to as the Bench, between Pahute Mesa and the Timber Mountain caldera complex. A secondary purpose of the well was to provide detailed hydrogeologic information for the shallow- to intermediate-depth Tertiary volcanic section in the Bench area. This well also provided detailed hydrogeologic information in the Tertiary volcanic section to reduce uncertainties within the Pahute Mesa–Oasis Valley hydrostratigraphic framework model (Bechtel Nevada, 2002).

The main 52.1-centimeter hole was drilled to a depth of 507.5 meters and then opened to a diameter of 66.0 centimeters. It was cased with 50.8-centimeter casing to 504.9 meters. The hole diameter was then decreased to 47.0 centimeters, and drilling continued to a total depth of 979.3 meters. It was then cased with 34.0-centimeter casing set at 965.5 meters. The hole diameter was then decreased to 31.1 centimeters and the borehole was drilled to a total depth of 1,264.3 meters. The completion casing string, set to the depth of 1,262.5 meters, consists of 19.4-centimeter stainless-steel casing hanging from 19.4-centimeter carbon-steel casing. The stainless-steel casing has two slotted intervals open to the Tiva Canyon and Topopah Spring aquifers.

Four piezometer strings were installed in Well ER-EC-11. A string of carbon-steel 6.0-centimeter tubing with one slotted interval was inserted outside the 50.8-centimeter casing, within the 66.0-centimeter borehole for access to the Timber Mountain aquifer, and landed at 475.3 meters. A second string of 6.0-centimeter tubing with one slotted interval was inserted outside the 34.0-centimeter casing, within the 47.0-centimeter borehole for access to the Benham aquifer, and landed at 911.7 meters. A third piezometer string consists of 7.3-centimeter stainless-steel tubing that hangs from 6.0-centimeter carbon-steel tubing via a crossover sub. This string was landed at 1,029.5 meters to monitor the Tiva Canyon aquifer. The deepest string of 7.3-centimeter tubing was landed at 1,247.8 meters to monitor the Topopah Spring aquifer.

Data collected during and shortly after hole construction include composite drill cuttings samples collected every 3.0 meters, 67 percussion gun and rotary sidewall core samples, various geophysical logs, fluid samples (for groundwater chemistry analysis and tritium measurements), and water-level measurements. The well penetrated 1,264.3 meters of Tertiary volcanic rock, including three saturated welded-tuff aquifers and one saturated lava-flow aquifer.

A water level was measured in the Timber Mountain aquifer at 449.6 meters, during open-hole geophysical logging on September 20, 2009. The fluid level measured after the total depth was reached and the upper aquifer was cased off was 450.0 meters when measured in the open borehole on October 17, 2009. Measurements on samples taken from the undeveloped well indicated that tritium levels averaging approximately 12,430 picocuries per liter (less than Safe Drinking Water Act levels) were encountered within the Benham aquifer. Tritium was below the minimum detectable activity concentration for samples collected from the Tiva Canyon aquifer and the Topopah Spring aquifer.

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List of Acronyms and Abbreviations

BA	Benham aquifer
BN	Bechtel Nevada
CA	contamination area
CAIP	Corrective Action Investigation Plan
CAU	Corrective Action Unit
CBIL	Circumferential Borehole Imaging Log
CHCU	Calico Hills confining unit
CHZCM	Calico Hills zeolitic composite unit
cm	centimeter(s)
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DRI	Desert Research Institute
EPA	U.S. Environmental Protection Agency
FAWP	Field Activity Work Package
FCCU	Fluorspar Canyon confining unit
FFACO	Federal Facility Agreement and Consent Order
FMP	Fluid Management Plan
ft	foot (feet)
gpm	gallon(s) per minute
HFM	hydrostratigraphic framework model
HSU	hydrostratigraphic unit
in.	inch(es)
LANL	Los Alamos National Laboratory
LLD	lower limit of detection
LLNL	Lawrence Livermore National Laboratory
Lpm	liter(s) per minute
m	meter(s)
m^3	cubic meter(s)
MDC	minimum detectable concentration
mg/L	milligram(s) per liter
NAD	North American Datum
NAIL	nuclear annulus investigation log
NARA	National Archives and Records Administration
N-I	Navarro-Intera, LLC

NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NNSS	Nevada National Security Site
NSTec	National Security Technologies, LLC
NTMMSZ	northern Timber Mountain moat structural zone
PM–OV	Pahute Mesa–Oasis Valley
pCi/L	picocurie(s) per liter
RCT	radiological control technician
SCCC	Silent Canyon caldera complex
SDWA	Safe Drinking Water Act
SNJV	Stoller-Navarro Joint Venture
STAR	Borehole Resistivity Imaging Tool
TD	total depth
TCA	Tiva Canyon aquifer
TMA	Timber Mountain aquifer
TMCC	Timber Mountain caldera complex
TSA	Topopah Spring aquifer
TWG	Technical Working Group
UGTA	Underground Test Area
UGT	underground nuclear test
UDI	United Drilling, Incorporated
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
yd^3	cubic yard(s)

1.0 Introduction

1.1 Project Description

Well ER-EC-11 was drilled for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office (NNSA/NSO) in support of the Nevada Environmental Restoration Project at the Nevada National Security Site (NNSS; formerly Nevada Test Site), Nye County, Nevada. Well ER-EC-11 was the third well drilled as part of a Phase II hydrogeologic investigation well drilling program in the Central and Western Pahute Mesa area of Nye County, Nevada.

The Pahute Mesa Phase II drilling program is also part of the Corrective Action Investigation Plan (CAIP) for the Central and Western Pahute Mesa Corrective Action Units (CAUs) 101 and 102, respectively (NNSA/NSO, 2009a). The CAIP is a requirement of the *Federal Facility Agreement and Consent Order* (FFACO, 1996, as amended March 2010).

The Central and Western Pahute Mesa CAUs and the associated well drilling program are part of the NNSA/NSO Environmental Restoration Project's Underground Test Area (UGTA) Sub-Project at the NNSS. Two goals of the UGTA Sub-Project are to evaluate the nature and extent of contamination in groundwater due to underground nuclear testing, and to establish a long-term groundwater monitoring network. As part of the UGTA Sub-Project, scientists are developing computer models to predict groundwater flow and contaminant migration within and near the NNSS. To build and test these models, it is necessary to collect geologic, geophysical, and hydrologic data from new and existing wells to define groundwater quality, migration pathways, and migration rates. Data from these wells will allow for more accurate modeling of groundwater flow and radionuclide migration in the region. Some of the wells may be used as long-term monitoring wells.

Well ER-EC-11 is located on the Nevada Test and Training Range, approximately 716.3 meters (m) (2,350 feet [ft]) west of the northwestern NNSS boundary (Figure 1-1). The primary purpose of this well was to further investigate the migration of radionuclides from the nearby up-gradient underground nuclear tests (UGTs) TYBO (U20y) and BENHAM (U-20c). Radionuclides were discovered at Well Cluster ER-20-5 (U.S. Department of Energy Nevada Operations Office [DOE/NV], 1997) and at Well ER-20-7 (NNSA/NSO, 2010a), located northeast of Well ER-EC-11 (Figure 1-2). Detailed hydrogeologic information about the Tertiary volcanic section obtained from this well will reduce uncertainties within the Pahute

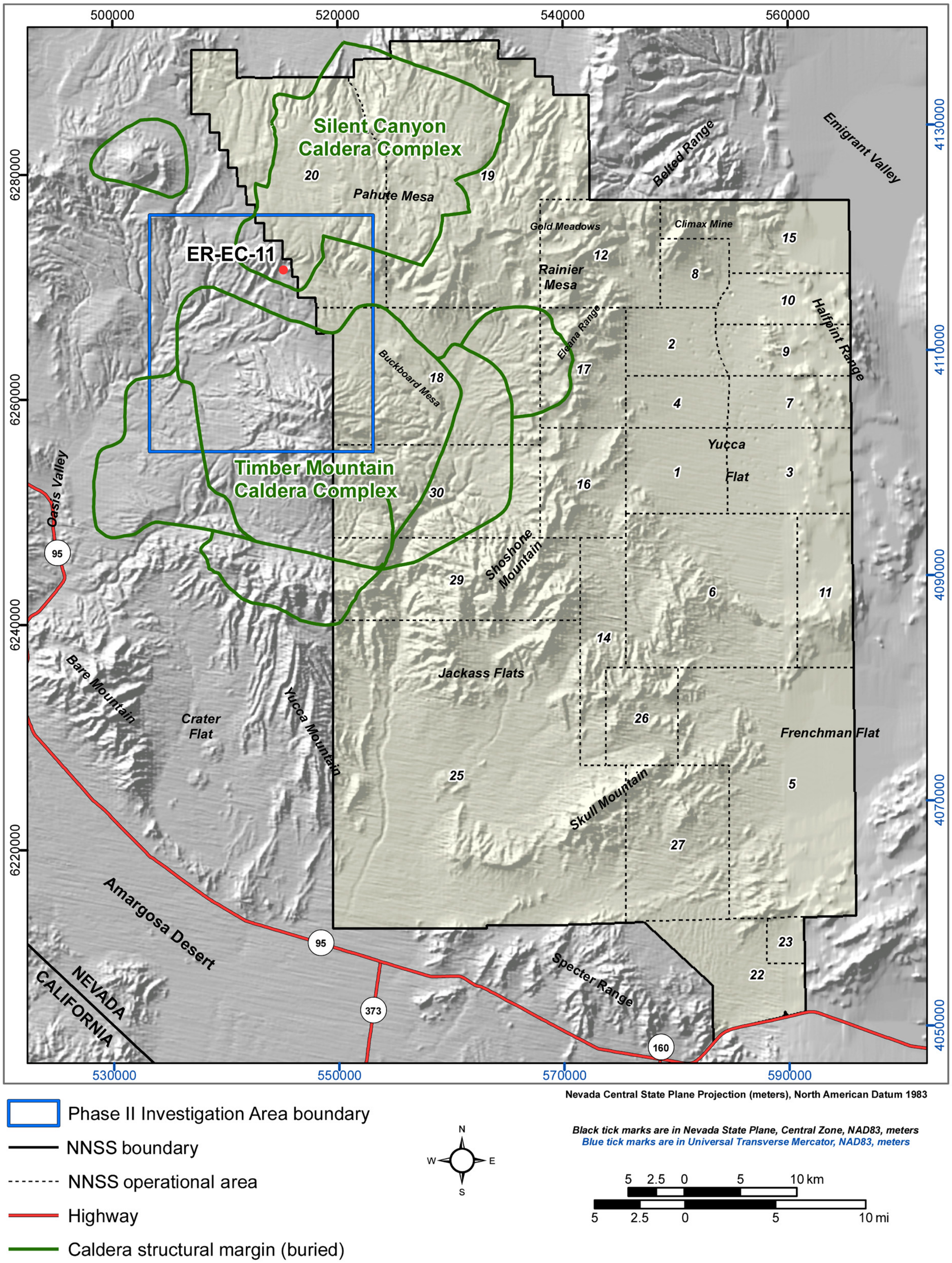


Figure 1-1
Reference Map Showing Location of Well ER-EC-11

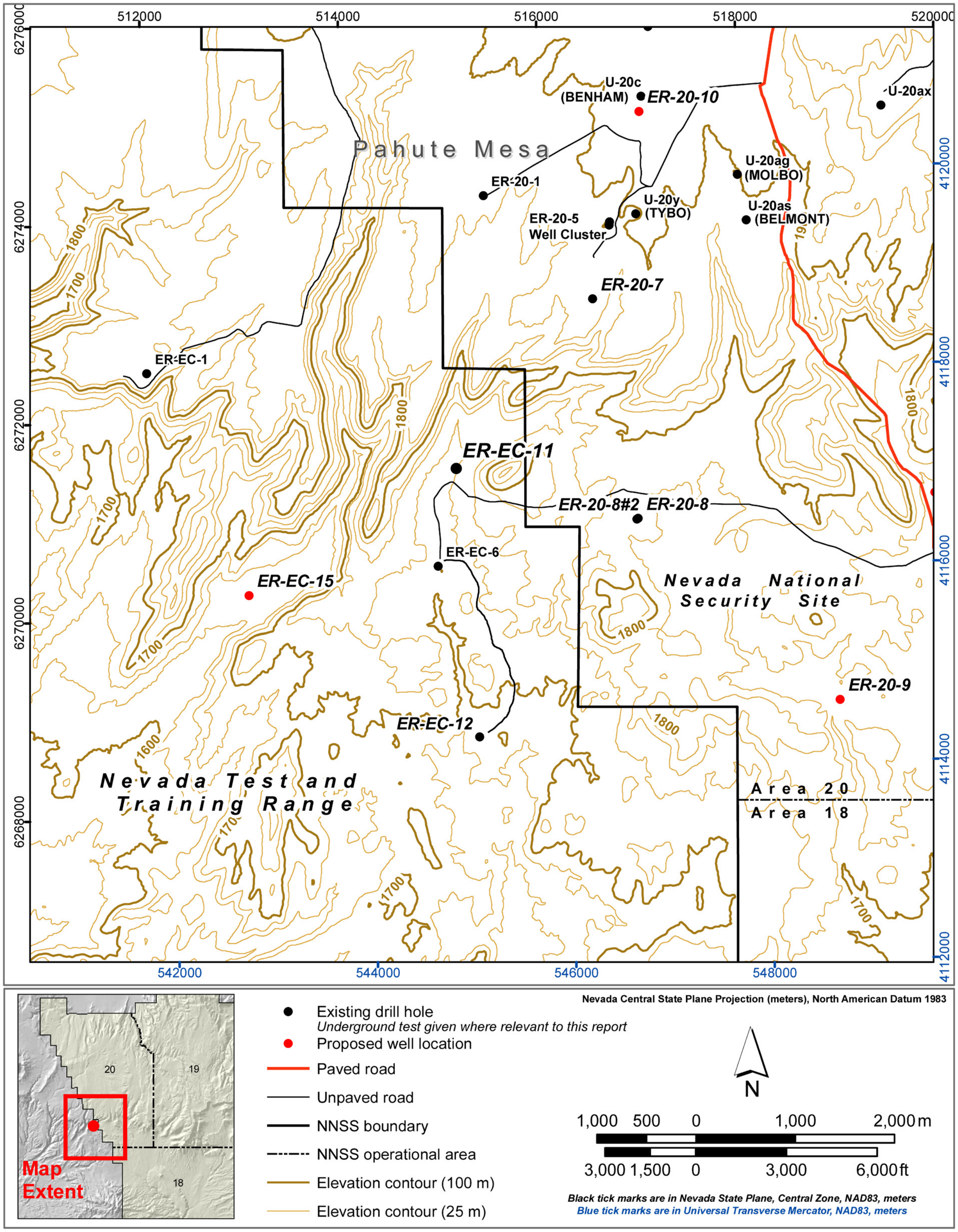


Figure 1-2
Topographic Map of the Well ER-EC-11 Area Showing the Locations of Roads and Nearby Drill Holes

Mesa–Oasis Valley (PM–OV) hydrostratigraphic framework model (HFM) (Bechtel Nevada [BN], 2002) and subsequent flow and transport modeling.

1.2 Project Organization

The construction of Well ER-EC-11 was intended to help fulfill the goals of the UGTA Sub-Project. Several groups function within the sub-project, whose responsibilities include ensuring that the sub-project goals are properly planned and achieved. The roles of these groups regarding successful construction of Well ER-EC-11 are described in this section.

The UGTA Technical Working Group (TWG) is a committee of scientists and engineers from NNSA/NSO, Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), the Nevada Division of Environmental Protection, the Desert Research Institute (DRI), the U.S. Geological Survey (USGS), National Security Technologies, LLC (NSTec; NNSS management and operating contractor), and Stoller-Navarro Joint Venture (SNJV; environmental contractor at the time, now Navarro-Intera, LLC [N-I]). The TWG has responsibility for providing technical advice and recommendations to the UGTA Sub-Project Manager to promote the effective closure of CAUs on the NNSS and ensure the continuing protection of the public health. The TWG's Pahute Mesa CAU Guidance Team and the TWG CAIP subcommittee assisted NNSA/NSO in developing the CAIP for the Pahute Mesa CAUs. The TWG's Well ER-EC-11 Drilling Advisory Team, which included the NNSA/NSO UGTA Sub-Project Manager, the SNJV field manager, the NSTec UGTA manager/drilling engineer, a hydrologist, a geologist, and a radio-chemist, provided technical advice during drilling, design, and construction of the well, to ensure that Well ER-EC-11 was constructed to meet scientific objectives identified in the CAIP and the drilling criteria. See *Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria* (SNJV, 2009a) for descriptions of the general plan and goals of the Pahute Mesa Phase II drilling initiative project, as well as specific goals for each well.

SNJV was the principal environmental contractor for the project, and SNJV personnel collected geologic and hydrologic data during drilling. (SNJV's name was changed to Navarro-Intera, LLC in July 2010; all subsequent references to the activities of this entity in this report will be N-I.) Site supervision, engineering, construction, inspection, and geologic support were provided by NSTec. The drilling company was United Drilling, Inc. (UDI), a subcontractor to NSTec. The roles and responsibilities of these and other contractors involved in the project are described in NSTec subcontract number 107553 and in field activity work package (FAWP) numbers D-004-001.09 and D-009-001.09 (NSTec, 2009a; 2009b).

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) (NNSA/NSO, 2009b). Estimates of expected production of fluid and drill cuttings for the Pahute Mesa holes are given in Appendix O of the drilling and completion criteria document for the drilling project (SNJV, 2009a), along with sampling requirements and contingency plans for management of any hazardous waste produced. All activities were conducted according to specific FAWPs (e.g., NSTec, 2009a, 2009b; SNJV 2009b) and the UGTA Project Health and Safety Plan (NSTec, 2008).

This report presents construction data and summarizes scientific data gathered during the drilling of Well ER-EC-11. Some of the information in this report is preliminary and unprocessed, but is being released with the drilling and completion data for convenient reference. A well data report prepared by N-I contains additional information on fluid management, waste management, and environmental compliance for the project (N-I, 2010). Hydrogeologic information for this area is presented in the data documentation package for the PM–OV HFM prepared by BN (2002). Documentation for Phase I flow and transport modeling, which guided this Phase II data collection activity, can be found in SNJV (2006, 2007, and 2009c). Pre-drilling geologic information for this area (including any changes in the geologic interpretation since production of the PM–OV HFM [BN, 2002]) is compiled in the Phase II drilling criteria document (SNJV, 2009a). Information on well development, aquifer testing, and groundwater analytical sampling (which are outside the scope of this report) will be compiled and disseminated separately.

1.3 Location and Significant Nearby Features

Well ER-EC-11 is located on the Nevada Test and Training Range at an elevation of 1,724.0 m (5,656.3 ft). It is located south of Pahute Mesa, 990.6 m (3,250 ft) north of Well ER-EC-6 and 3,261.4 m (10,700 ft) southeast of Well ER-EC-1. Wells drilled as part of the Phase II drilling program in 2009 include Well ER-20-7, which is located 2,210.4 m (7,252 ft) to the northeast, and Wells ER-20-8 and ER-20-8 #2, which are located approximately 1,910.8 m (6,269 ft) to the southeast. The locations of these features in relation to Well ER-EC-11 are shown in Figure 1-2. Additional information about Well ER-EC-11 is provided in Table 1-1.

The Well ER-EC-11 site is located in an area known as the Bench, a structural region defined as the area between the northern Timber Mountain moat structural zone (NTMMSZ) and the Timber Mountain caldera complex (TMCC) (Figure 1-3). The well site is located near one of the major drainage areas from Pahute Mesa, on a small ridge. Surface drainage at the well site is to the south.

Table 1-1
Well ER-EC-11 Site Data Summary

Site Coordinates [a]	Nevada State Plane (Central Zone) (NAD 83): N 6,271,544.2 m N 20,575,932.4 ft E 515,180.3 m E 1,690,224.2 ft Nevada State Plane (Central Zone) (NAD 27): N 890,930.4 ft E 550,068.6 ft UTM (Zone 11)(NAD 83): N 4,116,900.2 m E 544,758.8 m
Surface Elevation [a, b]	1,724.0 m (5,656.3 ft)
Drilled Depth	1,264.3 m (4,148 ft)
Fluid-Level Depth [c]	**TMA:** 449.6 m (1,475 ft) (September 20, 2009) **BA:** 450.2 m (1,477 ft) (October 6, 2009) **TCA and TSA:** 450.0 m (1,476.5 ft) (October 17, 2009)
Fluid-Level Elevation [d]	1,274.4 m (4,181.3 ft)
Surface Geology	mafic-rich Ammonia Tanks Tuff

a Measurements made by NSTec Survey. NAD = North American Datum (National Archives and Records Administration [NARA], 1989; U.S. Coast and Geodetic Survey, 1927). UTM = Universal Transverse Mercator.

b Measurement made by NSTec Survey. Elevation at top of construction pad. National Geodetic Vertical Datum, 1929 (NARA, 1973).

c Measured during open hole geophysical well logging on dates indicated.
TMA = Timber Mountain aquifer; BA = Benham aquifer; TCA = Tiva Canyon aquifer; TSA = Topopah Spring aquifer

d Elevation of the water level as measured in the TMA prior to installation of the completion string.

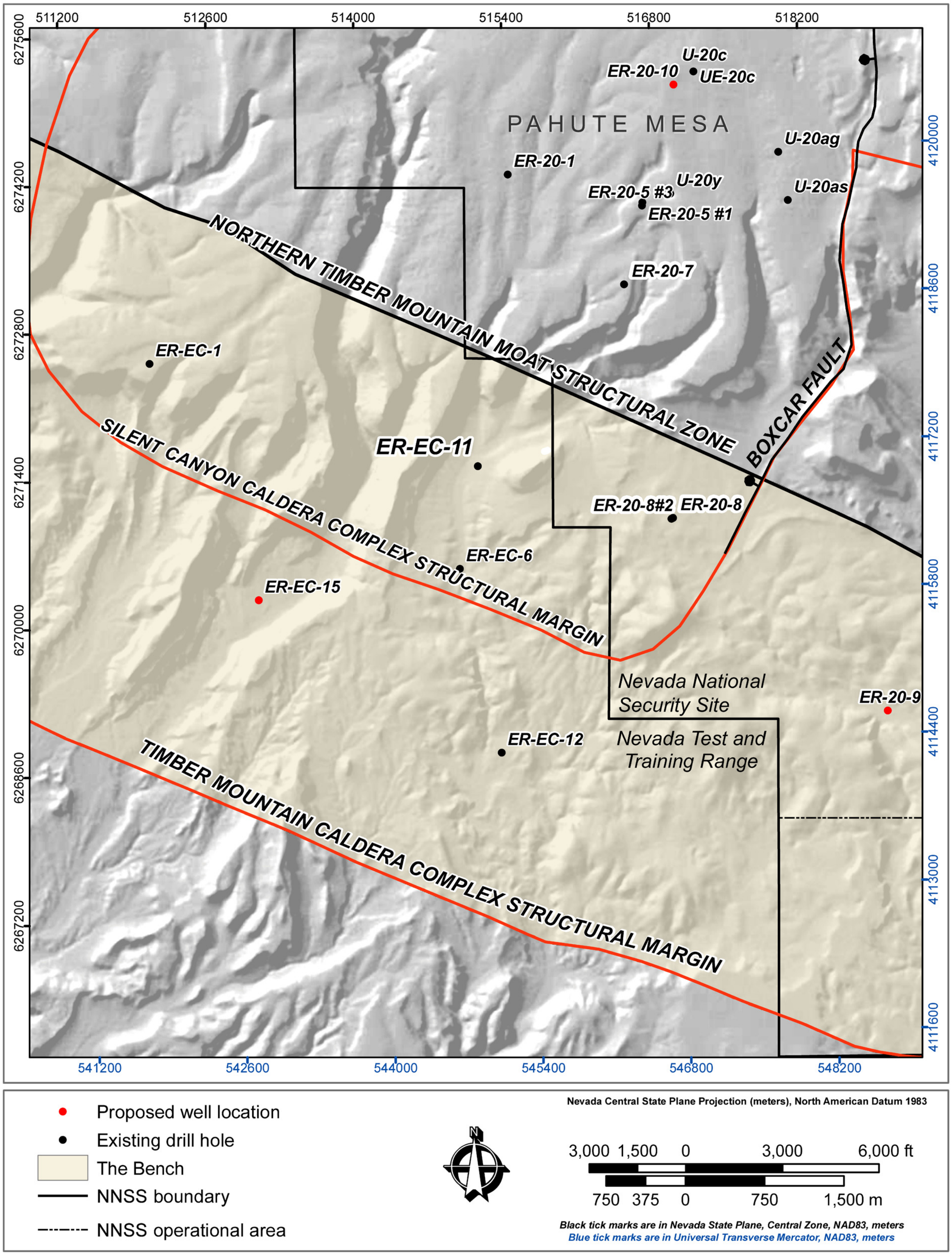


Figure 1-3
Orthophoto of the Well ER-EC-11 Site Area Showing Location of the "Bench"

The UGTs closest to and immediately up-gradient from Well ER-EC-11 are TYBO (U-20y) and BENHAM (U-20c) (Figure 1-2), which were conducted below the water table. Well ER-EC-11 was sited 3,170 m (10,400 ft) south-southwest of the TYBO test location, and 4,200 m (13,800 ft) south-southwest of the BENHAM test location. Table 1-2 provides additional information regarding these and other nearby tests.

1.4 Objectives

The primary purpose for Well ER-EC-11 is to investigate migration of contaminant plumes down-gradient from the TYBO and BENHAM UGTs executed in Emplacement Holes U-20y and U-20c, respectively. Radionuclides were first identified at Well Cluster ER-20-5 and later at Well ER-20-7. An important secondary objective is to obtain information that will help characterize the hydrogeology of southwestern Pahute Mesa, and specifically the northern portion of the Bench (NNSA/NSO, 2009a). Well ER-EC-11 is expected to produce data that will improve flow and transport modeling for CAUs 101 and 102. The Well ER-EC-11 location may be a favorable location for a long-term monitoring well.

The objectives for Well ER-EC-11, as described in Appendix B of the drilling and completion criteria document for the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells (SNJV, 2009a), are listed below, along with well-specific activities necessary to accomplish the objectives:

1. Investigate radionuclide migration down-gradient from the TYBO and BENHAM UGTs.
2. Characterize the hydrogeology of southwestern Pahute Mesa and the northern portion of the Bench to reduce uncertainties within this area of the PM–OV HFM. In particular, data from the well are expected to aid in accomplishing the following specific goals:
   - Refine the location of the NTMMSZ.
   - Provide detailed hydrogeologic information for the shallow- to moderate-depth Tertiary volcanic section.
   - Provide detailed geology and configuration of aquifer units in the upper portion of the saturated section where contaminant transport is most likely.
3. Obtain hydraulic properties such as detailed fracture data and hydrologic information for the Benham aquifer (BA), the Tiva Canyon aquifer (TCA), and the Topopah Spring aquifer (TSA), to improve subsequent flow and transport modeling for the area between the former test areas at Pahute Mesa and the TMCC.

Table 1-2
Selected Information for Underground Nuclear Tests Relevant to Well ER-EC-11

Emplacement Hole Name	Distance to Well ER-EC-11 meters (feet)	Test Name [a]	Test Date [a]	Surface Elevation [b] meters (feet)	Working Point		Regional Water Level		Announced Yield [a] (kilotons)	Working Point Formation [c, d]	Working Point HSU [c, e]
					Depth [b] meters (feet)	Elevation meters (feet)	Depth [b] meters (feet)	Elevation meters (feet)			
U-20y	3,170 (10,400)	TYBO	5/14/1975	1,907 (6,257)	765 (2,510)	1,142 (3,747)	630 (2,067)	1,277 (4,190)	200–1,000	Tpt	TSA
U-20as	3,870 (12,700)	BELMONT	10/16/1986	1,898 (6,227)	605 (1,985)	1,293 (4,242)	614 (2,014)	1,284 (4,213)	20–150	Tpb(b)	UPCU
U-20ag	4,115 (13,500)	MOLBO	2/12/1982	1,900 (6,234)	638 (2,093)	1,262 (4,141)	619 (2,031)	1,281 (4,203)	20–150	Tpb	BA
U-20c	4,200 (13,800)	BENHAM	12/19/1968	1,914 (6,281)	1,402 (4,600)	512 (1,681)	639 (2,096)	1,275 (4,185)	1,150	Th	CHZCM

a DOE/NV, 2000a
b DOE/NV, 1999
c BN, 2002

d Stratigraphic nomenclature:
- **Tpt** = Topopah Spring Tuff
- **Tpb(b)** = rhyolite of Benham, bedded
- **Tpb** = rhyolite of Benham
- **Th** = Calico Hills Formation

e Hydrostratigraphic nomenclature:
- **TSA** = Topopah Spring aquifer
- **UPCU** = upper Paintbrush confining unit
- **BA** = Benham aquifer
- **CHZCM** = Calico Hills zeolitic composite unit

The following activities are necessary to accomplish these goals:

- Collect drill cuttings and other geologic samples for geologic evaluation and for detailed mineralogic analysis. The mineralogic data will help define the vertical distribution of reactive minerals such as clays, zeolites, and iron oxides in the Tertiary volcanic section.
- Obtain geophysical log data from the borehole, including image logs for fracture identification and other logs for lithologic and stratigraphic identification and interpretation of rock properties.
- Collect aqueous geochemistry samples for analysis to determine whether tritium and other radionuclides have migrated to the well location. These analyses will also make it possible to better define possible groundwater flow paths based on water chemistry.
- Obtain detailed water-level data to determine the regional water level and investigate potential local groundwater flow down-gradient from the TYBO UGT.

Additional data that will help characterize the hydrology in southwestern Pahute Mesa will be obtained during later hydraulic testing at this well. Specific criteria for these later tests will be provided in future documents (e.g., FAWPs and a well development and testing plan), but ultimately, Well ER-EC-11 is expected to provide data for determination of horizontal and vertical conductivity and hydraulic properties of saturated hydrostratigraphic units (HSUs) penetrated.

The completed well will accommodate single-well hydraulic testing. This well could also be a potential observation well for multiple-well aquifer tests.

1.5 Project Summary

This section summarizes Well ER-EC-11 construction operations; the details are provided in Sections 2.0 through 7.0 of this report.

A 106.7-centimeter (cm) (42-inch [in.]) diameter surface conductor hole was constructed by drilling to the depth of 33.2 m (109 ft), and installing a string of 76.2-cm (30-in.) conductor casing to the depth of 32.3 m (105.7 ft). Drilling of the main hole with a 20½-in. tri-cone bit, using an air-foam/polymer fluid in conventional circulation, began on September 13, 2009. Due to previously unknown faulting, an upper aquifer, the Timber Mountain aquifer (TMA), was encountered, which had not been expected (see Section 4.4). The decision was made by NNSA/NSO and the Pahute Mesa Guidance Team to case off this upper aquifer and proceed as planned to the target aquifers, the BA, TCA, and TSA. After opening the hole to 66.0 cm (26 in.), a string of 20-in. casing was set to 504.9 m (1,656.4 ft), and a 47.0-cm (18.5-in.) hole was drilled to the depth of 979.3 m (3,213 ft). The BA was encountered over 311 m (1,020 ft) deeper than predicted and was saturated. Tritium was encountered in the BA at a depth of approximately 828.8 m (2,719 ft), approximately 379.2 m (1,244 ft) below the fluid-level depth of 449.6 m (1,475 ft). Because of the tritium, though the levels were less than Safe Drinking Water Act (SDWA) standards, the decision was made by NNSA/NSO and the Pahute Mesa Guidance Team to case off the BA and advance the well as planned to the deeper target aquifers, the TCA and TSA. It was also agreed at this time that it would be necessary to drill another well from this location to investigate the BA. A string of 13⅜-in. intermediate casing was set to 965.5 m (3,167.7 ft) on October 11, 2009. The hole size was reduced to 31.1 cm (12.25 in.) and drilled through the TCA and the TSA to a total depth (TD) of 1,264.3 m (4,148 ft), which was reached on October 13, 2009.

The well was completed with 7⅝-in. stainless-steel casing suspended from 7⅝-in. epoxy-coated carbon-steel casing (which ends 12.3 m [40 ft] above the water level). The completion casing was landed at 1,262.5 m (4,142.0 ft) and is slotted in two intervals. The upper interval is slotted from 970.5 to 1,028.5 m (3,183.9 to 3,374.3 ft) to allow access to the TCA, and the lower interval is slotted from 1,110.8 to 1,249.9 m (3,644.2 to 4,100.7 ft) to allow access to the TSA. Four piezometer strings were set to monitor water levels during hydraulic testing. A string of 6.03-cm (2⅜-in.) carbon-steel tubing was placed at 475.3 m (1,559.3 ft) within the TMA. A second string of 6.03-cm (2⅜-in.) carbon-steel tubing was set at 911.7 m (2,991.2 ft) within the BA. Two strings of 7.3-cm (2⅞-in.) stainless-steel tubing were set; each hangs from a string of 6.03-cm (2⅜-in.) carbon-steel tubing, connected via a crossover sub to the carbon-steel tubing. The upper of these two piezometer strings is slotted from 962.7 to 1,029.5 m (3,158.6 to 3,377.6 ft) for monitoring within the TCA. The lower string is slotted from 1,109.7 to 1,247.8 m (3,640.8 to 4,093.8 ft) for monitoring within the TSA. Tritium remained below the minimum detectable concentration (MDC) in both the TCA and the TSA.

The open-hole fluid level was measured at the depth of 450.0 m (1,476.5 ft) on October 16, 2009, during geophysical logging conducted prior to installation of the completion string.

Composite drill cuttings were collected every 3.0 m (10 ft) from the depth of 33.2 m (109 ft) to TD, and 67 sidewall core samples were obtained at various depths between 527.3 and 1,264.3 m (1,730 and 4,148 ft). Open-hole geophysical logging of the well was conducted to help verify the geology and characterize the hydrologic properties of the rocks; some logs also aided in the construction of the well by indicating borehole volume and condition. The well was drilled entirely within Tertiary volcanic rocks.

1.6 Project Director

Inquiries concerning Well ER-EC-11 should be directed to the UGTA Federal Project Director at:

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

2.0 Drilling Summary

2.1 Introduction

This section contains detailed descriptions of the drilling process and a discussion of fluid management issues. The general drilling requirements for all the 2009 Pahute Mesa Phase II wells were provided in *Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria* (SNJV, 2009a). Specific requirements for Well ER-EC-11 were outlined in FAWP numbers D-004-001.09 and D-009-001.09 (NSTec, 2009a; 2009b). Figure 2-1 shows the layout of the drill site, and Figure 2-2 is a chart of the drilling and completion history for Well ER-EC-11. A summary of drilling statistics for the well is given in Table 2-1. The following information was compiled primarily from NSTec daily drilling reports.

2.2 Drilling History

Field operations at Well ER-EC-11 began on July 20, 2009, when an NSTec crew, using the Mobile B-59 drill rig, drilled a 25.4-cm (10-in.) diameter pilot hole to the depth of 29.0 m (95 ft). On July 21, 2009, NSTec drillers used the Auger II drill rig to auger the 106.7-cm (42-in.) conductor hole to the depth of 33.2 m (109 ft). A string of 30-in. conductor casing was set at the depth of 32.2 m (105.7 ft). The conductor casing was cemented in place on July 29, 2009, using 6.1 cubic meters (m^3) (8.0 cubic yards [yd^3]) of Redi-Mix Formula 400 (see cement composition in Appendix A-3). The cement was pumped into the annulus between the casing and the formation, with a rise inside the casing of 2.9 m (9.5 ft) to the depth of 29.3 m (96 ft).

The UDI crews began mobilizing from Well ER-20-8 #2 on September 11, 2009, and completed rigging up the Wilson Mogul 42B drill rig on Well ER-EC-11 on September 12, 2009. The crew began drilling through the cement at the bottom of the 30-in. casing at 29.3 m (96 ft) with a center-punch assembly consisting of a 20½-in. rotary bit mounted 3.2 m (10.5 ft) below a 26-in. hole opener. The drilling fluid was an air/water/soap mix with a polymer additive (when necessary) in conventional circulation. The hole opener was removed when the hole reached the depth of 34.4 m (113 ft).

Drilling of the surface hole with a 20½-in. rotary tricone bit and air-foam began September 13, 2009. Drilling continued uneventfully with little or no fill accumulating when drilling was stopped to add drill pipe (to make a connection). On September 15, 2009, the

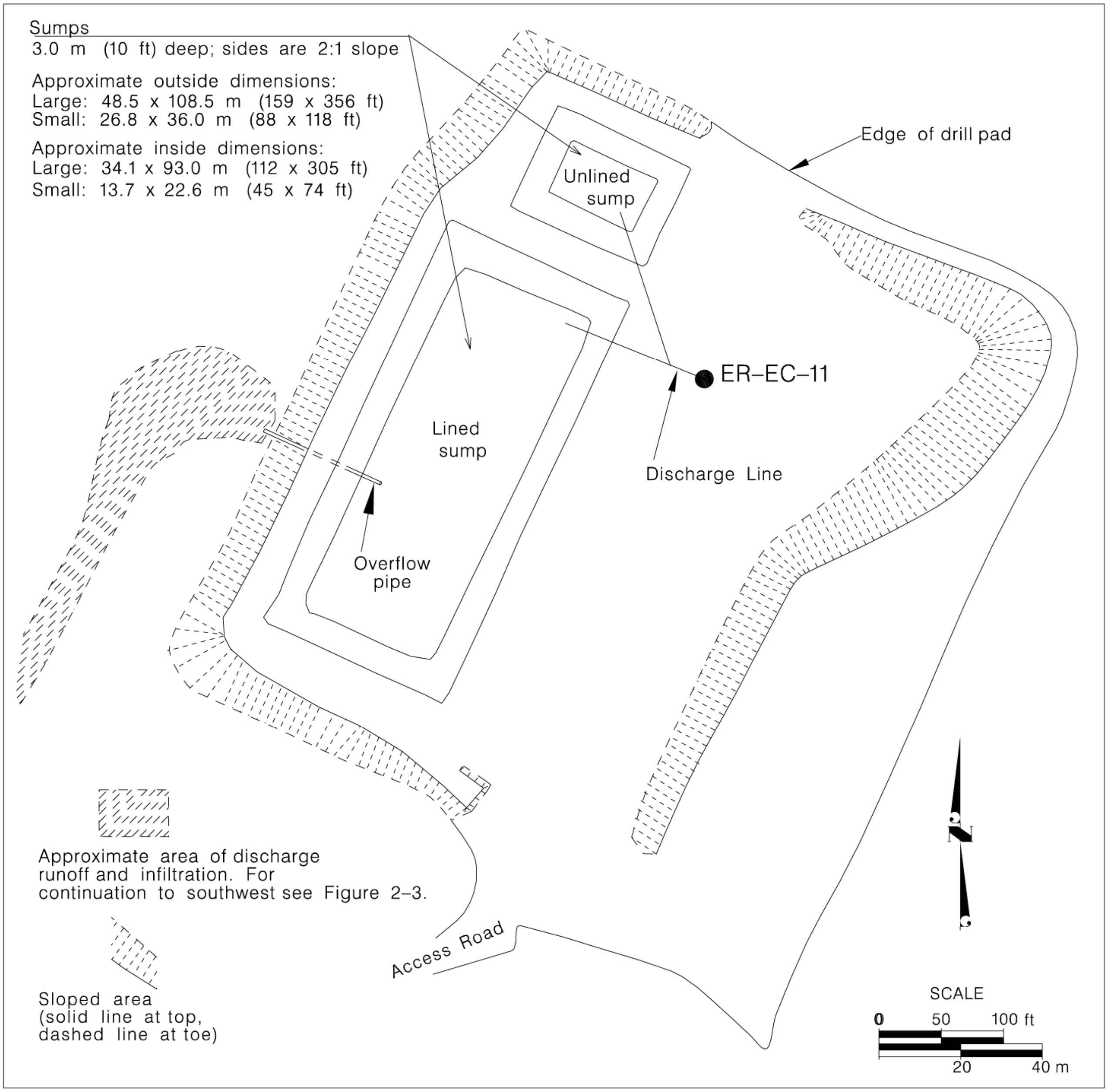
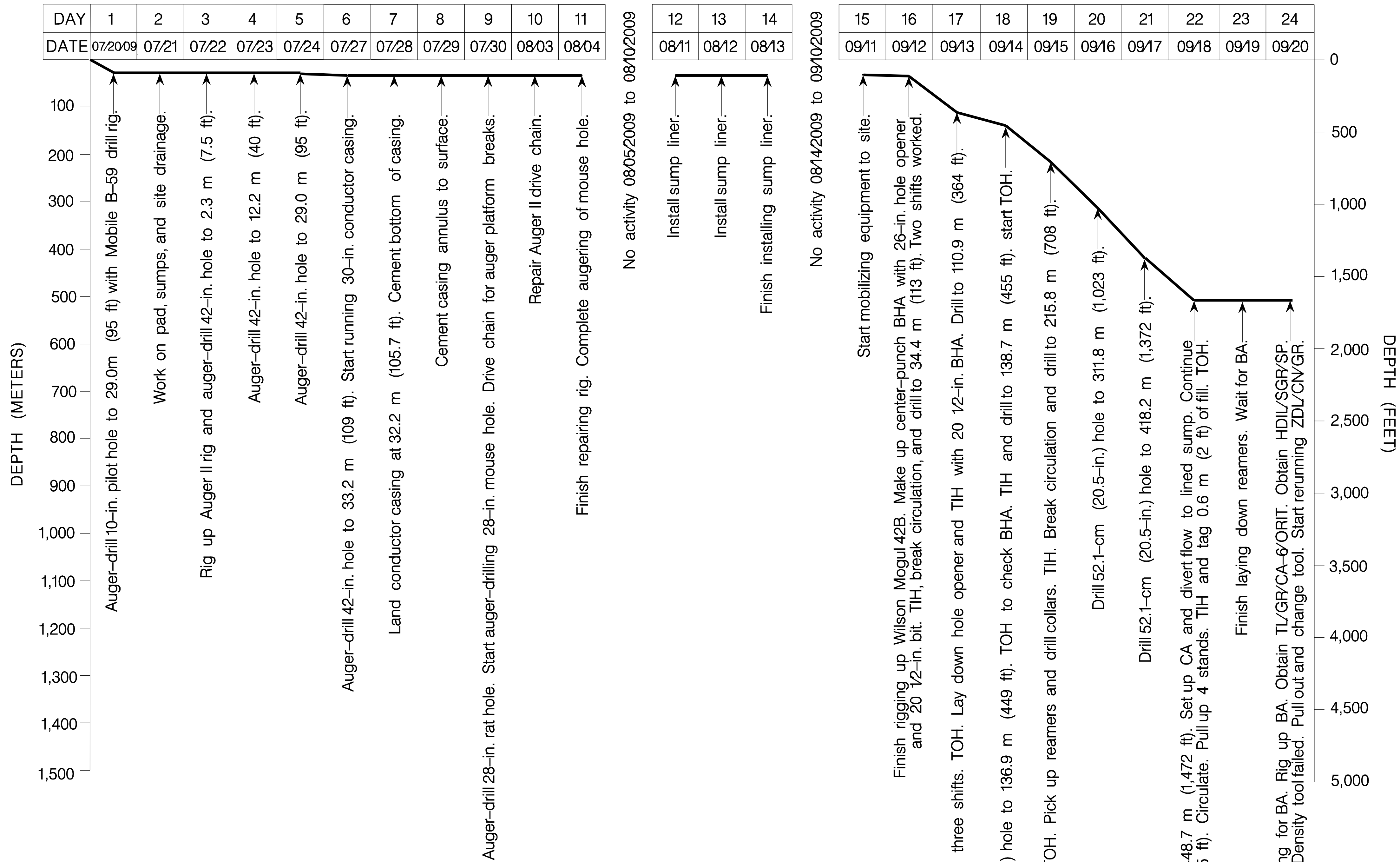


Figure 2-1
Drill Site Configuration for Well ER-EC-11

LEGEND

BA	Baker Atlas
BHA	bottom hole assembly
CA	contamination area
CA–6	six–arm caliper
CBIL	Circumferential borehole imaging log
CN	compensated neutron
CT	chemistry–temperature
cu. m	cubic meters
cu. yd	cubic yards
DLL	Dual Laterolog
DRI	Desert Research Institute
ft	foot (feet)
GR	gamma ray
hr	hour(s)
HDIL	high density induction log
in.	inch(es)
LMS	lower monitoring string
m	meter(s)
NAIL	nuclear annulus investigation log
NNES	Navarro Nevada Environmental Services
NSTec	National Security Technologies
ORIT	orientation log
SGR	spectral gamma ray
SLM	steel line measurement
SP	spontaneous potential
TD	total depth
TIH	trip into hole
TOC	top of cement
TOF	top of fluid
TL	temperature log
TOH	trip out of hole
UDI	United Drilling Inc.
UMS	Upper monitoring string
WOC	Wait on cement
XMAC	cross–multipole array acoustilog
ZDL	Z–densilog



WELL ER–EC–11 SUMMARY

Activity	Date
Begin drilling for conductor hole:	07/21/2009
Conductor hole completed and 30–in. casing set at 31.5 m (103.4 ft):	07/29/2009
Begin drilling 26–in. surface hole:	09/12/2009
Set 20–in. surface casing at 604.9 m (1,656.4 ft):	09/28/2009
Land 13 3/8–in. casing at 965.5 m (3,167.7 ft):	10/11/2009
Begin drilling 12 1/4–in. hole:	10/12/2009
Reach total drilled depth of 1,264.3 m (4,148.0 ft):	10/13/2009
Well completed:	10/21/2009

FIGURE 2–2

WELL ER–EC–11
DRILLING AND COMPLETION
HISTORY
SHEET 1 OF 2

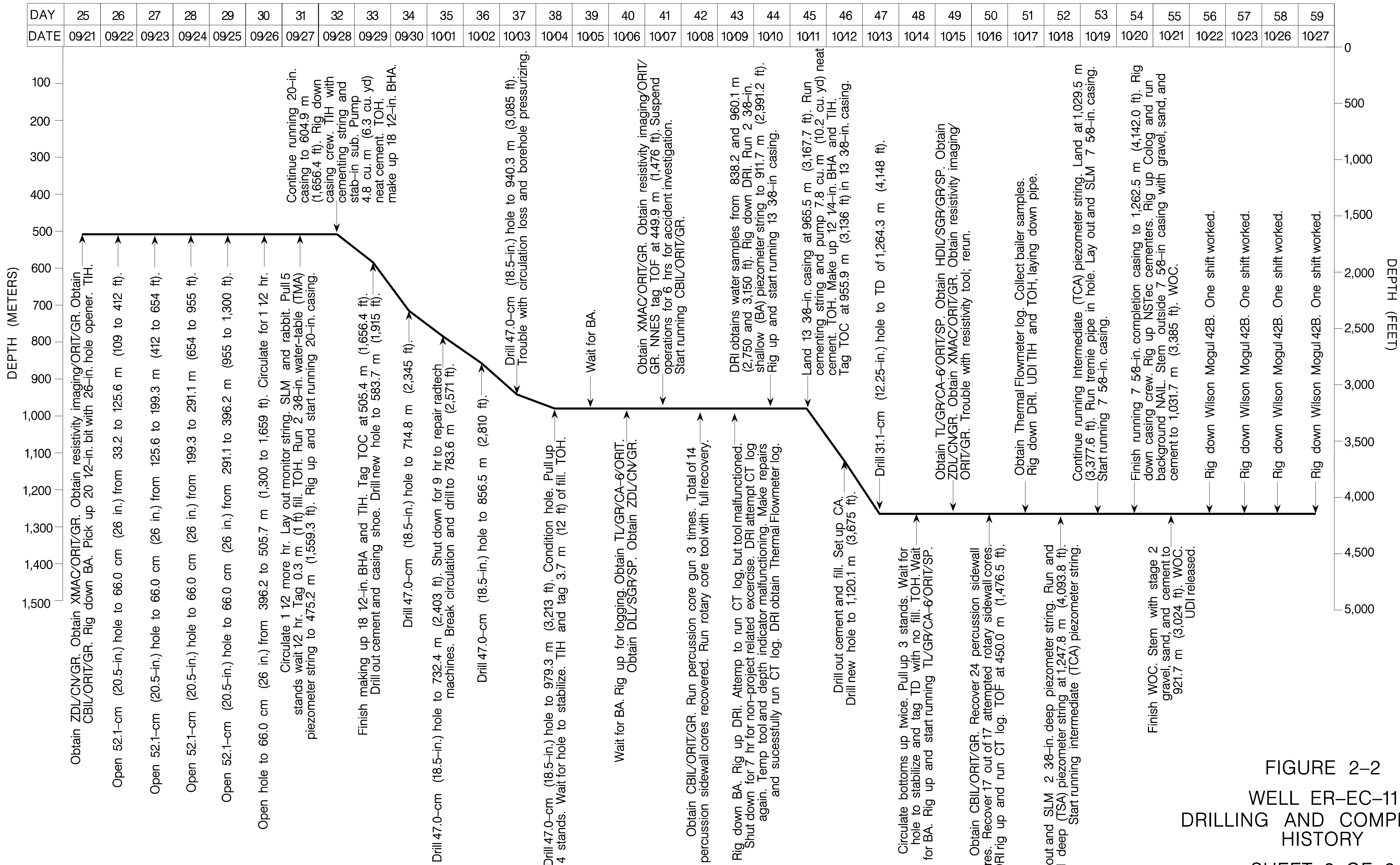


FIGURE 2–2
WELL ER–EC–11
DRILLING AND COMPLETION HISTORY
SHEET 2 OF 2

Table 2-1
Abridged Drill Hole Statistics for Well ER-EC-11

LOCATION DATA:

Coordinates:	Nevada State Plane (Central Zone)	(NAD 27):	N 890,930.4 ft	E 550,068.6 ft
	Nevada State Plane (Central Zone)	(NAD 83):	N 6,271,544.2 m	E 515,180.3 m
	Universal Transverse Mercator (Zone 11)	(NAD 83):	N 4,116,900.2 m	E 544,758.8 m

Surface Elevation [a]: 1,724.0 m (5,656.3 ft)

DRILLING DATA:

Spud Date:	9/13/2009 (main hole drilling with Wilson Mogul 42B rig)
Total Depth (TD):	1,264.3 m (4,148 ft)
Date TD Reached:	10/13/2009
Date Well Completed:	10/22/2009 (date completion string was cemented in place)
Hole Diameter:	106.7 cm (42 in.) from surface to 33.2 m (109 ft); 66.0 cm (26.0 in.) from 33.2 to 505.7 m (109 to 1,659 ft); 52.1 cm (20.5 in.) from 505.7 to 507.5 m (1,659 to 1,665 ft); 47.0 cm (18.5 in.) from 507.5 to 979.3 m (1,665 to 3,213 ft); 31.1 cm (12.25 in.) from 979.3 m (3,213 ft) to TD of 1,264.3 m (4,148 ft).
Drilling Techniques:	Dry-hole auger from surface to 33.2 m (109 ft); center-punch with 20½-in. tricone bit mounted below a 26-in. hole opener to 34.4 m (113 ft); rotary drill with 20½-in. tricone bit to 507.5 m (1,665 ft); open hole to 66.0 cm (26 in.) from 33.2 to 505.7 m (109 to 1,659 ft); rotary drill with 18½-in. tricone bit to 979.3 m (3,213 ft); rotary drill with 12¼-in. tricone bit to TD at 1,264.3 m (4,148 ft).

CASING DATA: 30-in. conductor casing to 32.2 m (105.7 ft); 20-in. surface casing to 504.9 m (1,656.4 ft); 13⅜-in. intermediate casing to 965.5 m (3,167.7 ft).

WELL COMPLETION DATA:

A string of 7⅝-in. stainless-steel casing hangs from 7⅝-in. epoxy-coated carbon-steel casing via a crossover sub. The carbon-steel casing extends through the unsaturated zone to approximately 12.5 m (41 ft) above the water table. The 7⅝-in. casing (ID [b] of 17.70 cm [6.969 in.]) has two slotted intervals and was landed at 1,262.5 m (4,142.0 ft). A string of carbon-steel 2⅜-in. tubing (ID of 5.07 cm [1.995 in.]) with one slotted interval was inserted outside the 20-in. casing within the 66.0-cm (26-in.) hole and landed at 475.3 m (1,559.3 ft). A second string of carbon-steel 2⅜-in. tubing with one slotted interval was inserted outside the 13⅜-in. casing within the 18.5-in. hole and landed at 911.7 m (2,991.2 ft). Two lower 2⅞-in. (ID of 5.92 cm [2.33 in.]) stainless-steel tubing strings were set; both hang from strings of 2⅜-in. carbon-steel tubing, connected via crossover subs. Both lower strings were inserted outside the 7⅝-in. completion casing and within the 12.25-in. hole. The third piezometer string was landed at 1,029.5 m (3,377.6 ft), and the fourth piezometer string was landed at 1,247.8 m (4,093.8 ft). Detailed data for the completion interval are provided in Section 7.0 of this report.

Depth of Slotted Section:	7⅝-in. completion casing:	970.5 to 1,028.5 m (3,183.9 to 3,374.4 ft) 1,110.8 to 1,249.9 m (3,644.2 to 4,100.7 ft)
	upper 2⅜-in. piezometer string (TMA)	445.7 to 475.3 m (1,462.2 to 1,559.3 ft)
	lower 2⅜-in. piezometer string (BA)	816.1 to 911.7 m (2,677.5 to 2,991.2 ft)
	upper 2⅞-in. piezometer string (TCA)	962.7 to 1,029.5 m (3,158.6 to 3,377.6 ft)
	lower 2⅞-in. piezometer string (TSA)	1,109.8 to 1,247.8 m (3,641 to 4,093.8 ft)
Depth of Sand Packs:	944.9 to 955.2 m (3,100 to 3,134 ft)	1,094.2 to 1,103.4 m (3,590 to 3,620 ft)
Depth of Gravel Packs:	955.2 to 1,031.8 m (3,134 to 3,385 ft)	1,103.4 to 1,264.3 m (3,620 to 4,148 ft)
Depth of Pump:	Not installed at the time of completion	
Water Depth [c]:	Preliminary fluid level of 449.6 m (1,475 ft) for the TMA measured inside the 52.1-cm (20.5-in.) hole on September 20, 2009, during geophysical logging, and 450.2 m (1,477 ft) for the BA measured inside the 47.0-cm (18.5-in.) hole on October 6, 2009, during geophysical logging. Preliminary fluid level of 450.0 m (1,476.5 ft) for the TCA and TSA was measured inside the 31.1-cm (12.25-in.) hole on October 17, 2009.	

DRILLING CONTRACTOR: United Drilling, Inc.

GEOPHYSICAL LOGS BY: Baker Atlas

SURVEYING CONTRACTOR: National Security Technologies, LLC

a Elevation of ground level at wellhead. National Geodetic Vertical Datum of 1929 (NARA, 1973).
b ID = inside diameter.
c Fluid level tag by Baker Atlas. TMA = Timber Mountain aquifer; BA = Benham aquifer; TCA = Tiva Canyon aquifer; TSA = Topopah Spring aquifer

bottom hole assembly was re-configured with eight additional drill collars, a shock sub, a set of jars, and an additional roller reamer. Drilling resumed with little to no fill on connections. When drilling had reached the depth of 434.3 m (1,425 ft), in anticipation of encountering groundwater, radiological control technicians (RCTs) set up a contamination area (CA) zone around the rig floor, catwalk, and subbase. The first observation of water in the returns was reported at the depth of 472.1 m (1,549 ft) on September 18, 2009. Upon reaching 507.5 m (1,665 ft), the decision was made to suspend drilling and install casing to isolate the saturated Rainier Mesa Tuff (TMA), which had not been expected in this well. This would allow proper characterization of the target aquifers (BA, TCA, and TSA) expected deeper in the hole. Geophysical logging began September 20, 2009, and a fluid level of 449.6 m (1,475 ft) was measured the same day. After logging operations were completed on September 21, 2009, the 52.1-cm (20½-in.) hole was opened to a diameter of 66.0-cm (26-in.) from 33.2 to 505.8 m (109 to 1,659.5 ft) to accommodate the 20-in. surface casing.

On September 27, 2009, a piezometer string of 2⅜-in. Hydril® steel tubing was landed at 475.3 m (1,559.3 ft) to permit monitoring within the TMA ("water-table [TMA] piezometer string"). On the same day, the casing subcontractor installed a string of 20-in. casing, which was set at the depth of 505.0 m (1,656.4 ft), and which isolates the 2⅜-in. tubing string in the annulus. The bottom of the casing was cemented with 4.8 m^3 (6.3 yd^3) of Type II neat cement. Drilling of a 47.0-cm (18.5-in.) hole began on September 29, 2009, when the top of cement was tagged at 505.4 m (1,658 ft). Cement and the casing shoe were drilled from 505.4 to 506.9 m (1,658 to 1,663 ft), and fill was drilled from 506.9 to 507.5 m (1,663 to 1,665 ft). The top of cement in the annulus is estimated to be at the depth of 483.1 m (1,585 ft), based on geophysical log data.

Drilling continued with no fill on connections until October 1, 2009, when the power supply units on both liquid scintillation counters (equipment used to analyze fluid samples for tritium) failed. After nine hours of standby while this problem was addressed, drilling resumed with little or no fill accumulating on connections. Tritium values exceeding background levels were initially detected in drilling effluent on October 2, 2009, at the depth of 828.8 m (2,719 ft). A maximum level of tritium as measured by field instruments was 37,229 picocuries per liter (pCi/L), detected at the depth of 855.9 m (2,808 ft) (N-I, 2010). However, laboratory measurements made later on fluid samples from this interval indicated tritium levels of 13,600 pCi/L (LLNL, 2009) (see Section 2.4 for more information about tritium results).

Drilling with the 18½-in. bit continued without incident until October 3, 2009, when one of the two air compressors used in the fluid circulation system failed. Approximately 15 minutes passed before the standby compressor was brought online, and after re-establishing circulation, 6.1 m (20 ft) of fill had to be cleaned out.

On October 4, 2009, at the depth of 972.3 m (3,190 ft), a noticeable decrease in penetration rate was observed and the onsite geologist requested that drilling be stopped so he could evaluate the drill cuttings. The drillers circulated fluid in the hole, and after approximately 30 minutes, the decision was made to resume drilling for approximately 2 hours, after which, on October 5, 2009, NSTec and N-I determined that the welded Tiva Canyon Tuff (TCA) had been reached.

At this time NNSA/NSO and the Pahute Mesa Guidance Team decided to stop drilling and case off the BA because of the tritium encountered, even though the tritium levels were less than SDWA standards. This would prevent cross-contamination between the BA and the deeper target aquifers, TCA and TSA. Drilling of the 47.0-cm (18.5-in.) borehole was stopped at the depth of 979.3 m (3,213 ft).

Geophysical logging and sidewall sampling began on October 6, 2009. N-I measured the fluid level at the depth of 449.9 m (1,476 ft) inside the water-table (TMA) piezometer string the same day. On October 7, 2009, the drill site was placed on standby, and geophysical logging operations were suspended for approximately six hours during investigation of an accident involving Baker Atlas personnel. Difficulties with a malfunctioning sidewall coring tool caused additional delays (see Section 3.3). Logging operations were not completed until October 10, 2009, after DRI personnel ran chemistry, temperature and flow logs, and collected water samples.

The drill crew landed a string of 2⅜-in. Hydril® tubing at 911.7 m (2,991.2 ft), which will permit monitoring within the BA ("shallow [BA] piezometer string"). On October 11, 2009, the casing subcontractor installed a string of 13⅜-in. casing, which was set at the depth of 965.5 m (3,167.7 ft). The bottom of the casing was cemented with 7.8 m^3 (10.2 yd^3) of Type II neat cement. Drilling of a 31.1-cm (12.25-in.) hole began on the same day. The top of cement was tagged at 955.8 m (3,136 ft); cement and the casing shoe were drilled from 955.9 to 971.7 m (3,136 to 3,188 ft), and fill was drilled from 971.7 to 979.3 m (3,188 to 3,213 ft). The top of cement in the annulus is estimated to be at the depth of 927.5 m (3,043 ft) based on geophysical log data.

Drilling with the 12¼-in. bit continued with no fill on connections until October 13, 2009, when the borehole had advanced through the lower target aquifer, the TSA, and entered the underlying composite unit. The TD was called at 1,264.3 m (4,148 ft). The drillers then cleaned and conditioned the borehole by circulating the borehole volume twice. The depth check tagged no fill, and the crew began removing the drill string from the hole for geophysical logging.

Geophysical logging and sidewall sampling operations were conducted with no problems by Baker Atlas crews October 14–16, 2009. Then DRI personnel ran chemistry, temperature, and flow logs; collected water samples; and tagged the top of fluid at 450.0 m (1,476.5 ft). DRI operations were completed on October 17, 2009.

On October 18–19, 2009, the drill crew installed two 2⅜-in. piezometer strings, each having one slotted interval. The "deep (TSA) piezometer string" was set at 1,242.6 m (4,093.8 ft), and the "intermediate (TCA) piezometer string" was set at 1,029.5 m (3,377.6 ft).

A 7⅝-in. stainless-steel completion string with two slotted intervals was inserted into the hole on October 19–20, 2009, and landed at a depth of 1,262.5 m (4,142.0 ft). The hole was noted as tight at 294.7 m (967 ft). The annulus around the production casing and the two piezometer strings was packed with sand and gravel, and cemented (see Section 7.2). Stemming operations were completed on October 21, 2009, and the drillers started demobilizing the rig and drilling equipment. The crews worked one shift per day after that, until demobilization was completed on October 29, 2009. A removable bridge plug that isolates the two lower aquifers from each other was installed at 1,045.5 m (3,430 ft) by Baker Atlas on October 29, 2009.

The inclination of the borehole was determined from Directional Survey logs run by Baker Atlas during each logging operation (September 20, October 6, and October 15, 2009). According to the composite survey plot, there is a dogleg effect in borehole orientation at approximately 609.6 m (2,000 ft). However, there is no corresponding change in drilling parameters or geologic unit in this depth range to indicate the cause of the deviation. The average borehole inclination is 1.6 degrees to the south-southwest in the upper part of the hole, and 1.2 degrees to the north-northwest in the lower part of the hole. The greatest deviation of 3.4 degrees is at 373.4 m (1,225 ft). The bottom of the borehole is 22.2 m (72.7 ft) northwest of the wellhead.

A graphical depiction of drilling parameters, including penetration rate, rotary revolutions per minute, pump pressure, and weight on the bit, is presented in Appendix A-1. See Appendix A-2 for a listing of tubing and casing materials. Drilling fluids and cements used in Well ER-EC-11 are listed in Appendix A-3.

2.3 Drilling Problems

Drilling delays at Well ER-EC-11 were mainly due to operational problems rather than drilling problems. However, although borehole sloughing was not a major problem during drilling, surface casing had to be installed to case off the TMA (isolating it from the lower aquifers) and to address potential hole stability issues. The larger hole size was also required to accommodate the 7⅝-in. completion string plus two additional piezometer strings. This caused a delay because the hole size had to be increased from 52.1 to 66.0 cm (20.5 to 26.0 in.) to accommodate the 20-in. casing. The presence of tritium, first encountered at a depth of approximately 828.8 m (2,719 ft) within the BA, also prompted the installation of 13⅜-in. intermediate casing to case off the BA from the TCA and TSA below. See discussion of completion design in Section 7.2.3.

2.4 Fluid Management

During drilling of Well ER-EC-11, the drilling effluent was monitored according to the methods prescribed in the UGTA Project FMP (NNSA/NSO, 2009b) and the associated state-approved, well-specific, fluid management strategy letter (SNJV, 2009e). The air-foam/polymer drill fluid was circulated down the inside of the drill string and back up the hole through the annulus (conventional or direct circulation) and then discharged into a sump. Water used to prepare drilling fluids came from Area 20 Water Well (U-20WW). Lithium bromide was added to the drill fluid as a tracer to provide a means of estimating groundwater production. The rate of water production was estimated from the dilution of the tracer in the drill fluid returns.

2.4.1 Drilling Effluent Sump Information

Radionuclides exceeding fluid quality objectives were expected at Well ER-EC-11, based on the results of analysis of groundwater from Well ER-20-5#1, located 2,950.0 m (9,679 ft) northeast of Well ER-EC-11, and at Well ER-20-7, located 2,210.4 m (7,252 ft) to the northeast (Figure 1-2) (DOE/NV, 1997; NNSA/NSO, 2010a). To manage the anticipated water production, one unlined sump (sump #1) and one lined sump (sump #2) were constructed prior to drilling (Figure 2-1). On September 18, 2009, when the borehole was at the depth of 434.3 m (1,425 ft), flow was diverted from the unlined sump to the lined sump. When the level of (uncontaminated) fluid in sump #2 reached the level of 2.5 m (8.2 ft) on the staff gauge in the sump, on October 9, 2009, fluid from the sump was pumped to a surface infiltration area (Figure 2-1) at a rate of approximately 757 to 946 liters per minute (Lpm) (200 to 250 gallons per minute [gpm]). The transfer line was pressure tested prior to pumping, and the line was checked for leaks, with none found. The fluid followed a natural drainage, and later that day it had intersected the dirt access

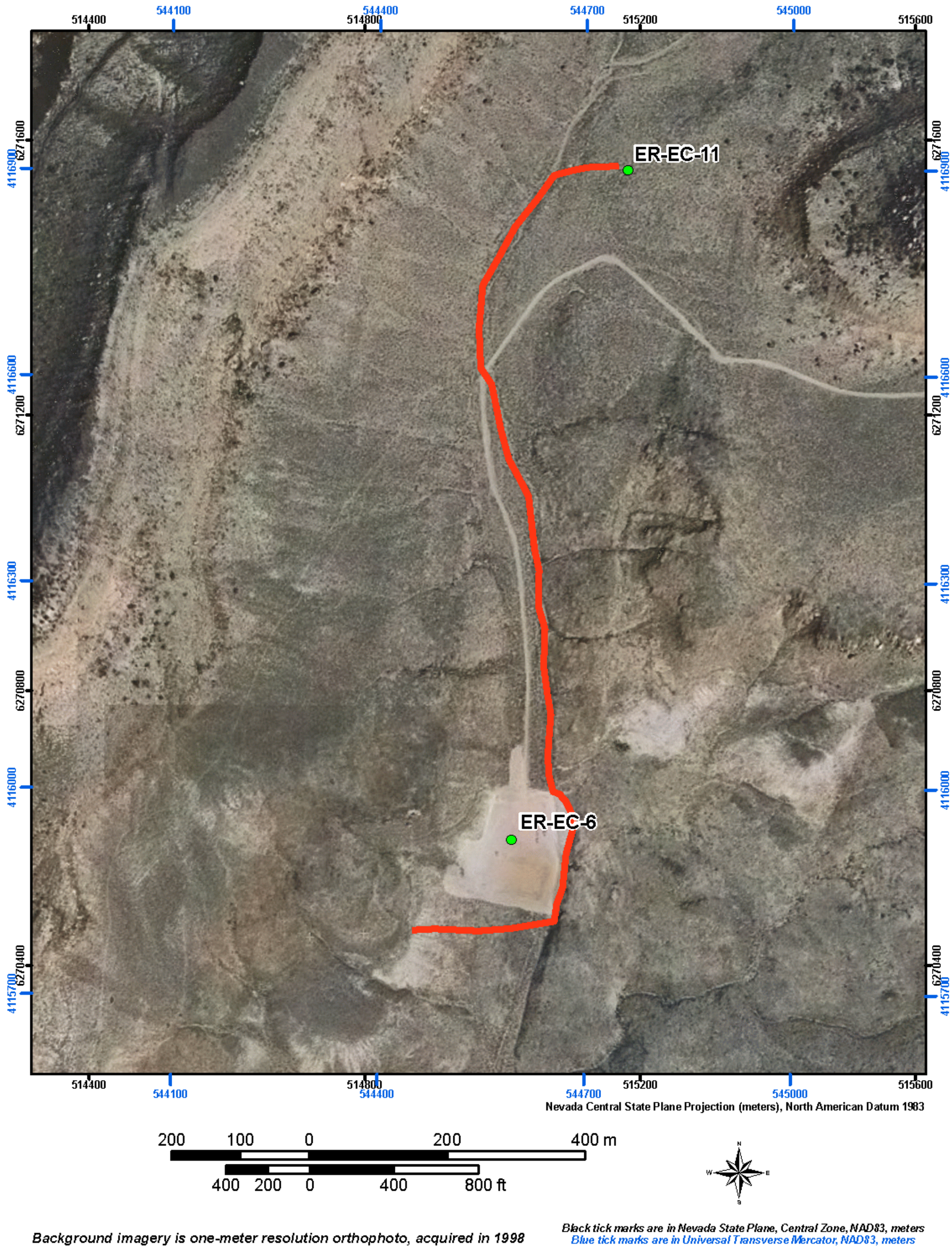


Figure 2-3
Orthophoto of the Well ER-EC-11 Area
Red line indicates flow path of uncontaminated drilling effluent pumped from sump #2.

road to Well ER-EC-6. It then continued flowing adjacent to the access road, past the Well ER-EC-6 construction pad, then to the west into a low area south of the pad, as marked on the orthophoto of the area shown in Figure 2-3.

A second pump was added at sump #2 on October 10, 2009, so that fluid could be pumped to the infiltration area at a higher rate.

2.4.2 Radionuclide Monitoring

Samples of drilling effluent were collected hourly by N-I and analyzed on site by RCTs for the presence of tritium. As detailed in the N-I data report (N-I, 2010), the onsite monitoring results indicated that tritium levels measured in the drilling fluid exceeded background levels, as measured by field instruments, starting at the depth of approximately 828.8 m (2,719 ft), while drilling in the rhyolite of Benham (BA).

Inconsistencies in field tritium analyses resulted in several samples being re-analyzed on site by RCTs. Samples with high levels were re-run, and most repeat results showed much lower tritium levels that were well below the SDWA limit of 20,000 pCi/L (U.S. Code of Federal Regulations, 2004). For example, a sample collected while drilling at the depth of 453.5 m (1,488 ft) had a reported tritium level of 6,805 pCi/L. The sample was counted an additional three times, and a final tritium level of 1,514 pCi/L was finally reported (N-I, 2010). The erroneous high readings are believed to be due to chemoluminescence.

To verify field measurements of tritium levels, duplicate samples of the drilling effluent were sent for analysis by the NSTec Radiological Control organization and to the N-I Radiation Services laboratory, both located in Mercury, Nevada. In addition, 29 composite samples of drilling effluent collected while drilling in the interval 451.1 to 1,097.3 m (1,480 to 3,600 ft) were sent to LLNL for analysis (LLNL, 2009). For further verification of tritium levels, 26 samples of drilling effluent collected while drilling below the depth of 451.1 m (1,480 ft) were sent to an offsite laboratory for radionuclide analysis, along with a sample from sump #2 and five depth-discrete groundwater characterization samples collected by DRI (N-I, 2010). N-I also attempted onsite gamma spectrometry analysis on fluid and solid (drill cuttings) samples, but for all samples analyzed, levels were less than the detection limit of the instrument (N-I, 2010). See Section 5.4 for more information about fluid samples collected from Well ER-EC-11.

Based on the 29 analyses by LLNL, tritium levels above the lower limit of detection were found in samples taken from the depth interval 856.5 to 990.6 m (2,810 to 3,250 ft) (LLNL, 2009; see also Section 5.5 of this report). Tritium values of the nine samples in this interval ranged from 6,480 to 13,600 pCi/L and averaged 12,431 pCi/L, which is below the SDWA standard for tritium of 20,000 pCi/L (U.S. Code of Federal Regulations, 2004). After the BA was cased off, and as drilling progressed through the underlying TCA and TSA, tritium levels remained below the MDC. The results of all these analyses are provided in N-I (2010).

No lead monitoring was performed. Lead monitoring is not initiated until discharge fluids exceed the UGTA Fluid Management Criteria for tritium (200,000 pCi/L), as specified in the Well ER-EC-11 Fluid Management Strategy Letter (SNJV, 2009e) approved by the Nevada Division of Environmental Protection. N-I personnel checked all down-hole equipment for lead and none was found.

2.4.3 Fluid Quality Objectives

All fluid quality objectives were met, as shown on the fluid management reporting form (Appendix B). The form lists volumes of solids (drill cuttings) and fluids produced during well-construction operations (vadose-zone drilling and saturated-zone drilling only; well development and aquifer testing are not addressed in this report). The volume of solids produced was calculated using the diameter of the borehole (from caliper logs) and the depth drilled, and includes added volume attributed to a rock bulking factor. The volumes of fluids listed on the report are estimates of total fluid production, and do not account for any infiltration or evaporation of fluids from the sumps.

3.0 Geologic Data Collection

3.1 Introduction

This section describes the sources of geologic data obtained from Well ER-EC-11 and the methods of data collection. Improving the understanding of the subsurface structure, stratigraphy, and hydrogeology in the southern portion of PM–OV CAU was among the primary objectives of Well ER-EC-11, so the proper collection of geologic and hydrogeologic data from the borehole was considered fundamental to successful completion of the drilling project.

Geologic data collected at Well ER-EC-11 consist of drill cuttings, sidewall core samples, and geophysical logs. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures, as listed in the SNJV FAWP (2009b).

3.2 Collection of Drill Cuttings

Composite drill cuttings were collected at 3-m (10-ft) intervals as drilling progressed. Eleven samples were collected by NSTec during construction of the conductor hole, from the surface to the depth of 33.5 m (0 to 110 ft). Below that depth, N-I personnel collected triplicate samples, each consisting of approximately 550 cubic centimeters of material, from 402 intervals from 33.5 m (110 ft) to TD. Samples are missing from two intervals, 926.6–929.6 m (3,040–3,050 ft) and 1,130.8–1,133.9 m (3,710–3,720 ft), due to poor returns and lost circulation.

These samples are stored under environmentally controlled, secure conditions at the USGS Geologic Data Center and Core Library in Mercury, Nevada. One of each triplicate sample set was sealed with custody tape at the rig site and remains sealed as an archive sample, one set was left unsealed in the original sample containers, and the third set was washed and stored according to standard USGS Core Library procedures. The washed set was used by NSTec geologists to construct the detailed lithologic log presented in Appendix C. The N-I field representative collected an additional set of reference drill cuttings samples from each of the cuttings intervals. This set was examined at the drill site for use in preparing field lithologic descriptions, and remains in the custody of N-I.

3.3 Sidewall Core Samples

Sidewall core samples were collected at selected depths in Well ER-EC-11 to verify the stratigraphy and lithology and for special analytical tests. Sample locations were selected by NSTec geologists and the N-I field representative on the basis of field lithologic logs, with consideration of borehole conditions determined from caliper logs. Baker Atlas used a percussion-gun sidewall coring tool to collect samples from two intervals. In the upper interval, between the depths of 527.3 and 969.3 m (1,730 and 3,180 ft), 50 sample depths were attempted, but only 14 cores were recovered due to misfires and other tool malfunctions. In the lower interval, between the depths of 1,034.2 and 1,264.3 m (3,393 and 4,148 ft), 25 sample depths were attempted and 20 cores were recovered. Baker Atlas also used a rotary sidewall coring tool to obtain sidewall samples in two intervals. In the upper interval, between 687.3 and 920.3 m (2,255 and 3,019.5 ft), all 14 rotary samples attempted were successfully recovered. In the lower interval, between the depths of 969.0 and 1,261.8 m (3,179 and 4,140 ft) all 19 rotary samples attempted were recovered. Table 3-1 summarizes the results of sidewall coring operations at Well ER-EC-11.

3.4 Sample Analysis

Seventeen samples of drill cuttings, one percussion sidewall core, and seven rotary sidewall cores from various depths were submitted to Comprehensive Volcanic Petrographics, LLC, for petrographic analysis. A split of the same 17 drill cuttings, 2 percussion sidewall cores, and 6 rotary sidewall cores from the similar depths were submitted to the Hydrology, Geochemistry, and Geology Group of the Earth and Environmental Sciences Division at LANL for mineralogic (x-ray diffraction) and chemical (x-ray fluorescence) analyses. The samples were selected after initial geologic evaluation of the cuttings and core samples and geophysical logs.

The primary purpose of the analytical data is to confirm stratigraphic identification and to characterize mineral alteration. In addition, the data provide detailed information on mineralogic composition, which will be used in transport modeling and will aid in evaluation of geophysical log signatures. The results of the petrographic analyses are reported in Warren (2010), and the results of the mineralogic and chemical analyses are reported in WoldeGabriel et al. (2010). Table 3-2 lists all samples analyzed.

3.5 Geophysical Log Data

Geophysical logs were run in the borehole to further characterize the lithology, structure, and hydrologic properties of the rocks encountered, and to evaluate borehole conditions. Geophysical logging was conducted in three stages (three different hole diameters) during drilling: (1) in the 50.8-cm (20.-in.) borehole, prior to opening the hole to 66.0 cm (26 in.) and before installation of the 20-in. surface casing at 504.9 m (1,656.4 ft); (2) in the 47.0-cm (18.5-in.) borehole, before installation of the 13⅜-in. intermediate casing; and (3) in the 31.1-cm (12.25-in.) borehole after the TD was reached at 1,264.3 m (4,148 ft), before installation of the 7⅝-in. completion casing. A complete listing of the logs, dates run, depths, and service companies is provided in Table 3-3.

Table 3-1
Sidewall Samples from Well ER-EC-11

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
527.3	1,730	SWC	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
527.3	1,730	SWC [d]	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
551.7	1,810	SWC	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
551.7	1,810	SWC [d]	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
551.7	1,810	SWC [e]	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
570.0	1,870	SWC	Misfire	rhyolite of Fluorspar Canyon	Nonwelded tuff, zeolitic
570.0	1,870	SWC [d]	3.51 (1.38)	rhyolite of Fluorspar Canyon	Nonwelded tuff, zeolitic
597.4	1,960	SWC	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
597.4	1,960	SWC [d]	3.18 (1.25)	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
608.1	1,995	SWC	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
608.1	1,995	SWC [d]	3.18 (1.25)	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
618.7	2,030	SWC	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
618.7	2,030	SWC [d]	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
635.2	2,084	SWC	Empty barrel	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
635.2	2,084	SWC [d]	Lost barrel	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
643.1	2,110	SWC	1.27 (0.50)	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
643.1	2,110	SWC [d]	Empty barrel	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
667.5	2,190	SWC	Misfire	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
667.5	2,190	SWC [d]	1.27 (0.50)	rhyolite of Fluorspar Canyon	Ash-flow tuff, nonwelded, zeolitic
687.3	2,255	SWC	Empty barrel	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
687.3	2,255	SWC [d]	2.54 (1.00)	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
687.3	2,255	RC	4.46 (1.75)	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
705.3	2,314	SWC	Misfire	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
705.3	2,314	SWC [d]	3.18 (1.25)	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
710.2	2,330	SWC	Misfire	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
710.2	2,330	SWC [d]	Empty barrel	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
710.2	2,330	SWC [e]	Misfire	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
710.2	2,330	RC	3.81 (1.50)	rhyolite of Fluorspar Canyon	Bedded tuff, zeolitic
723.0	2,372	SWC	Misfire	Timber Mountain Group, undivided	Bedded tuff, zeolitic
723.0	2,372	SWC [d]	2.54 (1.00)	Timber Mountain Group, undivided	Bedded tuff, zeolitic
723.0	2,372	RC	3.81 (1.50)	Timber Mountain Group, undivided	Bedded tuff, zeolitic
733.0	2,405	SWC	Misfire	rhyolite of Benham	Bedded tuff, zeolitic
733.0	2,405	SWC [d]	3.18 (1.25)	rhyolite of Benham	Bedded tuff, zeolitic
733.0	2,405	SWC [e]	Empty barrel	rhyolite of Benham	Bedded tuff, zeolitic

Table 3-1
Sidewall Samples from Well ER-EC-11 (continued)

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
744.6	2,443	SWC	Misfire	rhyolite of Benham	Bedded tuff, zeolitic
744.6	2,443	SWC [d]	1.91 (0.75)	rhyolite of Benham	Bedded tuff, zeolitic
744.6	2,443	RC	3.30 (1.30)	rhyolite of Benham	Bedded tuff, zeolitic
753.8	2,473	SWC	Misfire	rhyolite of Benham	Bedded tuff, zeolitic
753.8	2,473	SWC [d]	Empty barrel	rhyolite of Benham	Bedded tuff, zeolitic
760.2	2,494	SWC	2.54 (1.00)	rhyolite of Benham	Bedded tuff, zeolitic
760.2	2,494	SWC [d]	3.18 (1.25)	rhyolite of Benham	Bedded tuff, zeolitic
780.3	2,560	RC	3.81 (1.50)	rhyolite of Benham	Pumiceous lava
791.0	2,595	RC	3.30 (1.30)	rhyolite of Benham	Vitrophyric lava
812.4	2,666	RC	3.18 (1.25)	rhyolite of Benham	Rhyolitic lava
821.4	2,695	RC	1.91 (0.75)	rhyolite of Benham	Rhyolitic lava
833.6	2,735	RC	1.91 (0.75)	rhyolite of Benham	Rhyolitic lava
856.5	2,810	RC	2.54 (1.00)	rhyolite of Benham	Rhyolitic lava
884.1	2,901	RC	3.30 (1.30)	rhyolite of Benham	Rhyolitic lava
902.1	2,960	RC	2.54 (1.00)	rhyolite of Benham	Rhyolitic lava
906.8	2,975	RC	2.79 (1.10)	rhyolite of Benham	Rhyolitic lava
920.3	3,020	RC	3.18 (1.25)	rhyolite of Benham	Rhyolitic lava
932.7	3,060	SWC	Empty barrel	Paintbrush Group, undivided	Bedded tuff, zeolitic
932.7	3,060	SWC [d]	Misfire	Paintbrush Group, undivided	Bedded tuff, zeolitic
932.7	3,060	SWC [e]	Misfire	Paintbrush Group, undivided	Bedded tuff, zeolitic
944.9	3,100	SWC	Misfire	Paintbrush Group, undivided	Bedded tuff, zeolitic
944.9	3,100	SWC [d]	Misfire	Paintbrush Group, undivided	Bedded tuff, zeolitic
944.9	3,100	SWC [e]	Misfire	Paintbrush Group, undivided	Bedded tuff, zeolitic
955.5	3,135	SWC	Misfire	Paintbrush Group, undivided	Bedded tuff, zeolitic
955.5	3,135	SWC [d]	3.51 (1.38)	Paintbrush Group, undivided	Bedded tuff, zeolitic
963.2	3,160	SWC	Misfire	Paintbrush Group, undivided	Bedded tuff, zeolitic
963.2	3,160	SWC [d]	3.51 (1.38)	Paintbrush Group, undivided	Bedded tuff, zeolitic
969.0	3,179	RC	4.70 (1.85)	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
969.3	3,180	SWC	Misfire	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
969.3	3,180	SWC [d]	Misfire	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
969.3	3,180	SWC [e]	Misfire	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic

Table 3-1
Sidewall Samples from Well ER-EC-11 (continued)

Core Depth [a] meters	Core Depth [a] feet	Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
969.3	3,180	RC	3.43 (1.35)	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
991.8	3,254	RC	3.81 (1.50)	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
992.1	3,255	RC	1.52 (0.60)	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
999.7	3,280	RC	4.32 (1.70)	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
1,026.6	3,368	RC	3.81 (1.50)	Tiva Canyon Tuff	Ash-flow tuff, densely welded, quartzo-feldspathic
1,034.2	3,393	SWC	2.54 (1.00)	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
1,034.2	3,393	SWC [d]	3.18 (1.25)	Tiva Canyon Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
1,042.4	3,420	SWC	1.91 (0.75)	Tiva Canyon Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,042.4	3,420	SWC [d]	2.24 (0.88)	Tiva Canyon Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,049.1	3,442	SWC	Misfire	Paintbrush Group, undivided	Bedded tuff, quartzo-feldspathic and zeolitic
1,049.1	3,442	SWC [d]	3.18 (1.25)	Paintbrush Group, undivided	Bedded tuff, quartzo-feldspathic and zeolitic
1,049.1	3,442	RC	4.19 (1.65)	Paintbrush Group, undivided	Bedded tuff, quartzo-feldspathic and zeolitic
1,060.7	3,480	SWC	3.51 (1.38)	Paintbrush Group, undivided	Bedded tuff, quartzo-feldspathic and zeolitic
1,060.7	3,480	SWC [d]	3.81 (1.50)	Paintbrush Group, undivided	Bedded tuff, quartzo-feldspathic and zeolitic
1,072.9	3,520	SWC	1.60 (0.63)	Paintbrush Group, undivided	Bedded tuff, quartzo-feldspathic and zeolitic
1,072.9	3,520	SWC [d]	2.54 (1.00)	Paintbrush Group, undivided	Bedded tuff, quartzo-feldspathic and zeolitic
1,088.1	3,570	SWC	Misfire	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,088.1	3,570	SWC [d]	1.91 (0.75)	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,088.1	3,570	SWC [e]	3.18 (1.25)	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,088.1	3,570	RC	4.46 (1.75)	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic

Table 3-1
Sidewall Samples from Well ER-EC-11 (continued)

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
1,103.4	3,620	SWC	Mudcake	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,103.4	3,620	SWC [d]	Mudcake	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,103.4	3,620	RC	2.03 (0.80)	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,103.4	3,620	RC [d]	4.06 (1.60)	Topopah Spring Tuff	Ash-flow tuff, partially welded, quartzo-feldspathic
1,114.0	3,655	RC	3.18 (1.25)	Topopah Spring Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
1,133.6	3,719	RC	2.67 (1.05)	Topopah Spring Tuff	Ash-flow tuff, densely welded, quartzo-feldspathic
1,163.7	3,818	RC	3.30 (1.30)	Topopah Spring Tuff	Ash-flow tuff, densely welded, quartzo-feldspathic
1,187.2	3,895	RC	3.56 (1.40)	Topopah Spring Tuff	Ash-flow tuff, densely welded, quartzo-feldspathic
1,216.2	3,990	RC	4.70 (1.85)	Topopah Spring Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
1,223.5	4,014	RC	3.18 (1.25)	Topopah Spring Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
1,228.3	4,030	RC	3.30 (1.30)	Topopah Spring Tuff	Ash-flow tuff, moderately welded, quartzo-feldspathic
1,235.7	4,054	SWC	2.54 (1.00)	Calico Hills Formation (mafic-poor)	Ash-flow tuff, nonwelded, quartzo-feldspathic
1,235.7	4,054	SWC [d]	2.87 (1.13)	Calico Hills Formation (mafic-poor)	Ash-flow tuff, nonwelded, quartzo-feldspathic
1,240.5	4,070	RC	3.05 (1.20)	Calico Hills Formation (mafic-poor)	Ash-flow tuff, nonwelded, quartzo-feldspathic
1,245.1	4,085	SWC	3.51 (1.38)	Calico Hills Formation (mafic-poor)	Ash-flow tuff, nonwelded, quartzo-feldspathic
1,245.1	4,085	SWC [d]	2.87 (1.13)	Calico Hills Formation (mafic-poor)	Ash-flow tuff, nonwelded, quartzo-feldspathic
1,251.5	4,106	SWC	3.51 (1.38)	Calico Hills Formation (mafic-poor)	Ash-flow tuff, nonwelded, quartzo-feldspathic
1,251.5	4,106	SWC [d]	3.51 (1.38)	Calico Hills Formation (mafic-poor)	Ash-flow tuff, nonwelded, quartzo-feldspathic
1,257.3	4,125	SWC	3.18 (1.25)	Calico Hills Formation (mafic-poor)	Bedded tuff, quartzo-feldspathic and zeolitic
1,257.3	4,125	SWC [d]	2.54 (1.00)	Calico Hills Formation (mafic-poor)	Bedded tuff, quartzo-feldspathic and zeolitic

Table 3-1
Sidewall Samples from Well ER-EC-11 (continued)

Core Depth [a]		Tool Used [b]	Recovery [c] centimeters (inches)	Formation	Lithology
meters	feet				
1,261.9	4,140	RC	4.06 (1.60)	Calico Hills Formation (mafic-poor)	Bedded tuff, quartzo-feldspathic and zeolitic
1,264.3	4,148	SWC	Empty barrel	Calico Hills Formation (mafic-poor)	Bedded tuff, quartzo-feldspathic and zeolitic
1,264.3	4,148	WC [d]	2.54 (1.00)	Calico Hills Formation (mafic-poor)	Bedded tuff, quartzo-feldspathic and zeolitic

a All depths are drilled depths.

b SWC = percussion-gun sidewall coring tool; core diameter: 17.3 millimeters (0.68 in.).
RS = rotary sidewall coring tool; core diameter: 25.4 millimeters (1 in.).

c Shaded rows indicate samples attempted but not recovered.

d Second attempt.

e Third attempt.

Table 3-2
Rock Samples from Well ER-EC-11 Selected for Petrographic, Mineralogic, and Chemical Analysis

Depth [a]		Sample Identifier [b]	Analyses Performed [c]		
meters	feet		Petrographic	Mineralogic	Chemical
469.4	1,540	EREC11–1,540D	X	X	X
512.1	1,680	EREC11–1,680D	X	X	X
533.4	1,750	EREC11–1,750D	X	X	X
557.8	1,830	EREC11–1,830D	X	X [d]	X [d]
582.2	1,910	EREC11–1,910D	X	X	X
600.5	1,970	EREC11–1,970D	X	X	X
621.8	2,040	EREC11–2,040D	X	X	X
685.8	2,250	EREC11–2,250D	X	X	X
710.2	2,330	EREC11–2,330D	X	X	X
723.0	2,372	EREC11–2,372RS	X	X	X
744.6	2,443	EREC11–2,443RS	X	X	X
760.2	2,494	EREC11–2,494PS	X	X	X
791.0	2,595	EREC11–2,595RS	X	X	X
821.4	2,695	EREC11–2,695RS	X	N	N
859.5	2,820	EREC11–2,820D	X	X	X
877.8	2,880	EREC11–2,880D	X	X	X
920.5	3,020	EREC11–3,020D	X	X	X
944.9	3,100	EREC11–3,100D	X	X	X
955.5	3,135	EREC11–3,135D	X	X	X
1,049.1	3,442	EREC11–3,442RS	X	X	X
1,069.8	3,510	EREC11–3,510D	X	X	X
1,088.1	3,570	EREC11–3,570D	X	X	X
1,103.4	3,620	EREC11–3,620RS	X	X	X
1,245.1	4,085	EREC11–4,085PS	N	X	X
1,252.7	4,110	EREC11–4,110D	X	X	X
1,261.9	4,140	EREC11–4,140RS	X	X	X

a All depths are drilled depths.

b "D" in sample identifier indicates drill cuttings sample. "RS" indicates rotary sidewall core sample. "PS" indicates percussion-gun sidewall core sample.

c "**X**" indicates analysis complete. "**N**" indicates analysis not performed. Petrographic analysis of thin sections (Warren, 2010). Mineralogic analysis by x-ray diffraction and chemical analysis by x-ray fluorescence (WoldeGabriel et al., 2010). Analyses represent base of 3.0 m (10 ft) sample interval for drill cuttings samples.

d Sample separated into two fractions for analysis (WoldeGabriel et al., 2010).

Table 3-3
Well ER-EC-11 Geophysical Log Summary

Geophysical Log Type [a]	Log Purpose	Logging Service [b]	Date Logged	Run Number	Bottom of Logged Interval [c] meters (feet)	Top of Logged Interval [c] meters (feet)
Differential Temperature / Gamma Ray	Saturated zone: groundwater temperature; stratigraphic and depth correlation	BA	9/20/2009 10/06/2009 10/15/2009	TL-1 / GR-1 TL-2 / GR-8 TL-4 / GR-18	501.4 (1,645) 974.1 (3,196) 378.6 (1,242)	359.7 (1,180) 304.8 (1,000) 1,264.9 (4,150)
* 6-Arm Caliper / Aligned Borehole Profile / Gamma Ray	Borehole conditions, cement volume calculation; lithologic and stratigraphic correlation	BA	9/20/2009 10/06/2009 10/15/2009	CA6-1 / ORIT-1 / GR-2 CA6-2 / ORIT-5 / GR-9 CA6-3 / ORIT-9 / GR-19	503.8 (1,653) 971.1 (3,186) 1,261.0 (4,137)	4.6 (15) 472.4 (1,550) 945.0 (3,100)
* Digital Spectralog / * Gamma Ray	Stratigraphy, mineralogy, and natural and man-made radiation determination	BA	9/20/2009 10/06/2009 10/15/2009	SGR-1 / GR-3 SGR-2 / GR-10 SGR-3 / GR-20	495.6 (1,626) 962.6 (3,158) 1,253.3 (4,112)	6.4 (21) 457.2 (1,500) 893.1 (2,930)
* High Definition Induction / * Gamma Ray / Spontaneous Potential	Lithologic determination; saturation of formations; stratigraphic and depth correlation	BA	9/20/2009	HDIL-1 / GR-3 / SP-1	502.3 (1,648)	32.3 (106)
* Compensated Z-Densilog / * Compensated Neutron / Gamma Ray / Caliper	Stratigraphic and lithologic determination; identification of welding, alteration, rock porosity, and water content	BA	9/21/2009 10/06/2009 10/15/2009	ZDL-1 / CN-1 / GR-4 / CAL-1 ZDL-2 / CN-2 / GR-11 / CAL-2 ZDL-3 / CN-3 / GR-21/ CAL-3	505.1 (1,657) 973.2 (3,193) 1,261.0 (4,147)	32.3 (106) 442.0 (1,450) 856.5 (2,810)
Circumferential Borehole Imaging / Aligned Borehole Profile / Gamma Ray	Structural analysis, including fracture characterization; recognition of lithologic features	BA	9/21/2009 10/08/2009 10/16/2009	CBIL-1 / ORIT-4 / GR-7 CBIL-2 / ORIT-8 / GR-14 CBIL-3 / ORIT-12 / GR-24	501.4 (1,645) 973.5 (3,194) 1,264.0 (4,147)	449.6 (1,475) 493.8 (1,620) 965.3 (3,167)
* X-Multipole Array Acoustilog / Aligned Borehole Profile / Gamma Ray	Primary matrix porosity	BA	9/21/2009 10/07/2009 10/15/2009	XMAC-1 / ORIT-2 / GR-5 XMAC-2 / ORIT-6 / GR-12 XMAC-3 / ORIT-10 / GR-22	500.0 (1,640) 969.3 (3,180) 1,262.8 (4,143)	449.6 (1,475) 495.0 (1,624) 899.2 (2,950)
Resistivity Imaging / Aligned Borehole Profile / Gamma Ray / Caliper	Saturated zone: lithologic characterization, bedding dip, fracture and void analysis.	BA	9/21/2009 10/07/2009 10/15/2009	STAR-1 / ORIT-3 / GR-6 STAR-2 / ORIT-7 / GR-13 STAR-3 / ORIT-11 / GR-23	504.4 (1,655) 973.2 (3,193) 1,263.7 (4,146)	449.6 (1,475) 509.0 (1,670) 966.2 (3,170)
Percussion Gun Sidewall Tool / Gamma Ray	Geologic samples	BA	10/08/2009 10/08/2009 10/16/2009	SWC-1 / GR-15 SWC-2 / GR-16 SWC-4 / GR-25	969.2 (3,180) 969.2 (3,180) 1,264.3 (4,148)	527.3 (1,730) 527.3 (1,730) 1,034.2 (3,393)

Table 3-3
Well ER-EC-11 Geophysical Log Summary (continued)

Geophysical Log Type [a]	Log Purpose	Logging Service [b]	Date Logged	Run Number	Bottom of Logged Interval [c] meters (feet)	Top of Logged Interval [c] meters (feet)
* Dual Laterolog / * Gamma Ray / Spontaneous Potential	Lithologic determinations, identification of alteration, recognition of welding; distinguishing low versus high porosity	BA	10/06/2009 10/15/2009	DLL-1 / GR-10 / SP-2 DLL-2 / GR-20 / SP-3	970.2 (3,183) 1,260.7 (4,136)	504.7 (1,656) 965.3 (3,167)
Rotary Sidewall Coring Tool / Gamma Ray	Geologic samples	BA	10/08/2009 10/16/2009	RCOR-1 / GR-17 RCOR-2 / GR-26	920.5 (3,020) 1,261.9 (4,140)	687.3 (2,255) 969.0 (3,179)
Gamma Ray / Depth Determination	Depth determination	BA	10/16/2009	GR-27 / DD-1	1264.6 (4,150)	1,222.9 (4,012)
* Chemistry / * Temperature Log	Groundwater chemistry and temperature	DRI	10/09/2009 10/16/2009	Chem-1 / TL-3 Chem-2 / TL-5	976.0 (3,202) 1,267.7 (4,159)	450.8 (1,479) 944.9 (3,100)
* Heat Pulse Flow Log	Groundwater flow rate and direction	DRI	10/09/2009 10/17/2009	HPFlow-1 HPFlow-2	960.1 (3,150) 1,249.7 (4,100)	518.2 (1,700) 981.5 (3,220)
Nuclear Annulus Investigation Log	Determine height of stemming materials in annulus	Colog	10/17/2009	NAIL-1	1,261.9 (4,140)	298.7 (980)

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

b BA = Baker Atlas; DRI = Desert Research Institute; Colog = Layne Christensen Co., Colog Division

c Drilled depth

The logs are available from NSTec in Mercury, Nevada, and copies are on file at the office of N-I in Las Vegas, Nevada, and at the USGS Geologic Data Center and Core Library in Mercury, Nevada. Plots of selected geophysical data are provided in Appendix D.

The overall quality of the geophysical log data collected was good. However, the circumferential borehole imaging log tool ("CBIL") and the borehole resistivity imaging tool ("STAR") produced images with poor resolution in the first logged interval. This was due to the tools being run in a borehole that was 50.8 cm (20 in.) in diameter, which is larger than the tools' recommended maximum hole diameter of 40.6 cm (16-in.).

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4.0 Geology and Hydrogeology

4.1 Introduction

This section describes the geology and hydrogeology of Well ER-EC-11. The basis for the discussions here is the detailed geologic characterization of Well ER-EC-11 presented as a detailed lithologic log in Appendix C. The detailed lithologic log was developed using drill cuttings and sidewall core samples, geophysical logs, and drilling parameters. Data from petrographic, mineralogic, and chemical analyses on select lithologic samples from Well ER-EC-11 were incorporated into the detailed lithologic log. Information on bedding dip orientations and fractures was obtained from the interpretation of borehole image logs (Prothro, 2010).

4.2 Geology

This section is divided into three discussions relating to the geology of Well ER-EC-11. Section 4.2.1 briefly describes the geologic setting of the Pahute Mesa and Bench areas and Well ER-EC-11. The stratigraphic and lithologic units penetrated at the well are discussed in detail in Section 4.2.2. Because of the significant influence some alteration products have on the hydraulic properties of certain rocks, alteration of the rocks encountered at the well is discussed separately in Section 4.2.3. Detailed descriptions of the stratigraphy, lithology, and alteration of the rocks encountered are provided in the detailed lithologic log presented in Appendix C. Tables 4-1 and 4-2 provide the definitions of stratigraphic units and HSUs, respectively, used in various figures in this report.

4.2.1 Geologic Setting

Well ER-EC-11 is located within a geologically complex area that is mainly the result of volcanism and related structural movements associated with nearby calderas that formed approximately 9 to 14 million years ago (Ma) (Sawyer et al., 1994). The well was drilled below the southern rim of Pahute Mesa, a high volcanic plateau composed of lava and tuff of generally rhyolitic composition. The volcanic rocks that compose Pahute Mesa bury the Silent Canyon caldera complex (SCCC), which consists of two overlapping calderas—the Grouse Canyon caldera and the younger Area 20 caldera (Sawyer and Sargent, 1989). These calderas were formed by voluminous eruptions of ash-flow tuffs of generally rhyolitic composition, between approximately 14 and 13 Ma (Sawyer et al., 1994). The SCCC was eventually filled and buried by younger tuff and lava erupted from nearby vents and calderas between approximately 13 and 9 Ma. The Well ER-EC-11 site lies just inside the Area 20 caldera boundary (BN, 2002);

Table 4-1
Key to Stratigraphic Units and Symbols Used in this Report

Stratigraphic Unit	Map Symbol
Quaternary Surficial Deposits Young alluvial deposits Colluvium Intermediate alluvial deposits	 Qay QTc Qai
Thirsty Canyon Group, undivided Trail Ridge Tuff Pahute Mesa Tuff Rocket Wash Tuff	Tt Ttt Ttp Ttr
Beatty Wash Formation	Tfb
Ammonia Tanks Tuff mafic-rich Ammonia Tanks Tuff mafic-poor Ammonia Tanks Tuff bedded Ammonia Tanks Tuff	Tma Tmar Tmap Tmab
rhyolite of Tannenbaum Hill	Tmat (b)
debris-flow breccia	Tmatx
Rainier Mesa Tuff mafic-rich Rainier Mesa Tuff mafic-poor Rainier Mesa Tuff	Tmr Tmrr Tmrp
rhyolite of Fluorspar Canyon	Tmrf
Paintbrush Group, undivided	Tp
rhyolite of Benham [a]	Tpb
rhyolite of Scrugham Peak [a]	Tps
Tuff of Pinyon Pass	Tpcy
Tiva Canyon Tuff Pahute Mesa lobe of the Tiva Canyon Tuff	Tpc Tpcm
Topopah Spring Tuff Pahute Mesa lobe of the Topopah Spring Tuff	Tpt Tptm
Calico Hills Formation mafic-poor Calico Hills Formation	Th Thp
Crater Flat Group	Tc
rhyolite of Inlet	Tci
rhyolite of Kearsarge	Tcpk
rhyolite of EC-1	Tcpe
Bullfrog Tuff	Tcb

a Unit included within upper Paintbrush Group rhyolites (Tpu) on Figure 4-1.

Table 4-2
Key to Hydrostratigraphic Units and Symbols Used in this Report

Hydrostratigraphic Unit	Symbol
Thirsty Canyon volcanic aquifer	TCVA
Timber Mountain composite unit	TMCM
Tannenbaum Hill lava-flow aquifer	THLFA
Tannenbaum Hill composite unit	THCM
Timber Mountain aquifer	TMA
Fluorspar Canyon confining unit	FCCU
Paintbrush vitric-tuff aquifer	PVTA
Benham aquifer	BA
upper Paintbrush confining unit	UPCU
Tiva Canyon aquifer	TCA
lower Paintbrush confining unit	LPCU
Topopah Spring aquifer	TSA
Calico Hills zeolitic composite unit	CHZCM
Calico Hills confining unit	CHCU
Inlet aquifer	IA
Crater Flat composite unit	CFCM
Bullfrog confining unit	BFCU

however, the TD is well above the volcanic rocks associated with the formation of the Area 20 caldera. Well ER-EC-11 also is located approximately 3,960 m (13,000 ft) northeast of the buried northern structural margin of the TMCC (BN, 2002). This caldera complex formed as a result of the eruptions of the Rainier Mesa Tuff and Ammonia Tanks Tuff 11.6 and 11.45 Ma, respectively (Sawyer et al., 1994). The youngest volcanic units in the area are a series of ash-flow tuffs erupted from the Black Mountain caldera located approximately 13 kilometers (8 miles) northwest of the well (Slate et al., 1999). These units include the 9.4-Ma Rocket Wash and Pahute Mesa tuffs and the 9.3-Ma Trail Ridge Tuff.

The well site is constructed on the Ammonia Tanks Tuff (Slate et al., 1999), which overlies a thick pile of rhyolite lava extruded onto a structural bench (Figure 4-1). This structural bench, designated the Northwestern Timber Mountain Bench by Warren et al. (2000), but referred to as simply the Bench in this and other Phase II documents (SNJV, 2009a; NNSA/NSO, 2010a), is bounded on the north by the NTMMSZ and on the south by the buried northern structural margin of the TMCC (Figure 1-3). The NTMMSZ is a west-northwest-trending, buried structural zone that was first recognized geophysically (Mankinen et al., 1999; Grauch et al., 1999) and subsequently confirmed by data from PM–OV Phase I drilling (DOE/NV, 2000b). The NTMMSZ is a down-on-the-southwest fault (or fault zone) that displaces rock units as young as the Rainier Mesa Tuff by more than 300 m (1,000 ft). The NTMMSZ appears to be related to the formation of the TMCC, with major movement certainly occurring between the eruptions of the Rainier Mesa Tuff and Ammonia Tanks Tuff (DOE/NV, 2000b), but possibly also prior to the eruption of the Rainier Mesa Tuff, based on information obtained from Well ER-EC-11.

Numerous normal faults have been mapped at the surface on Pahute Mesa, particularly east of the Boxcar fault (Slate et al., 1999; Figure 4-1). These faults generally strike in a northerly direction and dip to the west. Several normal faults similar in orientation to those on Pahute Mesa are mapped at the surface in the vicinity of Well ER-EC-11 (Byers and Cummings, 1967; Slate et al., 1999). The faults in the vicinity of Well ER-EC-11, however, are generally shorter and more discontinuous, with only minor amounts of offset of surface units.

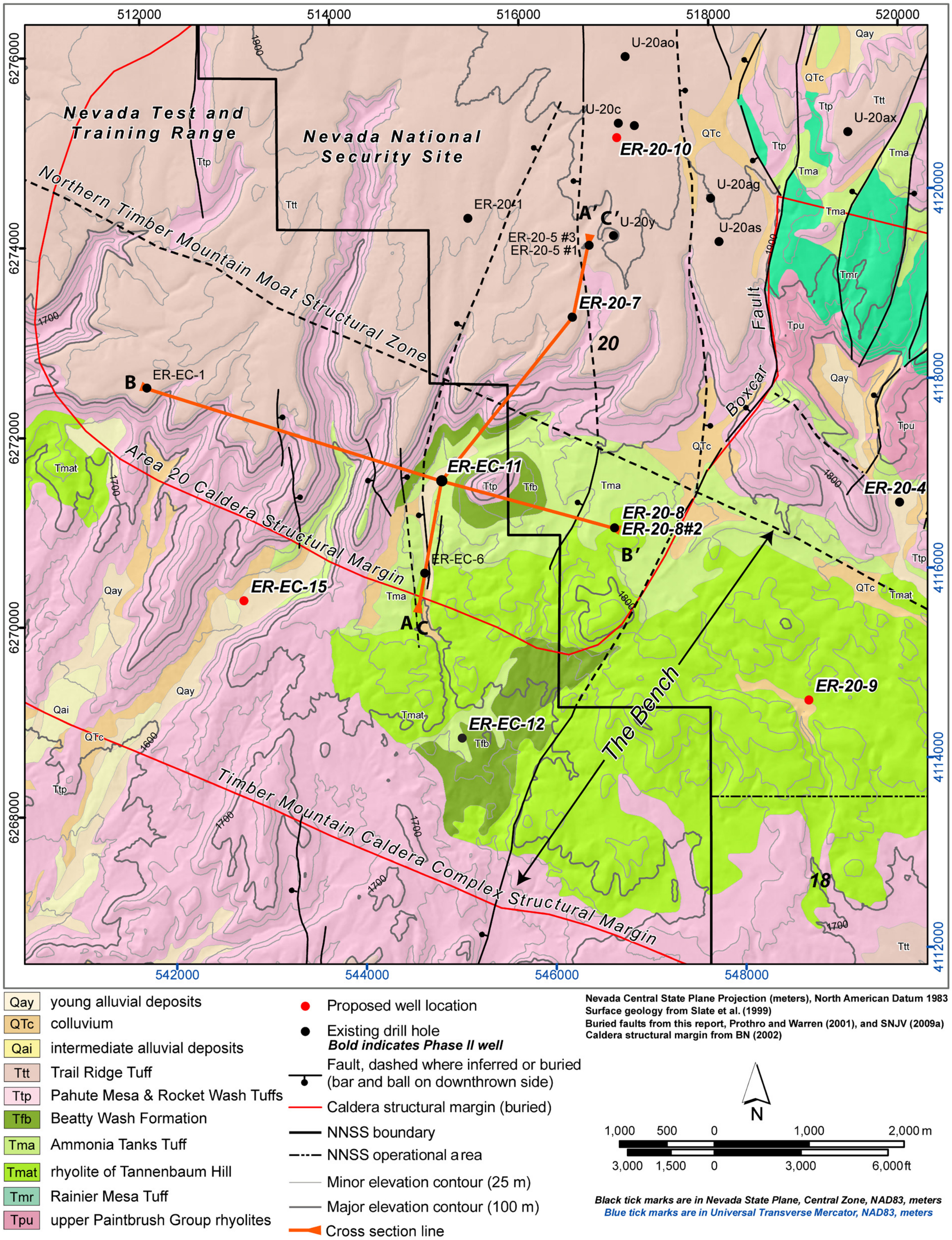

Figure 4-1
Surface Geologic Map of the Well ER-EC-11 Site

4.2.2 Stratigraphy and Lithology

The stratigraphic and lithologic units penetrated at Well ER-EC-11 are illustrated in Figure 4-2, and a preliminary interpretation of the distribution of stratigraphic units in the vicinity of the well is shown in cross section in Figures 4-3 and 4-4. The determination of the stratigraphic and lithologic units penetrated by Well ER-EC-11 was aided by examination of, and correlation with, nearby Wells ER-20-8 and ER-20-8#2 (located 1,911 m [6,267 ft] southeast of the Well ER-EC-11 site). These two wells were the second and third holes drilled in the 2009 Phase II drilling campaign (NNSA/NSO, 2010b). In addition, geologic information from Well ER-EC-6 (DOE/NV, 2000b) and Well ER-EC-1 (DOE/NV, 2000c), located south and northwest of Well ER-EC-11, respectively, were also correlated to Well ER-EC-11.

It should be noted throughout the following discussions that the cross sections in Figures 4-3 and 4-4 do not necessarily reflect the detailed bedding dip patterns described from the borehole image logs. Bedding dip patterns from boreholes in complex volcanic environments like the Bench can be difficult to interpret and to extrapolate beyond the near-wellbore region because they represent the cumulative dip of complex structural and depositional processes, some of which may be local in origin (e.g., draping over paleo-topography). The significance of bedding dip patterns acquired from all the Phase II wells, as well as from previous Phase I wells, however, will be evaluated together with other geologic data after completion of Phase II data acquisition.

Drilling at Well ER-EC-11 began in the partially welded Ammonia Tanks Tuff of the Timber Mountain Group, which forms the ground surface in the vicinity of the well (Byers and Cummings, 1967; Slate et al., 1999) (Figure 4-1). The Ammonia Tanks Tuff was encountered from the surface to the depth of 81.1 m (266 ft). The mafic-rich member of the Ammonia Tanks Tuff was identified in the upper 494 m (162 ft), and the mafic-poor member was identified in the depth interval 49.4 to 59.7 m (162 to 196 ft). The lowermost 21.4 m (70 ft) of Ammonia Tanks Tuff consists of vitric bedded tuff. The stratigraphic assignment of the Ammonia Tanks Tuff is based on surface mapping (Byers and Cummings, 1967), ash-flow tuff lithology, and mineralogic assemblage, including the presence of quartz phenocrysts, minor to common biotite, relatively abundant lithic fragments, and sphene. The relatively thin occurrence of the Ammonia Tanks Tuff in Well ER-EC-11 indicates that the unit is an extra-caldera out-flow sheet and that the well location lies outside of the Ammonia Tanks caldera.

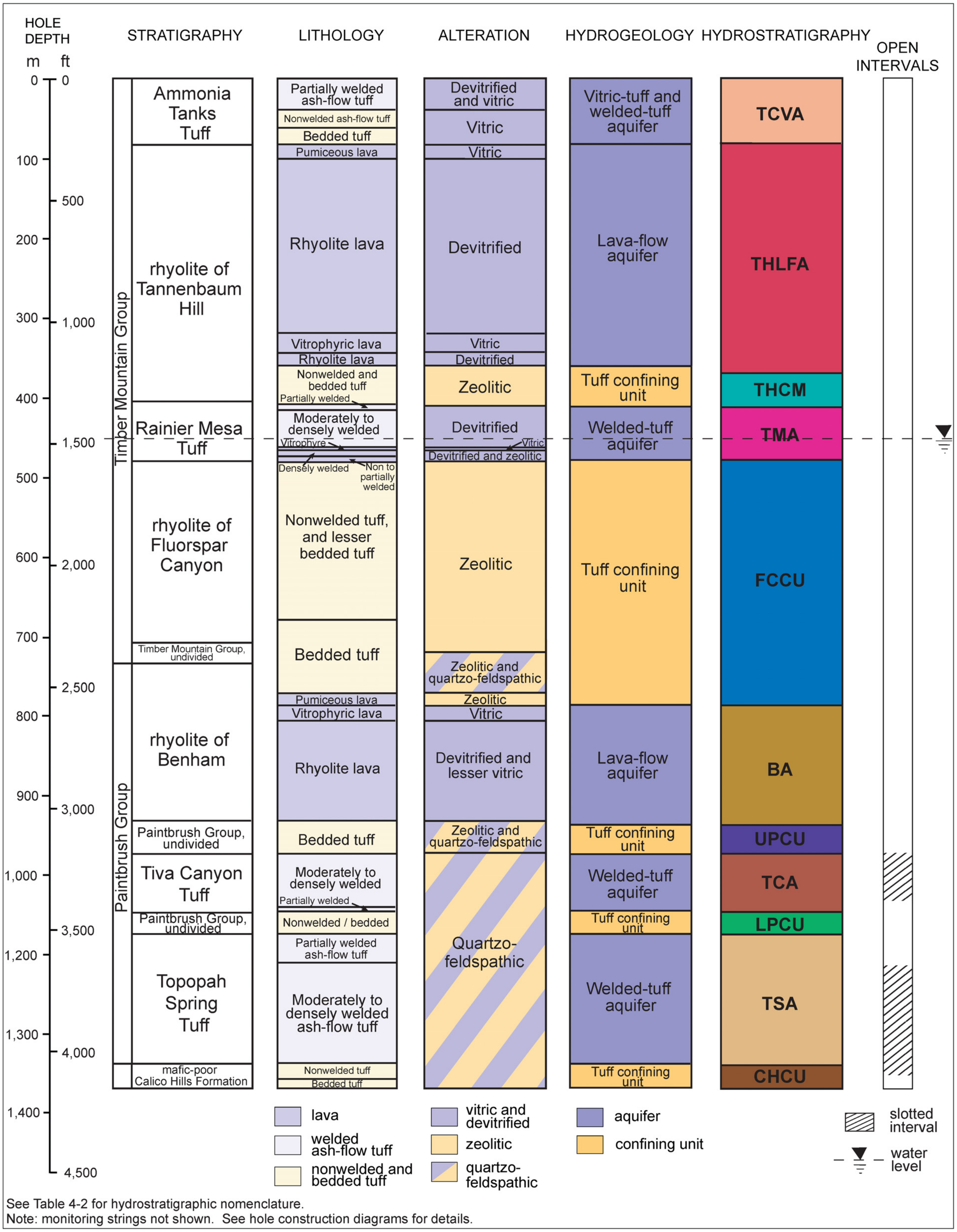

Figure 4-2
Geology and Hydrogeology of Well ER-EC-11

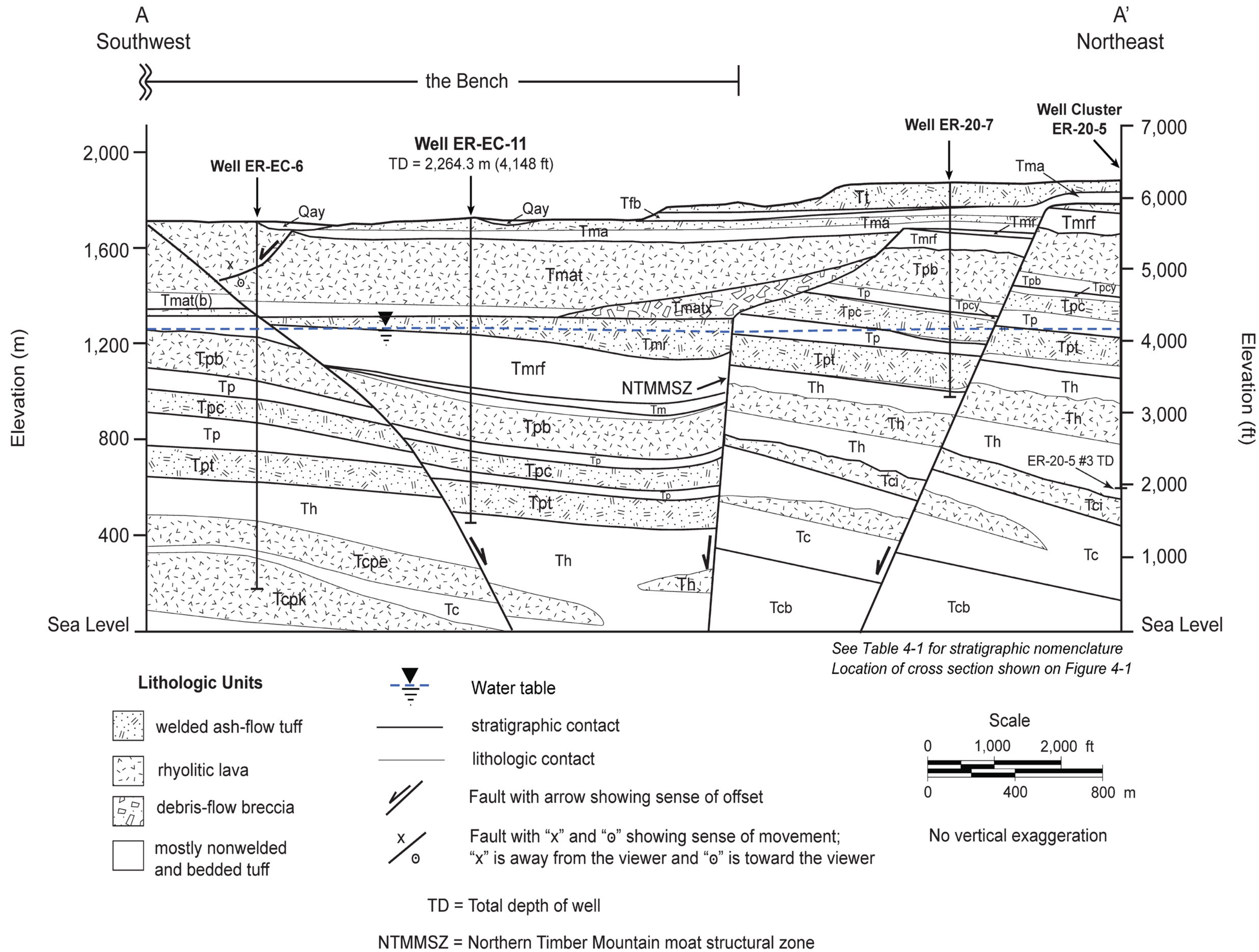

Figure 4-3
Southwest–Northeast Geologic Cross Section A–A' through Well ER-EC-11

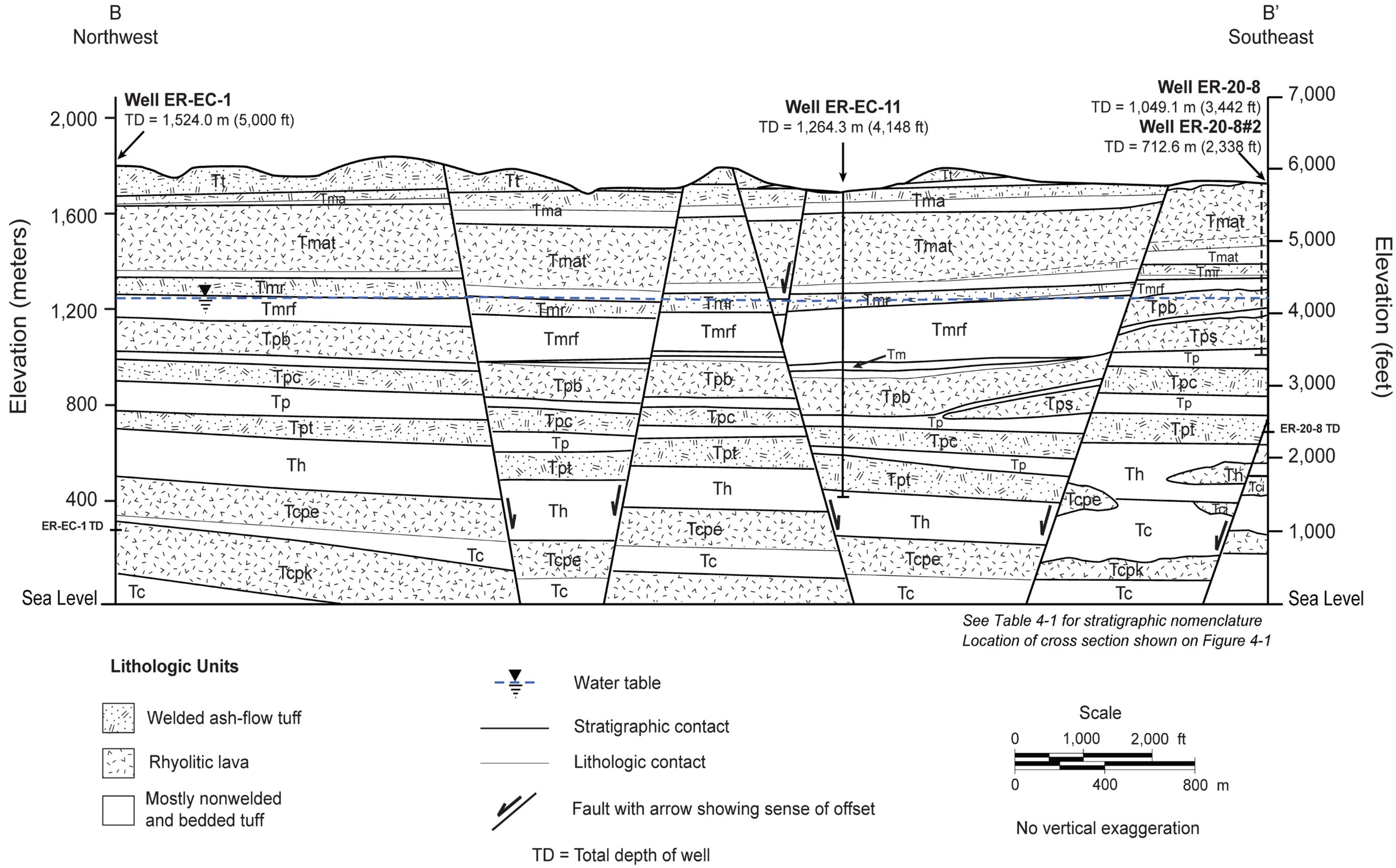

Figure 4-4
Northwest–Southeast Geologic Cross Section B–B’ through Well ER-EC-11

Below the Ammonia Tanks Tuff, Well ER-EC-11 penetrated the rhyolite of Tannenbaum Hill, in the Timber Mountain Group, consisting of a 276.8-m (908-ft) thick rhyolitic lava flow that overlies 44.5 m (146 ft) of bedded tuff. The upper 21.0 m (69 ft) of the lava flow is vitric and pumiceous. This upper pumiceous zone overlies 216.1 m (709 ft) of devitrified rhyolite lava that represents the dense stony interior portion of the flow. The devitrified rhyolite lava overlies 21.4 m (70 ft) of grayish-black vitrophyric lava. This lower vitrophyric lava is underlain by 18.3 m (60 ft) of devitrified and less vitric rhyolite lava that may represent the basal flow breccia of the flow. The lowermost 44.5 m (146 ft) of the rhyolite of Tannenbaum Hill consists of zeolitic bedded tuff. The stratigraphic assignment of the rhyolite of Tannenbaum Hill is based on comparisons with nearby surface exposures (Byers and Cummings, 1967; Slate et al., 1999), lava-flow lithology, stratigraphic position below the Ammonia Tanks Tuff and above the Rainier Mesa Tuff (see discussion below), and mineralogic assemblage, including the presence of quartz phenocrysts and rare to minor biotite. The rhyolite of Tannenbaum Hill was deposited onto the Bench during a time period between the caldera-forming eruptions of the Rainier Mesa and Ammonia Tanks Tuffs.

Below the rhyolite of Tannenbaum Hill, Well ER-EC-11 penetrated 76.2 m (250 ft) of nonwelded to vitrophyric ash-flow tuff assigned to the Rainier Mesa Tuff, also a formation of the Timber Mountain Group. The interval exhibits a typical ash-flow tuff welding profile, with a non- to partially welded top and bottom, and a highly welded interior, including a prominent vitrophyre. The assignment of Rainier Mesa Tuff is based on the stratigraphic position of the interval below the rhyolite of Tannenbaum Hill and above the quartz-deficient units of the Paintbrush Group (see discussion below), ash-flow tuff lithology, and mineralogic assemblage, which includes quartz phenocrysts and no sphene. The relatively thin occurrence of the Rainier Mesa Tuff in Well ER-EC-11 indicates that the unit is an extra-caldera out-flow sheet and that the well location lies outside of the Rainier Mesa caldera.

Below the Rainier Mesa Tuff, Well ER-EC-11 penetrated 230.4 m (756 ft) of quartz-bearing, zeolitic, nonwelded, and bedded tuffs. The presence of quartz phenocrysts and the stratigraphic position of the interval directly beneath the Rainier Mesa Tuff indicate that this interval is rhyolite of Fluorspar Canyon, which is typically the basal formation of the Timber Mountain Group in the area. The rhyolite of Fluorspar Canyon is more than 167.7 m (550 ft) thicker in Well ER-EC-11 than in nearby Wells ER-20-8 (NNSA/NSO, 2010b) and ER-EC-6 (DOE/NV, 2000b). Above 676.7 m (2,220 ft) in Well ER-EC-11, this unit consists mostly of a series of nonwelded tuffs separated by thinner intervals of bedded tuffs. Below 676.7 m (2,220 ft), bedded tuffs dominate. Analysis of borehole image logs indicates that most bedding contacts above approximately 646.2 m (2,120 ft) dip less than 8 degrees to the west-northwest. Below approximately 646.2 m (2,120 ft), bedding within the rhyolite of Fluorspar Canyon also dips mostly less than 8 degrees, but in a slightly more northwest direction (Prothro, 2010).

A 21.3-m (70-ft) interval of quartz-bearing, zeolitic, pumice-rich bedded tuff was penetrated below the rhyolite of Fluorspar Canyon. Detailed petrographic analyses from two depths within the interval suggest that these rocks, although quartz-bearing, are not rhyolite of Fluorspar Canyon. Based on its stratigraphic position above the Paintbrush Group and on the presence of quartz, the interval is assigned stratigraphically to the Timber Mountain Group. However, detailed petrographic analyses indicate that these tuffs likely represent transitional units between the Paintbrush Group and Timber Mountain eruptive cycles, such as the rhyolite of Windy Wash and rhyolite of the Loop (Warren, 2010). Bedding within the interval dips less than 10 degrees to the north-northeast, a direction that is 90 degrees different from that of the overlying rhyolite of Fluorspar Canyon, but similar to that of the underlying Paintbrush Group bedded tuffs (Prothro, 2010).

The next major stratigraphic interval in Well ER-EC-11 is the Paintbrush Group, which consists mainly of rhyolitic lava and ash-flow tuff and is characterized by the almost complete absence of quartz phenocrysts (Slate et al., 1999). In Well ER-EC-11, lava and bedded tuff compose the upper portion of the Paintbrush Group, and welded ash-flow tuff and bedded tuff compose the lower portion. The Paintbrush Group was erupted from calderas and related vents that are approximately spatially coincident with the TMCC, between 12.7 and 12.8 Ma (Sawyer et al., 1994).

The first (youngest) Paintbrush Group unit encountered below the Timber Mountain Group in Well ER-EC-11 is the rhyolite of Benham. Well ER-EC-11 encountered zeolitic and quartzo-feldspathic bedded tuff in the upper 39.3 m (129 ft) of the interval. Bedding within the interval dips north-northeast, similar to the overlying unit. Bedding-dip magnitudes, however, increase with depth from less than 10 degrees near the top of the interval to more than 20 degrees near the contact with the underlying lava (Prothro, 2010). This increase in dip with depth is interpreted to be the result of in-filling of paleo-topography formed on top of the underlying lava flow.

The bedded tuff is underlain by a 160.6-m (527-ft) thick rhyolitic lava flow. The top of the flow consists of 16.8 m (55 ft) of zeolitic pumiceous lava, of which the lower 8.8 m (29 ft) is silicified. A thin interval (17.7 m [58 ft]) of conspicuously dark yellowish-orange vitrophyric lava underlies the pumiceous lava. This upper vitrophyric lava is underlain by 25.0 m (82 ft) of rhyolitic lava that is a heterogeneous mixture of vitric and perlitic lava, devitrified lava, and silicified flow breccia. The lower 101.2 m (332 ft) consists of devitrified rhyolitic lava that is flow-banded in places. The lower contact of the rhyolite of Benham is uncertain because a wash-out in the borehole wall in the interval 923.5 to 929.6 m (3,030 to 3,050 ft) reduced geophysical log quality in that interval, and no sample was collected in the interval 926.6 to 929.6 m (3,040 to 3,050 ft).

The rhyolite of Benham was identified on the basis of its lava-flow lithology, its stratigraphic position at the top of the Paintbrush Group section, and its mineralogic assemblage that includes minor biotite, very rare quartz phenocrysts, and sphene. As expected in a lava-flow interval, lithic and pumice fragments (i.e., pyroclasts) are noticeably absent. Lava of the rhyolite of Benham occurs throughout the area. It is exposed at the surface along the up-thrown side of the Boxcar fault approximately 3,700 m (12,000 ft) northeast of the well site (map unit Trpq in Byers and Cummings, 1967) and is present in all wells drilled in the area west of the Boxcar fault (Prothro and Warren, 2001; DOE/NV, 2000b; 2000c; NNSA/NSO, 2010a; 2010b).

A 38.4-m (126-ft) interval of quartzo-feldspathic and zeolitic bedded tuff was penetrated below the rhyolite of Benham. The absence of quartz phenocrysts throughout the interval and stratigraphic position below the rhyolite of Benham and above the Tiva Canyon Tuff (see discussion below) indicate that the rocks within the interval belong to the Paintbrush Group. Analysis of borehole image logs from Well ER-EC-11 indicates that bedding within this interval dips approximately 10 degrees to the west-northwest (Prothro, 2010).

Below the Paintbrush Group bedded tuffs, Well ER-EC-11 encountered quartzo-feldspathic, nonwelded to densely welded, ash-flow tuff of the Tiva Canyon Tuff, also part of the Paintbrush Group, in the interval from 968.7 to 1,045.5 m (3,178 to 3,430 ft). The interior of the ash-flow tuff consists of 24.4 m (80 ft) of densely welded tuff that is enclosed within 43.9 m (144 ft) of moderately welded tuff. The lower 8.5 m (28 ft) of the Tiva Canyon Tuff is partially welded to nonwelded ash-flow tuff. Lithophysae were observed in the borehole image logs within the moderately to densely welded portions of the unit. Borehole image logs also indicate that most fractures occur in a single cluster near the middle of the unit (Prothro, 2010). The Tiva Canyon Tuff was identified by the relatively thick ash-flow tuff lithology, stratigraphic position between the rhyolite of Benham and the underlying Topopah Spring Tuff (see discussion below), and its mineralogic assemblage, which includes a notable absence of quartz and the presence of biotite. The Tiva Canyon Tuff was erupted 12.7 Ma from the Claim Canyon caldera, located south of the well site, between Timber Mountain and Yucca Mountain (Sawyer et al., 1994). The northern portion of the Claim Canyon caldera, including its northern margin, was obliterated by the younger TMCC. The relatively thin occurrence of the Tiva Canyon Tuff in Well ER-EC-11 is consistent with a location outside of the Claim Canyon caldera.

Beneath the Tiva Canyon Tuff, a 33.6-m (110-ft) interval of bedded and nonwelded tuff was penetrated. The alteration of the tuff in this interval is quartzo-feldspathic and zeolitic. The position of these tuffs between two Paintbrush Group ash-flow tuffs, the Tiva Canyon Tuff and the Topopah Spring Tuff (see discussion below), strongly suggests that they also belong to the Paintbrush Group. However, detailed petrographic analyses of two samples from the interval suggest that the interval may include other stratigraphic units coeval with the Paintbrush Group or possibly even units older than the Paintbrush Group (i.e., mafic-poor Calico Hills Formation) deposited by debris flows (Warren, 2010). Analysis of borehole image logs indicates that the bedded tuff within the interval dips approximately 15 degrees to the southeast (Prothro, 2010).

The Topopah Spring Tuff was encountered at the base of the Paintbrush Group at 1,079.0 m (3,540 ft). This unit consists of an unusually thick (28.7 m [94 ft]) partially welded zone at the top, which overlies 127.5 m (418 ft) of moderately to densely welded tuff. The Topopah Spring Tuff has strong quartzo-feldspathic alteration throughout the entire interval. Analysis of borehole image logs indicates that most fractures occur in the upper half of the unit (Prothro, 2010). The Topopah Spring Tuff was identified by its ash-flow tuff lithology, the absence of quartz phenocrysts, and its stratigraphic position at the base of the Paintbrush Group section. The Topopah Spring Tuff was erupted 12.8 Ma from a caldera whose location is unknown but is likely buried beneath the TMCC (Sawyer et al., 1994). The relatively thick occurrence of Topopah Spring Tuff, although probably too thick to be intra-caldera, is consistent with a nearby caldera source.

The mafic-poor Calico Hills Formation was encountered at 1,235.0 m (4,052 ft). The upper 17.1 m (56 ft) of the interval consists of quartzo-feldspathic nonwelded tuff. Well ER-EC-11 reached TD within quartzo-feldspathic and zeolitic bedded tuff that underlies the nonwelded tuff. The mafic-poor Calico Hills Formation is recognized by its stratigraphic position below the Topopah Spring Tuff, the presence of quartz phenocrysts, and the generally rare occurrence of felsic phenocrysts and biotite.

4.2.3 Alteration

The volcanic rocks penetrated at Well ER-EC-11 show a variety of secondary alteration mineral assemblages that can significantly affect both flow and transport properties. These mineral assemblages result from three main alteration processes: devitrification, zeolitization, and quartzo-feldspathic alteration.

Vitric Rocks (unaltered). Above 357.8 m (1,174 ft) in Well ER-EC-11, low-density, high-porosity units such as nonwelded and bedded tuffs and pumiceous lavas that are composed primarily of ash-size glass shards are unaltered and retain their original vitric character. Also, vitrophyric zones within both lavas and welded tuffs are typically very dense, low-porosity zones, and although they may be below the upper level of alteration, they tend to be resistant to alteration processes and, thus, tend to retain their vitric (i.e., glassy) character.

Devitrification. The interior portions of lava flows and welded ash-flow tuffs are typically devitrified as a result of the original glass being converted to microcrystalline quartz and feldspar during cooling, compaction, and degassing shortly after emplacement. In Well ER-EC-11, most of the interior portions of the lavas of the rhyolite of Tannenbaum Hill and rhyolite of Benham are devitrified. The welded portions of the Ammonia Tanks Tuff and Rainier Mesa Tuff are also mostly devitrified.

Zeolitization. Below 357.8 m (1,174 ft) to a depth of 930.2 m (3,052 ft), the low-density, high-porosity rock types have been zeolitized, resulting in the original glass being converted to zeolite minerals such as clinoptilolite and mordenite.

Quartzo-Feldspathic Alteration. Below the depth of 930.2 m (3,052 ft), quartzo-feldspathic alteration is pervasive. In this zone of alteration, quartzo-feldspathic minerals (i.e., quartz and feldspar) and the zeolite mordenite are the main alteration minerals for the initially porous rocks (nonwelded and bedded tuffs). The denser devitrified rocks such as the welded portions of the Tiva Canyon and Topopah Spring Tuffs can also undergo quartzo-feldspathic alteration. Because quartzo-feldspathic alteration yields a mineral assemblage that is very similar to devitrification (Prothro and Warren, 2001), the basic mineralogy of these units in Well ER-EC-11 is essentially unchanged.

Alteration Summary. Above 357.8 m (1,174 ft) in Well ER-EC-11, welded tuffs and lavas are mostly devitrified, and nonwelded and bedded tuffs and pumiceous lavas are unaltered and, thus, retain their original vitric character. Below 357.8 m (1,174 ft), which can be considered to be the top of pervasive zeolitization at the well location, nonwelded and bedded tuffs and pumiceous lava are zeolitic, with the zeolites clinoptilolite and mordenite being the main alteration minerals within these rocks. Below 930.2 m (3,052 ft), quartzo-feldspathic alteration minerals and the zeolite mordenite are the main alteration products.

4.3 Predicted and Actual Geology

The geology encountered at Well ER-EC-11 is significantly different than predicted prior to drilling (Figure 4-5). The main differences occur between the rhyolitic lavas of the rhyolite of Tannenbaum Hill and the rhyolite of Benham. Within this interval, the rhyolite of Fluorspar Canyon is more than 167.6 m (550 ft) thicker than in nearby Wells ER-EC-6 and ER-20-8 (DOE/NV, 2000b; NNSA/NSO. 2010b) and represents the greatest thickness of the rhyolite of Fluorspar Canyon encountered in any well in the area (BN, 2002). Units that are older than the rhyolite of Fluorspar Canyon in Well ER-EC-11, particularly the rhyolite of Benham, Tiva Canyon Tuff, and Topopah Spring Tuff, have similar thicknesses in nearby wells but occur at considerably lower elevations in Well ER-EC-11. This indicates that the anomalously thick rhyolite of Fluorspar Canyon in Well ER-EC-11 was deposited within a structural basin and that faulting within the Bench domain pre-dates the formation of the Rainier Mesa caldera. The shallow dips and lack of increasing dips with depth through the rhyolite of Fluorspar Canyon in Well ER-EC-11 suggest that, in the vicinity of the well, the structural basin subsided as a fault-bounded block, with little tilting.

The Rainier Mesa Tuff, which was found above the rhyolite of Fluorspar Canyon in Well ER-EC-11, was not initially predicted to occur in the well. The original predicted geology for Well ER-EC-11 was based on the geology encountered in nearby Well ER-EC-6, which did not encounter Rainier Mesa Tuff (DOE/NV, 2000b). In fact, prior to Phase II drilling, it was thought that Rainier Mesa Tuff was not present on much of the Bench, based on Phase I drilling results (e.g., Well ER-EC-6) and on the distribution of Rainier Mesa Tuff within the Southwest Pahute Mesa domain (i.e., that the unit thins to the south, toward the elevated rim of the Rainier Mesa caldera). However, Phase II Well ER-20-8, drilled just prior to Well ER-EC-11, did encounter Rainier Mesa Tuff, and thus its occurrence in Well ER-EC-11 was not surprising. Based on drilling results from Wells ER-20-8 and ER-EC-11, the Rainier Mesa Tuff is likely present within much of the Bench domain and may in fact be faulted out at Well ER-EC-6.

Below the rhyolite of Fluorspar Canyon in Well ER-EC-11, two stratigraphic intervals consisting of bedded tuff were unexpectedly encountered between the rhyolite of Fluorspar Canyon and the rhyolite of Benham lava. The upper interval is quartz-bearing and is, thus, likely related to the Timber Mountain Group or units that are transitional between the eruptive cycles of the Paintbrush and Timber Mountain Groups. The lower bedded interval is very quartz-poor and,

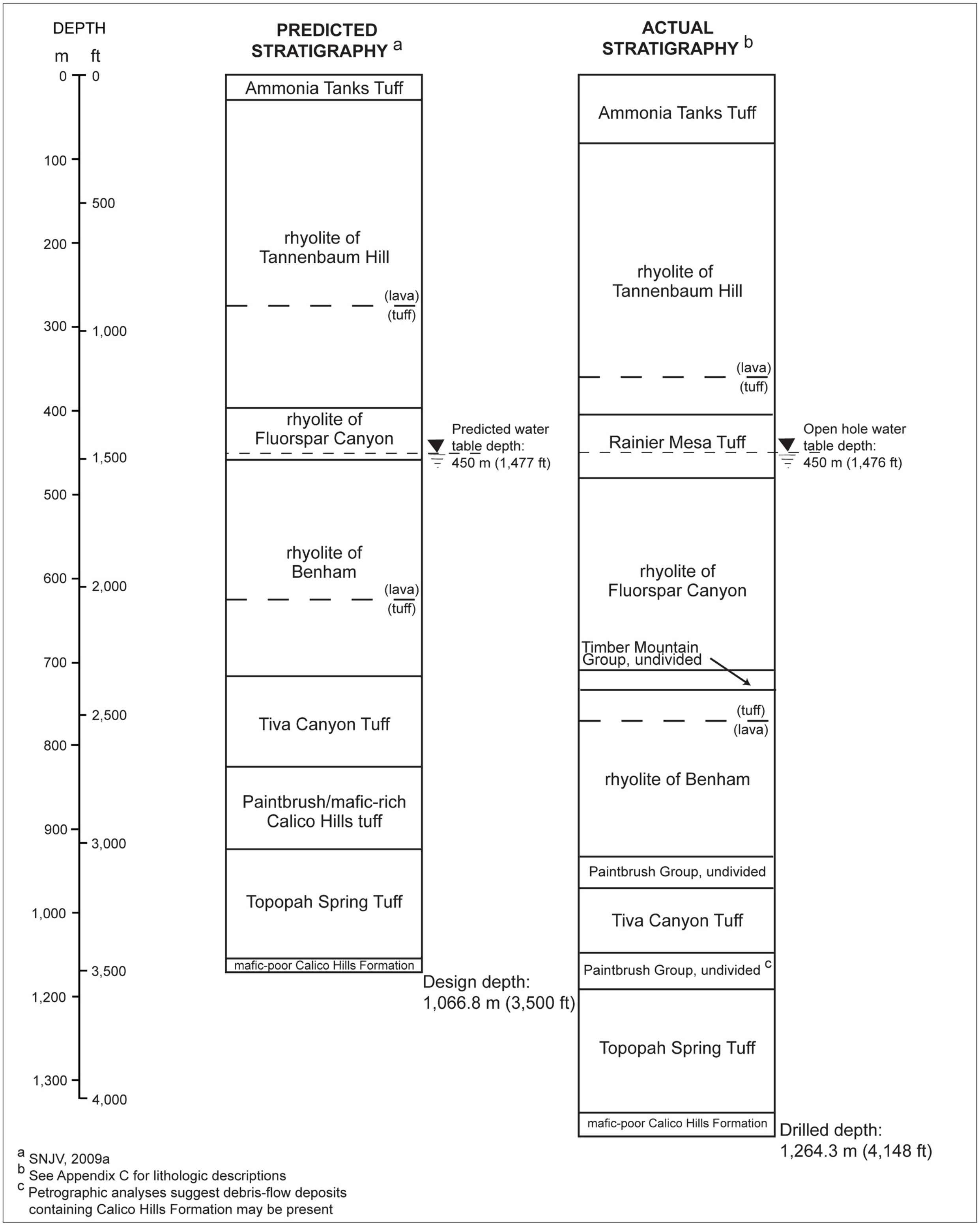

Figure 4-5
Predicted and Actual Stratigraphy at Well ER-EC-11

thus, likely is related to the underlying rhyolite of Benham lava. Neither interval has been previously recognized in the area. The occurrence of these two bedded intervals below the anomalously thick rhyolite of Fluorspar Canyon may indicate that the structural basin responsible for the great thickness of the rhyolite of Fluorspar Canyon was active prior to the eruption of not only the rhyolite of Fluorspar Canyon, but also the Timber Mountain Group in general. Thus, faulting within the Bench domain may pre-date the eruption of the Timber Mountain Group and may be as old as at least the latest eruptive cycle of the Paintbrush Group (i.e., rhyolite of Benham).

4.4 Hydrogeology

The saturated portion of Well ER-EC-11 consists of an alternating sequence of welded-tuff aquifers, lava-flow aquifers, and tuff confining units. Welded ash-flow tuffs of the Rainier Mesa Tuff (TMA HSU), the Tiva Canyon Tuff (TCA HSU), and Topopah Spring Tuff (TSA HSU) form three distinct welded-tuff aquifers in the well, though only the lower portion of the Rainier Mesa Tuff is saturated. Devitrified rhyolitic lava of the rhyolite of Benham forms a thick lava-flow aquifer (BA HSU). The zeolitic and quartzo-feldspathic bedded and nonwelded tuffs that occur between the welded-tuff aquifers and below the welded Topopah Spring Tuff form tuff confining units.

Using stratigraphic information, the hydrogeologic units encountered in Well ER-EC-11 can be grouped into eleven HSUs (Figure 4-2). An interpretation of the possible distribution of the HSUs in the vicinity of Well ER-EC-11 is shown in cross section in Figure 4-6.

Prior to drilling, it was predicted that the water table would be encountered at a depth of 450.2 m (1,477 ft), within bedded tuff of the rhyolite of Fluorspar Canyon. The actual water table depth on October 17, 2009, was 450.0 m (1,476.5 ft) and was within the welded Rainier Mesa Tuff, a welded-tuff aquifer that forms the TMA HSU.

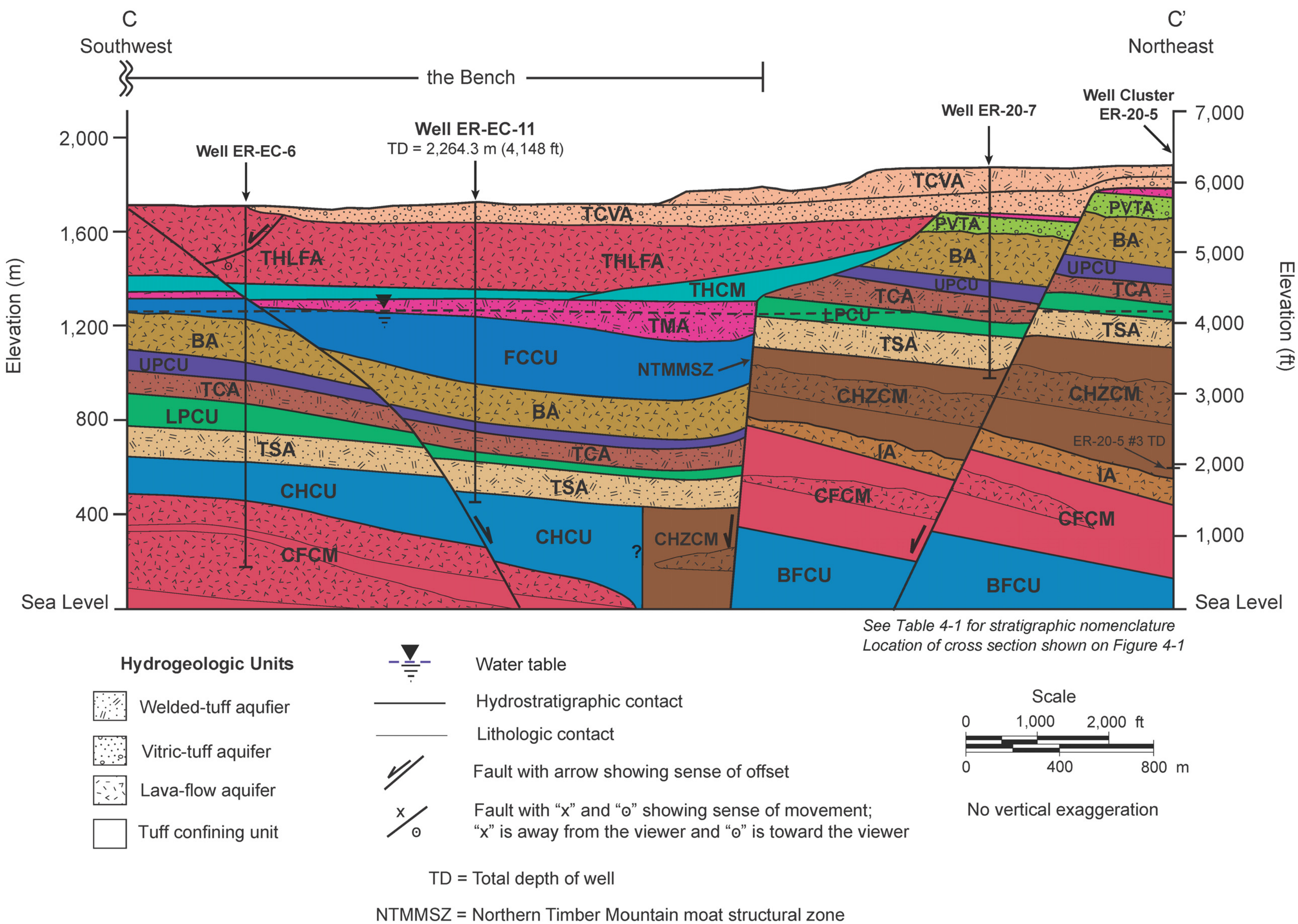

Figure 4-6
Southwest–Northeast Hydrostratigraphic Cross Section C–C' through Well ER-EC-11

5.0 Hydrology

5.1 Preliminary Water-Level Information

Prior to drilling, the water level at Well ER-EC-11 was estimated to be 450.2 m (1,477 ft) below ground surface, within the Fluorspar Canyon confining unit (FCCU). During open-hole geophysical logging operations on September 20, 2009, after the borehole had penetrated the TMA, a fluid-level depth of 449.6 m (1,475 ft) or 1,274.8 m (4,182.3 ft) elevation was measured. After the TMA was isolated behind casing and the borehole had reached TD (October 14, 2009), a fluid-level depth for the TMA was measured at 450.0 m (1,476.5 ft) on October 17, 2009.

5.2 Water Production

Water production was estimated during drilling of Well ER-EC-11 on the basis of dilution of a lithium-bromide tracer, as measured by N-I field personnel (N-I, 2010). The first observation of water in the drill fluid returns was reported on September 18, 2009, while drilling at the depth of 472.1 m (1,549 ft). Estimated water production ranged from 56.8 to 113.6 Lpm (15 to 30 gpm) while drilling the TMA. These numbers should be used cautiously, as only the lower 27.1 m (89 ft) of the TMA is saturated, and production rates may not be representative of the saturated section due to the nature of air-foam drilling. Estimated water production during drilling in the BA ranged from 757 to 2,227 Lpm (200 to 600 gpm). A high of 5,061 Lpm (1,337 gpm) was estimated at the depth of approximately 941.2 m (3,088 ft), which is in the confining unit below the BA, though it probably includes flow from the BA. Estimated water production during drilling in the TCA (after the upper portion of the hole was cased off) ranged from 15 to 1,579 Lpm (4 to 417 gpm). Water production rates were estimated at 167 to 314 Lpm (44 to 83 gpm) during drilling in the bedded tuffs and non- to partially welded tuffs of the Paintbrush Group, between the depths of approximately 1,030.2 and 1,108.3 m (3,380 and 3,636 ft). Estimated water production during drilling in the TSA ranged from 1,257 to 3,785 Lpm (332 to 1,000 gpm), with an estimated high of 10,292 Lpm (2,719 gpm) at the depth of approximately 1,207.0 m (3,960 ft).

Estimated water production rates during drilling are presented graphically in Appendix A-1. More accurate water production information will be available after hydraulic testing is conducted following completion and development of the well.

5.3 Preliminary Flow Meter Data

Flow meter data, along with temperature, electrical conductivity, and pH measurements, are typically used in UGTA wells to characterize borehole fluid variability, which may indicate inflow and outflow zones. DRI personnel ran their chemistry log to obtain temperature, electrical conductivity, and pH measurements, and their heat-pulse flow log to obtain flow direction within the TMA, shortly after the TD was reached (DRI, 2010). The DRI flow log indicated downward flow above 795.5 m (2,610 ft) and upward flow below this depth. The 795.5-m (2,610-ft) depth corresponds to a drilling break (where the drilling penetration rate increased dramatically for 3.0 m [10 ft]) and to borehole breakout on the caliper log within the BA, which may indicate fracturing. In addition, DRI reported upward flow between the depths of 1,027.2 and 1,250.0 m (3,370 and 4,100 ft).

5.4 Preliminary Groundwater Characterization Samples

DRI and N-I personnel used a bailer on a wireline assembly to collect five depth-discrete preliminary groundwater characterization samples. Analytical data from these samples will provide a framework of initial groundwater chemistry. Three samples were collected following geophysical logging on October 9, 2009, at the depths of 746.8, 838.2, and 960.1 m (2,450, 2,750, and 3,150 ft), when the borehole was at the depth of 979.3 m (3,213 ft) and had penetrated the Ammonia Tanks and Rainier Mesa Tuffs. The second set of groundwater characterization samples was collected by DRI on October 17, 2009, after the borehole had reached TD. These samples were obtained with the bailer at the depths of 1,001.3 and 1,144.5 m (3,285 and 3,755 ft). These water samples (plus one duplicate) were sent to an outside laboratory for analysis, as detailed in the data report by N-I (2010).

5.5 Other Groundwater Samples

N-I personnel collected 29 composite samples of drilling effluent for radionuclide analysis by LLNL. Each sample was collected during drilling through a 15.2-m (50-ft) interval between the depths of 451.1 and 1,097.3 m (1,480 and 3,600 ft). The samples, each approximately 3.8 liters (1 gallon) in volume, are listed in Table 5-1, along with the analytical results for tritium (LLNL, 2009). These results will be available in UGTA project reports (e.g., the water chemistry database and the transport data document). The details of the analyses conducted on these and other samples from Well ER-EC-11 are provided in N-I (2010). Other tritium results are summarized in Section 2.4.2 of this report.

Table 5-1
Fluid Samples Collected During Drilling of Well ER-EC-11 for Tritium Analysis by Lawrence Livermore National Laboratory [a]

Navaro-Intera Sample Number [b]	LLNL Sample Number [a]	Depth Interval [b] meters (feet)	Tritium Level picocuries per liter
ER-EC-11-091809-1	1	451.1–466.3 (1,480–1,530)	< LLD [c]
ER-EC-11-091809-2	2	466.3–481.6 (1,530–1,580)	< LLD
ER-EC-11-091809-3	3	481.6–496.8 (1,580–1,630)	< LLD
ER-EC-11-092909-4	4	546.6–560.8 (1,790–1,840)	< LLD
ER-EC-11-092909-5	5	560.8–576.1 (1,840–1,890)	< LLD
ER-EC-11-093009-6	6	576.1–591.3 (1,890–1,940)	< LLD
ER-EC-11-093009-7	7	591.3–606.6 (1,940–1,990)	< LLD
ER-EC-11-093009-8	8	606.6–621.8 (1,990–2,040)	< LLD
ER-EC-11-093009-9	9	621.8–637.0 (2,040–2,090)	< LLD
ER-EC-11-093009-10	10	637.0–652.3 (2,090–2,140)	< LLD
ER-EC-11-093009-11	11	652.3–667.5 (2,140–2,190)	< LLD
ER-EC-11-093009-12	12	667.5–682.8 (2,190–2,240)	< LLD
ER-EC-11-093009-13	13	682.8–698.0 (2,240–2,290)	< LLD
ER-EC-11-100309-14	14	856.5–868.7 (2,810–2,850)	13,600 (± 300)
ER-EC-11-100309-15	15	868.7–883.9 (2,850–2,900)	13,500 (± 300)
ER-EC-11-100309-16	16	883.9–899.2 (2,900–2,950)	13,300 (± 300
ER-EC-11-091809-17	17	899.2–914.4 (2,950–3,000)	12,700 (± 300)
ER-EC-11-100309-18	18	914.4–929.6 (3,000–3,050)	12,700 (± 300)
ER-EC-11-100409-19	19	929.6–944.9 (3,050–3,100)	13,500 (± 300)
ER-EC-11-100409-20	20	944.9–960.1 (3,100–3,150)	13,300 (± 300)
ER-EC-11-100409-21	21	960.1–975.4 (3,150–3,200)	12,800 (± 300)
ER-EC-11-101209-1	22	975.4–990.6 (3,200–3,250)	6,480 (± 150)
ER-EC-11-101209-2	23	990.6–1,005.8 (3,250–3,300)	< LLD
ER-EC-11-101209-3	24	1,005.8–1,021.1 (3,300–3,350)	< LLD
ER-EC-11-101209-4	25	1,021.1–1,036.3 (3,350–3,400)	< LLD
ER-EC-11-101209-5	26	1,036.3–1,051.6 (3,400–3,450)	< LLD
ER-EC-11-101209-6	27	1,051.6–1,066.8 (3,450–3,500)	200 (± 90)
ER-EC-11-101209-7	28	1,066.8–1,082.0 (3,500–3,550)	280 (± 100)
ER-EC-11-101209-8	29	1,082.0–1,097.3 (3,550–3,600)	< LLD

a Samples collected by N-I personnel from fluid discharge line are approximately 3.8 liters (1 gallon) in volume, and are composites of samples collected during drilling through a 15.2-m (50-ft) interval. Source: LLNL (2009)

b Sample composite intervals from N-I (2010).

c Less than the Lower Limit of Detection (LLD).

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6.0 Precompletion and Open-Hole Development

Initial well development conducted in Well ER-EC-11 consisted of using the drill string to air-lift groundwater to remove residual cuttings and drilling fluids from the borehole. This took place prior to the final logging operation, after the TD was reached.

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7.0 Well Completion

7.1 Introduction

Well completion refers to the installation in a borehole of a string of tubing 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 placed between or above the open intervals to isolate them. The string serves as a conduit for inserting a pump in the well, for inserting devices for measuring fluid level, and for sampling, so that accurate potentiometric and water chemistry data can be collected from known portions of the borehole.

The proposed design for Well ER-EC-11 was presented in SNJV (2009a) and in the NSTec FAWP (NSTec, 2009b). The completion plans are summarized here in Section 7.2.1, and the actual well completion design, based on the hydrogeology encountered in the borehole, is presented in Section 7.2.2. The rationale for differences between the planned and actual designs is discussed in Section 7.2.3, and the completion methods are presented in Section 7.3. Figure 7-1 is a schematic diagram of the well completion design. Figure 7-2 shows a plan view and profile of the final wellhead surface completion. Table 7-1 is a construction summary for the completion strings.

7.2 Well Completion Design

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

7.2.1 Proposed Completion Design

The original completion design (SNJV, 2009a) was based on the assumption that Well ER-EC-11 would penetrate the water table near the base of the FCCU and reach TD just below the TSA, within the Calico Hills confining unit (CHCU). The primary goal of the proposed completion design was to provide groundwater production data from the BA, TCA, and TSA, and to provide access to groundwater for monitoring and sampling. A 16-in. surface casing string was intended to extend to the depth of approximately 450.2 m (1,477 ft) to isolate the unsaturated zone from the underlying saturated rocks.

The well was planned to be completed using a string of 7⅝-in. casing with three slotted intervals that would provide access to the BA, the TCA, and the TSA. The 7⅝-in. stainless-steel casing string was to be positioned approximately 3 m (10 ft) above the bottom of the borehole, with a

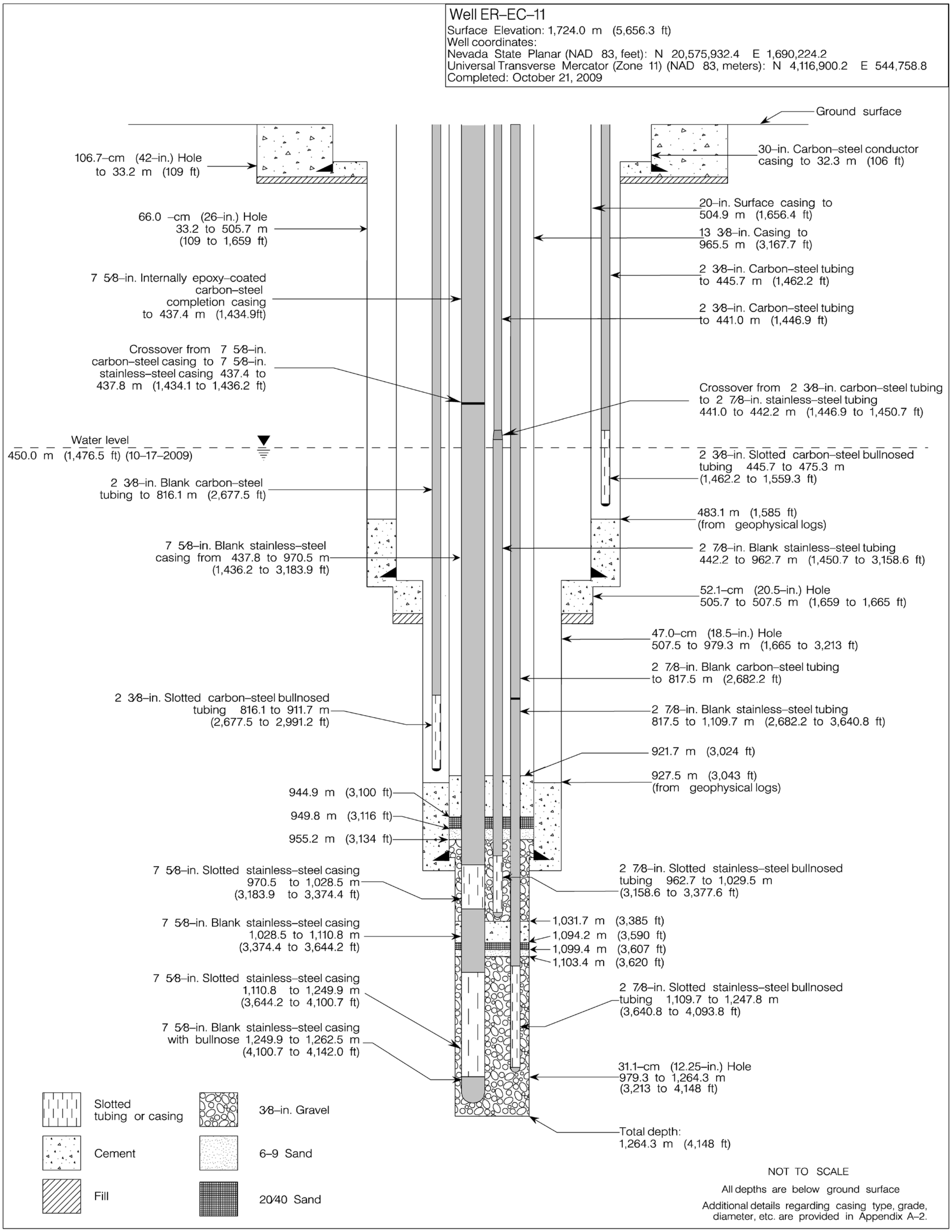

Figure 7-1
As-Built Completion Schematic for Well ER-EC-11

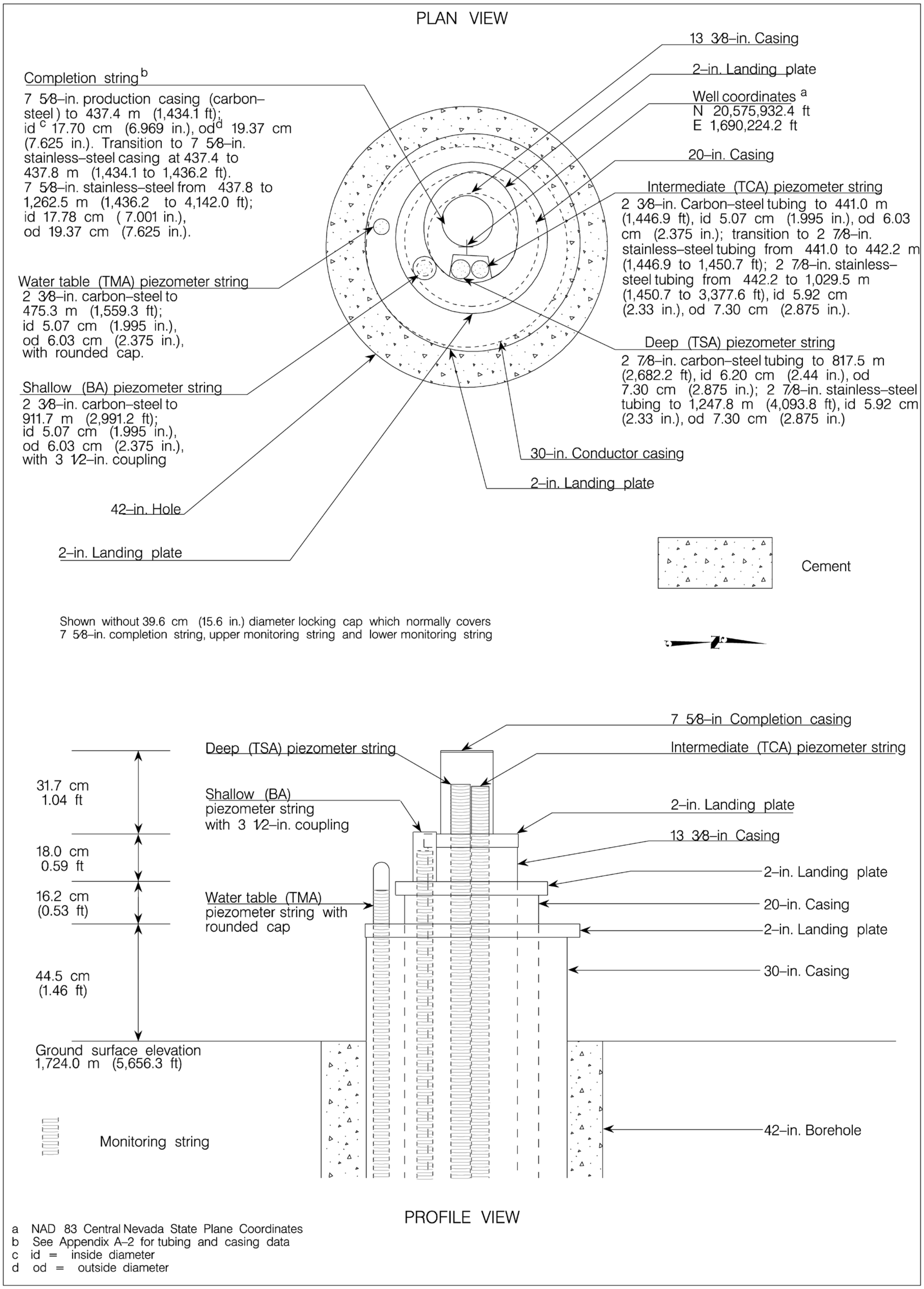

Figure 7-2
Wellhead Diagram for Well ER-EC-11

Table 7-1
Well ER-EC-11 As-Built Completion String Construction Summary

String	Casing and Tubing	Configuration meters (feet)		Cement meters (feet)	Sand/Gravel meters (feet)
Water Table (TMA) Piezometer	2⅜-in. carbon-steel tubing	0 to 465.3 (0 to 1,559.3)	**Blank** 0 to 445.7 (0 to 1,462.2)	None	
			3 slotted joints [a] (lowest is bull-nosed) 445.7 to 475.3 (1,462.2 to 1,559.3)		
Shallow (BA) Piezometer	2⅜-in. carbon-steel tubing	0 to 911.7 (0 to 2,991.2)	**Blank** 0 to 816.1 (0 to 2,677.5)	None	
			10 slotted joints [b] (lowest is bull-nosed) 816.1 to 911.7 (2,677.5 to 2,991.2)		
Intermediate (TCA) Piezometer	2⅜-in. carbon-steel tubing with cross-over sub	0 to 442.2 (0 to 1,450.7)	**Blank**	None	
	2⅞-in. stainless-steel tubing	442.2 to 1,029.5 (1,450.7 to 3,377.6)	**Blank** 442.2 to 962.7 (1,450.7 to 3,158.6)	**Type II Neat Cement** 921.7 to 944.9 (3,043 to 3,100)	None
			11 slotted joints [c] (lowest joint is blank and bull-nosed) 962.7 to 1,029.5 (3,158.6 to 3,377.6)	None	**20/40 Sand** 944.9 to 949.8 (3,100 to 3,116) **6-9 Sand** 949.8 to 955.2 (3,116 to 3,134) **⅜-in. Washed Gravel** 955.2 to 1,031.8 (3,134 to 3,385)

Table 7-1
Well ER-EC-11 As-Built Completion String Construction Summary, continued

String	Casing and Tubing	Configuration meters (feet)		Cement meters (feet)	Sand/Gravel meters (feet)
Deep (TSA) Piezometer	2⅞-in. carbon-steel tubing with cross-over sub	0 to 817.5 (0 to 2,682.2)	**Blank**	None	
	2⅞-in. stainless-steel tubing	817.5 to 1,247.8 (2,682.2 to 4,093.8)	**Blank** 817.5 to 1,109.7 (2,682.2 to 3,640.8)	**Type II Neat Cement** 1,031.8 to 1,094.2 (3,385 to 3,590)	None
			23 slotted joints [c] (lowest is bull-nosed) 1,109.7 to 1,247.8 (3,640.8 to 4,093.8)	None	**20/40 Sand** 1,094.2 to 1,099.4 (3,590 to 3,607) **6-9 Sand** 1,099.4 to 1,103.4 (3,607 to 3,620) **⅜-in. Washed Gravel** 1,103.4 to 1,264.3 (3,620 to 4,148)
Completion Casing	7⅝-in. epoxy-coated carbon-steel casing with cross-over sub	0 to 437.8 (0 to 1,436.2)	**Blank**	None	
	7⅝-in. stainless-steel production casing	437.8 to 1,262.5 (1,436.2 to 4,142.0)	**Blank** 437.8 to 970.5 (1,436.2 to 3,183.9)	Same as for Intermediate (TCA) Piezometer String	None
			5 slotted joints [d] 970.5 to 1,028.5 (3,183.9 to 3,374.4)	None	Same as for Intermediate (TCA) Piezometer String
			Blank 1,028.5 to 1,110.8 (3,374.4 to 3,644.2)	Same as for Deep (TSA) Piezometer String	None
			12 slotted joints [d] 1,110.8 to 1,249.9 (3,644.2 to 4,100.7)	None	Same as for Deep (TSA) Piezometer String
			Blank and bull-nosed 1,249.9 to 1,262.5 (4,100.7 to 4,142.0)		

a Each joint contains 15 torch-cut slots that are 0.159 cm (0.0625 in.) wide and 30.5 cm (12.0 in) long, and arranged in three rows.
b Each joint contains 15 torch-cut slots that are 0.312 cm (0.125 in.) wide and 30.5 cm (12 in.) long, and arranged in three rows.
c Each joint contains 480 slots that are 0.159 cm (0.0625 in.) wide and 5.1 cm (2.0 in.) long, arranged in 8 rows, offset 45 degrees.
d Slots are 0.159 cm (0.0625 in.) wide and 5.1 cm (2.0 in.) long, arranged in 18 rows, on staggered 15.2-cm (6.0-in.) centers.

blank bull-nose section at its terminal end. The three slotted sections would be separated by blank stainless-steel casing. The 7⅝-in. stainless-steel completion string would transition to a string of internally epoxy-coated carbon-steel 7⅝-in. casing at approximately 30 m (97 ft) above the water table via a 0.6-m (2-ft) long stainless-steel crossover sub. Gravel packs would have been placed outside the slotted intervals, and layers of sand and cement would have been placed between the gravel layers to prevent communication between aquifers.

Before the installation of the well-completion string, up to three 2⅜-in. carbon-steel piezometer strings were planned to be installed between the borehole wall and the completion string so that the water levels could be monitored during testing, and water samples could be taken directly from the developed intervals. The piezometer strings were planned to be stainless-steel below the water table. Similar to the completion string, the crossover from epoxy-coated carbon-steel to stainless-steel tubing would be at approximately 30 m (97 ft) above the water table.

7.2.2 As-Built Completion Design

Changes to the design of Well ER-EC-11 were initially considered due to penetration of the saturated TMA and saturated BA, the latter which contained tritium activities greater than the MDC. The final design of the Well ER-EC-11 completion was determined after the final TD of 1,264.3 m (4,148 ft) was reached, through consultation with members of the UGTA Well ER-EC-11 Drilling Advisory Team, on the basis of onsite evaluation of data such as lithology and water production, drilling data, and data from various geophysical logs. As shown in Figure 7-1, a completion casing string and four piezometer strings were installed in Well ER-EC-11.

The main completion string consists of a section of 7⅝-in. stainless-steel casing suspended from 7⅝-in. internally epoxy-coated carbon-steel casing, which was set at the depth of 1,262.5 m (4,142 ft). The 7⅝-in. epoxy-coated carbon-steel casing extends from the surface to the depth of 437.8 m (1,436.2 ft), which is 12.3 m (40 ft) above the water table. The stainless-steel 7⅝-in. casing is slotted in the interval from 1,110.8 to 1,249.9 m (3,644.2 to 4,100.7 ft) within the TSA, and in the interval from 970.5 to 1,028.5 m (3,183.9 to 3,374.4 ft) within the TCA. The completion string was terminated with 12.6 m (41.3 ft) of blank stainless-steel casing and a 0.72 m (2.4 ft) stainless-steel bullnose to function as a sediment sump. The openings in each slotted casing joint are 0.159 cm (0.0625 in.) wide and 5.1 cm (2.0 in.) long. The machine-cut slots are arranged in rows of 18, with rows staggered 22.5 degrees on 15.2-cm (6-in.) centers.

The production casing was installed in the open borehole with two separate intervals of gravel packing, sand, and cement. The slotted interval positioned at the depth of 970.5 to 1,028.5 m (3,183.9 to 3,374.4 ft) provides access to the TCA. The slotted interval positioned at the depth of 1,110.8 to 1,249.9 m (3,644.2 to 4,100.7 ft) provides access to the TSA. The string of 13⅜-in. intermediate casing isolates both slotted intervals from the formations immediately above.

Four piezometer strings were installed in the annular space of the well. The water table (TMA) string was installed outside the 20-in. surface casing; the shallow (BA) string was installed outside the 13⅜-in. surface casing; and the intermediate (TCA) and deep (TSA) strings were installed outside the two slotted intervals of the completion casing. See Table 7-1 for information about the slots in these tubing strings.

On October 29, 2009, a removable bridge plug was installed at 1,045.5 m (3,430 ft) between the two slotted intervals in the 7⅝-in. completion string to isolate the two lower aquifers from each other.

7.2.3 Rationale for Differences between Planned and Actual Well Design

The geology of Well ER-EC-11 was significantly different than predicted (see Section 4.3), which required several changes to the original proposed well completion design. The original completion design was based on the expectation that three saturated aquifers would be encountered in the well, which would be drilled to a TD of 1,066.8 m (3,500 ft), approximately 15 m (50 ft) below the predicted top of the Calico Hills Formation (confining unit). However, the rhyolite of Fluorspar Canyon was approximately 167.7 m (550 ft) thicker than predicted, which required that the well be drilled deeper than planned, reaching the Calico Hills Formation at the depth of 1,235.0 m (4,052 ft).

In addition, the saturated TMA was unexpectedly encountered above the three target aquifers and had to be isolated from them. As a result, the hole diameter had to be increased to accommodate a string of 20-in. casing. Enlarging the borehole ensured that at the desired completion depth for the lower target aquifers (TCA and TSA), the hole would be large enough to permit installation of the required 7⅝-in. production casing and two 2⅞-in. piezometer strings.

Tritium levels above the MDC were detected in the BA, so a string of 13⅜-in. (intermediate) casing was installed to isolate the aquifer, which had not been planned.

7.3 Well Completion Method

On September 27, 2009, before installation of the 20-in. surface casing, a string of 2⅜-in. Hydril® tubing was set at the depth of 475.3 m (1,559.3 ft). This piezometer string provides access to the TMA (water table [TMA] piezometer) and is isolated from the other aquifers by the 20-in. casing. Another string of 2⅜-in. Hydril® tubing was inserted into the borehole prior to installation of the 13⅜-in. casing. This string was set at the depth of 911.7 m (2,991.2 ft) on October 10, 2009, and provides access to the BA (shallow [BA] piezometer).

After the borehole TD was reached, completion activities began on October 18, 2009, when the drill crew began running the two lower 2⅞-in. piezometer strings. The deep (TSA) slotted 2⅞-in. stainless-steel string was landed within the 12.25-in. borehole at 1,247.6 m (4,093.8 ft), and the intermediate (TCA) 2⅞-in. piezometer string was landed at 1,029.5 m (3,377.6 ft), also within the 12.25-in. borehole. The crew also inserted a 2⅞-in. tubing string to serve as a tremie during placement of stemming materials.

After the three tubing strings were inserted, the casing crew began running the 7⅝-in. completion casing on October 19, 2009. The inside of the casing was scraped to remove any burrs that could damage equipment inserted in the casing later for pumping or sampling. The production casing was landed at 1,262.5 m (4,142.0 ft) on October 20, 2009. Colog ran a nuclear annulus investigation logging tool (NAIL log) in the borehole to monitor the stemming process. Before stemming began, N-I ran a 3.8-cm (1.5-in.) diameter electric tape probe in the two piezometer strings and the tremie line to determine tubing clearance.

The lower gravel pack was emplaced in the annulus of the borehole from the bottom of the borehole to the depth of 1,103.4 m (3,620 ft), encompassing the lower slotted interval of the completion string and the slotted portion of the deep piezometer string. Next a 4.0-m (13-ft) layer of 6-9 silica sand was placed through the tremie line, followed by a 5.2-m (17-ft) thick layer of 20/40 sand. The NSTec cement crew next placed 62.5 m (205 ft) of Type II cement, followed by water to balance the plug. The crew pulled up the tremie line as each layer of material was placed. The sand sections prevent cement from infiltrating the gravel pack.

After waiting an hour for the cement to set, the upper gravel pack was placed in two stages with a total rise of 76.5 m (251 ft). Next, two stages each of 6-9 silica sand (total rise of 5.5 m [18 ft]) and 20/40 sand (total rise of 4.9 m [16 ft]) were placed. Each addition was monitored using the NAIL log, and the tremie line was pulled up as each section was added. The cement crew then emplaced the upper 23.2 m (76-ft) layer of Type II cement, again balancing the plug using water.

After this final stage of completion stemming was completed, on October 21, 2009, the tremie line was removed and the cement and logging crews rigged down.

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

All well construction materials used for the completion were inspected according to relevant procedures, as listed in SNJV (2009a). Standard decontamination procedures were employed to prevent the introduction of contaminants into the well.

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8.0 Planned and Actual Costs and Scheduling

The original NSTec-approved baseline task plan cost estimate for drilling and completing Well ER-EC-11 was based on drilling to a planned TD of 1,066.8 m (3,500 ft) from the surface and installing one completion string and up to three piezometer strings.

Well ER-EC-11 was drilled to a TD of 1,264.3 m (4,148 ft), which is 197.5 m (648 ft) deeper than originally planned because the geology encountered was significantly different than expected and the target aquifers were deeper than expected. Additional construction time was also required because the borehole had to be re-drilled to a larger diameter to allow installation of 20-in. surface casing. Enlarging the surface hole and setting the larger 20-in. surface casing was required as a means of isolating the target aquifers from the unexpected upper aquifer units, while allowing for setting a larger intermediate casing. The installation of the additional intermediate casing required an additional geophysical logging episode.

The baseline schedule for drilling and completing Well ER-EC-11 was 29 days. Approximately five additional days were spent increasing the hole size and installing the 20-in. casing. Approximately two additional days were spent drilling to the final TD. Installation of the completion strings took approximately three days less than planned.

The cost analysis for Well ER-EC-11 begins with the mobilization of the UDI drill rig to the drill site, where the conductor hole had already been constructed. The total cost for Well ER-EC-11 includes all drilling costs: charges by the drilling subcontractor, charges by other support subcontractors (including compressor services, drilling fluids, casing services, down-hole tools, and geophysical logging), and charges by NSTec for mobilization and demobilization of equipment, cementing services, RCT services, inspection services, site supervision, and geotechnical consultation. The cost of building the access roads, drill pad, sumps, and conductor hole is not included, nor is the cost of well-site support by N-I personnel.

The total planned cost for constructing Well ER-EC-11 was $5,614,292. The actual cost was $4,971,157, or 11.5 percent less than the planned cost. Figure 8-2 presents a comparison of the planned and actual costs, by day, for construction of Well ER-EC-11.

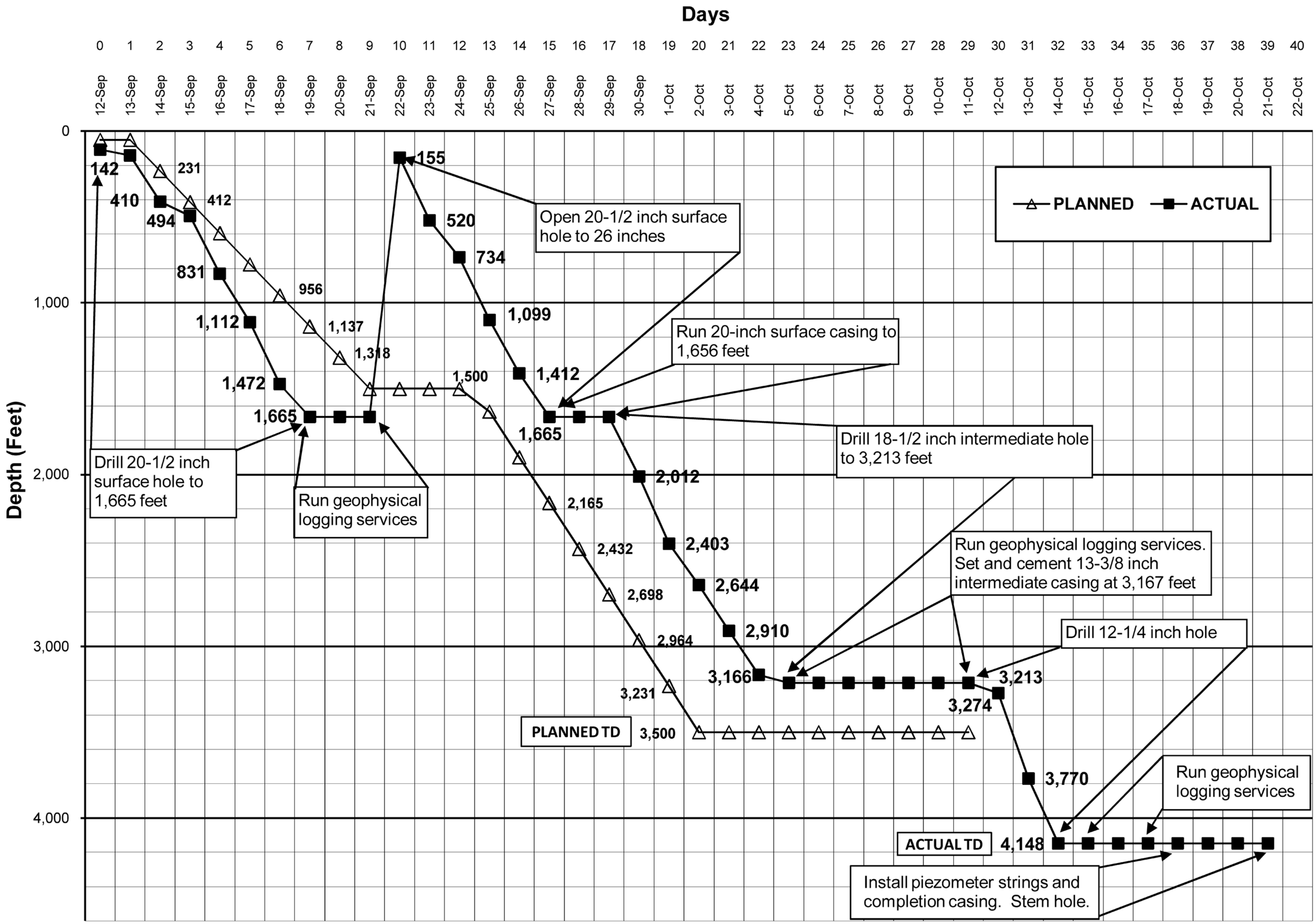

Figure 8-1
Planned and Actual Construction Progress for Well ER-EC-11

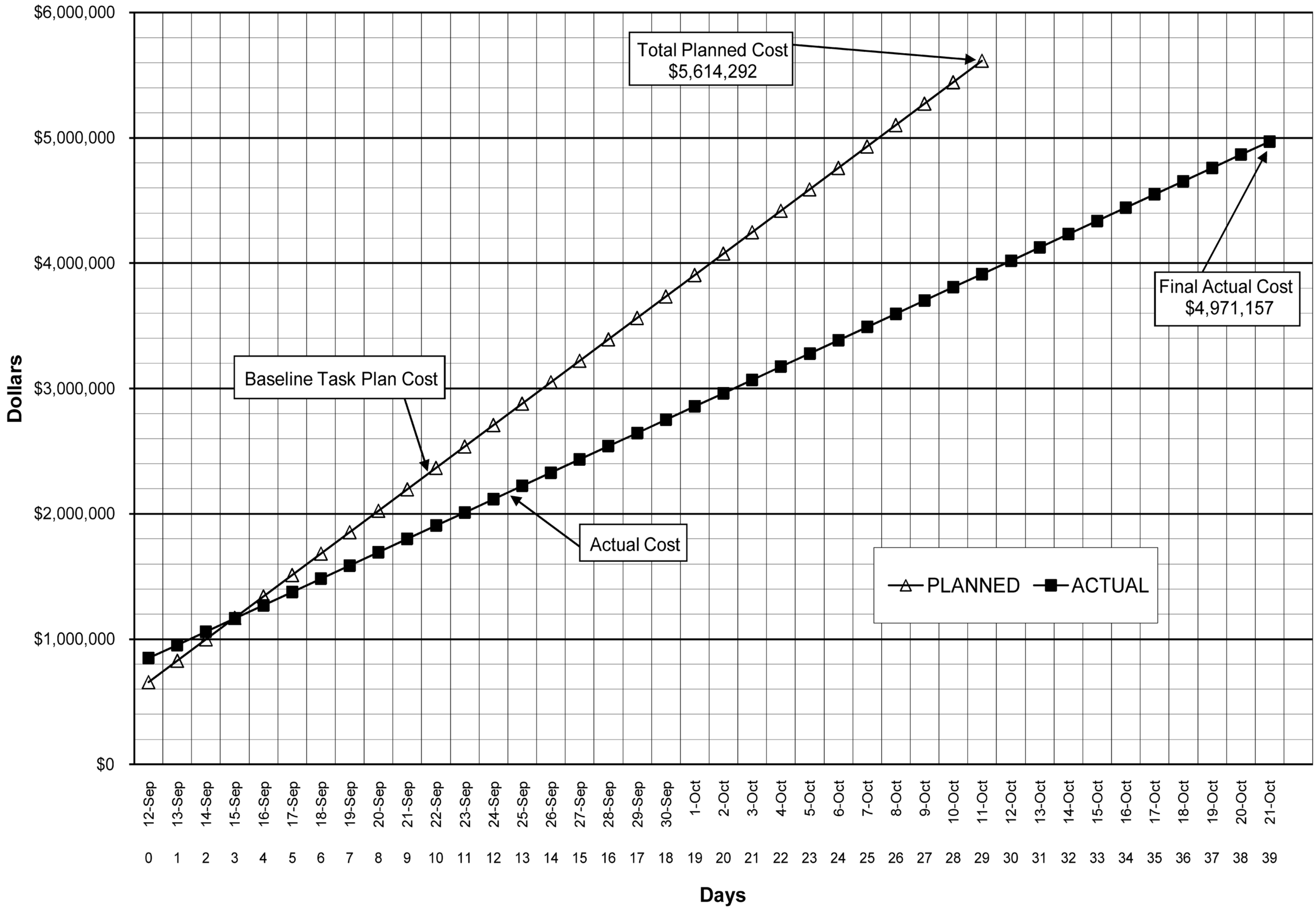

Figure 8-2
Planned and Actual Cost of Constructing Well ER-EC-11

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9.0 Summary, Recommendations, and Lessons Learned

9.1 Summary

Main hole drilling at Well ER-EC-11 commenced on September 12, 2009, and concluded on October 14, 2009, at a total drilled depth of 1,264.3 m (4,148 ft). Few problems were encountered during drilling, though the borehole had to be opened from 52.1 to 66.0 cm (20.5 to 26.0 in.) to accommodate a string of 20-in. casing needed to isolate the saturated TMA. Tritium levels above the MDC were detected in the BA, so a string of 13⅜-in. casing was installed to isolate this aquifer from the deeper target aquifers. The borehole was completed within the TCA and the TSA, which were encountered in the bottom portion of the drill hole.

The completion string consists of 7⅝-in. stainless-steel casing suspended from 7⅝-in. carbon-steel casing. The carbon-steel casing is internally epoxy-coated and extends to a depth that is 12.3 m (40 ft) above the water table. The stainless-steel 7⅝-in. casing is slotted in the interval from 1,110.8 to 1,249.9 m (3,644.2 to 4,100.7 ft) within the TSA, and in the interval from 970.5 to 1,028.5 m (3,183.9 to 3,374.4 ft) within the TCA. The top slotted section consists of five consecutive stainless-steel slotted joints and the bottom slotted section consists of twelve consecutive stainless-steel slotted joints. Each slotted interval is gravel packed, and the gravel intervals are separated by 62.5 m (205 ft) of cement.

Four piezometer strings were set to monitor the water levels in different portions of the borehole during hydraulic testing. A 2⅜-in. carbon-steel piezometer string was installed outside the 20-in. surface casing at 475.3 m (1,559.3 ft), within the TMA (“water table [TMA]”). A second 2⅜-in. carbon-steel piezometer string was set at 911.7 m (2,991.2 ft) within the BA (“shallow [BA]”). Two lower 2⅞-in. stainless-steel piezometer strings were set, and both hang from strings of 2⅜-in. carbon-steel tubing, connected via crossover subs. The uppermost of these (“intermediate [TCA]”) is slotted from 962.7 to 1,029.5 m (3,158.6 to 3,377.6 ft) for monitoring within the TCA. The lower string (“deep [TSA]”) is slotted from 1,109.7 to 1,247.8 m (3,640.8 to 4,093.8 ft) for monitoring within the TSA.

Geologic data collected during drilling included composite drill cuttings samples collected every 3.0 m (10 ft) from 33.5 m (110 ft) to TD. In addition, 67 sidewall core samples were collected in the interval 527.3 m (1,730 ft) to TD. Open-hole geophysical logging was conducted in the upper portion of the borehole before installation of the surface casing, in the middle portion of the borehole before installation of the intermediate casing and after the TD of the well was reached. 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.

Well ER-EC-11 is collared in welded Ammonia Tanks Tuff of the Timber Mountain Group, and penetrated 1,264.3 m (4,148 ft) of Tertiary volcanic rocks, consisting largely of bedded and nonwelded to densely welded ash-flow tuffs, rhyolitic lavas, and zeolitic nonwelded tuffs. The water level was measured in the well within the TMA at 449.6 m (1,475 ft) on September 20, 2009, and within the BA at 450.2 m (1,477 ft) on October 6, 2009. On October 17, 2009, the water level was measured in the well within the TCA and TSA at 450.0 m (1,476.5 ft). The elevation of the composite water level (as measured in the TMA prior to installation of the completion string) is 1,274.4 m (4,181.3 ft).

Tritium levels in the drilling fluid were at or below background levels (as measured by field instruments) while drilling the surface hole to a depth that is approximately 379.2 m (1,244 ft) below the water table. At this point (828.8 m [2,719 ft] drilled depth), tritium above background levels was encountered in the drilling fluids from Well ER-EC-11. Laboratory measurements on samples from this interval gave an average value of 12,431 pCi/L of tritium in the BA, but tritium levels were below the MDC limits for the TCA and TSA.

9.2 Recommendations

All the geologic and hydrologic data and interpretations from Well ER-EC-11 should be integrated into the PM–OV Phase II HFM. This will allow for more precise characterization of groundwater flow direction and velocity in the Pahute Mesa area.

The water level in Well ER-EC-11 should be monitored during the drilling and testing of nearby wells. Groundwater chemistry, particularly with respect to radionuclides, should be monitored on a routine basis to learn more about the migration of the contaminants from the TYBO and BENHAM UGTs. These data will also improve the understanding of aquifer connectivity.

In addition, long-term water-level monitoring instrumentation should be installed in one or two of the piezometer strings. This would allow hydrologists to learn about how water levels at the Bench, and their variations over time, compare with those in other parts of Pahute Mesa, and would improve the understanding of the groundwater flow system in this part of the model 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. Sometimes difficult drilling conditions are encountered and challenges are confronted. Several new lessons were learned during the construction of Well ER-EC-11, the fourth well in the 2009 Pahute Mesa Phase II drilling initiative.

- The development of drilling criteria should be started further in advance of actual drilling operations. This would allow for smoother transitions from the development of scientific objectives and borehole design phases to the logistics and implementation phases.

- CAU guidance teams and hole-specific drilling advisory teams formed by the UGTA TWG can provide timely assistance and guidance for addressing "surprises" and assessing their impacts on the overall program.

- Poor sidewall core gun firing and recovery results on October 8, 2009, were due to steam cleaning of the equipment, which caused intermittent problems in the electrical wiring. Seals on logging tools should be inspected after steam cleaning.

- Real-time tritium monitoring in the field, particularly for low levels, is problematic. The chemoluminescence problem needs to be investigated further.

- Idiosyncracies in tritium levels can be attributed to variations in fracture occurrences and are further complicated by high water production, which can result in dilution of tritium levels.

- The quality of some geophysical logs (i.e., CBIL and STAR) is degraded in the large-diameter boreholes. When the hole diameter is greater than the effective tool response diameter, image resolution is poor, which results in essentially useless data. Cost efficiencies can be gained by not running these tools in boreholes larger than the tools' recommended maximum diameter (i.e., 40.6 cm [16 in.]).

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Appendix A
Drilling Data

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Appendix A-1
Drilling Parameter Log for Well ER-EC-11

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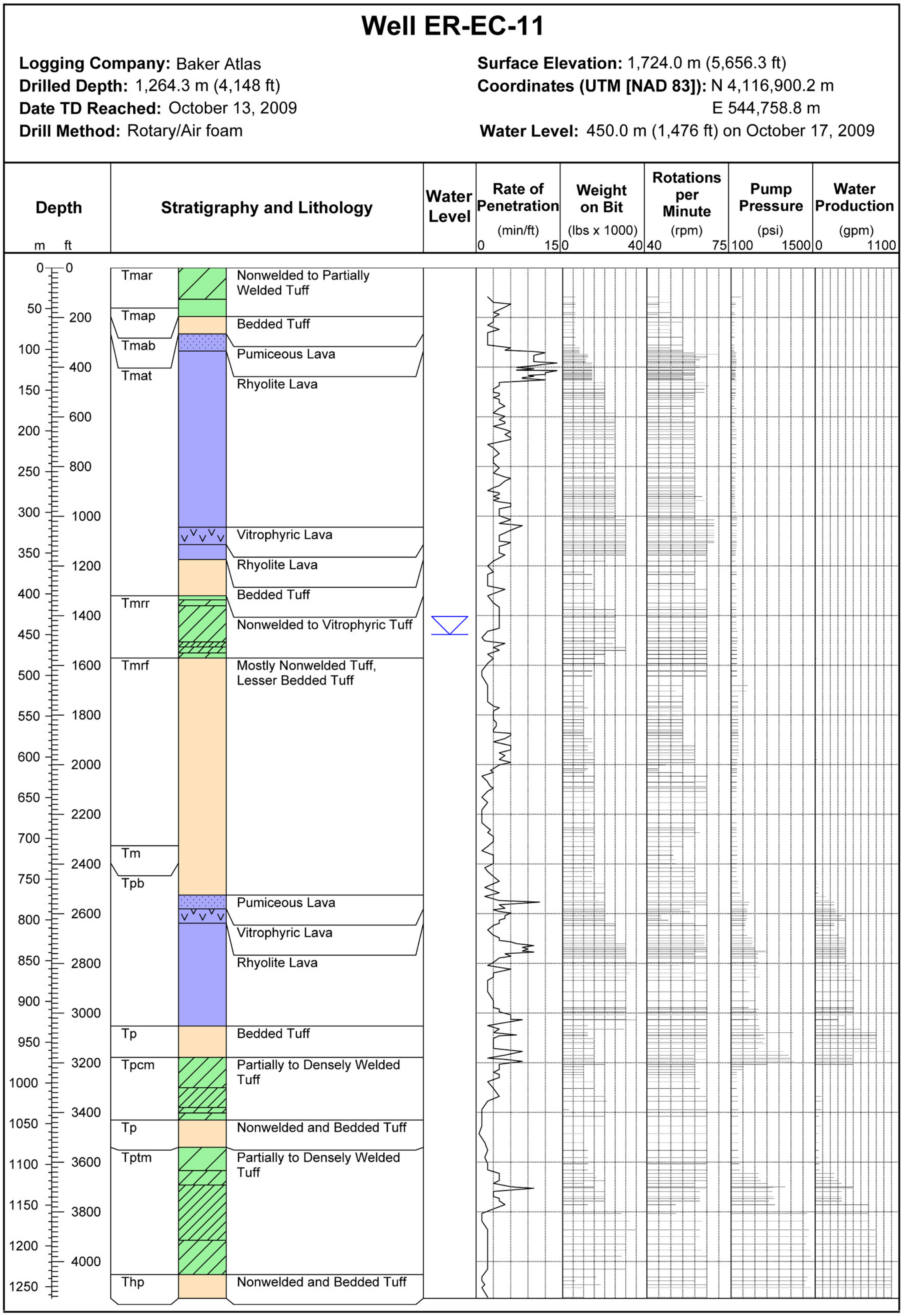

See legend for lithology symbols on page D-2.

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Appendix A-2
Tubing and Casing Data for Well ER-EC-11

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Table A-2
Tubing and Casing Data for Well ER-EC-11

Casing and Tubing	**Depth Interval** meters (feet)	**Type**	**Grade**	**Outside Diameter** centimeters (inches)	**Inside Diameter** centimeters (inches)	**Wall Thickness** centimeters (inches)	**Weight per foot** (pounds)
Conductor Casing	0 to 32.3 (0 to 106)	Carbon Steel	B	76.20 (30)	73.66 (29.0)	1.27 (0.50)	158.0
Surface Casing	0 to 262.5 (0 to 861.3)	Carbon Steel	K55	50.8 (20)	48.3 (19)	1.27 (0.50)	106.5
	262.5 to 504.9 (861.3 to 1,656.4)	Carbon Steel	K55	50.8 (20)	48.6 (19.124)	1.11 (0.438)	94
Intermediate Casing	0 to 438.9 (0 to 1,439.8)	Carbon Steel	K55	33.97 (13.375)	31.5 (12.415)	1.22 (0.480)	68
	438.9 to 561.3 (1,439.8 to 1,841.4)	Carbon Steel	K55	33.97 (13.375)	31.8 (12.515)	1.09 (0.430)	61
	561.3 to 965.5 (1,841.4 to 3,167.7)	Carbon Steel	K55	33.97 (13.375)	32.0 (12.615)	0.97 (0.380)	54.5
Completion Casing with Crossover	0 to 437.8 (0 to 1,436.2)	Epoxy Coated Carbon Steel	N80	19.37 (7.625)	17.70 (6.969)	0.83 (0.328)	26.4
Completion Casing	437.8 to 1,262.5 (1,436.2 to 4,142)	Stainless Steel	SS	19.37 (7.625)	17.78 (7.001)	0.79 (0.312)	25.8
Piezometer Tubing	0 to 475.3 (0 to 1,559.3)	Carbon Steel	N80	6.03 (2.375)	5.067 (1.995)	0.483 (0.190)	4.7
Piezometer Tubing	0 to 911.7 (0 to 2,991.2)	Carbon Steel	N80	6.03 (2.375)	5.067 (1.995)	0.483 (0.190)	4.7
Piezometer Tubing	0 to 441.0 (0 to 1,446.9)	Carbon Steel	N80	6.03 (2.375)	5.067 (1.995)	0.483 (0.190)	4.7
	441.0 to 1,029.5 (1,446.9 to 3,377.6	Stainless Steel	P110	7.303 (2.875)	5.918 (2.33)	0.692 (0.273)	7.66
Piezometer Tubing	0 to 817.5 (0 to 2,682.2)	Carbon Steel	N80	7.303 (2.875)	6.2 (2.441)	0.551 (0.217)	6.5
	817.5 to 1,247.8 (2,682.2 to 4,093.8)	Stainless Steel	SS	7.303 (2.875)	5.92 (2.33)	0.699 (0.275)	7.66

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Appendix A-3
Well ER-EC-11 Drilling Fluids and Cement Composition

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Table A-3-1
Drilling Fluids Used in Well ER-EC-11

Typical Air-Foam/Polymer Mix
37.9 to 56.8 liters (10 to 15 gallons) Geofoam® [a] 0 to 5.7 liters (0 to 1.5 gallons) LP701® [a] 0.05 to 1.5 liters of Lithium Bromide per 7,949 liters (50 barrels) water

a Geofoam ® foaming agent and LP701® polymer additive are products of Geo Drilling Fluids, Inc.

NOTES:

1. All water used to mix drilling fluids for Well ER-EC-11 came from Area 20 Water Well (U-20WW).

2. A concentrated solution of lithium bromide was added to all introduced fluids to make up a final concentration of approximately 10 to 40 milligrams per liter.

Table A-3-2
Well ER-EC-11 Cement Composition

Cement Composition	30-inch Conductor Casing	20-inch Surface Casing	13⅜-inch Intermediate Casing	7⅝-inch Completion Casing
Redi-Mix: Formula 400 (17,520 pounds sand and 5,795 pounds Portland cement)	In annulus: 0 to 32.8 m [a] (0 to 107.7 ft) [b] Inside casing: 29.3 to 32.2 m (96.2 to 105.7 ft)	N/A	N/A	N/A
Type II neat	N/A	483.1 to 506.9 m (1,585 to 1,663 ft)	927.5 to 979.3 m (3,043 to 3,213 ft)	921.7 to 944.9 m (3,024 to 3,100 ft) 1,031.7 to 1,094.2 m (3,385 to 3,590 ft)

a meter(s)
b foot (feet)

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Appendix B
Well ER-EC-11 Fluid Management Data

Table B-1
Well ER-EC-11 Fluid Disposition Reporting Form

FLUID DISPOSITION REPORTING FORM

Site Identification: ER-EC-11
Site Location: Nevada Test and Training Range
Site Coordinates (UTM, NAD 27, Zone 11): N: 4,116,703.12 m E: 544,838.93 m
Well Classification: ER Hydrologic Investigation Well
Project No: UG10-203

Report Date: February 2010
NNSA/NSO Federal Sub-Project Director: Bill Wilborn
SNJV Project Manager: Sam Marutzky
SNJV Site Representative: Steven Hopkins
SNJV Environmental Specialist: Mark Heser

Well Construction Activity	Activity Duration		#Ops. Days[a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes[c] (m^3)		Volume of Infiltration Area (m^3)	Other[d] (m^3)	Fluid Quality Objectives Met?
	From	To				Solids[b]	Liquids	Solids	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	9/12/09	9/26/09	12	450.2	385	254	536	5	6	N/A	N/A	Yes
Phase I: Saturated-Zone Drilling	9/18/09	10/13/09	12	1,264.6	595	12	45	174	6,634	6,129[1]	N/A	Yes
Phase II: Initial Well Development	-	-	-	-	-	-	-	-	-	-	-	-
Phase II: Aquifer Testing	-	-	-	-	-	-	-	-	-	-	-	-
Phase II: Final Development	-	-	-	-	-	-	-	-	-	-	-	-
Cumulative Production Totals to Date:			**24**	**1,264.6**	**980**	**266**	**581**	**179**	**6,640**	**6,129**	**N/A**	**Yes**

[a] Operational days refer to the number of days that fluids were produced during at least part (≥3 hours) of one shift. 20.5-in. vadose and saturated zone drilling from 9/12/09 to 9/18/09. Borehole opened to 26-in. diameter from 9/21/09 to 9/26/09.
[b] Solids volume estimates include calculated added volume attributed to rock bulking factor (150%).
[c] Optional fluid management devices not installed for this well site.
[d] Other refers to fluid conveyance to other fluid management locations or facilities away from the well site, such as vacuum truck transport to another well site.
N/A = Not Applicable; m^3 = cubic meters

Total Facility Capacities (at 8 ft fluid level): Sump #1 = 1,547 m^3 **Total Facility Capacities (at 10 ft fluid level):** Sump #2 = 11,958 m^3

Infiltration Area (assuming negligible infiltration) = 264,000 m^3

Remaining Facility Capacity (approximate) as of 10/24/09: Sump #1 = 985 m^3 (64 %) Sump #2 = 5,694 m^3 (48 %)

Current Tritium Sump #1 (unlined) = -130 (Less than minimum detectable concentration) pCi/L

Current Tritium Sump #2 (lined) = 4,720 pCi/L

Notes: [1]Fluid was pumped from Sump #2 (lined) to surface infiltration area.

Authorizing Signature/Date: [signature] 4-19-10

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Table B-2
Analytical Results for Fluid Management Samples from Sump #1 (Unlined) at Well ER-EC-11

Sample Number	Date Collected	Comment		*Resource Conservation Recovery Act Metals* (mg/L)							
				Arsenic	Barium	Cadmium	Chromium	Lead	Selenium	Silver	Mercury
ER-EC-11-101409-5	10/14/2009	Sample from Sump #1	Total	0.027	0.12	0.005 U	0.02	0.066 J	0.017	0.01	0.0002 U
			Dissolved	0.01 U	0.014J-	0.005 U	0.01 U	0.003 UJ	0.005	0.01	0.0002 U
ER-EC-11-101409-6	10/14/2009	Duplicate Sample from Sump #1	Total	0.019 U	0.11	0.005 U	0.02	0.061 J	0.006	0.01	0.0002 U
			Dissolved	0.01 U	0.015 J-	0.005	0.01	0.003 UJ	0.005	0.01	0.0002 U
Detection Limit				0.01	0.1	0.005	0.01	0.003	0.005	0.01	0.0002
Nevada Drinking Water Standard				0.05	2.0	0.005	0.1	0.015	0.05	0.1	0.002

Sample Number	Date Collected	Comment		Radiological Indicator Parameters (pCi/L)		
				Tritium	Gross Alpha	Gross Beta
ER-EC-11-101409-5	10/14/2009	Sample from Sump #1	Result	-130	141	137
			Error	140	24	23
			MDC	230	6	10
ER-EC-11-101409-6	10/14/2009	Duplicate Sample from Sump #1	Result	10 U	126	137
			Error	210	22	23
			MDC	350	5	7
Nevada Drinking Water Standard				15	50	20,000

Data provided by Navarro-Intera, LLC (N-I, 2010)

Analyses for metals and radionuclides performed by ALS Laboratory Group.

Notes: U = Compound was analyzed for but was not detected ("nondetect"). J = Result is estimated. J- = Result is estimated bias low.
mg/L = milligrams per liter pCi/L = picocuries per liter
MDC = minimum detectable concentration. MDC varies by matrix, instrument, and count rates.

Analytical methods: For commercial laboratory analysis, the most current Environmental Protection Agency (EPA) or equivalent accepted standard laboratory analytical methods may be used as appropriate to attain specified detection limits.
All metals except mercury: EPA 6010
Mercury: EPA 7470
Tritium: EPA 906.0
Gross alpha and gross beta: EPA 900.0

Table B-3
Analytical Results for Fluid Management Samples from Sump #2 (Lined) at Well ER-EC-11

Sample Number	Date Collected	Comment		*Resource Conservation Recovery Act* Metals (mg/L) Arsenic	Barium	Cadmium	Chromium	Lead	Selenium	Silver	Mercury
ER-EC-11-101409-3	10/14/2009	Sample from Sump #2	Total	0.009 J-	0.41 J-	0.005	0.0062 J-	0.0098 J	0.0034	0.01	0.0002 U
			Dissolved	0.01 U	0.017 J-	0.005	0.01 U	0.0016 J-	0.005	0.01	0.0002
ER-EC-11-101409-4	10/14/2009	Duplicate Sample from Sump #2	Total	0.01 U	0.05 J-	0.005	0.01 U	0.012 J	0.003	0.01 U	0.0002 U
			Dissolved	0.01 U	0.013 J-	0.005	0.01 U	0.003 J-	0.0023	0.01	0.0002
Detection Limit				0.01	0.1	0.005	0.01	0.003	0.005	0.01	0.0002
Nevada Drinking Water Standard				0.05	2.0	0.005	0.1	0.015	0.05	0.1	0.002

Sample Number	Date Collected	Comment		Radiological Indicator Parameters (pCi/L) Tritium	Gross Alpha	Gross Beta
ER-EC-11-101409-3	10/14/2009	Sample from Sump #2	Result	4,720	17.3	31.7
			Error	780	3.5	5.6
			MDC	350	2	3.2
ER-EC-11-101409-4	10/14/2009	Duplicate Sample from Sump #2	Result	4,240	14.2	25.9
			Error	680	2.9	4.5
			MDC	230	1.8	2.4
Nevada Drinking Water Standard				15	50	20,000

Data provided by Navarro-Intera, LLC (N-I, 2010)

Analyses for metals and radionuclides performed by ALS Laboratory Group.

Notes: U = Compound was analyzed for but was not detected (“nondetect”). J = Result is estimated. J- = Result is estimated bias low.
mg/L = milligrams per liter pCi/L = picocuries per liter
MDC = minimum detectable concentration. MDC varies by matrix, instrument, and count rates.

Analytical methods: For commercial laboratory analysis, the most current Environmental Protection Agency (EPA) or equivalent accepted standard laboratory analytical methods may be used as appropriate to attain specified detection limits.
All metals except mercury: EPA 6010
Mercury: EPA 7470
Tritium:
EPA 906.
Gross alpha and gross beta: Standard Method 7110

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Appendix C
Detailed Lithologic Log for Well ER-EC-11

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Table C-1
Detailed Lithologic Log for Well ER-EC-11

Logged by Dawn Haugstad, Lance Prothro, and Sigmund Drellack, National Security Technologies, LLC, November and December 2009
Updated to incorporate analytical data, June 2010

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
0–38.4 (0–126)	38.4 (126)	AC DA	none	**Partially Welded Ash-Flow Tuff:** Brownish gray (5YR 4/1) and pale brown (5YR 5/2) to medium dark gray (N4); mostly devitrified, lesser vitric including dark yellowish brown (10YR 4/2) glass shards; minor to common white (N9) to very light gray (N8) vitric pumice and dark yellowish orange (10YR 6/6) vapor-phase pumice up to 2 cm in size; common felsic phenocrysts of feldspar and quartz including chatoyant sanidine; common to abundant mafic minerals of biotite and lesser clinopyroxene; minor to common grayish brown (5YR 3/2) to dark gray (N3) lithic fragments up to 5 cm in size; sphene is present.	mafic-rich Ammonia Tanks Tuff (Tmar)
38.4–49.4 (126–162)	11.0 (36)	DA	none	**Nonwelded Ash-Flow Tuff:** Moderate brown (5YR 4/4) and moderate yellowish brown (10YR 5/4) to dark yellowish brown (10YR 4/2); mostly vitric; devitrified from 42.7 to 45.7 m (140 to 150 ft) with some vapor-phase mineralization; minor to common very pale orange (10YR 8/2) to dark yellowish orange (10YR 6/6) vesicular pumice up to 3 mm in size; rare to minor felsic phenocrysts of quartz and feldspar; minor biotite; minor to common lithic fragments, averaging 1 to 2 mm in size; sphene is present.	
49.4–59.7 (162–196)	10.3 (34)	DA	none	**Nonwelded Ash-Flow Tuff:** Pale reddish brown (10R 5/4) to moderate brown (5YR 4/4); vitric; minor to common yellowish gray (5Y 8/1) pumice; rare to minor felsic phenocrysts of feldspar and quartz, including chatoyant sanidine; rare to minor mafic minerals of biotite and lesser hornblende; trace lithic fragments less than 1 mm in size; sphene is present.	mafic-poor Ammonia Tanks Tuff (Tmap)
59.7–81.1 (196–266)	21.4 (70)	DB4	none	**Bedded Tuff:** Very pale orange (10YR 8/2) to yellowish gray (5Y 8/1); vitric; very abundant white (N9) vitric pumice; rare to minor felsic phenocrysts of feldspar and quartz, rare to minor biotite and lesser hornblende.	bedded Ammonia Tanks Tuff (Tmab)

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
81.1–102.1 (266–335)	21.0 (69)	DA	none	**Pumiceous Lava:** Yellowish gray (5Y 7/2); vitric; conspicuously pumiceous; rare to minor felsic phenocrysts of feldspar and quartz, trace chatoyant sanidine; rare biotite. Becoming mottled with strong vapor-phase mineralization in bottom 4.6 m (15 ft) of interval.	rhyolite of Tannenbaum Hill (Tmat)
102.1–143.3 (335–470)	41.2 (135)	DA	none	**Rhyolite Lava:** Brownish gray (5YR 4/1) to grayish red (10R 4/2); silicified, with fragments of secondary chalcedony and opal; rare to minor felsic phenocrysts of feldspar and quartz; trace to rare biotite. Top of interval marked by abrupt increase in density as observed on the density log.	
143.3–234.7 (470–770)	91.4 (300)	DA	none	**Rhyolite Lava:** Medium gray (N5) to medium light gray (N6); devitrified; rare to minor felsic phenocrysts of feldspar and quartz; rare to minor biotite.	
234.7–318.2 (770–1,044)	83.5 (274)	DA	none	**Rhyolite Lava:** Brownish gray (5YR 4/1) to medium gray (N5); devitrified; rare to minor felsic phenocrysts of feldspar and quartz; rare biotite; some quartz-filled hairline fractures.	
318.2–339.5 (1,044–1,114)	21.4 (70)	DA	none	**Vitrophyric Lava:** Grayish black (N2); rare to minor felsic phenocrysts of feldspar and quartz; rare biotite.	
339.5–357.8 (1,114–1,174)	18.3 (60)	DA	none	**Rhyolite Lava:** Moderate brown (5YR 4/4) to moderate reddish brown (10R 4/6); devitrified, lesser vitric; rare to minor felsic phenocrysts of quartz and lesser feldspar; rare biotite. Interval may represent basal flow breccia. Base of interval is marked by a conspicuous decrease in density, resistivity, and total gamma ray as observed on geophysical logs.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
357.8–402.3 (1,174–1,320)	44.5 (146)	DA	none	**Bedded Tuff:** Light brown (5YR 6/4) to moderate orange pink (10R 7/4); zeolitic; minor light brown (5YR 5/6) pumice; minor to common felsic phenocrysts of quartz and lesser feldspar; minor biotite; rare to minor blackish red (5R 2/2) to grayish red (5R 4/2) lithic fragments. Interval shows characteristic lower total gamma ray, resistivity, and density as observed on geophysical logs.	rhyolite of Tannenbaum Hill (Tmat)
402.3–407.2 (1,320–1,336)	4.9 (16)	DA	none	**Nonwelded Ash-Flow Tuff:** Pale reddish brown (10R 5/4); zeolitic; common white (N9) pumice; minor to common felsic phenocrysts of quartz and lesser feldspar; common biotite; rare lithic fragments.	mafic-rich Rainier Mesa Tuff (Tmrr)
407.2–414.5 (1,336–1,360)	7.3 (24)	DA	none	**Partially Welded Ash-Flow Tuff:** Pale red (10R 6/2) to pale brown (5YR 5/2); devitrified; minor to common white (N9) pumice; minor to common felsic phenocrysts of quartz and lesser feldspar; common biotite; rare to minor lithic fragments less than 1 mm in size. Interval characterized by an increase in resistivity and density with depth that corresponds to an increase in welding.	
414.5–429.8 (1,360–1,410)	15.3 (50)	DA	none	**Moderately to Densely Welded Ash-Flow Tuff:** Grayish red (10R 4/2) to brownish gray (5YR 4/1); devitrified; with minor silicification; minor white (N9) pumice; minor to common felsic phenocrysts of feldspar and quartz; common biotite; trace to rare lithic fragments. Interval shows characteristic high density and resistivity corresponding to the high degree of welding.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
429.8–459.0 (1,410–1,506)	29.3 (96)	DA	none	**Moderately Welded Ash-Flow Tuff:** Pale red (5R 6/2) and grayish red (5R 4/2) to pale brown (5YR 5/2); devitrified; minor to common white (N9) pumice; common felsic phenocrysts of quartz and feldspar; minor to common biotite, some altered; rare lithic fragments. Interval shows characteristic high density and resistivity corresponding to the high degree of welding.	mafic-rich Rainier Mesa Tuff (Tmrr)
459.0–465.1 (1,506–1,526)	6.1 (20)	DA	469.4 (1,540) [d]	**Vitrophyre:** Black (N1) to moderate reddish brown (10R 4/6); vitric; rare to minor felsic phenocrysts of quartz and lesser feldspar; minor to common biotite; trace to rare lithic fragments. Interval shows the highest density and resistivity values for the ash-flow tuff interval which is characteristic of vitrophyric ash-flow tuff. XRD analysis of drill cuttings from this interval show 70% glass.	
465.1–472.4 (1,526–1,550)	7.3 (24)	DA	none	**Densely Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4) to moderate reddish brown (10R 4/6); devitrified; minor to common pumice; minor to common felsic phenocrysts of quartz and feldspar; minor to common biotite; rare lithic fragments.	
472.4–478.5 (1,550–1,570)	6.0 (20)	DA	none	**Nonwelded to Partially Welded Ash-Flow Tuff:** Grayish red (10R 4/2) to moderate reddish orange (10R 6/6); devitrified and zeolitic; common to abundant pinkish gray (5YR 8/1) pumice; minor to common felsic phenocrysts of quartz and feldspar; minor to common biotite, rare lithic fragments. From 476.7 to 478.5 m (1,564 to 1,570 ft), there is an anomalously high-density signature (> 2.3 grams/cubic centimeter) as indicated on the density log. This may correlate to a cobble bed commonly found at the base of the Tmr, which has been seen in surface exposures east of Well ER-EC-11 along the south face of Pahute Mesa.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
478.5–562.4 (1,570–1,845)	83.9 (275)	DB4 DA	512.1 (1,680) 533.4 (1,750) 557.8 (1,830)	**Nonwelded Tuff and lesser Bedded Tuff:** Moderate reddish orange (10R 6/6) to moderate reddish brown (10R 4/6); zeolitic; common to abundant very pale orange (10YR 8/2) to pinkish gray (5YR 8/1) pumice up to 1 cm in size; rare to minor felsic phenocrysts of quartz and feldspar; rare to minor biotite; rare to minor lithic fragments >1 mm in size. Cement present in cuttings sample from 509.0 to 515.1 m (1,670 to 1,690 ft). Interval shows consistently lower resistivity and density, which is characteristic of zeolitic nonwelded and bedded tuffs. Borehole image log indicates that most bedding contacts within interval dip less than 8 degrees to the west-northwest. XRD analysis of drill cuttings from 3 depths within interval indicate greater than 50% zeolite.	rhyolite of Fluorspar Canyon (Tmrf)
562.4–589.8 (1,845–1,935)	27.4 (90)	DB4 PSWC	582.2 (1,910)	**Nonwelded Tuff:** Moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6) becoming more moderate orange pink below 582.2 m (1,910 ft); zeolitic with minor moderate reddish brown (10R 4/6) silicification; common to abundant yellowish gray (5Y 8/1) pumice with an average size of 0.5 to 1 mm, but as large as 5 mm; rare to minor felsic phenocrysts of quartz and lesser feldspar; rare biotite; rare to common lithic fragments ranging from less than 0.5 mm up to 1 cm in size. Interval shows consistently lower resistivity and density values, characteristic of zeolitic nonwelded tuffs. XRD analysis shows greater than 50% zeolite.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
589.8–606.6 (1,935–1,990)	16.8 (55)	DB4 PSWC	600.5 (1,970)	**Nonwelded Tuff:** Moderate orange pink (10R 7/4) to light brown (5YR 6/4); zeolitic; minor to common very pale orange (10YR 8/2) pumice, up to 5 mm in size; trace to rare felsic phenocrysts of quartz and feldspar; rare strongly altered biotite; rare lithic fragments increasing to minor lithic fragments towards base of interval. Interval shows consistently lower resistivity and density values, characteristic of zeolitic nonwelded tuffs. XRD analysis shows greater than 50% zeolite.	rhyolite of Fluorspar Canyon (Tmrf)
606.6–627.9 (1,990–2,060)	21.4 (70)	DB4 PSWC	621.8 (2,040)	**Nonwelded Tuff and Bedded Tuff:** Light brown (5YR 6/4) to grayish orange (10YR 7/4) to moderate orange pink (10R 7/4); zeolitic; common to abundant grayish orange pink (10R 8/2) pumice; trace to rare felsic phenocrysts of quartz and feldspar; rare altered biotite; rare to minor lithic fragments. Interval shows consistently lower resistivity and density values, characteristic of zeolitic nonwelded tuffs. XRD analysis shows greater than 50% zeolite.	
627.9–646.2 (2,060–2,120)	18.3 (60)	DA PSWC	none	**Bedded Tuff:** Pale greenish yellow (10Y 8/2) to yellowish gray (5Y 7/2); zeolitic; rare to minor very pale orange (10YR 8/2) argillic pumice; trace to rare felsic phenocrysts of quartz and feldspar; rare altered biotite; rare lithic fragments. Borehole image log indicates most bedding within interval dips less than 8 degrees to the west-northwest.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
646.2–676.7 (2,120–2,220)	30.5 (100)	DA PSWC	none	**Nonwelded Tuff:** Moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6); zeolitic and partially argillic(?); rare to minor grayish orange pink (10R 8/2) pumice; trace to rare felsic phenocrysts of quartz and feldspar; rare altered biotite; trace to rare lithic fragments. Interval shows consistently lower resistivity and density values, characteristic of zeolitic nonwelded tuffs.	rhyolite of Fluorspar Canyon (Tmrf)
676.7–709.0 (2,220–2,326)	32.3 (106)	DA RSWC	685.8 (2,250)	**Bedded Tuff:** Moderate orange pink (10R 7/4); zeolitic; common to abundant grayish orange pink (10R 8/2) to white (N9) pumice, average size 1 to 2 mm, but up to 5 mm; rare felsic phenocrysts of quartz and feldspar; rare biotite; minor to common lithic fragments, average >1 mm in size. Borehole image log indicates most bedding dips less than 8 degrees to the northwest. Drill cuttings sample from 685.8 m (2,250 ft) is 45% zeolite according to XRD analysis.	
709.0–719.3 (2,326–2,360)	10.3 (34)	DA RSWC	710.2 (2,330)	**Bedded Tuff:** Moderate reddish brown (10R 4/6) to pale reddish brown (10R 5/4); zeolitic; abundant to very abundant pale greenish yellow (10Y 8/2) pumice averaging 1 to 2 mm and up to 1 cm in size; rare felsic phenocrysts of quartz and feldspar; rare to minor biotite; common to abundant lithic fragments. Borehole image log indicates that bedding within interval generally dip less than 10 degrees to the north-northeast.	Timber Mountain Group, undivided (Tm)

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
719.3–730.3 (2,360–2,396)	11.0 (36)	DB4 RSWC	723.0 (2,372)	**Bedded Tuff:** Moderate reddish brown (10R 4/6) to dark reddish brown (10R 3/4); quartzo-feldspathic; rare white (N9) pumice; rare felsic phenocrysts of quartz and feldspar; rare biotite; trace to rare lithic fragments. Borehole image log indicates that bedding within interval generally dip less than 10 degrees to the north-northeast.	Timber Mountain Group, undivided (Tm)
730.3–769.6 (2,396–2,525)	39.3 (129)	DA PSWC	744.6 (2,443) 760.2 (2,494)	**Bedded Tuff:** Grayish yellow (5Y 8/4) to yellowish gray (5Y 7/2); zeolitic (mordenite), lesser quartzo-feldspathic; becoming silicified at base of interval; trace to rare felsic phenocrysts of feldspar; rare to minor biotite; trace pseudomorphs after sphene.	rhyolite of Benham (Tpb)
769.6–786.4 (2,525–2,580)	16.8 (55)	DA RSWC	none	**Pumiceous Lava:** Dark yellowish orange (10YR 6/6) to dusky yellow (5Y 6/4) to greenish yellow (10Y 7/4); zeolitic; trace felsic phenocrysts of feldspar; rare biotite; sphene is present. Bottom 9 m (29 ft) is silicified. Sidewall core at 780.3 m (2,560 ft) contains a 1.5- to 2-mm wide quartz-filled fracture and numerous hairline fractures.	
786.4–804.1 (2,580–2,638)	17.7 (58)	DA RSWC	791.0 (2,595)	**Vitrophyric Lava:** Conspicuously dark yellowish orange (10YR 6/6) to dusky yellow (5Y 6/4); vitric; perlitic. XRD analysis of RSWC at 791.0 m (2,525 ft) shows 79% glass. Interval shows a marked increase in density and resistivity.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
804.1–829.1 (2,638–2,720)	25.0 (82)	DB4 RSWC	821.4 (2,695)	**Rhyolite Lava:** (1) Pale yellowish brown (10YR 6/2) to pale brown (5YR 5/2) vitric and perlitic; (2) pale greenish yellow (10Y 8/2) to very pale orange (10YR 8/2) devitrified lava with remnant perlitic texture; and (3) grayish red (10R 4/2) silicified flow breccia; rare to minor felsic phenocrysts of feldspar; rare biotite; numerous cuttings show quartz-filled fractures. Sidewall core at 812.4 m (2,665.5 ft) contains 0.5- to 1-mm wide, quartz-filled fractures, and dendritic manganese/iron (MnFe)-oxide coating on broken surface.	rhyolite of Benham (Tpb)
829.1–874.8 (2,720–2,870)	45.7 (150)	DA RSWC	859.5 (2,820)	**Rhyolite Lava:** Upper portion is brownish gray (5YR 4/1) and pale red (10R 6/2) becoming grayish orange pink (10R 8/2) to pale red (10R 6/2) to light gray (N7) to pinkish gray (5YR 8/1) at 835.2 m (2,740 ft); flow-banded; devitrified; rare felsic phenocrysts of feldspar; rare bronze biotite.	
874.8–899.2 (2,870–2,950)	24.4 (80)	DA RSWC	877.8 (2,880)	**Rhyolite Lava:** Yellowish gray (5Y 8/1) to very light gray (N8); devitrified; rare felsic phenocrysts of feldspar; trace bronze biotite; MnFe-oxide fracture-fill.	
899.2–930.2 (2,950–3,052)	31.1 (102)	DA RSWC	920.5 (3,020)	**Rhyolite Lava:** Mottled greenish gray (5GY 6/1) with grayish orange pink (10R 8/2); some rimmed with thin moderate reddish brown (10R 4/6); devitrified; rare felsic phenocrysts of feldspar; trace biotite. Sidewall core at 902.1 m (2,959.5 ft) shows flow banding. Lower contact is uncertain due to a wash-out in the interval 923.5–929.6 m (3,030–3,050 ft) as indicated by geophysical logs. No sample was collected in the interval 926.6–929.6 m (3,040–3,050 ft).	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
930.2–968.7 (3,052–3,178)	38.4 (126)	DB4 PSWC RSWC	944.9 (3,100) 955.5 (3,135)	**Bedded Tuff:** Grayish orange (10YR 7/4); quartzo-feldspathic and zeolitic (mordenite); rare to minor pale greenish yellow (10Y 8/2) pumice; rare to minor felsic phenocrysts of quartz and lesser feldspar; minor biotite; rare lithic fragments. Borehole image log indicates bedding dips approximately 10 degrees to the west-northwest.	Paintbrush Group, undivided (Tp)
968.7–1,005.8 (3,178–3,300)	37.2 (122)	DA RSWC	none	**Moderately Welded Ash-Flow Tuff:** Pale reddish brown (10R 5/4) to grayish red (10R 4/2); quartzo-feldspathic; rare to minor white (N9) to very pale orange (10YR 8/2) pumice; rare to minor felsic phenocrysts of feldspar and corroded pseudomorphs after feldspar; rare bronze biotite; numerous MnFe-oxide fracture-fill in cuttings.	Pahute Mesa lobe of Tiva CanyonTuff (Tpcm)
1,005.8–1,030.2 (3,300–3,380)	24.4 (80)	DA	none	**Densely Welded Ash-Flow Tuff:** Mottled grayish red (10R 4/2) to moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6); quartzo-feldspathic, becoming silicified below 1,021.1 m (3,350 ft); rare to minor pumice; rare to minor felsic phenocrysts of feldspar; rare biotite. Numerous hairline fractures in cuttings from interval 1,024.1–1,027.2 m (3,360–3,370 ft).	
1,030.2–1,036.9 (3,380–3,402)	6.7 (22)	DA PSWC	none	**Moderately Welded Ash-Flow Tuff:** Moderate reddish brown (10R 4/6) is vitric and pale reddish brown (10R 5/4) is silicic; rare pumice; rare felsic phenocrysts of feldspar; rare biotite. Hairline fractures at 1,036.3 m (3,400 ft) are filled with silica.	
1,036.9–1,045.5 (3,402–3,430)	8.5 (28)	DA	none	**Partially Welded to Nonwelded Ash-Flow Tuff:** Light brown (5YR 5/6) to pale reddish brown (10R 5/4); quartzo-feldspathic; rare to minor pumice; remnant glass shards; rare felsic phenocrysts of feldspar; rare biotite; trace lithic fragments.	

Depth Interval meters (feet)	**Thickness** meters (feet)	**Sample Type** [a]	**Depth of Analytical Samples** [b] meters (feet)	**Lithologic Description** [c]	**Stratigraphic Unit** (map symbol)
1,045.5–1,068.0 (3,430–3,504)	22.6 (74)	DB4 RSWC	1,049.1 (3,442)	**Bedded Tuff:** Grayish yellow (5Y 8/4) to slightly pale greenish yellow (10Y 8/2); quartzo-feldspathic and zeolitic (mordenite); minor pumice; rare to minor felsic phenocrysts of feldspar and lesser quartz; rare biotite; rare to minor lithic fragments. Borehole image logs indicate bedding dips approximately 15 degrees to the southeast.	Paintbrush Group, undivided (Tp)
1,068.0–1,079.0 (3,504–3,540)	11.0 (36)	DA RSWC	1,069.8 (3,510)	**Nonwelded Tuff:** Pinkish gray (5YR 8/1) to light gray (N7); quartzo-feldspathic and zeolitic (mordenite); minor to common very pale orange (10YR 8/2) to white (N9) pumice; rare felsic phenocrysts of feldspar; rare to minor biotite; rare to minor lithic fragments.	
1,079.0–1,091.8 (3,540–3,582)	12.8 (42)	DA RSWC	1,088.1 (3,570)	**Partially Welded Ash-Flow Tuff:** Light brownish gray (5YR 6/1); quartzo-feldspathic; minor to common grayish orange pink (10R 8/2) pumice; rare to minor felsic phenocrysts of feldspar, some altered; minor bronze biotite; rare lithic fragments.	Pahute Mesa lobe of Topopah Spring Tuff (Tptm)
1,091.8–1,107.6 (3,582–3,634)	15.8 (52)	DA RSWC	1,103.4 (3,620)	**Partially Welded Ash-Flow Tuff:** Light gray (N7); quartzo-feldspathic; minor to common pumice; minor to common felsic phenocrysts of feldspar, some altered; minor biotite; rare lithic fragments.	
1,107.6–1,125.3 (3,634–3,692)	17.7 (58)	DA RSWC	none	**Moderately Welded Ash-Flow Tuff:** Pale reddish brown (10R 5/4) to grayish red (10R 4/2); quartzo-feldspathic; minor grayish orange pink (10R 8/2) pumice; minor felsic phenocrysts of feldspar; minor biotite, some altered; rare lithic fragments.	
1,125.3–1,161.3 (3,692–3,810)	36.0 (118)	DA RSWC	none	**Densely Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4) to pale reddish brown (10R 5/4); quartzo-feldspathic; minor felsic phenocrysts of feldspar, some altered; rare to minor biotite; rare to minor lithic fragments.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type [a]	Depth of Analytical Samples [b] meters (feet)	Lithologic Description [c]	Stratigraphic Unit (map symbol)
1,161.3–1,193.0 (3,810–3,914)	31.7 (104)	DA RSWC	none	**Densely Welded Ash-Flow Tuff:** Moderate yellowish brown (10YR 5/4) to moderate brown (5YR 4/4); quartzo-feldspathic; minor white (N9) pumice; minor felsic phenocrysts of feldspar; rare to minor biotite; rare lithic fragments.	Pahute Mesa lobe of Topopah Spring Tuff (Tptm)
1,193.0–1,235.0 (3,914–4,052)	42.0 (138)	DA RSWC	none	**Moderately Welded Ash-Flow Tuff:** Moderate brown (5YR 4/4) to dark reddish brown (10R 3/4); quartzo-feldspathic; minor pumice; rare to minor felsic phenocrysts of feldspar, some altered; rare bronze biotite; minor lithic fragments.	
1,235.0–1,252.1 (4,052–4,108)	17.1 (56)	DA PSWC	1,245.1 (4,085)	**Nonwelded Tuff:** Light brown (5YR 6/4) to grayish orange (10YR 7/4); quartzo-feldspathic alteration with minor argillization(?); minor to common pumice; rare felsic phenocrysts of feldspar and minor quartz; rare biotite; rare lithic fragments.	mafic-poor Calico Hills Formation (Thp)
1,252.1–1,264.3 (4,108–4,148) Total depth	12.2 (40)	DA RSWC	1,252.7 (4,110) 1,261.9 (4,140)	**Bedded Tuff:** Pale reddish brown (10R 5/4) to moderate reddish brown (10R 4/6); quartzo-feldspathic and zeolitic (minor mordenite); minor to common pumice up to 1 mm in size; rare felsic phenocrysts of feldspar and quartz; rare biotite; rare to minor lithic fragments. Numerous hairline fractures in cuttings in interval 1,261.9–1,264.9 m (4,140–4,150 ft).	

NOTES

a **AC =** auger cuttings; **DA** = drill cuttings that represent lithologic character of interval; **DB4** = cuttings that are intimate mixtures of units; generally less than 50% of drill cuttings represent lithologic character of interval; **RSWC =** rotary sidewall core; **PSWC** = percussion sidewall core. See Table 3-1 in this report for more information about sidewall samples.

b Depth of lithologic samples selected for laboratory analyses. Laboratory analyses include petrography (from polished thin sections), mineralogy (x-ray diffraction), and chemistry (x-ray fluorescence). See Table 3-2 in this report for a complete list of laboratory analyses.

NOTES, continued

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 unless otherwise noted.
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%.

d Sample is representative of the indicated interval rather than the interval corresponding with the depth due to drilling lag time.

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Appendix D
Geophysical Logs Run in Well ER-EC-11

Appendix D contains plots of selected geophysical log data for Well ER-EC-11. Table D-1 summarizes the logs presented. See Table 3-3 for more information.

Table D-1
Well ER-EC-11 Geophysical Logs Presented

Log Type	Run Number	Date	Log Interval meters	Log Interval feet
Caliper	CA6-1 CA6-2 CA6-3	9/20/2009 10/06/2009 10/15/2009	4.6–503.8 472.4–971.1 945.0–1,261.0	15–1,653 1,550–3,186 3,100–4,137
X-Multipole Array Acoustilog (sonic)	XMAC-1 XMAC-2 XMAC-3	9/21/2009 10/07/2009 10/15/2009	449.6–500.0 495.0–969.3 899.2–1,262.8	1,475–1,640 1,624–3,180 2,950–4,143
Gamma Ray	GR-3 GR-10 GR-20	9/20/2009 10/06/2009 10/15/2009	6.4–495.6 457.2–962.6 893.1–1,253.3	21–1,626 1,500–3,158 2,930–4,112
Spectral Gamma Ray (potassium, thorium, uranium)	SGR-1 SGR-2 SGR-3	9/20/2009 10/06/2009 10/15/2009	6.4–495.6 457.2–962.6 893.1–1,253.3	21–1,626 1,500–3,158 2,930–4,112
High Definition Induction and Dual Laterolog (resistivity)	HDIL-1 DLL-1 DLL-2	9/20/2009 10/06/2009 10/15/2009	32.3–502.3 504.7–970.2 965.3–1,260.7	106–1,648 1,656–3,183 3,167–4,136
Density	ZDL-1 ZDL-2 ZDL-3	9/21/2009 10/06/2009 10/15/2009	32.3–505.1 442.0–973.2 856.5–1,261.0	106–1,657 1,450–3,193 2,810–4,147
Compensated Neutron	CN-1 CN-2 CN-3	9/21/2009 10/06/2009 10/15/2009	32.3–505.1 442.0–973.2 856.5–1,261.0	106–1,657 1,450–3,193 2,810–4,147
Chemistry (pH and conductivity) Temperature	Chem-1/TL-3 Chem-2/TL-5	10/09/2009 10/16/2009	450.8–976.0 944.9–1,267.7	1,479–3,202 3,100–4,159
Heat Pulse Flow Log	HPFlow-1 HPFlow-2	10/09/2009 10/17/2009	518.2–960.1 981.5–1,249.7	1,700–3,150 3,220–4,100

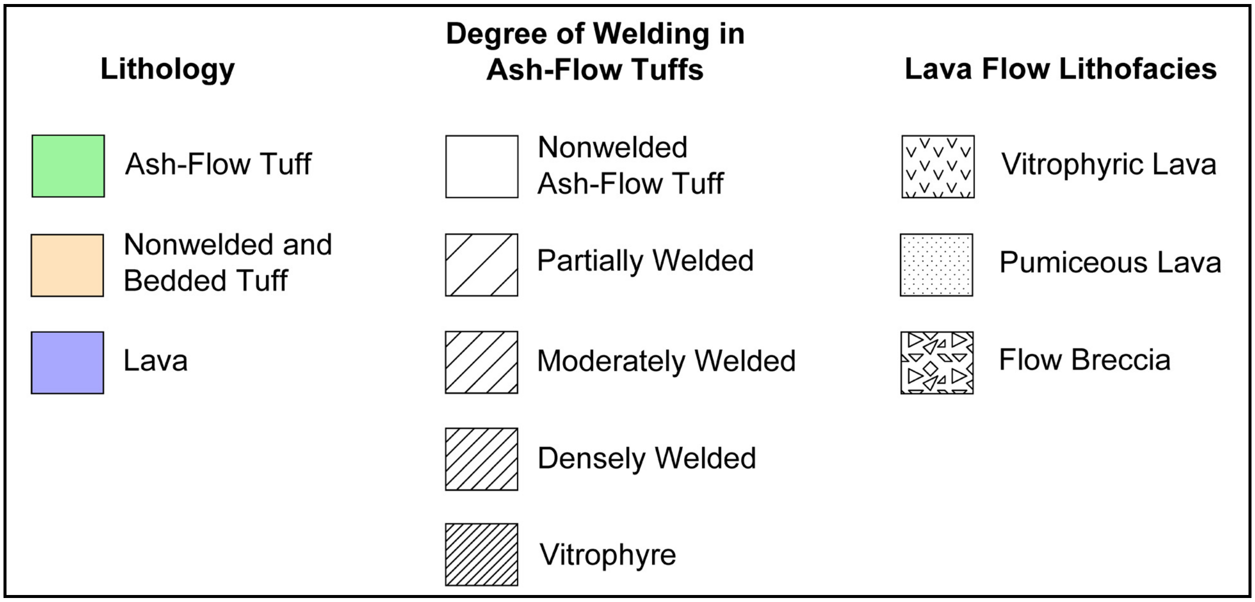
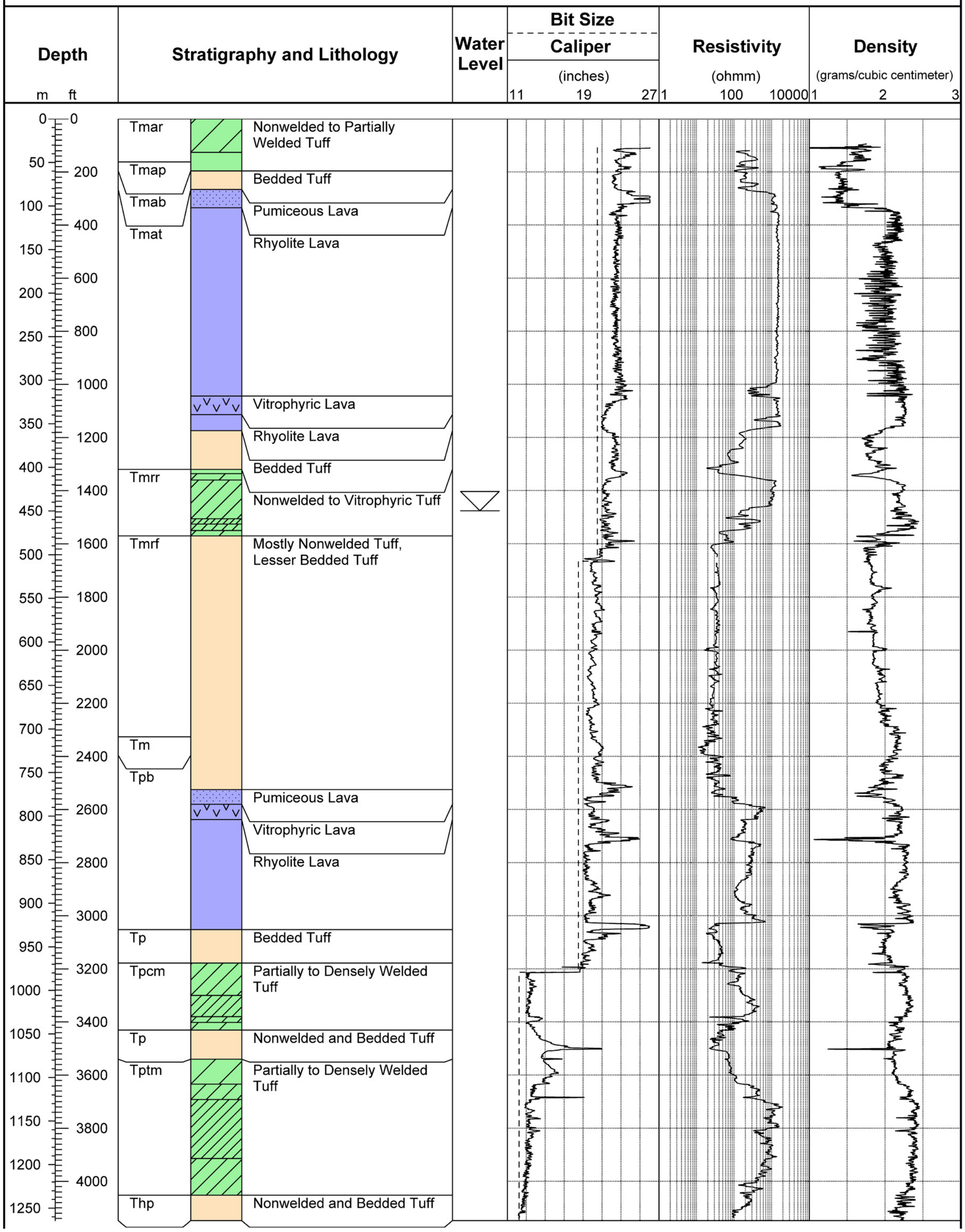


Figure D-1
Legend for Lithology Symbols Used on Log Plots

Well ER-EC-11

Logging Company: Baker Atlas
Date Logged: September 20, 21, October 6, and 15, 2009
Drilled Depth: 1,264.3 m (4,148 ft)
Date TD Reached: October 13, 2009
Drill Method: Rotary/Air foam

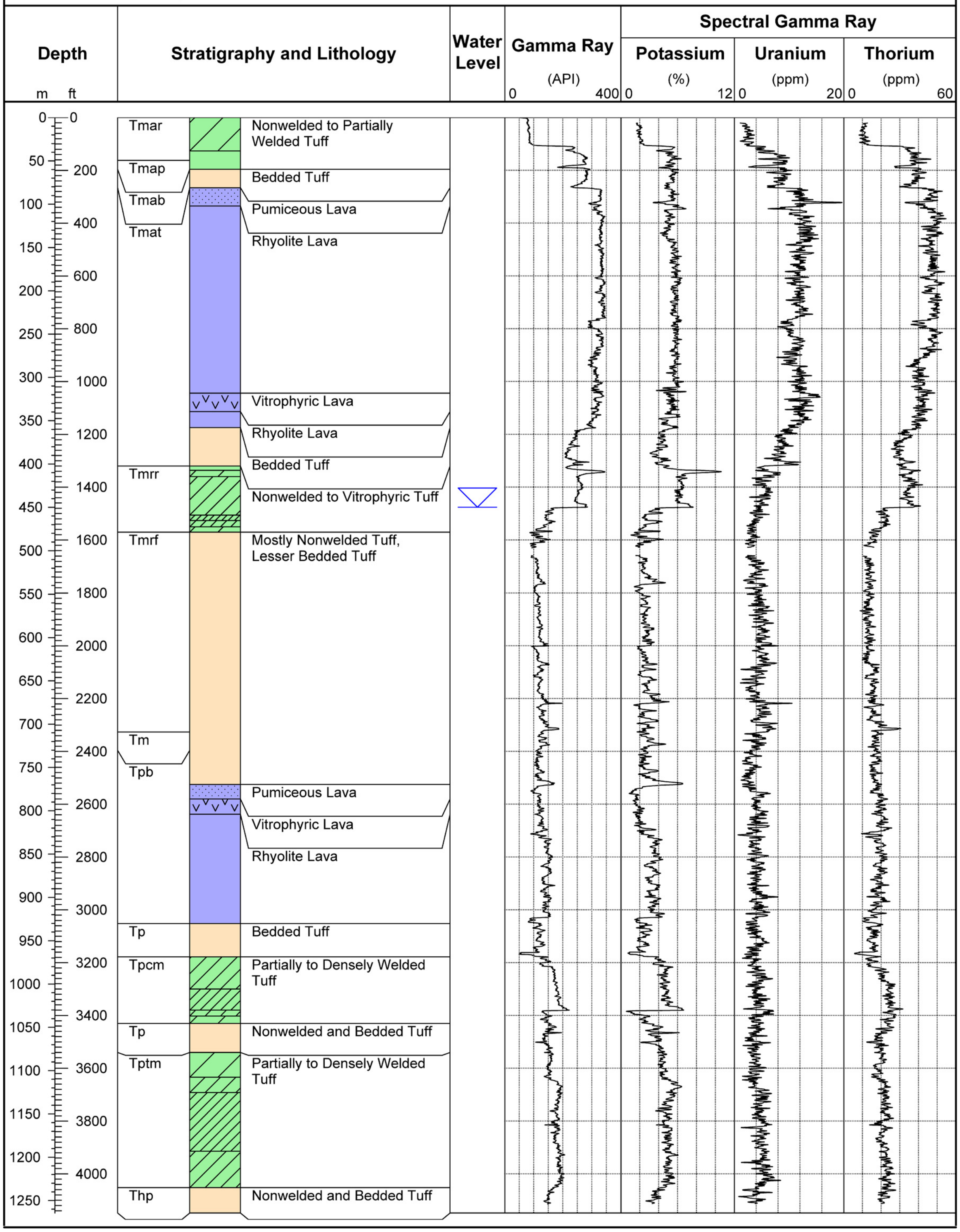
Surface Elevation: 1,724.0 m (5,656.3 ft)
Coordinates (UTM [NAD 83]): N 4,116,900.2 m
E 544,758.8 m
Water Level: 450.0 m (1,476 ft) on October 17, 2009



Well ER-EC-11

Logging Company: Baker Atlas
Date Logged: September 20 and October 6 and 15, 2009
Drilled Depth: 1,264.3 m (4,148 ft)
Date TD Reached: October 13, 2009
Drill Method: Rotary/Air foam

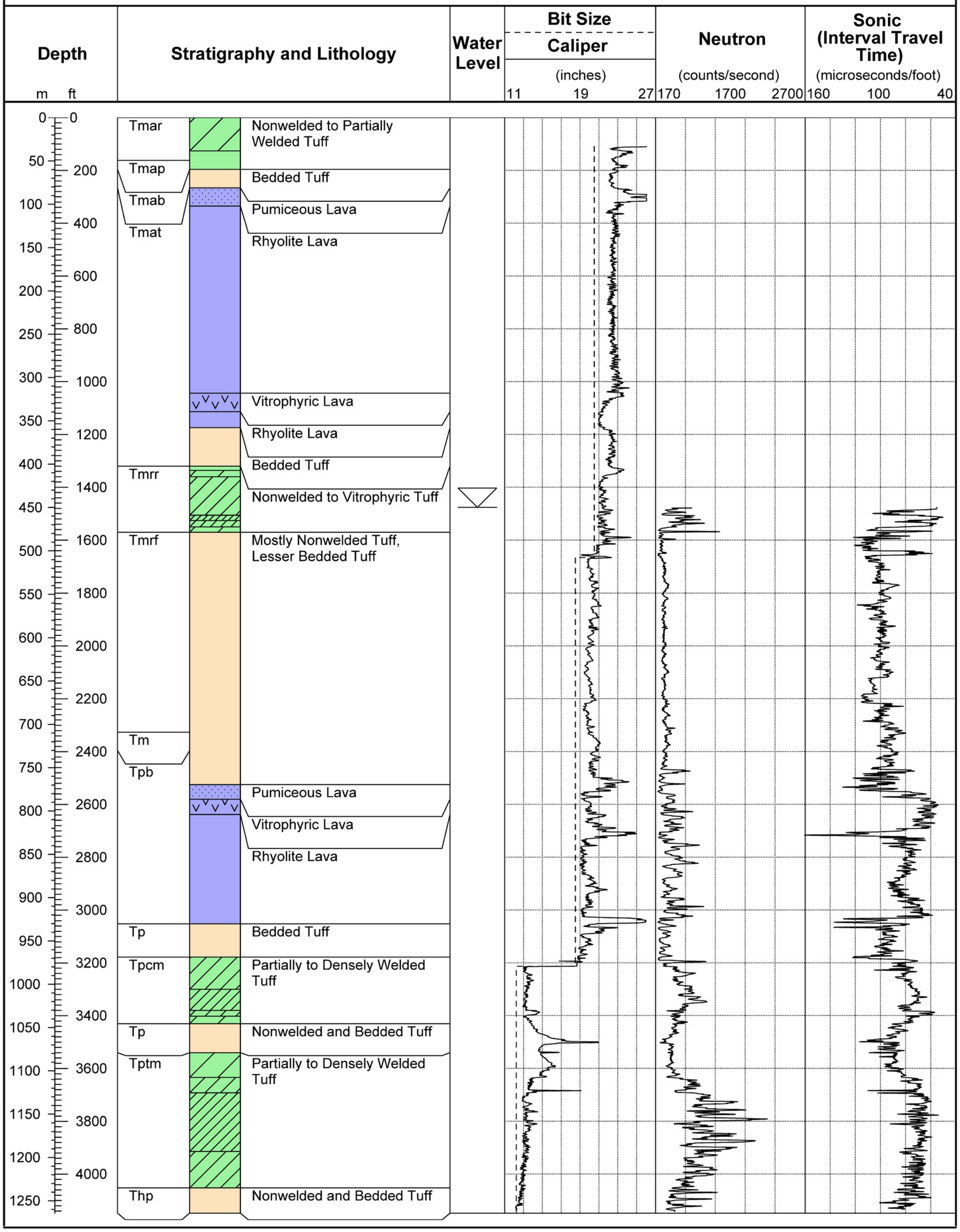
Surface Elevation: 1,724.0 m (5,656.3 ft)
Coordinates (UTM [NAD 83]): N 4,116,900.2 m
E 544,758.8 m
Water Level: 450.0 m (1,476 ft) on October 17, 2009



Well ER-EC-11

Logging Company: Baker Atlas
Date Logged: September 20, 21, October 6, 7, and 15, 2009
Drilled Depth: 1,264.3 m (4,148 ft)
Date TD Reached: October 13, 2009
Drill Method: Rotary/Air foam

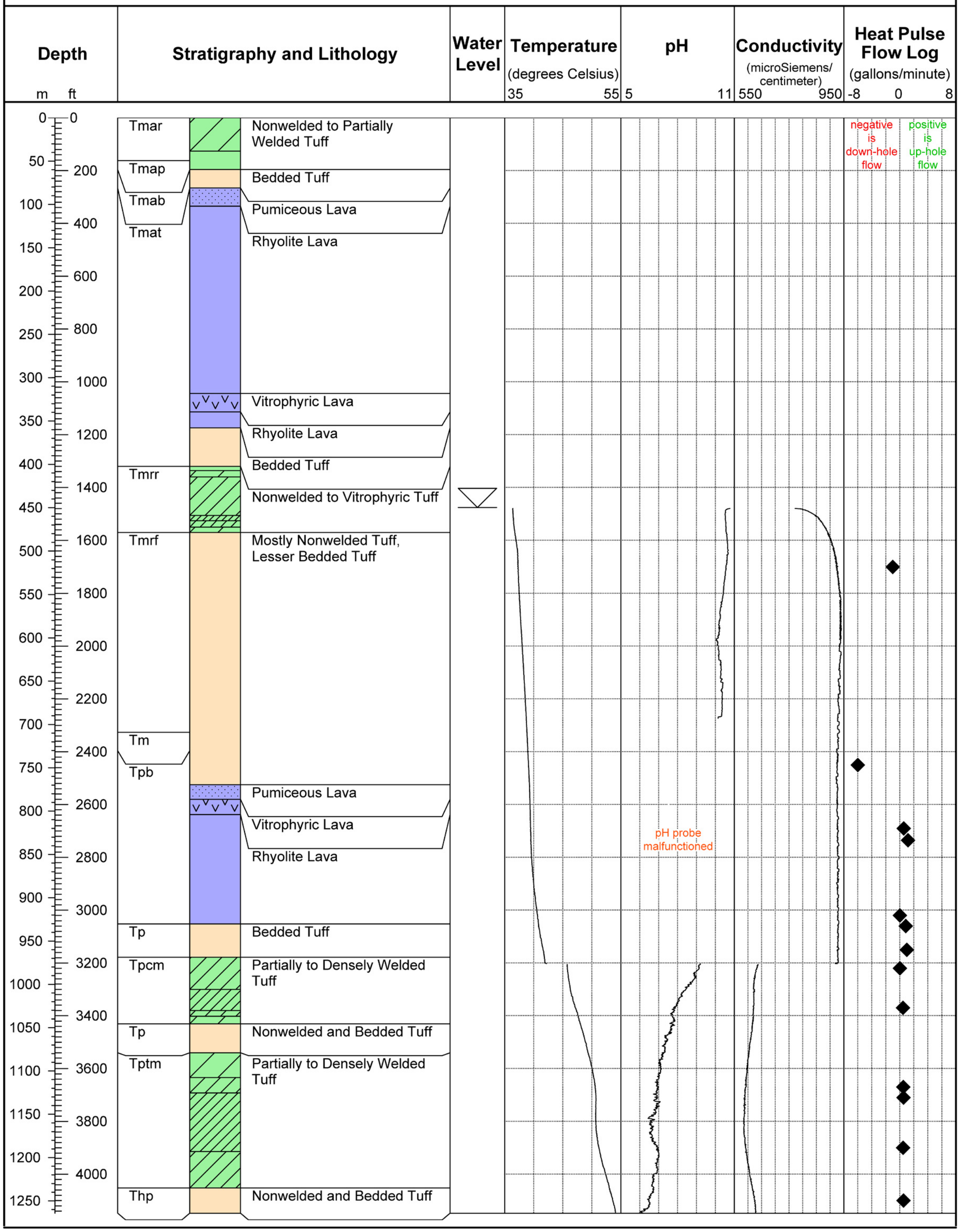
Surface Elevation: 1,724.0 m (5,656.3 ft)
Coordinates (UTM [NAD 83]): N 4,116,900.2 m
E 544,758.8 m
Water Level: 450.0 m (1,476 ft) on October 17, 2009



Well ER-EC-11

Logging Company: Desert Research Institute
Date Logged: October 9, 16, and 17, 2009
Drilled Depth: 1,264.3 m (4,148 ft)
Date TD Reached: October 13, 2009
Drill Method: Rotary/Air foam

Surface Elevation: 1,724.0 m (5,656.3 ft)
Coordinates (UTM [NAD 83]): N 4,116,900.2 m
E 544,758.8 m
Water Level: 450.0 m (1,476 ft) on October 17, 2009



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