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Completion Report for Well ER-20-11

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

February 2013

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

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Completion Report for Well ER-20-11

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

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February 2013

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COMPLETION REPORT FOR WELL ER-20-11

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

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Abstract

Well ER-20-11 was drilled for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office in support of the Nevada Environmental Management Operations Underground Test Area (UGTA) Activity at the Nevada National Security Site (formerly Nevada Test Site), Nye County, Nevada. The well was drilled in September 2012 as part of the Central and Western Pahute Mesa Corrective Action Unit Phase II drilling program. Well ER-20-11 was constructed to further investigate the nature and extent of radionuclide-contaminated groundwater encountered in two nearby UGTA wells, to help define hydraulic and transport parameters for the contaminated Benham aquifer, and to provide data for the UGTA hydrostratigraphic framework model.

The 44.5-centimeter (cm) surface hole was drilled to a depth of 520.0 meters (m) and cased with 34.0-cm casing to 511.5 m. The hole diameter was then decreased to 31.1 cm, and the borehole was drilled to a total depth of 915.6 m. The hole was completed to allow access for hydrologic testing and sampling in the target aquifer, which is a lava-flow aquifer known as the Benham aquifer.

The completion casing string, set to the depth of 904.3 m, consists of a string of 6⁵/₈-inch (in.) stainless-steel casing hanging from a string of 7⁵/₈-in. carbon-steel casing. The stainless-steel casing has one slotted interval at 796.3 to 903.6 m. One piezometer string was installed, which consists of 2⁷/₈-in. stainless-steel tubing that hangs from 2³/₈-in. carbon-steel tubing via a crossover sub. This string was landed at 903.8 m and is slotted in the interval 795.3 to 903.1 m.

Data collected during and shortly after hole construction include composite drill cuttings samples collected every 3.0 m, various geophysical logs, fluid samples (for groundwater chemistry analysis and tritium measurements), and water-level measurements. The well penetrated 915.6 m of Tertiary volcanic rock, including one saturated lava flow aquifer.

Measurements on samples taken from the undeveloped well indicated elevated tritium levels within the Benham aquifer. The maximum tritium level measured with field equipment was 146,131 picocuries per liter from a sample obtained at the depth of 912.0 m. The fluid level was measured in the piezometer string at a depth of 504.5 m on September 26, 2012.

All Fluid Management Plan (FMP) requirements for Well ER-20-11 were met. Analysis of monitoring samples and FMP confirmatory samples indicated that fluids generated during drilling at Well ER-20-11 met the FMP criteria for discharge to an unlined sump or designated infiltration area.

Well development, hydrologic testing, and sampling will be conducted at a later date.

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Nevada National Security Site

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List of Acronyms and Abbreviations

BA	Benham aquifer
BN	Bechtel Nevada
CAIP	Corrective Action Investigation Plan
CAU	Corrective Action Unit
CFR	Code of Federal Regulations
cm	centimeter(s)
DOE/NV	U.S. Department of Energy, Nevada Operations Office
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)
gal	gallon(s)
gpm	gallon(s) per minute
HFM	hydrostratigraphic framework model
HSU	hydrostratigraphic unit
id	inside diameter
in.	inch(es)
L	liter(s)
LANL	Los Alamos National Laboratory
LiBr	lithium bromide
Lpm	liter(s) per minute
LSC	liquid scintillation counter
m	meter(s)
m ³	cubic meter(s)
Ma	million years ago
MDA	minimum detectable activity
NAD	North American Datum
NARA	National Archives and Records Administration
NDEP	Nevada Division of Environmental Protection
N-I	Navarro-Intera, LLC
NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office

List of Acronyms and Abbreviations (continued)

NNSS	Nevada National Security Site
NSTec	National Security Technologies, LLC
NTMMSZ	Northern Timber Mountain moat structural zone
NTTR	Nevada Test and Training Range
pCi/L	picocurie(s) per liter
PM–OV	Pahute Mesa–Oasis Valley
RCT	radiological control technician
SCCC	Silent Canyon caldera complex
SNJV	Stoller-Navarro Joint Venture
TD	total depth
THLFA	Tannenbaum Hill lava-flow aquifer
TMCC	Timber Mountain caldera complex
TWG	Technical Working Group
UDI	United Drilling, Inc.
UGT	underground nuclear test
UGTA	Underground Test Area
UPCU	upper Paintbrush confining unit
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
yd ³	cubic yard(s)

1.0 Introduction

1.1 Project Description

Well ER-20-11 was drilled for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office (NNSA/NSO) in support of the Nevada Environmental Management Operations Underground Test Area (UGTA) Activity at the Nevada National Security Site (NNSS; formerly Nevada Test Site). Well ER-20-11 was the ninth 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 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), agreed to by the U.S. Department of Energy, the Nevada Division of Environmental Protection (NDEP), and the U.S. Department of Defense.

The Central and Western Pahute Mesa CAUs and the associated well drilling program are part of the UGTA Activity at the NNSS. Two goals of the UGTA Activity 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 Activity, scientists are developing computer models to forecast 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 reliable modeling of groundwater flow and radionuclide migration in the region. Some wells may be used as long-term monitoring wells.

Well ER-20-11 is located on the NNSS, near the Nevada Test and Training Range (NTTR) boundary (Figure 1-1). The well is located in the area immediately downgradient of the Area 20 test area on Pahute Mesa and is intended to provide information that will refine the understanding of the hydrogeology in this important area. The primary purpose of this well is to investigate the nature and extent of radionuclide-contaminated groundwater encountered in nearby UGTA Wells ER-EC-11 (NNSA/NSO, 2010a) and ER-20-8/ER-20-8#2 (NNSA/NSO, 2011a), and to obtain detailed hydrogeologic information for the contaminated Benham aquifer (BA) (Navarro-Intera, LLC [N-I], 2011).

Detailed hydrogeologic information about the Tertiary volcanic section obtained from this well will support Phase II efforts, including improving the Phase I hydrostratigraphic framework model (HFM) of the Pahute Mesa–Oasis Valley (PM–OV) area (Bechtel Nevada [BN], 2002) and subsequent flow and transport modeling.

1.2 Project Organization

The construction of Well ER-20-11 was intended to help fulfill the goals of the UGTA Activity. Several groups function within the Activity, whose responsibilities include ensuring that UGTA goals are properly planned and achieved. The roles of these groups regarding construction of Well ER-20-11 are described in this section.

The UGTA Technical Working Group (TWG) is a group of scientists and engineers from NNSA/NSO, Lawrence Livermore National Laboratory, Los Alamos National Laboratory (LANL), NDEP, the Desert Research Institute, the U.S. Geological Survey (USGS), National Security Technologies, LLC (NSTec; NNS management and operating contractor), and N-I (NNS environmental contractor). The TWG's Pahute Mesa Phase II CAIP *ad hoc* subcommittee (Stoller-Navarro Joint Venture [SNJV], 2009a) assisted NNSA/NSO in developing the CAIP for the Pahute Mesa CAUs. The Well ER-20-11 Drilling Advisory Team, which included the NNSA/NSO UGTA Activity Lead, the CAU Lead, the N-I field manager, the NSTec UGTA manager/drilling engineer, a hydrologist, a geologist, and a radiochemist, provided technical advice during drilling, design, and construction of the well, to ensure that Well ER-20-11 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. See *Addendum #2 to the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria for Investigation Wells ER-EC-14 and ER-20-11* (N-I, 2011) for well-specific goals.

NSTec provided site supervision, engineering, construction, inspection, and geologic support. 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-011-001.12 and D-007-001.12 (NSTec, 2011; 2012).

N-I was the principal environmental contractor for the project and was responsible for general environmental compliance and waste management at the drill site. N-I was responsible for collecting and analyzing fluid samples for water quality and chemistry, and for monitoring and documenting disposition of fluids and drill cuttings produced from the borehole. N-I personnel

also collected geologic, hydrologic, and drilling parameter data during drilling, as described in N-I (2012a).

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). Well-specific operation strategies for fluid management are further identified in the well-specific fluid management strategy letter (N-I, 2012b; reproduced in Appendix B-2 of this report) as required by the FMP and approved by NDEP before fluid-generating activities are initiated. 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 Phase II 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, 2011; 2012; N-I, 2012a) and the UGTA Project Health and Safety Plan (NSTec, 2008).

This report presents construction, environmental compliance, and waste management data, and summarizes scientific data gathered during the drilling of Well ER-20-11. Some of the information in this report is preliminary and unprocessed, but is being released with the drilling and completion data for convenient reference. Some of these data were obtained from N-I's preliminary Well ER-20-11 data package (N-I, 2013), which is now superseded by this document. 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; 2009b). Pre-drilling geologic information for this area is compiled in Addendum #2 to the Phase II drilling criteria document (N-I, 2011). 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-20-11 is located in NNSS Area 20 at an elevation of 1,778.2 meters (m) (5,834.0 feet [ft]). It is located approximately 229 m (752 ft) east of the NTTR boundary, just below the southern topographic edge of Pahute Mesa (Figures 1-1 and 1-2). Surface drainage in the vicinity of Well ER-20-11 is generally into south- or southwest-flowing washes that are tributaries of Rocket Wash to the south.

Figure 1-2
Topographic Map of the Well ER-20-11 Area Showing the Locations of
Roads and Nearby Drill Holes

Well ER-20-11 is located on the northern section of the Bench, which is defined as the area between the northern Timber Mountain moat structural zone (NTMMSZ) on the north and the Timber Mountain caldera complex (TMCC) on the south (Figure 1-3). Additional information about the Well ER-20-11 site is provided in Table 1-1.

The Well ER-20-11 site is located about midway between existing UGTA characterization Wells ER-EC-11 (NNSA/NSO, 2010a) and ER-20-8/ER-20-8#2 (NNSA/NSO, 2011a). Well ER-20-11 is located approximately 952 m (3,124 ft) southeast of Well ER-EC-11, and approximately 967 m (3,172 ft) northwest of Well ER-20-8. The Well ER-20-11 site is approximately 1,377 m (4,518 ft) northeast of Well ER-EC-6 (U.S. Department of Energy, Nevada Operations Office [DOE/NV], 2000a), and approximately 1,931 m (6,334 ft) southwest of Well ER-20-7 (NNSA/NSO, 2010b). See Figures 1-2 and 1-3 for the locations of these and other nearby UGTA wells.

The Well ER-20-11 drill site is approximately 2,877 m (9,439 ft) southwest of surface ground zero of the TYBO underground nuclear test (UGT), which was conducted in Emplacement Hole U-20y and is the closest UGT to Well ER-20-11. Other UGTs near Well ER-20-11 are BELMONT (U-20as), MOLBO (U-20ag), and BENHAM (U-20c). TYBO, MOLBO, and BENHAM were conducted below the regional water table. BELMONT was conducted just above the regional water table, although its cavity is estimated to extend below the water table. Figures 1-2 and 1-3 show the locations of the nearby tests in relation to Well ER-20-11. Table 1-2 provides additional information regarding these nearby tests.

1.4 Objectives

Well ER-20-11 is an intermediate-depth (915.6 m [3,004 ft]) hydrogeologic investigation well. The primary purpose of Well ER-20-11 was to provide detailed hydrogeologic information for the BA. The BA is the primary aquifer implicated in transport of radionuclides from UGTs on Pahute Mesa across the Bench area between Pahute Mesa and the TMCC (Figure 1-2). Radionuclides were first identified in groundwater at Well Cluster ER-20-5 (DOE/NV, 1997) and later at Well ER-20-7 (NNSA/NSO, 2010b), Wells ER-20-8/20-8#2 (NNSA/NSO, 2011a), and Well ER-EC-11 (NNSA/NSO, 2010a). Well ER-20-11 was also expected to provide information regarding the nature and hydrologic effect of the NTMMSZ and Basin and Range faults presumed to be nearby.

Well ER-20-11 was initially planned as Well ER-EC-11#2, to be completed in the BA on or near the Well ER-EC-11 site. Tritium had been detected while drilling in the BA at Well ER-EC-11 (NNSA/NSO, 2010a). Though the levels were below the limits prescribed in National Primary Drinking Water Regulations (Code of Federal Regulations [CFR], 2010), the decision was made

Figure 1-3
Shaded Relief Map of the Well ER-20-11 Area Showing the Locations of
Nearby Drill Holes and the Bench

**Table 1-1
Well ER-20-11 Site Data Summary**

Hole Name	Well ER-20-11
Site Coordinates ^a	Nevada State Plane – Central Zone, NAD 27 N 890,418.4 feet (ft) E 553,150.4 ft
	Nevada State Plane – Central Zone, NAD 83 N 6,271,400.7 meters (m) E 516,120.7 m
	UTM – Zone 11, NAD 83 N 4,116,747.6 m E 545,698.4 m
	UTM – Zone 11, NAD 27 N 4,116,550.4 m E 545,778.6 m
	Geographic – NAD 83 (degrees, minutes, seconds) Latitude: 37° 11' 45.85" Longitude: 116° 29' 06.26"
	Township and Range ^c Northwest ¼ of Southeast ¼ of Section 34 Township 8 South, Range 49 East
Surface Elevation ^{a, b}	1,778.2 m (5,834.0 ft)
Drilled Depth	915.6 m (3,004 ft)
Fluid-Level Depth ^d	504.5 m (1,655.2 ft)
Fluid-Level Elevation	1,273.7 m (4,178.8 ft)
Surface Geology	Beatty Wash Formation

- a Measurements made by NSTec Survey using NAD 27 Nevada State Plane coordinates in feet. All other coordinates listed were calculated from NAD 27 feet using Corpscon (U.S. Army Corps of Engineers, 2004). 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 Quarter and quarter/quarter section values were visually estimated using data from Public Land Survey System (Bureau of Land Management Cadastral Survey, 2006).
- d Measured by N-I personnel in piezometer string on September 26, 2012, 12 days after well completion.

Table 1-2
Selected Information for Underground Nuclear Tests Relevant to Well ER-20-11

Emplacement Hole Name	Test Name ^a	Test Date ^a	Surface Elevation ^b meters (feet)	Depth of Burial ^b meters (feet)	Estimated Depth to Regional Water Level ^b meters (feet)	Announced Yield ^a (kilotons)	WP Formation ^{c, d}	WP HSU ^{c, e}	Lateral Distance to Well ER-20-11 Location meters (feet)
U-20y	TYBO	5/14/1975	1,907 (6,257)	765 (2,510)	630 (2,067)	200–1,000	Tpt	TSA	2,877 (9,439)
U-20as	BELMONT	10/16/1986	1,898 (6,227)	605 (1,985)	614 (2,014)	20–150	Tpb(b)	UPCU	3,351 (10,995)
U-20ag	MOLBO	2/12/1982	1,900 (6,234)	638 (2,093)	619 (2,031)	20–150	Tpb	BA	3,667 (12,032)
U-20c	BENHAM	12/19/1968	1,915 (6,281)	1,402 (4,600)	639 (2,096)	1,150	Th	CHZCM	4,034 (13,237)

a DOE/NV (2000b)

b NNSA/NSO (2009a)

c BN (2002)

d Stratigraphic Nomenclature:

Tpt = Topopah Spring Tuff

Tpb(b) = rhyolite of Benham, bedded

Tpb = rhyolite of Benham, lava flow

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

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 Tiva Canyon aquifer and the Topopah Spring aquifer (NNSA/NSO, 2010a). It was also agreed at that time that it would be necessary to drill another well from this location to investigate the BA. However, during the subsequent planning phase, it was decided to relocate this BA-completion well to a position between Wells ER-EC-11 and ER-20-8 to expand the area of investigation of the potential contamination (N-I, 2011).

An important secondary objective was to obtain geologic information that may help reduce uncertainties in the HFM for the area of the Bench, and thus improve flow and transport modeling for CAUs 101 and 102. The Well ER-20-11 location may be a favorable location for a long-term monitoring well.

The specific objectives for drilling, completion, and initial sampling at Well ER-20-11, as described in *Addendum #2 to the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria for Investigation Wells ER-EC-14 and ER 20-11* (N-I, 2011), are listed below:

- Obtain groundwater samples for analysis to investigate the possibility of contaminant transport downgradient from the TYBO and BENHAM UGTs and across the NTMMSZ to the Bench.
- Obtain geologic information that may help reduce uncertainties in the HFM for the area between the former testing areas on Pahute Mesa and the TMCC:
 - Detailed hydrogeologic information for the shallow to intermediate Tertiary volcanic section
 - Information regarding the location, geometry, and hydrologic characteristics of the NTMMSZ
 - Information that will help characterize nearby north-south trending Basin and Range faults
 - Detailed information on the geology and configuration of volcanic units in the upper portion of the saturated section where contaminant transport is most likely
- Obtain properties of the BA such as detailed fracture data and hydrologic information.
- Obtain data that can be used to investigate contaminant transport paths through the Bench predicted by the Phase I transport model (SNJV, 2009b):
 - Representative aqueous geochemistry samples from the BA to better define possible groundwater flow paths based on water chemistry
 - Detailed water-level data to determine the regional water level and investigate local groundwater flow toward and/or along nearby structures

- Collect geologic samples for detailed mineralogical analyses. These will help define the distribution of reactive minerals such as clays, zeolites, and iron oxides in the Tertiary volcanic section.

Additional data that will help characterize the hydrology in southern Pahute Mesa and the Bench will be obtained during later hydraulic testing at this well. Specific criteria for these tests will be provided elsewhere (e.g., FAWPs and specific hydrologic testing plans), but, ultimately, Well ER-20-11 is expected to provide the following:

- Data to determine the vertical hydraulic gradient
- Data to determine vertical and horizontal hydraulic conductivity
- Hydraulic properties of the saturated hydrostratigraphic units (HSUs) penetrated

The completed well was expected to accommodate single-well hydraulic testing and could be a potential observation well for multi-well aquifer tests. However, due to its central location among several UGTA characterization wells, Well ER-20-11 may be best suited as a pumping well for a multi-well aquifer test. Any consideration for using Well ER-20-11 as the pumping well for a multi-well aquifer test must be carefully weighed against the potential acceleration of the tritium plume that may result.

1.5 Project Summary

This section summarizes Well ER-20-11 construction operations; the details are provided in Sections 2.0 through 8.0 of this report.

A 106.7-centimeter (cm) (42-inch [in.]) diameter surface conductor hole was constructed by augering to a depth of 18.3 m (60 ft), and installing a string of 30-in. conductor casing to the depth of 17.8 m (58.4 ft). Drilling of the 44.5-cm (17.5-in.) diameter surface hole began on September 1, 2012, and reached the depth of 520.0 m (1,706 ft); a string of 13³/₈-in. casing was set to 511.5 m (1,678.2 ft) on September 6, 2012. The 31.1-cm (12.25-in.) main hole was then drilled to the total depth (TD) of 915.6 m (3,004 ft), which was reached on September 9, 2012.

The well was drilled entirely within Tertiary volcanic rocks. The BA was encountered at the depth of 797.1 m (2,615 ft), near the predicted depth, and was saturated. Tritium was encountered in the BA at a depth of approximately 828.8 m (2,719 ft), approximately 324.3 m (1,064 ft) below the fluid-level depth of 504.4 m (1,655 ft).

Composite drill cuttings were collected every 3.0 m (10 ft) from the depth of 18.3 m (60 ft) to TD. No sidewall core samples were attempted. 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 completed with a string of 6⁵/₈-in. stainless-steel casing that is suspended from a string of 7⁵/₈-in. epoxy-coated carbon-steel casing. The completion casing was landed at 904.3 m (2,966.8 ft) and has one slotted interval. This slotted interval, from 796.3 to 903.6 m (2,612.4 to 2,964.5 ft), allows access to the BA. One piezometer string was installed to monitor water levels during hydraulic testing. This string consists of 7.3-cm (2⁷/₈-in.) stainless-steel tubing suspended via a crossover sub from a string of 6.03-cm (2³/₈-in.) carbon-steel tubing. The piezometer string is slotted from 795.3 to 903.1 m (2,609.3 to 2,963.0 ft) also within the BA. The fluid level was measured inside the piezometer string at the depth of 504.5 m (1,655.2 ft) on September 26, 2012.

1.6 *Contact Information*

Inquiries concerning Well ER-20-11 should be directed to the Federal UGTA Activity Lead at:

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

2.0 Drilling Summary

2.1 Introduction

This section contains detailed descriptions of Well ER-20-11 drilling operations. The general drilling requirements for both 2012 Pahute Mesa Phase II wells were provided in *Addendum #2 to the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria for Investigation Wells ER-EC-14 and ER-20-11* (N-I, 2011). Specific requirements for Well ER-20-11 were outlined in FAWP numbers D-011-001.12 and D-007-001.12 (NSTec, 2011; 2012).

Figure 2-1 shows the layout of the drill site. Figure 2-2 is a chart of the drilling and completion history for Well ER-20-11. A summary of drilling statistics for the well is given in Table 2-1. The information in this section was compiled primarily from NSTec daily drilling reports.

By industry convention, casing and tubing are identified using English units (e.g., 30-in. casing or 2⁷/₈-in. carbon-steel tubing), which is usually equivalent to the outside diameter of the pipe. In this report, these descriptors are used to designate the type of casing or tubing (its “name”), and no metric conversion is provided. The same is true for drill bits (e.g., 12¹/₄-in. bit), but when the size of the resulting hole is mentioned, both metric and English units are given.

2.2 Drilling History

Field operations at Well ER-20-11 began on January 3, 2012, when an NSTec crew started to auger the conductor hole. The 106.7-cm (42-in.) conductor hole was augered to the depth of 18.3 m (60 ft), and a string of 30-in. conductor casing was set at the depth of 17.8 m (58.4 ft). The conductor casing was cemented in place on January 09, 2012, using 1.9 cubic meters (m³) (2.5 cubic yards [yd³]) of Redi-Mix Formula 400 to set a plug inside the bottom of the casing. The next day 9.9 m³ (13 yd³) of cement was pumped into the annulus between the casing and the formation, filling it to ground level. See cement composition information in Appendix A-3.

The site was inactive until UDI crews arrived on August 23, 2012, and began rigging up the Wilson Mogul 42B drill rig. They finished rigging up on August 31, 2012, and began drilling from the top of cement inside the 30-in. casing at 14.0 m (46 ft) on September 1, 2012. The drill crew worked through the cement at the bottom of the 30-in. casing with a center-punch assembly consisting of a 17¹/₂-in. rotary bit mounted 7.6 m (25 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 25.3 m (83 ft).

Figure 2-1
Drill Site Configuration for Well ER-20-11

BA
BHA
cm
cu. ft
cu. m
DC
ft
in.
m
NAIL
N-I
NSTec
RIH
SLM
TD
TIH
TOC
TOF
TOG
TOH
TOS
UDI
WOC

LEGEND

Baker Atlas
bottom hole assembly
centimeter(s)
cubic feet
cubic meters
drill collars
foot (feet)
inch(es)
meter(s)
nuclear annulus investigation log
Navarro-Intera, LLC
National Security Technologies
run in hole
steel line measurement
total depth
trip into hole
top of cement
top of fluid
top of gravel
trip out of hole
top of sand
United Drilling Inc.
Wait on cement

DEPTH (METERS)

DAY	1	2	3	4	5	6
DATE	01/03/12	01/04	01/05	01/09	01/10	01/12
100	Mobilize Auger rig and drill 106.7-cm (42-in.) conductor hole to 7.3 m (23 ft).	↑	↑	↑	↑	↑
200		↑	↑	↑	↑	↑
300		↑	↑	↑	↑	↑
400	TOH. Replace 42-in. auger with 26-in. auger and drill to 15.2 m (50 ft). TOH. TIH with 42-in. auger and ream to 14.3 m (47 ft).	↑	↑	↑	↑	↑
500		↑	↑	↑	↑	↑
600	Remove 42-in. auger and replace with 26-in. auger. Auger to 18.9 m (62 ft). Switch back to 42-in. auger and ream to 17.2 m (56.5 ft).	↑	↑	↑	↑	↑
700		↑	↑	↑	↑	↑
800	Ream hole to 106.7 cm (42 in.) 18.3 m (60 ft). TOH. Run 30-in. casing to 17.8 m (58.4 ft). Cement bottom of casing.	↑	↑	↑	↑	↑
900		↑	↑	↑	↑	↑
1,000	Cement annulus of 30-in. casing to surface. Auger anchor holes.	↑	↑	↑	↑	↑
1,100		↑	↑	↑	↑	↑
1,200	Demobilize auger rig and equipment.	↑	↑	↑	↑	↑
1,300		↑	↑	↑	↑	↑
1,400		↑	↑	↑	↑	↑
1,500	↑	↑	↑	↑	↑	↑

No activity 01/13/2012 to 08/22/2012

	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
	08/23	08/24	08/25	08/28	08/29	08/30	08/31	09/01	09/02	09/03	09/04	09/05	09/06	09/07	09/08	09/09	09/10	09/11	09/12	09/13	09/14
SUMMARY	Start mobilizing Wilson Mogil 42B rig and equipment to site.	Continue mobilizing rig and UDI equipment to site.	Continue mobilizing and rigging up.	Continue rigging up.	Continue rigging up.	Continue rigging up.	Make up center-punch BHA with 26-in. hole opener and 17 1/2-in. bit. Tag TOC at 14.0 m (46 ft). Wait for flow-line inspection. Two shifts worked.	Start working three shifts. Wait on welding inspection. Drill out cement with center-punch BHA. TOH. TIH with 17 1/2-in. bit and drill to 61.0 m (200 ft). TOH. Pick up reamer and drill collars.	TIH. Drill to 146.3 m (480 ft). TOH to add DC and jars to BHA. TIH and drill to 192.0 m (630 ft).	Drill 44.5-cm (17.5-in.) hole to 310.0 m (1,017 ft).	Circulate hole clean and pull up one stand.	Make short trip. Tag 4.3 m (14 ft) of fill. Clean out fill. Make short trip and tag fill at 515.7 m (1,692 ft). Wait on BA. Start geophysical logging.	Wait on casing crew. Run 13 3/8-in. casing to 511.5 m (1,678.2 ft).	with cementing string, stab into shoe and pump 7.1 cu m (250 cu ft) cement. 1/4-in. BHA. Tag cement at 504.1 m (1,654 ft) and drill to 516.0 m (1,693 ft).	and drill new 31.1-cm (12.25 -in.) hole to 807.7 m (2,650 ft).	4 ft). Circulate hole clean. Make short trip. No fill.	ing. N-I tags fluid at 504.7 m (1,655.7 ft). Collect from two depths. TIH and TOH, laying down string.	RIH to 903.8 m (2,965.2 ft). RIH with tremie string. rig up casing crew. Start RIH with 6 5/8-in casing.	heat cement until TOC is 729.4 m (2,393 ft). WOC. obtains final NAIL. TAG TOC at 734.3 m (2,409 ft) ie. TOH with tremie tubing and start rigging down.		

Start mobilizing Wilson Mogil 42B rig and equipment to site.

Continue mobilizing rig and UDI equipment to site.

Continue mobilizing and rigging up.

Continue rigging up.

Continue rigging up.

Continue rigging up.

Make up center-punch BHA with 26-in. hole opener and 17 1/2-in. bit. Tag TOC at 14.0 m (46 ft). Wait for flow-line inspection. Two shifts worked.

Start working three shifts. Wait on welding inspection. Drill out cement with center-punch BHA. TOH. TIH with 17 1/2-in. bit and drill to 61.0 m (200 ft). TOH. Pick up reamer and drill collars.

TIH. Drill to 146.3 m (480 ft). TOH to add DC and jars to BHA. TIH and drill to 192.0 m (630 ft).

Drill 44.5-cm (17.5-in.) hole to 310.0 m (1,017 ft).

Drill 44.5-cm (17.5-in.) hole to 520.0 m (1,706 ft). Circulate hole clean and pull up one stand.

Make short trip. Tag 4.3 m (14 ft) of fill. Clean out fill. Make short trip and tag fill at 515.7 m (1,692 ft). Wait on BA. Start geophysical logging.

Finish geophysical logging. Rig down BA. Wait on casing crew. Run 13 3/8-in. casing to 511.5 m (1,678.2 ft). Rig down casing crew. TIH with cementing string, stab into shoe and pump 7.1 cu m (250 cu ft) cement. TOH. TIH with 12 1/4-in. BHA. Tag cement at 504.1 m (1,654 ft) and drill to 516.0 m (1,693 ft).

Clean out fill and drill new 31.1-cm (12.25 -in.) hole to 807.7 m (2,650 ft).

Drill to TD of 915.6 m (3,004 ft). Circulate hole clean. Make short trip. No fill.

TOH. Rig up BA. Start geophysical logging.

Finish geophysical logging. N-I tags fluid at 504.7 m (1,655.7 ft). Collect water samples from two depths. TIH and TOH, laying down string.

SLM piezometer string and RIH to 903.8 m (2,965.2 ft). RIH with tremie string. SLM completion casing and rig up casing crew. Start RIH with 6 5/8-in casing.

Continue adding neat cement until TOC is 729.4 m (2,393 ft). WOC. Colog obtains final NAIL. TAG TOC at 734.3 m (2,409 ft) with tremie. TOH with tremie tubing and start rigging down.

Demobilization of Wilson Mogul 42B 09/15/2012 to 09/25/2012

DEPTH (FEET)

FIGURE 2-2
WELL ER-20-11
DRILLING AND COMPLETION
HISTORY
SHEET 1 OF 1

Activity	Date
Begin drilling for conductor hole:	01/03/2012
Conductor hole completed and 30-in. casing set at 17.8 m (58.4 ft):	01/09/2012
Begin drilling 26-in. surface hole:	09/01/2012
Set 13 3/8-in. surface casing at 511.5 m (1,678.2 ft):	09/06/2012
Begin drilling 12 1/4-in. hole:	09/07/2012
Reach total drilled depth of 915.6 m (3,004 ft):	09/09/2012
Well completed:	09/14/2012

Table 2-1
Abridged Drill Hole Statistics for Well ER-20-11

LOCATION DATA			
Coordinates:	Nevada State Plane (Central Zone)	(NAD 27)	N 890,418.4 ft E 553,150.4 ft
	Nevada State Plane (Central Zone)	(NAD83)	N 6,271,400.7 m E 516,120.7 m
	Universal Transverse Mercator (Zone 11)	(NAD83)	N 4,116,747.6 m E 545,698.4 m
	Universal Transverse Mercator (Zone 11)	(NAD 27)	N 4,116,550.4 m E 545,778.6 m
Surface Elevation: 1,778.2 m (5,834.0 ft) ^a			
DRILLING DATA			
Spud Date:	09/01/2012 (main hole drilling with Wilson Mogul 42B rig)		
Total Depth (TD):	915.6 m (3,004 ft)		
Date TD Reached:	09/09/2012		
Date Well Completed:	09/14/2012 (date completion string was stemmed)		
Hole Diameter:	106.7 cm (42 in.) from surface to 18.3 m (60 ft); 44.5 cm (17.5 in.) from 18.3 m (60 ft) to 520.0 m (1,706 ft); 31.1 cm (12.25 in.) from 520.0 m (1,706 ft) to TD of 915.6 m (3,004 ft).		
Drilling Techniques:	Drill 106.7-cm (42-in.) hole from surface to 18.3 m (60 ft) with dry-hole auger. Center-punch with 17½-in. tricone bit mounted below a 26-in. hole opener to 25.3 m (83 ft); rotary drill with a 17½-in. tricone bit, using air-foam in direct circulation from 25.3 to 520.0 m (83 to 1,706 ft); rotary drill with 12¼-in. tricone bit, using air-foam and polymer (when necessary) in direct circulation from 520.0 m (1,706 ft) to TD of 915.6 m (3,004 ft).		
CASING DATA			
	30-in. conductor casing to 17.8 m (58.4 ft); 13¾-in. surface casing 0 to 511.5 m (0 to 1,678.2 ft).		
WELL COMPLETION DATA			
A string of 6⅝-in. stainless-steel casing hangs from 7⅝-in. epoxy coated carbon-steel casing via a crossover sub. The carbon-steel casing is positioned in the unsaturated zone to a point approximately 11.9 m (39 ft) above the water table. The 7⅝-in. outside-diameter casing has an inside diameter (id) of 17.701 cm (6.969 in.). The 6⅝-in. stainless-steel casing has an id of 15.504 cm (6.104 in.). The completion string was landed at 904.3 m (2,966.8 ft). The 6⅝-in. stainless-steel casing has one slotted interval. A string of 2⅞-in. stainless-steel tubing with one slotted interval was installed adjacent to the completion casing. The 2⅞-in. stainless-steel tubing hangs from a string of 2⅝-in. carbon-steel tubing, and was landed at 903.8 m (2,965.2 ft). Detailed data for the completion interval are provided in Section 8.0 of this report.			
Depth of Slotted Section:	6⅝-in. casing: 796.3 to 903.6 m (2,612.4 to 2,964.5 ft) 2⅞-in. tubing: 795.3 to 903.1 m (2,609.3 to 2,963.0 ft)		
Depth of Sand Pack:	780.9 to 789.7 m (2,562 to 2,591 ft)		
Depth of Gravel Pack:	789.7 to 915.6 m (2,591 to 3,004 ft)		
Depth of Pump:	Not installed at the time of completion		
Water Depth:	Fluid level depth measured at 504.5 m (1,655.2 ft) in the 2⅞-in. piezometer string on September 26, 2012 ^b .		
DRILLING CONTRACTOR: United Drilling, Inc.			
GEOPHYSICAL LOGS BY: Baker Atlas			
SURVEY CONTRACTOR: National Security Technologies, LLC			

a Elevation of ground at wellhead, relative to mean sea level. National Geodetic Vertical Datum, 1929 (NARA, 1973).

b Fluid level tag by N-I.

Drilling of the surface hole with a 17½-in. rotary tricone bit and air-foam began September 1, 2012, and continued to the depth of 520.0 m (1,706 ft), reached on September 4, 2012.

The hole began making small amounts of water at about 499.9 m (1,640 ft), as evidenced by slight dilution of lithium bromide tracer (see discussion of water production in Section 6.2 and water production data presented in Appendix B). It had been planned to install the surface casing approximately 15.2 m (50 ft) below the static water level, which was predicted to be at the depth of approximately 504.1 m (1,654 ft). However, when drilling had reached the depth of 520.0 m (1,706 ft), the hole was producing less than 18.9 liters per minute (Lpm) (5 gallons per minute [gpm]) water. Despite the low water production, the decision was made to suspend drilling and install the surface casing.

The drill string was removed and geophysical logging of the 44.5-cm (17.5-in.) surface hole began September 5, 2012. A fluid level could not be determined by logging instruments. After logging operations were completed, on September 6, 2012, a string of 13¾-in. surface casing was installed in the hole. As the casing was being lowered into the hole, it hit an obstruction at the depth of approximately 487.4 m (1,599 ft). The drillers added weight to the casing string and worked through the obstruction. Below the obstruction, the casing continued to drag until it was landed at the depth of 511.5 m (1,678.2 ft), approximately 7.0 m (23 ft) below the water level. The tight spots encountered in the borehole during casing operations may be due to borehole deviation (see description of borehole inclination in Section 2.3). The NSTec cementing crew pumped 7.1 m³ (250 ft³) of Type II neat cement at the base of the casing string, using a stab-in type cementing shoe, from the top of fill at approximately 511.5 m (1,678 ft). The top of cement in the annulus of the 13¾-in. surface casing is estimated to be at the depth of 429.8 m (1,410 ft), based on geophysical log data.

When drilling of the 31.1-cm (12.25-in.) hole began on September 7, 2012, the bit tagged the top of cement inside the surface casing at 504.1 m (1,654 ft). The cement and casing shoe were drilled out, and fill was drilled to the original bottom of the surface hole at 520.0 m (1,706 ft). Drilling of the 31.1-cm (12.25-in.) hole continued to TD with no fill accumulation when drilling was stopped to add drill pipe (to make a connection).

Tritium values exceeding levels detectable by field instruments were initially detected in drilling effluent on September 9, 2012, at the depth of 828.8 m (2,719 ft). A maximum tritium level, as measured by field instruments during drilling operations, was 146,131 picocuries per liter (pCi/L), detected at the depth of 912.0 m (2,992 ft) (N-I, 2013). Tritium levels measured on site during drilling did not exceed the FMP criteria for far-field drilling on the NNSS (tritium in excess of 400,000 pCi/L [see FMP strategy letter reproduced in Appendix B-2]), so drilling

continued under a far-field management strategy. See Section 3.1.2 for more information about onsite tritium analyses.

On September 9, 2012, at the depth of 915.6 m (3,004 ft), it was determined that the BA had been penetrated and the underlying bedded tuff had been reached, so the decision was made to stop drilling. The drillers circulated fluid in the borehole to remove cuttings and fill. The depth check tagged no fill, and the crew began removing the drill string from the hole for geophysical logging.

Geophysical logging began on September 10, 2012. N-I measured the fluid level at the depth of 504.7 m (1,655.7 ft) inside open hole on September 11, 2013, and obtained a pair of water samples from one depth (see Section 6.3). No sidewall cores were taken.

On September 12, 2012, the drill crew installed a piezometer string consisting of 2³/₈-in stainless-steel tubing suspended from 2⁷/₈-in. carbon-steel tubing. This string was landed at 903.8 m (2,965.2 ft). A casing crew installed a 6⁵/₈-in. stainless-steel completion string with one slotted interval (suspended from 7⁵/₈-in internally epoxy-coated carbon-steel casing), which was landed at a depth of 904.3 m (2,966.8 ft) on September 13, 2012. The annulus around the production casing and the piezometer string was packed with sand and gravel, and cemented (see Section 8.2). Stemming operations were completed on September 14, 2012, and the drillers started demobilizing the rig and drilling equipment. The crews worked one shift per day after that, until demobilization was completed on September 25, 2012.

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-20-11 are listed in Appendix A-3.

2.3 Borehole Inclination

The inclination of the borehole was determined from Directional Survey logs run by Baker Atlas during both logging operations (September 5 and 10, 2012). According to the composite survey plot, the maximum dogleg severity in the borehole is 1.65 degrees per 30.5 m (100 ft) between the depths of 249.9 and 265.2 m (820 and 870 ft). The greatest deviation is 2.3 degrees at 295.7 m (970 ft). The average borehole inclination is 1.4 degrees to the southwest. The bottom of the borehole is 17.3 m (56.9 ft) southwest of the wellhead. Figure 2-3 is a three-dimensional view of the borehole showing deviation, borehole profile from the caliper log, and stratigraphy.

Figure 2-3
Well ER-20-11 Directional Survey Showing Caliper Profile and Stratigraphy
(See Table 5-1 for definitions of stratigraphic symbols)

2.4 *Drilling Problems*

There were few problems or delays during the drilling of ER-20-11. However, the surface casing stuck slightly during insertion, possibly due to the borehole deviation (see Section 2.3 and Figure 2-3).

3.0 Management of Fluids, Drill Cuttings, and Waste

This section describes how fluids and drill cuttings produced from the Well ER-20-11 borehole and hydrocarbon and sanitary waste generated during well construction were managed. The information in this section was obtained from N-I (2013).

In summary, all FMP requirements for Well ER-20-11 were met. Analysis of monitoring samples and FMP confirmatory samples indicated that fluids generated during drilling at Well ER-20-11 met the FMP criteria for discharge to an unlined sump or designated infiltration area.

3.1 Fluid and Drill Cuttings Management

3.1.1 Fluid Management Strategy

The management of drilling fluids and solid waste (i.e., drill cuttings) is addressed in the *Underground Test Area Project Waste Management Plan; Attachment 1 Fluid Management Plan for the Underground Test Area Project* (NNSA/NSO, 2009b). The *Final Well Specific Fluid Management Strategy for UGTA Well ER-20-11, Area 20, Nevada National Security Site* (reproduced in Appendix B-2), as required by the UGTA FMP, addresses specific fluid management strategies to be employed at Well ER-20-11 for fluid-generating activities relating to well drilling, well construction, and well development and testing activities. The drilling fluid discharge was monitored routinely during drilling in accordance with these plans to guide operational decisions for proper fluid containment and, ultimately, proper fluid disposal.

Two onsite containment basins (Sumps #1 and #2) were constructed to contain fluids and drill cuttings during operations at Well ER-20-11 (Figure 2-1). Both sumps were unlined. The air-foam drilling fluid was circulated down the inside of the drill string and back up the hole through the annulus (conventional, or direct, circulation). The drilling effluent was discharged into Sump #1. Sump #2 was not used.

Water used to prepare the drilling fluids was obtained from Water Well 8, an NNSS water supply well located in Area 18, south of Pahute Mesa. Water from this well is routinely sampled and analyzed; the most recent sample analysis for Water Well 8 was collected by NSTec on October 19, 2010. All analytes detected were below the limits prescribed in National Primary Drinking Water Regulations (CFR, 2010).

3.1.2 Fluid Management Sampling Results

An important element of the FMP strategy (NNSA/NSO, 2009b) is the onsite monitoring program. The program is intended to provide the timely detection of indicator contaminants and determines onsite fluid management requirements.

Discharged drilling fluid samples were collected hourly by N-I personnel during periods of borehole advancement. NSTec radiological control technicians (RCTs) used NSTec-supplied liquid scintillation counters (LSCs) to analyze the fluid samples on site for tritium for the purpose of fluid management and worker protection. A minimum detectable activity (MDA) is associated with the analysis of each sample; the average MDA for the onsite LSCs at Well ER-20-11 was approximately 1,540 pCi/L (N-I, 2013). Samples collected and analyzed for tritium were for screening purposes, and the reported results are not intended to accurately represent lower concentrations of tritium (i.e., less than approximately 1,540 pCi/L) due to errors in counting statistics or issues relating to the nature of fluids analyzed (e.g., drilling fluids). All onsite monitoring results are presented in Appendix B-1.

In accordance with NNSS radiological control guidelines (Radiological Control Managers' Council, 2012), fluid samples measured on site that had initial tritium levels greater than their respective MDAs were re-analyzed until the results stabilized. All but nine fluid samples from the unsaturated zone returned results below their respective MDA, and re-analysis of these nine samples indicated stabilized values less than their MDAs (Table B-1-1). However, below the depth of approximately 823.0 m (2,700 ft), within the saturated zone, tritium concentrations increased rapidly from 4,375 pCi/L at the depth of 821.1 m (2,694 ft) to more than 25,000 pCi/L at 828.8 m (2,719 ft), exceeding the National Primary Drinking Water Regulations (CFR, 2012a) standard of 20,000 pCi/L. This increase in tritium activity coincided with an increase in groundwater production from less than 37.9 Lpm (10 gpm) at the depth of 823.9 m (2,703 ft) to approximately 378.5 Lpm (100 gpm) at 837.3 m (2,747 ft), while drilling in the BA (see water production data in Appendix F). Only the first tritium result that was greater than 25,000 pCi/L (obtained from the sample taken at the depth of 828.8 m [2,719 ft]), was reanalyzed to verify the result was not in error.

Tritium activity steadily increased to a level of 146,131 pCi/L, which was recorded for the final sample collected during drilling, from the depth of 912.0 m (2,992 ft). Before installation of the piezometer and completion casing, N-I personnel collected a pair of depth-discrete bailer samples from a depth of 856.5 m (2,810 ft); the onsite analysis of this sample gave a tritium result of 165,095 pCi/L. A sample from the depth-discrete bailer was also analyzed for tritium by an offsite laboratory, which reported the tritium level of 186,000 pCi/L (see further discussion of the bailer samples in Section 6.3, and the data presented in Appendix B-1).

On September 12, 2012, after drilling and geophysical logging activities were completed, N-I personnel collected an FMP (NNSA/NSO, 2009b) confirmatory sample and duplicate from Sump #1. The samples were analyzed by an offsite laboratory for total and dissolved metals,

gross alpha and beta, and tritium. The analytical results for the FMP confirmatory samples from Sump #1 are presented in Appendix B-1.

3.1.3 Disposition of Fluid and Drill Cuttings

The FMP (NNSA/NSO, 2009b) and the Well ER-20-11 FMP strategy letter (Appendix B-2) establish concentrations for specified parameters below which drilling fluids may be discharged either to an unlined sump or a designated infiltration area. The results of Well ER-20-11 monitoring samples and FMP confirmatory samples indicated that fluids generated from drilling the unsaturated and saturated zones at Well ER-20-11 met the FMP criteria for discharge to an unlined sump or designated infiltration area. However, fluid levels in Sump #1 (unlined) did not reach the overflow pipe before the TD of the borehole was reached, and all discharged fluids were contained in the sump. The volumes of fluids produced during unsaturated and saturated zone drilling at Well ER-20-11 are listed on the Well ER-20-11 Fluid Disposition Reporting Form, which is reproduced in Appendix B-1. At the completion of drilling on September 9, 2012, an estimated combined total of 1,443 m³ (381,087 gallons [gal]) of drilling fluid and cuttings remained in unlined Sump #1.

3.2 Environmental Compliance and Waste Management

N-I was responsible for environmental compliance and waste management at the Well ER-20-11 site. Periodic site evaluations were conducted during site operations to ensure compliance with the Occupational Safety and Health Act (CFR, 2012b), the Resource Conservation and Recovery Act (CFR, 2012c), the UGTA Waste Management Plan (NNSA/NSO, 2009b), and internal contractor procedures.

Waste generated during drilling operations at the Well ER-20-11 site consisted of hydrocarbon and sanitary wastes. A summary of waste type, volume, and disposition of waste streams generated during drilling is provided in Appendix C. Sanitary waste generated at the well site during drilling operations was routinely collected by NSTec and disposed of at the Area 23 solid waste landfill. Hydrocarbon waste generated at the well site was packaged into 208.2-liter (L) (55-gal) drums, removed from the Well ER-20-11 drill site, and transported by N-I personnel to N-I Building 6-909 at the NNSS for interim storage pending disposal by NSTec. The 7,571-L (2,000-gal) condensate tank was drained by NSTec before mobilizing to the next well site (Well ER-EC-14), and the contents transported by NSTec to the Area 12 surface impoundment at the NNSS for evaporation. All waste was characterized using process knowledge and onsite monitoring results.

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4.0 Geologic Data Collection

4.1 Introduction

This section describes the sources of geologic data obtained from Well ER-20-11 and the methods of data collection. Improving the understanding of the subsurface structure, stratigraphy, and hydrogeology immediately south of the Pahute Mesa CAUs was among the primary objectives of Well ER-20-11, 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-20-11 consist of drill cuttings and geophysical logs. Data collection, sampling, transfer, and documentation activities were performed according to applicable contractor procedures, as listed in the NSTec FAWP (NSTec, 2012).

4.2 Drill Cuttings

Composite drill cuttings were collected at 3-m (10-ft) intervals as drilling progressed. No samples were collected during construction of the conductor hole, from the surface to the depth of 18.3 m (0 to 60 ft). Below that depth, N-I personnel collected triplicate samples, each consisting of approximately 550 cubic centimeters of material, from 294 intervals from 18.3 m (60 ft) to TD. Samples are missing from one interval, 521.2–524.3 m (1,710–1,720 ft) due to poor fluid returns (N-I, 2013). Overall cuttings quality (e.g., size, volume, and purity) was good throughout the borehole.

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, and one set was left unsealed in the original sample containers. The third set was handled and stored according to standard USGS Core Library procedures, except that because the samples had been adequately rinsed at the rig site to remove residual drilling fluid, washing of the samples by the USGS was not necessary. This third set was used by NSTec geologists to construct the detailed lithologic log presented in Appendix D. The N-I field representatives 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.

4.3 Sidewall Core Samples

No sidewall core samples were collected at Well ER-20-11, because the stratigraphy and lithology were well enough understood from the drill cuttings and geophysical logs, and data from nearby Wells ER-EC-11 and ER-20-8.

4.4 Sample Analysis

Eleven samples of drill cuttings from various depths were submitted to Comprehensive Volcanic Petrographics, LLC, for petrographic analysis. Splits of the same 11 samples 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 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 in the evaluation of geophysical log signatures. The results of the petrographic analyses are reported in Warren (2013), and the results of the mineralogic and chemical analyses are reported in WoldeGabriel et al. (2013). Table 4-1 lists all samples analyzed.

4.5 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 two stages (two different hole diameters) during drilling: (1) in the 44.5-cm (17.5-in.) borehole, before installation of the 13³/₈-in. surface casing at 511.5 m (1,678.2 ft) and (2) in the 31.1-cm (12.25-in.) borehole after the TD was reached at 915.6 m (3,004 ft), before installation of the 7⁵/₈-in. completion casing. A complete listing of the logs, dates run, depths, and service companies is provided in Table 4-2. Note that a gamma-ray log is typically included with each logging run for depth correlation.

The logs are available from NSTec in Mercury, Nevada, and copies are on file at the N-I office 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 E.

The overall quality of the geophysical log data collected was good.

Table 4-1
Rock Samples from Well ER-20-11 Selected for
Petrographic, Mineralogic, and Chemical Analysis ^a

Depth ^{b, c}		Sample Identifier ^d
meters	feet	
429.8	1,410	ER20/11–1,410D
438.9	1,440	ER20/11–1,440D
472.4	1,550	ER20/11–1,550D
557.8	1,830	ER20/11– 1,830D
606.6	1,990	ER20/11–1,990D
673.6	2,210	ER20/11–2,210D
691.9	2,270	ER20/11–2,270D
755.9	2,480	ER20/11–2,480D
780.3	2,560	ER20/11–2,560D
844.3	2,770	ER20/11–2,770D
911.4	2,990	ER20/11–2,990D

a Mineralogic analysis by x-ray diffraction; chemical analyses by x-ray fluorescence.

b All depths are drilled depths.

c Depth listed for petrographic, mineralogic, and chemical analyses represents the base of a 3.0-m (10-ft) aggregate sample.

d “D” in sample identifier indicates drill cuttings sample.

Table 4-2
Well ER-20-11 Geophysical Log Summary

Geophysical Log Type ^a	Log Purpose	Date Logged	Run Number	Bottom of Logged Interval ^b meters (feet)	Top of Logged Interval ^b meters (feet)
*Differential Temperature / Gamma Ray	Saturated zone: groundwater temperature / stratigraphic and depth correlation	9/10/2012	TL-1 / GR-4	915.2 (3,002.5)	382.2 (1,254)
*Aligned Borehole Profile (i.e., Oriented 6-Arm Caliper) / Gamma Ray	Borehole conditions, cement volume calculation, lithologic features, borehole orientation / stratigraphic and depth correlation	9/5/2012 9/10/2012	CA6-1 / ORIT-1 / GR-1 CA6-2 / ORIT-2 / GR-5	511.5 (1,678) 912.3 (2,993)	17.7 (58) 510.8 (1,676)
*Gamma Ray / *Digital Spectralog	Stratigraphy, mineralogy, and natural and man-made radiation determination	9/5/2012 9/10/2012	GR-1 / SGR-1 GR-5 / SGR-2	503.2 (1,651) 905.9 (2,972)	0 (0) 476.4 (1,563)
*High Definition Induction / Gamma Ray	Lithologic determination; saturation of formations; stratigraphic and depth correlation	9/5/2012	HDIL-1 / GR-2	509.3 (1,671)	17.7 (58)
*Compensated Z-Densilog / *Compensated Neutron / Gamma Ray	Stratigraphic and lithologic determination / identification of welding, alteration, rock porosity, and water content	9/6/2012 9/10/2012	ZDL-1 / CN-1 / GR-3 ZDL-2 / CN-2 / GR-7	510.8 (1,676) 914.4 (3,000)	17.7 (58) 409.7 (1,344)
Circumferential Borehole Imaging / Gamma Ray	Structural analysis, including fracture characterization. Recognition of lithologic features.	9/11/2012	CBIL-1 / ORIT-5 / GR-10	912.3 (2,993)	504.1 (1,654)
*X-Multipole Array Acoustilog / Gamma Ray	Primary matrix porosity	9/10/2012	XMAC-1 / ORIT-3 / GR-8	908.3 (2,980)	510.8 (1,676)
Resistivity Imaging / Gamma Ray	Saturated zone: lithologic characterization, bedding dip, fracture and void analysis	9/11/2012	STAR-1 / ORIT-4 / GR-9	914.4 (3,000)	515.1 (1,690)
*R _t Explorer / Gamma Ray / Spontaneous Potential	Lithologic determinations, identification of alteration, recognition of welding, distinguishing low versus high porosity	9/10/2012	RTEX-1 / GR-6 / SP-1	909.2 (2,983)	510.8 (1,676)

Note: All logs provided by Baker Atlas, a division of Baker Hughes, Inc.

a Logs presented in geophysical log summary, Appendix E, are indicated by *. A gamma-ray log is included on each logging run to aid in depth correlation.

b Drilled depth

5.0 Geology and Hydrogeology

5.1 Introduction

This section describes the geology and hydrogeology of Well ER-20-11. The basis for the discussions here is the detailed geologic characterization of Well ER-20-11 presented as a detailed lithologic log in Appendix D. The detailed lithologic log was developed using drill cuttings, geophysical logs, and drilling parameters. Data from petrographic analyses on selected lithologic samples from Well ER-20-11 were incorporated into the detailed lithologic log. Orientations of geologic features were obtained from the interpretation of borehole image logs.

5.2 Geology

This section is divided into three discussions relating to the geology of Well ER-20-11. Section 5.2.1 briefly describes the geologic setting of ER-20-11. The stratigraphic and lithologic units penetrated at the well are discussed in detail in Section 5.2.2. 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 5.2.3. Detailed descriptions of the stratigraphy, lithology, and alteration of the rocks encountered are provided in the detailed lithologic log presented in Appendix D. Tables 5-1 and 5-2 provide the definitions of stratigraphic and hydrostratigraphic units used in various figures in this report.

5.2.1 Geologic Setting

Well ER-20-11 is located within a geologically complex area that was formed mainly as 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 ground collapse after 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. Well ER-20-11 is located within the southwestern corner of the Area 20 caldera; however, this caldera and its associated geologic units are well below the TD of Well ER-20-11. Well ER-20-11 also is located approximately 4,124 m (13,530 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).

Table 5-1
Key to Stratigraphic Units and Symbols Used in This Report

Stratigraphic Unit	Map Symbol
Young alluvial deposits	Qay
Thirsty Canyon Group, undivided	Tt
Beatty Wash Formation	Tfb
Ammonia Tanks Tuff	Tma
mafic-rich Ammonia Tanks Tuff	Tmar
mafic-poor Ammonia Tanks Tuff	Tmap
bedded Ammonia Tanks Tuff	Tmab
rhyolite of Tannenbaum Hill	Tmat
bedded rhyolite of Tannenbaum Hill	Tmat(b)
debris-flow breccia	Tmatx
Rainier Mesa Tuff	Tmr
mafic-rich Rainier Mesa Tuff	Tmrr
rhyolite of Fluorspar Canyon	Tmrf
Timber Mountain Group, undivided	Tm
rhyolite of Windy Wash	Tpw
rhyolite of Benham	Tpb
Paintbrush Group, undivided	Tp
Tiva Canyon Tuff	Tpc
Topopah Spring Tuff	Tpt
Calico Hills Formation	Th
rhyolite of Inlet	Tci
rhyolite of ER-EC-1	Tcpe
Crater Flat Group, undivided	Tc
rhyolite of Kearsage	Tcpk
Bullfrog Tuff	Tcb
Volcanics of Oak Spring Butte	To

Table 5-2
Key to Hydrostratigraphic Units and Symbols Used in This Report

Hydrostratigraphic Unit	Symbol
Thirsty Canyon volcanic aquifer	TCVA
Tannenbaum Hill lava-flow aquifer	THLFA
Tannenbaum Hill composite unit	THCM
Timber Mountain welded-tuff aquifer	TMWTA
Fluorspar Canyon confining unit	FCCU
Timber Mountain lower vitric-tuff aquifer	TMLVTA
Benham aquifer	BA
upper Paintbrush confining unit	UPCU
Scrugham Peak aquifer	SPA
middle Paintbrush confining unit	MPCU
Tiva Canyon aquifer	TCA
lower Paintbrush confining unit	LPCU
Topopah Spring aquifer	TSA
Calico Hills zeolitic composite unit	CHZCM
Inlet aquifer	IA
Crater Flat composite unit	CFCM
Bullfrog confining unit	BFCU

Well ER-20-11 is located in an area referred to as the Bench, which is a structural region defined as the area between the structural margin of the TMCC and the NTMMSZ (Figure 5-1). 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, 2000a). 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, 2000a), but possibly also prior to the eruption of the Rainier Mesa Tuff, based on information obtained from Well ER-EC-11 (NNSA/NSO, 2010a). Well ER-20-11 is approximately 747 m (2,450 ft) southwest of the NTMMSZ.

The surface geology of the surrounding area consists of relatively flat-lying Miocene-age volcanic rocks, mainly lavas and nonwelded to welded and bedded tuffs. Well ER-20-11 is located on the southeastern slope of a small hill on nonwelded and bedded tuff of the Beatty Wash Formation, which is less than 15.2 m (50 ft) thick at this location (Figures 5-1 and 5-2).

Figure 5-1
Surface Geologic Map of the Well ER-20-11 Area

Figure 5-2
Geology and Hydrogeology of Well ER-20-11

Nonwelded to partially welded Ammonia Tanks Tuff is exposed to the north, east, and south of the Well ER-20-11 site (Byers and Cummings, 1967). Extensive exposures of Trail Ridge, Pahute Mesa, and Rocket Wash Tuffs occur to the north and west (Slate et al., 1999). An extensive exposure of rhyolite of Tannenbaum Hill occurs approximately 732 m (2,400 ft) to the south of Well ER-20-11 (Slate et al., 1999). The rocks in the vicinity of Well ER-20-11 have been cut by a few high-angle normal faults related to Basin and Range extension (Byers et al., 1976). The closest fault with significant displacement (down on the west), is located about 579 m (1,900 ft) east of the Well ER-20-11 collar location (Slate et al., 1999) (Figure 5-1). Although showing only minor displacement at the surface, this fault has significantly greater displacement at depth (NNSA/NSO, 2010a; 2011a).

5.2.2 Stratigraphy and Lithology

The stratigraphic and lithologic units penetrated at Well ER-20-11 are illustrated in Figure 5-2, and an interpretation of the distribution of stratigraphic units in the vicinity of the well is shown in cross section in Figures 5-3 and 5-4. The determination of the stratigraphic and lithologic units penetrated by Well ER-20-11 was aided by examination of, and correlation with, nearby Wells ER-20-8/20-8#2 and ER-EC-11 (located 967 m [3,172 ft] southeast and 952 m [3,124 ft] northwest of Well ER-20-11 site, respectively).

It should be noted throughout the following discussions that the cross sections in Figures 5-3 and 5-4 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-20-11 began in the nonwelded and bedded tuffs of the Beatty Wash Formation, which forms the ground surface in the vicinity of the well (Byers and Cummings, 1967; Slate et al., 1999) (Figure 5-1). The depth of the base of the Beatty Wash Formation in Well ER-20-11 is uncertain because cuttings were not collected during conductor hole drilling. However, the unit must be less than 18.9 m (62 ft) thick, because drilling of the main hole began at 18.9 m (62 ft) in the underlying Ammonia Tanks Tuff, part of the Timber Mountain Group. The mafic-rich member of the Ammonia Tanks Tuff was identified between 18.9 and 36.6 m (62 and 120 ft), and the mafic-poor member was identified below that to a depth of 46.3 m

Figure 5-3
Southwest-Northeast Geologic Cross Section A-A' through Well ER-20-11

Figure 5-4
Northwest-Southeast Geologic Cross Section B-B' through Well ER-20-11

(152 ft). The lowermost 31.1 m (102 ft) of the Ammonia Tanks Tuff consists of vitric bedded tuff. The stratigraphic assignment of the Ammonia Tanks Tuff is based on nearby surface mapping (Byers and Cummings, 1967), ash-flow tuff lithology, mineralogic assemblage (including the presence of quartz phenocrysts), and relatively abundant lithic fragments. The relatively thin occurrence of the Ammonia Tanks Tuff in Well ER-20-11 indicates that the unit is an extra-caldera out-flow sheet and that the well location lies outside of the Ammonia Tanks caldera.

Below the Ammonia Tanks Tuff, Well ER-20-11 penetrated the rhyolite of Tannenbaum Hill, consisting of a 270.1-m (886-ft) thick rhyolitic lava flow that overlies 82.3 m (270 ft) of bedded and nonwelded tuff. The upper 29.3 m (96 ft) of the lava flow is vitric and pumiceous. This upper pumiceous zone overlies 185.9 m (610 ft) of devitrified rhyolite lava that represents the dense stoney interior portion of the flow. The devitrified rhyolite lava overlies 29.3 m (96 ft) of brownish-black vitrophyric lava. This vitrophyric lava is underlain by 18.3 m (60 ft) of mostly devitrified rhyolite lava that probably represents the basal flow breccia of the flow. The lowermost 82.3 m (270 ft) of the rhyolite of Tannenbaum Hill consists of zeolitic bedded and nonwelded 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, rare to minor biotite, and sphene. 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-20-11 penetrated 60.4 m (198 ft) of nonwelded to densely welded ash-flow tuff assigned to the Rainier Mesa Tuff, also a formation of the Timber Mountain Group. The top of the interval consists of a thin moderately to densely welded ash-flow tuff. The nonwelded to partially welded top of a typical ash-flow tuff welding profile was not observed. The dense, welded portion of the ash flow is thin and transitions abruptly into nonwelded tuff, suggesting it may be truncated by faulting. The vitrophyre seen in the Rainier Mesa Tuff in Well ER-EC-11 (NNSA/NSO, 2010a) was not seen in Well ER-20-11. Below the welded tuff, the Rainier Mesa member includes 51.2 m (168 ft) of zeolitic bedded and nonwelded tuff and devitrified partially welded tuff. 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-20-11 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-20-11 penetrated 185.0 m (607 ft) of quartz-bearing, zeolitic, nonwelded and bedded tuffs. The presence of quartz phenocrysts, the characteristically low thorium signature on the spectral gamma log, 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 thickness of the rhyolite of Fluorspar Canyon is comparable to that seen in Well ER-EC-11 (NNSA/NSO, 2010a) where it was 230.4m (756 ft) thick. In nearby Wells ER-20-8/20-8#2 (NNSA/NSO, 2011a) and Well ER-EC-6 (DOE/NV, 2000a), the rhyolite of Fluorspar Canyon is much thinner. In Well ER-20-11 this unit consists mostly of a series of nonwelded tuffs separated by intervals of bedded tuffs. Below 576.1 m (1,890 ft), bedded tuffs dominate. Analysis of borehole image logs indicates that most bedding contacts above approximately 602.6 m (1,977 ft) dip 5 degrees to the west-northwest. Below this depth bedding dips within the rhyolite of Fluorspar Canyon average 7 to 8 degrees to the southwest.

A 10.7-m (35-ft) thick interval of quartz-bearing, zeolitic and quartzo-feldspathically altered, pumice-rich bedded tuff was penetrated below the 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 on a correlative interval in ER-EC-11 (NNSA/NSO, 2010a) indicated that this tuff likely represents a transitional unit between the Paintbrush Group and Timber Mountain eruptive cycles (Warren, 2010). As seen on image logs, this tuff is more crudely bedded and lithic-rich than the overlying rhyolite of Fluorspar Canyon. Bedding within the interval dips 10 degrees to southeast, a dip direction more similar to that of the underlying Paintbrush Group bedded tuffs than it is to that of the overlying rhyolite of Fluorspar Canyon.

Underlying this thin bedded tuff of the undivided Timber Mountain Group is 15.6 m (248 ft) of zeolitic and quartzo-feldspathically altered bedded tuff assigned to the rhyolite of Windy Wash. This assignment was made based on stratigraphic position between the Timber Mountain tuffs and the Benham lavas, and petrographic analysis (Warren, 2013). The mineralogic assemblage includes hornblende, sphene, and clinopyroxene. Although quartz-bearing, the rhyolite of Windy Wash is included with the Paintbrush Group (Slate et al., 1999). 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 next major stratigraphic interval in Well ER-20-11 is the rhyolite of Benham, a part of the Paintbrush Group, which consists mainly of rhyolitic lava lacking in quartz phenocrysts (Slate et al., 1999). In Well ER-20-11, a zeolitic and quartzo-feldspathically altered bedded tuff comprises the upper 10.7 m (35 ft) of the rhyolite of Benham. The main part of the rhyolite of

Benham is a 131.1-m (430-ft) thick rhyolitic lava flow. The top of the flow consists of 16.8 m (82 ft) of zeolitic pumiceous lava. Below this is 25.9 m (85 ft) of dark yellowish-brown vitrophyric lava that is vitric and perlitic in places and devitrified in others. Flow layering dipping 61 degrees to the north-northeast was observed on image logs in this part of the lava. The lower 80.2 m (263 ft) consists of devitrified rhyolitic lava that is flow-banded in places. Flow layering in this lower section was observed to dip 45 degrees to the northeast. Beneath the Benham lava, 12.2 m (40 ft) of zeolitized and quartzo-feldspathically altered bedded tuff, also part of the rhyolite of Benham, was penetrated before the well reached TD. Analysis of borehole image logs from within this deepest interval of Well ER-20-11 revealed a single bedding plane dipping 11 degrees to the south.

The rhyolite of Benham was identified on the basis of its largely lava-flow lithology, its stratigraphic position near the top of the Paintbrush Group section, and its mineralogic assemblage that includes minor biotite, very rare quartz phenocrysts, and sphene. As expected, lithic and pumice fragments (i.e., pyroclasts) are noticeably absent in the lava-flow interval. 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 northeast of the well site (map unit Tpu on Figure 5-1, and 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, 2000a; 2000c; NNSA/NSO, 2010a; 2010b).

5.2.3 Alteration

The volcanic rocks penetrated at Well ER-20-11 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 355.1 m (1,165 ft) in Well ER-20-11, low-density, high-porosity units such as nonwelded and bedded tuffs and pumiceous lavas that are composed primarily of ash-size glass shards are largely unaltered and retain their original vitric character. 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-20-11, 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 355.1 m (1,165 ft) to a depth of 675.1 m (2,215 ft), the low-density, high-porosity rock types have been zeolitized, resulting in the original glass being converted to zeolite minerals such as clinoptilolite. Below the depth of 675.1 m (2,215 ft), zeolitic alteration minerals are still common but are generally less abundant.

Argillic Alteration. Nonwelded and bedded tuffs and pumiceous lavas below 675.1 m (2,215 ft) show minor argillic alteration. The presence of the clay minerals illite and, in one sample, smectite, was documented by X-ray diffraction data (WoldeGabriel et al., 2013).

Quartzo-Feldspathic Alteration. Petrographic, x-ray diffraction and geophysical log data, as well as inspection with a binocular microscope, show that below 675.1 m (2,215 ft) quartzo-feldspathic alteration is common, particularly within the less dense rocks. The denser vitrophyric and stony rhyolite lavas are mostly unaltered (vitric to devitrified), but show some minor quartzo-feldspathic alteration, according to petrographic analysis (Warren, 2013). Within the quartzo-feldspathically altered interval, zeolites and clay minerals are present to a lesser extent.

Alteration Summary. Above 355.1 m (1,165 ft) in Well ER-20-11, welded tuffs and lavas are mostly devitrified, and nonwelded and bedded tuffs and pumiceous lavas are unaltered, retaining their original vitric character. Below 355.1 m (1,165 ft), which can be considered the top of pervasive zeolitization at the well location, and continuing to the depth of 675.1 m (2,215 ft), nonwelded and bedded tuffs and pumiceous lava are zeolitic, with clinoptilolite and lesser mordenite being the main alteration minerals within these rocks. Below 675.1 m (2,215 ft) quartzo-feldspathic alteration is common, particularly within the less dense rocks. The denser vitrophyric and stoney rhyolite lavas remain mostly unaltered, with minor quartzo-feldspathic alteration. Within the quartzo-feldspathically altered interval, zeolites and clay minerals are present to a lesser extent.

5.3 Predicted and Actual Geology

The stratigraphic and lithologic units penetrated at Well ER-20-11 are illustrated in Figure 5-2, and the distribution of stratigraphic units in the vicinity of the well is shown in cross section in Figures 5-3 and 5-4. The geology encountered at Well ER-20-11 is not significantly different than predicted prior to drilling (Figure 5-5) (N-I, 2011). The geologic section penetrated is similar to that of the upper 944.9 m (3,100 ft) of Well ER-EC-11 (NNSA/NSO, 2010a). The minor differences are described below.

The Ammonia Tanks Tuff is 31.7 m (104 ft) thicker than predicted, and the underlying rhyolite of Tannenbaum Hill is 30.8 m (101 ft) thinner than predicted. The rhyolite of Tannenbaum Hill

Figure 5-5
Predicted and Actual Stratigraphy at Well ER-20-11

includes a lava section that is 65.2 m (214 ft) thinner than predicted and a nonwelded and bedded tuff section that is 33.5 m (110 ft) thicker than predicted.

The Rainier Mesa Tuff was encountered at the predicted depth, and is 17.7 m (58 ft) thicker than predicted. The Rainier Mesa Tuff was expected in Well ER-20-11, since it was found in both Wells ER-EC-11 and ER-20-8 (NNSA/NSO 2010a; 2011a). Its presence here further supports the conclusion, based on drilling results from Wells ER-20-8 and ER-EC-11, that the Rainier Mesa Tuff is likely present within much of the Bench domain, and is anomalously missing at Well ER-EC-6 due to faulting (DOE/NV, 2000a).

Minor stratigraphic differences occur within the thick section of bedded and nonwelded tuff that separates the Rainier Mesa Tuff from the Benham lava, although lithologically this interval is much as predicted. Within this interval, the rhyolite of Fluorspar Canyon is 58.8 m (193 ft) thinner than predicted and 45.4 m (149 ft) thinner than in nearby Well ER-EC-11. The 185 m (607 ft) of rhyolite of Fluorspar Canyon penetrated by Well ER-20-11 is, nevertheless, much thicker than the rhyolite of Fluorspar Canyon found in nearby Wells ER-EC-6 and ER-20-8 (DOE/NV, 2000b; NNSA/NSO, 2011a), making Well ER-20-11 similar stratigraphically to Well ER-EC-11. This thick rhyolite of Fluorspar Canyon in Well ER-20-11 indicates that the well is within the same structural basin as Well ER-EC-11, a basin formed by faulting within the Bench domain that pre-dates the formation of the Rainier Mesa caldera.

Also within this interval between the Rainier Mesa Tuff and the Benham lava, 75.6 m (248 ft) of bedded tuff was assigned to the rhyolite of Windy Wash, part of the Paintbrush Tuff, based on thin-section petrography (Warren, 2013). The rhyolite of Windy Wash in Well ER-20-11 is found between the overlying undivided bedded Timber Mountain tuff and the underlying bedded tuff of the rhyolite of Benham, both of which are thinner than predicted. Despite these stratigraphic differences, the 281.9 m (925 ft) of bedded and nonwelded tuffs that separate the Rainier Mesa Tuff from the Benham lava is very close to the 289.6 m (950 ft) predicted.

The rhyolite of Benham in Well ER-20-11 has an upper interval of bedded tuff that was predicted to be 30.5 m (100 ft) thick but which was found to be only 10.7 m (35 ft) thick. The Benham lava was 9.1 m (30 ft) thicker than expected, and the well reached TD in bedded tuff of the rhyolite of Benham.

5.4 Hydrogeology

Using stratigraphic information, the hydrogeologic units encountered in Well ER-20-11 can be grouped into seven HSUs (Figure 5-2) according to BN (2002) and Prothro et al. (2009). An interpretation of the possible distribution of the HSUs in the vicinity of Well ER-20-11 is shown in cross section in Figure 5-6.

Figure 5-6

Southwest-Northeast Hydrostratigraphic Cross Section C-C' through Well ER-20-11

The Fluorspar Canyon confining unit (FCCU) and the BA are the predominant HSUs in the saturated portion of Well ER-20-11. The Upper Paintbrush confining unit (UPCU) was encountered in the bottom 12.5 m (41 ft) of the borehole. Devitrified rhyolitic lava of the rhyolite of Benham forms the BA, a thick lava-flow aquifer, which was the target aquifer for this well. Zeolitic and quartzo-feldspathic bedded and nonwelded tuffs form the FCCU and UPCU.

Some of the rocks encountered above the water table in Well ER-20-11 are assigned to aquifer HSUs but are unsaturated. The upper 347.5 m (1,140 ft) of the borehole penetrated 77.4 m (254 ft) of the Thirsty Canyon vitric tuff aquifer, which overlies the thick Tannenbaum Hill lava-flow aquifer (THLFA). The Tannenbaum Hill composite unit separates the THLFA from the underlying welded ash-flow tuff of the Rainier Mesa Tuff, which forms the thin Timber Mountain welded-tuff aquifer.

Prior to drilling, it was predicted that the water table would be encountered at a depth of 504 m (1,654 ft), within the FCCU (N-I, 2011). The preliminary water table depth measured by N-I on September 26, 2012 was 504.5 m (1,655.2 ft), within the FCCU as expected.

6.0 Hydrology

Hydrologic data collected at the well site included water-level measurements, estimates of groundwater production during drilling, and borehole water quality measurements from discharged drilling fluids. The following subsections summarize well hydrology data obtained during drilling and well completion operations, as modified from N-I (2013). Well ER-20-11 is open to the BA, as planned. An interpretation of the possible distribution of the HSUs in the vicinity of Well ER-20-11 is shown in Figure 5-6.

6.1 Water Levels

The water level at Well ER-20-11 was predicted to be approximately 504.1 m (1,654 ft) deep, near the top of the rhyolite of Fluorspar Canyon, a tuff confining unit (N-I, 2011). Baker Atlas did not detect fluid in the borehole during the first episode of geophysical logging, when the borehole had been drilled to the depth of 520.0 m (1,706 ft). During final geophysical logging operations conducted after TD was reached, fluid levels were recorded on several geophysical logs, ranging from the depths of 510.6 to 504.1 m (1,676 to 1,654 ft), all within the rhyolite of Fluorspar Canyon. N-I measured the fluid level in Well ER-20-11 at the depth of 504.7 m (1,655.7 ft) in the 13³/₈-in. surface casing on September 11, 2012, after completion of geophysical logging and before collection of the depth-discrete bailer sample. On September 26, 2012, N-I measured the fluid level at the depth of 504.5 m (1,655.2 ft) in the piezometer string before installation of the pressure transducer. All fluid-level data are summarized in Table 6-1.

The fluid levels presented here should be considered preliminary, and may not represent a discrete, equilibrated groundwater level. Well development and hydrologic testing at Well ER-20-11, which will provide more accurate water level data, is planned to take place later in 2013.

6.2 Water Production

Water production was estimated during drilling of Well ER-20-11 on the basis of dilution of a lithium-bromide tracer, as measured at the rig site by N-I field personnel. The tracer was added to drilling fluids before being injected down-hole. Concentrations of bromide in mixing tanks and in discharged fluids were monitored regularly as drilling progressed. Differences between injected and discharged bromide concentrations were used to calculate groundwater production rates. However, while this method is fairly good for relatively low water production (less than about 757 Lpm [200 gpm]), it is subject to several variables and conditions. More accurate water production estimates are possible when other information, such as visual estimates of water

Table 6-1
Well ER-20-11 Water Level Measurements

Date Time	Fluid Depth ^a		Fluid Elevation ^b		Notes
	meters	feet	meters	feet	
09/10/2012 07:45	510.8	1,676	1,267.4	4,158	Estimated fluid level reported by Baker Atlas on the temperature log.
09/10/2012 22:00	504.4	1,655	1,273.8	4,179	Estimated fluid level reported by Baker Atlas on the ZDL/CN log.
09/11/2012 12:45	504.1	1,654	1,274.1	4,180	Estimated fluid level reported by Baker Atlas on the CBIL log.
09/11/2012 14:15	504.7	1,655.7	1,273.5	4,178.3	Fluid level measured by N-I within the 13 $\frac{3}{8}$ -in. surface casing using a calibrated Solinst e-tape.
09/26/2012 10:10	504.5	1,655.2	1,273.7	4,178.8	Fluid level measured by N-I within the 2 $\frac{3}{8}$ -in. piezometer string using a calibrated Solinst e-tape.

Data from N-I (2013)

a Depths are below ground surface elevation.

b Ground surface used as reference datum. Ground surface elevation was surveyed by NSTec on January 16, 2013, at 1,778.2 m (5,834.0 ft) above mean sea level.

Notes:

ZDL/CN log= compensated Z-Density/compensated neutron log

CBIL log = circumferential borehole imaging log

production at the flow line and water level in the sump, is incorporated. When appropriate, visual estimates of water production were used to improve upon production rates calculated from bromide tracer data, and these modified rates are shown in the drilling parameters plot in Appendix A-1. Table F-1 in Appendix F presents the bromide tracer results and calculated water production rates from Well ER-20-11, with no modifications based on visual estimates. Table F-2 presents estimated water production rates incorporating visual data, as plotted in Appendix A-1.

Indications of water production, based on bromide dilution calculations, of approximately 19 Lpm (5 gpm) were first noted in Well ER-20-11 at the depth of approximately 512.1 m (1,680 ft) within nonwelded ash-flow tuff in the upper portion of the FCCU. Estimated water production rates remained low, at 4 to 19 Lpm (1 to 5 gpm), while drilling through the nonwelded ash-flow and bedded tuffs of the rhyolite of Fluorspar Canyon and Timber Mountain Group, the rhyolite of Windy Wash, and the upper part of the rhyolite of Benham (all of which are grouped in the FCCU) between the depths of 512.1 and 828.1 m (1,680 and 2,717 ft). Fluid production increased rapidly from approximately 95 Lpm (25 gpm) at 828.1 m (2,717 ft) to 379 Lpm (100 gpm) within rhyolitic lava of the BA at 833.6 m (2,735 ft). From the depth of

approximately 833.6 m (2,735 ft) to TD at 915.6 m (3,004 ft), the estimated water production gradually increased from about 379 to 1,893 Lpm (100 to 500 gpm), during drilling in rhyolitic lava of the rhyolite of Benham.

More accurate water production information will be available after hydraulic testing is conducted following completion and development of the well.

6.3 Groundwater Chemistry

N-I monitored discharged drilling fluids during borehole advancement for pH, temperature, and electrical conductivity to evaluate changes in groundwater conditions during drilling. Water quality measurements were affected by cement and the use of drilling foam and polymer during drilling operations, and do not accurately reflect natural groundwater quality; however, they may indicate changing conditions within the borehole during drilling.

N-I collected one set of depth-discrete bailer samples (and duplicate) in the open borehole on September 11, 2012, after completion of the second episode of geophysical logging and before the installation of the well completion casing. The samples were collected at the depth of 856.5 m (2,810 ft) within the open borehole using a wireline-deployed 6-L (25-gal) stainless-steel bailer. The purpose of the samples was to provide initial groundwater chemistry based on select groundwater characterization parameters as identified in the UGTA Quality Assurance Project Plan (NNSA/NSO, 2011b). The bailer and associated sampling equipment were decontaminated according to appropriate procedures before sample collection. The groundwater characterization samples were sent to an outside laboratory for analysis, and the analytical results are presented in Appendix B-1, Table B-1-2.

6.4 Radionuclides Encountered

As described in Section 3.1.2, N-I site personnel collected discharged drilling fluid samples hourly during periods of borehole advancement as part of the FMP and for worker protection. The samples were analyzed on site by NSTec RCTs using LSCs. The average MDA for the LSCs was approximately 1,540 pCi/L.

Tritium levels were below the limit of 20,000 pCi/L established in the National Primary Drinking Water Regulations (CFR, 2012a) during drilling in the vadose zone and in the upper part of the saturated zone, to a depth of approximately 821.1 m (2,694 ft). Within this interval, tritium values ranged from 0 to 1,193 pCi/L, all below the MDA, except for the sample at 821.1 m (2,694 ft), which had a tritium result of 4,375 pCi/L and an MDA of 1,585.95 pCi/L (see Appendix B-1, Table B-1-1).

Elevated levels of tritium (25,973 pCi/L) were encountered in the fluid returns when the borehole reached the depth of 828.8 m (2,719 ft), approximately 324.3 m (1,064 ft) below the static water level depth of 504.4 m (1,655 ft), within lava of the rhyolite of Benham. This abrupt increase in tritium concentration correlates with an increase in water production from about 8 to 38 Lpm (2 to 5 gpm), to approximately 379 Lpm (100 gpm) by the time drilling reached the depth of 833.6 m (2,735 ft). Tritium levels continued to increase with depth and water production to a maximum of 146,131 pCi/L recorded at the depth of 912.0 m (2,992) within lava of the rhyolite of Benham. The results of all the tritium analyses are listed in Appendix B-1. See Section 3.1.2 for additional discussion of onsite tritium analyses.

These field monitoring data may not be representative of the groundwater at Well ER-20-11 due to the disturbance of drilling. More precise laboratory methods will be used on samples to be collected later during well development and sampling activities that will be more representative of the formation.

7.0 Precompletion and Open-Hole Development

Initial well development conducted in Well ER-20-11 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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8.0 Well Completion

8.1 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-20-11 was presented in *Addendum #2 to the Central and Western Pahute Mesa Phase II Hydrogeologic Investigation Wells Drilling and Completion Criteria for Investigation Wells ER-EC-14 and ER-20-11* (N-I, 2011). The completion plans are summarized in Section 8.2.1 of this report, and the actual well completion design, based on the hydrogeology encountered in the borehole, is presented in Section 8.2.2. The rationale for differences between the planned and actual design is discussed in Section 8.2.3, and the completion methods are presented in Section 8.3. Figure 8-1 is a schematic diagram of the well completion design. Figure 8-2 shows a plan view and profile of the final wellhead surface completion. Figure 8-3 is a photograph showing the ER-20-11 wellhead. Table 8-1 is a construction summary for the completion strings.

8.2 Well Completion Design

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

8.2.1 Proposed Completion Design

The original completion design (N-I, 2011) was based on the assumption that Well ER-20-11 would penetrate the water table near the top of the rhyolite of Fluorspar Canyon, in the FCCU, and reach TD in the confining unit just below the BA. The primary goal of the proposed completion design was to provide groundwater production data from the BA and to provide access to groundwater for monitoring and sampling. A surface casing string was intended to extend to the depth of approximately 504.1 m (1,654 ft) to isolate the unsaturated zone from the underlying saturated rocks.

Figure 8-1
As-Built Completion Schematic for Well ER-20-11

Figure 8-2
Wellhead Diagram for Well ER-20-11

Photograph by NSTec, January 24, 2013

Figure 8-3
Photograph of the Well ER-20-11 Wellhead

The well was planned to be completed using a string of 6⁵/₈-in. casing with a slotted interval that would provide access to the BA. The 6⁵/₈-in. stainless-steel casing string was to be positioned approximately 3 m (10 ft) above the bottom of the borehole, with a blank bull-nose section at its terminal end. The 6⁵/₈-in. stainless-steel completion string would transition to a string of internally epoxy-coated carbon-steel 7⁵/₈-in. casing at approximately 16.5 m (54 ft) above the water table via a 0.6-m (2-ft) long stainless-steel crossover sub. Gravel packs would be placed outside the slotted intervals, to at least 9.1 m (30 ft) above the top of the slots, and layers of sand and cement would be placed above the gravel.

Before the installation of the well-completion string, two 2⁷/₈-in. piezometer strings were planned to be installed, one with slots open to approximately the same interval as the 6⁵/₈-in. completion string, and one with its slotted section just below the static water level.

Table 8-1
Well ER-20-11 Completion String Construction Summary

Casing and Tubing	Configuration meters (feet)		Cement meters (feet)	Sand/Gravel meters (feet)
7 ⁵ / ₈ -in. epoxy-coated carbon-steel production casing with crossover sub	0 to 492.7 (0 to 1,616.5)	Blank	None	
6 ⁵ / ₈ -in. stainless-steel production casing	492.7 to 796.3 (1,616.5 to 2,612.4)	Blank	None	
6 ⁵ / ₈ -in. stainless-steel production casing	796.3 to 903.6 (2,612.4 to 2,964.5)	Slotted ^a	Type II Neat Cement 734.3 to 780.9 (2,409 to 2,562)	20/40 Sand 780.9 to 785.8 (2,562 to 2,578)
6 ⁵ / ₈ -in. stainless-steel production casing	903.6 to 904.3 (2,964.5 to 2,966.8)	Blank and bullnosed		6-9 Sand 785.8 to 789.7 (2,578 to 2,591) ³/₈-in. Washed Gravel 789.7 to 915.6 (2,591 to 3,004)
2 ³ / ₈ -in. carbon-steel tubing with crossover sub	0 to 494.7 (0 to 1,623.1)	Blank	None	
2 ⁷ / ₈ -in. stainless-steel tubing	494.7 to 795.3 (1,623.1 to 2,609.3)	Blank	None	
2 ⁷ / ₈ -in. stainless-steel tubing	795.3 to 903.1 (2,609.3 to 2,963.0)	Slotted ^b	Same as for production string	Same as for production string
2 ⁷ / ₈ -in. stainless-steel tubing	903.1 to 903.8 (2,963.0 to 2,965.2)	Blank and bullnosed		

a Vertical slots in each joint are 0.159 cm (0.0625 in.) wide and 7.0 cm (2.75 in.) long, arranged in 66 rows, on 7.62-cm (3.0-in.) centers. The 12 slots per row are positioned radially around the casing at 30 degrees. Each row is offset by 15 degrees from the next.

b Vertical slots in each joint are 0.159 cm (0.0625 in.) wide and 5.4 cm (2.125 in.) long, arranged in 68 rows, on 7.62-cm (3.0-in.) centers. The 8 slots per row are positioned radially around the tubing at 45 degrees. Each row is offset by 22.5 degrees from the next.

8.2.2 As-Built Completion Design

The final design of the Well ER-20-11 completion was determined after the final TD of 915.6 m (3,004 ft) was reached, through consultation with members of the UGTA Well ER-20-11 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 8-1 and listed in Table 8-1, a completion casing string and one piezometer string were installed in Well ER-20-11.

The main completion string consists of a section of 6 $\frac{5}{8}$ -in. stainless-steel casing suspended from 7 $\frac{5}{8}$ -in. internally epoxy-coated carbon-steel casing, which was set at the depth of 904.3 m (2,966.8 ft). The 7 $\frac{5}{8}$ -in. epoxy-coated carbon-steel casing extends from the surface to the depth of 492.7 m (1,616.5 ft), which is approximately 11.9 m (39 ft) above the water table. The stainless-steel 6 $\frac{5}{8}$ -in. casing is slotted in the interval from 796.3 to 903.6 m (2,612.4 to 2,964.5 ft) within the BA. The slotted section consists of 17 consecutive slotted joints, and terminates with a 0.7-m (2.3-ft) length of blank stainless-steel bullnosed casing that functions as

Photograph by N-I, October 13, 2012

Figure 8-4
Photograph of Slotted Casing for
Well ER-20-11

a sediment sump. The machine-cut openings in each slotted casing joint are 0.159 cm (0.0625 in.) wide and 7.0 cm (2.75 in.) long. The vertical slots in each joint are arranged in 66 rows on 7.62-cm (3.0-in.) centers. The 12 slots per row are positioned radially around the casing at 30 degrees. Each row is offset by 15 degrees from the next. The slotted section of the casing string is gravel-packed from the bottom of the borehole to the depth of 789.7 m (2,591 ft). Figure 8-4 illustrates the arrangement of slots on the casing joints installed in Well ER-20-11.

The piezometer string consists of a section of 2 $\frac{7}{8}$ -in. stainless-steel tubing that hangs from 2 $\frac{3}{8}$ -in. carbon-steel tubing via a crossover sub. The bottom of the piezometer string was set at the depth of 903.8 m (2,965.2 ft). The 2 $\frac{3}{8}$ -in. carbon-steel tubing (with crossover sub) extends from the surface to the depth of 494.7 m

(1,623.1 ft), which is approximately 9.8 m (32 ft) above the water table. The stainless-steel 2 $\frac{7}{8}$ -in. tubing is slotted in the interval from 795.3 to 903.1 m (2,609.3 to 2,963.0 ft) within the BA.

The slotted section consists of 17 consecutive slotted joints, and terminates with a 0.6-m (2.1-ft) length of stainless-steel bullnosed tubing that functions as a sediment sump. The openings in the slotted tubing joints are 0.159 cm (0.0625 in.) wide and 5.4 cm (2.125 in.) long. The vertical slots in each joint are arranged in 68 rows, on 7.62-cm (3.0-in.) centers. The eight slots per row are positioned radially around the tubing at 45 degrees. Each row is offset by 22.5 degrees from the next. The slotted portion of the piezometer string lies within the same gravel pack as the slotted section of the 6 $\frac{5}{8}$ -in. production casing.

8.2.3 Rationale for Differences between Planned and Actual Well Design

The geology of Well ER-20-11 was similar to that predicted (see Section 5.3), so little change was required to the original proposed well completion design. Although the static water level was very close to where predicted, the well was producing so little water when this depth was reached, that the decision was made to drill a little deeper before installing the surface casing.

The original completion design was based on the expectation that one saturated lava-flow aquifer would be encountered in the well, which would be drilled to a TD of 899.2 m (2,950 ft), within bedded Paintbrush Group tuffs below the BA. The stratigraphy was close to the expected; however, the BA was slightly deeper than expected, which required that the well be drilled 16.5 m (54 ft) deeper than planned.

The upper piezometer string was deemed unnecessary because the units present at and just below the water level are confining units and not very hydraulically conductive.

8.3 Completion Method

Completion activities began on September 12, 2012, after the borehole TD was reached. The drill crew ran the piezometer string, and landed it within the 12.25-in. borehole at 903.8 m (2,965.2 ft). The crew also inserted a 2 $\frac{7}{8}$ -in. tubing string to serve as a tremie during placement of stemming materials, which was removed as the stemming material was emplaced.

After the two tubing strings were inserted, the casing crew began running the completion casing. The production casing was landed at 904.3 m (2,966.8 ft) on September 13, 2012. Colog ran a nuclear annulus investigation logging tool in the borehole to monitor the stemming process. The lower gravel pack was emplaced in the annulus of the borehole outside the completion strings from the bottom of the borehole to the depth of 789.7 m (2,591 ft), encompassing the slotted intervals of the completion string and the piezometer string. Next a 4.0-m (13-ft) thick layer of

6-9 silica sand was placed above the gravel through the tremie line, followed by a 4.9-m (16-ft) thick layer of 20/40 sand. The NSTec cement crew next placed Type II neat cement in two stages, resulting in a rise of 46.6 m (153 ft) above the sand. 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 the final stage of completion stemming was completed, on September 14, 2012, the tremie line was removed and the cement and logging crews rigged down. The UDI rig was released and drillers began rigging down.

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.

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.

9.0 Planned and Actual Costs and Scheduling

This section provides brief discussions of the planned and actual schedule and costs for constructing Well ER-20-11.

The original NSTec-approved baseline task plan cost estimate for drilling and completing Well ER-20-11 was based on drilling to a planned TD of 975.4 m (3,200 ft) and installing one completion string and two piezometer strings. This estimate was submitted before the drilling criteria document (N-I, 2011) was issued with an updated planned TD of 899.2 m (2,950 ft). In the baseline estimate, a 21-day schedule for constructing a 975.4-m (3,200-ft) deep well was used.

Well ER-20-11 was drilled to a TD of 915.6 m (3,004 ft), which is 59.7 m (196 ft) less than originally planned, and 16.5 m (54 ft) deeper than specified in the drilling criteria (N-I, 2011). Drilling went smoothly with no problems. A single completion casing string was installed, as planned, but only one of two planned piezometer strings was installed. A graphical comparison, by day, of planned and actual well-construction activities is presented in Figure 9-1.

The baseline schedule for drilling and completing Well ER-20-11 was 21 days. Drilling and casing of the surface hole took 4 days less than planned, and drilling of the main hole took 2 days less than planned.

The cost analysis for Well ER-20-11 begins with the mobilization of the UDI drill rig to the drill site, where the conductor hole had already been constructed. The total construction cost for Well ER-20-11 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, inspection services, site supervision, and geotechnical consultation. The cost of building the roads, drill pad, sumps, and conductor hole is not included, nor is the cost of well-site support by N-I personnel.

The approved baseline work package cost for constructing Well ER-20-11 was \$3,758,088. The actual cost was \$2,646,527, or 29.6 percent less than the planned cost, due to the shallower TD and simpler completion design. Figure 9-2 presents a comparison of the planned and actual costs, by day, for construction of Well ER-20-11.

Figure 9-1

Planned and Actual Construction Progress for Well ER-20-11

Note that the planned TD is based on a preliminary plan developed prior to issue of the drilling criteria document (N-I, 2011)

Figure 9-2
Planned and Actual Cost of Constructing Well ER-20-11

Note that the planned TD is based on a preliminary plan developed prior to issue of the drilling criteria document (N-I, 2011)

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10.0 Summary, Recommendations, and Lessons Learned

10.1 Summary

Main hole drilling at Well ER-20-11 commenced on September 1, 2012, and concluded on September 9, 2012, at a total drilled depth of 915.6 m (3,004 ft). Few problems were encountered during drilling. A string of 13³/₈-in. casing was installed to isolate the saturated portion of the well from the unsaturated portion above. The borehole was completed within the BA, which was encountered in the depth range expected in the bottom portion of the drill hole.

The completion string consists of 6⁵/₈-in. stainless-steel casing suspended from 7⁵/₈-in. carbon-steel casing. The carbon-steel casing is internally epoxy-coated and extends to a depth that is approximately 11.9 m (39 ft) above the water table. The stainless-steel 6⁵/₈-in. casing is slotted in the interval from 796.3 to 903.6 m (2,612.4 to 2,964.5 ft), within the BA. The slotted section consists of 17 consecutive stainless-steel slotted joints. One piezometer string consisting of 2⁷/₈-in. stainless-steel tubing suspended from 2³/₈-in. carbon-steel tubing, was set at 903.8 m (2,965.2 ft) to monitor the water level in the borehole during hydraulic testing. The piezometer string is slotted between 795.3 and 903.1 m (2,609.3 and 2,963.0 ft). The slotted intervals of both strings are surrounded by a single layer of gravel pack in the depth interval 789.7 to 915.6 m (2,591 to 3,004 ft). The gravel is topped with 8.8 m (29 ft) of sand and 46.6 m (153 ft) of cement.

Geologic data collected during drilling included composite drill cuttings samples collected every 3.0 m (10 ft) from 18.3 m (60 ft) to TD. Open-hole geophysical logging was conducted in the upper portion of the borehole before installation of the surface casing and in the lower portion 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-20-11 is collared in nonwelded and bedded tuffs of the Beatty Wash Formation, and penetrated 915.6 m (3,004 ft) of Tertiary volcanic rocks, consisting largely of bedded and nonwelded to densely welded ash-flow tuffs, rhyolitic lavas, and zeolitic to quartzo-feldspathic nonwelded tuffs. The target aquifer, the BA, was encountered between the depths of 797.1 and 903.1 m (2,615 and 2,963 ft). A fluid-level depth of 504.5 m (1,655.2 ft) was measured in the piezometer string 12 days after well completion, on September 26, 2012.

Tritium in the drilling fluid exceeded the minimum detection limits of the field equipment at the rig site, starting at the depth of 828.8 m (2,719 ft) while drilling in the BA. The maximum tritium level as measured on site was 146,131 pCi/L, which was detected while drilling at the

depth of 912.0 m (2,992 ft). Analysis by an offsite laboratory of a depth-discrete bailer sample taken at the depth of 856.5 m (2,810 ft) returned a tritium value of 186,000 pCi/L.

All FMP requirements for Well ER-20-11 were met. Analysis of monitoring samples and FMP confirmatory samples indicated that fluids generated during drilling at Well ER-20-11 met the FMP criteria for discharge to an unlined sump or designated infiltration area.

10.2 Recommendations

All the geologic and hydrologic data and interpretations from Well ER-20-11 should be integrated into the PM–OV Phase II HFM. This will allow for more confidence in the characterization of groundwater flow direction and velocity in the Pahute Mesa area.

The water level in Well ER-20-11 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 the piezometer string. 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.

10.3 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. Continuous improvements in communication stand out for this project, as described below.

- The CAU guidance teams and drilling advisory team formed by the UGTA TWG continued to provide timely assistance and guidance during drilling, to ensure that the scientific objectives of the well were met.
- The multiple contractors performing work during construction of Well ER-20-11 continue to improve communication during drilling, radionuclide monitoring, and completion activities. Daily pre-task hazard reviews and individual company safety briefings contributed toward a project with no safety incidents, near misses, or accidents.

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Appendix A

Drilling Data

- A-1 Drilling Parameter Log for Well ER-20-11**
- A-2 Tubing and Casing Data for Well ER-20-11**
- A-3 Well ER-20-11 Drilling Fluids and Cement Composition**

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Appendix A-1
Drilling Parameter Log for Well ER-20-11

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Well ER-20-11

Logging Company: Baker Atlas
Drilled Depth: 915.6 m (3,004 ft)
Date TD Reached: September 9, 2012
Drill Method: Rotary/Air foam

Surface Elevation: 1,778.2 m (5,834.0 ft)
Coordinates (UTM [NAD 83]): N 4,116,747.6 m
 E 545,698.4 m
Water Level: 504.5 m (1,655.2) on September 26, 2012

See Table 5-1 for key to stratigraphic symbols.

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Appendix A-2
Tubing and Casing Data for Well ER-20-11

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Table A-2-1
Tubing and Casing Data for Well ER-20-11

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	0 to 3.4 (0 to 11.3)	Carbon steel	B	76.20 (30)	73.66 (29.0)	1.270 (0.500)	157
Conductor	3.4 to 17.8 (11.3 to 58.4)	Carbon steel	B	76.2 (30)	73.58 (28.97)	1.308 (0.515)	162.3
Surface	0 to 219.7 (0 to 720.8)	Carbon steel	K55 and J55	33.97 (13.375)	32.042 (12.615)	0.965 (0.380)	54.5
Surface	219.7 to 511.5 (720.8 to 1,678.2)	Carbon steel	J	33.97 (13.375)	31.788 (12.515)	1.092 (0.430)	61
Completion (with crossover)	0 to 492.7 (0 to 1,616.5)	Epoxy-coated carbon steel	J55	19.368 (7.625)	17.701 (6.969)	0.833 (0.328)	26.4
Completion (with bullnose)	492.7 to 904.3 (1,616.5 to 2,966.8)	Stainless steel	304L	16.828 (6.625)	15.504 (6.104)	0.662 (0.261)	NR ^a
Piezometer (with crossover)	0 to 494.7 (0 to 1,623.1)	Carbon steel	N80	6.033 (2.375)	5.067 (1.995)	0.483 (0.190)	4.7
Piezometer (with bullnose)	494.7 to 903.8 (1,623.1 to 2,965.2)	Stainless steel	SS	7.303 (2.875)	5.90 (2.323)	0.701 (0.276)	7.66

a NR = not recorded. Schedule 40 stainless-steel casing of this size may range in weight from approximately 18 to 19 pounds per foot

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Appendix A-3
Well ER-20-11 Drilling Fluids and Cement Composition

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Table A-3-1
Drilling Fluids Used in Well ER-20-11

Typical Air-Foam/Polymer Mix
37.85 liters (10 gallons) Bachman Foam ^{® a} 0 to 1.89 liters (0 to 0.5 gallons) LP701 ^{® b} per 7,949 liters (50 barrels) water

a Bachman[®] foaming agent is a product of Bachman Services, Inc.

b LP701[®] polymer additive is a product of Geo Drilling Fluids, Inc.

Notes:

1. All water used to mix drilling fluids for Well ER-20-11 came from Water Well 8 in NNSS Area 18.
2. A concentrated lithium bromide (LiBr) solution was added to all introduced fluids (1 liter LiBr per 50 barrels of fluid), to make up a final concentration of approximately 20 to 30 parts per million LiBr. The concentration was increased in zones of higher water production to make up a solution of 50 to 60 parts per million LiBr.

Table A-3-2
Well ER-20-11 Cement Composition

Cement Composition	30-inch Conductor Casing	13 ³ / ₈ -inch Surface Casing	Production Casing and Piezometer
Redi-Mix Formula 400; 998 kilograms (2,200 pounds) sand, 326 kilograms (719 pounds) Portland cement, and 232 liters (61 gallons) water per cubic yard	0 to 18.3 m ^a (0 to 60.0 ft) ^b	None	None
Type II neat	None	429.8 to 511.5 m (1,410 to 1,678 ft)	734.3 to 780.9 m (2,409 to 2,562 ft)

a meter(s)

b foot (feet)

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Appendix B

Fluid Management Data for Well ER-20-11

- B-1 Fluid Management Data for Well ER-20-11**
- B-2 Final Well Specific Fluid Management Strategy for UGTA
Well ER-20-11, Area 20, Nevada National Security Site**

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Appendix B-1
Fluid Management Data for Well ER-20-11

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Table B-1-1
Tritium Activities Measured on Fluid Samples during Drilling at Well ER-20-11 (5 pages)

Sample Identification Number	Depth		NSTec Onsite Tritium Analysis Results			Sample Description
	meters	feet	Tritium Results (pCi/L)	MDA (pCi/L)	Recount #1 (pCi/L)	
ER-20-11-090112-01	–	N/A	684	1,466.97	–	Baker Tank
ER-20-11-090112-02	23.2	76	694	1,427.36	–	Discharge Line
ER-20-11-090112-03	26.2	86	706	1,502.48	–	Discharge Line
ER-20-11-090112-04	32.3	106	0	1,584.73	–	Discharge Line
ER-20-11-090112-05	36.8	121	0	1,544.18	–	Discharge Line
ER-20-11-090112-06	42.7	140	4,020	1,794.84 ^a	0	Discharge Line
ER-20-11-090112-07	49.1	161	0	1,794.84	–	Discharge Line
ER-20-11-090112-08	53.9	177	29	1,585.91	–	Discharge Line
ER-20-11-090112-09	61.0	200	0	1,585.91	–	Discharge Line
ER-20-11-090212-10	62.5	205	929	1,289.82	–	Discharge Line
ER-20-11-090212-11	74.7	245	736	1,502.48	–	Discharge Line
ER-20-11-090212-12	84.1	276	0	1,544.18	–	Discharge Line
ER-20-11-090212-13	93.6	307	650	1,585.91	–	Discharge Line
ER-20-11-090212-14	100.6	330	459	1,543.09	–	Discharge Line
ER-20-11-090212-15	109.7	360	42	1,289.82	–	Discharge Line
ER-20-11-090212-16	113.1	371	7,947	1,280.45 ^a	332	Discharge Line
ER-20-11-090212-17	–	N/A	886	1,397.11	–	Baker Tank
ER-20-11-090212-18	116.4	382	956	1,582.58	–	Discharge Line
ER-20-11-090212-19	120.4	395	1,038	1,620.12	–	Discharge Line
ER-20-11-090212-20	125.6	412	2,055	1,620.12 ^a	663	Discharge Line
ER-20-11-090212-21	128.9	423	380	1,320.53	–	Discharge Line
ER-20-11-090212-22	139.6	458	952	1,544.18	–	Discharge Line
ER-20-11-090212-23	143.3	470	0	1,610.03	–	Discharge Line
ER-20-11-090212-24	149.0	489	1,897	1,707.69 ^a	0	Discharge Line
ER-20-11-090212-25	153.9	505	0	1,707.69	–	Discharge Line
ER-20-11-090212-26	160.0	525	0	1,627.56	–	Discharge Line
ER-20-11-090212-27	172.2	565	0	1,707.69	–	Discharge Line
ER-20-11-090212-28	182.9	600	0	1,627.56	–	Discharge Line
ER-20-11-090312-29	192.6	632	646	1,498.98	–	Discharge Line

Table B-1-1
Tritium Activities Measured on Fluid Samples during Drilling at Well ER-20-11 (5 pages)

Sample Identification Number	Depth		NSTec Onsite Tritium Analysis Results			Sample Description
	meters	feet	Tritium Results (pCi/L)	MDA (pCi/L)	Recount #1 (pCi/L)	
ER-20-11-090312-30	200.3	657	0	1,463.95	–	Discharge Line
ER-20-11-090312-31	206.7	678	816	1,378.94	–	Discharge Line
ER-20-11-090312-32	211.5	694	0	1,624.23	–	Discharge Line
ER-20-11-090312-33	217.9	715	0	1,579.62	–	Discharge Line
ER-20-11-090312-34	224.0	735	0	1,544.18	–	Discharge Line
ER-20-11-090312-35	230.7	757	0	1,584.73	–	Discharge Line
ER-20-11-090312-36	235.6	773	114	1,544.10	–	Discharge Line
ER-20-11-090312-37	–	N/A	144	1,544.10	–	Baker Tank
ER-20-11-090312-38	240.2	788	0	1,502.65	–	Discharge Line
ER-20-11-090312-39	246.0	807	0	1,397.11	–	Discharge Line
ER-20-11-090312-40	249.0	817	0	1,431.19	–	Discharge Line
ER-20-11-090312-41	256.0	840	198	1,508.38	–	Discharge Line
ER-20-11-090312-42	262.1	860	1,565	1,620.12 ^a	772	Discharge Line
ER-20-11-090312-43	264.6	868	1,141	1,311.68	–	Discharge Line
ER-20-11-090312-44	270.1	886	537	1,624.23	–	Discharge Line
ER-20-11-090312-45	274.3	900	0	1,662.75	–	Discharge Line
ER-20-11-090312-46	278.6	914	214	1,624.23	–	Discharge Line
ER-20-11-090312-47	281.0	922	0	1,544.18	–	Discharge Line
ER-20-11-090312-48	284.1	932	0	1,624.23	–	Discharge Line
ER-20-11-090312-49	291.1	955	0	1,584.73	–	Discharge Line
ER-20-11-090312-50	295.7	970	0	1,544.18	–	Discharge Line
ER-20-11-090312-51	298.4	979	420	1,544.10	–	Discharge Line
ER-20-11-090312-52	302.1	991	0	1,544.10	–	Discharge Line
ER-20-11-090312-53	306.0	1,004	0	1,714.46	–	Discharge Line
ER-20-11-090412-54	309.4	1,015	232	1,629.96	–	Discharge Line
ER-20-11-090412-55	313.9	1,030	0	1,466.97	–	Discharge Line
ER-20-11-090412-56	316.7	1,039	1,645	1,463.95 ^a	140	Discharge Line
ER-20-11-090412-57	321.6	1,055	46	1,466.97	–	Discharge Line
ER-20-11-090412-58	327.7	1,075	0	1,466.97	–	Discharge Line

Table B-1-1
Tritium Activities Measured on Fluid Samples during Drilling at Well ER-20-11 (5 pages)

Sample Identification Number	Depth		NSTec Onsite Tritium Analysis Results			Sample Description
	meters	feet	Tritium Results (pCi/L)	MDA (pCi/L)	Recount #1 (pCi/L)	
ER-20-11-090412-59	335.3	1,100	0	1,469.54	–	Discharge Line
ER-20-11-090412-60	343.5	1,127	0	1,541.09	–	Discharge Line
ER-20-11-090412-61	349.9	1,148	1,193	1,433.80	–	Discharge Line
ER-20-11-090412-62	–	N/A	0	1,708.05	–	Baker Tank
ER-20-11-090412-63	363.6	1,193	258	1,466.97	–	Discharge Line
ER-20-11-090412-64	375.8	1,233	258	1,459.54	–	Discharge Line
ER-20-11-090412-65	385.0	1,263	2,770	1,543.09 ^a	0	Discharge Line
ER-20-11-090412-66	400.2	1,313	555	1,504.58	–	Discharge Line
ER-20-11-090412-67	413.6	1,357	616	1,459.54	–	Discharge Line
ER-20-11-090412-68	428.2	1,405	1,035	1,463.95	–	Discharge Line
ER-20-11-090412-69	435.3	1,428	814	1,406.43	–	Discharge Line
ER-20-11-090412-70	442.0	1,450	7,255	1,581.73 ^a	380	Discharge Line
ER-20-11-090412-71	454.2	1,490	1,696	1,581.73 ^a	686	Discharge Line
ER-20-11-090412-72	463.3	1,520	1,251	1,581.73	–	Discharge Line
ER-20-11-090412-73	469.1	1,539	298	1,581.73	–	Discharge Line
ER-20-11-090412-74	474.6	1,557	0	1,543.09	–	Discharge Line
ER-20-11-090412-75	481.6	1,580	0	1,540.62	–	Discharge Line
ER-20-11-090412-76	490.7	1,610	0	1,771.17	–	Discharge Line
ER-20-11-090412-77	498.3	1,635	319	1,453.48	–	Discharge Line
ER-20-11-090412-78	506.6	1,662	73	1,585.91	–	Discharge Line
ER-20-11-090412-79	512.1	1,680	0	1,502.48	–	Discharge Line
ER-20-11-090412-80	518.8	1,702	585	1,422.11	–	Discharge Line
ER-20-11-090412-81	520.3	1,707	896	1,498.98	–	Discharge Line
ER-20-11-090812-82	525.8	1,725	0	1,629.96	–	Discharge Line
ER-20-11-090812-83	534.9	1,755	564	1,585.95	–	Discharge Line
ER-20-11-090812-84	548.3	1,799	0	1,544.18	–	Discharge Line
ER-20-11-090812-85	564.5	1,852	0	1,714.46	–	Discharge Line
ER-20-11-090812-86	576.1	1,890	264	1,585.91	–	Discharge Line
ER-20-11-090812-87	589.5	1,934	0	1,427.36	–	Discharge Line

Table B-1-1
Tritium Activities Measured on Fluid Samples during Drilling at Well ER-20-11 (5 pages)

Sample Identification Number	Depth		NSTec Onsite Tritium Analysis Results			Sample Description
	meters	feet	Tritium Results (pCi/L)	MDA (pCi/L)	Recount #1 (pCi/L)	
ER-20-11-090812-88	602.3	1,976	0	1,466.97	–	Discharge Line
ER-20-11-090812-89	616.3	2,022	694	1,652.74	–	Discharge Line
ER-20-11-090812-90 ^b	630.3	2,068	N/A	N/A	–	Discharge Line
ER-20-11-090812-91	–	N/A	335	1,260.51	–	Baker Tank
ER-20-11-090812-92	642.5	2,108	268	1,629.96	–	Discharge Line
ER-20-11-090812-93	661.4	2,170	367	1,359.39	–	Discharge Line
ER-20-11-090812-94	672.1	2,205	879	1,392.54	–	Discharge Line
ER-20-11-090812-95	685.8	2,250	1,189	1,903.14	–	Discharge Line
ER-20-11-090812-96	700.4	2,298	1,169	1,463.95	–	Discharge Line
ER-20-11-090812-97	710.8	2,332	0	1,582.58	–	Discharge Line
ER-20-11-090812-98	722.7	2,371	24	1,544.18	–	Discharge Line
ER-20-11-090812-99	735.8	2,414	779	1,453.48	–	Discharge Line
ER-20-11-090812-100	747.7	2,453	1,000	1,540.62	–	Discharge Line
ER-20-11-090812-101	759.6	2,492	0	1,197.52	–	Discharge Line
ER-20-11-090812-102 ^b	773.0	2,536	N/A	N/A	–	Discharge Line
ER-20-11-090812-103	783.3	2,570	616	1,540.62	–	Discharge Line
ER-20-11-090812-104	789.4	2,590	0	1,582.58	–	Discharge Line
ER-20-11-090812-105	798.0	2,618	0	1,197.52	–	Discharge Line
ER-20-11-090812-106	803.5	2,636	436	1,502.48	–	Discharge Line
ER-20-11-090912-107	808.6	2,653	1,080	1,680.59	–	Discharge Line
ER-20-11-090912-108	814.7	2,673	850	2,114.60	–	Discharge Line
ER-20-11-090912-109	821.1	2,694	4,375	1,585.95	–	Discharge Line
ER-20-11-090912-110	828.8	2,719	27,604	1,585.91 ^a	25,973	Discharge Line
ER-20-11-090912-111	831.2	2,727	22,913	1,422.11	–	Discharge Line
ER-20-11-090912-112	833.9	2,736	27,141	1,427.36	–	Discharge Line
ER-20-11-090912-113	837.6	2,748	29,019	1,505.49	–	Discharge Line
ER-20-11-090912-114	839.4	2,754	25,247	1,415.23	–	Discharge Line
ER-20-11-090912-115	841.2	2,760	23,871	1,584.16	–	Discharge Line
ER-20-11-090912-116	844.3	2,770	33,295	1,502.48	–	Discharge Line

Table B-1-1
Tritium Activities Measured on Fluid Samples during Drilling at Well ER-20-11 (5 pages)

Sample Identification Number	Depth		NSTec Onsite Tritium Analysis Results			Sample Description
	meters	feet	Tritium Results (pCi/L)	MDA (pCi/L)	Recount #1 (pCi/L)	
ER-20-11-090912-117	846.7	2,778	35,551	1,620.12	–	Discharge Line
ER-20-11-090912-118	848.9	2,785	44,372	1,392.54	–	Discharge Line
ER-20-11-090912-119	–	N/A	415	1,546.02	–	Baker Tank
ER-20-11-090912-120	856.5	2,810	52,046	1,431.19	–	Discharge Line
ER-20-11-090912-121	857.7	2,814	65,115	1,431.19	–	Discharge Line
ER-20-11-090912-122	859.8	2,821	95,372	1,297.60	–	Discharge Line
ER-20-11-090912-123	862.9	2,831	94,678	1,466.97	–	Discharge Line
ER-20-11-090912-124	865.9	2,841	86,775	1,431.19	–	Discharge Line
ER-20-11-090912-125	866.5	2,843	87,660	1,359.39	–	Discharge Line
ER-20-11-090912-126	871.4	2,859	85,657	1,392.54	–	Discharge Line
ER-20-11-090912-127	876.3	2,875	71,476	1,870.32	–	Discharge Line
ER-20-11-090912-128	884.5	2,902	92,054	1,504.58	–	Discharge Line
ER-20-11-090912-129	886.1	2,907	122,671	1,900.41	–	Discharge Line
ER-20-11-090912-130	887.9	2,913	127,708	1,692.60	–	Discharge Line
ER-20-11-090912-131	893.1	2,930	143,820	1,582.58	–	Discharge Line
ER-20-11-090912-132	895.2	2,937	145,517	1,662.75	–	Discharge Line
ER-20-11-090912-133	898.6	2,948	102,252	1,504.40	–	Discharge Line
ER-20-11-090912-134	904.3	2,967	141,763	1,700.37	–	Discharge Line
ER-20-11-090912-135	912.0	2,992	146,131	1,548.73	–	Discharge Line
ER-20-11-091112-136	856.5	2,810	165,095	1,629.96	–	Depth-discrete Bailer
ER-20-11-091112-136 ^c	856.5	2,810	186,000	1,000	–	Depth-discrete Bailer

Data from N-I (2013)

a MDA provided is for the recounted tritium result.

b Sample lost during processing.

c Analysis by ALS Laboratory Group

MDA: minimum detectable activity

N/A: not applicable

NSTec: National Security Technologies, LLC

pCi/L: picocuries per liter

–: no recorded data

Baker tank is the holding tank from which water is obtained for mixing the down-hole drilling fluids

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Table B-1-2
Analytical Results for Depth-Discrete Bailer Samples from Well ER-20-11
 (Page 1 of 2)

Analyte	Analytical Method ^a	Detection Limit	09/11/2012 Sample Number 103-091112-1 Taken at Depth of 856.5 meters (2,810 feet)		09/11/2012 Sample Number 103-091112-2 (Duplicate) Taken at Depth of 856.5 meters (2,810 feet)	
			Total	Dissolved	Total	Dissolved
Metals (milligrams per liter)						
Aluminum	SW-846 6010 ^b	0.2	0.67	0.2 U	0.66	0.2 U
Arsenic		0.01	0.0054 J+	0.0054 J+	0.01 U	0.01 U
Barium		0.1	0.1 U	0.1 U	0.1 U	0.1 U
Cadmium		0.005	0.005 U	0.005 U	0.00038	0.005 U
Calcium		1.0		2.3 J		2.3 J
Chromium		0.01	0.015	0.00066 J	0.012	0.01 U
Iron		0.1	13	0.36	12	0.29
Lead		0.003	0.003 U	0.003 U	0.003 U	0.003 U
Lithium		0.01		0.13 J		0.13 J
Magnesium		1.0		1 U		1 U
Manganese		0.01	0.12	0.011	0.11	0.01 U
Potassium		1.0		2.3		2.2
Selenium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Silicon		0.05	26	24	26	24
Silver		0.01	0.01 U	0.01 U	0.01 U	0.01 U
Sodium		1.0		99 J		100 J
Strontium		0.01		0.01 U		0.01 U
²³⁸ Uranium		SW-846 6020 ^b	0.0001		0.0035 J	
Mercury	SW-846 7470 ^b	0.0002	0.000045 J	0.0002 U	0.0002 U	0.0002 U
Inorganic Compounds (milligrams per liter unless otherwise noted)						
Bromide	EPA 300.1 ^c	0.2		0.5 J		0.48 J
Chloride		1.00		43 J		45 J
Fluoride		0.1		3 J		3.1 J
Sulfate		1.00		64 J		65 J
Bicarbonate as CaCO ₃	EPA 310.1 ^d	20	120 J		120 J	
Carbonate as CaCO ₃		20	20 J		20 J	
Total Dissolved Solids	EPA 160.1 ^d	20	360 J		360 J	
pH (SU)	EPA 150.1 ^d	0.1	8.2 J		8.2 J	
Specific Conductivity (µmhos/centimeter)	EPA 120.1 ^d	1.0	540 J		540 J	
Organics (milligrams per liter)						
Total Organic Carbon	EPA 415.1 ^d	1.00	2.8 J			
Redox Parameter (milligrams per liter)						
Total Sulfide ^e	EPA 376.1 ^d					

Table B-1-2
Analytical Results for Depth-Discrete Bailer Samples from Well ER-20-11
 (Page 2 of 2)

Analyte	Analytical Method ^a	Detection Limit	09/11/2012 Sample Number 103-091112-1 Taken at Depth of 856.5 meters (2,810 feet)		09/11/2012 Sample Number 103-091112-2 (Duplicate) Taken at Depth of 856.5 meters 2,810 (feet)	
			Total	Dissolved	Total	Dissolved
Radiological Indicator Parameters-Level I (picocuries per liter)						
		MDC ^f	Result	Error	Result	Error
Tritium	EPA 906.0 ^g	1,000, 1,000	186,000	28,000	187,000	29,000
Gross Alpha	EPA 900.0 ^g	1.00, 1.20	4.8	1.20	3.7	1.10
Gross Beta		2.20, 2.00	6.4	1.70	5.1	1.50
²³⁸ Pu	HASL 300 ^h / ASTM D3865-02 ⁱ	0.031, 0.022	-0.002 U	0.023	0 U	0.03
^{239/240} Pu	HASL 300 ^h / ASTM D3865-02 ⁱ	0.017, 0.041	0.006 U	0.023	-0.003 U	0.03
Gamma Spectroscopy	EPA 901.1 ^h	Varies by nuclide	ND	Varies by nuclide	ND	Varies by Nuclide
Radiological Indicator Parameters-Level II (picocuries per liter)						
14C	EERF C-01 ^j	410, 410	60 U	240	180 U	250

Samples collected September 11, 2012

Source: N-I (2013)

- ^a For commercial laboratory analysis, the most current EPA or equivalent accepted standard laboratory analytical methods may be used as appropriate to attain specified detection limits. Analyses for all analytes were performed by ALS Laboratory Group.
- ^b EPA (2012)
- ^c EPA (1997)
- ^d EPA (1983)
- ^e Water sample for sulfide analysis was shipped to ALS at ambient temperature. The sample should have been shipped on ice; therefore, the sulfide analysis was cancelled.
- ^f MDC varies by matrix, instrument, and count rates. Where two detection limits are given, the first corresponds with sample number 103-091112-1, the second with 103-091112-2.
- ^g EPA (1980)
- ^h U.S. Department of Energy (1997)
- ⁱ ASTM (2002)
- ^j EPA (1984)

ASTM: ASTM International

C: Carbon

CaCO₃: Calcium carbonate

EERF: Eastern Environmental Radiation Facility

EPA: U.S. Environmental Protection Agency

HASL: Health and Safety Laboratory, U.S. Department of Energy

J: Result is estimated

J+: Result is estimated bias high

MDC: Minimum detectable concentration

ND: No gamma spectroscopy radionuclides detected above detection limit

Pu: Plutonium

SU: Standard unit

SW: Solid waste

U: Compound was analyzed for but was not detected ("non-detect")

Table B-1-3
Analytical Results for Fluid Management Plan Confirmatory Samples from
Sump #1 (Unlined) at Well ER-20-11

Analyte	Analytical Method ^a	Detection Limit	Sample Number 103-091212-1		Sample Number 103-091212-2 Duplicate	
			Total	Dissolved	Total	Dissolved
Metals (milligrams per liter)						
Arsenic	SW-846 6010 ^b	0.01	0.011 J+	0.01 U	0.014 J+	0.01 U
Barium		0.1	0.1 U	0.1 U	0.1 U	0.1 U
Cadmium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Chromium		0.01	0.019	0.01 U	0.018	0.01 U
Lead		0.003	0.021	0.003 U	0.022	0.003 U
Selenium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Silver		0.01	0.0028 J-	0.01 U	0.0024 J-	0.01 U
Mercury	SW-846 7470 ^b	0.0002	0.00025 J	0.0002 U	0.00022 J	0.0002 U
Radiological Indicator Parameters (picocuries per liter)						
		MDC ^c	Result	Error	Result	Error
Tritium	EPA 906.0 ^d	1,000, 1,000	123,000	19,000	123,000	19,000
Gross Alpha	EPA 900.0 ^d	2.00, 2.10	10.1	2.70	5.6	1.90
Gross Beta		2.70, 2.70	14.6	3.10	10	2.50

Samples collected September 12, 2012

Source: N-I (2013)

^a For commercial laboratory analysis, the most current EPA or equivalent accepted standard laboratory analytical methods may be used as appropriate to attain specified detection limits. Analyses were performed by ALS Laboratory Group.

^b EPA (2012)

^c MDC varies by matrix, instrument, and count rates. Where two detection limits are given, the first corresponds with sample number 103-091212-1 and the second with 103-091212-2.

^d EPA (1980)

EPA: U.S. Environmental Protection Agency

FMP: Fluid Management Plan

MDC: Minimum detectable concentration

J+: Result is estimated bias high

J-: Result is estimated bias low

U: Compound was analyzed for but was not detected ("non-detect")

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Table B-1-4
Fluid Disposition Reporting Form for Well ER-20-11

Site Identification: **Well ER-20-11**
 Site Location: **Nevada National Security Site**
 Site Coordinates: (UTM NAD 27, Zone 11) **N 4,116,550.43 m, E 545,778.61 m**
 Well Classification: **ER Hydrogeologic Investigation Well**
 N-I Project No: **UG12-425**

Report Date: **January 15, 2013**
 NNSA/NSO UGTA Activity Lead: **Bill Wilborn**
 N-I Project Manager: **Sam Marutzky**
 N-I Site Representative: **Jeff Wurtz**
 N-I Field Environmental Specialist: **Mark Hesser**

Well Construction Activity	Activity Duration		#Ops. Days ^a	Well Depth (m)	Import Fluid (m ³)	Sump #1 Volumes (m ³)		Sump #2 Volumes (m ³)		Infiltration Area ^c (m ²)		Other ^d (m ³)	Fluid Quality Objective Met?
	From	To				Solids ^b	Liquids	Solids ^b	Liquids		Liquids		
Phase I: Vadose-Zone Drilling	09/01/2012	09/04/2012	4	504.60	310	113	143	N/A	N/A	N/A	N/A	N/A	Yes
Phase I: Saturated-Zone Drilling	09/08/2012	09/09/2012	1	915.57	165	49	1,138	N/A	N/A	N/A	N/A	N/A	Yes
Phase II: Initial Well Development	--	--	--	--	--	--	--	--	--	--	--	--	--
Phase II: Aquifer Testing	--	--	--	--	--	--	--	--	--	--	--	--	--
Phase II: Final Development	--	--	--	--	--	--	--	--	--	--	--	--	--
Cumulative Production Totals to Date:			5	915.57	475	162	1,281	N/A	N/A	N/A	N/A	N/A	N/A

^a Operational days refer to the number of days that fluids were produced during at least part (>3 hours) of one shift.

^b Solids volume estimates include calculated added volume attributed to rock bulking factor.

^c Discharge to an NDEP-approved infiltration area as defined in the Final Well-Specific Fluid Management Strategy for UGTA Well ER-20-11.

^d Other refers to fluid conveyance to other fluid management devices or facilities; e.g., baker tank or transported to another well site for storage.

N/A = Not applicable; m = Meter; m³ = Cubic meter

Total Facility Capacities (at 8 ft fluid level): Sump # 1 (unlined) = 1,547 m³ Sump #2 (unlined) = 1,547 m³ Infiltration Area (assuming very low/no infiltration) = N/A

Remaining Facility Capacity (Approximate) as of 09/20/2012: Sump #1 (unlined) = 559 m³ Sump #2 (unlined) = 1,547 m³

Sump #1 FMP samples were 123,000 pCi/L for tritium.

Notes: Sump #1 did not discharge to the approved infiltration area.

N-I Authorizing Signature/Date:

1-15-13

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Appendix B-2
Final Well Specific Fluid Management Strategy for UGTA
Well ER-20-11, Area 20, Nevada National Security Site
(8 pages)

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FINAL
WELL SPECIFIC FLUID MANAGEMENT STRATEGY
FOR UGTA WELL ER-20-11 AREA 20, NEVADA NATIONAL SECURITY SITE

August 29, 2012

INTRODUCTION

The U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Site Office (NNSA/NSO), Underground Test Area Project (UGTA) is proposing to drill and construct hydrologic investigation Well ER-20-11 as part of the Pahute Mesa Phase II Drilling Initiative. The program of hydrologic investigations is to be conducted in accordance with the Nevada Division of Environmental Protection (NDEP) approved Phase II Corrective Action Investigation Plan for Western and Central Pahute Mesa, CAU 101 and 102 (NNSA/NSO 2009a). The planned Well ER-20-11 is located in the area of Western Pahute Mesa on lands of the Nevada National Security site (NNSS), proximal to the northwestern boundary of the NNSS, in NNSS operable Area 20. The purpose of the drilling and construction of Well ER-20-11 is to acquire geologic, hydrologic and groundwater chemistry data from an area located to the south and southwest of areas of historic underground nuclear testing. The acquisition of data from this planned well location will be used to further develop flow and contaminate transport models of the area. This well specific fluid management strategy letter describes the monitoring and management of fluids generated during the drilling, well development, testing and sampling of the well in accordance with the requirements of the Fluid Management Plan (FMP) for the Underground Test Area Project, Rev 5., (NNSA/NSO 2009b).

Well ER-20-11 is a planned hydrogeologic investigation well to be drilled and constructed by the NNSA/NSO, UGTA project as part of the Pahute Mesa Phase II drilling initiative. Well ER-20-11 was sited by the Pahute Mesa Technical Advisory Team in 2011 to better examine hydrogeologic conditions and the nature and extent of radionuclide contamination encountered in recently drilled and nearby Wells ER-EC-11 and ER-20-8. The purpose of Well ER-20-11 is to provide additional scientific data regarding the hydrogeologic character of the subsurface in an area that is interpreted to be down gradient from the sites of past underground nuclear testing principally at Benham (U-20c) and Tybo (U-20y). Pahute Mesa Phase I hydrogeologic investigation wells were drilled and constructed in 1998 and 1999 as part of the Phase I investigation of Corrective Action Units 101 and 102, Western and Central Pahute Mesa (DOE 1998). Additional wells were constructed in 2009 and 2010 as part of Phase II investigations (NNSA/NSO 2009a). Figure 1 shows the location of planned Well ER-20-11 relative to other existing wells that were drilled and completed as part of the Phase I and Phase II investigations of Corrective Action Units 101 and 102, Western and Central Pahute Mesa (DOE 1998). Figure 2 provides an orthophoto view of the planned Well ER-20-11 location, showing the general physiographic character of the area and the proposed infiltration area. The planned completed depth of Well ER-20-11 is approximately 899.2 meters (2,950 ft), below ground surface (bgs) with the predicted water table located at an approximate depth of 504 m (1,654 ft) bgs.

There is potential for encountering radionuclide contamination exceeding the SDWA for tritium (20,000 pCi/L) in groundwater resulting from fluid generating activities associated with well drilling, well construction, well pumping, hydraulic testing, monitoring and sampling activities. This is based on the results of the groundwater generated during drilling and aquifer testing at Wells ER-EC-11 and ER-20-8. Well ER-EC-11 located approximately 884 m (2900 ft) west-northwest west of Well ER-20-11 encountered tritium in groundwater within the Benham Aquifer (BA) with reported concentrations during drilling averaging 14,409 pCi/L. Well ER-20-8 is located approximately 1,030 m (3,381 ft) east of Well ER-20-11 also encountered tritium during drilling with tritium concentrations observed in field monitoring averaging 4,750 pCi/L over the interval of the BA. Well ER-20-11 is located in an area believed to be downgradient of two principal underground tests. The Well ER-20-11 is located 2.97 km (1.849 mi) south-southwest of the TYBO (U-20y) test with an announced yield of 200-1,000 kt and 4.14 km (2.575 mi) south-southwest of the BENHAM (U-20c) underground nuclear test with an announced yield of 1.15 Mt (DOE 2000b). Both these underground tests were detonated below the water table and radionuclides from the tests have been identified in the BA at Wells ER-20-7 and ER-20-5 #1.

Based on the present understanding of the groundwater flow and transport model, and the tritium encountered in groundwater at nearby wells ER-20-8 and ER-EC-11, the radionuclide concentrations to be encountered within the groundwater at Well ER-20-11 may exceed the SDWA limit for tritium (20,000 pCi/L). However it is not expected that tritium concentrations in groundwater will exceed 400,000 pCi/L. This knowledge supports the conductance of Well ER-20-11 well drilling, construction, pumping and monitoring under a FMP Far-field fluid management strategy. In the case that contaminated groundwater in excess of the FMP criteria for Far-field operations (tritium in excess of 400,000 pCi/L) on the NNSS were encountered the site operations would be transitioned to a FMP Near-field strategy for operations on the NNSS.

Figure 1
Well ER-20-11 Location Map

Figure 2
Orthophoto Map of Proposed Well ER-20-11 Showing Proposed Infiltration Area

BACKGROUND AND ANALYTICAL DATA FROM NEARBY WELLS

As shown in Figure 1, several existing wells are in the vicinity of the Well ER-20-11 location. The following provides a summary of the two closest wells and their groundwater chemistry. These wells generally provide background analytical data for groundwater that is contained within volcanic aquifers near or at the water table.

Well ER-EC-11: The ER-EC-11 well was drilled in 2009 as part of the Pahute Mesa Phase II Drilling Initiative. Well ER-EC-11 was drilled to a depth of 1,264 m (4,148 ft) and completed with two cased completion intervals, one within the Tiva Canyon Aquifer (TCA) and the Topopah Springs Aquifer (TSA). Well ER-EC-11 is located on the NTTR within the eastern portion of the EC-South portion of the range, approximately 884 m (2900 ft) west-northwest of the Well ER-20-11. Drilling at Well ER-EC-11 was conducted under a Far-field FMP strategy. During drilling, on-site monitoring indicated tritium in excess of the Minimum Detectable Activity (MDA) within the Benham Aquifer (BA) and the upper portion of the TCA. Tritium concentrations averaged 14,409 pCi/L within these aquifers between depths of 828.75 – 979.01 m (2,719 and 3,212 ft bgs). Subsequent well development and sampling did not detect tritium or other parameters in excess of the FMP criteria. Well ER-EC-11 was sampled for all FMP parameters and met the FMP criteria for discharge to a unlined sump or designated infiltration area. The results of the most recent laboratory analysis of groundwater from ER-EC-11 are shown in Exhibit 1.

Wells ER-20-8 and ER-20-8 #2: Wells ER-20-8 and ER-20-8#2 were drilled in 2009 as part of the Pahute Mesa Phase II Drilling Initiative. These wells were drilled to depths 1,409.2 m (3,442.25 ft) bgs and 7812.8 m (2,338.62 ft) bgs, respectively within Tertiary volcanics. Well ER-20-8 is located approximately 1,030.5 m (3,381 ft) east of the Well ER-20-11 location and Well ER-20-8#2 is located approximately 1,014.8m (3,329.64 ft) from the Well ER-20-11 location. Drilling at Wells ER-20-8 and ER-20-8 #2 was conducted under a Far-field FMP strategy. Tritium was encountered in Well ER-20-8 when drilled in excess of the SDWA limit for tritium (20,000 pCi/L), with reported field screening results for tritium of averaging 4,750 pCi/L over the depth intervals of 509 – 719 m (1,670 – 2,362 ft bgs) within the BA and Scrugham Peak Lava Flow (SPLA) Aquifer. The highest reported tritium screening result was at 2,011 ft bgs where a tritium concentration of 97,182 pCi/L was reported. Well ER-20-8#2 although only located 15.84 m (52 ft) west of Well ER-20-8 did not encounter anomalous tritium. The average tritium concentration within the saturated BA and SPLA Aquifers was 2,234.6 pCi/L. Both wells were sampled for all FMP parameters and met the FMP criteria for discharge to an unlined sump or designated infiltration area. The results of the most recent laboratory analysis of groundwater from Well ER-20-8 are shown in Exhibit 1.

WELL OPERATIONS STRATEGY

Based on the information presented above, it is proposed that fluid generating activities related to drilling, well construction, pumping and sampling at Well ER-20-11 will be conducted using the Far-field well site operations strategy for wells located on the NNSS as specified in the FMP. This strategy may be transitioned to a Near-field strategy based on results of on-site monitoring as specified in the FMP and detailed below.

Fluid Containment and Discharge Criteria- The NNSA/NSO proposes the following fluid containment and discharge strategy for Well ER-20-11:

- Fluids or groundwater generated from the well during drilling, well construction, well pumping and sampling will be routed from the well through a well head, well head manifold, through a flow line (drilling) or flexible piping (pumping operations) and discharged to an unlined sump constructed on the Well ER-20-11 drill pad based on the FMP discharge criteria for wells located on the NNSS.
- In the event that on-site monitoring results do not exceed the FMP Far-field criteria for tritium (400,000 pCi/L) for wells located on the NNSS, operations will be conducted under a FMP Far-field operational strategy and both the unlined sumps may be utilized to contain generated fluids.
- Fluids that do not exceed the FMP criteria for tritium (400,000 pCi/L) for wells located on the NNSS may also be discharged or conveyed from the existing unlined sumps to a designated posted (or fenced) infiltration area as shown in Figure 2. Fluids will be routed and discharged to this infiltration area in a manner that minimizes the degradation or erosion of the natural ground surface.
- In the event that on-site monitoring results exceed the FMP Far-field criteria for tritium (400,000 pCi/L) for wells located on the NNSS, operations are to be conducted under a FMP Near-field operational strategy. Fluids generated will be contained within an on-site lined sump.
- In the unlikely case that on-site fluid containment capacity (lined sump) may be exceeded under a Near-field operational strategy well site operations will be suspended until sufficient suitable fluid storage can be made available.

On-Site Monitoring – In accordance with the FMP, tritium monitoring samples will be collected from the discharge line during fluid generating activities. Tritium monitoring samples at a minimum will be collected and analyzed hourly during drilling operations, except during periods where the borehole is not being advanced (e.g. circulating, well construction etc.). The results of on-site tritium monitoring will be compared to the FMP discharge criteria as results are available. For other fluid or groundwater generating well activities, tritium monitoring samples will be collected from the discharge line and analyzed on a daily basis.

In accordance with the FMP, lead monitoring samples will be collected during drilling from the discharge and analyzed every eight hours if tritium monitoring results exceed 200,000 pCi/L. The results of on-site lead monitoring will be compared to the FMP discharge criteria as results are available.

Notifications – NDEP will be notified of on-site monitoring results that exceed action levels as specified in the FMP.

Exhibit 1

Analytical Data for Wells ER-EC-11 and ER-20-8

Analysis Performed	ER-EC-11 ^a	ER-20-8 ^b
(mg/l)		
Aluminum	0.2 U	200
Arsenic	0.098	0.056J
Barium	0.4 J	100
Cadmium	0.003 U	0.003U
Calcium	3.9	2.09
Chloride	43	33
Chromium	0.0050	0.0050
Fluoride	3.09	3.79 J
Iron	0.049 J	0.010
Lithium	0.0017J	0.0095J
Lead	0.008 U	0.0012
Magnesium	0.013 U	1
Manganese	0.0027J	0.010
Mercury	0.0009 U	0.0009U
Potassium	0.75J	2.40 J
Selenium	0.003 U	0.003 U
Silicon	19	25.0 J
Silver	0.001 U	0.001 U
Sodium	95	52.7
Strontium	0.0030	0.0022 J
Sulfate	70	49 J
Total Organic Carbon	0.11 U	1
²³⁸ U	0.16 U	0.025
Alkalinity (as CaCO ₃)	120	120
Specific Conductance (μmhos/cm)	538	430
pH (SU)	8.5 J	8.5 J
Total Dissolved Solids	330	280
Radionuclides (pCi/L)		
Gross Alpha	2.4 U	4.09
Gross Beta	0.1 U	3.79 U
⁹⁹ Tc	0.3 U	2.5 U
Tritium	-80 U	3,020 U
⁹⁰ Sr	0.109 U	0.23 U
²³⁸ Pu	-0.004 U	0.001 U

Source: N-I, 2012

^a Composite GWC sample collected by SNJV on 05/18/2010.

^b Composite GWC sample collected by N-I on 06/27/2011.

^c Specific conductance reported in S/cm.

J = Estimated value.

U = Compound was analyzed for, but was not detected ("Non-detect").

UJ = Compound was Non-detect, but result is biased low.

SU = Standard unit

μmhos/cm = Micromhos per centimeter

S/cm = Microsiemens per centimeter

CaCO₃ = Calcium carbonate

Appendix C
Waste Disposition Data for Well ER-20-11

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Table C-1
Final Waste Disposition for Well ER-20-11 Drilling Operations

Container ID Number	Contents	Container Type and Size liters (gallons)	Estimated Volume liters (gallons)	Disposition	Status/Comments
ER-20-11-01	Hydrocarbon solids; absorbent pads, absorbent, used fuel and oil filters	Open-top steel drum 208.2 (55)	189.3 (50)	Transferred to UGTA Building 6-909 on 09/15/2012	Temporary storage pending disposal
ER-20-11-02	Used oil	Closed-top steel drum 208.2 (55)	132.5 (35)	Transferred to UGTA Building 6-909 on 09/15/2012	Temporary storage pending disposal
ER-20-11-03	Used synthetic oil	Closed-top steel drum 208.2 (55)	79.5 (21)	Transferred to UGTA Building 6-909 on 09/15/2012	Temporary storage pending disposal
ER-20-11-04	Hydrocarbon solids; absorbent pads, absorbent, hydrocarbon stained soil, used oil filters	Open-top steel drum 208.2 (55)	189.3 (50)	Transferred to UGTA Building 6-909 on 09/19/2012	Temporary storage pending disposal
ER-20-11-05	Hydrocarbon solids; absorbent	Open-top steel drum 208.2 (55)	189.3 (50)	Transferred to UGTA Building 6-909 on 09/19/2012	Temporary storage pending disposal
ER-20-11-06	Oily condensate from compressors	Condensate tank 7,570.8 (2,000)	4,163.5 (1,100)	Drained by NSTec on 09/21/2012	Area 12 Surface Impoundment
ER-20-11-07	Hydrocarbon solids; absorbent pads	Open-top steel drum 208.2 (55)	56.8 (15)	Transferred to UGTA Building 6-909 on 09/22/2012	Temporary storage pending disposal
Total Waste Containers					
Hydrocarbon solids: 4					
Used oils (liquid): 2					
Total number of 208.2-liter (55-gallon) waste containers: 6					
Total number of 7,570.8-liter (2,000-gallon) waste containers: 1					

Source: N-I (2013)

ID = Identification

NSTec = National Security Technologies, LLC

Building 6-909 is located in Area 6 of the Nevada National Security Site.

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Appendix D
Detailed Lithologic Log for Well ER-20-11

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Table D-1
Detailed Lithologic Log for Well ER-20-11
 Logged by Heather Huckins-Gang, National Security Technologies, LLC, January 2013

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples ^b meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
0–15.2 (0–50)	15.2 (50)	none	none	Nonwelded and Bedded Tuff: Cuttings were not collected during conductor hole drilling, and interval was not logged before running casing. Stratigraphic and lithologic determination is based on geologic map description and site reconnaissance. Basal depth uncertain.	Beatty Wash Formation (Tfb)
15.2–36.6 (50–120)	21.3 (70)	DB1	none	Nonwelded to Partially Welded Ash-Flow Tuff: Moderate brown (5YR 4/4); mostly devitrified, some vapor phase mineralization; abundant vitric pumice, white, moderate brown (5YR 4/4), dark yellowish orange (10YR 6/6), and light brown (5YR 5/6), some pumice is devitrified with vapor phase mineralization; minor felsic phenocrysts, including subhedral quartz and feldspar; common biotite; minor lithic fragments.	mafic-rich Ammonia Tanks Tuff (Tmar)
36.6–46.3 (120–152)	9.8 (32)	DB1	none	Nonwelded Ash-Flow Tuff: Dark yellowish orange (10YR 6/6) to light brown (5YR 5/6), vitric; abundant dark yellowish orange pumice and glass shards; minor quartz and feldspar phenocrysts; rare biotite; minor lithic fragments. Lithic fragments are abundant between 44.8 and 46.3 m (147 and 152 ft) as delineated on density log.	mafic-poor Ammonia Tanks Tuff (Tmap)
46.3–77.4 (152–254)	31.1 (102)	DB1	none	Bedded Tuff: White (N9) and vitric, with subhedral dipyrarnidal quartz, abundant sand-sized lithic fragments, some surrounded by silicification. Also abundant dark yellowish orange (10YR 6/6) to moderate yellowish brown (10YR 5/4) and light brown (5YR 5/6) vitric pumice; chatoyant sanidine noted; rare to minor biotite. Cuttings are very mixed and enriched in hard components. Interval may include lapilli tuff.	bedded Ammonia Tanks Tuff (Tmab)

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
77.4–106.7 (254–350)	29.3 (96)	DA	none	Pumiceous Rhyolite Lava: Light olive gray (5Y 6/1) to yellowish gray (5Y 8/1), vitric. Pumiceous texture is fibrous in places, perlitic in others; minor feldspar and quartz phenocrysts; scarce biotite; sphene noted. Below about 95.1 m (312 ft) becomes dark yellowish brown (10YR 4/2) and denser, with occasional spherulites.	rhyolite of Tannenbaum Hill (Tmat)
112.8–168.9 (350–554)	62.2 (204)	DA	none	Stoney Rhyolite Lava: Grayish brown (5YR 3/2), devitrified, with light gray and light bluish gray silicified bands in places. Minor felsic phenocrysts, including quartz and chatoyant sanidine; rare biotite. Secondary chalcedony/opal noted. Flow banding discernable in places.	
168.9–292.6 (554–960)	123.7 (406)	DA	none	Stoney Rhyolite Lava: Brownish gray (5YR 4/1), devitrified, with bands of light brownish gray (5YR 6/1) to medium light gray (N/6) vitric lava and rare spherulites; minor felsic phenocrysts, including quartz; rare biotite. Below 219.5 m (720 ft), pale brown (5YR 5/2) to grayish brown (5YR 3/2), mottled with light brownish gray (5YR 6/1) and pale red (10R 6/2), still containing small lenses of the gray vitric lava. Some brownish black vitric (perlitic vitrophyric) fragments noted below 277.4 m (910 ft).	
292.6–321.9 (960–1,056)	29.3 (96)	DB1	none	Vitrophyric Rhyolite Lava: Brownish black (5YR 2/1), perlitic structure; rare felsic phenocrysts; rare biotite.	
321.9–329.2 (1,056–1,080)	7.3 (24)	DA	none	Basal Flow Breccia: Moderate brown (5YR 4/4) to dark yellowish brown (10YR 4/2), vitric to devitrified and silicified, with vitrophyric inclusions. Rare felsic phenocrysts, including quartz; rare biotite. Transition zone at base of vitrophyre.	
329.2–347.5 (1,080–1,140)	18.3 (60)	DA	none	Basal Flow Breccia: Pale brown (5YR 5/2); devitrified with abundant angular to round, sand-sized, dense, devitrified fragments (in contrast to lighter-colored matrix), porous with visible shard outlines; common felsic phenocrysts, including quartz and feldspar; minor biotite. Contains some vugs lined with drusy crystals. Below 338.3 m (1,110 ft) cuttings exhibit corroded porosity with sucrosic, vapor-phase-like character.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
347.5–380.4 (1,140–1,248)	32.9 (108)	DA	none	Bedded Tuff: Pale brown (5YR 5/2), weakly zeolitic above 355.1 m (1,165 ft), pervasively zeolitized below, remnant shards and shard casts (porosity) reminiscent of corroded vapor-phase mineralization; rare eroded orange and pink pumice becoming slightly more common toward base of interval; minor felsic phenocrysts including quartz (some subhedral dipyrimal) and feldspar; minor biotite; rare lithic fragments, increasing to minor near base of interval. At 362.7 m (1,190 ft) mottled with reddish orange (10R 6/6).	rhyolite of Tannenbaum Hill (Tmat)
380.4–393.2 (1,248–1,290)	12.8 (42)	DA	none	Nonwelded Tuff: Moderate brown (5YR 6/4), zeolitic; common light brown pumice with corroded appearance reminiscent of vapor-phase mineralization; common felsic phenocrysts, including quartz and feldspar; minor biotite; minor small dark red lithic fragments.	
393.2–420.6 (1,290–1,380)	27.4 (90)	DA	none	Nonwelded Tuff: Light brown (5YR 6/4 to 5YR 5/6) to pale reddish brown (10R 5/4); zeolitic; abundant pumice, moderate reddish brown (10R 4/6) to moderate reddish orange (10R 6/6), also yellowish, corroded, sucrosic pumice reminiscent of vapor phase; common felsic phenocrysts, including quartz; common biotite; common lithic fragments, decreasing toward base of interval. Upper contact gradational.	
420.6–429.8 (1,380–1,410)	9.1 (30)	DA	429.8 (1,410)	Bedded Tuff: Grayish orange (10YR 7/4) to pale reddish brown (10R 5/4) and moderate reddish brown (10R 4/6); zeolitic; common grayish yellow (5Y 8/4) and light red (5R 6/6) pumice, some zeolitic, some reminiscent of vapor phase; common felsic phenocrysts, including quartz, minor to common biotite. Opaque minerals and sphene are present. Minor to common lithic fragments. Rare silicified beds or lenses.	
429.8–438.9 (1,410–1,440)	9.1 (30)	DA	none	Moderately to Densely Welded Ash-Flow Tuff: Grayish red (10R 4/2), pale brown (5YR 5/2) where less welded; devitrified; minor light gray pumice, silicified in places, rare vapor phase in upper part of interval; abundant felsic phenocrysts and biotite, clinopyroxene noted; rare lithic fragments. Higher density on density log. Possible fault at base.	mafic-rich Rainier Mesa Tuff (Tmrr)

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
438.9-451.1 (1,440-1,480)	12.2 (40)	DB4	438.9 (1,440)	Nonwelded Ash-Flow Tuff: Pale yellowish brown (10YR 6/2) to light brown (5YR 6/4), zeolitic; minor to common pumice, yellowish, pinkish, and same color as rock matrix, zeolitic with some vapor-phase alteration; common felsic phenocrysts, including quartz; abundant biotite, some altered; minor lithic fragments. Poorly represented in cuttings samples.	mafic-rich Rainier Mesa Tuff (Tmrr)
451.1-471.2 (1,480-1,546)	20.1 (66)	DA	none	Partially Welded Ash-Flow Tuff: Pale reddish brown (10R 5/4), devitrified; abundant zeolitic white (N9) to yellowish gray (5Y 8/1) pumice; minor felsic phenocrysts, including quartz; minor to common mafic minerals, including biotite; rare lithic fragments. Near base of interval becomes light brown (5YR 6/4); devitrified, pumice shows vapor-phase alteration, and felsic phenocrysts increase to common to abundant.	
471.2-490.1 (1,546-1,608)	18.9 (62)	DA	472.4 (1,550)	Nonwelded Ash-Flow Tuff: Light brown (5YR 6/4) to moderate reddish orange (10R 6/6), zeolitic; abundant zeolitic pumice, white (N9) to yellowish gray (5Y 8/1); minor to common felsic phenocrysts, including quartz; minor to common biotite, rare lithic fragments. Possibly bedded Rainier Mesa Tuff at 485.2 to 490.1 m (1,592 to 1,608 ft). Possible fault at 471.2 m (1,546 ft).	
490.1-502.9 (1,608-1,650)	12.8 (42)	DA	none	Nonwelded Tuff: Grayish orange (10YR 7/4) to very pale orange (10YR 8/2), zeolitic; minor white to grayish yellow (5Y 8/4) and lesser moderate orange pink (10R 7/4) zeolitic pumice; minor to common felsic phenocrysts; common biotite; minor lithic fragments.	rhyolite of Fluorspar Canyon (Tmrf)
502.9-525.8 (1,650-1,725)	22.9 (75)	DA	none	Nonwelded Tuff: Light brown (5YR 6/4), zeolitic; abundant to very abundant white (N9), zeolitic pumice; rare to minor felsic phenocrysts, including quartz; minor biotite, magnetite noted; rare to minor lithic fragments.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
525.8–537.1 (1,725–1,762)	11.3 (37)	DA	none	Bedded Tuff: Grayish yellow (5Y 8/4), moderate reddish orange (10R 6/6) (reworked tuff), and pale yellowish brown (10YR 6/2), zeolitic with silicified patches; white to yellow zeolitic pumice, varying in abundance with bedding. Felsic phenocrysts are rare to minor, varying with bedding, and include quartz; mafic minerals, including biotite, are rare to common, varying with bedding; lithic fragments are rare to minor, but conspicuous.	rhyolite of Fluorspar Canyon (Tmrf)
537.1–576.1 (1,762–1,890)	39.0 (128)	DA	557.8 (1,830)	Nonwelded Tuff: Very pale orange (10YR 8/2) to grayish orange pink (5YR 7/2), zeolitic, with rare silicified patches; common moderate orange pink (10R 7/4) and white (N9) zeolitic pumice up to 1.5 centimeters; rare felsic phenocrysts, including quartz; rare biotite; rare to minor, but conspicuous, lithic fragments. Possible fault seen at 537.4 m (1,763 ft) on image log.	
576.1–586.1 (1,890–1,923)	10.1 (33)	DB4	none	Bedded and Reworked Tuff: Moderate orange pink (10R 7/4) to moderate reddish orange (10YR 8/2), zeolitic; abundant rounded zeolitic pumice (some with corrosion reminiscent of vapor-phase alteration; some possibly argillic); felsic phenocrysts, including quartz, are rare to minor, varying with bedding; minor to rare biotite; rare to common sand-sized lithic fragments.	
586.1–602.6 (1,923–1,977)	16.5 (54)	DA	161.6 (1,990) ^d	Nonwelded Tuff: Moderate orange pink (5YR 8/4) to light brown (5YR 6/4), zeolitic; very abundant, zeolitic, very pale orange (10YR 8/2) to white pumice (some with corrosion reminiscent of vapor-phase alteration); rare to minor felsic phenocrysts; rare biotite; rare to minor lithic fragments.	
60.26–637.6 (1,977–2,092)	35.1 (115)	DA	none	Bedded Tuff: Yellowish gray (5Y 7/2) and moderate reddish orange (10YR 8/2), zeolitic; rare to common zeolitic pink and yellow pumice (some with corrosion reminiscent of vapor-phase alteration); rare to common felsic phenocrysts varying with bedding, including subhedral quartz crystals to 3 millimeters and unaltered feldspar; minor to common mafic minerals, biotite and magnetite; rare to minor lithic fragments.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
637.6–657.5 (2,092–2,157)	19.8 (65)	DA	none	Nonwelded Tuff: Moderate orange pink (10R 7/4) to moderate reddish orange (10R 6/6), zeolitic, silicified in places, especially near lithic fragments; common very pale orange (10YR 8/2) zeolitic and lesser silicified pumice; rare to minor felsic phenocrysts including quartz and unaltered feldspar; rare biotite; rare to common lithic fragments.	rhyolite of Fluorspar Canyon (Tmrf)
657.5–675.1 (2,157–2,215)	17.7 (58)	DA	673.6 (2,210)	Bedded Tuff: Grayish orange (10YR 7/2) and moderate reddish brown (10R4/6) to moderate reddish orange (10R 6/6), zeolitic; rare to abundant grayish yellow (5Y 8/4) and lesser grayish pink (5R 8/2) pumice; rare to minor felsic phenocrysts, including quartz and feldspar; minor biotite; rare lithic fragments, increasing toward base of interval. Possible fault dipping 74 degrees to the south seen at 675.1 m (2,215 ft) on image log.	
675.1–685.8 (2,215–2,250)	10.7 (35)	DA	none	Bedded Tuff: Dark reddish brown (10R 3/4), zeolitic and quartz-feldspathic alteration; very abundant white (N9) to grayish orange pink (10R 8/2) zeolitic pumice; common felsic phenocrysts of quartz, milky to chalky feldspar, and rare unaltered feldspar; rare mafic minerals, including biotite; rare lithic fragments.	Timber Mountain Group, undivided (Tm)
685.8–718.1 (2,250–2,356)	32.3 (106)	DA	691.9 (2,270)	Bedded Tuff: Light brown (5YR 6/4) to pale yellowish brown (10YR 6/2), zeolitic; abundant very pale orange (10YR 8/2) to dark yellowish orange (10YR 6/6) zeolitic pumice; common felsic phenocrysts of quartz and feldspar; minor mafic minerals including biotite, magnetite, and hornblende; trace sphene and clinopyroxene; rare lithic fragments. Below 716.3 m (2,350 ft), becomes pale reddish brown (10R 5/4) to moderate yellowish brown (10YR 5/4) with grayish orange (10YR 7/4) pumice, increasing lithic fragments and/or silicified patches.	rhyolite of Windy Wash (Tpw)

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
718.1–752.9 (2,356–2,470)	34.7 (114)	DA	755.9 (2,480) ^d	Bedded Tuff: Moderate brown (5YR 3/4) to light brown (5YR 5/6), zeolitic and quartz-feldspathic alteration; abundant pale yellowish orange (10YR 8/6) to dark yellowish orange (10YR 6/6) zeolitic pumice, becoming common near base of interval; minor felsic phenocrysts, including unaltered feldspar; common biotite; minor lithic fragments. Also includes moderate reddish brown (10R4/6) bedded tuff with zeolitic and quartz-feldspathic alteration; abundant white, yellowish, and pinkish zeolitic pumice, minor felsic phenocrysts, including altered and unaltered feldspar and quartz; minor biotite and rare lithic fragments.	rhyolite of Windy Wash (Tpw)
752.9–761.4 (2,470–2,498)	8.5 (28)	DA	none	Bedded Tuff: Grayish orange (5Y 7/6), zeolitic and quartz-feldspathic alteration with few reddish brown (10R 3/4) silicified patches; minor very pale orange (10YR 8/2) zeolitic pumice; minor felsic phenocrysts, including quartz; common biotite; rare lithic fragments.	
761.4–772.1 (2,498–2,533)	10.7 (35)	DA	none	Bedded Tuff: Pale reddish brown (10R 5/4) to moderate reddish orange (10R 6/6) with moderate reddish brown (10R 4/6) bands, quartz-feldspathic alteration; common felsic phenocrysts, including altered feldspar, lesser quartz and unaltered feldspar; common biotite; minor lithic fragments, except in a few beds where they are concentrated. Basal contact dips 9 degrees to the south-southwest.	rhyolite of Benham (Tpb)
772.1–797.1 (2,533–2,615)	25.0 (82)	DA	780.3 (2,560)	Pumiceous Rhyolite Lava: Moderate yellow (5Y 7/6) to dusky yellow (5Y 6/4) near base of unit; zeolitic with minor quartz-feldspathic alteration; includes grayish red (10R 4/2) silicified lenses that increase in abundance with depth; minor felsic phenocrysts, mostly unaltered feldspar (feldspar is altered in and near silicified patches); minor to common biotite.	

Depth Interval meters (feet)	Thickness meters (feet)	Sample Type ^a	Depth of Analytical Samples meters (feet)	Lithologic Description ^c	Stratigraphic Unit (Map Symbol)
797.1–823.0 (2,615–2,700)	25.9 (85)	DA	none	Vitrophryic Rhyolite Lava: Dark yellowish brown (10YR 4/2) to dusky brown (5YR 2/2), devitrified to vitric/perlitic (at 807.7 to 815.3 m [2,650 to 2,675 ft]); rare felsic phenocrysts, minor biotite. At base of unit there is a flow-banded transition zone consisting of inter-layered dark yellowish brown (10YR 4/2) vitric and grayish orange (10YR 7/4) devitrified lava.	rhyolite of Benham (Tpb)
823.0–903.1 (2,700–2,963)	80.2 (263)	DA	844.3 (2,770)	Stoney Rhyolite Lava: Very light gray (N8) to medium light gray (N6) and light brownish gray (5YR 6/1), devitrified, spherulitic in places near top of interval; rare to minor felsic phenocrysts; minor biotite. Darker in color with rare phenocrysts near base of interval. Image log reveals flow layering dipping approximately 45 degrees to the northeast.	
903.1–915.6 (2,963–3,004) Total depth	12.5 (41)	DA	911.4 (2,990)	Bedded Tuff: Light brown (5YR 6/4), zeolitic and quartzo-feldspathic alteration; minor to common yellow and reddish orange pumice; minor felsic phenocrysts, mostly unaltered feldspar; minor biotite; rare to minor volcanic lithic fragments.	

- a Lithologic samples collected from interval during drilling and logging operations and utilized for lithologic interpretation. **DA** = drill cuttings that represent lithologic character of interval; **DB1** = cuttings that are enriched in hard or light components; **DB4** = cuttings that are intimate mixtures of units; generally less than 50% of drill cuttings represent lithologic character of interval.
- 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 4-1 in this report for a complete list of samples analyzed.
- 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** = $\leq 1\%$; **minor** = 5%; **common** = 10%; **abundant** = 15%; **very abundant** $\geq 20\%$.
- Abundances for mafic minerals: **trace** = only one or two individuals observed; **rare** = $\leq 0.05\%$; **minor** = 0.2%; **common** = 0.5%; **abundant** = 1%; **very abundant** = $\geq 2\%$.
- d Sample is representative of the indicated interval rather than the interval corresponding with the depth due to drilling lag time.

Appendix E
Geophysical Logs Run in Well ER-20-11

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Appendix E contains plots of selected geophysical logs run in Well ER-20-11. Table E-1 summarizes the logs presented. See Table 4-2 for more information about geophysical logs. See Table 5-1 for key to stratigraphic unit symbols used on following log plots.

Table E-1
Well ER-20-11 Geophysical Logs Presented

Log Type	Run Number	Date	Log Interval	
			meters	feet
Caliper	CA6-1	9/5/2012	17.7–511.5	58–1,678
	CA6-2	9/10/2012	510.8–912.3	1,676–2,993
X-Multipole Array Acoustilog (sonic)	XMAC-1	9/10/2012	510.8–908.3	1,676–2,980
Gamma Ray	GR-1	9/5/2012	0–503.2	0–1,651
	GR-5	9/10/2012	476.4–905.9	1,563–2,972
Spectral Gamma Ray (potassium, thorium, uranium)	SGR-1	9/5/2012	0–503.2	0–1,651
	SGR-2	9/10/2012	476.4–905.9	1,563–2,972
High Definition Induction and R _t Explorer (resistivity)	HDIL-1	9/5/2012	17.7–509.3	58–1,671
	RTEX-1	9/10/2012	510.8–909.2	1,676–2,983
Density	ZDL-1	9/6/2012	17.7–510.8	58–1,676
	ZDL-2	9/10/2012	409.7–914.4	1,344–3,000
Compensated Neutron	CN-1	9/6/2012	17.7–510.8	58–1,676
	CN-2	9/10/2012	409.7–914.4	1,344–3,000
Temperature	TL-1	9/10/2012	382.2–915.2	1,254–3,002.5

Well ER-20-11

Logging Company: Baker Atlas

Date Logged: September 5, 6, and 10, 2012

Drilled Depth: 915.6 m (3,004 ft)

Date TD Reached: September 9, 2012

Drill Method: Rotary/Air foam

Surface Elevation: 1,778.2 m (5,834.0 ft)

Coordinates (UTM [NAD 83]): N 4,116,747.6 m

E 545,698.4 m

Water Level: 504.5 m (1,655.2) on September 26, 2012

Well ER-20-11

Logging Company: Baker Atlas

Date Logged: September 5 and 10, 2012

Drilled Depth: 915.6 m (3,004 ft)

Date TD Reached: September 9, 2012

Drill Method: Rotary/Air foam

Surface Elevation: 1,778.2 m (5,834.0 ft)

Coordinates (UTM [NAD 83]): N 4,116,747.6 m

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Well ER-20-11

Logging Company: Baker Atlas

Date Logged: September 5, 6, and 10, 2012

Drilled Depth: 915.6 m (3,004 ft)

Date TD Reached: September 9, 2012

Drill Method: Rotary/Air foam

Surface Elevation: 1,778.2 m (5,834.0 ft)

Coordinates (UTM [NAD 83]): N 4,116,747.6 m

E 545,698.4 m

Water Level: 504.5 m (1,655.2) on September 26, 2012

Appendix F
Water Production Data for Well ER-20-11

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Table F-1
Bromide Concentrations and Calculated Water Production during Drilling
at Well ER-20-11 (3 pages)

Date	Time	Depth Below Ground Surface		Bromide Concentration (milligrams per liter)		Injection Rate (barrels per hour)	Water Production ^a	
		meters	feet	Mixing Tank	Discharge Line		liters per minute	gallons per minute
09/01/2012	14:00	25.3	83	22.0	12.3	10	22.7	6
09/01/2012	20:00	44.2	145	13.5	11.3	10	3.8	1
09/02/2012	02:00	63.7	209	13.4	11.7	15	7.6	2
09/02/2012	06:00	102.7	337	45.7	42.4	15	3.8	1
09/02/2012	10:00	119.8	393	40.0	33.0	15	7.6	2
09/02/2012	14:00	144.2	473	34.2	33.6	15	0	0
09/02/2012	20:00	154.2	506	29.6	28.2	15	3.8	1
09/03/2012	00:00	192.6	632	27.9	25.9	15	3.8	1
09/03/2012	04:00	217.9	715	57.6	45.2	15	11.4	3
09/03/2012	08:00	240.2	788	44.8	38.9	15	7.6	2
09/03/2012	12:00	262.1	860	47.0	44.4	15	3.8	1
09/03/2012	16:00	278.3	913	9.46	12.2	15	-7.6	-2
09/03/2012	20:05	296.0	971	10.7	8.91	15	7.6	2
09/04/2012	00:10	310.0	1,017	20.1	17.8	15	3.8	1
09/04/2012	04:00	328.6	1,078	9.34	8.71	15	3.8	1
09/04/2012	08:00	350.8	1,151	9.41	9.24	15	0	0
09/04/2012	12:00	394.7	1,295	47.0	36.6	15	11.4	3
09/04/2012	16:00	441.0	1,447	15.5	16.6	15	-3.8	-1
09/04/2012	17:00	454.2	1,490	20.2	20.0	15	0	0
09/04/2012	18:00	462.7	1,518	19.9	17.2	15	7.6	2
09/04/2012	19:00	473.0	1,552	14.6	18.3	15	-7.6	-2
09/04/2012	20:00	481.6	1,580	16.1	12.6	15	11.4	3
09/04/2012	20:45	490.7	1,610	17.5	14.4	15	7.6	2
09/04/2012	21:25	499.9	1,640	59.8	17.2	15	98.4	26
09/04/2012	22:05	509.0	1,670	59.6	35.3	15	26.5	7
09/04/2012	22:45	518.2	1,700	60.5	45.7	15	11.4	3
09/04/2012	23:05	520.3	1,707	60.0	60.2	15	0	0
09/08/2012	00:30	525.8	1,725	21.2	12.1	15	30.3	8
09/08/2012	01:35	535.5	1,757	19.7	12.8	15	22.7	6
09/08/2012	02:35	550.5	1,806	69.8	49.6	15	15.1	4
09/08/2012	03:40	564.8	1,853	71.0	44.2	15	22.7	6
09/08/2012	04:40	579.4	1,901	74.6	50.3	15	18.9	5
09/08/2012	05:40	591.6	1,941	14.8	13.5	15	3.8	1
09/08/2012	06:25	602.3	1,976	13.0	11.1	15	7.6	2

Table F-1
Bromide Concentrations and Calculated Water Production during Drilling
at Well ER-20-11 (3 pages)

Date	Time	Depth Below Ground Surface		Bromide Concentration (milligrams per liter)		Injection Rate (barrels per hour)	Water Production ^a	
		meters	feet	Mixing Tank	Discharge Line		liters per minute	gallons per minute
09/08/2012	07:30	617.5	2,026	15.9	12.9	15	7.6	2
09/08/2012	08:30	630.0	2,067	18.7	16.5	15	3.8	1
09/08/2012	09:25	642.2	2,107	21.2	19.0	15	3.8	1
09/08/2012	10:30	662.0	2,172	20.6	22.1	15	-3.8	-1
09/08/2012	11:35	674.5	2,213	10.9	10.4	15	3.8	1
09/08/2012	12:30	686.1	2,251	10.1	10.4	15	0	0
09/08/2012	13:30	699.8	2,296	10.7	8.61	15	11.4	3
09/08/2012	14:30	711.7	2,335	11.7	13.2	15	-3.8	-1
09/08/2012	15:30	724.8	2,378	79.4	52.0	15	22.7	6
09/08/2012	16:30	735.8	2,414	82.6	61.6	15	15.1	4
09/08/2012	17:25	747.1	2,451	98.2	81.1	15	7.6	2
09/08/2012	18:20	759.0	2,490	116	60.8	15	37.9	10
09/08/2012	19:40	775.7	2,545	49.6	33.3	15	18.9	5
09/08/2012	20:30	783.9	2,572	44.4	34.6	15	11.4	3
09/08/2012	21:30	790.0	2,592	22.8	27.4	15	-7.6	-2
09/08/2012	22:30	798.0	2,618	19.4	16.7	15	7.6	2
09/08/2012	23:30	803.8	2,637	20.8	16.7	15	11.4	3
09/09/2012	00:30	809.2	2,655	27.0	17.1	15	22.7	6
09/09/2012	01:30	815.6	2,676	26.3	19.9	15	11.4	3
09/09/2012	02:30	823.9	2,703	25.2	15.1	15	26.5	7
09/09/2012	03:30	829.1	2,720	25.1	4.94	15	162.8	43
09/09/2012	04:30	834.8	2,739	26.8	3.86	15	234.7	62
09/09/2012	05:30	837.3	2,747	27.3	2.55	15	386.1	102
09/09/2012	06:20	841.2	2,760	26.0	3.28	15	276.3	73
09/09/2012	07:40	846.7	2,778	43.4	1.24	15	1,351.4	357
09/09/2012	08:30	851.9	2,795	44.1	1.98	15	844.1	223
09/09/2012	09:30	857.7	2,814	43.2	1.95	15	840.4	222
09/09/2012	10:30	863.5	2,833	57.6	1.57	15	1,419.5	375
09/09/2012	11:30	866.5	2,843	53.3	1.79	15	1,143.2	302
09/09/2012	12:30	875.7	2,873	57.9	1.74	15	1,283.3	339
09/09/2012	13:30	880.6	2,889	62.2	1.81	15	1,324.9	350
09/09/2012	14:30	886.1	2,907	56.5	1.51	15	1,446.0	382
09/09/2012	15:30	886.7	2,909	53.5	1.39	15	1,491.4	394
09/09/2012	16:30	890.3	2,921	59.5	0.916	15	2,543.8	672

Table F-1
Bromide Concentrations and Calculated Water Production during Drilling
at Well ER-20-11 (3 pages)

Date	Time	Depth Below Ground Surface		Bromide Concentration (milligrams per liter)		Injection Rate (barrels per hour)	Water Production ^a	
		meters	feet	Mixing Tank	Discharge Line		liters per minute	gallons per minute
09/09/2012	17:30	894.9	2,936	54.5	0.652	15	3,281.9	867
09/09/2012	18:30	896.7	2,942	58.4	1.48	15	1,529.3	404
09/09/2012	19:30	901.6	2,958	54.2	1.27	15	1,658.0	438
09/09/2012	20:40	907.4	2,977	66.1	1.57	15	1,635.3	432

Source: N-I (2013)

- a Calculated water production values above the water table are not indicative of water yield from the formation.

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Table F-2
Estimated Water Production during Drilling at Well ER-20-11 Based on Bromide Tracer
Data and Visual Data (4 pages)

Top of Interval (meters)	Base of Interval (meters)	Top of Interval (feet)	Base of Interval (feet)	Water Production Rate (liters/minute)	Water Production Rate (gallons/minute)	Date	Time
14.3	14.9	47	49	0	0	9/1/2012	1145
19.5	20.1	64	66	0	0	9/1/2012	1240
24.7	25.3	81	83	0	0	9/1/2012	1345
25.3	25.9	83	85	0	0	9/1/2012	1640
28.3	29.0	93	95	0	0	9/1/2012	1715
32.9	33.5	108	110	0	0	9/1/2012	1810
42.1	42.7	138	140	0	0	9/1/2012	2000
49.4	50.0	162	164	0	0	9/1/2012	2051
57.0	57.6	187	189	0	0	9/1/2012	2200
62.5	63.1	205	207	0	0	9/2/2012	200
74.4	75.0	244	246	0	0	9/2/2012	300
82.6	83.2	271	273	0	0	9/2/2012	355
94.2	94.8	309	311	0	0	9/2/2012	501
100.9	101.5	331	333	0	0	9/2/2012	600
110.9	111.6	364	366	0	0	9/2/2012	730
114.0	114.6	374	376	0	0	9/2/2012	830
117.3	118.0	385	387	0	0	9/2/2012	925
120.4	121.0	395	397	0	0	9/2/2012	1010
126.2	126.8	414	416	0	0	9/2/2012	1110
128.9	129.5	423	425	0	0	9/2/2012	1210
134.7	135.3	442	444	0	0	9/2/2012	1305
136.9	137.5	449	451	0	0	9/2/2012	1330
146.0	146.6	479	481	0	0	9/2/2012	1810
150.3	150.9	493	495	0	0	9/2/2012	1925
159.4	160.0	523	525	0	0	9/2/2012	2058
170.7	171.3	560	562	0	0	9/2/2012	2150
176.5	177.1	579	581	0	0	9/2/2012	2235
187.5	188.1	615	617	0	0	9/2/2012	2335
195.7	196.3	642	644	0	0	9/3/2012	32
202.4	203.0	664	666	0	0	9/3/2012	128
209.1	209.7	686	688	0	0	9/3/2012	228
214.9	215.5	705	707	0	0	9/3/2012	333
221.9	222.5	728	730	0	0	9/3/2012	444
228.9	229.5	751	753	0	0	9/3/2012	538
232.6	233.2	763	765	0	0	9/3/2012	630

Table F-2
Estimated Water Production during Drilling at Well ER-20-11 Based on Bromide Tracer
Data and Visual Data (4 pages)

Top of Interval (meters)	Base of Interval (meters)	Top of Interval (feet)	Base of Interval (feet)	Water Production Rate (liters/minute)	Water Production Rate (gallons/minute)	Date	Time
235.9	236.5	774	776	0	0	9/3/2012	715
240.2	240.8	788	790	0	0	9/3/2012	815
246.3	246.9	808	810	0	0	9/3/2012	915
249.3	249.9	818	820	0	0	9/3/2012	1015
256.3	256.9	841	843	0	0	9/3/2012	1115
261.5	262.1	858	860	0	0	9/3/2012	1215
264.0	264.6	866	868	0	0	9/3/2012	1315
269.4	270.1	884	886	0	0	9/3/2012	1415
274.9	275.5	902	904	0	0	9/3/2012	1515
278.3	278.9	913	915	0	0	9/3/2012	1615
280.7	281.3	921	923	0	0	9/3/2012	1715
285.3	285.9	936	938	0	0	9/3/2012	1815
289.0	289.6	948	950	0	0	9/3/2012	1900
293.5	294.1	963	965	0	0	9/3/2012	1935
294.7	295.4	967	969	0	0	9/3/2012	2000
296.6	297.2	973	975	0	0	9/3/2012	2040
297.8	298.4	977	979	0	0	9/3/2012	2100
299.6	300.2	983	985	0	0	9/3/2012	2130
301.1	301.8	988	990	0	0	9/3/2012	2200
305.7	306.3	1,003	1,005	0	0	9/3/2012	2300
308.2	308.8	1,011	1,013	0	0	9/3/2012	2345
308.8	309.4	1,013	1,015	0	0	9/4/2012	0
310.3	310.9	1,018	1,020	0	0	9/4/2012	30
314.2	314.9	1,031	1,033	0	0	9/4/2012	115
316.1	316.7	1,037	1,039	0	0	9/4/2012	150
319.7	320.3	1,049	1,051	0	0	9/4/2012	250
323.7	324.3	1,062	1,064	0	0	9/4/2012	320
327.1	327.7	1,073	1,075	0	0	9/4/2012	400
330.4	331.0	1,084	1,086	0	0	9/4/2012	430
335.3	335.9	1,100	1,102	0	0	9/4/2012	520
341.4	342.0	1,120	1,122	0	0	9/4/2012	600
348.7	349.3	1,144	1,146	0	0	9/4/2012	800
358.4	359.1	1,176	1,178	0	0	9/4/2012	840
369.1	369.7	1,211	1,213	0	0	9/4/2012	935
377.6	378.3	1,239	1,241	0	0	9/4/2012	1015

Table F-2
Estimated Water Production during Drilling at Well ER-20-11 Based on Bromide Tracer
Data and Visual Data (4 pages)

Top of Interval (meters)	Base of Interval (meters)	Top of Interval (feet)	Base of Interval (feet)	Water Production Rate (liters/minute)	Water Production Rate (gallons/minute)	Date	Time
386.2	386.8	1,267	1,269	0	0	9/4/2012	1110
391.7	392.3	1,285	1,287	0	0	9/4/2012	1140
402.9	403.6	1,322	1,324	0	0	9/4/2012	1215
418.8	419.4	1,374	1,376	0	0	9/4/2012	1320
432.8	433.4	1,420	1,422	0	0	9/4/2012	1440
435.3	435.9	1,428	1,430	0	0	9/4/2012	1520
438.3	438.9	1,438	1,440	0	0	9/4/2012	1540
441.7	442.3	1,449	1,451	0	0	9/4/2012	1610
453.8	454.5	1,489	1,491	0	0	9/4/2012	1710
462.4	463.0	1,517	1,519	0	0	9/4/2012	1815
476.4	477.0	1,563	1,565	0	0	9/4/2012	1930
482.5	483.1	1,583	1,585	0	0	9/4/2012	2000
487.7	488.3	1,600	1,602	0	0	9/4/2012	2030
492.3	492.9	1,615	1,617	0	0	9/4/2012	2100
495.3	495.9	1,625	1,627	0	0	9/4/2012	2120
504.4	505.1	1,655	1,657	0	0	9/4/2012	2200
512.1	512.7	1,680	1,682	18.9	5	9/4/2012	2230
518.5	519.1	1,701	1,703	18.9	5	9/4/2012	2250
523.6	524.3	1,718	1,720	0	0	9/8/2012	19
533.7	534.3	1,751	1,753	0	0	9/8/2012	119
547.4	548.0	1,796	1,798	0	0	9/8/2012	222
563.3	563.9	1,848	1,850	7.6	2	9/8/2012	323
575.2	575.8	1,887	1,889	7.6	2	9/8/2012	424
587.7	588.3	1,928	1,930	7.6	2	9/8/2012	521
613.9	614.5	2,014	2,016	7.6	2	9/8/2012	723
627.6	628.2	2,059	2,061	0	0	9/8/2012	825
647.1	647.7	2,123	2,125	3.8	1	9/8/2012	945
658.7	659.3	2,161	2,163	3.8	1	9/8/2012	1030
676.7	677.3	2,220	2,222	3.8	1	9/8/2012	1145
692.5	693.1	2,272	2,274	3.8	1	9/8/2012	1308
705.0	705.6	2,313	2,315	7.6	2	9/8/2012	1415
726.6	727.3	2,384	2,386	7.6	2	9/8/2012	1545
735.5	736.1	2,413	2,415	3.8	1	9/8/2012	1630
757.4	758.0	2,485	2,487	7.6	2	9/8/2012	1816
773.3	773.9	2,537	2,539	18.9	5	9/8/2012	1930

Table F-2
Estimated Water Production during Drilling at Well ER-20-11 Based on Bromide Tracer
Data and Visual Data (4 pages)

Top of Interval (meters)	Base of Interval (meters)	Top of Interval (feet)	Base of Interval (feet)	Water Production Rate (liters/minute)	Water Production Rate (gallons/minute)	Date	Time
782.7	783.3	2,568	2,570	18.9	5	9/8/2012	2028
789.7	790.3	2,591	2,593	18.9	5	9/8/2012	2131
798.3	798.9	2,619	2,621	18.9	5	9/8/2012	2236
803.5	804.1	2,636	2,638	18.9	5	9/8/2012	2332
808.6	809.2	2,653	2,655	18.9	5	9/9/2012	30
814.7	815.3	2,673	2,675	18.9	5	9/9/2012	129
823.0	823.6	2,700	2,702	18.9	5	9/9/2012	231
828.1	828.8	2,717	2,719	94.6	25	9/9/2012	327
833.6	834.2	2,735	2,737	378.5	100	9/9/2012	431
837.3	837.9	2,747	2,749	378.5	100	9/9/2012	537
841.2	841.9	2,760	2,762	378.5	100	9/9/2012	628
845.2	845.8	2,773	2,775	757.1	200	9/9/2012	710
850.4	851.0	2,790	2,792	946.4	250	9/9/2012	820
858.0	858.6	2,815	2,817	1,135.6	300	9/9/2012	945
866.5	867.2	2,843	2,845	1,135.6	300	9/9/2012	1125
872.3	872.9	2,862	2,864	1,211.3	320	9/9/2012	1213
878.1	878.7	2,881	2,883	1,324.9	350	9/9/2012	1315
886.4	887.0	2,908	2,910	1,514.2	400	9/9/2012	1545
887.3	887.9	2,911	2,913	1,589.9	420	9/9/2012	1645
893.7	894.3	2,932	2,934	1,779.1	470	9/9/2012	1720
901.3	901.9	2,957	2,959	1,892.7	500	9/9/2012	1933
911.0	911.7	2,989	2,991	1,892.7	500	9/9/2012	2053

Source: Unpublished data from N-I, January 17, 2013.

Note: Data in this table were used in the water-production plot shown in Appendix A-1.

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