N/0002653--043

Yucca Flat Well Development and Testing Analyses for Wells ER-3-3 and ER-4-1, Nevada National Security Site, Nye County, Nevada

Revision No.: 0

January 2018

Prepared for U.S. Department of Energy under Contract No. DE-NA0002653.

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YUCCA FLAT WELL DEVELOPMENT AND TESTING ANALYSES FOR WELLS ER-3-3 AND ER-4-1, NEVADA NATIONAL SECURITY SITE, NYE COUNTY, NEVADA

Revision No.: 0
January 2018
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Las Vegas, NV 89193-8952

Prepared for U.S. Department of Energy under Contract No. DE-NA0002653.

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LIST OF ACRONYMS AND ABBREVIATIONS

General Acronyms and Abbreviations

ALS	ALS Laboratory Group
ags	Above ground surface
amsl	Above mean sea level
bgs	Below ground surface
CAIP	Corrective action investigation plan
CAU	Corrective action unit
cm	Centimeter
CS	Carbon steel
DOE	U.S. Department of Energy
DRI	Desert Research Institute
DTW	Depth to water
DVD	Digital versatile disc
EERF	Eastern Environmental Radiation Facility
EOI	Effective open interval
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
e-tape	Electric tape
FFACO	*Federal Facility Agreement and Consent Order*
FMI	Formation MicroImager
FMP	Fluid management plan
ft	Foot
ft/day	Feet per day
ft/min	Feet per minute
FTC	Fluid temperature conductivity
FY	Fiscal year
gal	Gallon
GEL	General Engineering Laboratories
GMWL	Global meteoric water line
gpm	Gallons per minute
gpm/ft	Gallons per minute per foot
GR	Gamma ray

List of Acronyms and Abbreviations (continued)

GWC	Groundwater characterization
HASL	Health and Safety Laboratory
HFM	Hydrostratigraphic framework model
HGU	Hydrogeologic unit
HSU	Hydrostratigraphic unit
Hz	Hertz
ID	Identification
in.	Inch
km	Kilometer
Lat	Latitude
LLNL	Lawrence Livermore National Laboratory
LMWL	Local meteoric water line
Long	Longitude
LTWLM	Long-term water-level monitoring
LVF	Load Verification Form
m	Meter
m/day	Meters per day
m^2/day	Square meters per day
m^3	Cubic meter
mBar	Millibar
MDA	Minimum detectable activity
MDC	Minimum detectable concentration
mg/L	Milligrams per liter
mm	Millimeter
M&O	Management and operating
MWAT	Multiple-well aquifer test
N/A	Not applicable
NA	Not available
NAD 27	North American Datum, 1927
NAD 83	North American Datum, 1983
NDEP	Nevada Division of Environmental Protection
NNSA/NFO	U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office
NNSS	Nevada National Security Site

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

NSPC	Nevada State Plane Coordinate
NSTec	National Security Technologies, LLC
NTU	Nephelometric turbidity unit
pCi/L	Picocuries per liter
pmc	Percent modern carbon
ppb	Parts per billion
ppm	Parts per million
psi	Pounds per square inch
psia	Pounds per square inch absolute
PST	Pacific Standard Time
PXD	Pressure transducer
QC	Quality control
RN	Radionuclide
S	Storativity
SDWA	*Safe Drinking Water Act*
SEC	Specific electrical conductance
SGR	Spectral gamma ray
SN	Serial number
SNJV	Stoller-Navarro Joint Venture
SS	Stainless steel
SWL	Static water level
SU	Standard unit
TBD	To be determined
TD	Total depth
TIH	Trip into hole
UGT	Underground test
UGTA	Underground Test Area
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
VSC	Variable speed controller
WDT	Well development and testing
YF	Yucca Flat
°C	Degree Celsius

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

%meq/L	Milliequivalents per liter
µmhos/cm	Micromhos per centimeter
µS/cm	Microsiemens per centimeter

Stratigraphic, Geologic, Hydrostratigraphic, and Hydrogeologic Unit Abbreviations and Symbols

AA	Alluvial aquifer
AA3	Alluvial aquifer
ATCU	Argillic tuff confining unit
CA	Carbonate aquifer
Ds	Simonson Dolomite
DSsl	Sevy and Laketown Dolomite, undivided
Kg	Granitic rocks
LCA	Lower carbonate aquifer
LTCU	Lower tuff confining unit
MDe	Eleana Formation
Oe	Eureka Quartzite
Op	Pogonip Group
OSBCU	Oak Spring Butte confining unit
Qai	Intermediate alluvial deposits
Qay	Young alluvial deposits
Qeo	Old eolian sand deposits
QTa	Quaternary/Tertiary alluvium
QTc	Quaternary/Tertiary colluvium
Tbg	Grouse Canyon Tuff
Tbgb	Grouse Canyon bedded tuff
Tc	Crater Flat Group
Tcb	Bullfrog Tuff
TCU	Tuff confining unit
Tem	Monotony Tuff
Tes	Shingle Pass Tuff
Tgy	Basin-fill sediments, undivided
Tlc/To	Paleocolluvium/Older tuffs

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

Tm	Timber Mountain Group
Tma	Ammonia Tanks Tuff
Tmab	Ammonia Tanks bedded tuff
TMLVTA	Timber Mountain lower vitric-tuff aquifer
Tmr	Rainier Mesa Tuff
Tmrh	Tuff of Holmes Road
Tmrp	Rainier Mesa mafic-poor Tuff
Tmrr	Rainier Mesa mafic-rich Tuff
Tm/Tw	Pre-Timber Mountain Tuff - Post-Wahmonie Tuff (undifferentiated)
TMUVTA	Timber Mountain upper vitric-tuff aquifer
TMWTA	Timber Mountain welded-tuff aquifer
Tn	Tunnel Formation
Tn3	Tunnel Member 3
Tn3A	Tunnel Member 3, bed A
Tn4	Tunnel Member 4
To3	Volcanics of Oak Spring Butte, tunnel bed 3
Ton	Older Tunnel Beds
Ton1	Tunnel Bed 1
Ton2	Tunnel Bed 2
Tot	Tuff of Twin Peaks
Toy	Tuff of Yucca Flat
Tp	Paintbrush Group
Tpt	Topopah Spring Tuff
Ttb	Basalt of Black Mountain
Tub	Tub Spring Tuff
Tv	Tertiary Volcanics
Tw	Wahmonie Formation
VA	Volcanic aquifer
VTA	Vitric-tuff aquifer
WTA	Welded-tuff aquifer
Zj	Johnnie Formation
Zs	Stirling Quartzite
Ꞓbb	Banded Mountain Member

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

Ꞓbp	Papoose Lake Member
Ꞓc	Carrara Formation
Ꞓn	Nopah Formation
ꞒZ	Zabriskie Quartzite
ꞒZw	Wood Canyon Formation
PIPt	Tippipah Limestone
Pz	Paleozoic rocks

Symbols for Elements and Compounds

Bi	Bismuth
C	Carbon
Ca	Calcium
$CaCO_3$	Calcium carbonate
Cl	Chloride
CO_2	Carbon dioxide
CO_3	Carbonate
DO	Dissolved oxygen
H	Hydrogen
HCl	Hydrochloric acid
HCO_3	Bicarbonate
K	Potassium
LiBr	Lithium bromide
Mg	Magnesium
Mn	Manganese
Na	Sodium
O	Oxygen
Pb	Lead
SiO_2	Silicon dioxide
SO_4	Sulfate
Sr	Strontium
$\delta^{13}C$	Delta carbon-13
δD	Delta deuterium
$\delta^{18}O$	Delta oxygen-18

1.0 INTRODUCTION

This report documents the well development and testing (WDT) data and analysis of Wells ER-3-3 and ER-4-1 during fiscal year (FY) 2017. Wells ER-3-3 and ER-4-1 were constructed to evaluate possible radionuclides (RNs) in groundwater from nearby underground tests (UGTs), to provide hydrogeologic information to support refinement of the Yucca Flat hydrostratigraphic framework model (HFM) (BN, 2006), and to provide supplemental data to the Yucca Flat groundwater flow and contaminant transport model (N-I, 2013) to help address priority concerns and recommendations of the Yucca Flat External Peer Review Team. Of particular interest is the characterization of specific groundwater flow pathways (i.e., faults, fractured aquifers) along which RNs in groundwater could migrate from individual UGTs. Another important objective is to determine the hydraulic properties of the volcanic aquifers (VAs) and carbonate aquifers (CAs) in the former underground testing areas in Yucca Flat, and specifically in the areas proximal to existing UGTs.

As shown in Figure 1-1, Well ER-3-3 is located near the northwest corner of Area 3, downgradient from the WAGTAIL (U-3an) UGT; and Well ER-4-1 is located near the northeast corner section of Area 4, downgradient from the STRAIT (U-4a) UGT. As recommended by the external peer review of the Yucca Flat Corrective Action Investigation Plan (CAIP) stage (N-I, 2015) of the *Federal Facility Agreement and Consent Order* (FFACO) (1996, as amended), both wells could be used in multiple-well aquifer tests (MWATs) near large faults. As shown in Figures 1-2 and 1-3, respectively, Well ER-3-3 is located near the Yucca Fault to the west, and Well ER-4-1 is located between the Yucca Fault to the east and the Topgallant Fault to the west.

Wells ER-3-3 and ER-4-1 were drilled for the U.S. Department of Energy (DOE), National Nuclear Security Administration Nevada Field Office (NNSA/NFO) in support of the Underground Test Area (UGTA) Activity as part of the CAIP for Yucca Flat/Climax Mine Corrective Action Unit (CAU) 97 (DOE/NV, 2000). Well ER-3-3 was drilled and completed from February 21 to March 15, 2016, to a total depth (TD) of 3,193 feet (ft) below ground surface (bgs). Well ER-4-1 was drilled and completed from March 23 to April 13, 2016, to a TD of 3,035 ft bgs.

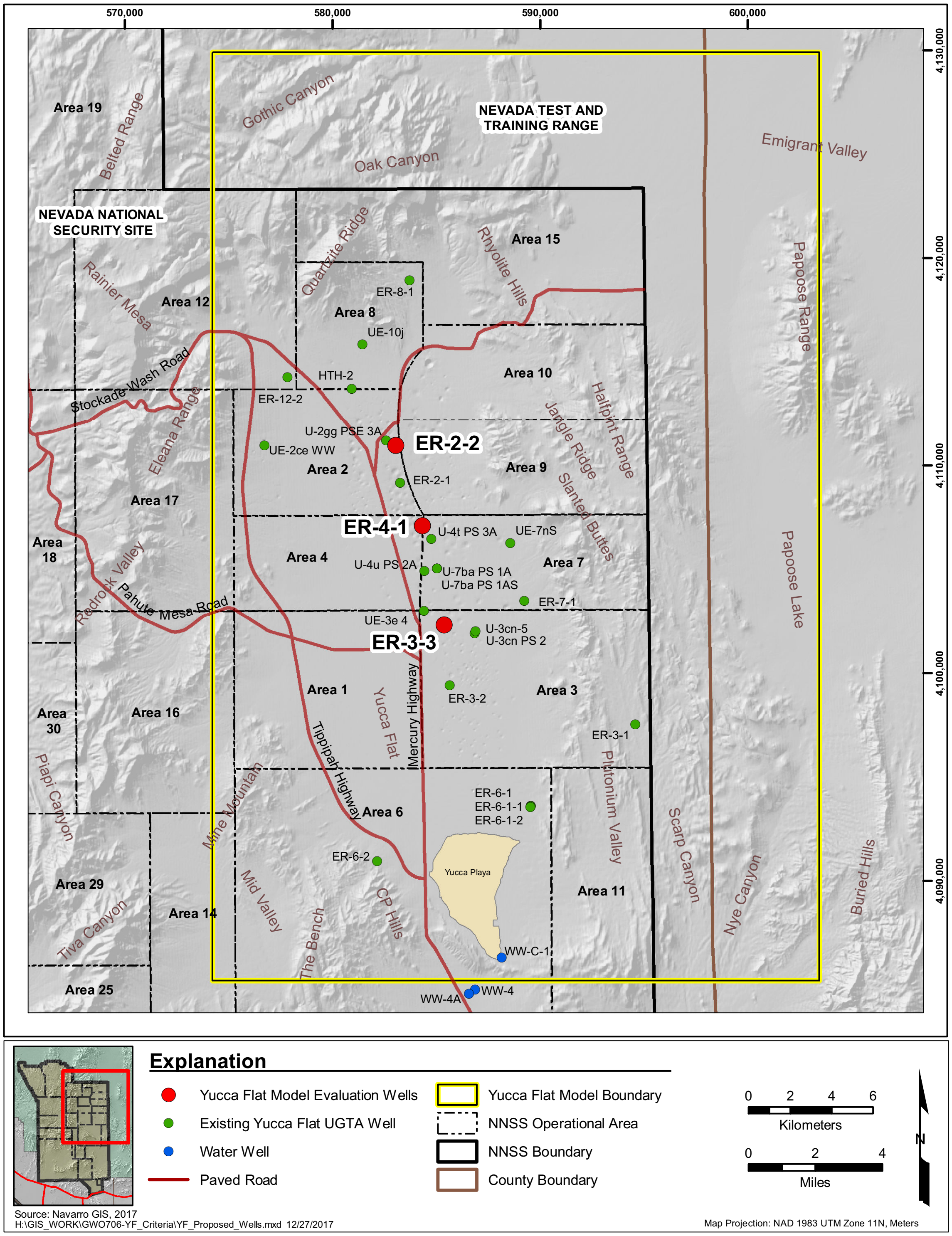

Figure 1-1
Location of Wells ER-3-3 and ER-4-1

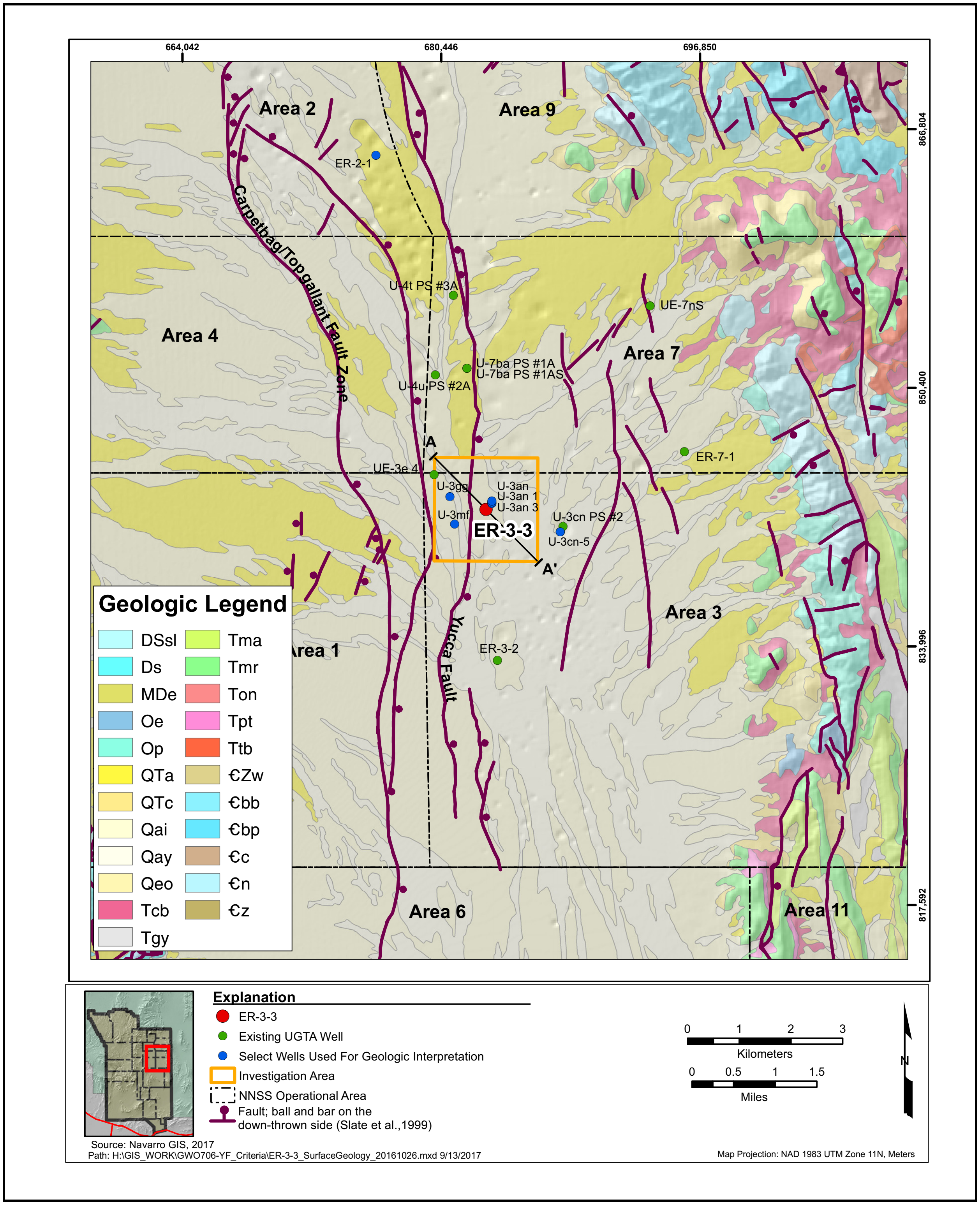

Figure 1-2
Surface Geology at Well ER-3-3

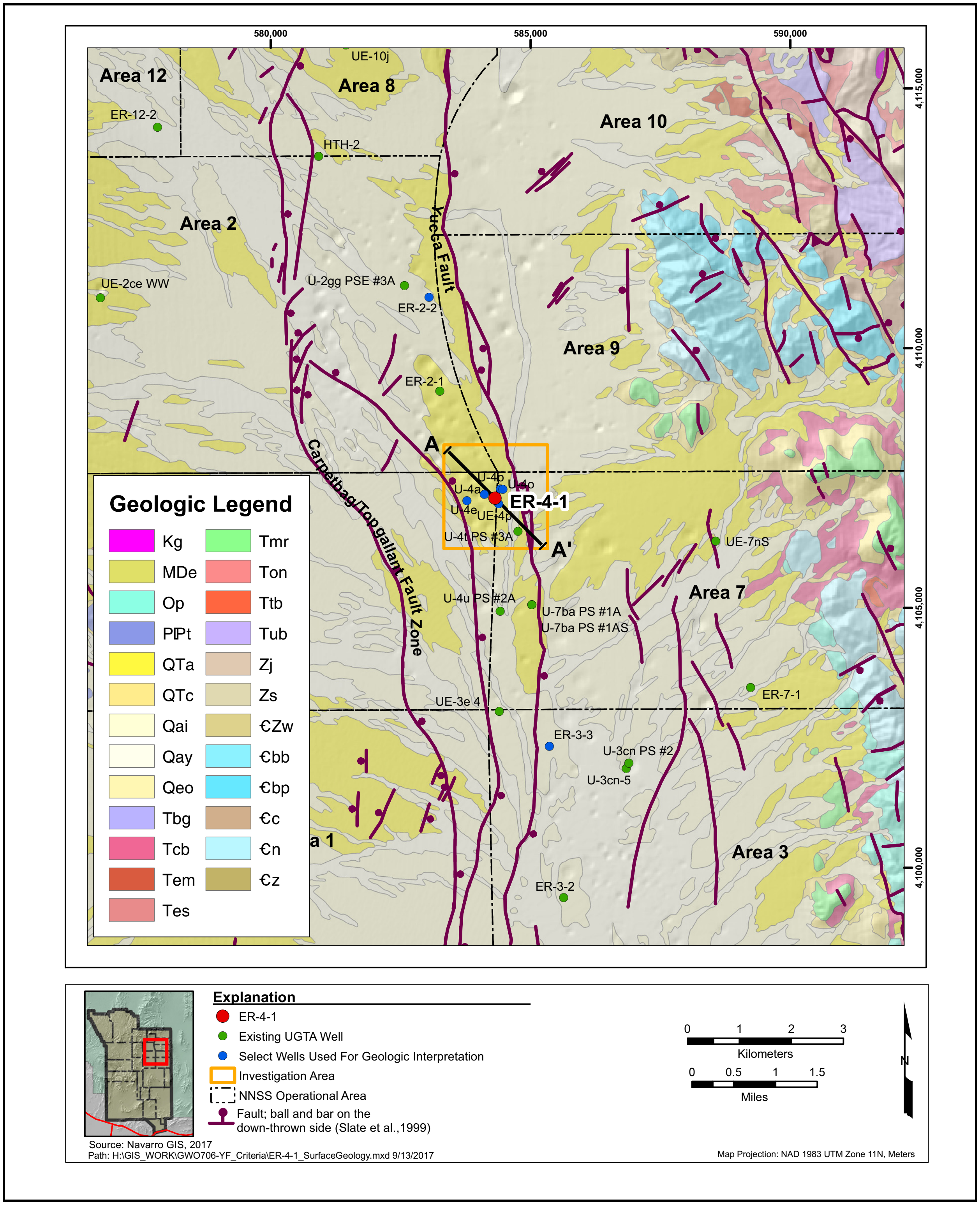

Figure 1-3
Surface Geology at Well ER-4-1

The well drilling and completion, development, and testing information is presented in the following reports:

- *Completion Report for Well ER-3-3 Corrective Action Unit 97: Yucca Flat/Climax Mine* (NNSA/NFO, 2017a)
- *Completion Report for Well ER-4-1 Corrective Action Unit 97: Yucca Flat/Climax Mine* (NNSA/NFO, 2017b)

This report documents the data collected during the ER-3-3 and ER-4-1 WDT activities and analysis of the data. The report is organized into the following sections:

- Wells ER-3-3 and ER-4-1 Specifications and Completion during Testing (Section 2.0)
- Wells ER-3-3 and ER-4-1 Development and Testing (Section 3.0)
- Geology and Hydrgeology (Section 4.0)
- Pumping Well Hydraulics (Section 5.0)
- Groundwater Chemistry (Section 6.0)
- Environmental Compliance (Section 7.0)
- Observations and Conclusions (Section 8.0)
- References (Section 9.0)

2.0 WELLS ER-3-3 AND ER-4-1 SPECIFICATIONS AND COMPLETION DURING TESTING

Well completion is the process of making a well ready for use and involves preparing the bottom of the hole to the required specifications. This includes placing the production/sampling tubing, pumps, and pressure transducers (PXDs).

2.1 Well ER-3-3 Specifications and Completion

The Well ER-3-3 completion design was based on the onsite evaluation of lithology, water production, water levels, borehole conditions, drilling data, geophysical logs, and tritium levels obtained during drilling. The completion design was modified from the original to accommodate unstable borehole conditions encountered during drilling. The final completion design consists of the m1 and m2 main completion intervals; and the p1, p2, and p3 piezometers.

Well ER-3-3 was drilled to a depth of 3,192.9 ft bgs. The main completion string is composed of 7.625-inch (in.) blank carbon-steel (CS) casing to 1,595.44 ft bgs, 6.625-in. stainless-steel (SS) blank to 2,203.18 ft bgs, and an SS slotted interval (m2) from 2,203.18 to 2,441.44 ft bgs completed within the base of the Timber Mountain welded-tuff aquifer (TMWTA), the Timber Mountain lower vitric-tuff aquifer (TMLVTA), and lower tuff confining unit (LTCU) hydrostratigraphic units (HSUs). Below the m2 slotted interval is a section of 6.625-in. blank SS casing from 2,441.44 to 3,018.20 ft bgs. A second slotted interval (m1) open to the LTCU, argillic tuff confining unit (ATCU) and the lower carbonate aquifer (LCA) HSUs is completed with 6.625-in. SS slotted casing from 3,018.20 to 3,097.54 ft bgs with a bullnose termination to 3,099.79 ft bgs. The screened interval is partially situated within fill from 3,046 to 3,099.79 ft bgs (approximately 54 ft), which may affect the WDT of the LCA.

The 13.375-in. CS surface casing was installed from 2.42 ft above ground surface (ags) to a depth of 2,039.72 ft bgs and cemented in place. The p3 piezometer was installed in the annulus between the borehole wall and 13.375-in. casing from 2.68 ft ags to a depth of 1,882.07 ft bgs. The p3 piezometer consists of 2.375-in. CS blank tubing and 2.875-in. SS slotted interval completed in the alluvial aquifer (AA3) and Timber Mountain upper vitric-tuff aquifer (TMUVTA) HSUs.

The p2 piezometer was completed within the TMWTA, TMLVTA and LTCU welded and bedded tuffs and consists of 2.375-in. diameter CS blank tubing from 3.09 ft ags to 1,533.69 ft with a crossover to 2.875-in. SS blank tubing to a depth of 2,203.58 ft bgs. The slotted SS tubing consists of 2.875-in. tubing for 240 ft with a bullnose termination extending to 2,466.57 ft.

The p1 piezometer was completed within the LTCU, ATCU, and LCA and consists of 2.375-in. diameter CS tubing extending from 3.07 ft ags to 1,754.35 ft bgs. The crossover, from the 2.375-in. CS tubing to the 2.875-in. SS blank tubing, extends to 1,755.20 ft bgs. Blank SS tubing extends from 1,755.20 to 2,999.17 ft bgs. The slotted SS tubing consists of 30-ft lengths of 2.875-in. diameter tubing, and a bullnose termination, extending to 3,093.90 ft. The screened interval is partially situated within fill from 3,046 to 3,091.8 ft bgs (approximately 46 ft), which may affect the WDT of the LCA.

Before WDT activities, the depth to water (DTW) levels were measured in the three piezometers on November 8, 2016. The DTW in p1 was measured at 1,658.29 ft bgs; the DTW in p2 was measured at 1,653.18 ft bgs; and the DTW in p3 was measured at 1,444.06 ft bgs. On November 15, 2016, the DTW in the main completion was measured at 1,653.43 ft bgs. Various activities occurred before WDT. On November 17, 2016, a bridge plug at 2,560 ft bgs was removed from the main completion. On November 22, 2016, a straddle packer was installed in the main completion between the m1 and m2 slotted intervals. The packer was set at 2,115 to 2,123 ft bgs, with the double cup strada assembly at 2,495 to 2,500 ft bgs. On November 28, 2016, a dedicated low-flow electric submersible pump was installed in the m1 main production casing on 2.875-in. SS tubing. The pump was installed with the bottom of the shroud at a depth of 1,999.39 ft bgs, and the intake of the pump set at 1,979.44 ft bgs; the intake was approximately 326 ft below the static water level (SWL).

The water levels in the p1 and p2 piezometers were re-measured on November 29, 2016; DTW in p1 was at 1,667.44 ft bgs, and DTW in p2 was at 1,653.0 ft bgs. A PXD was installed in the p1 piezometer and set at a depth of 2,990 ft bgs, approximately 1,322 ft below the water level. Another PXD was installed in the p2 piezometer at a depth of 1,673 ft bgs, approximately 20 ft below water level. The DTW in the p3 piezometer was not measured, and no PXD was installed due to approximately 530 ft of mud in the piezometer. The PXDs were removed from the piezometers after WDT activities were completed.

The final completion design is shown in Figure 2-1. Figure 2-2 shows a plan view and profile of the final wellhead surface completion.

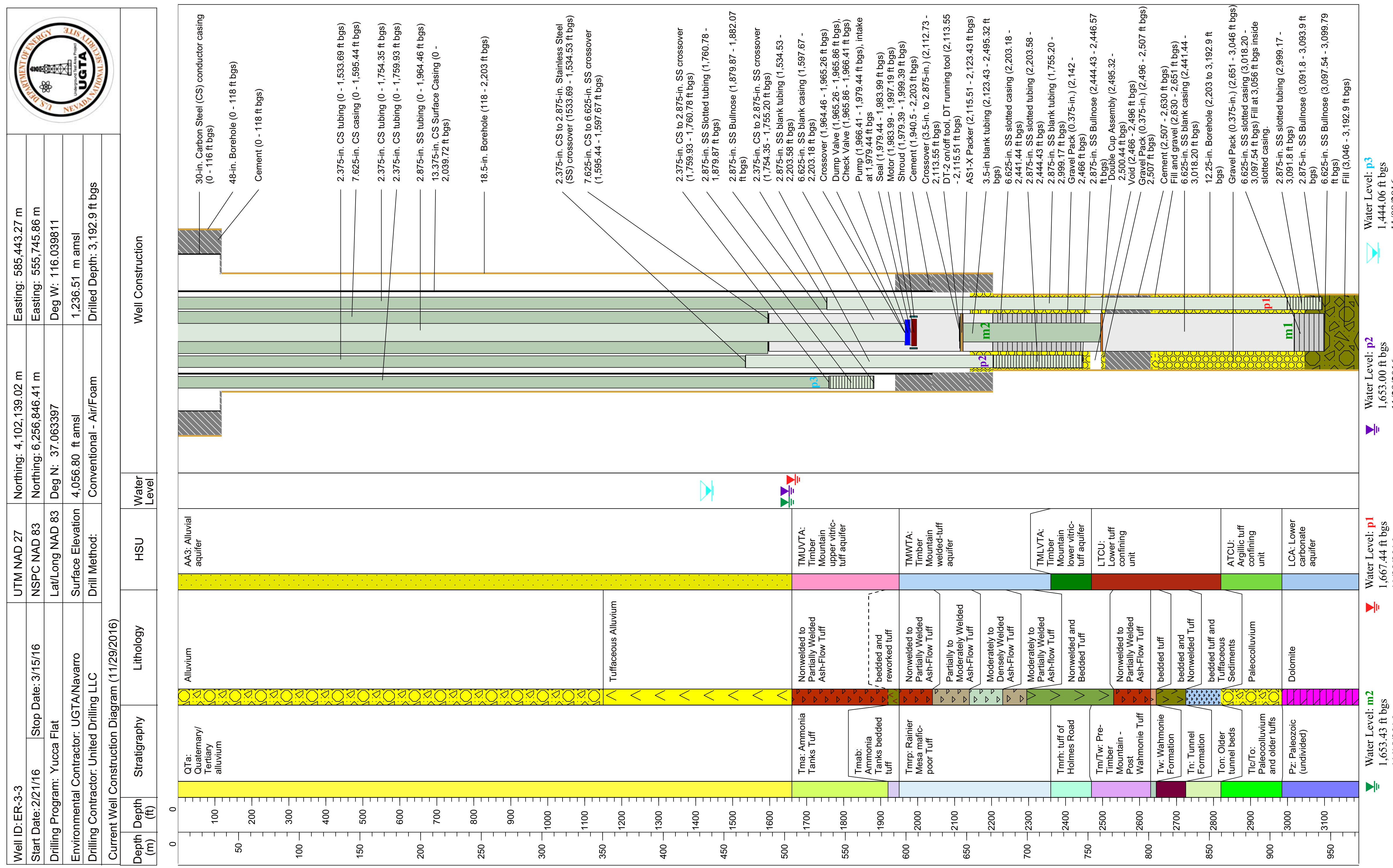

Figure 2-1
Well Completion Diagram for Well ER-3-3

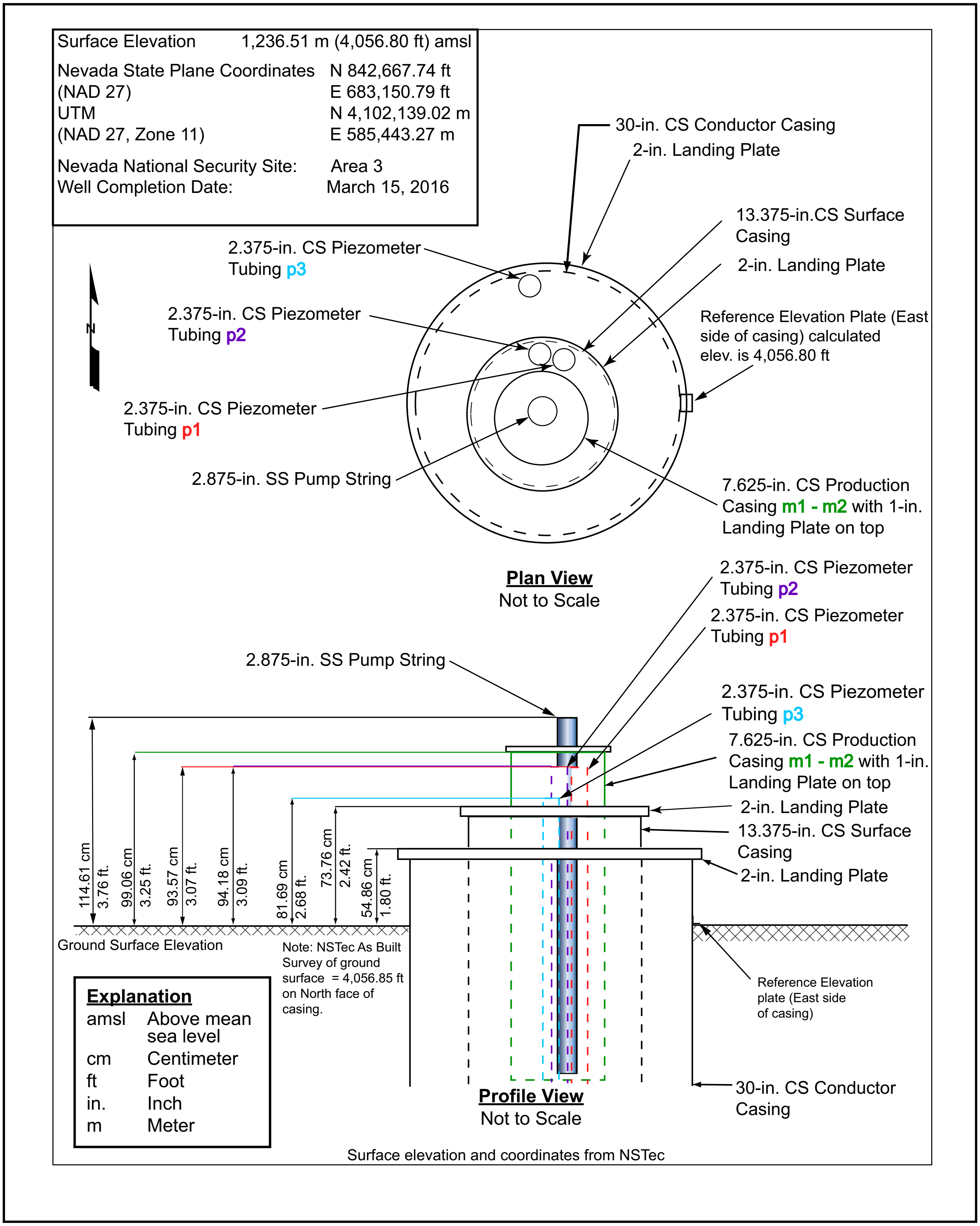

Figure 2-2
Wellhead Completion Diagram for Well ER-3-3

2.2 Well ER-4-1 Specifications and Completion

The Well ER-4-1 completion design was based on the onsite evaluation of lithology, water production, water level, borehole conditions, drilling data, geophysical logs, and tritium levels obtained during drilling. The completion design was modified from the original to accommodate unstable borehole conditions encountered during drilling. The final completion design consists of the m1 main completion interval, the p1 piezometer, and the a1 access line.

Well ER-4-1 was drilled to a depth of 3,035.19 ft bgs. The main completion string is composed of 7.625-in. blank CS casing from surface to 1,700.60 ft bgs; a CS-to-SS 6.625-in. crossover from 1,700.60 ft to 1,702.85 ft bgs; 6.625-in. SS blank casing from 1,702.85 ft to 2,853.75 ft bgs; and a 6.625-in. SS slotted interval (m1) from 2,853.75 to 2,972.78 ft bgs completed within the LCA, with a bullnose termination installed on the bottom of the completion string from 2,972.78 ft to 2,975.05 ft bgs. Approximately 17 ft of the slotted interval in m1 is within fill, which may affect the WDT results.

Well completion began with installation of the 13.375-in. CS surface casing from 2.30 ft ags to a depth of 2,654.21 ft bgs and cementing the casing in place. A piezometer (p1) was installed in the annulus between the borehole wall and 13.375-in. casing from 2.38 ft ags to a depth of 2,175.71 ft bgs. The p1 piezometer consists of 2.375-in. CS blank tubing and 2.875-in. SS screen interval open to the TMWTA, TMLVTA, LTCU, and Oak Spring Butte confining unit (OSBCU) HSUs. The p1 piezometer slotted interval is from 2,023.98 to 2,173.61 ft bgs, in the saturated LTCU and OSBCU confining units, which may affect the hydraulic conductivity between m1 and p1 during aquifer testing.

Before WDT activities, the water level in the m1 main completion was measured at 1,768.44 ft bgs on December 12, 2016. The water level in the p1 piezometer was measured at 1,051.16 ft bgs on January 4, 2017. The water level in the p1 piezometer is elevated about 400 to 500 ft relative to the regional water table; the water level is highly pressurized from nearby nuclear testing due to the low permeability of the LTCU.

On January 11, 2017, a dedicated electric submersible pump was installed in the m1 main production casing on 2.875-in. SS tubing. The pump was installed to a depth of 2,139.28 ft bgs, with the intake of the pump set at 2,088.51 ft bgs; the intake was approximately 320 ft below the SWL. On January 12, 2017, 1.9-in. CS access line was installed in the m1 main completion, next to the pump string, at a depth of 2,021.40 ft bgs, approximately 42.2 ft above the top of the dedicated pump. A PXD was then installed in the access line and set at a depth of 2,010 ft bgs, approximately 242 ft below SWL. A PXD was also installed in the p1 piezometer at a depth of 1,075 ft bgs, approximately 24 ft below the water level. The PXDs were removed from the access line and p1 piezometer after WDT activities were completed.

The final completion design is shown in Figure 2-3. Figure 2-4 shows a plan view and profile of the final wellhead surface completion.

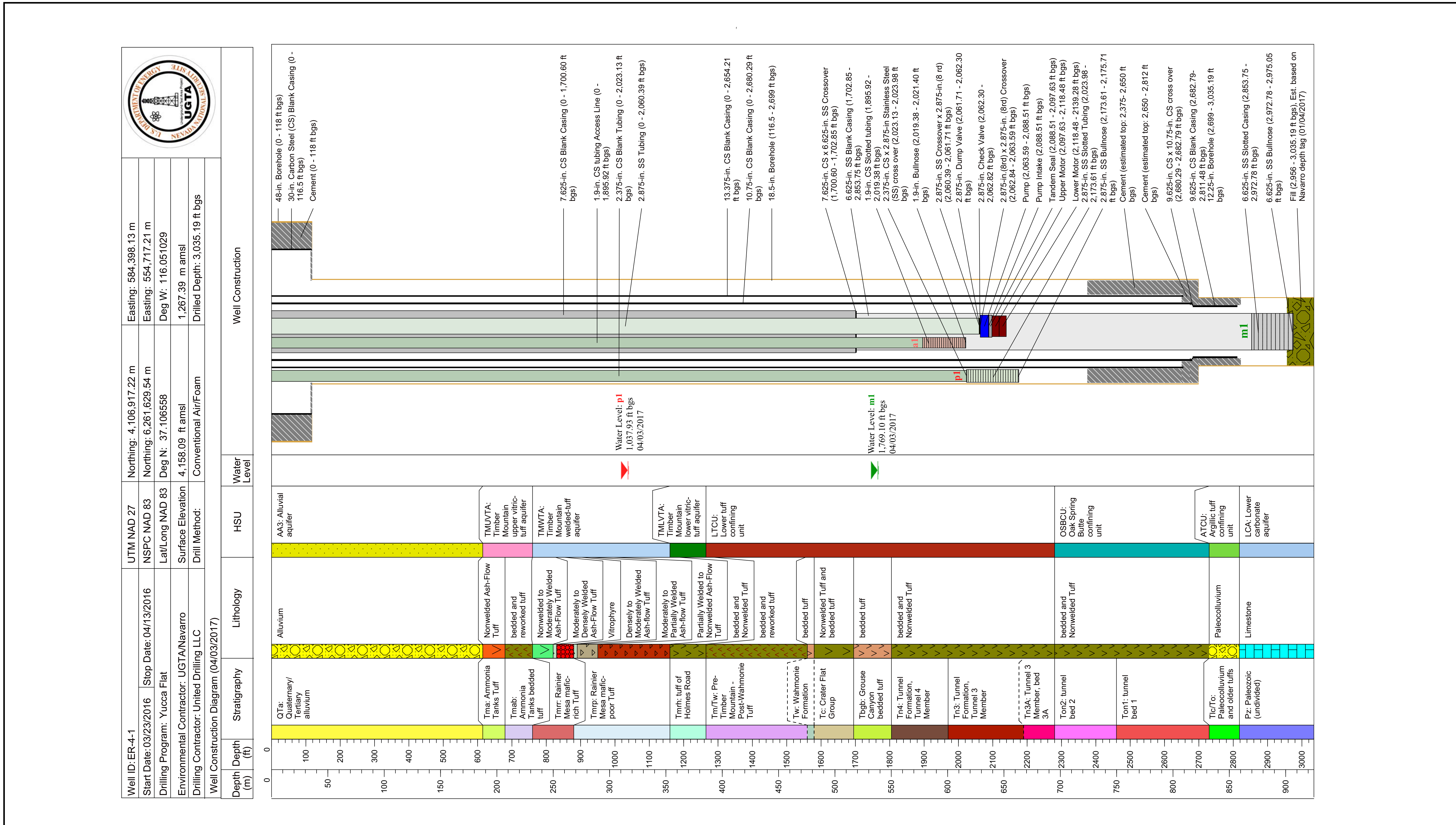

Figure 2-3
Well Completion Diagram for Well ER-4-1

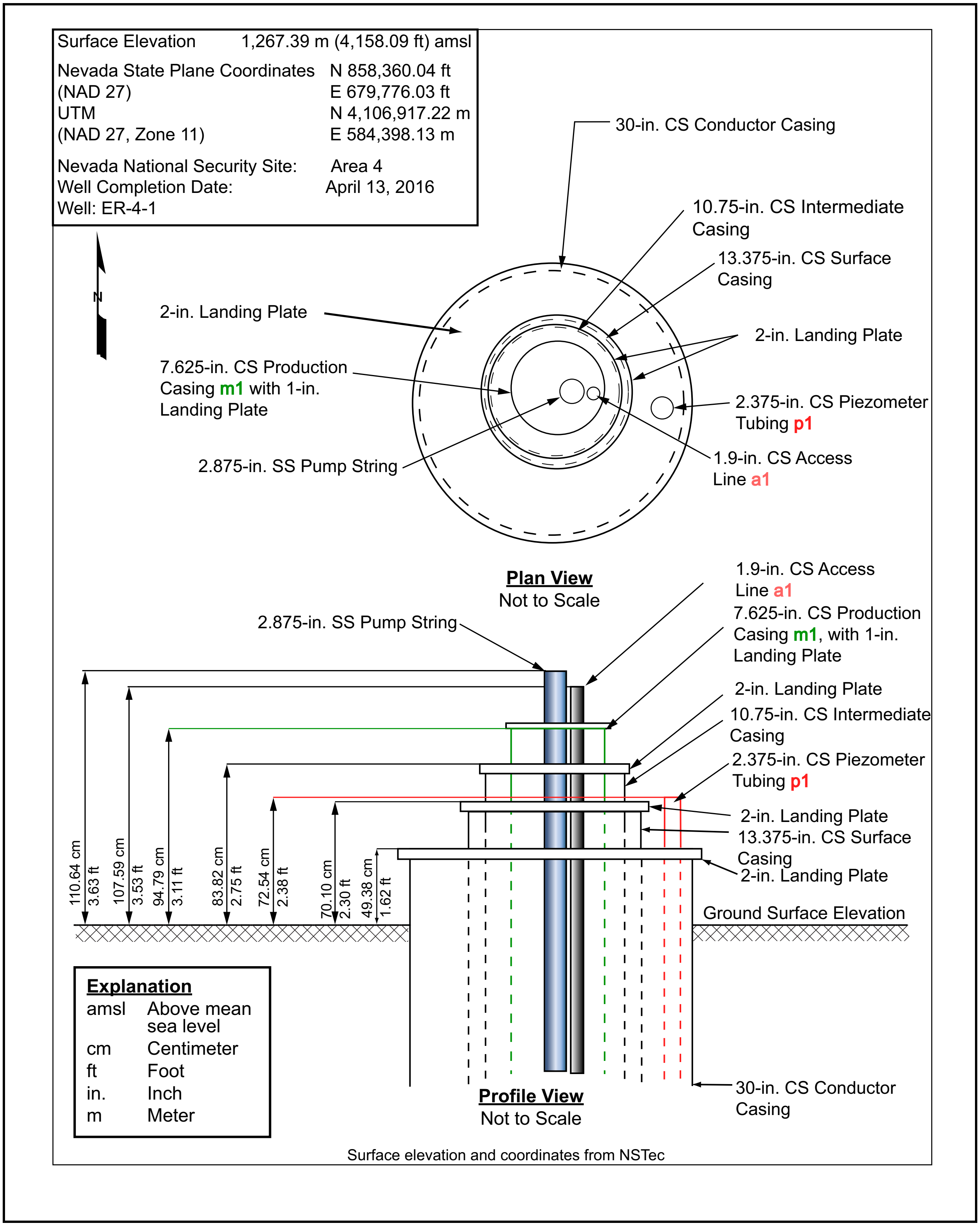

Figure 2-4
Wellhead Completion Diagram for Well ER-4-1

3.0 Wells ER-3-3 and ER-4-1 Development and Testing

The purpose of well development is to remove drilling fluids and drilling-associated fines from the formation adjacent to a well so that samples reflecting ambient groundwater quality can be collected, and to restore hydraulic properties near the wellbore. Drilling fluids can contaminate environmental samples from the well, resulting in nonrepresentative measurements. Both drilling fluids and drilling-associated fines in the formation adjacent to the well can impede the flow of water from the formation to the well, altering the hydraulic response measured in the well from pumping. The purpose of well testing is to determine the hydraulic properties, and obtain groundwater samples at the well that are representative of the formation. WDT activities included well development, step-drawdown testing, constant-rate testing, and groundwater sampling for geochemical and radiochemistry data.

3.1 Generic WDT Schedule

The WDT scheduled activities for ER-3-3 and ER-4-1 included pre-WDT and post-WDT long-term water-level monitoring (LTWLM), well logging by the Desert Research Institute (DRI), pre-WDT groundwater sampling, well development pumping, step-rate pump testing, and constant-rate pump testing.

The generic schedule for WDT activities is outlined below:

- Conduct predevelopment water-level monitoring in testing and observation wells (30 or more days).
- Collect groundwater characterization (GWC) samples from piezometers using depth-discrete bailers.

For each completion interval to be tested:

- Mobilize equipment; configure the well; and install the testing pump and monitoring equipment (3 to 5 days).
- Conduct well development, step-drawdown testing, and flow and chemistry logging under pumping conditions (5 days).

- Monitor post-development, water-level recovery (minimum of 5 days).
- Conduct constant-rate pumping test and GWC sampling (up to 20 days).
- Monitor post-test water-level recovery (up to 20 days).
- Perform flow and chemistry logging under ambient conditions (3 days).
- Remove the testing pump and instrumentation (2 days).

After completing WDT activities:

- Install dedicated sampling pump and LTWLM instrumentation (2 days).
- Complete demobilization (5 days).

3.2 Schedule of Activities

3.2.1 Well ER-3-3

Table 3-1 provides a detailed schedule of daily WDT activities conducted at Well ER-3-3; not all the WDT activities listed in the generic schedule were conducted. Because of excess drawdown in Well ER-3-3 when the pump was running, the step-rate and constant-rate tests could not be conducted as planned. Instead, cycled pump testing was conducted, where the pump was completely shut off to allow water recovery, then turned on again, in repeated cycles. Although cyclic testing is somewhat analogous to a step-rate test by increasing the stress to an aquifer in increasing increments, a step-rate test is able to sustain each given pump rate as the rate is increased.

Table 3-1
Detailed Summary of WDT Activities at Well ER-3-3
(Page 1 of 4)

Date[a]	Activities
11/09/2016	Mobilization of equipment and facilities. Removed PXDs from p1, p2, and p3 piezometers. DTW measured in p1 piezometer at 1,658.29 ft bgs; DTW measured in p2 piezometer at 1,653.18 ft bgs; DTW measured in p3 piezometer at 1,444.06 ft bgs. TD measured in p1 piezometer at 3,048 ft bgs.
11/10/2016	Collection of tritium samples using a depth-discrete bailer from the p1 piezometer at 3,010 ft bgs and the p2 piezometer at 2,320 ft bgs.
11/11 to 11/15/2016	No activity on site.

Table 3-1
Detailed Summary of WDT Activities at Well ER-3-3
(Page 2 of 4)

Date[a]	Activities
11/16/2016	DTW measured in main completion at 1,653.43 ft bgs. DRI rigged up and calibrated Idronaut chemistry tool. DRI personnel tripped in the hole (TIH) with tool and logged down from 0 to 3,035 ft bgs at 50 feet per minute (ft/min); pH probe failed during run. DRI DTW from Idronaut log measured at 1,659 ft bgs.
11/17/2016	Workover rig positioned at well, mast raised, guy wire installed; rig floor, catwalk and pipe racks moved into position.
11/18/2016	Finish rigging up; TIH and retrieve removable bridge plug from 2,560 ft bgs.
11/19 to 11/21/2016	No activity on site.
11/22/2016	Measured top of fill in main completion at 3,030 ft bgs with sinker bar; at 3,040 ft bgs experienced significant weight loss. Measured top of fill in p1 piezometer with sinker bar at 3,052 ft bgs. Tagged top of fill with 2.875-in. tubing in main completion at 3,056 ft bgs.
11/23/2016	Installed straddle packer in main completion at 2,115 to 2,123 ft bgs, with strada cup assembly at 2,495 to 2,500 ft bgs.
11/24/2016	Assemble and service low-flow electric submersible pump, and begin installation of pump.
11/25 to 11/28/2016	No activity on site.
11/29/2016	Install low-flow pump; intake set at 1,979.44 ft bgs with bottom of shroud at 1,999.39 ft bgs.
11/30/2016	Pump connected to variable speed controller (VSC) and programmed with high-speed clamp at 65 hertz (Hz), low speed clamp at 45 Hz, overload at 134 amps, and limiting amps at 130 amps. DTW measured in p1 piezometer at 1,667.44 ft bgs; DTW measured in p2 piezometer at 1,653.0 ft bgs. PXD installed in p1 piezometer at 2,990 ft bgs (575.61 pounds per square inch [psi]). The workover rig and associated equipment was secured and moved away from the wellhead.
12/01/2016	DTW measured in p2 piezometer at 1,653.0 ft bgs; PXD installed at 1,673 ft bgs (20.68 psi). No DTW measured in p3 piezometer and no PXD installed due to mud in piezometer. Wellhead manifold, flow meter, and discharge hoses positioned. Function test of pump conducted; pump started in reverse at 50 Hz in Mode 1; water to surface in 17 minutes, production rate at 12 gallons per minute (gpm). Drawdown monitored in p1 piezometer; 259 ft in 22 minutes; pump shut off, and recovery monitored.
12/02/2016	Conducted two pumping intervals in Mode 1 at 50 Hz, VSC at 78 to 79 amps, 242 volts, to improve well production. Pump started; production rate of 14 gpm. Pump shut down due to excessive drawdown in p1 piezometer of 269 ft; well allowed to recover to 68 ft below SWL. Pump restarted; production rate at 15 gpm. Daily tritium sample and water-quality samples collected. Pump again shut down due to excessive drawdown of 262 ft; well allowed to recover overnight.
12/03/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, VSC at 71 to 72 amps, 242 volts, to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started; production rate of 14 gpm. Pump shut down due to excessive drawdown of 270 ft; well allowed to recover to 160 ft below SWL. Pump restarted for second time; production rate at 14 gpm. Pump again shut down due to excessive drawdown of 266 ft; well allowed to recover to 160 ft below SWL. Pump restarted for a third time; production rate of 14 gpm. Pump shut down due to excessive drawdown of 266 ft. Well allowed to recover overnight.

Table 3-1
Detailed Summary of WDT Activities at Well ER-3-3
(Page 3 of 4)

Date[a]	Activities
12/04 to 12/05/2016	No activity on site.
12/06/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, VSC at 71 amps, 242 volts, to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started; production rate of 14 gpm. Pump shut down due to excessive drawdown of 279 ft; well allowed to recover to 160 ft below SWL. Pump restarted for second time; production rate at 13.5 gpm. Pump again shut down due to excessive drawdown of 268 ft; well allowed to recover to 160 ft below SWL. Pump restarted for a third time; production rate of 13 gpm. Pump shut down due to excessive drawdown of 269 ft. Well allowed to recover overnight.
12/07/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, VSC at 71 amps, 242 volts, to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started; production rate of 13 gpm. Pump shut down due to excessive drawdown of 269 ft; well allowed to recover to 160 ft below SWL. Pump restarted for second time; production rate at 13.5 gpm. Pump again shut down due to excessive drawdown of 268 ft; well allowed to recover to 160 ft below SWL. Pump restarted for a third time; production rate of 13 gpm. Pump shut down due to excessive drawdown of 269 ft. Well allowed to recover overnight. During shift, rate of recovery improved by approximately 7 minutes.
12/08/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, VSC at 76 to 78 amps, 241 to 242 volts, to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started; production rate of 13 gpm. Pump shut down due to excessive drawdown of 269 ft; well allowed to recover to 160 ft below SWL. Attempted to pump at 45 Hz, 67 amps, 217 volts; production rate from 2 to 8 gpm; increased frequency to 47 Hz, 68 amps, 227 volts with production rate of 6 to 12 gpm; decreased frequency to 46 Hz, 66 amps, 222 volts with production rate of 0 to 4 gpm. Pump shut off and well allowed to recover. Pump restarted at 50 Hz; production rate at 13 gpm. Pump again shut down due to excessive drawdown of 276 ft; well allowed to recover to 175 ft below SWL. Pump restarted at 50 Hz; production rate of 13.5 gpm. Pump shut down due to excessive drawdown of 262 ft. Well allowed to recover overnight.
12/09/2016	Conducted one pumping interval in Mode 1 at 45 Hz, 66 amps, 217 volts, and two pumping intervals at 50 Hz, 70 to 72 amps, 242 volts to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started at 45 Hz with production rate of 13 to 14 gpm. Production rate decreased considerably and pump shut down with a drawdown of 190 ft; well allowed to recover to 160 ft below SWL. Pump restarted for second time at 50 Hz; production rate at 13.5 gpm. Pump again shut down due to excessive drawdown of 304 ft (within 10 ft of pump intake); well allowed to recover to 200 ft below SWL. Pump restarted for a third time in Mode 1; production rate of 13.5 gpm. Pump shut down due to excessive drawdown of 301 ft. Well allowed to recover overnight.
12/10/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, 71 amps, 242 volts, to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started; production rate of 12 to 13 gpm. Pump shut down due to excessive drawdown of 301 ft; well allowed to recover to 100 ft below SWL. Pump restarted at 50 Hz; production rate at 13.3 gpm. Pump again shut down due to excessive drawdown of 301 ft; well allowed to recover to 100 ft below SWL. Pump restarted at 50 Hz; production rate of 12.5 gpm. Pump shut down due to excessive drawdown of 296 ft. Well allowed to recover overnight.

Table 3-1
Detailed Summary of WDT Activities at Well ER-3-3
(Page 4 of 4)

Date[a]	Activities
12/11 to 12/12/2016	No activity on site.
12/13/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, 71 amps, 242 volts, to improve well production. Pump started; production rate of 12 to 13 gpm. Daily tritium sample and water-quality samples collected during pumping. Pump shut down due to excessive drawdown of 288 ft; well allowed to recover to 88 ft below SWL. Pump restarted at 50 Hz; production rate at 13 gpm. Pump again shut down due to excessive drawdown of 306 ft; well allowed to recover to 105 ft below SWL. Pump restarted at 50 Hz; production rate of 12.5 gpm. Pump shut down due to excessive drawdown of 307 ft. Well allowed to recover overnight.
12/14/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, 71 amps, 242 volts, to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started; production rate of 12 to 13 gpm. Pump shut down due to excessive drawdown of 306 ft; well allowed to recover to 105 ft below SWL. Pump restarted at 50 Hz; production rate at 13.5 gpm. Pump again shut down due to excessive drawdown of 304 ft; well allowed to recover to 104 ft below SWL. Pump restarted at 50 Hz; production rate of 13.5 gpm. Pump shut down due to excessive drawdown of 304 ft. Well allowed to recover overnight.
12/15/2016	Conducted three pumping intervals in Mode 1 at 50 Hz, 71 amps, 242 volts, to improve well production. Daily tritium sample and water-quality samples collected during pumping. Pump started; production rate of 12 to 13 gpm. Pump shut down due to excessive drawdown of 306 ft; well allowed to recover to 105 ft below SWL. Pump restarted at 50 Hz; production rate at 13 gpm. Pump again shut down due to excessive drawdown of 295 ft; well allowed to recover to 95 ft below SWL. Pump restarted at 50 Hz; production rate of 13 gpm. Pump shut down due to excessive drawdown of 297 ft. Well allowed to recover overnight.
12/16/2016	Pump started in Mode 1 at 50 Hz, VSC at 71 amps and 242 volts; production rate of 12 to 13 gpm. Daily tritium sample and water-quality samples collected before groundwater sampling. GWC samples were collected before pump shutting down due to excessive drawdown of 268 ft. A total of 9,416 gallons (gal) of groundwater was pumped from the well during WDT activities. Recovery monitored in p1 piezometer; final pumping data download. WDT activities completed.
12/17/2016 to 01/03/2017	No activity on site.
01/04 to 01/05/2017	Completed demobilization of equipment and facilities.

[a] The WDT information is provided in the Navarro UGTA WDT Morning Reports and Logbook for Well ER-3-3. The chronology of operations is based on 24-hour operational days ending at 07:00 on the date shown.The dates shown agree with the dates on the respective morning reports.The dates shown reflect the beginning and end of an activity, and not the operational days to complete the activity.

3.2.2 Well ER-4-1

Table 3-2 provides a detailed schedule of daily WDT activities conducted at Well ER-4-1.

Table 3-2
Detailed Summary of WDT Activities at Well ER-4-1
(Page 1 of 7)

Date[a]	Activities
12/15/2016	DRI personnel rigged up and calibrated the Fluid Temperature Conductivity (FTC) tool in the m1 main completion. The tool stopped collecting data multiple times, and DRI troubleshot the tool. No data were obtained from the FTC tool.
12/16/2016	DRI personnel rigged up and calibrated Idronaut chemistry tool. DRI TIH with tool and logged down from 0 to 2,957 ft bgs at 50 ft/min. DRI DTW from Idronaut log measured at 1,772 ft bgs. Tool rinsed with water on out run; post-calibrated; data obtained from tool.
12/17/2016 to 01/04/2017	No activity on site.
01/05/2017	Mobilization of equipment and facilities. Removed PXD from p1 piezometer, then measured DTW in same at 1,051.16 ft bgs. Tagged fill with sinker bar in m1 main completion at 2,956 ft bgs.
01/06/2017	Continued mobilization of equipment and facilities. DTW measured in the m1 main completion at 1,768.44 ft bgs. Tritium samples were collected with a depth-discrete bailer from the p1 piezometer at 2,045 ft bgs. Workover rig positioned at well; mast raised; guy wire installed. Rig floor, catwalk, and pipe racks moved into position.
01/07 to 01/09/2017	No activity on site.
01/10/2017	Completed mobilization of equipment and facilities.
01/11/2017	Baker Hughes personnel serviced the lower and upper pump motors, and pump seal. The intake was connected to top of seal, and then the pump was installed onto the intake. The resistance of the tandem motors was below specifications.The tandem pump motors were replaced by different motors. The replacement motors were serviced and remeasured for resistance, which was within specifications.
01/12/2017	Baker Hughes personnel serviced the pump seal and measured the pump motor through the power cord for resistance; readings within specifications. Pump was then run into the m1 main completion casing and landed at 2,139.28 ft bgs with the intake set at 2,088.51 ft bgs.
01/13/2017	A 1.9-in. CS access line was installed within the m1 main completion casing at 2,021.40 ft bgs, approximately 42.2 ft above top of the dedicated pump. Baker Hughes personnel remeasured resistance of pump motor through the power cable; readings within specifications. The pump power cable was connected to the VSC and programmed with high clamp at 65 Hz, low clamp at 30 Hz, overload at 134 amps, under-load at 36 amps, voltage at 480, and frequency at 47 Hz. The workover rig and associated equipment was secured and moved away from the wellhead. DTW measured in 1.9-in. access line (m1_a) at 1,777.95 ft bgs. A PXD was installed in the access line and landed at 2,010 ft bgs (115.848 psi), approximately 242 ft below the water level.
01/14/2017	A PXD was installed in the p1 piezometer and landed at 1,075 ft bgs (22.501 psi). Wellhead manifold, flow meter, and discharge hoses positioned. Function test of pump conducted. Pump started in forward rotation at 50 Hz in Mode 1; after 1 minute, the VSC displayed an error message of F-14 overload. The overload on the VSC was reset to 160 amps then restarted. After 4 minutes, the pump shut down due to excessive drawdown of greater than 236 ft. The recovery was monitored until water level reached approximately 37 ft from pre-pumping level. The pump was then restarted at 44 Hz; water to surface in 2 minutes with a production rate of 17 gpm. Daily tritium sample and water-quality samples collected. Six minutes after starting pump, the production rate dropped from 17 to 0 gpm; readings from PXD indicated that water had not been drawn down below the PXD. Pump shut off; hoses drained.

Table 3-2
Detailed Summary of WDT Activities at Well ER-4-1
(Page 2 of 7)

Date[a]	Activities
01/15 to 01/17/2017	No activity on site.
01/18/2017	Pump started Mode 1 at 47 Hz as it was determined that 44 Hz was not enough to overcome the hydrostatic head. Water to surface immediately; daily tritium sample and water-quality sample collected. Pump shut off after approximately 19 minutes with the water level drawn down past the PXD. Recovery of well monitored, then pump restarted at 47 Hz, 139 amps, 383 volts, with production rate of approximately 40 gpm. After 18 minutes, the pump again shut off and production rate had dropped to 30 gpm. Pump again restarted at 47 Hz, 138 amps, 382 volts, with production rate of 40 gpm. Pump was shut off overnight and well allowed to recover. Water-quality samples collected during pumping.
01/19/2017	The PXD in the access line was removed and DTW was measured at 1,769.15 ft bgs, approximately 8.8 ft lower than measured on 01/12/2017. The PXD was reinstalled in the access line. A step-rate test was conducted with the pump started in Mode 1 at 50 Hz with production rate of approximately 51 gpm; rate decreased to approximately 47 gpm. The VSC frequency was then increased to 55 Hz, 449 volts, 152 amps, with a rate of 69.5 gpm. After 20 minutes, the frequency was lowered to 50 Hz due to excessive drawdown of 226 ft. Well began to recover, and the frequency was lowered to 47 Hz with a rate of about 29 gpm. Daily tritium and water-quality samples collected during pumping operations. Pump ran at 47 Hz overnight.
01/20/2017	Pump continued to run overnight at 47 Hz, 136 amps, 382 volts, 49,450 gal of water purged from well, with 128.5 ft of drawdown in the m1 completion; pump then shut off and well was allowed to recover. After 1.5 hours, the second step-rate test was conducted. The pump was started in Mode 1 at 48 Hz, 135 amps, 382 volts; production rate of approximately 40 gpm; drawdown stabilized at 10 ft. After 1 hour, the frequency was increased to 50 Hz with 141 amps, 408 volts, water production increased to 50 gpm; drawdown in m1 zone increased to 14.94 ft. After 1 hour, frequency of VSC increased to 52 Hz with 147 amps and 423 volts, production increased to 59 gpm; drawdown increased to 31.53 ft and had not stabilized. After 1 hour, frequency of VSC increased to 54 Hz with 151 amps and 439 volts, production increased to 67 gpm; drawdown increased to 36.40 ft. Attempted to test VSC in Mode 2 at 66 gpm; VSC panel locked up and settings could not be input; drawdown was 54.84 ft. Pump was then shut off to reset the VSC; the control panel was changed out and pump parameters reentered. Daily tritium and water-quality samples collected during pumping operations. Pump restarted in Mode 1 at 50 Hz and allowed to run overnight.
01/21/2017	Pump continued to run overnight at 50 Hz, 144 amps, 408 volts, production rate of approximately 49 gpm with drawdown from m1 zone of 18.8 ft, 112,110 gal purged. Daily tritium and water-quality sample collected. Pump was then shut off and well allowed to recover; within 5 minutes, well had recovered to 2.5 ft below SWL. Pump was started in Mode 1 at 50 Hz with 49 gpm; after water was to surface, the VSC was switched from Mode 1 to Mode 2 but did not communicate with flow meter. Pump shut off due to low frequency while in Mode 2; insufficient to pump water to surface. Pump restarted in Mode 1 at 50 Hz; switched to Mode 2 and raised the low clamp to 50 Hz with pumping rate at 50 gpm, and drawdown of 11.2 ft in m1 zone. The VSC was then set at 55 Hz in Mode 2, low clamp adjusted to 55 Hz; after 10 minutes, VSC shut down with F-19 underload error. Daily tritium and water-quality samples collected during pumping operations. VSC reset, and pump restarted in Mode 1 at 52 Hz and allowed to run overnight.

Table 3-2
Detailed Summary of WDT Activities at Well ER-4-1
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Date[a]	Activities
01/22/2017	Pump continued to run overnight in Mode 1 at 52 Hz, 146 amps, 423 volts, 184,547 gal purged at rate of approximately 57 gpm with drawdown from m1 zone of 44.8 ft. Pump was then shut off and well allowed to recover; within 5 minutes, well had recovered to 2.5 ft below SWL. Pump started in Mode 2 but desired pumping rate could not be entered into VSC; pump shut down. Troubleshoot the VSC and flow meter to operate in Mode 2 with no success. Reset VSC and start pump in Mode 1 at 52 Hz; pump allowed to run overnight.
01/23/2017	Pump continued to run overnight in Mode 1 at 52 Hz, 140 amps, 415 volts, 253,357 gal purged at rate of approximately 56 gpm with drawdown from m1 zone of 44.8 ft. Pump was then shut off and well allowed to recover; within 5 minutes, well had recovered to 2.0 ft below SWL. Continued step-rate test; started pump in Mode 1 at 50.5 Hz, production rate of 50 gpm, drawdown in m1 zone of 13.38 ft. Attempted to set production rate at 70 gpm on VSC in Mode 2 with no success. Switched to Mode 1, and changed frequency to 55.2 Hz with production rate of 70 gpm, drawdown in m1 zone of 59.53 ft, 268,824 gal pumped. Frequency increased to 61.8 Hz in Mode 1, production rate increased to 90 gpm, drawdown in m1 zone of 158.43 ft, 275,089 gal purged. Daily tritium and water-quality samples collected during pumping operations. Step-rate test completed; VSC set to Mode 1 at 50 Hz; pump allowed to run overnight.
01/24/2017	Pump continued to run overnight in Mode 1 at 50 Hz, 137 amps, 399 volts, 327,712 gal purged at rate of approximately 45 gpm with drawdown from m1 zone of 62 ft. Pump was then shut off for 1 hour. Continued step-rate test in 2-hour increments; started pump in Mode 1 at 50.5 Hz, production rate of 49.7 gpm; drawdown in m1 zone of 9.96 ft with 333,589 gal purged. Second step-rate test conducted in Mode 1 with starting frequency of 55.1 Hz increasing to 55.4 Hz, production rate of 70.1 gpm, 44.10 ft of drawdown in m1 zone. Third step-rate test conducted in Mode 1 with starting frequency of 61 Hz with production rate of 90 gpm. Frequency was increased in steps to 62.1 Hz due to decreasing production rate; stabilized at 90 gpm, with 144.44 ft of drawdown. Daily tritium and water-quality samples collected during pumping operations. Step-rate test completed; VSC set to Mode 1 at 50 Hz; pump allowed to run overnight.
01/25/2017	Pump not running upon arrival on site. Pump restarted in Mode 1, 50 Hz, production rate of 45 gpm. VSC then shut down with F-15 fault; generator was lugging down, which caused the VSC fault. Site generator shut down, and auxiliary generator started. Pump restarted in Mode 1, 50 Hz, 141 amps, 339 volts, production rate of 45 gpm. Attempted to switch to Mode 2 and 50 gpm; VSC Hz dropped to low clamp setting. VSC switched back to Mode 1, 50.8 Hz, production rate stable at 50.2 gpm, drawdown of 9.14 ft in m1 zone. Attempted to switch to Mode 2 unsuccessfully multiple times; troubleshoot VSC Mode 2 issue. Daily tritium and water-quality samples collected during pumping operations. Pump shut down with approximately 403,000 gal purged at 49.9 gpm. The Centrilift 4500 VSC replaced with a Centrilift 2200 VSC, the auxiliary generator was shut down and site generator restarted. The replacement VSC key pad and control board were replaced, but the VSC continued to shut down with error message when it was restarted. Pump remained off overnight.

Table 3-2
Detailed Summary of WDT Activities at Well ER-4-1
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Date[a]	Activities
01/26/2017	Site generator shut off, original VSC reconnected and “no load” test conducted and checked good. Started first step-rate test in Mode 1, 50.4 Hz, production rate of 50 gpm, water to surface immediately; frequency increased to 50.8 Hz to maintain 50 gpm. Second step-rate test conducted at 70 gpm, 55.2 Hz, 148 amps, 443 volts, drawdown in m1 zone of 19 ft. To maintain 70 gpm, the frequency was increased to 55.3 Hz. Water production rate decreased to 69.7 gpm and the frequency was increased to 55.4 Hz which produced a rate of 70.2 gpm. Drawdown in m1 zone at 5.5 ft, a total of 426,890 gal purged. Daily tritium and water-quality samples collected during pumping operations. Pump allowed to run overnight in Mode 1 at 55.4 Hz.
01/27/2017	Pump continued to run overnight in Mode 1 at 55.4 Hz, production rate of 70 gpm with drawdown from m1 zone of 39.2 ft. Pump shut off and well allowed to recover. Centrilift personnel troubleshoot VSC, inspected internal connections in VSC and settings were reviewed with no issues found. Pump started in Mode 1, 50.5 Hz, 48.3 gpm; switched VSC to Mode 2 at 50 gpm; frequency dropped to low clamp setting; pump and site generator shut off. Interface boards replaced on VSC. Pump restarted in Mode 1, 50.7 Hz, 49 gpm then switched to Mode 2; frequency dropped and pump shut off. Digital interface board replaced on VSC; pump restarted in Mode 1, 50.7 Hz, 49 gpm; switched to Mode 2; frequency dropped and pump shut off. Pump restarted in Mode 1, 50.8 Hz, 145 amps, 405 volts, with a production rate of 49.8 gpm. Pumped for 1 hour, then increased frequency to 55.4 Hz with production rate of 69.9 gpm, 147 amps, 443 volts. Daily tritium and water-quality samples collected during pumping operations. Pump allowed to run overnight in Mode 1 at 55.5 Hz, 70 gpm.
01/28/2017	Pump continued to run overnight in Mode 1 at 55.4 Hz, production rate of 70 gpm with drawdown from m1 zone of 39.8 ft, 572,059 gal purged. Pump shut off and well allowed to recover for 1 hour; well recovered to 1 ft below SWL. Pump started in Mode 1, 55.5 Hz, 70.1 gpm, with drawdown in m1 at 28.9 ft. Production rate decreased to 69.8 gpm and frequency was increased to 55.8 Hz which produced a rate of 70.20 gpm, with drawdown in m1 at 43.82 ft. After 3 hours, the VSC frequency was increased to 62 Hz with a production rate of approximately 90 gpm. Readings began fluctuating so frequency was lowered to 58.7 Hz with production rate of approximately 80 gpm. Readings continued to fluctuate; shut down pump and switched to backup generator. The well recovered to 3.5 ft of static; pump restarted in Mode 1, 58.3 Hz, 80 gpm; frequency increased to 61.7 Hz, 90 gpm, drawdown in m1 of 69.8 ft. Production rate decreased to 89.5 gpm, so frequency was increased to 61.9 Hz with rate increasing to 90.2; drawdown in m1 at 95.864 ft; 602,080 total gal purged. Daily tritium and water-quality samples collected during pumping operations. Pump shut down over weekend.
01/29 to 01/30/2017	No activity on site.
01/31/2017	Both Centrilift VSCs were disconnected, rigged down, and moved off site. A Schlumberger UNICONN 200 KVA VSC was brought to the site and connected to site power and energized, then shut down for the night.
02/01/2017	No activity on site.

Table 3-2
Detailed Summary of WDT Activities at Well ER-4-1
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Date[a]	Activities
02/02/2017	Schlumberger personnel function tested the VSC in Target Speed (Mode 1) and Feedback (Mode 2) via the Schlumberger laptop computer; the management and operating (M&O) contractor laptop did not communicate with VSC. Pump started in Target Speed at 50 Hz, no water to surface; pump rotation changed, water to surface immediately. VSC Target Speed adjusted to 52.5 Hz with production rate of 50 gpm. Frequency increased to 57 Hz, production rate of 70 gpm. Frequency increased again to 64.1 Hz with production rate of 90 gpm. VSC settings changed from Target Speed to Feedback at 50 gpm. Production rate decreased numerous times and Target Speed was reset to 53.3 Hz; VSC settings adjusted to compensate for fluctuations in signal from flow meter. Schlumberger personnel troubleshoot VSC operations at 70 and 90 gpm. Pump, VSC, and site power shut down to hook up auxiliary generator; site power restored. Pump restarted in Feedback at 50 gpm, then increased to 70 gpm and 90 gpm. At 90 gpm, rate began to decrease; pump was running at maximum set frequency. VSC parameters re-adjusted to 62 Hz with production rate of 80 gpm; pump allowed to run overnight. Daily tritium and water-quality samples collected during pumping operations.
02/03/2017	Pump continued to run overnight in Feedback (Mode 2) at 61.8 Hz, 145.3 amps, 364.4 volts, production rate of 80.45 gpm with drawdown from m1 zone of 117.6 ft, 696,270 gal purged. Daily tritium and water-quality samples collected. Pump shut down for weekend; at end of shift total purged volume was 697,986 gal and well had recovered to within 4.5 ft below SWL.
02/04 to 02/06/2017	No activity on site.
02/07/2017	M&O contractor connected laptop computer to VSC, set Target Speed at 58.5 Hz, production rate of 82 gpm. VSC switched to Feedback at 70 gpm, but production continued at 82 gpm, VSC reading 61 Hz, 146.1 amps, 360.8 volts. Determined that M&O contractor laptop was not communicating with VSC. Settings for Target Speed and Feedback input manually; pump started in Target Speed at 58.5 Hz, 71 gpm; VSC switched to Feedback at 70 gpm, production decreased to 38 gpm. Troubleshoot VSC issues. Pump restarted in Target Speed at 58.5 Hz, 72.5 gpm; VSC switched to Feedback at 70 gpm. Daily tritium and water-quality samples collected during pumping operations; one low-level tritium sample also collected. Pump then shut off and well allowed to recover overnight.
02/08/2017	Day 1 of constant-rate test at 70-71 gpm. Started VSC in Target Speed at 58.5 Hz, production rate of 72 gpm. VSC was set to run in Feedback at 70 gpm. Pump ran steady at 70-71 gpm, 56.3 HZ, 125.2 amps, 420.3 volts. At end of shift 728,902 gal of groundwater had been purged; drawdown in m1 was 38.93 ft, and drawdown in p1 was -7.1 ft. Daily tritium and water-quality samples collected during pumping operations; a low-level tritium sample was also collected. Pumping continued at 70-71 gpm overnight.
02/09/2017	Day 2 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70-71 gpm, 56.9 Hz, 126.7 amps, 424.8 volts. At end of shift 830,931 gal of groundwater had been purged; drawdown in m1 was 57 ft. Daily tritium and water-quality samples collected during pumping operations. Pumping continued at 70-71 gpm overnight.
02/10/2017	Day 3 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70-71 gpm, 57 Hz, 126.7 amps, 426 volts. The maximum speed frequency (high clamp) was increased to 58 Hz to prevent the possibility of reaching peak Hz values and causing a decrease in production rate below 70 gpm. At end of shift 932,830 gal of groundwater had been purged; drawdown in m1 was 65.96 ft. Daily tritium and water-quality samples collected during pumping operations. Pumping continued at 70-71 gpm overnight.

Table 3-2
Detailed Summary of WDT Activities at Well ER-4-1
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Date[a]	Activities
02/11/2017	Day 4 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70-71 gpm, 57.1 Hz, 126.5 amps, 427.6 volts, with drawdown in m1 at 71.82 ft and in p1 at -6.28 ft. At end of shift 1,036,219 gal of groundwater had been purged; drawdown in m1 was 70.6 ft. Daily tritium and water-quality samples collected during pumping operations. Pumping continued at 70-71 gpm overnight.
02/12/2017	Day 5 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70-71 gpm, 57.1 Hz, 127.3 amps, 428.2 volts, with drawdown in m1 at 78.16 ft and in p1 at -6.93 ft. At end of shift 1,137,005 gal of groundwater had been purged; drawdown in m1 was 81.01 ft. Daily tritium and water-quality samples collected during pumping operations; a low-level tritium sample was also collected. Pumping continued at 70-71 gpm overnight.
02/13/2017	Day 6 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70-71 gpm, 57.1 Hz, 127.2 amps, 427.2 volts, with drawdown in m1 at 85.63 ft and in p1 at -6.89 ft. At end of shift 1,238,384 gal of groundwater had been purged; drawdown in m1 was 84.58 ft. Daily tritium and water-quality samples collected during pumping operations; a low-level tritium sample was also collected for offsite analysis. Pumping continued at 70-71 gpm overnight.
02/14/2017	Day 7 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70-71 gpm, 57.2 Hz, 127.2 amps, 428.9 volts, with drawdown in m1 at 81.85 ft and in p1 at -7.51 ft. At end of shift 1,339,949 gal of groundwater had been purged; drawdown in m1 was 85.07 ft. Daily tritium and water-quality samples collected during pumping operations. Pumping continued at 70-71 gpm overnight.
02/15/2017	Day 8 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70-71 gpm, 57.2 Hz, 127.5 amps, 428.5 volts, with drawdown in m1 at 80.97 ft and in p1 at -7.79 ft. At end of shift 1,441,959 gal of groundwater had been purged; drawdown in m1 was 79.27 ft. Daily tritium and water-quality samples collected during pumping operations. Pumping continued at 70-71 gpm overnight.
02/16/2017	Day 9 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 71 gpm, 57.5 Hz, 128.2 amps, 432.1 volts, with drawdown in m1 at 87.4 ft and in p1 at -8.14 ft. At end of shift 1,543,033 gal of groundwater had been purged; drawdown in m1 was 87.44 ft. Daily tritium and water-quality samples collected during pumping operations. Pumping continued at 70-71 gpm overnight.
02/17/2017	Day 10 of constant-rate test at 70-71 gpm. Pump continued to run steady in Feedback at 70 gpm, 57.5 Hz, 128.2 amps, 431.9 volts, with drawdown in m1 at 94.0 ft and in p1 at -5.17 ft. At end of shift 1,644,628 gal of groundwater had been purged; drawdown in m1 was 94.26 ft. Daily tritium and water-quality samples collected during pumping operations; one low-level tritium sample was also collected for offsite analysis. Pumping continued at 70-71 gpm overnight.
02/18/2017	Pump continued to run overnight in Feedback at 57.6 Hz, VSC at 128.6 amps and 233.5 volts; production rate of 70.9 gpm. Water-quality samples were collected before groundwater sampling, and a final water-quality and the daily tritium sample were collected after sampling. GWC samples were collected from the wellhead manifold. A total of 1,732,160 gal of groundwater was pumped from the well during WDT activities. The pump was shut off and the m1 zone had recovered to approximately 4.5 ft below SWL in 4 minutes; final pumping data download. WDT activities completed.

Table 3-2
Detailed Summary of WDT Activities at Well ER-4-1
(Page 7 of 7)

Date[a]	Activities
02/19 to 02/21/2017	No activity on site.
02/22 to 02/23/2017	Completed demobilization of equipment and facilities.

[a] The WDT information is provided in the Navarro UGTA WDT Morning Reports and Logbook for Well ER-4-1. The chronology of operations is based on 24-hour operational days ending at 07:00 on the date shown.The dates shown agree with the dates on the respective morning reports.The dates shown reflect the beginning and end of an activity, and not the operational days to complete the activity.

3.3 DTW Measurements

DTW measurements were made with calibrated electric tapes (e-tapes) on select dates as well as before installation and after removal of PXDs. These water levels are measured as part of the LTWLM program. The water levels measured after PXDs were removed from the piezometers in preparation for WDT activities are assumed to represent the ambient, pre-pumping (pre-WDT) equilibrium head. This assumption can be evaluated based on the PXD pressures recorded at the times at which stresses were applied to the well, as identified in the activity schedule (Tables 3-1 and 3-2).

3.3.1 Well ER-3-3

DTW measurements in the m1 main completion and the p1, p2, and p3 piezometers in ER-3-3 are listed in Table 3-3.

Table 3-3
Well ER-3-3 Water-Level Measurements
(Page 1 of 2)

Date	Activity	DTW (ft bgs) [a]	DTW (m bgs)	Water-Level Elevation	
				(ft amsl)	(m amsl)
m1 Main Completion					
11/15/2016	DRI Logging	1,653.43	503.97	2,403.42	732.56
p1 Piezometer					
11/08/2016	PXD Removal	1,658.29	505.45	2,398.56	731.08
11/29/2016	PXD Installation	1,667.44	508.24	2,389.41	728.29
01/03/2017	PXD Removal	1,645.85	501.66	2,411.00	734.87
01/05/2017	PXD Installation	1,644.34	501.19	2,412.51	735.33

Table 3-3
Well ER-3-3 Water-Level Measurements
(Page 2 of 2)

Date	Activity	DTW (ft bgs) [a]	DTW (m bgs)	Water-Level Elevation	
				(ft amsl)	(m amsl)
p2 Piezometer					
11/08/2016	PXD Removal	1,653.18	503.89	2,403.67	732.64
11/29/2016	PXD Installation [b]	1,653.00	503.83	2,403.85	732.69
11/30/2016	PXD Installation	1,653.05	503.85	2,403.80	732.68
01/03/2017	PXD Removal	1,653.04	503.85	2,403.81	732.68
01/05/2017	PXD Installation	1,652.78	503.77	2,404.07	732.76
p3 Piezometer					
11/08/2016	PXD Removal	1,444.06	440.15	2,612.79	796.38

[a] Water levels for LTWLM program.
[b] PXD installation aborted due to inclement weather.

Ground surface elevation = 4,056.85 ft amsl
1 ft = 0.3048 m

3.3.2 Well ER-4-1

DTW measurements in the m1 main completion and the p1 piezometer in ER-4-1 are listed in Table 3-4.

Table 3-4
Well ER-4-1 Water-Level Measurements

Date	Activity	DTW (ft bgs) [a]	DTW (m bgs)	Water-Level Elevation	
				(ft amsl)	(m amsl)
m1 Main Completion and m1_a Access Line					
12/12/2016	PXD Removal	1,768.92	539.17	2,389.17	728.22
04/03/2017	PXD Removal	1,769.10	539.22	2,388.99	728.16
04/25/2017 [b]	PXD Installation	1,769.03	539.20	2,389.06	728.19
p1 Piezometer					
01/04/2017	PXD Removal	1,051.16	320.39	3,106.93	947.00
04/03/2017	PXD Removal	1,037.93	316.36	3,120.16	951.03
04/25/2017	PXD Installation	1,038.99	316.68	3,119.10	950.70

[a] Water levels for LTWLM program.
[b] Water level measured in m1_a access line.

3.4 LTWLM PXD Installation

PXDs were installed in the piezometers and/or access lines in ER-3-3 and ER-4-1 before WDT activities for data collection as part of the LTWLM program.

Typically during pump testing, the monitored interval is a substantial vertical distance below the top of the water column. During pumping, the temperature distribution in the well may change during the monitoring period. To eliminate the potential temperature effects on the pressures monitored, an INW PT12 PXD rated for 0 to 2,000 pounds per square inch absolute (psia) was used to monitor the water level in the piezometer for WDT activities. The PXD was set to near the base of the screened interval in the piezometer.

The PXD installation depth is calculated by the use of the DTW measurement and the PXD pressure at the installation depth attributable to water pressure. The PXD pressure at the set depth minus the PXD pressure in air above the water surface is multiplied by a calculated density conversion factor to give the PXD depth below the SWL. The PXD depth below SWL is then added to the measured DTW to determine the PXD installation depth.

The PXD installation depth is calculated rather than measured because of two uncertainties associated with the direct depth measurement provided by the wireline unit: (1) the hanging length of the cable is not as accurately known, as the length of the e-tape and cannot be measured directly; and (2) when the PXD is removed, the wireline counter may not return to zero. The counter reading at the top of the casing during removal is recorded as the wireline offset value. The wireline offset value provides an indication of the uncertainty of the depth measurements from differences in wireline diameters and slippage in the wireline counter.

The PXD installation depth is generally checked by calculating the removal depth using a DTW measurement made after the PXD is removed from the well. When water levels and water temperature are relatively stable, there is generally good agreement between the calculated installation and removal depths.

3.5 Predevelopment Monitoring

3.5.1 Well ER-3-3

The ER-3-3 p1, p2, and p3 piezometers were instrumented on September 8 and September 13, 2016, with 0 to 30 psia PXDs for data collection as part of the LTWLM program. Pressure data and groundwater temperatures were recorded until the PXDs were removed November 8, 2016, in preparation for the WDT activities. The PXD in p1 piezometer was installed at a depth of 1,679.32 ft bgs; the PXD in p2 piezometer was installed at a depth of 1,673.14 ft bgs; and the PXD in the p3 piezometer was installed at a depth of 1,464.42 ft bgs. Figures 3-1 through 3-3 show the PXD and barometric pressure data for the predevelopment period in the p1, p2, and p3 piezometers. The scale of the barometric pressure readings, shown in millibar (mBar), has been adjusted to be comparable with the scale of the PXD pressure reading, shown in psia. The PXD pressures shown in Figures 3-1 through 3-3 are total pressures. Sealed, absolute type PXDs were used to measure the combined water head and barometric pressure on the PXD.

Figure 3-1 (p1 piezometer) shows a slight decrease beginning approximately September 27, 2016, then an increase in the total pressure data from approximately October 18, 2016, for the remainder of the predevelopment monitoring. The barometric pressure, although varied, generally mirrors the total pressure. When the LTWLM program PXD was removed on November 8, 2016, before the WDT began, the DTW measurement was 1,658.29 ft bgs.

Figure 3-2 (p2 piezometer) shows a gradual increase in the total pressure data during the entire predevelopment LTWLM period of September 13 through November 8, 2016. The barometric pressure, although varied, generally mirrors the total pressure. When the LTWLM program PXD was removed on November 8, 2016, before the WDT began, the DTW measurement was 1,653.18 ft bgs.

Figure 3-3 (p3 piezometer) shows a gradual decrease in the total pressure data until approximately October 19, 2016, when the pressure, although varied, was generally stable. The barometric pressure, although varied, generally mirrors the total pressure. When the LTWLM program PXD was removed on November 8, 2016, before the WDT began, the DTW measurement was 1,444.06 ft bgs.

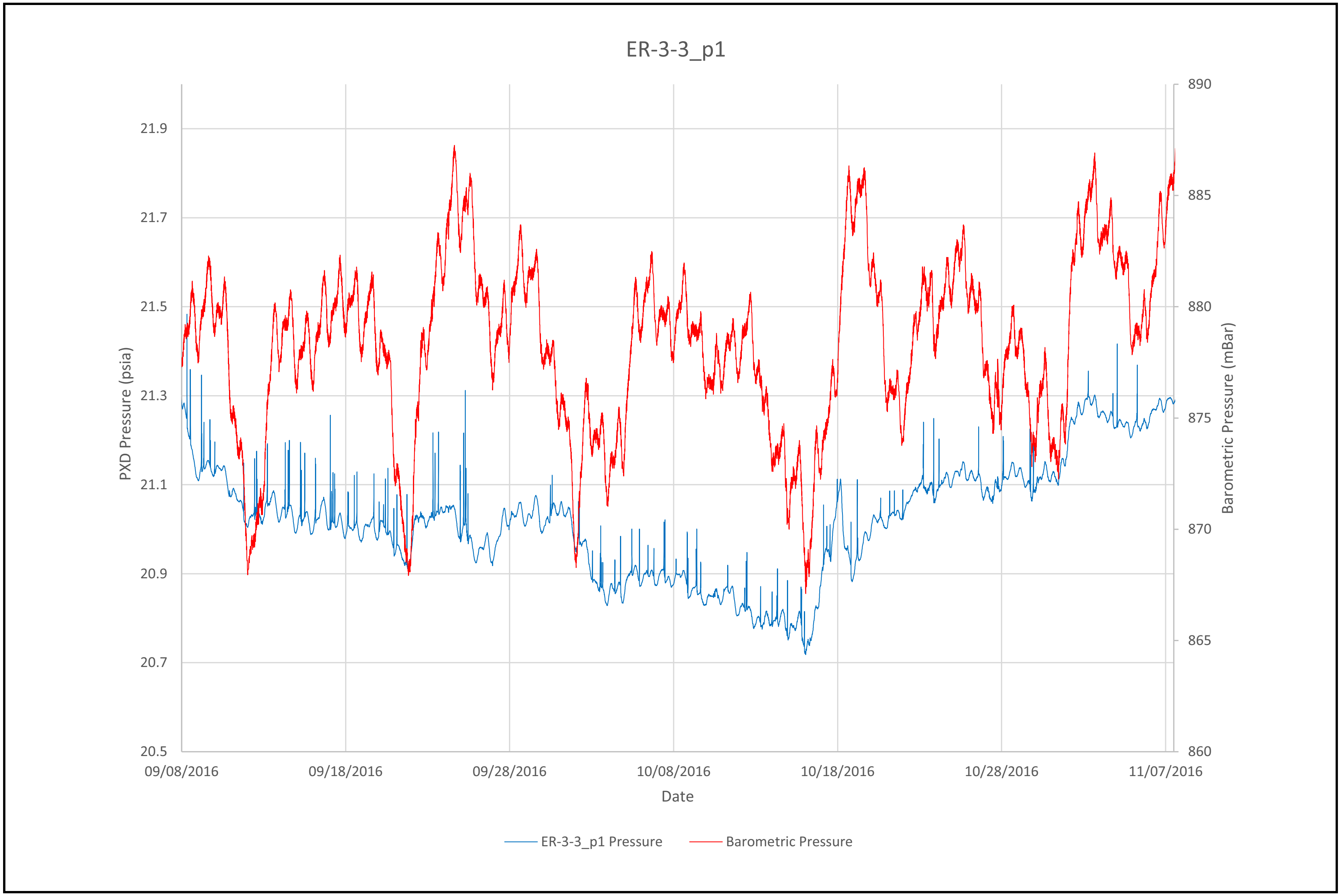

Figure 3-1
Well ER-3-3_p1 Predevelopment Monitoring

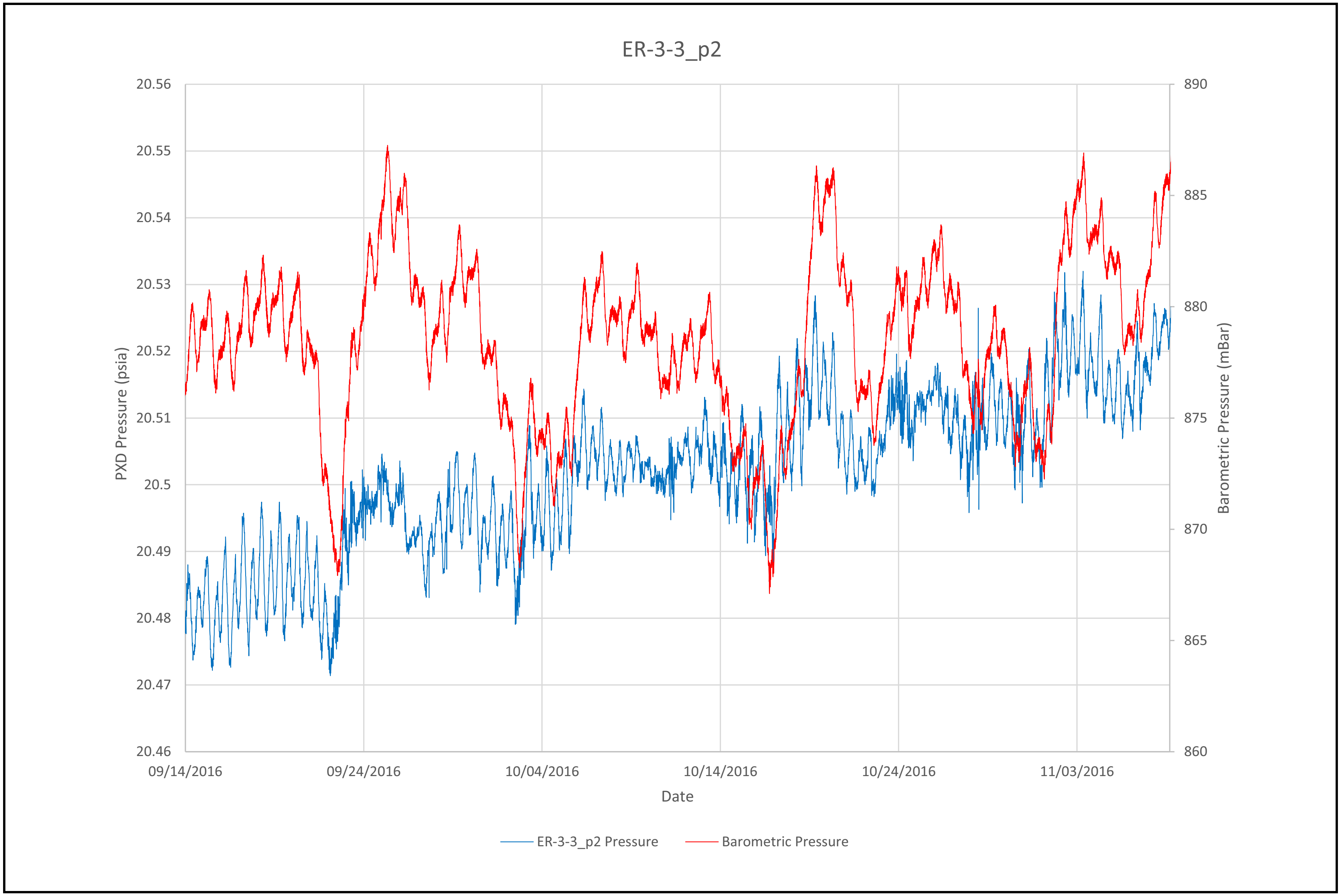

Figure 3-2
Well ER-3-3_p2 Predevelopment Monitoring

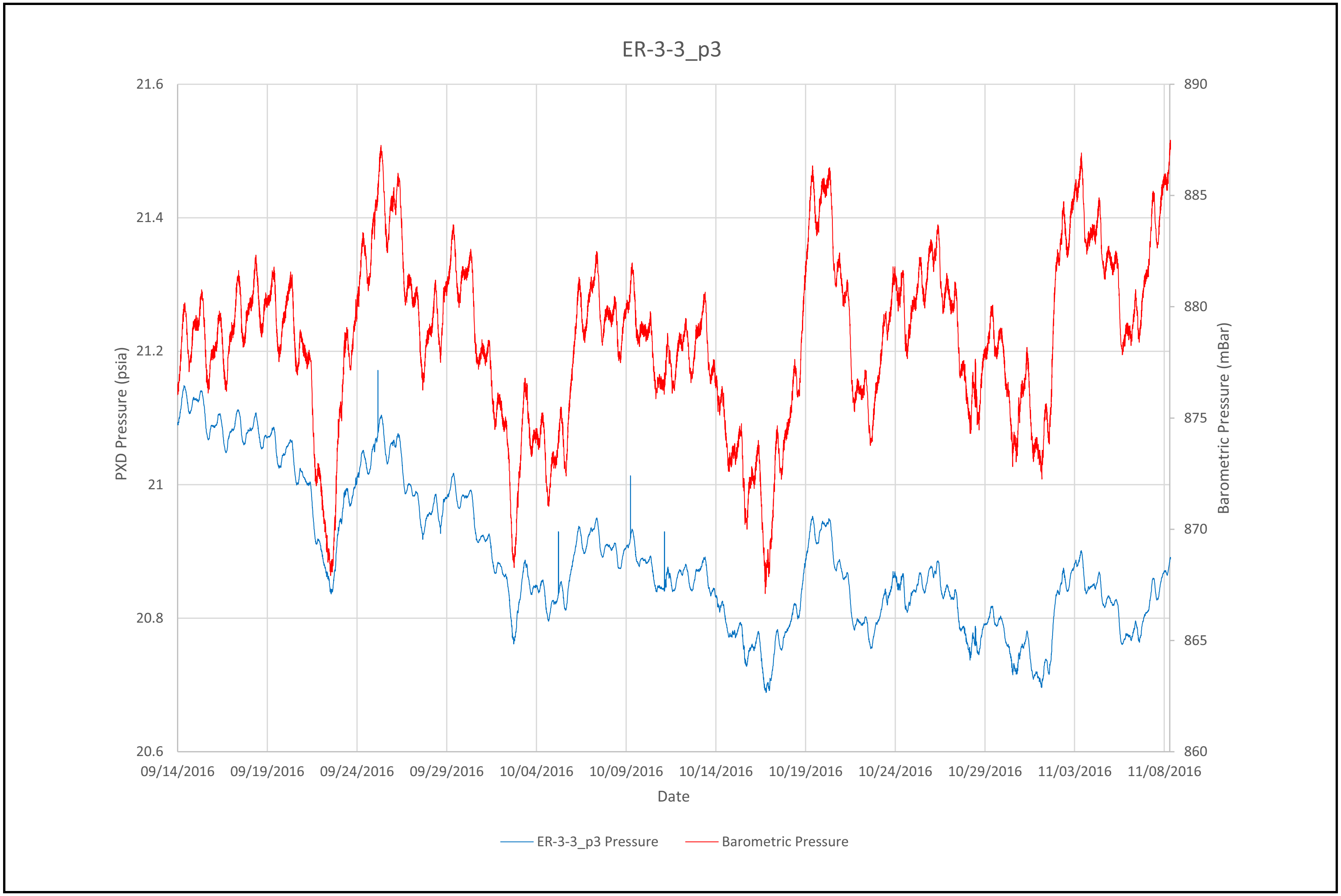

Figure 3-3
Well ER-3-3_p3 Predevelopment Monitoring

3.5.2 Well ER-4-1

The ER-4-1 m1 main completion and the p1 piezometer were instrumented on September 8, 2016, with 0 to 30 psia PXDs as part of the LTWLM program. The PXD in p1 piezometer was installed at a depth of 1,087.75 ft bgs, and the PXD in the m1 main completion was installed at a depth of 1,790.54 ft bgs. Pressure data and groundwater temperatures were recorded until the PXD in the m1 main completion was removed on December 12, 2016, before pump installation. Pressure data were recorded until the PXD in the p1 piezometer was removed on January 4, 2017, in preparation for the pre-WDT hydrophysical logging by DRI and collection of bailer samples. Figures 3-4 and 3-5 show the PXD and barometric pressure data for the predevelopment period in the m1 main completion and p1 piezometer. The scale of the barometric pressure readings, shown in mBar, has been adjusted to be comparable with the scale of the PXD pressure reading, shown in psia. The PXD pressures shown in Figures 3-4 and 3-5 are total pressures. Sealed, absolute type PXDs were used to measure the combined water head and barometric pressure on the PXD.

Figure 3-4 (m1 main completion) shows that, although varied, both the total pressure and barometric pressure were generally stable. The barometric pressure generally mirrors the total pressure. When the LTWLM program PXD was removed on December 12, 2016, before the WDT began, the DTW measurement was 1,768.92 ft bgs.

Figure 3-5 (p1 piezometer) shows an increase in total pressure from the start of LTWLM until about October 22, 2016. The total pressure then dropped on approximately October 27, 2016, a gradual increase of pressure began. The pressure increased until approximately December 9, 2016, when the pressure dropped. Again the total pressure gradually increased for the remainder of the predevelopment monitoring. The barometric pressure, although varied, was generally stable. When the LTWLM program PXD was removed on December 12, 2016, before the WDT began, the DTW measurement was 1,051.16 ft bgs.

3.6 Predevelopment Hydrophysical Logging

3.6.1 Well ER-3-3

DRI personnel conducted a predevelopment logging run on November 15, 2016, before WDT activities. DRI logged the p1 piezometer with a calibrated Idronaut chemistry tool, which measures pressure, temperature, conductivity, pH, redox potential, and dissolved oxygen (DO) with depth. DRI

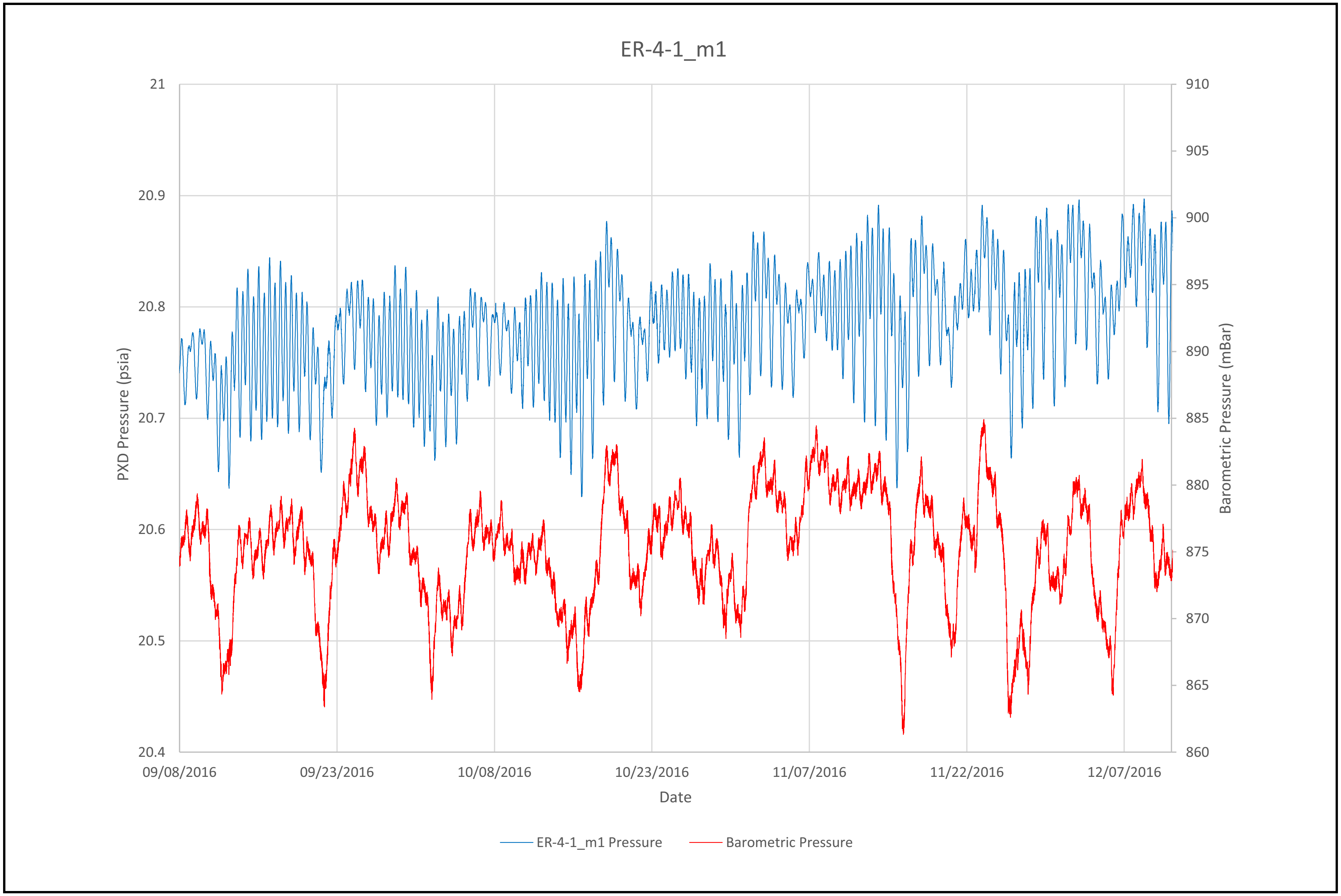

Figure 3-4
Well ER-4-1_m1 Predevelopment Monitoring

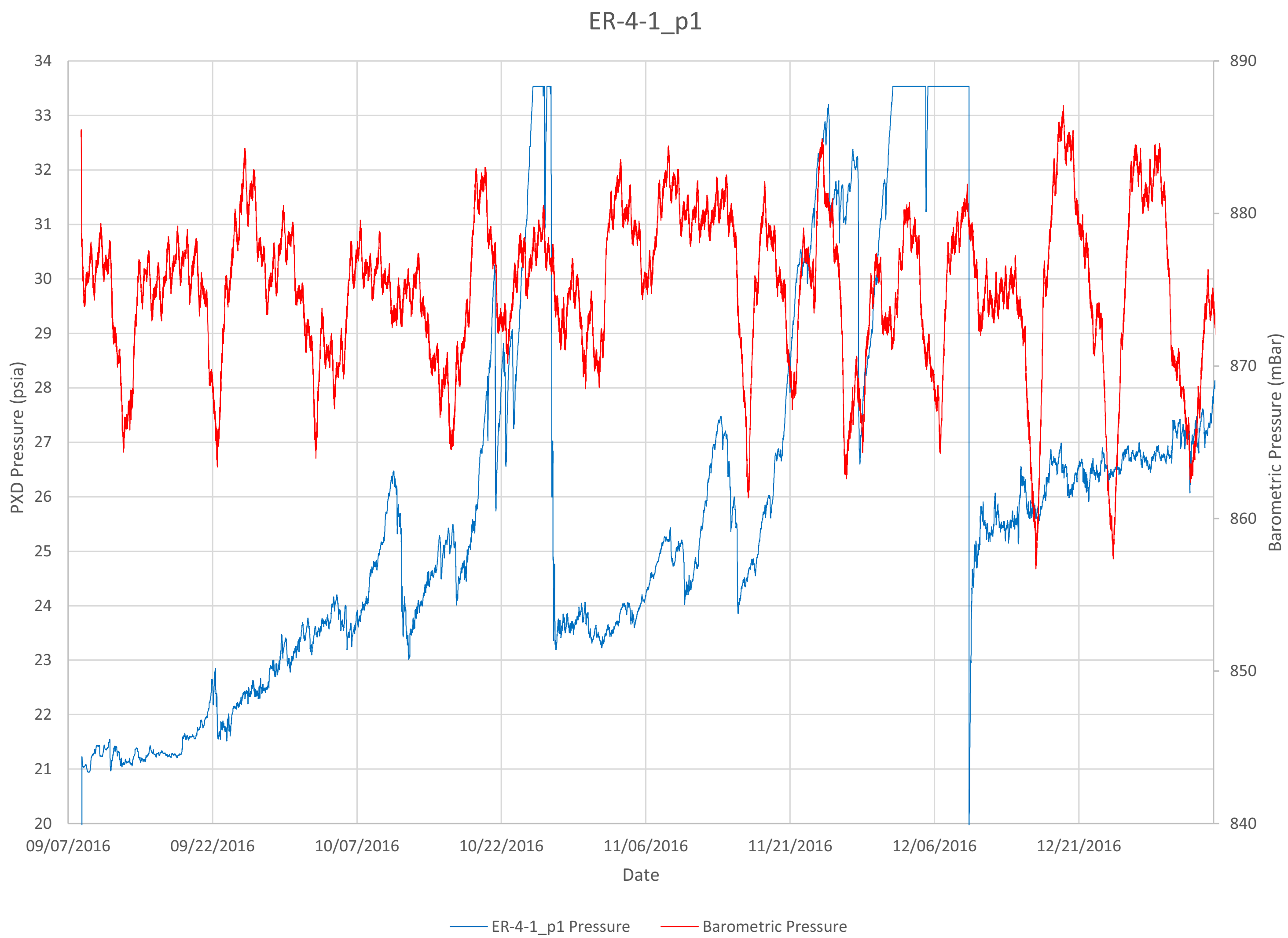

Figure 3-5
Well ER-4-1_p1 Predevelopment Monitoring

logged down from 0 to 3,035 ft bgs at 50 ft/min. The pH probe failed at approximately 2,763 ft bgs. The DRI chemistry tool measured DTW at 1,659 ft bgs, 6 ft lower than the DTW measured by Navarro at 1,653.43 ft bgs. Figure 3-6 shows the Idronaut chemistry tool log obtained by DRI.

3.6.2 Well ER-4-1

DRI personnel conducted predevelopment logging runs on December 14 and 15, 2016, before WDT activities. DRI attempted to log the m1 main completion with the Fluid Temperature Conductivity (FTC) tool on December 14, 2016. DRI logged down from 0 to 2,038 ft at 50 ft/min, when the FTC tool stopped collecting data; water level was indicated at 1,771.80 ft bgs on the first run. DRI attempted to troubleshoot the FTC tool four times with no success. DRI made four incomplete runs, with the tool failing to collect data each time. No data were provided by DRI.

DRI logged the m1 main completion with a calibrated Idronaut chemistry tool. DRI logged down from 0 to 2,957.50 ft bgs at 50 ft/min; water level was indicated at 1,772 ft bgs. The temperature readings in air were consistent with ambient and PXD temperatures; the pressure response was noisy in air. No readings were recorded in air for redox, DO, conductivity, and pH. The temperature reading in water were consistent with the PXD temperatures; readings were also recorded in water for redox, DO, conductivity, pH, and pressure. Figure 3-7 shows the Idronaut chemistry tool log obtained by DRI.

3.7 Pump Installation

3.7.1 Well ER-3-3

Before the pump was installed, a straddle packer was installed in the main completion at 2,115 to 2,123 ft bgs, with a strada cup assembly at 2,495 to 2,500 ft bgs. A low-flow dedicated electric submersible pump, controlled through a VSC, was used in Well ER-3-3 for testing and sampling. The pump was installed on November 28, 2016. The pump assembly used for the WDT and GWC sampling consisted of a seal above one motor and one pump above the seal. A motor shroud was installed over the motor, with the bottom of the shroud at 1,999.39 ft bgs. The pump intake was located at the base of the pump section above the seal at a depth of 1,979.44 ft bgs. The overall pump assembly length was 30.78 ft. The pump was installed on 2.875-in. SS tubing. A check valve was incorporated in the production tubing just above the pump. The function of the check valve was to

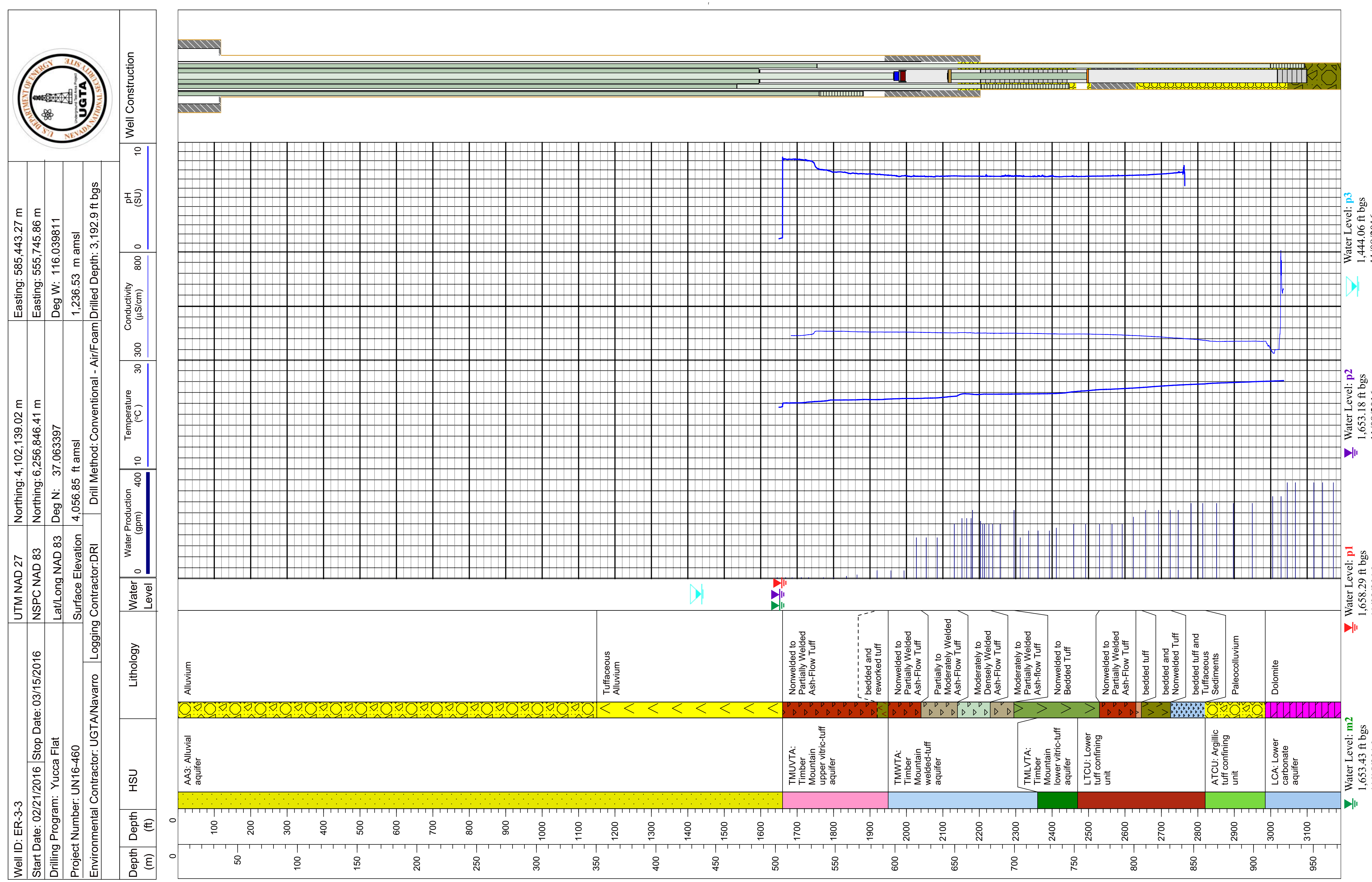

Figure 3-6
DRI Idronaut Log from Predevelopment Activities at Well ER-3-3

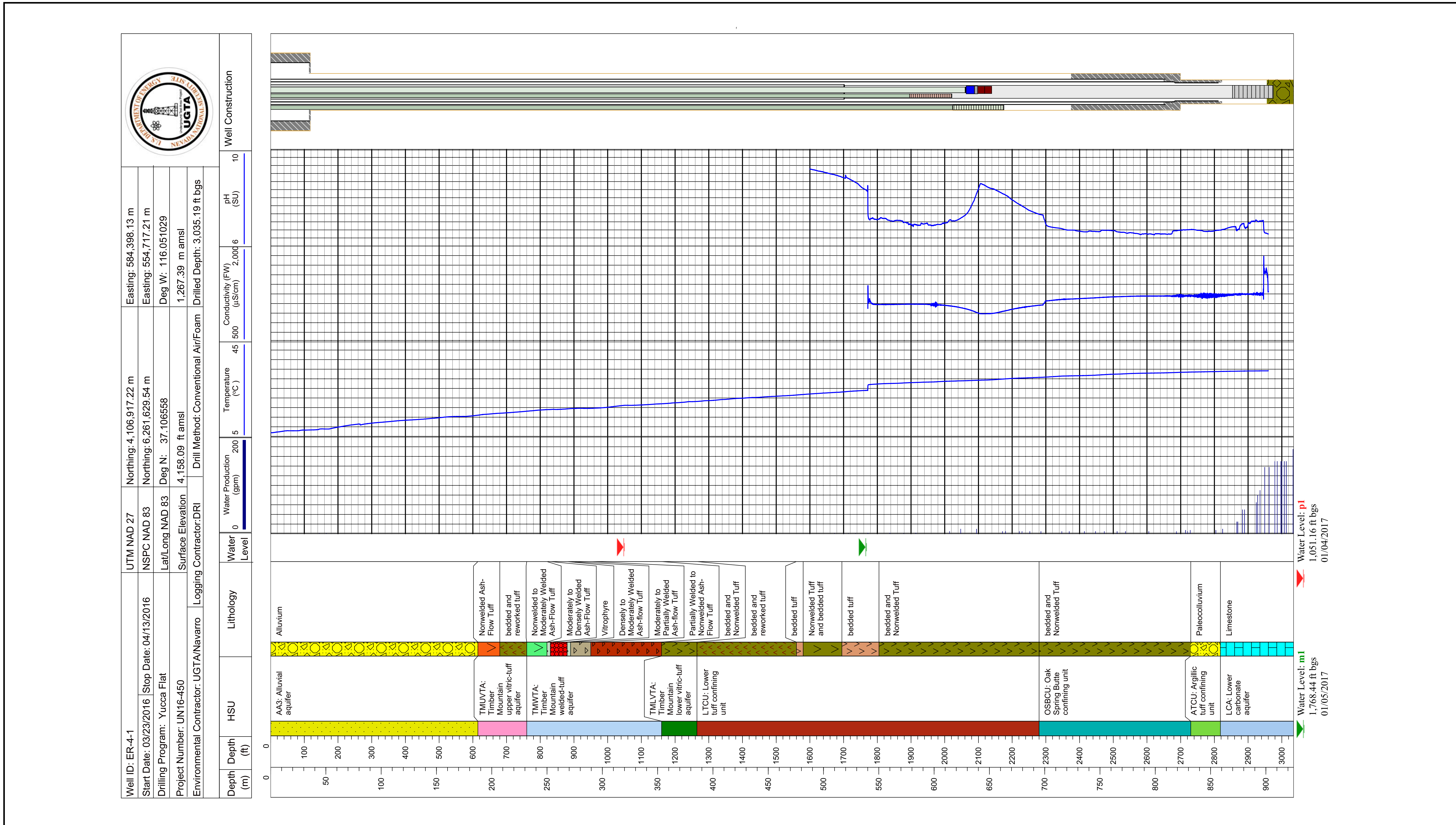

Figure 3-7
DRI Idronaut Log from Predevelopment Activities at Well ER-4-1

prevent water in the production tubing above the water level in the well from flowing back into the well when the pump was turned off. In addition, a properly functioning check valve provides immediate flow-rate information at the surface when the pump is started. The pump remains in the well. Table 3-5 identifies the pump installed in ER-3-3. The total dynamic head versus production curves for the pump is included in Appendix B.

Table 3-5
Pump Specifications for Well ER-3-3

Pump Components	Length (ft)	Model/Type/Series	SN
Pump	13.03	338 FER/149-DC550/DPMT1	13799176
Seal	4.55	338/DSFB3 FER SB PFSA CL5 HLNOPNT	13738833
Motor	13.20	375/MSP 44 HP	13696507

SN = Serial number

3.7.2 Well ER-4-1

A dedicated electric submersible pump, controlled through a VSC, was used in Well ER-4-1 for testing and sampling. The pump was installed on January 11, 2017. The pump assembly used for the WDT and GWC sampling consisted of a seal above two motors and one pump above the seal. The pump intake was located at the base of the pump section above the seal at a depth of 2,088.51 ft bgs. The overall pump assembly length was 75.69 ft. The pump was installed on 2.875-in. SS tubing. A check valve was incorporated in the production tubing just above the pump. The function of the check valve was to prevent water in the production tubing above the water level in the well from flowing back into the well when the pump was turned off. In addition, a properly functioning check valve provides immediate flow-rate information at the surface when the pump is started. The pump remains in the well. Table 3-6 identifies the pump installed in ER-4-1. The total dynamic head versus production curves for the pump is included in Appendix B.

3.8 Variable Speed Controller

The VSC is used to regulate the power to the pump and vary the production rate. The VSC has two modes of operation. Mode 1 (or Target Speed, depending on VSC manufacturer) is used to set the power frequency (in Hz cycles per second) to a fixed value. The amperage automatically adjusts to

Table 3-6
Pump Specifications for Well ER-4-1

Pump Components	Length (ft)	Model/Type/Series	SN
Pump	24.92	Flex 31/PMSSD	14017827
Seal	9.12	Centrilift/DFST3	11852029
Upper Motor	20.85	Centrilift/DMFL1	21D47843
Lower Motor	20.80	Centrilift/DMFU1	21D47849

meet the motor requirement; the input voltage is fixed via the power transformer. The typical frequency range is approximately 45 to 70 Hz to stay within the pump motor operating range for amperage and temperature. When starting the pump, achieving full speed (i.e., production rate) required up to 30 seconds. Mode 2 (or Feedback, depending on VSC manufacturer) is designed to automatically meter the discharge rate by communicating with the in-line flowmeter and adjusting the pump operating parameters. In Mode 2, the VSC regulates the pump to maintain a constant-flow rate.

3.9 Pump Function Test

Function testing refers to starting the pump, producing water to the surface, running the pump at different frequencies throughout the operating range, checking for proper operation, and confirming that pump operating parameters are within acceptable limits. In addition, the production rates at each frequency setting are determined. The manually recorded function test information for ER-3-3 and ER-4-1 is reported in Table 3-7.

Table 3-7
Function Test Results for Pump Installation at Wells ER-3-3 and ER-4-1

Date	Time	VSC (Hz)	VSC (Amps)	Flow Rate (gpm)
ER-3-3				
11/30/2016	13:45	50	74	12
ER-4-1				
01/13/2017	11:33	50	144	NA
01/13/2017	14:17	44	126	17
02/01/2017	14:45	53.1	120.8	51.7
02/01/2017	15:00	58.3	139.5	70.13
02/01/2017	15:30	65	163.2	90.33

3.10 PXD Installation before Well Development and Step-Drawdown Testing

3.10.1 Well ER-3-3

Before WDT activities, on November 29, 2016, a higher pressure range PXD (0 to 2,000 psia) was installed in the p1 piezometer at a depth of 2,990 ft bgs. Another PXD (0 to 30 psia) was installed on November 30, 2016, in p2 piezometer at a depth of 1,673 ft bgs. Both of these PXDs were removed after GWC sampling. No PXD was installed in the p3 piezometer due to excessive mud.

3.10.2 Well ER-4-1

Before WDT activities, on January 12, 2017, a higher pressure range PXD (0 to 300 psia) was installed in the m1 access line at a depth of 2,010 ft bgs. Another PXD (0 to 50 psia) was installed on January 13, 2017, in p1 piezometer at a depth of 1,075 ft bgs. The PXDs are still installed in the p1 piezometer and m1 access line.

3.11 Well Development and Step-Drawdown Testing

UGTA wells are developed and step-drawdown tested concurrently. Step-rate testing is pumping the well at increasing production rates for short, adjacent periods and monitoring the drawdown at each rate. The time series plot of the discharge rate looks like steps. This testing helps determine well efficiency and the pumping rate to be used for the subsequent constant-rate testing. Note that step-drawdown testing was not conducted at ER-3-3, only at ER-4-1.

Pump information during the well development and step-drawdown testing was recorded manually on UGTA pumping rate and drawdown data forms and reported in UGTA morning reports. This information is compared with the datalogger record to verify the recorded pumping rates.

3.11.1 Well ER-3-3

Step-drawdown testing was not feasible at ER-3-3 due to excessive drawdown in the p1 piezometer during pumping; therefore, cyclic pumping of the well was conducted. The first attempts to conduct well development and step-drawdown testing began with two tests on December 1, 2016. During the first test, the pumping was conducted in Mode 1 at 50 Hz, VSC at 78 to 79 amps, 242 volts. The production rate was approximative 14 gpm. The pump was shut down due to excessive drawdown in the p1 piezometer. The well was allowed to recover, and the pump was restarted with the same frequency and VSC parameters. Approximately 53 gal of water was purged from the well during this pumping event.

For the remainder of the field WDT activities from December 2 through December 15, 2016, the pump was run an additional 25 times; the durations and yields of the tests summarized from the daily morning reports appear in Table 3-1. In general, for each test the pump rate was approximately 13.5 gpm. Between each test, the well was allowed to recover to approximately 100 to 160 ft of SWL, or was left to recover overnight. During these operations, a total of 9,416 gal of water was purged from the well and discharged to Sump #1.

3.11.2 Well ER-4-1

Well development and step-drawdown testing began on January 18 and ended on February 1, 2017. During these operations, a total of 624,894 gal of fluid was discharged into Sump #1. Of the 624,894 gal of fluid, approximately 126,094 gal of fluid was transferred to Sump #2. Detailed step-drawdown testing activities are summarized from the daily morning reports in Table 3-2.

3.12 Water-Quality Monitoring during Development and Step-Drawdown Testing

Water-quality monitoring was conducted during pumping operations to provide data on water chemistry and as an indication of the progress achieved in well development. Monitoring the pumped discharge was accomplished through the use of two different methods: (1) grab samples collected from the wellhead sampling port and (2) continuous in-line monitoring with a Hydrolab Quanta Multiprobe (at ER-4-1 only). The grab samples and in-line monitoring results represent the composite parameter values for the groundwater produced.

The standard monitoring parameters measured during WDT operations included pH, specific electrical conductance (SEC), groundwater temperature, turbidity, bromide ion, and DO. Bromide was added to the drilling fluid as a tracer and is monitored in grab samples to gauge the progress of drilling fluid removal. Stabilization of the water-quality parameters is an indication that water produced from the well is representative of the formation water.

Samples for tritium analysis were collected and analyzed in compliance with the approved fluid-management strategy. Tritium monitoring results for fluid management are presented in Section 7.1.2.

3.12.1 Grab Sample Monitoring during Development and Step-Drawdown Testing

Grab samples were obtained approximately once every hour during daylight operations. The grab sample analyses used the equipment and methods described in Appendix B. All instruments were calibrated at the beginning of each shift in accordance with Navarro procedures. Calibration checks were completed at the end of each shift. A Hydrolab Quanta Multiprobe and a Horiba pH/ION Meter were used to analyze water-quality grab samples.

3.12.1.1 Well ER-3-3

Figures 3-8 and 3-9 show plots of the grab sample water-quality parameter data as well as the cumulative production volume during the cyclic pumping of Well ER-3-3.

Figure 3-8 shows values for SEC increased from approximately 410 micromhos per centimeter (µmhos/cm) on December 1, 2016, to about 550 µmhos/cm on December 5, 2016. The SEC then decreased slightly to 510 µmhos/cm and remained generally stable until December 9, 2016. The SEC increased to approximately 552 µmhos/cm on December 12, 2016, then decreased for the remainder of the cyclic pumping. On December 15, 2016, the last day of cyclic pumping, the value of SEC increased to 480 µmhos/cm.

Figure 3-8 shows turbidity increasing during the initial cyclic pumping from approximately 240 nephelometric turbidity units (NTUs) to approximately 800 NTUs on December 2, 2016. Note that eight high turbidity values, from 1,100 to 2,000 NTUs (the high end of the detection limit of the instrument) are not included on the graph, but are listed in the grab water-quality data in Appendix C. From December 2 through 6, 2016, the turbidity was over 1,000 NTUs. The turbidity then gradually decreased to 168 NTUs on December 13, 2016, before increasing to 660 NTUs on December 14, 2016. The turbidity was then generally stable; the last turbidity reading during cyclic pumping before collection of groundwater samples was 316 NTUs.

Figure 3-8 shows the bromide concentrations and cumulative production volume. Bromide is mixed with the drilling fluid as a tracer, and its concentration is an indication of the well development achieved. Figure 3-8 shows that during the cyclic pumping of the well, bromide concentrations gradually declined from an initial concentration of approximately 1.69 milligrams per liter (mg/L) to about 0.169 mg/L.

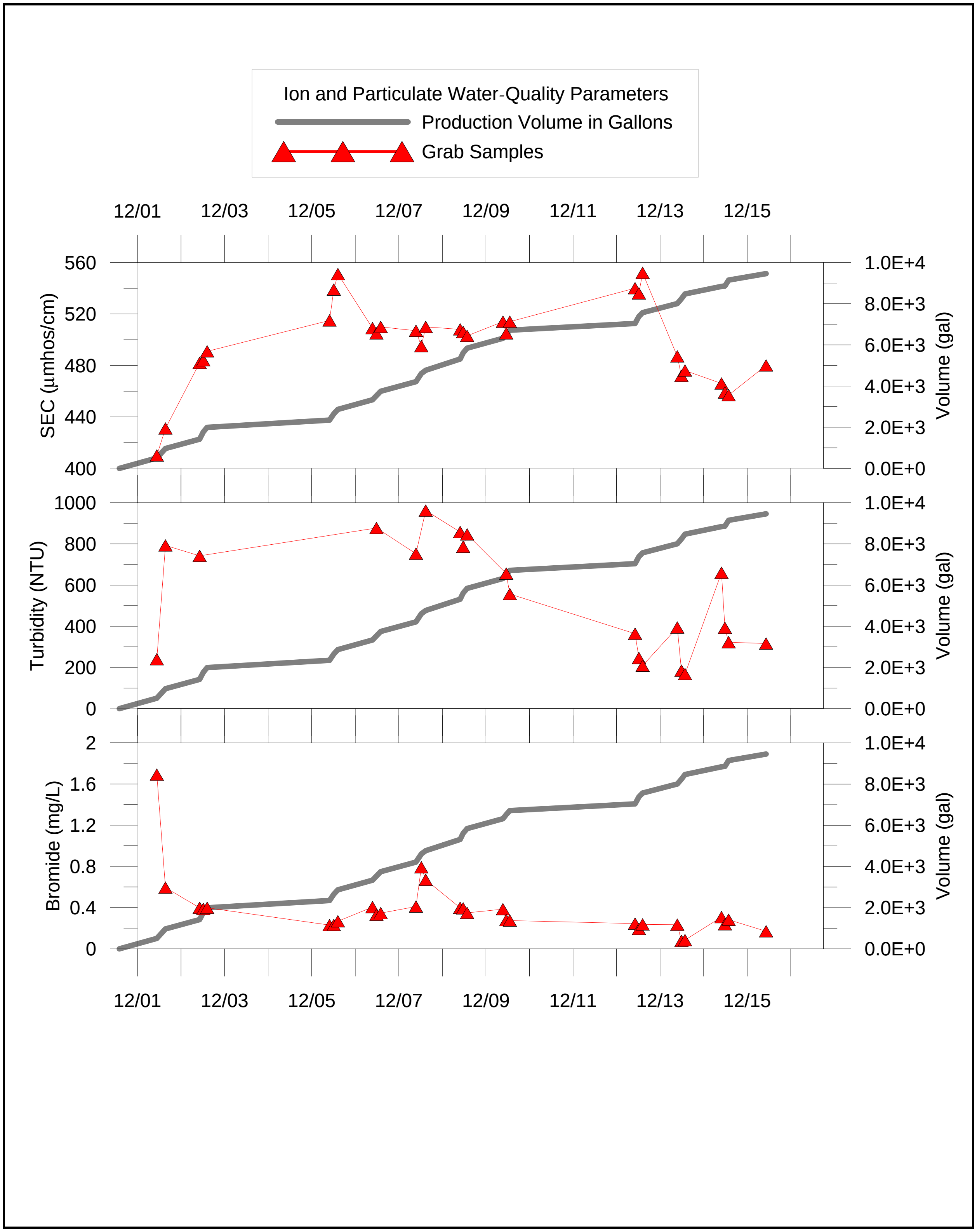

Figure 3-8
Well ER-3-3 SEC, Turbidity, and Bromide during WDT Conducted in December 2016

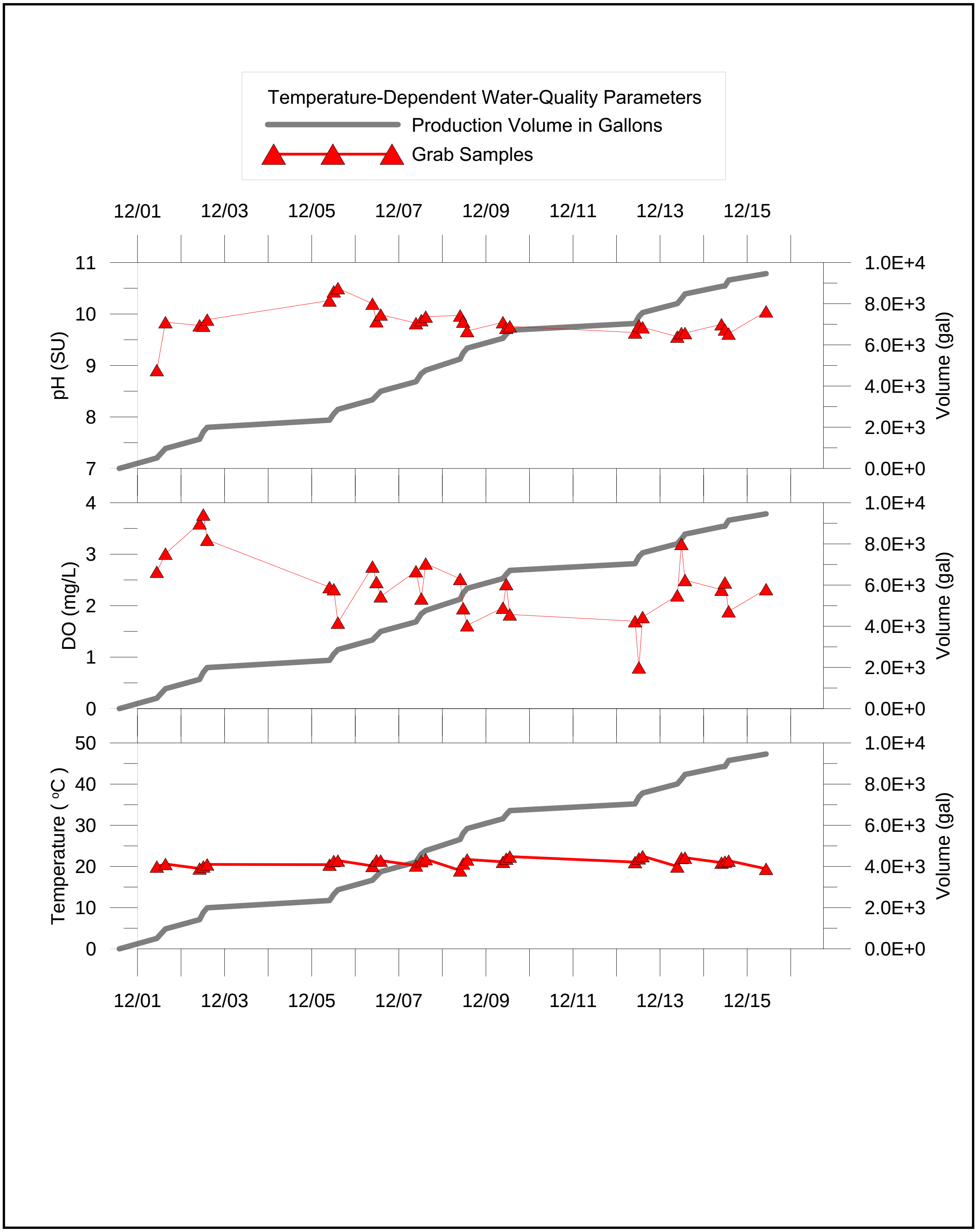

Figure 3-9
Well ER-3-3 pH, DO, and Temperature during WDT Conducted in December 2016

Figure 3-9 shows that the pH monitored in the grab samples increased from an initial reading of approximately 8.9 standard units (SU) on December 1, 2016, to a high reading of 10.50 SUs on December 5, 2016. The pH readings then decreased slightly and remained generally stable between 9.6 and 10.0 SUs. There was more variation in the DO concentrations than was seen in the results for pH. DO concentrations started near 2.7 mg/L; increased to approximately 3.8 mg/L on December 2, 2016; and then exhibited much greater scatter through the end of the cyclic pumping in ER-3-3. From December 5 through 15, 2016, values of DO generally ranged between 1.8 and 2.7 mg/L with a couple of high and low value outliers. On December 15, 2016, the last day of cyclic pumping, the DO reading was 2.32 mg/L. Figure 3-9 also shows the temperature of the grab samples; throughout the cyclic pumping, the temperature ranged from 19.0 to 22.4 degrees Celsius (°C) and was generally stable.

During the development and step-drawdown testing/cyclic pumping, the grab sample water-quality parameters varied as follows:

- The pH levels ranged between 8.90 to 10.50 SU.
- The DO levels ranged between 0.80 to 3.77 mg/L.
- The SEC values ranged between 410 to 552 µmhos/cm.
- The turbidity ranged between 134 to 2,000 NTUs. Note that the 2,000 NTU value represents the high end of the detection limit of the instrument.
- The bromide concentrations ranged between 0.169 to 1.69 mg/L.

The grab sample analytical data are presented in tables in Appendix C.

3.12.1.2 Well ER-4-1

Figures 3-10 and 3-11 show plots of the grab sample water-quality parameter data as well as the cumulative production volume and in-line data during well development and step-drawdown testing, and during the constant-rate test. The data on the left side of the break in dates in the graphs indicate step-drawdown testing data, while the data on the right side of the break in dates are from the constant-rate testing.

Figure 3-10 shows values for SEC increased from approximately 910 µmhos/cm on January 18, 2017, to about 1,020 µmhos/cm on January 19, 2017. The SEC values then ranged from approximately 950 to 1,000 µmhos/cm and were generally stable. On February 2, 2017, the last day of development and step-drawdown testing, the value of SEC was approximately 950 µmhos/cm.

Figure 3-10 shows turbidity increased sharply during the initial development and step-drawdown testing from approximately 25 to about 2,000 NTUs between January 17 and 18, 2017. The turbidity values then decreased to between approximately 10 and 30 NTUs, with one reading of 107 NTUs. On January 22, 2017, the turbidity value spiked at approximately 540 NTUs, then ranged from approximately 5 to 190 NTUs.

Figure 3-10 shows the bromide concentrations and the cumulative production volume. Bromide is mixed with the drilling fluid as a tracer, and its concentration is an indication of the well development achieved. Figure 3-10 shows that during the well development and step-drawdown testing, bromide concentrations gradually declined from an initial concentration of approximately 2.8 to about 0.8 mg/L on January 19, 2017. From January 19 to 22, 2017, the bromide concentrations increased and ranged from approximately 1.2 to 3.3 mg/L. From January 23 through the remainder of the step-drawdown test, the bromide concentrations ranged from approximately 0.46 to 1.05 mg/L.

Figure 3-11 shows that the pH monitored in the grab samples remained generally stable between 6.5 and 7.1 SU, with a pH reading of approximately 7 mg/L on the first day of the step-drawdown testing (January 18, 2017). There was more variation in the DO concentrations than was seen in the results for pH. DO concentrations started near 3.0 mg/L. The DO concentrations ranged from approximately 2.0 to 4.6 mg/L during the step-drawdown testing.

Figure 3-11 also shows the temperature of the grab samples; throughout the step-drawdown testing, the temperature ranged from approximately 25 to 32 °C, except for the first grab sample (approximately 21 °C). The temperature was generally stable throughout the step-drawdown testing.

During the development and step-drawdown testing, the grab sample water-quality parameters varied as follows:

- The pH levels ranged between 6.60 to 8.39 SU.
- The DO levels ranged between 1.91 to 4.66 mg/L.

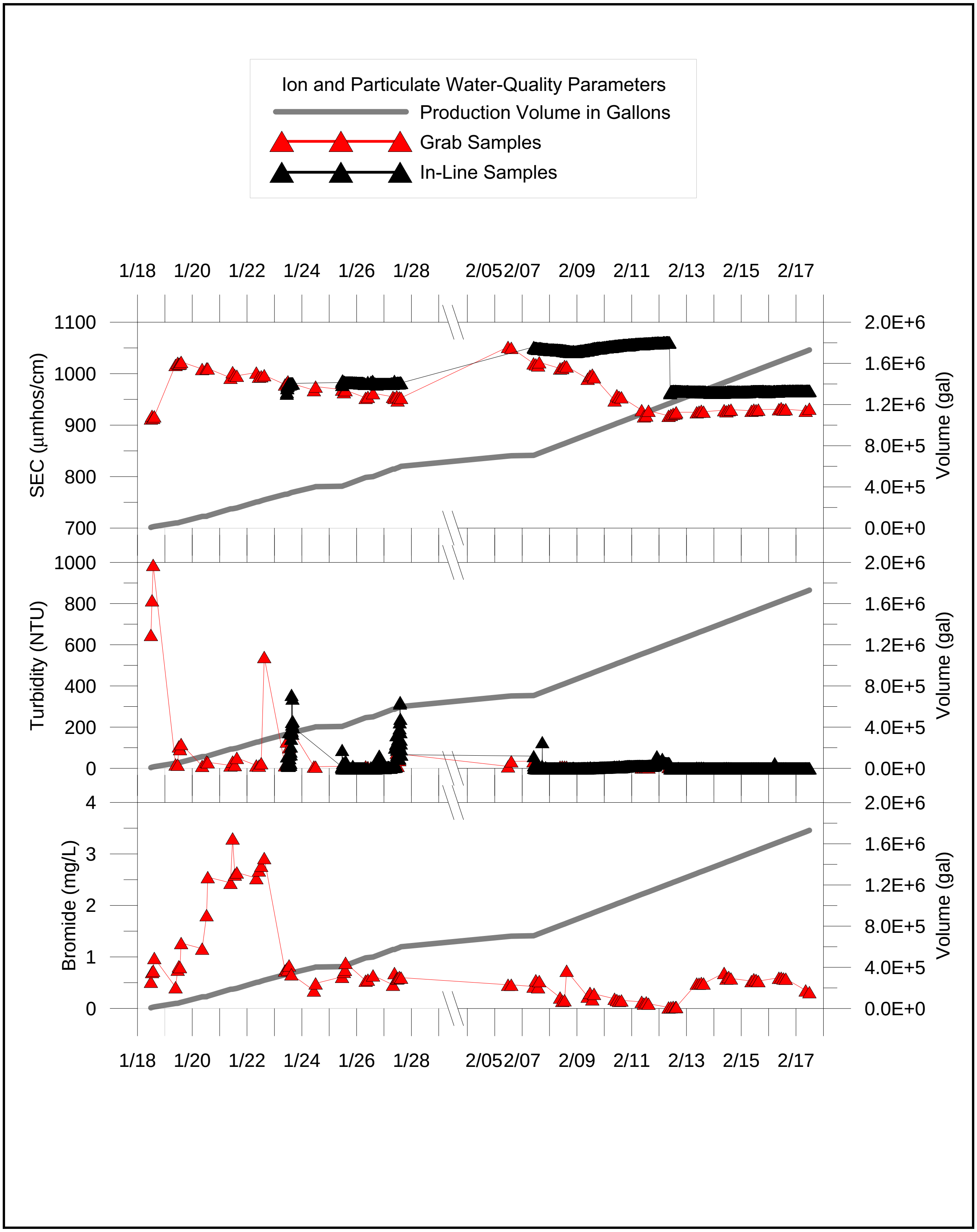

Figure 3-10
Well ER-4-1 SEC, Turbidity, and Bromide during WDT Conducted in January and February 2017

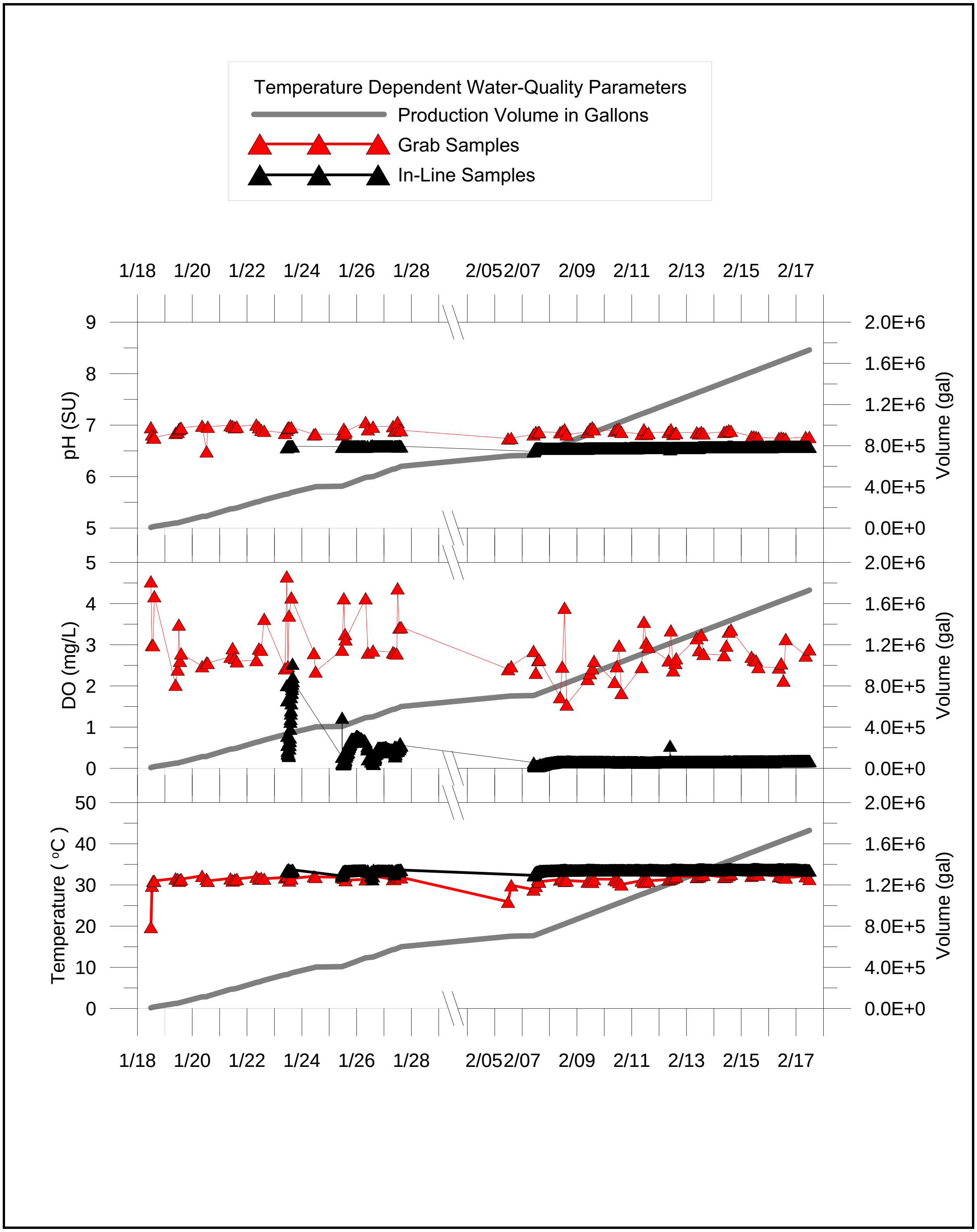

Figure 3-11
Well ER-4-1 pH, DO, and Temperature during WDT Conducted in January and February 2017

- The SEC values ranged between 752 to 1,023 µmhos/cm.
- The turbidity ranged between 0.0 to 2,000 NTUs. Note that the 2,000 NTU value represents the high end of the detection limit of the instrument.
- The bromide concentrations ranged between 0.460 to 3.30 mg/L.

The grab sample analytical data are presented in tables in Appendix C.

3.12.2 In-Line Monitoring during Development and Step-Drawdown Testing

In-line water-quality monitoring was conducted with a Hydrolab Quanta Multiprobe. Groundwater temperature, SEC, DO, pH, and turbidity were recorded by a datalogger at 10-minute intervals during development and step-drawdown testing. The Hydrolab Quanta Multiprobe was taken offline during pump shutdowns/startups to prevent damage to the sensors. The flow rate to the Hydrolab Quanta Multiprobe was measured with a Kobold flowmeter and recorded by the datalogger separately from the main production flowmeter. The Hydrolab Quanta Multiprobe was calibrated, and maintenance was performed before well development and again before the constant-rate testing in accordance with Navarro procedures and the manufacturer's instructions.

Because the Hydrolab Quanta Multiprobe is calibrated relatively infrequently as compared to the grab sampling instruments, the grab sample results are taken as the definitive values. The in-line data are meant to indicate trends and to reveal changes that occur when personnel are not on site to collect and analyze grab samples.

3.12.2.1 Well ER-3-3

No in-line water-quality monitoring was conducted during the development and step-drawdown/cyclic pumping at Well ER-3-3.

3.12.2.2 Well ER-4-1

In-line water-quality monitoring at ER-4-1 began on January 27, 2017. The pump had shut down at approximately 16:00 on January 24, 2017, and was restarted at approximately 09:00 on January 25, 2017. As noted above, the in-line water-quality parameter data are shown with the cumulative production volume and grab sample data on Figures 3-10 and 3-11. The data on the left side of the break in the graphs indicate step-drawdown testing data, while the data on the right side of the break are from the constant-rate testing. Bromide concentrations were not measured with the in-line water-quality instrumentation.

Figure 3-10 shows that values for in-line SEC ranged generally stable from approximately 950 to 990 µmhos/cm during the step-rate testing. On February 2, 2017, the last day of step-drawdown testing, the value of SEC was approximately 948 µmhos/cm.

Figure 3-10 shows turbidity values ranged from 0 to approximately 355 NTUs. The turbidity bounced around during the entire step-drawdown testing, due to the pump being turned on and off at specific intervals.

Figure 3-11 shows that the pH measured in-line was relatively stable, with readings ranging from 6.57 to 6.6 SUs. These values are slightly lower than those seen in the grab sample analyses. Figure 3-11 also shows the temperature of the in-line samples; throughout the step-drawdown testing, the temperature ranged from approximately 31.5 to 34 °C, which generally agreed with the grab samples temperature reading. The temperature was generally stable throughout the step-drawdown testing.

Figure 3-11 shows DO concentrations ranged from 0.3 to 2.54 mg/L on January 23, 2017, before the pump shut down. The DO concentrations then fluctuated between 0.1 and 0.8 mg/L during the remainder of the step-drawdown test. Near the end of the step-drawdown testing, the DO concentrations became relatively stable.

During development and step-drawdown testing, the in-line water-quality parameters varied as follows:

- The pH levels ranged between 6.57 and 6.61 SU.
- The DO levels ranged between 0.09 and 2.54 mg/L.
- The SEC values ranged between 948 and 987 µmhos/cm.
- The turbidity ranged between 0.0 to 356.6 NTU.

Bromide concentrations were not monitored in-line. The electronic data files for the in-line monitoring data are included in Appendix D.

3.13 Pressure Response during Development and Step-Drawdown Testing

3.13.1 Well ER-3-3

Figure 3-12 shows the barometric pressure at the surface and the PXD total pressures during the development and step-drawdown testing/cyclic pumping at ER-3-3_p1. The PXD was suspended at a depth of 2,990 ft bgs, at the top of the screened zone. The range of PXD total pressures and barometric pressures in this figure are not equivalent. The range of PXD total pressures observed equate to an equivalent change of approximately 45 mBar. A pressure range of 50 mBar was used for the barometric pressure scale. Pumping in Well ER-3-3 dominated the pressure response.

3.13.2 Well ER-4-1

Figure 3-13 shows the barometric pressure at the surface and the PXD total pressures during the development and step-drawdown testing at ER-4-1_m1_a. The PXD was suspended at a depth of 2,010 ft bgs, near the bottom of the screened zone. The range of PXD total pressures and barometric pressures in this figure are not equivalent. The range of PXD total pressures observed equate to an equivalent change of approximately 105 mBar. A pressure range of 15 mBar was used for the barometric pressure scale. Pumping in Well ER-4-1 dominated the pressure response.

3.14 Constant-Rate Testing

The extended pumping period of the constant-rate test provided the best data for determining the large-scale transmissivity of the formation because the volume of aquifer interrogated was much larger than the volume interrogated by the step-drawdown tests.

3.14.1 Well ER-3-3

The main completion of ER-3-3 has a very low productivity and could not sustain a constant-rate test due to excessive drawdown in the well.

3.14.2 Well ER-4-1

A 10-day constant-rate test was conducted at ER-4-1; the test began on February 7 and ended on February 17, 2017. Water-level monitoring is still occurring at this well. During these operations, a total of 946,642 gal of water was discharged into Sump #2. During the constant-rate testing, the

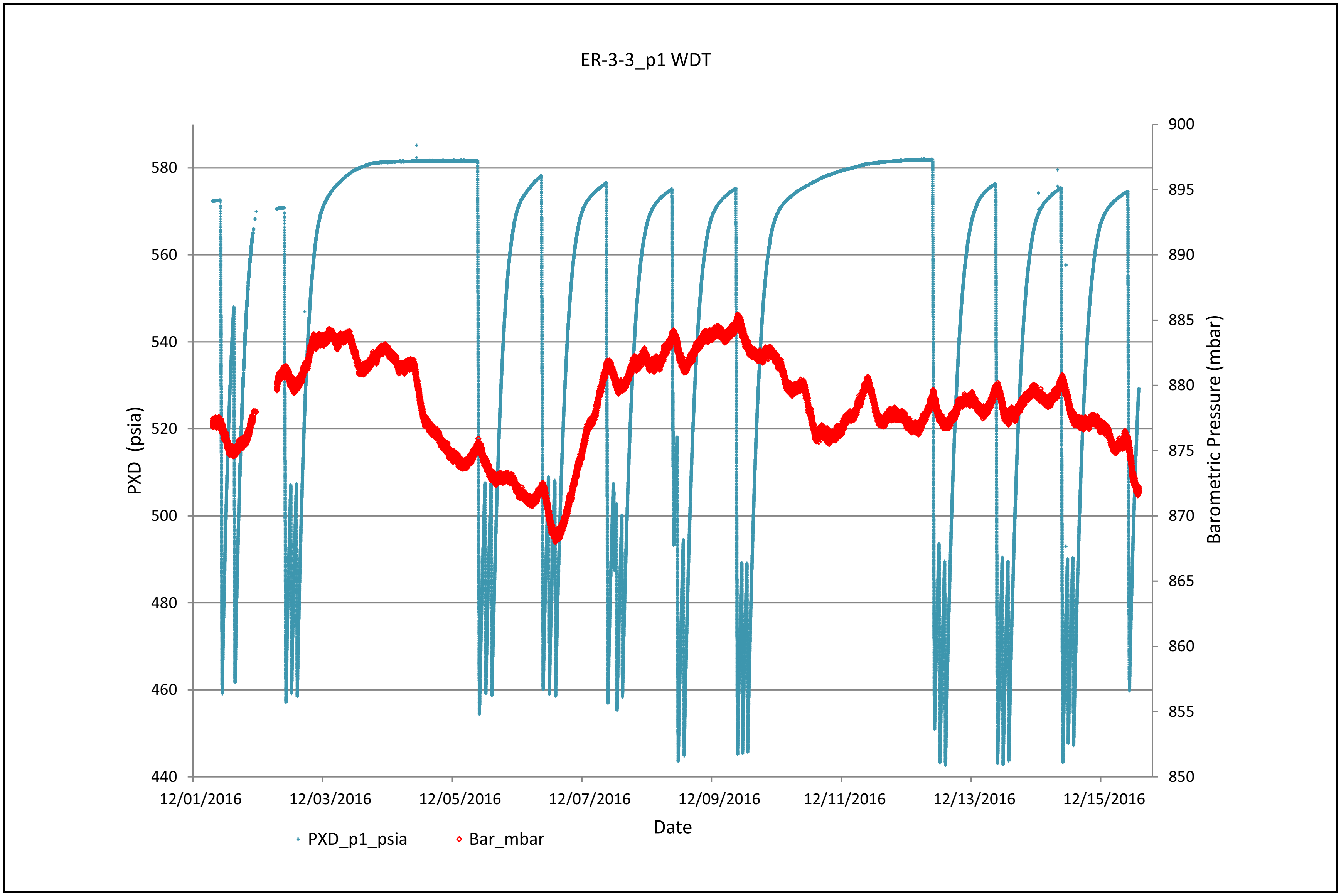

Figure 3-12
PXD Pressure Response and Barometric Pressure during Development and Step-Drawdown Testing at Well ER-3-3_p1

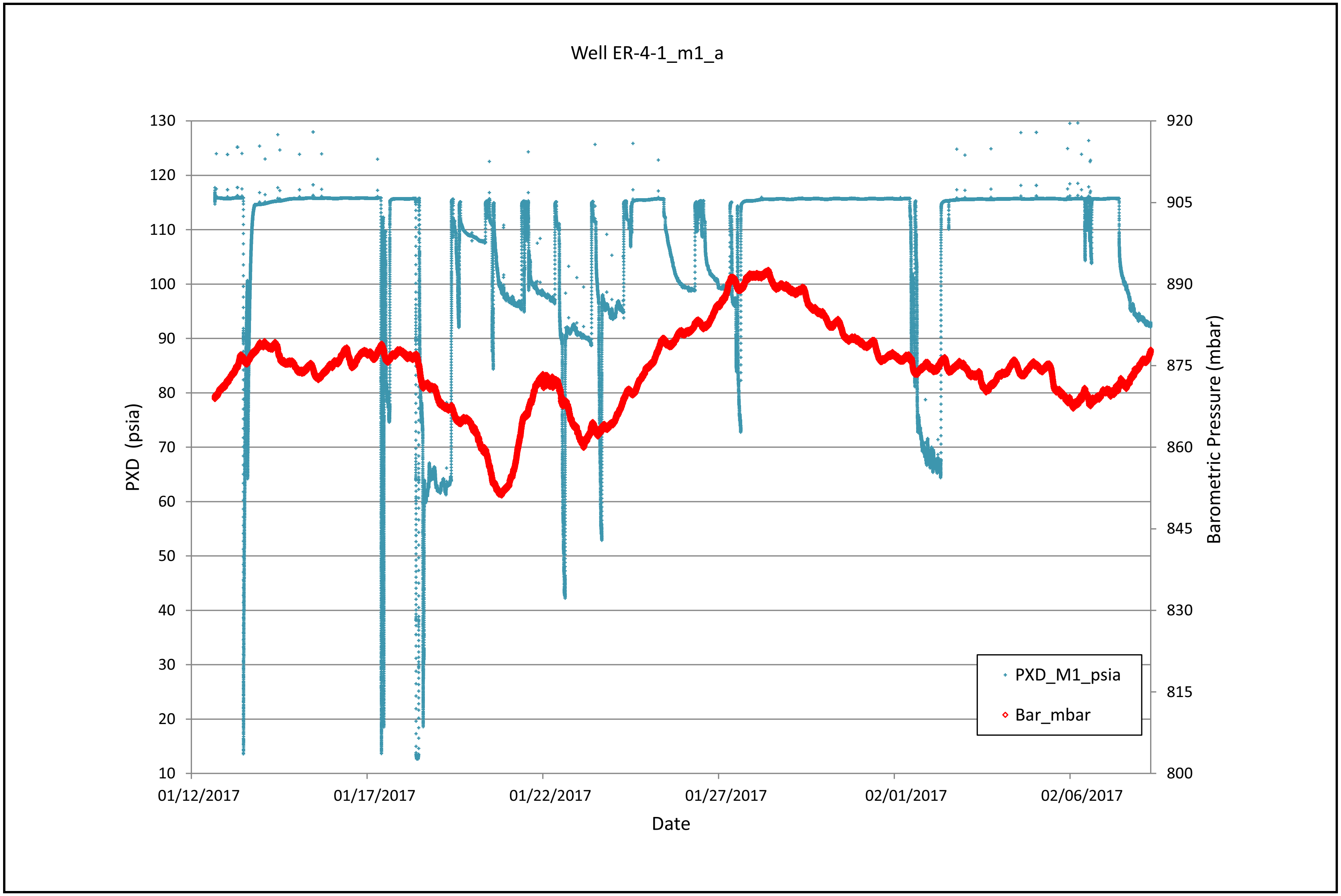

Figure 3-13
PXD Pressure Response and Barometric Pressure during Development and Step-Drawdown Testing at Well ER-4-1_m1_a

production rate ranged from 70 to 71 gpm. The pump ran steady throughout the test without shutting off. Pump information during the constant-rate testing was recorded manually on UGTA pumping rate and drawdown data forms and reported in UGTA morning reports. This information is compared with the datalogger record to verify the recorded pumping rates.

3.15 Water-Quality Monitoring during Constant-Rate Testing

Monitoring the pumped discharge was accomplished through the use of two different methods: (1) grab samples collected from the wellhead sampling port and (2) continuous in-line monitoring with a Hydrolab Quanta Multiprobe. In addition, GWC samples were collected at the wellhead on February 17, 2017; analytical results are presented in Section 6.0.

3.15.1 Grab Sample Monitoring during Constant-Rate Testing at Well ER-4-1

Figures 3-10 and 3-11 show plots of the grab sample water-quality parameter data as well as the cumulative production volume and in-line data during well development and step-drawdown testing, and during the constant-rate test. The data on the left side of the break in the graphs indicate step-drawdown testing data, while the data on the right side of the break are from the constant-rate testing.

Figure 3-10 shows values for SEC decreased from approximately 1,050 µmhos/cm on February 6, 2017, to about 920 µmhos/cm on February 12, 2017. The SEC values then ranged from approximately 920 to 935 µmhos/cm and were generally stable. On February 17, 2017, the last day of constant-rate testing, the value of SEC was approximately 932 µmhos/cm.

Figure 3-10 shows turbidity increased during the first day of constant-rate testing from approximately 9 to about 35 NTUs. The turbidity values then fluctuated between approximately 0 and 10.5 NTUs for the remainder of the constant-rate test and were generally stable the last three days of the test. On February 17, 2017, the last day of constant-rate testing, the value of turbidity was approximately 0.9 NTUs.

Figure 3-10 shows the bromide concentrations and the cumulative production volume. Bromide is mixed with the drilling fluid as a tracer, and its concentration is an indication of the well development achieved. Figure 3-10 shows that during the constant-rate testing, bromide concentrations ranged from approximately 0.02 to 0.73 mg/L.

Figure 3-11 shows that the pH monitored in the grab samples remained generally stable between 6.75 and 6.96 SUs. There was more variation in the DO concentrations than was seen in the results for pH. The DO ranged from 2.79 to 4.66 mg/L during the constant-rate test; there were no anomalous readings.

Figure 3-11 also shows the temperature of the grab samples; throughout the constant-rate testing, the temperature ranged from approximately 29 to 33 °C, except for the first grab sample, which was slightly lower at approximately 26 °C. The temperature was generally stable throughout the constant-rate testing.

During the development and constant-rate testing, the grab sample water-quality parameters varied as follows:

- The pH levels ranged between 6.75 to 6.96 SU.
- The DO levels ranged between 2.79 to 4.66 mg/L.
- The SEC values ranged between 917 to 1,052 µmhos/cm.
- The turbidity ranged between 0.0 to 34.6 NTU.
- The bromide concentrations ranged between 0.020 to 0.732 mg/L.

The grab sample analytical data are presented in tables in Appendix C.

3.15.2 In-Line Monitoring during Constant-Rate Testing at Well ER-4-1

As noted above, the in-line water-quality parameter data are shown with the cumulative production volume and grab sample data on Figures 3-10 and 3-11. The data on the left side of the break in the graphs indicate step-drawdown testing data, while the data on the right side of the break are from the constant-rate testing. Bromide concentrations were not measured with the in-line water-quality instrumentation. Note that on February 12, 2017, the in-line Hydrolab probes were serviced.

Figure 3-10 shows values for in-line SEC values ranged from approximately 1,040 to 1,060 µmhos/cm from the start of the constant-rate test on February 7 through February 12, 2012, and were generally stable. On February 12 at 09:40, the SEC value decreased to approximately 962 µmhos/cm. The SEC values then ranged from approximately 960 to 970 µmhos/cm for the remainder of the constant-rate test and were stable.

Figure 3-10 shows turbidity values ranged from 0 to approximately 127 NTUs. The turbidity values fluctuated slightly during the test, but were generally stable. The turbidity was 0 NTUs during the last five days of the constant-rate test.

Figure 3-11 shows that the pH measured in-line was relatively stable, with readings ranging from 6.55 to 6.6 SUs. These values are slightly lower than those seen in the grab sample analyses.

Figure 3-11 also shows the temperature of the in-line samples; throughout the constant-rate testing, the temperature ranged from approximately 32 to 34 °C, which generally agreed with the grab samples temperature reading. The temperature was generally stable throughout the step-drawdown testing.

Figure 3-11 shows DO concentrations ranged from approximately 0.05 to 0.20 mg/L throughout the entire constant-rate test and were stable. An anomalous reading of 0.55 mg/L occurred at 09:40 on February 12, 2017.

During development and step-drawdown testing, the in-line water-quality parameters varied as follows:

- The pH levels ranged between 6.55 and 6.6 SU.
- The DO levels ranged between 0.05 and 0.55 mg/L.
- The SEC values ranged between 962 and 1,061 µmhos/cm.
- The turbidity ranged between 0.0 to 127.6 NTU.

Bromide concentrations were not monitored in-line. The electronic data files for the in-line monitoring data are included in Appendix D.

3.16 Pressure Response during Constant-Rate Testing

3.16.1 Well ER-4-1

Figure 3-14 shows the barometric pressure record and the total pressure response monitored during pumping at a rate of approximately 70 to 71 gpm. The plot begins on February 7, the first day of the constant-rate test, and ends on February 17, 2017, after groundwater sampling occurred. The range of PXD total pressures observed equate to an equivalent change of approximately 95 mBar. A pressure range of 15 mBar was used for the barometric pressure scale as even at this scale, the pressures plot almost as a flat line.

3.17 Cessation of Pumping and Recovery Monitoring

3.17.1 Well ER-3-3

Pumping was suspended at 10:29 on December 15, 2016, with a total of 9,416 gal of groundwater produced since the start of the WDT operations. All groundwater produced was discharged into Sump #1. Recovery monitoring is continuous and ongoing in the p1 and p2 piezometers via the automated PXD datalogger systems.

3.17.2 Well ER-4-1

Pumping was suspended at 12:07 on February 17, 2017, with a total of 1,732,160 gal of groundwater produced since the start of the WDT operations. The total flow was divided between the two sumps with 498,800 gal directed to Sump #1 and 1,233,360 gal directed to Sump #2. Recovery monitoring is continuous and ongoing in the m1 main completion access line and the p1 piezometer via the automated PXD datalogger systems.

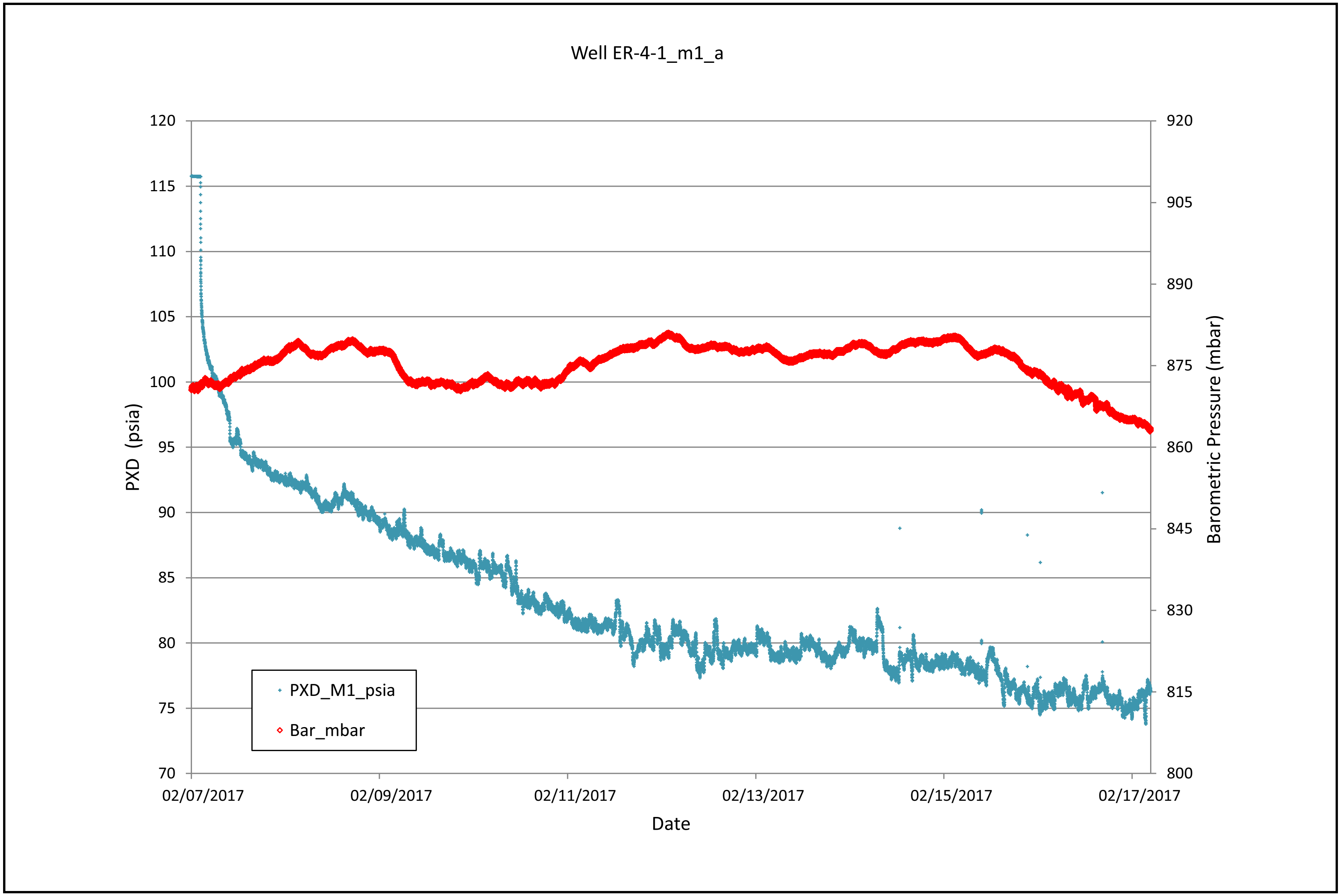

Figure 3-14
PXD Pressure Response and Barometric Pressure during Constant-Rate Testing at Well ER-4-1_m1_a

4.0 GEOLOGY AND HYDROGEOLOGY

4.1 Geology

This section discusses the geology and hydrogeology of Wells ER-3-3 and ER-4-1 in the context of Yucca Flat. The discussion and interpretations are primarily based on the lithologic logs presented in the appendices of the well completion reports (NNSA/NFO, 2017a and b). The overall geology with depth—including stratigraphy, lithology, and HSUs—is summarized on the well completion diagrams provided in this report for both ER-3-3 (Figure 2-1) and ER-4-1 (Figure 2-3). The lithologic logs were developed using the drill cuttings and borehole geophysical logs in the field. Figures and text in this report may not match field documents generated during drilling. The information presented in this report supersedes the information in field-generated reports.

4.1.1 Geology of Well ER-3-3

During advancement of Well ER-3-3, the following stratigraphic units were encountered beginning at ground surface and down through to TD:

- Quaternary/Tertiary alluvium (QTa)
- Ammonia Tanks Tuff (Tma)
- Ammonia Tanks bedded tuff (Tmab)
- Rainier Mesa mafic-poor Tuff (Tmrp)
- tuff of Holmes Road (Tmrh)
- Pre-Timber Mountain Tuff - Post-Wahmonie Tuff (undifferentiated) (Tm/Tw)
- Wahmonie Formation (Tw)
- Tunnel Formation (Tn)
- Older Tunnel Beds (Ton)
- Paleocolluvium/Older tuffs (Tlc/To)
- Paleozoic rocks (Ꝑz)

Surface geology of the northern portion of Yucca Flat is presented in Figure 1-2. Well ER-3-3 is located approximately 400 m (1,312 ft) east of Yucca Fault, which is a prominent basin forming normal fault. The stratigraphic units encountered in Well ER-3-3 were generally as predicted, although there are significant differences in unit thicknesses noted. The top of the Paleozoic rocks (Ꝑz) was predicted to be at a depth of 894.59 m (2,935 ft) bgs. Well ER-3-3 identified the actual top of the Paleozoic rocks (Ꝑz) at 909.83 m (2,985 ft) bgs, a difference of 15.24 m (50 ft). Differences between predicted and actual geology in boreholes are not uncommon and may result from complex relationships between paleotopographic depositional conditions, volcanic, and structural processes associated with basin forming systems.

4.1.1.1 Geologic Setting of Well ER-3-3

Well ER-3-3 is located in the east–central portion of the Nevada National Security Site (NNSS), within the topographical margins of Yucca Flat. Yucca Flat is a north–south elongated structural basin (half graben) on the eastern edge of the southwestern Nevada volcanic field and formed in response to basin and range extension. The prominent Yucca Fault is located immediately west of the well, a normal fault with down-dropped units to the east (i.e., in the area of Well ER-3-3). Surface drainage in the vicinity of Well ER-3-3 is generally to the Yucca Flat Playa near the south–central portion of the basin. Physiographically, the well site is located within the north–central portion of Yucca Flat and east of the topographic expression of the Timber Mountain caldera and its structural margin.

4.1.1.2 Stratigraphy and Lithology of Well ER-3-3

The stratigraphic units, lithologic units, and HSUs penetrated in Well ER-3-3 are listed in Tables 4-1 and 4-2. Lithologic descriptions, stratigraphic assignments, and their respective depth intervals can be found in Appendix A of the ER-3-3 well completion report (NNSA/NFO, 2017a). Identification of stratigraphic and lithologic units was aided by correlation with stratigraphic units and lithologies observed in nearby boreholes (U-3an, U-3an 1, U-3an 3, U-3gg, U-3mf, U-3cn5, ER-2-1), and in the Yucca Flat HFM presented in *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 98: Yucca Flat–Climax Mine, Lincoln and Nye Counties, Nevada* (BN, 2006).

Observations in the cuttings and a sharp increase in water production indicated that a geologic feature had been intercepted by the borehole. A significant geologic feature (e.g. tension fracture) cuts the Rainier Mesa mafic-poor Tuff (Tmrp) from 624.84 m (2,050 ft) to 655.32 m (2,150 ft) bgs and was observed in the Schlumberger Formation MicroImager (FMI) log. The FMI log shows a strong resistivity low, indicating an open or strongly fractured feature and thinly bedded material on either side with little to no apparent offset. It is interpreted that this structural feature extends into overlying units including the Quaternary/Tertiary alluvium (QTa); however, observations in the geologic cuttings and geophysical logs were generally inconclusive.

Table 4-1
Key to Stratigraphic Units and Symbols of the Well ER-3-3 Area

Stratigraphic Unit	Map Symbol
Quaternary/Tertiary alluvium	QTa
Timber Mountain Group	Tm
Ammonia Tanks Tuff	Tma
Ammonia Tanks bedded tuff	Tmab
Rainier Mesa mafic-poor Tuff	Tmrp
tuff of Holmes Road	Tmrh
Pre-Timber Mountain - Post-Wahmonie Tuff	Tm/Tw
Wahmonie Formation	Tw
Tunnel Formation	Tn
Older Tunnel Beds	Ton
Paleocolluvium/Older tuffs	Tlc/To
Paleozoic rocks	Pz

Table 4-2
Key to HSUs and Symbols of the Well ER-3-3 Area

HSU	Map Symbol
Alluvial aquifer	AA3
Timber Mountain upper vitric aquifer	TMUVTA
Timber Mountain welded-tuff aquifer	TMWTA
Timber Mountain lower vitric-tuff aquifer	TMLVTA
Lower tuff confining unit	LTCU
Argillic tuff confining unit	ATCU
Lower carbonate aquifer	LCA

Paleozoic rocks (Pz) were encountered from 909.83 m (2,985 ft) to 973.20 m (3,192.9 ft) bgs for a total of 63.37 m (207.9 ft). The Paleozoic rocks (Pz) were composed of dolomites with minor interbedded limestone. Many of the cuttings exhibited signs of fracturing, brecciation, and micro-stockwork veining. Additionally, an unusual bluish black, sooty mineral (possibly manganese [Mn] oxide) was noted on some fracture surfaces as well as fine to coarse grained pyrite. As expected, significant increases in water production were identified within this interval.

4.1.1.3 Alteration of Well ER-3-3

Generally, from 0 to 505.97 m (0 to 1,660 ft) bgs, the alluvium is unaltered to weakly clay altered with minor caliche. Once in the Tertiary Volcanics (Tv) section, alteration is minimal from 505.97 m (1,660 ft) to 719.33 m (2,360 ft) bgs. From 719.33 m (2,360 ft) to 752.86 m (2,470 ft) bgs, zeolitic/argillic alteration gradually increases with depth, becoming pervasive below 752.86 m (2,470 ft) bgs. Below 752.86 m (2,470 ft) bgs, beginning in the Pre-Timber Mountain - Post-Wahmonie (Tm/Tw) and continuing through the Older Tunnel Beds (Ton), the nonwelded and bedded tuffs are typically pervasively altered to zeolites, and locally intense argillized zones. Finally, the Paleozoic rocks (Pz) show only minor alteration.

4.1.2 Geology of Well ER-4-1

During advancement of Well ER-4-1, the following stratigraphic units were encountered beginning at ground surface and down through to TD:

- Quaternary/Tertiary alluvium (QTa)
- Ammonia Tanks Tuff (Tma)
- Ammonia Tanks bedded tuff (Tmab)
- Rainier Mesa mafic-rich Tuff (Tmrr)
- Rainier Mesa mafic-poor Tuff (Tmrp)
- tuff of Holmes Road (Tmrh)
- Pre-Timber Mountain Tuff - Post-Wahmonie Tuff (undifferentiated) (Tm/Tw)
- Wahmonie Formation (Tw)
- Crater Flat Group (Tc)
- Grouse Canyon bedded tuff (Tbgb)
- Tunnel Formation (Tn)
- Older Tunnel Beds (Ton)
- Paleocolluvium/Older tuffs (Tlc/To)
- Paleozoic rocks (Pz)

Surface geology of the northern portion of Yucca Flat is presented in Figure 1-3. The stratigraphic units encountered in Well ER-4-1 were generally as predicted in the upper portion, and some important differences were noted in the lower portion of the hole. The top of the Paleozoic rocks (Pz) was predicted to be at a depth of 822.35 m (2,698 ft) bgs. Well ER-4-1 identified the actual top of the Paleozoic rocks (Pz) at 858.93 m (2,818 ft) bgs, a difference of 36.58 m (120 ft). Differences between predicted and actual geology in boreholes are not uncommon and may result from complex relationships between paleotopographic depositional conditions, volcanic, and structural processes associated with basin forming systems.

4.1.2.1 Geologic Setting of Well ER-4-1

Well ER-4-1 is located in the area of Yucca Flat within the northeastern portion of the NNSS. Yucca Flat is a north–south elongated structural basin (half graben) on the eastern edge of the southwestern Nevada volcanic field and formed in response to basin and range extension. The prominent Yucca Fault is located about a 0.5 kilometer (km) east of the well, a normal fault with down-dropped units to the east, on the opposite side of the fault from the area of Well ER-4-1. Surface drainage in the vicinity of Well ER-4-1 is generally to the Yucca Flat Playa near the south–central portion of the basin. Physiographically, the well site is located within the north–central portion of Yucca Flat basin.

4.1.2.2 Stratigraphy and Lithology of Well ER-4-1

The stratigraphic units, lithologic units, and HSUs penetrated in Well ER-4-1 are listed in Tables 4-3 and 4-4. Lithologic descriptions, stratigraphic assignments, and their respective depth intervals can be found in Appendix A of the ER-4-1 well completion report (NNSA/NFO, 2017b). Identification of stratigraphic and lithologic units was aided by correlation with stratigraphic units and lithologies observed in nearby boreholes (U-4a, UE-4p, U-4p, U-4o, U-4e, ER-3-3, and ER-2-1), and in the Yucca Flat HFM presented in *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 97: Yucca Flat–Climax Mine, Lincoln and Nye Counties, Nevada* (BN, 2006).

Table 4-3
Key to Stratigraphic Units and Symbols of the Well ER-4-1 Area
(Page 1 of 2)

Stratigraphic Unit	Map Symbol
Quaternary/Tertiary Alluvium	QTa
Timber Mountain Group	Tm
Ammonia Tanks Tuff	Tma
Ammonia Tanks bedded tuff	Tmab
Rainier Mesa mafic-rich Tuff	Tmrr
Rainier Mesa mafic-poor Tuff	Tmrp
tuff of Holmes Road	Tmrh
Pre-Timber Mountain - Post-Wahmonie Tuff	Tm/Tw

Table 4-3
Key to Stratigraphic Units and Symbols of the Well ER-4-1 Area
(Page 2 of 2)

Stratigraphic Unit	Map Symbol
Wahmonie Formation	Tw
Crater Flat Group	Tc
Grouse Canyon bedded tuff	Tbgb
Tunnel Formation	Tn
Older Tunnel Beds	Ton
Paleocolluvium/Older tuffs	Tlc/To
Paleozoic rocks	Pz

Table 4-4
Key to HSUs and Symbols of the Well ER-4-1 Area

HSU	Map Symbol
Alluvial aquifer	AA3
Timber Mountain upper vitric aquifer	TMUVTA
Timber Mountain welded-tuff aquifer	TMWTA
Timber Mountain lower vitric-tuff aquifer	TMLVTA
Lower tuff confining unit	LTCU
Oak Spring Butte confining unit	OSBCU
Argillic tuff confining unit	ATCU
Lower carbonate aquifer	LCA

A strong anomalous response was noted in the average gamma ray (GR) and spectral gamma ray (SGR) logs (uranium and thorium tracks) from approximately 472.44 m (1,550 ft) to 480.06 m (1,575 ft) bgs. The interval corresponds primarily to the Wahmonie Formation (Tw). This anomaly suggests a prompt injection.

A second anomalous response in the average GR and SGR logs at approximately 537.97 m (1,765 ft) bgs was noted. This corresponds to the lower portion of the Grouse Canyon bedded tuff.

Older Tunnel Beds (Ton) were encountered below the Tunnel Formation (Tn) from 694.94 m (2,280 ft) to 832.10 m (2,730 ft) bgs. The lithologic and alteration types found in the Tunnel Formation (Tn) and the Older Tunnel Beds (Ton) contributed to the borehole stability issues, erosion, and tight hole conditions experienced at the well.

Paleozoic rocks (Pz) were encountered from 858.93 m (2,818 ft) to 925.13 m (3,035.19 ft) bgs for a total of 66.20 m (217.19 ft). The Paleozoic rocks (Pz) were composed of limestone. From approximately 880.87 m (2,890 ft) to 896.11 m (2,940 ft) bgs the cuttings exhibited signs of fracturing, brecciation, and open space filling mineralization indicating a breccia zone. Below 896.11 m (2,940 ft) to TD cuttings were primarily (80 to 90 percent) contamination, from the volcanics above, and less than 2 millimeters (mm) in size, indicating that they had been re-drilled. As expected, the principal water production occurred within the Paleozoic rocks (Pz).

4.1.2.3 Alteration in Well ER-4-1

Generally, from 0 to 187.45 m (0 to 615 ft) bgs, the alluvium is unaltered to weakly clay altered with minor caliche. The Ammonia Tanks Tuff (Tma) and Ammonia Tanks bedded tuff (Tmab), from 187.45 m (615 ft) to 231.65 m (760 ft) bgs, are vitric and alteration is nonexistent to minimal. From 231.65 m (760 ft) to 353.57 m (1,160 ft) bgs, the Rainier Mesa Tuff (Tmr) is mostly devitrified with minor vapor phase alteration. From 353.57 m (1,160 ft) to 385.57 m (1,265 ft) bgs, the tuff of Holmes Road (Tmrh) is vitric with alteration gradually increasing with depth. Below 385.57 m (1,265 ft) to 858.93 m (2,818 ft) bgs, beginning in the Pre-Timber Mountain - Post-Wahmonie (Tm/Tw) and continuing through the Older Tunnel Beds (Ton) and Paleocolluvium (Tlc/To), the nonwelded and bedded tuffs are typically pervasively altered to zeolites, and locally intense argillized zones. Finally, the Paleozoic rocks (Pz) show minor, to locally moderate, alteration.

4.2 Predicted and Actual Geology

Geologic conceptual model development is an open process. A comparison of the geology predicted from the model before drilling to the geology actually encountered gauges how well the conceptual model is working and where uncertainties exist.

4.2.1 Predicted and Actual Geology: Well ER-3-3

Overall, the actual stratigraphic sequence and lithology at Well ER-3-3 showed some differences with the predicted stratigraphic and related lithologic sequence. Figure 4-1 illustrates the differences between predicted and actual geology in Well ER-3-3. Thicknesses in the Quaternary/Tertiary alluvium (QTa) and the Timber Mountain Group (Tm) were significantly different than predicted. The predicted thickness of the Quaternary/Tertiary alluvium was 401.73 m (1,318 ft), and the actual thickness was found to be 505.97 m (1,660 ft), a difference of 104.24 m (342 ft). Timber Mountain Group (Tm) rocks (i.e., Ammonia Tanks Tuff [Tma], Ammonia Tanks bedded tuff [Tmab], Rainier Mesa mafic-poor Tuff [Tmrp], and the tuff of Holmes Road [Tmrh]) were also thicker than predicted. The predicted thickness for the group was 188.06 m (617 ft), and the actual thickness found was 246.89 m (810 ft), for a difference of 58.83 m (193 ft).

The Paintbrush Group (Tp) was not definitively identified in the well and may be represented by a portion of the Pre-Timber Mountain - Post-Wahmonie (Tm/Tw). The Tm/Tw had an actual thickness of 48.77 m (160 ft) as opposed to the predicted thickness of the Paintbrush Group (Tp) of 151.49 m (497 ft), for a difference of -102.72 m (-337 ft). No Grouse Canyon Tuff (Tbg) was identified in Well ER-3-3. The Wahmonie Formation (Tw), however, was identified, and the actual thickness is 4.57 m (15 ft) as opposed to the predicted thickness of the Grouse Canyon Tuff (Tbg) of 9.14 m (30 ft).

The Tunnel Formation (Tn) was identified but could not be further subdivided based on the quality and character of the cuttings from this interval. The predicted thickness of the Tunnel Formation (Tn) was 126.19 m (414 ft), and the actual thickness was 24.38 m (80 ft), a difference of -101.80 m (-334 ft). Preceding the Tunnel Formation (Tn) was the Older Tunnel Beds (Ton). This unit had not been predicted in Well ER-3-3 but had an actual thickness of 28.96 m (95 ft). Completing the Tertiary section was the expected Paleocolluvium (Tlc/To). The Paleocolluvium/Older tuffs (Tlc/To) had a predicted thickness of 17.98 m (59 ft), whereas the actual thickness was 50.29 m (165 ft).

The top of the Paleozoic rocks (Pz) was identified at 909.83 m (2,985 ft) bgs, a total of 15.24 m (50 ft) deeper than predicted. A total of 63.37 m (207.9 ft) of Paleozoic rocks (Pz) were penetrated in Well ER-3-3. Figure 4-2 illustrates the relationship between the stratigraphy, lithology, alteration, and hydrogeologic units (HGUs) identified in Well ER-3-3. Figure 4-3 shows the relationship between Well ER-3-3 and surrounding underground nuclear tests; other select wells; and the mapped surface effects from nearby underground tests, including the WAGTAIL test. The stratigraphic units and HSUs in the vicinity of the well are shown in cross section in Figures 4-4 and 4-5. Cross-section lines are shown on the surface geology map (Figure 1-2).

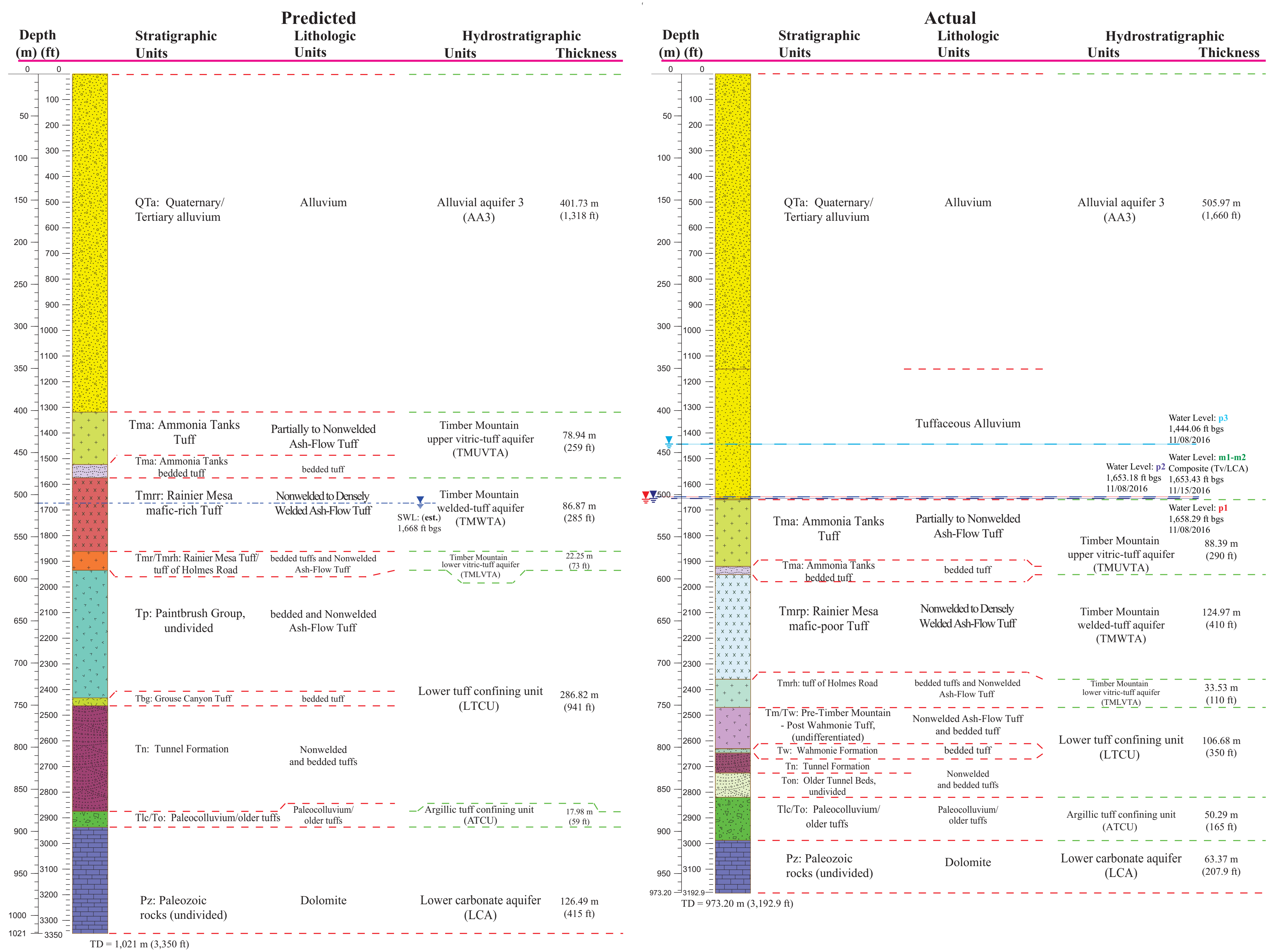

Figure 4-1
Predicted versus Actual Hydrogeology for Well ER-3-3

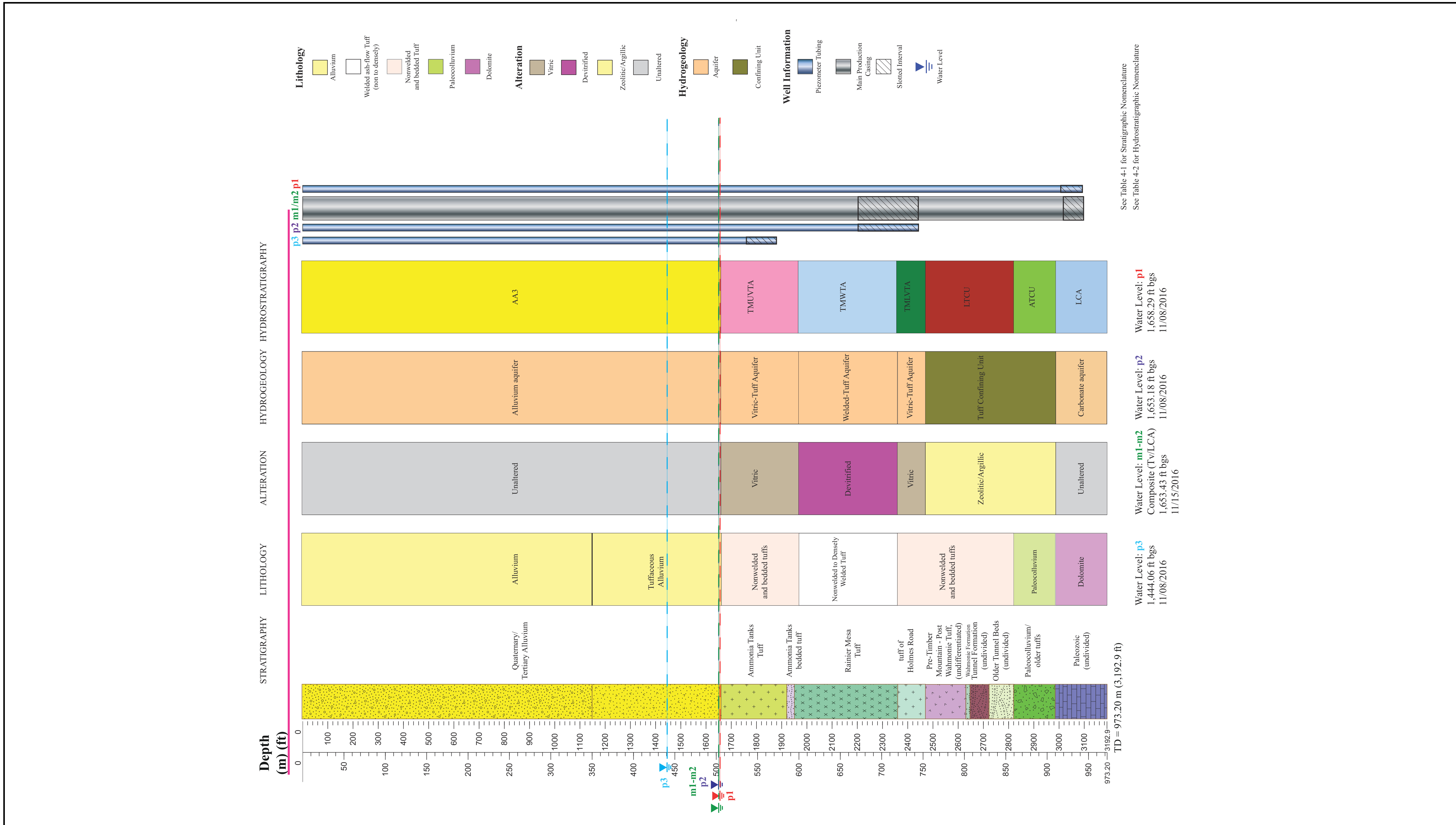

Figure 4-2
Graphical Presentation Showing Geology and Hydrogeology for Well ER-3-3

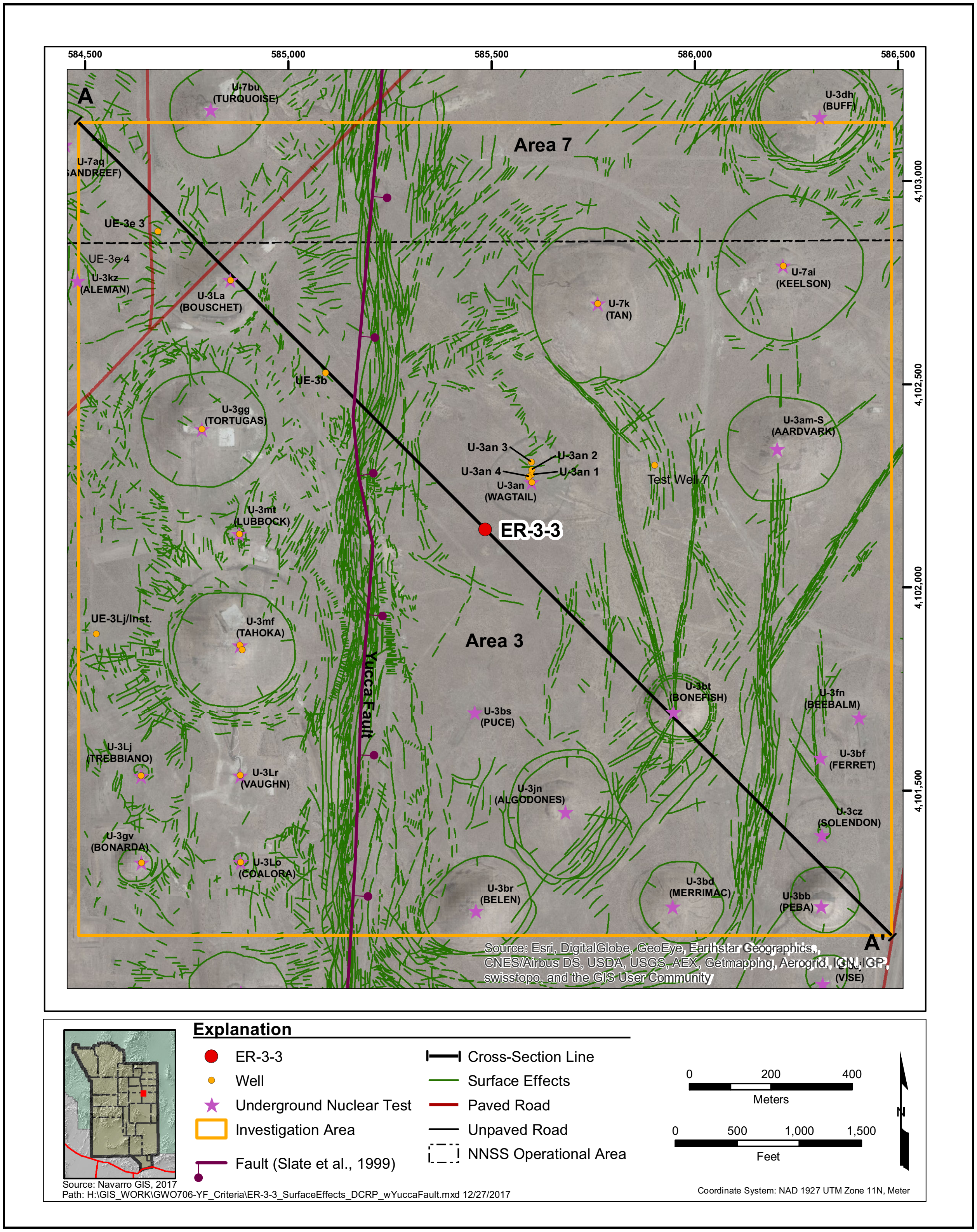

Figure 4-3
Surface Effects Map for the Well ER-3-3 Area

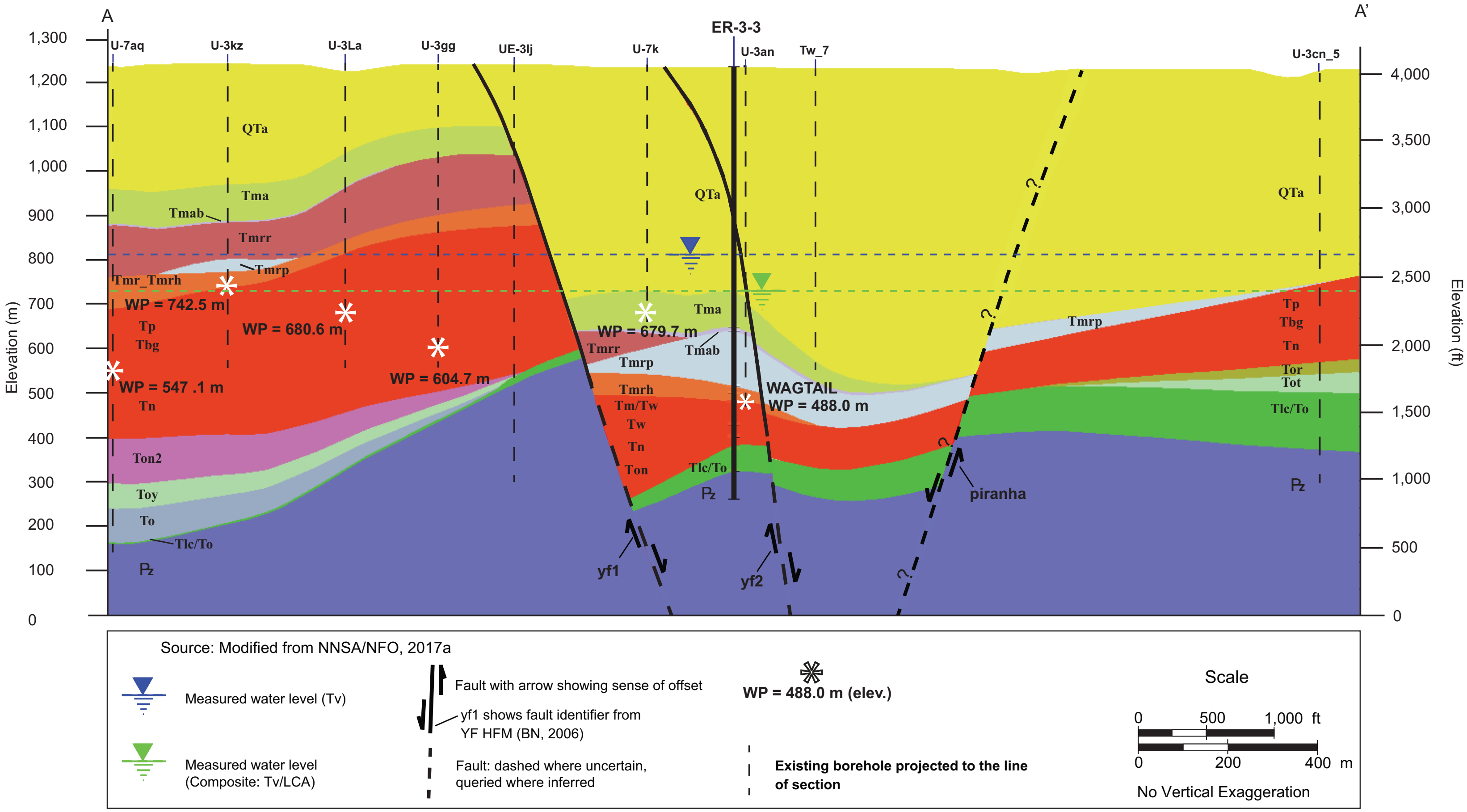

Figure 4-4

Stratigraphic Cross Section Northwest to Southeast in the Region of Well ER-3-3

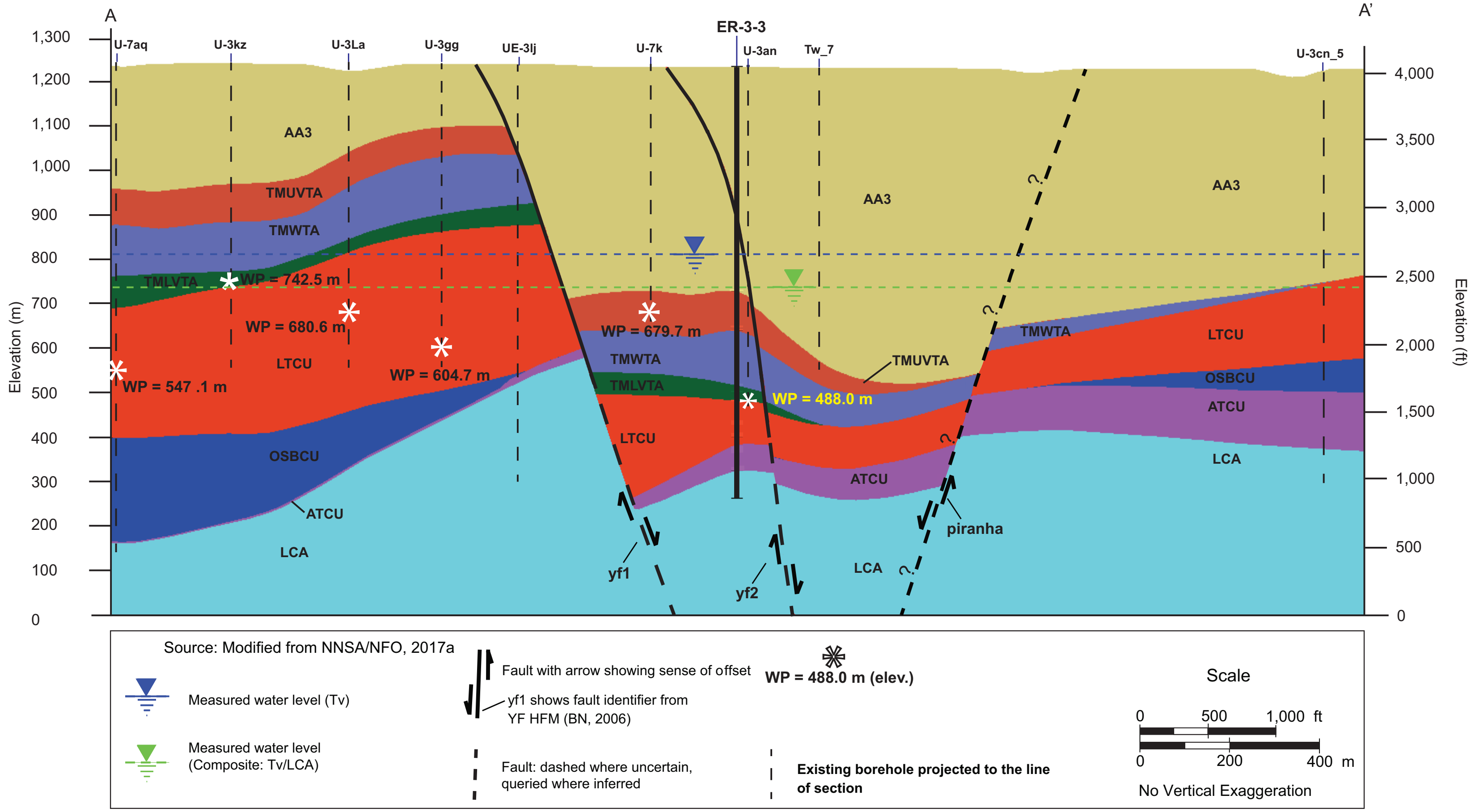

Figure 4-5
Hydrostratigraphic Cross Section Northwest to Southeast in the Region of Well ER-3-3

4.2.2 Predicted and Actual Geology: Well ER-4-1

Overall, the actual stratigraphic sequence and lithology at Well ER-4-1 showed some differences with the predicted stratigraphic and related lithologic sequence. Figure 4-6 illustrates the differences between predicted and actual geology in Well ER-4-1.

Thicknesses in the Quaternary/Tertiary alluvium (QTa) were slightly less than predicted. The predicted thickness of the alluvium was 199.03 m (653 ft), and the actual thickness of the alluvium (QTa) was found to be 187.45 m (615 ft), a difference of -11.58 m (-38 ft).

Timber Mountain Group (Tm) rocks (i.e., Ammonia Tanks Tuff [Tma], Ammonia Tanks bedded tuff [Tmab], Rainier Mesa mafic-rich Tuff [Tmrr], Rainier Mesa mafic-poor Tuff [Tmrp], and the tuff of Holmes Road [Tmrh]) was thicker than predicted. The predicted thickness for the group was 163.37 m (536 ft), and the actual thickness found was 198.12 m (650 ft), for a difference of 34.75 m (114 ft).

The Paintbrush Group (Tp) was not definitively identified in the well and may be represented by a portion of the identified sequence of the Pre-Timber Mountain - Post-Wahmonie (Tm/Tw), Wahmonie Formation (Tw), and the Crater Flat Group (Tc). The actual thicknesses for these units is as follows: Pre-Timber Mountain - Post-Wahmonie (Tm/Tw), an actual thickness of 89.92 m (295 ft); Wahmonie Formation (Tw), an actual thickness of 6.10 m (20 ft); and Crater Flat Group (Tc), an actual thickness of 35.05 m (115 ft). The total combined actual thickness for the units is 131.07 m (430 ft) as opposed to the predicted thickness of the Paintbrush Group (Tp) of 166.73 m (547 ft), for a difference of -35.66 m (-117 ft).

The Grouse Canyon bedded tuff (Tbgb) was identified in Well ER-4-1. The actual thickness is 33.53 m (110 ft) as opposed to the predicted thickness of the Grouse Canyon Tuff (Tbg) of 11.89 m (39 ft), for a difference of 21.64 m (71 ft).

The Tunnel Formation (Tn) was identified and subdivided as follows: Tunnel Member 4 (Tn4), Tunnel Member 3 (Tn3), and Tunnel Member 3, bed A (Tn3A). The actual thicknesses for these units is as follows: Tn4, an actual thickness of 50.29 m (165 ft); Tn3, an actual thickness of 67.06 m (220 ft); and Tn3A, an actual thickness of 27.43 m (90 ft). The predicted total thickness of the Tunnel Formation, Members 3&4 (Tn3 and Tn4) was 81.69 m (268 ft), and the actual thickness was

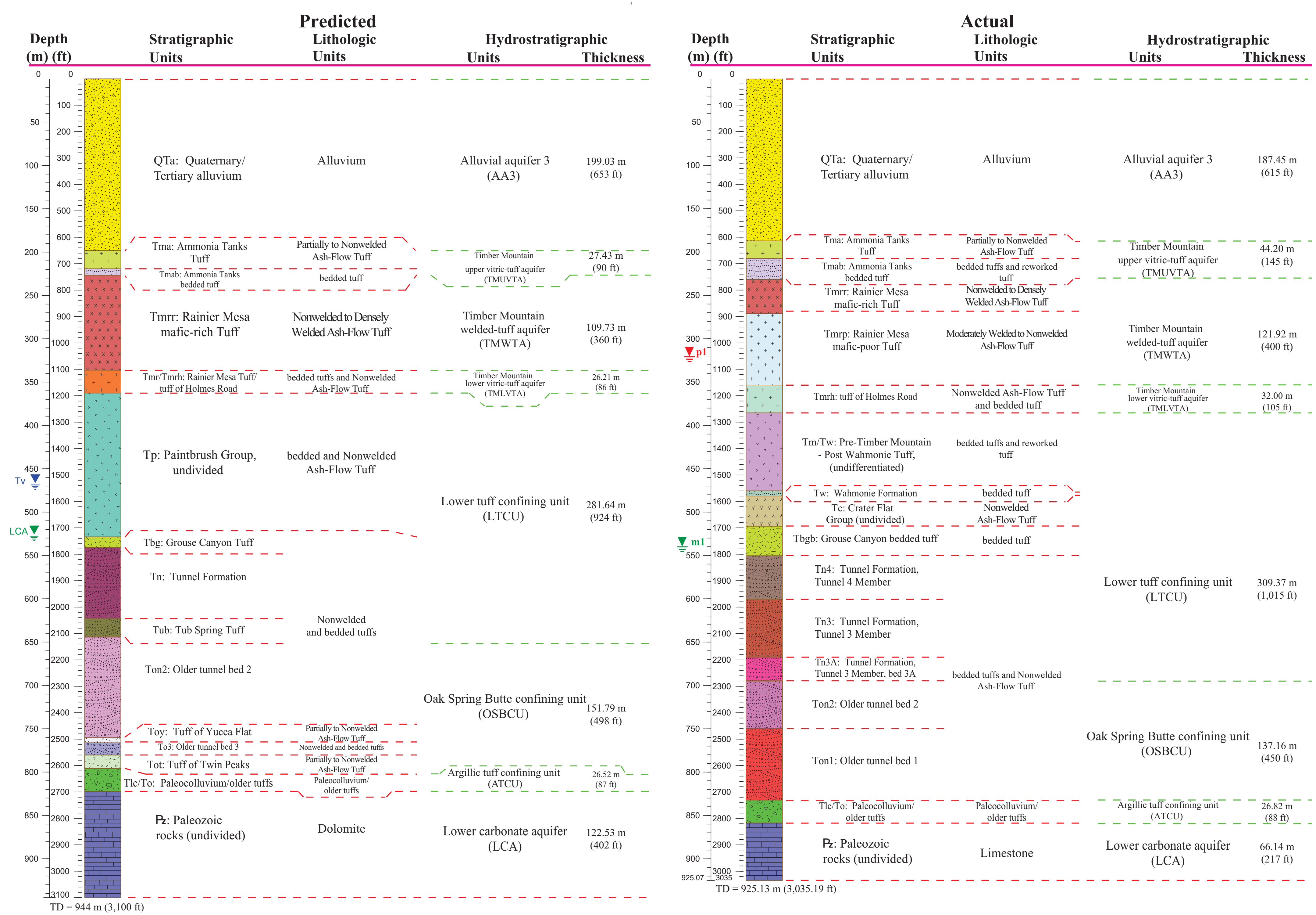

Figure 4-6
Predicted versus Actual Hydrogeology for Well ER-4-1

144.78 m (475 ft), a difference of 63.09 m (207 ft). The Tub Spring Tuff (Tub), which had a predicted thickness of 21.34 m (70 ft), was not identified in the well. Preceding the Tunnel Formation (Tn) was the Older Tunnel Beds (Ton), tunnel bed 2 (Ton2), and tunnel bed 1 (Ton1). The actual thickness of Ton2 was 54.86 m (180 ft) versus a predicted thickness of 113.69 m (373 ft). Ton1 had not been predicted in Well ER-4-1 but had an actual thickness of 82.30 m (270 ft). Ton1 was identified instead of the predicted Tuff of Yucca Flat (Toy), Volcanics of Oak Spring Butte, tunnel bed 3 (To3), and Tuff of Twin Peaks (Tot) units. The predicted thickness of tunnel bed 2 (Ton2) and the older tuffs (Toy, To3, Tot) was 151.79 m (498 ft); and the actual thickness of the Ton was 137.16 m (450 ft), a difference of -14.63 m (-48 ft). Completing the Tertiary section was the expected Paleocolluvium (Tlc/To). The Paleocolluvium/Older tuffs (Tlc/To) had a predicted thickness of 26.52 m (87 ft), whereas the actual thickness was 26.82 m (88 ft), a difference of 0.3 m (1 ft).

The top of the Paleozoic rocks (Pz) was identified at 858.93 m (2,818 ft) bgs, a total of 36.58 m (120 ft) deeper than predicted. A total of 66.20 m (217.19 ft) of Paleozoic rocks (Pz) were penetrated in Well ER-4-1. Figure 4-7 illustrates the relationship between the stratigraphy, lithology, alteration, and HGUs identified in Well ER-4-1. Figure 4-8 shows the relationship between Well ER-4-1 and surrounding UGTs; other select wells; and the mapped surface effects from nearby UGTs including the STRAIT test. The stratigraphic units and HSUs in the vicinity of the well are shown in cross section in Figures 4-9 and 4-10. Note in Figure 4-9 that the stratigraphic units below the Timber Mountain Group (Tm) and above Older tunnel bed 2 (Ton2) are grouped as “Undivided” for the purpose of modeling. These units are only shown in the vicinity of Well ER-4-1 and may not extend across the section. The cross-section line is shown on the surface geology map (Figure 1-3).

4.3 Hydrogeology

HSUs are groups of contiguous stratigraphic units that have a particular hydrogeologic character—such as an aquifer, composite unit, or a confining unit—as defined in the *A Hydrostratigraphic Model and Alternatives for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 97: Yucca Flat–Climax Mine, Lincoln and Nye Counties, Nevada* (BN, 2006). Therefore, HSUs may cross stratigraphic boundaries where lithologic properties may be similar. HSUs are developed from a system of HGUs that categorize rock units as aquifers or confining units according to their porosity and permeability, primary lithology, type of post-depositional alteration, and propensity to fracture.

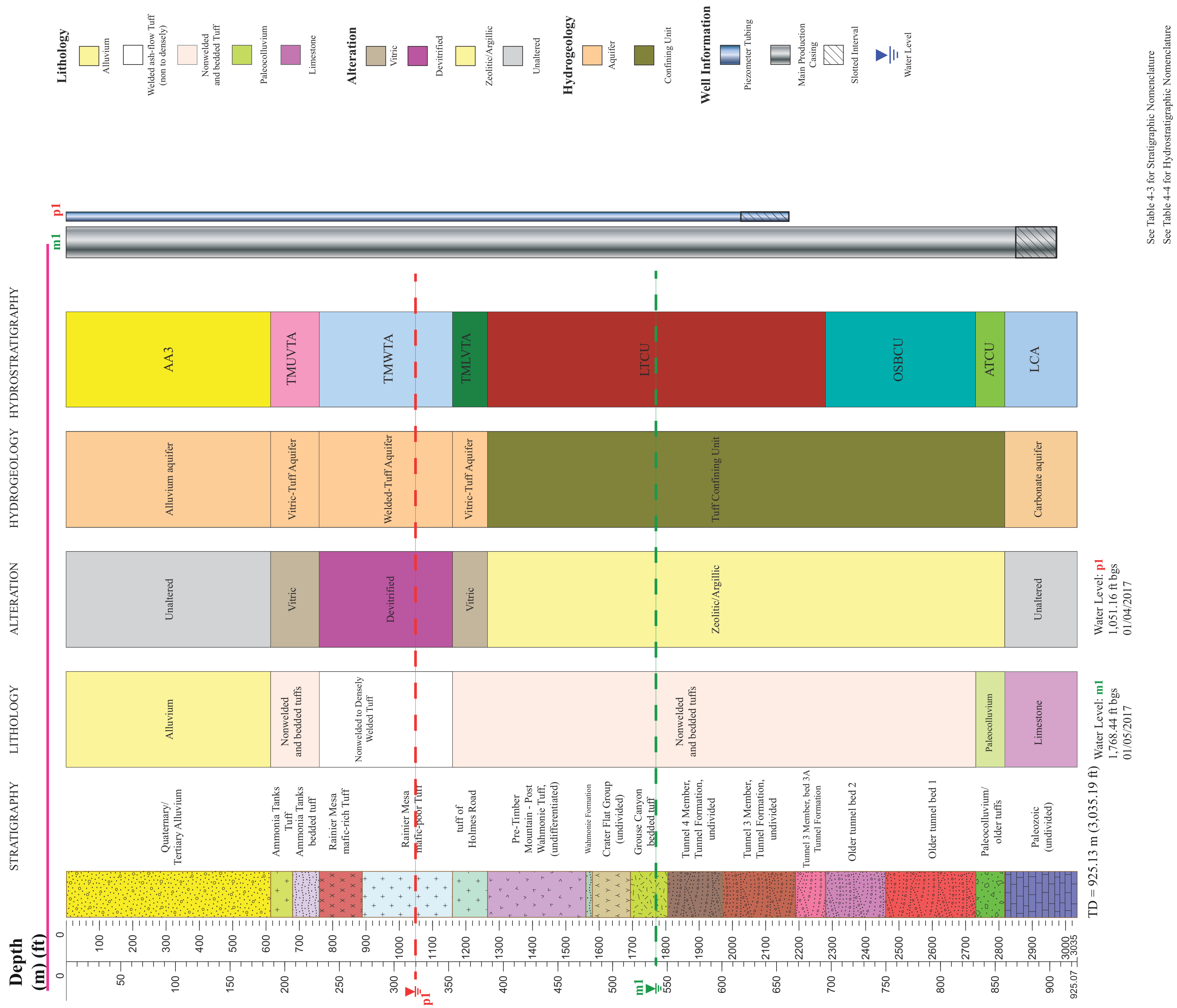

Figure 4-7
Graphical Presentation Showing Geology and Hydrogeology for Well ER-4-1

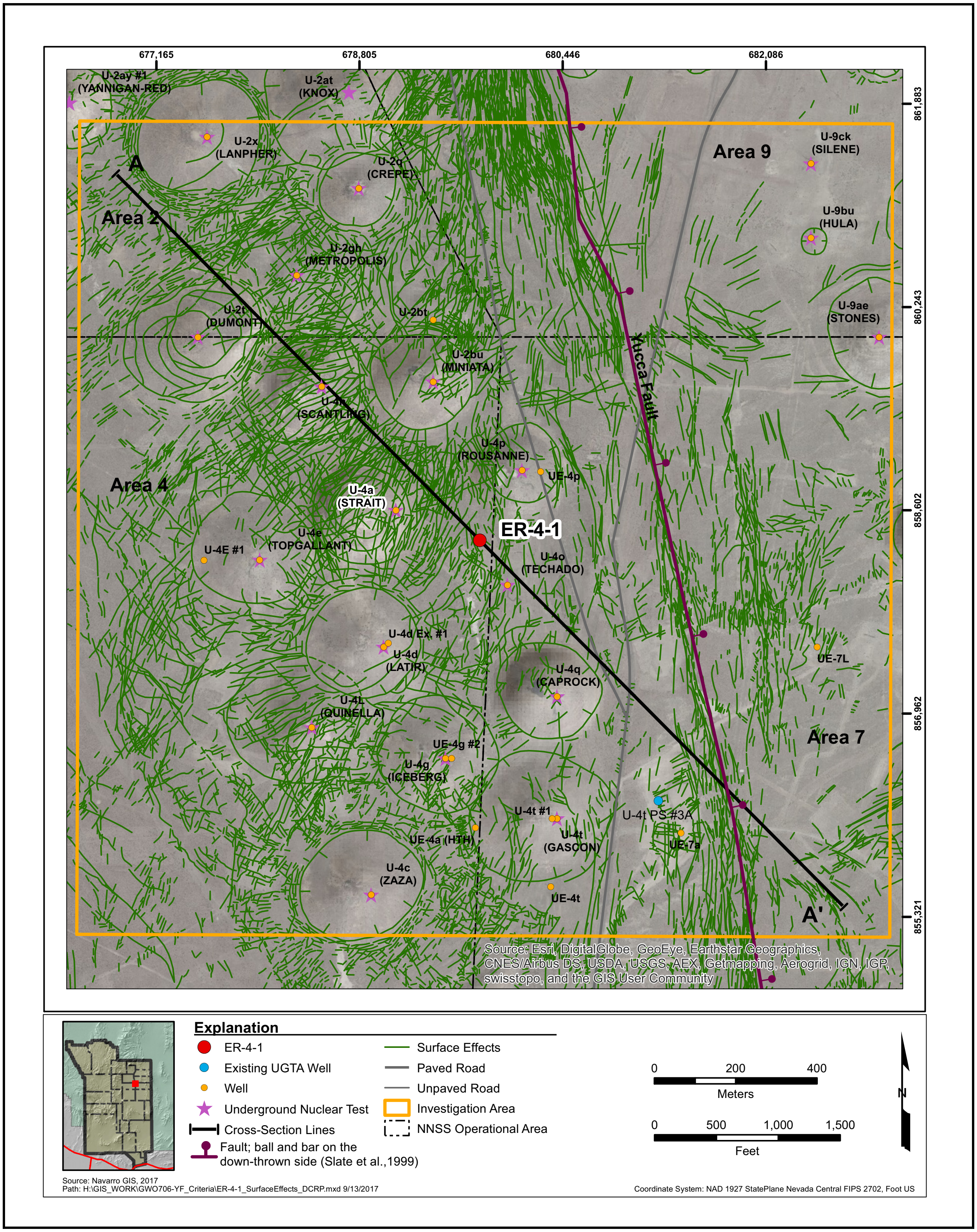

Figure 4-8
Surface Effects Map for the Well ER-4-1 Area

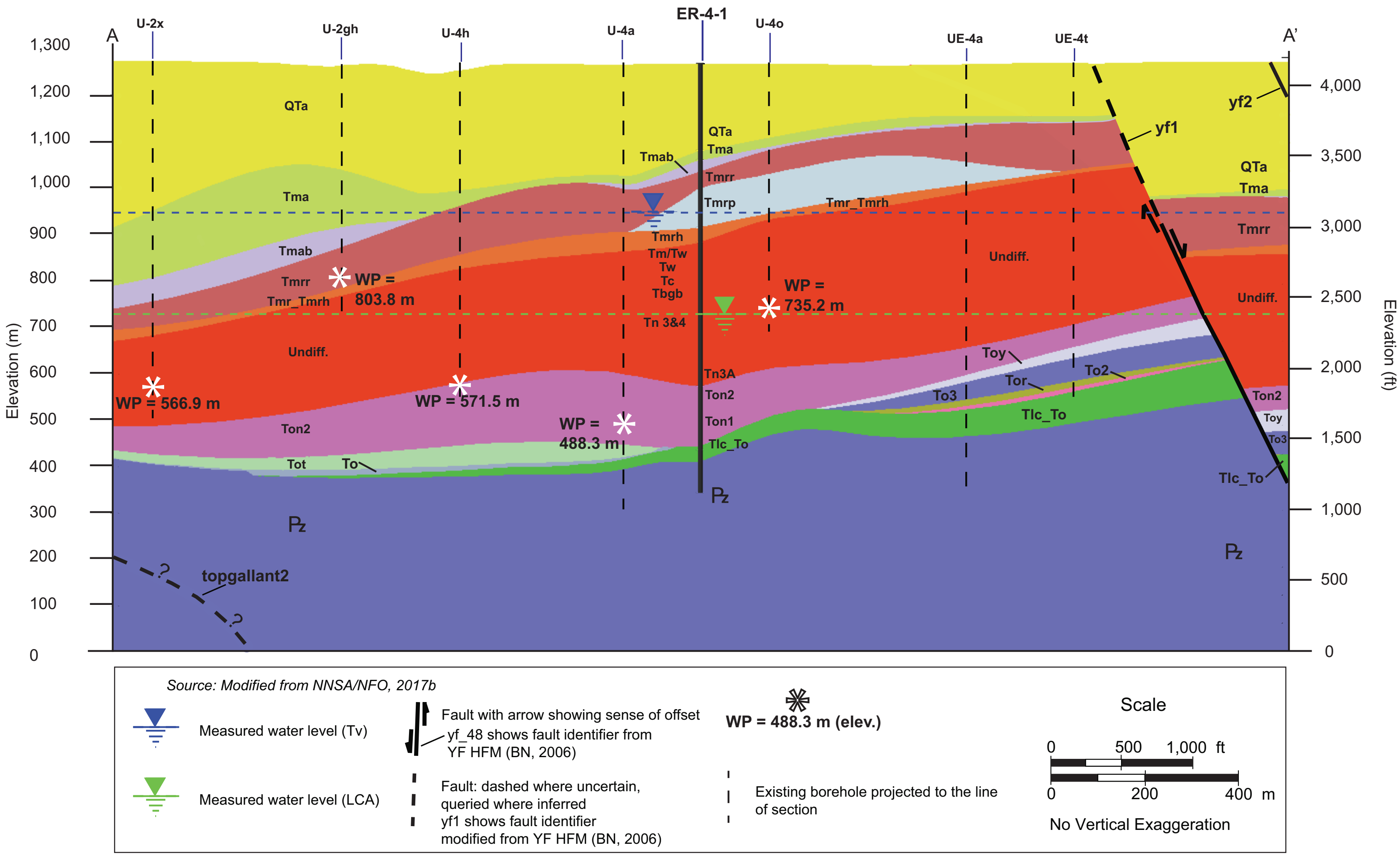

Figure 4-9
Stratigraphic Cross Section Northwest to Southeast in the Region of Well ER-4-1

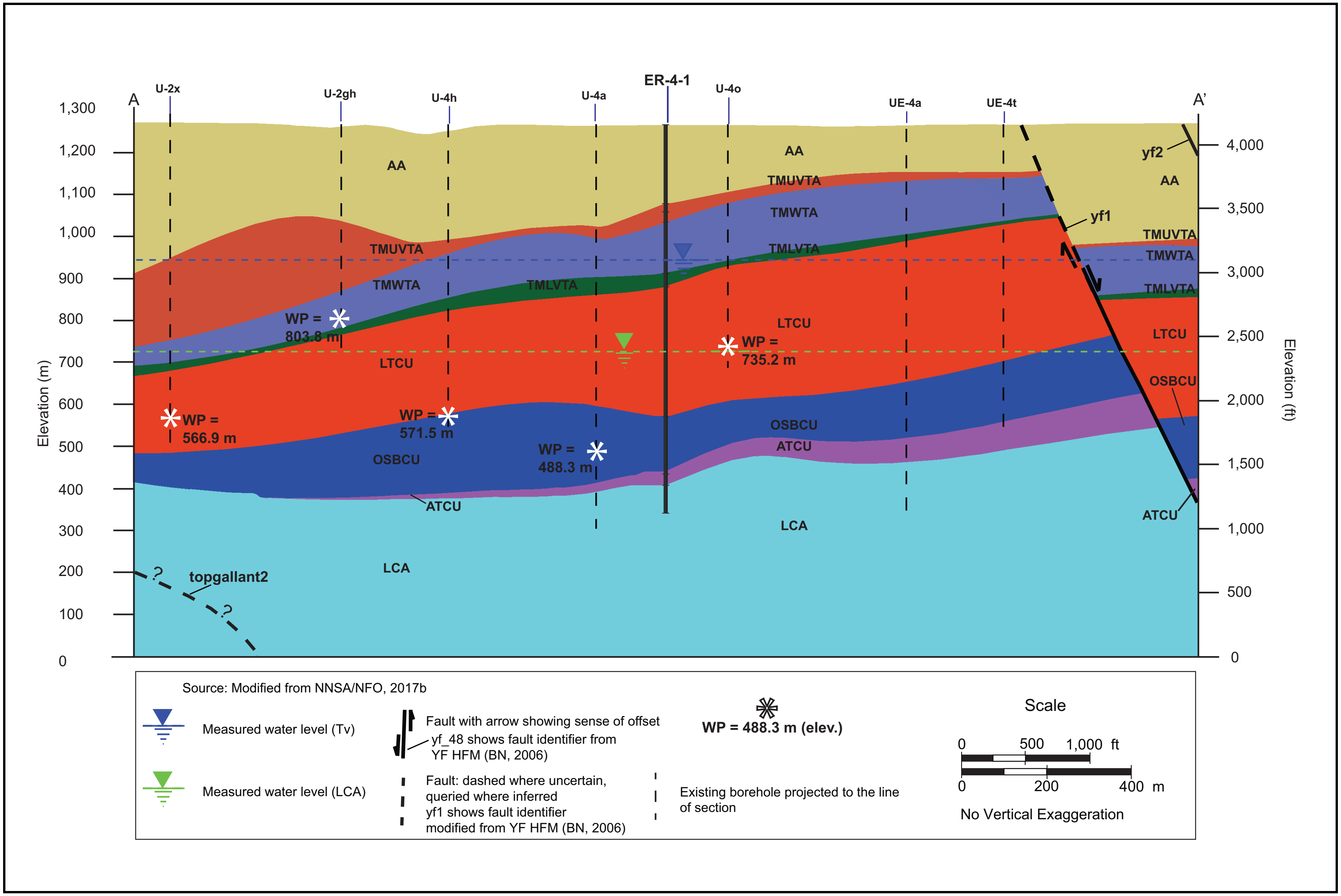

Figure 4-10
Hydrostratigraphic Cross Section Northwest to Southeast in the Region of Well ER-4-1

4.3.1 Hydrogeology of Well ER-3-3

Figure 4-1 provides a comparison of predicted versus actual geologic units, HGUs, and HSUs found at Well ER-3-3. HSUs present were generally as predicted. Based on the identification of key stratigraphic units (i.e., Ammonia Tanks Tuff [Tma], Rainier Mesa Tuff [Tmr], Wahmonie Formation [Tw], and Paleozoic rocks [₱z]), a high degree of confidence in the HSUs as identified and their assigned depths in Well ER-3-3 is warranted. Especially notable were the variations in actual versus predicted thickness of the AA3 and LTCU HSUs. The predicted thickness of the AA3 was 401.73 m (1,318 ft). Based on geophysical and lithologic information, the actual thickness was found to be 505.97 m (1,660 ft). The LTCU was predicted to be 286.82 m (941 ft) but was found to be 106.68 m (350 ft).

The distribution of HSUs in the vicinity of Well ER-3-3 is shown in cross section in Figure 4-5. The well penetrated a total of seven HSUs: (1) AA3 from 0.00 to 505.97 m (0 to 1,660 ft) bgs (unsaturated above 427.88 m [1,403.82 ft] bgs); (2) TMUVTA from 505.97 to 594.36 m (1,660 to 1,950 ft) bgs (saturated); (3) TMWTA from 594.36 to 719.33 m (1,950 to 2,360 ft) bgs (saturated); (4) TMLVTA from 719.33 to 752.86 m (2,360 to 2,470 ft) bgs (saturated); (5) LTCU from 752.86 to 859.54 m (2,470 to 2,820 ft) bgs (saturated); (6) ATCU from 859.54 to 909.83 m (2,820 to 2,985 ft) bgs (saturated); and (7) LCA from 909.83 to 973.20 m (2,985 to 3192.9 ft) bgs (saturated). Based on the HFM, the Tunnel Formation (Tn) and Older Tunnel Beds (Ton) have been assigned to the LTCU for Well ER-3-3. The relationship between the HSUs in the vicinity of Well ER-3-3 and the phenomenology of the WAGTAIL (U3an) UGT is illustrated in Figure 4-11.

The saturated portion of Well ER-3-3 consists of HGUs including the alluvial aquifer (AA), vitric-tuff aquifer (VTA), and welded-tuff aquifer (WTA) interbedded with tuff confining units (TCUs) and the lower carbonate aquifer (LCA), as shown in Figure 4-2. A significant geologic feature (possible tension fracture or other fault-related feature) was observed in the Schlumberger FMI, and this feature appears to significantly influence water production in the WTA. The package of aquifer-type rock units is divided by TCUs that consist of zeolitically and argillically altered nonwelded ash flows and bedded tuffs and paleocolluvium and are assigned to the LTCU and ACTU, respectively. The altered tuffs of the Wahmonie Formation (Tw) and Tunnel Formation (Tn) that underlie the Timber Mountain Group (Tm), although altered, appear to be somewhat productive based on water production estimates during drilling. This productivity may be related to possible fracturing within this unit.

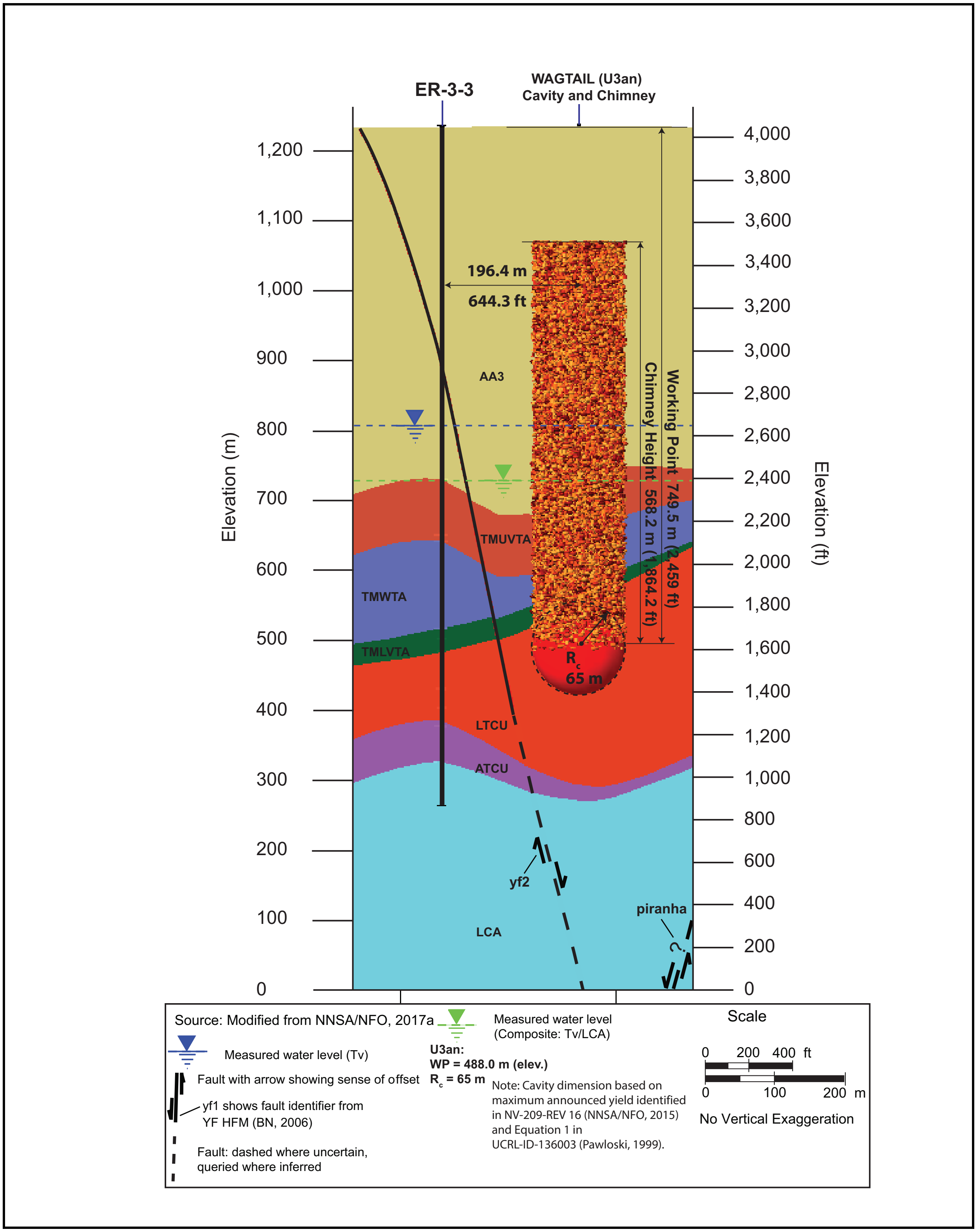

Figure 4-11
Schematic Diagram of the WAGTAIL Crater, Cavity, and Chimney near Well ER-3-3

The LCA was also productive in Well ER-3-3 as expected. Water production—which had been relatively steady since penetrating the TMWTA, at approximately 150 to 200 gpm—increased to approximately 300 to 350 gpm, by lithium bromide (LiBr) calculations.

Before drilling, it was predicted that the Tertiary Volcanics (Tv) SWL in Well ER-3-3 would be encountered at 508.41 m (1,668 ft) bgs within the TMWTA HSU. DTW was measured in piezometer p3, which is open to the TMUVTA, on March 18, 2016, at 427.88 m (1,403.82 ft) bgs and was found to occur higher than the predicted level (within the AA3 HSU). DTW in piezometer p2—which is open across the lower TMWTA, TMLVTA, and upper LTCU—was measured on March 18, 2016, at 504.09 m (1,653.83 ft) bgs. On March 18, 2016, Navarro personnel collected a water level from piezometer p1 in the LCA. The water level recorded was 502.29 m (1,647.92 ft) bgs. The slotted intervals of the main completion m1 and piezometer p1 are within the LCA.

4.3.2 Hydrogeology of Well ER-4-1

Figure 4-6 provides a comparison of predicted versus actual geologic units, HGUs, and HSUs found at Well ER-4-1. HSUs present were as predicted. Based on the identification of key stratigraphic units (i.e., Ammonia Tanks Tuff [Tma], Rainier Mesa Tuff [Tmr], Wahmonie Formation [Tw], Grouse Canyon bedded tuff [Tbgb] and Paleozoic rocks [Pz]), a high degree of confidence in the HSUs identified and depths assigned to them in Well ER-4-1 is warranted.

The distribution of HSUs in the vicinity of Well ER-4-1 is shown in cross section in Figure 4-10.

The well penetrated a total of eight HSUs: (1) AA3 from 0.00 to 187.45 m (0 to 615 ft) bgs, (unsaturated); (2) TMUVTA from 187.45 to 231.65 m (615 to 760 ft) bgs, (unsaturated); (3) TMWTA from 231.65 to 353.57 m (760 to 1,160 ft) bgs, (unsaturated above 320.39 m [1,051.16 ft] bgs); (4) TMLVTA from 353.57 to 385.57 m (1,160 to 1,265 ft) bgs, (saturated); (5) LTCU from 385.57 to 694.94 m (1,265 to 2,280 ft) bgs, (saturated); (6) OSBCU from 694.94 to 832.10 m (2,280 to 2,730 ft) bgs, (saturated); (7) ATCU from 832.10 to 858.93 m (2,730 to 2,818 ft) bgs, (saturated); and (8) LCA from 858.93 to 925.13 m (2,818 to 3,035.19 ft) bgs, (saturated). The relationship between the HSUs in the vicinity of Well ER-4-1 and the phenomenology of the STRAIT (U4a) UGT is illustrated in Figure 4-12.

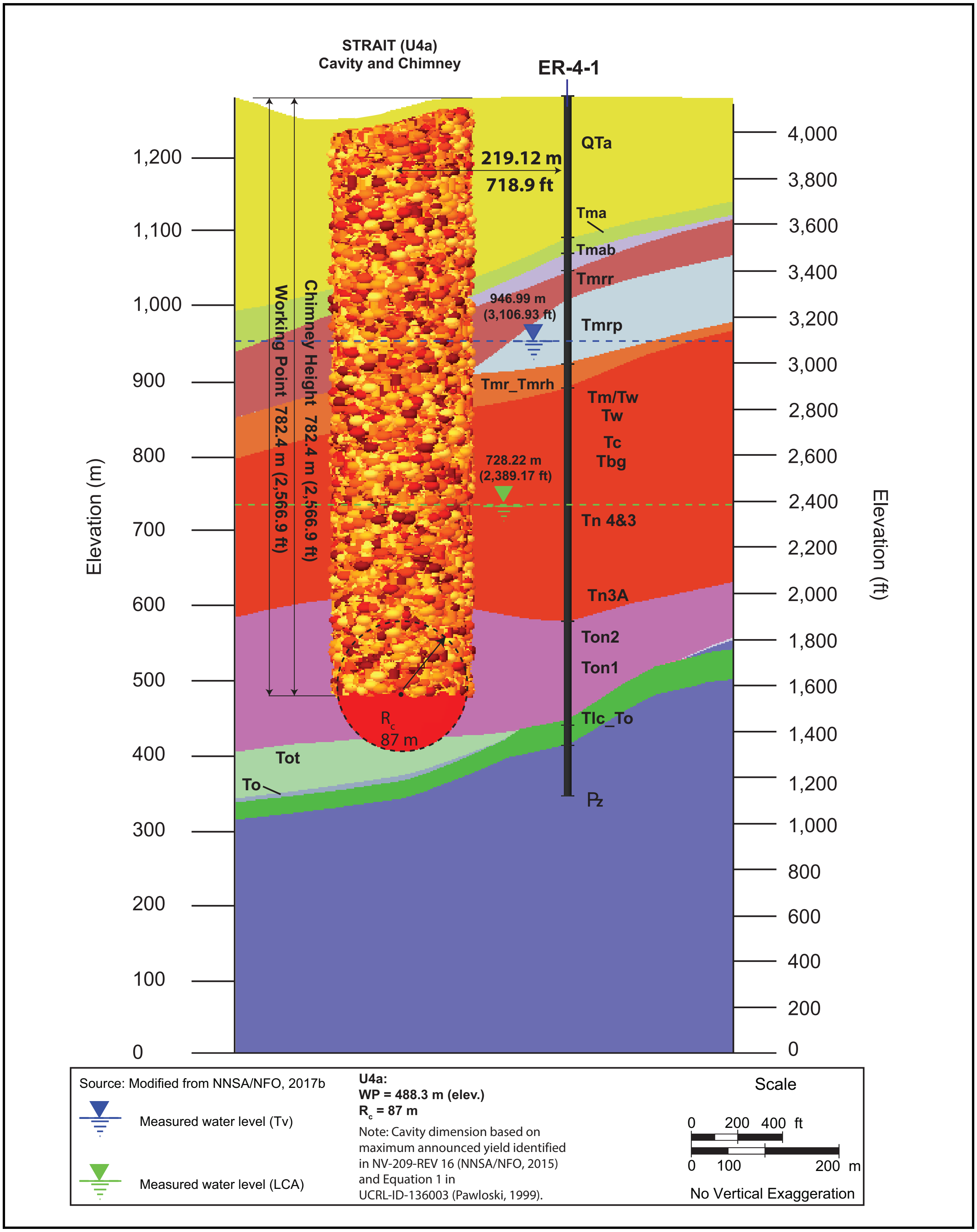

Figure 4-12
Schematic Diagram of the STRAIT Crater, Cavity, and Chimney near Well ER-4-1

The saturated portion of Well ER-4-1 consists of four HGUs, including a portion of the WTA HGU and all of the subsequent HGUs (VTA, TCU, and CA), as shown in Figure 4-10. The package of aquifer-type rock units is divided by TCUs that consist of zeolitically and argillically altered nonwelded ash flows and bedded tuffs and paleocolluvium and are assigned to the LTCU, OSBCU, and ATCU, respectively.

The altered tuffs below the TMUVTA are primarily confining units, and showed little to no water production based on LiBr calculations and visual estimates during drilling. The LCA was the productive HSU in Well ER-4-1 as expected. Water production—which had been minimal since penetrating the TMUVTA, at approximately 0 to 10 gpm—increased to approximately 25 to 50 gpm upon penetrating the LCA and increased to an estimated 175 gpm.

Before drilling, it was predicted that the Tertiary Volcanics (Tv) SWL would be encountered at 484.33 m (1,589 ft) bgs within the TMWTA HSU. DTW in the Tertiary Volcanics (Tv) units was measured in piezometer p1 on January 4, 2017, at 320.29 m (1,051.16 ft) bgs and was found to occur higher, than the predicted level, within the TMWTA HSU. On December 12, 2016, Navarro personnel collected a water level from the main production casing slotted interval m1 in the LCA. The water level recorded was 539.17 m (1,768.92 ft) bgs.

5.0 PUMPING WELL HYDRAULICS

The response of wells to pumping provides key information about formation properties and flow regime. The response is evaluated in the context of the geologic conceptual model to determine the following:

- *Well losses.* The drawdown observed in the well in response to pumping is composed of formation drawdown (linearly proportional to discharge); well losses from linear components (due to linear flow through the well skin, gravel pack and well screen); and non-linear components (due to turbulent water flow and associated friction in the gravel pack, well screen, and well casing).

- *Transmissivity.* Transmissivity is inversely proportional to the semi-log slope of drawdown in a pumping well. An extended period of constant-rate pumping is performed to estimate the large-scale transmissivity, sufficiently stressing the formation to see a late time response from a possibly dual-porosity system, and observing hydrogeologic features such as flow barriers.

- *Storage Coefficient.* The storage coefficient in confined aquifer is storativity: the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit volume of the aquifer, and thus has length-inverse dimensions. The release is due to the expansion of water, and compression of the soil or rock skeleton. The storage coefficient in unconfined aquifers is specific yield: the volume of water released from storage per unit decline in the water table, per unit area of the water table, and thus is dimensionless. The release is primarily due to drainage from porosity, with lesser contributions from the expansion of water and compression of the soil or rock skeleton. The storage coefficient most strongly influences the early drawdown data, and is determined by fitting a model to the early drawdown data. The LCA wells are confined.

A summary of pump test well monitoring intervals and water levels is provided in Table 5-1. The table provides spatial and water-level information, including land surface elevation at the wellhead, and the depths to water before pump testing, as well as details of the specific HSUs that intersect with the effective open intervals of the wells.

Installation of pumps and PXDs for aquifer testing were summarized in Sections 3.7 and 3.11, respectively. A pump test was only possible in Well ER-4-1, and is discussed in Sections 5.1 and 5.2. Section 5.3 summarizes a study of the effect of pumping on distal wells conducted by the U.S. Geological Survey (USGS) and provided in Appendices E and F of this report. Section 5.4 presents

Table 5-1
Summary of Pump Test Well Monitoring Intervals and Water Levels

Well	Land Surface Elevation	DTW (measured or PXD)	SWL Elevation	Completion Top-Bottom of EOI			EOI		HSU Contact Elevation			HSU Thickness of Fraction of EOI	HSU Contact Depth			Completion Top-Bottom of EOI		
	(ft amsl)	(ft bgs)	(ft amsl)	Top (ft amsl)	Bottom (ft amsl)	EOI Length (ft)	HSU	% of EOI	Top (ft amsl)	Bottom (ft amsl)	Thickness (ft)		Top Depth (ft bgs)	Bottom Depth (ft bgs)	Thickness (ft)	Top (ft bgs)	Bottom (ft bgs)	EOI Length (ft)
ER-3-3_p3	4,056.85	1,444.06	2,612.79	2,612.8	2,116.9	495.9	AA3	44%	4,057	2,397	1,660	215.9	0	1,660	1,660	1,444.06 [a]	1,940.00 [a]	495.9 [a]
							TMUVTA	56%	2,397	2,107	290	280.0	1,660	1,950	290			
ER-3-3_p2	4,056.85	1,653.00	2,403.85	1,914.9	1,549.9	365.0	TMWTA	60%	2,107	1,697	410	218.0	1,950	2,360	410	2,142	2,507	365.0
							TMLVTA	30%	1,697	1,587	110	110.0	2,360	2,470	110			
							LTCU	10%	1,587	1,237	350	37.0	2,470	2,820	350			
ER-3-3_p1	4,056.85	1,667.44	2,389.41	1,426.9	864.0	562.9	LTCU	34%	1,587	1,237	350	190.0	2,470	2,820	350	2,630	3,192.9	562.9
							ATCU	29%	1,237	1,072	165	165.0	2,820	2,985	165			
							LCA	37%	1,072	864	208	207.9	2,985	3,192.9	208			
ER-3-3_m2	4,056.85	1,653.43	2,403.42	1,914.9	1,549.9	365.0	TMWTA	60%	2,107	1,697	410	218.0	1,950	2,360	410	2,142	2,507	365.0
							TMLVTA	30%	1,697	1,587	110	110.0	2,360	2,470	110			
							LTCU	10%	1,587	1,237	350	37.0	2,470	2,820	350			
ER-3-3_m1	4,056.85	1,653.43	2,403.42	1,426.9	864.0	562.9	LTCU	34%	1,587	1,237	350	190.0	2,470	2,820	350	2,630	3,192.9	562.9
							ATCU	29%	1,237	1,072	165	165.0	2,820	2,985	165			
							LCA	37%	1,072	864	208	207.9	2,985	3,192.9	208			
ER-4-1_p1	4,158.09	1,037.93	3,120.16	3,120.2	1,783.1	1,337.1	TMWTA	9%	3,398	2,998	400	122.1	760	1,160	400	1,037.93 [a]	2,375 [a]	1,337.1 [a]
							TMLVTA	8%	2,998	2,893	105	105.0	1,160	1,265	105			
							LTCU	76%	2,893	1,878	1,015	1,015.0	1,265	2,280	1,015			
							OSBCU	7%	1,878	1,428	450	95.0	2,280	2,730	450			
ER-4-1_m1	4,158.09	1,769.10	2,388.99	1,346.1	1,122.9	223.2	LCA	100%	1,340	1,123	217	223.2	2,818	3,035.19	217	2,812	3,035.19	223.2

[a] EOI represents saturated interval from water table.

EOI = Effective open interval

% = HSU thickness of fraction of EOI divided by total thickness of EOI.

the data collected during cyclic pumping of ER-3-3, and the results of a slug test analysis from the initial pump induced bailing of the well.

5.1 Processing of the Water-Level Monitoring Record

Figure 5-1 shows all of the pressure, temperature, and flow data collected during WDT activities from January 12 through February 21, 2017. WDT operations for ER-4-1 produced a total of 1.7E+06 gal of water from January 17 to February 17, 2017. After a brief pump function test on January 13, 2017, the testing included a period from January 17 to January 27 of pumping at stepped constant pumping rates to determine the optimum pumping rate for the constant test; and a period of constant-rate testing from February 7 to February 17, 2017.

The raw pumping response record may be processed in several ways to render a more accurate record of the formation response to pumping. This may include removing effects of barometric pressure changes, and short-term smoothing for removing noise due to production variation. Additional processing may be employed to remove earth tides, background-water-level trends, well losses, and temperature effects. Commonly, the response is recorded as pressure changes of the water column above a PXD, which is converted to water-level changes by dividing the pressure changes by a conversion factor for water density and the acceleration of gravity.

Stepped pumping tests are used to monitor for the improvement in the hydraulic efficiency of the well and determine an optimum pump rate for subsequent constant-rate testing. Stepped pumping tests can also be used to estimate well losses by plotting the inverse of the specific capacity at each pump rate versus the pump rate, and fitting the Hantush-Bierschenk equation for linear and non-linear well losses (Bierschenk, 1963; Hantush, 1964). The losses represent well response due solely to pumping inefficiencies, provided the well is relatively clean, where development activities are merely drawing formation water to the well. Considerable drilling fluids remained in the borehole such that the stepped rates were being used to purge the well to complete development. Any well losses determined under these conditions would be attributable to the drilling fluids. The well was developed by the end of this period. However, a full recovery of the well is needed, once clean, to initiate a step test for the purpose of estimating well losses. Field activities proceeded on to constant-rate testing; thus, well losses were not determined.

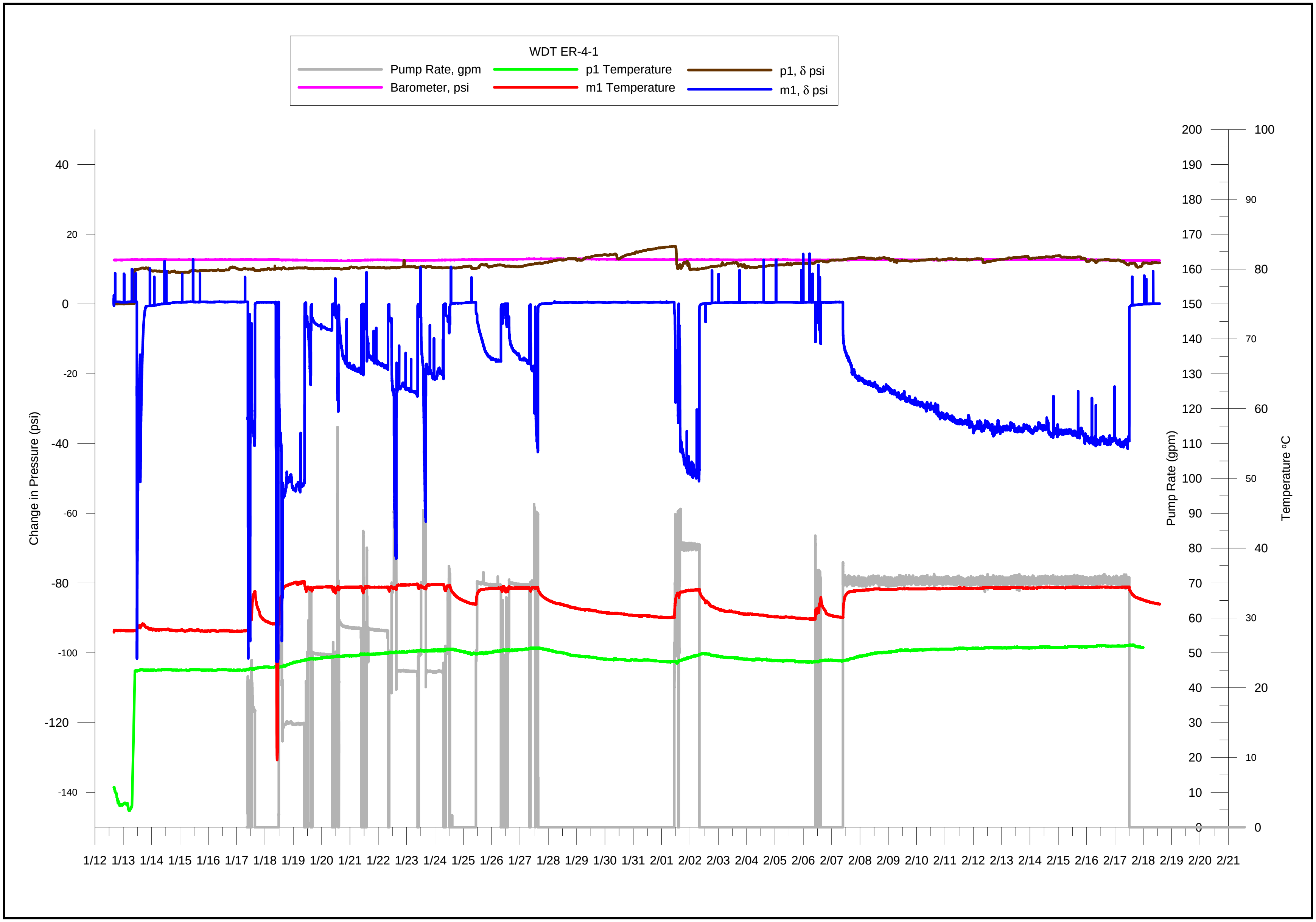

Figure 5-1
PXD Pressure Response, Temperature, and Barometric Pressure during WDT of Well ER-4-1

The background water-level trend identified in the predevelopment monitoring indicates that long-term changes in water levels are insignificant relative to the magnitude of drawdown. However, these effects were incorporated in the multiwell analysis conducted by USGS and summarized in Section 5.3.

5.2 Single-Well Aquifer Test Analyses

The following subsections present single-well evaluation of the hydraulic response to WDT pumping and estimation of aquifer properties. Step-drawdown testing analysis is used to determine the laminar and turbulent components of drawdown. Constant-rate testing analysis is used to determine aquifer transmissivity. Estimating storativity from single-well tests is problematic because the wellbore storage, skin effects, and storativity are interrelated. For this reason, storativity is not reliably estimated from single-well tests (Horne, 1995). Stepped pumping rates were used to develop the well but were not used to determine non-linear drawdown components.

5.2.1 Specific Capacity Estimates from Stepped Pumping Data

After the pump was installed in Well ER-4-1, a pump function test was run on January 13, 2017, for 175 minutes at approximately 15 gpm. On January 17, 2017, the well was pumped at approximately 35 gpm for 171 minutes to purge the well, and then was allowed to recover for 20 hours before initiating the step test. From January 18 through January 27, 2017, stepped pumping rates were used to develop Well ER-4-1. Table 5-2 summarizes the different pump rates used, along with the respective drawdown, for each period. The average pump rate was estimated, and the drawdown at the end of the period recorded from the datalogger, for the function test, pump purging test, and 29 successive pumping periods. Data from the tests were used to estimate specific capacity for each period in order to monitor improvement in well efficiency as an indicator of well development.

Frictional well loss is negligible for fully developed wells (Houben at al., 2016). Thus the constant-rate aquifer test analysis provides a better estimate of transmissivity when the well has been sufficiently developed. Both the specific capacity data and stabilized water-quality parameters, monitored in ER-4-1 m1 during well development and step-drawdown testing, indicate that the well was fully developed.

Table 5-2
Well ER-4-1 Stepped Pumping Rates
(Page 1 of 2)

Elapsed Time (minutes)	Pump Rate (gpm)	Record #	Date	Time	Calculated Drawdown from PXD Readings (ft) [a]	Specific Capacity (gpm/ft)
Pump Function Test						
0	0	1373	01/13/2017	11:29	0.08	--
175	15	2045	01/13/2017	14:24	-117.66	0.127
Initial Purge Event						
0	0	9043	01/17/2017	12:41	-27.34	--
171	35	9440	01/17/2017	15:32	-84.67	0.413
Stepped Drawdown Test						
0	0	10924	01/18/2017	11:42	1.25	--
3	50	10940	01/18/2017	11:45	-100.71	0.496
139	70	11258	01/18/2017	14:01	-222.92	0.314
159	40	11438	01/18/2017	14:21	-194.21	0.206
189	30	11537	01/18/2017	14:51	-118.52	0.253
1,309	0	12926	01/19/2017	09:31	-11.67	0.000
1,385	40	13131	01/19/2017	10:47	-8.59	4.659
1,445	50	13207	01/19/2017	11:47	-15.18	3.293
1,505	60	13276	01/19/2017	12:47	-27.97	2.145
1,571	70	13377	01/19/2017	13:52	-46.67	1.500
1,632	0	13574	01/19/2017	14:54	-5.06	0.000
1,686	50	13704	01/19/2017	15:47	-17.46	2.864
2,707	0	14749	01/20/2017	08:49	-2.17	0.000
2,882	50	14994	01/20/2017	11:44	-47.51	1.052
3,020	70	15255	01/20/2017	14:01	-69.74	1.004
3,027	0	15297	01/20/2017	14:09	-6.79	0.000
3,059	60	15410	01/20/2017	14:40	-45.46	1.320
4,194	0	16764	01/21/2017	09:35	-6.84	0.000
4,291	80	16906	01/21/2017	11:13	-45.98	1.740
4,296	55	16961	01/21/2017	11:18	-8.36	6.579
4,475	80	17376	01/21/2017	14:16	-35.74	2.238
4,481	55	17425	01/21/2017	14:23	-39.60	1.389
5,553	0	18634	01/22/2017	08:15	-4.28	0.000
5,612	50	18729	01/22/2017	09:14	-12.51	3.997

Table 5-2
Well ER-4-1 Stepped Pumping Rates
(Page 2 of 2)

Elapsed Time (minutes)	Pump Rate (gpm)	Record #	Date	Time	Calculated Drawdown from PXD Readings (ft) [a]	Specific Capacity (gpm/ft)
5,734	70	18872	01/22/2017	11:16	-60.30	1.161
5,853	90	19092	01/22/2017	13:15	-163.95	0.549
5,973	45	19496	01/22/2017	15:14	-9.38	4.797
7,234	70	21016	01/23/2017	12:16	-43.62	1.605
7,354	90	21191	01/23/2017	14:16	-137.25	0.656
7,475	45	21511	01/23/2017	16:17	-46.96	0.958
8,371	0	22592	01/24/2017	07:13	--	--
Constant Rate Test						
0	0	45454	02/07/2017	09:34	-2.00	--
14,553	70	62999	02/17/2017	12:08	-89.98	0.778

[a] Drawdown in feet calculated from change in PXD pressure (psi) at end of the period, relative to initial m1 PXD reading on 01/12/2017 at 16:04, datalogger record #167.

gpm/ft = Gallons per minute per foot

-- = Not applicable

5.2.2 Constant-Rate Testing Analysis

The analysis of drawdown transient data begins by reviewing the data with the log-log drawdown and drawdown derivative diagnostic plot in order to identify responses that are characteristic of certain types of flow regimes (Horne, 1995). These changes are evaluated in the context of the geologic conceptual model. Under ideal testing conditions, a log-log diagnostic analysis of the test pressure transient is used to diagnose aquifer behavior such as radial versus linear flow, dual porosity, boundaries, or leakage. For example, the wellbore storage period has a unit slope, and at the end of the wellbore storage period, a straight line depicting infinite-acting radial flow could be expected within 1.5 log cycles.

Well ER-4-1 was pumped at an approximate rate of 70 gpm from February 7 through February 17, 2017. Initial analysis of the pump test method using the Cooper and Jacob (1946) semi-log method showed several changes in slope. The different slopes were used to determine different corresponding values of transmissivity, including an early conductive response (Figure 5-2), an early barrier response (Figure 5-3), a late conductive response (Figure 5-4), and a late reduced response (Figure 5-5). The largest (and earliest) transmissivity value of 27.57 square meters per day (m^2/day) and smallest (and latest) transmissivity value of 5.139 m^2/day are summarized in Table 5-3, the values from the Cooper and Jacob (1946) AQTESOLV model parameters (Duffield, 2007) derived from the constant-rate testing (Figures 5-2 and 5-5, respectively).

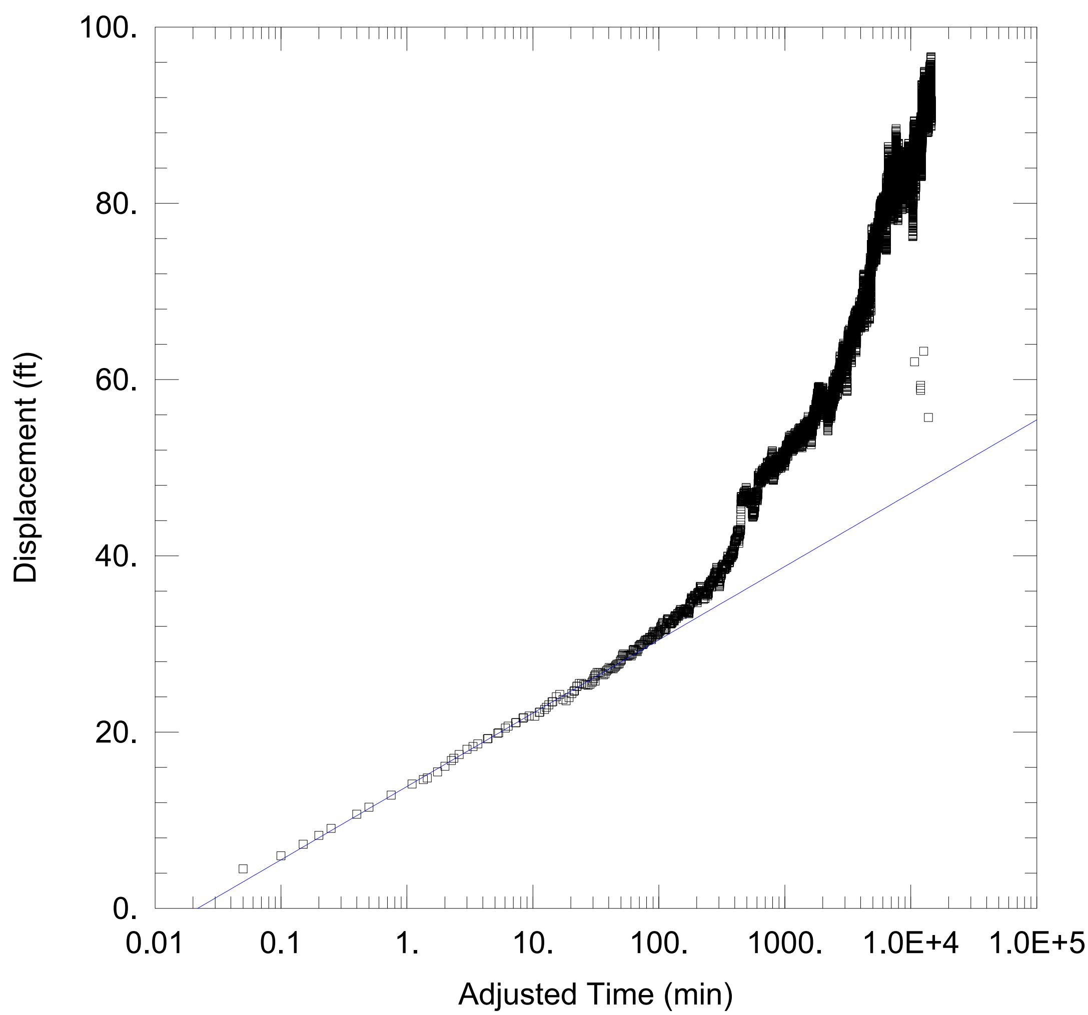

Figure 5-2
Cooper and Jacob (1946) Fit of Early Conductive Response at Well ER-4-1

The time at each break in slope on the Cooper and Jacob (1946) plot was used to estimate the radius of a specified [3-cm (0.1-ft)] drawdown assuming circular, radially symmetric flow under homogeneous and isotropic conditions (herein referred to as the "symmetrical radius"). The chosen

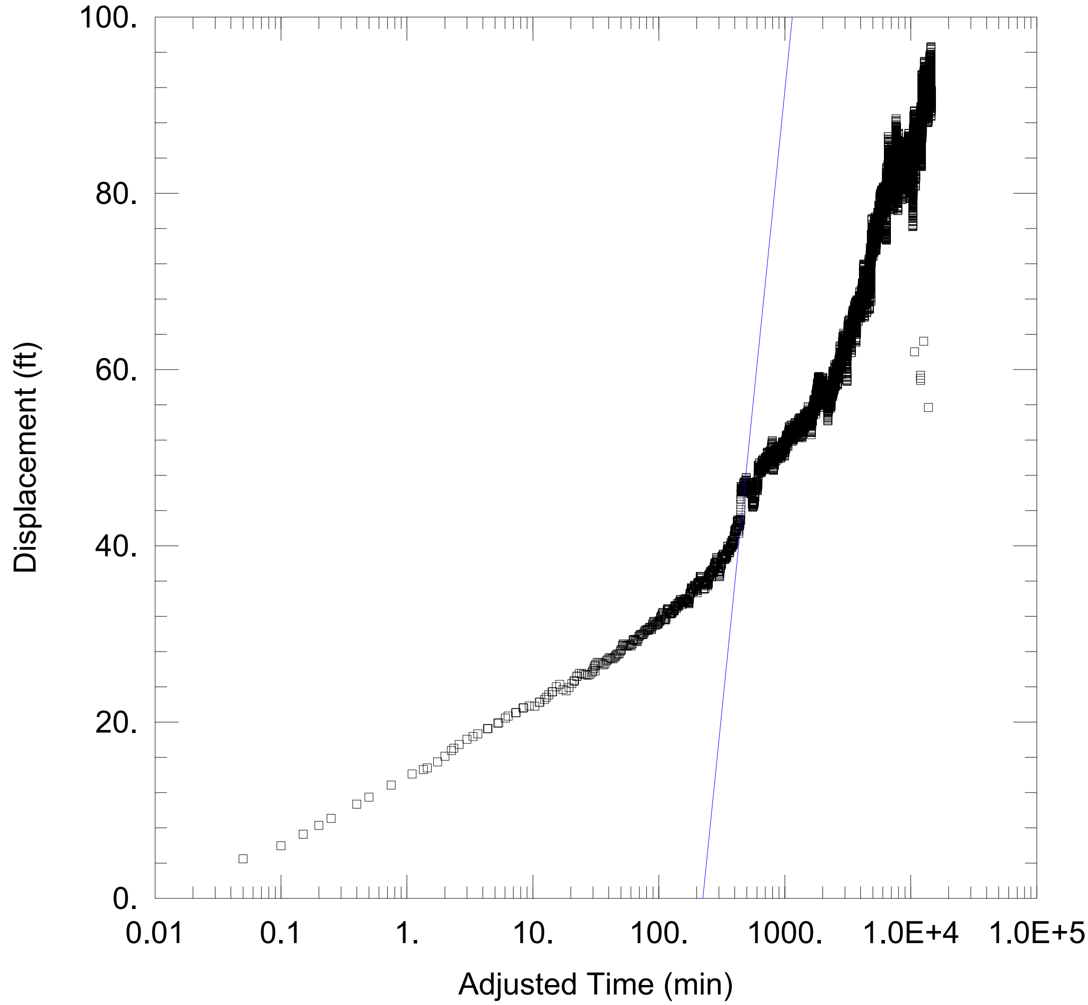

Figure 5-3
Cooper and Jacob (1946) Fit of Early Barrier Response at Well ER-4-1

3-cm (0.1-ft) drawdown represents a value that is reliably detectable by the installed PXD measuring equipment. The actual field conditions are considerably more complex, including heterogeneous conditions of both anisotropic, elliptically radial flow; asymmetric flow; and directional flow that cannot be modeled as a continuum at the scale of the domain. However, the symmetrical radius of the specified [3-cm (0.1-ft)] drawdown is informative of "average" response to which non-average and outlier values can be compared, and gives a relative scale of the radial size of the detectable cone of depression. The symmetrical radius was calculated for each change in slope on the Cooper and Jacob (1946) plot, using the Cooper and Jacob (1946) approximation of the Theis (1935) equation, solved for a drawdown of 3 cm (0.1 ft), which is considered detectable by the PXD. The radius calculation used (1) the elapsed time at the change in slope; (2) the largest (earliest) transmissivity value of

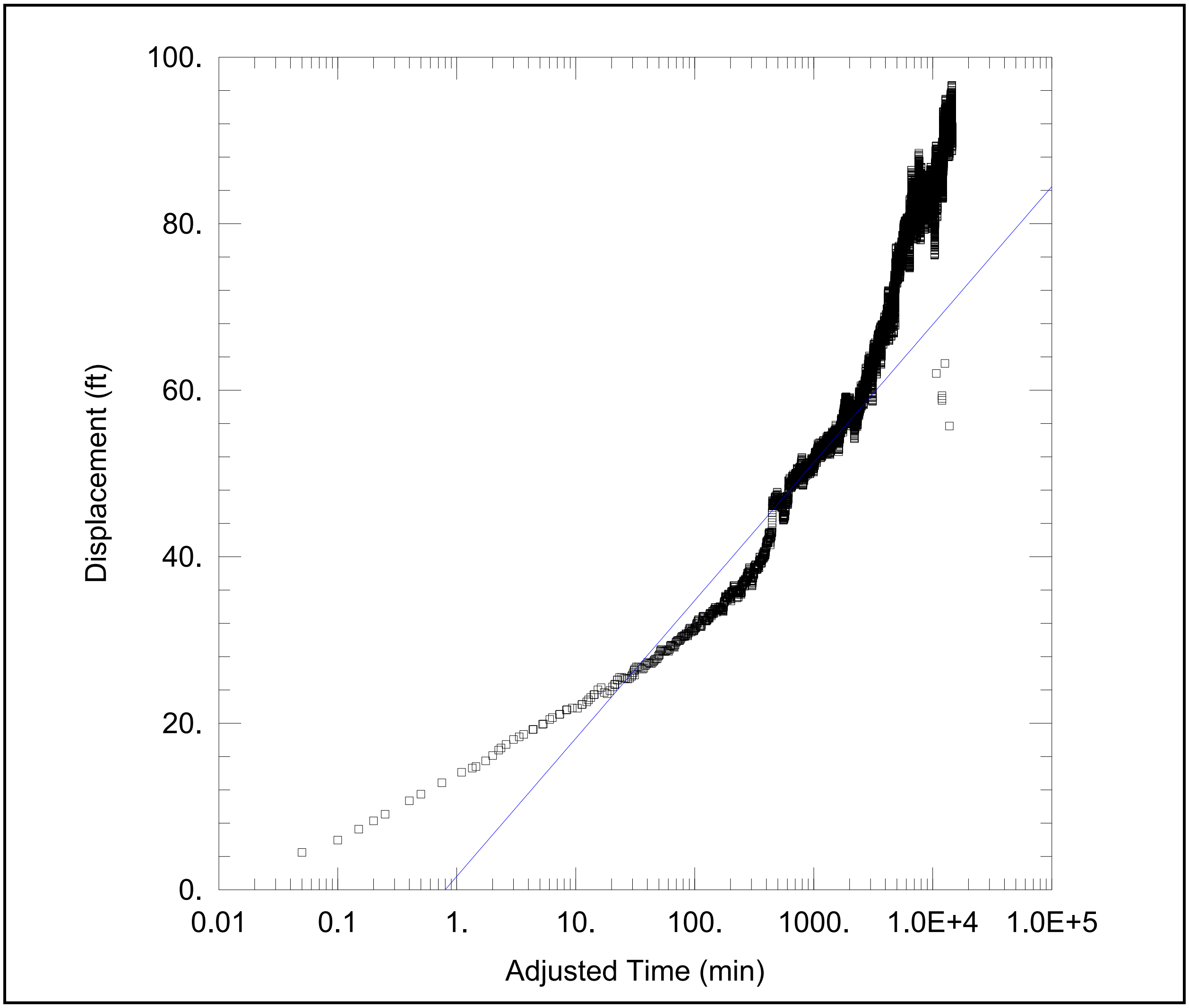

Figure 5-4
Cooper and Jacob (1946) Fit of Late Conductive Response at Well ER-4-1

27.57 m^2/day and smallest (latest) transmissivity value of 5.139 m^2/day; (3) the pump rate of 70 gpm; and (4) an upper (1.0E-4) and lower (1.0E-5) estimate for storativity taken from Winograd and Thordarson (1975). The radii are summarized on Table 5-3. The radii indicate an initial cone of depression governed by a transmissivity of 27.6 m^2/day grew from 0 to a range of 126 to 915 m in 200 minutes, at which point an effective reduction in the transmissivity occurred from encountering either a barrier to flow or reduction in flow from a previous source. At 400 minutes, the transmissivity effectively increased again at a distance ranging from 179 to 1,295 m. At 2,000 minutes, the transmissivity effectively decreased to 5.1 m^2/day at a distance ranging from 400 m to 2,895 m and beyond. The abrupt lowering of transmissivity at 200 minutes time suggests that some barrier to flow exists after which, about 400 minutes into the test, the transmissivity increases again. The final

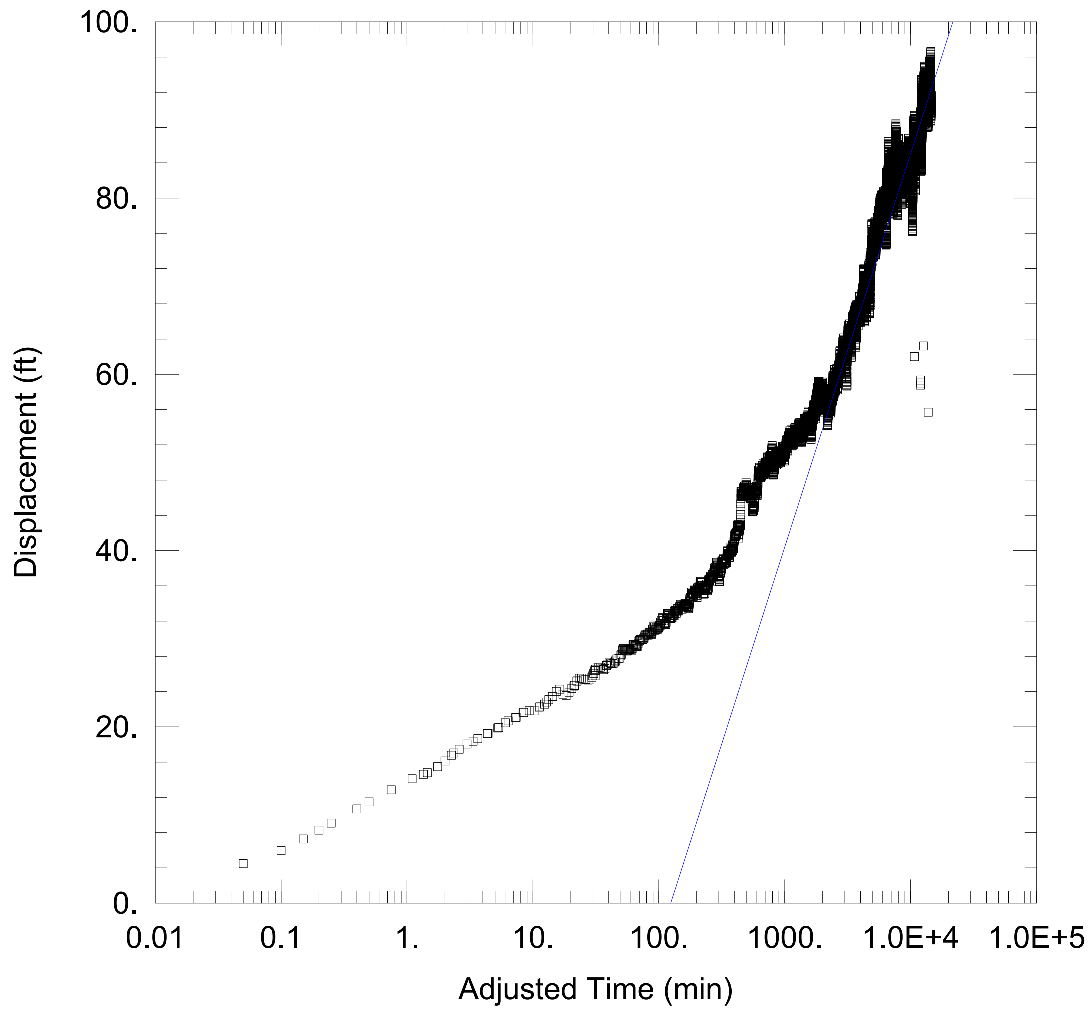

Figure 5-5
Cooper and Jacob (1946) Fit of Late Reduced Conductivity Response at Well ER-4-1

decreased transmissivity value beyond 2,000 minutes may be in response to a barrier to flow or an averaging effect as the cone grows to larger scales. The observed flow responses occurred within 2,000 minutes of the start of the test, with calculated symmetric radii within 3 km. The responses are characteristic of the fractured media, including jointing and local faults. A mix of small-scale fractures and larger-scale faults are present within 3 km of ER-4-1 on the fracture and fault map of Grasso (2000), and may be linked to the changes in flow response.

Beyond the duration of the 10-day pump test, symmetric radii were calculated for an elapsed time of 30 days [43,200 minutes] assuming the continuation of the 70 gpm pump rate. The elapsed time and pump rate approximate the effect of pumping over the entire record from January 13 through

Table 5-3
Well ER-4-1 Calculated Radii of 0.1 ft of Drawdown

Transmissivity (27.57 m²/day)		**Distance (m) to 0.1 ft of drawdown**	
	Time	**S = 0.00001**	**S = 0.0001**
Elapsed Time (minutes)	200	915	289
	400	1,295	409
	2,000	2,895	915
	43,200	13,452	4,254
Transmissivity (5.139 m²/day)		**Distance (m) to 0.1 ft of drawdown**	
	Time	**S = 0.00001**	**S = 0.0001**
Elapsed Time (minutes)	200	400	126
	400	565	179
	2,000	1,264	400
	43,200	5,873	1,857

USGS SeriesSEE Observed Drawdowns		
Well	**Distance (m)**	**Drawdown (ft)**
ER-6-1-2 main	14,536	0.06
ER-7-1	6,070	0.06
U-3cn 5	5,778	0.13
UE-7nS	4,249	0.08
UE-10j (2232-2297 ft)	9,187	0.04
WW- 2 (3422 ft)	7,406	0.02

Blue shading indicates calculated and observed radii of approximately 3 cm (0.1 ft) of drawdown.

S = Storativity

February 17 including the function test, purging event, stepped pump test, and constant test period (Figure 5-1). The symmetrical radii of 0.1-ft drawdown range from 1.8 to 13.5 km is comparable to the distances to the drawdowns observed in six wells in the SeriesSEE analysis by the USGS (Table 5-3; also see Section 5.3 and Appendix F). The 5,778-m distance to the largest drawdown observed in the USGS analysis, 0.13 ft in Well U-3cn 5, compares well to the 5,873-m distance calculated to 0.1 ft of drawdown, assuming the lower transmissivity (5.14 m²/day) and lower storativity (1.0E-05) estimates (Table 5-3).

5.2.3 Analysis of Discrete Production

Downhole hydrologic logging was not performed during the constant-rate testing. Water production zones during drilling are shown on the Idronaut log for ER-4-1 on Figure 3-7.

5.3 Drawdown at Distal Wells from WDT Operations

USGS provided an analysis of the influence of pumping on distal wells. The analysis was provided in a transmittal letter from Tracie R. Jackson, Hydrologist USGS, Nevada Water Science Center, Henderson, Nevada on June 1, 2017, included here as Appendix F. Time series analysis was conducted using the SeriesSEE Microsoft Excel Add-in (Halford, 2006; Halford et al., 2016). Drawdown was detected in six wells: ER-6-1-2 main, ER-7-1, U-3cn 5, UE-7nS, UE-10j, and WW-2. Drawdown was not detected in 11 wells: ER-2-1 main, ER-2-2, ER-3-1-2, ER-5-3-2, ER-6-2, TW-7, TW-D, UE-1h, UE-1q, UE-1r WW, and WW-A. Drawdown was estimated using continuous records of barometer, background water levels unaffected by pumping, earth tides, gravity tides, and pumping records. Graphs of these data are provided in Appendix A. Drawdowns were estimated at the 17 observation wells using water-level models that included a Theis (1935) drawdown model. Values of transmissivity and storativity are estimated in this model, and are part of the supporting electronic files of Appendix B but were not summarized in this report.

5.4 Cyclic Pumping of Well ER-3-3 and Analysis of Slug Test

Figure 5-6 shows the pressure, temperature, and flow data collected during WDT activities at Well ER-3-3 from November 29 through December 15, 2016. WDT operations for ER-3-3 produced a total of 9,461 gal of water during that period. Due to the relatively low hydraulic conductivity in the zone of the effective open interval, the well was not able to sustain a minimum pumping rate of 15 gpm required for the pump, and thus the pump was cycled on and off.

Due to the relatively low hydraulic conductivity with respects to pumping period durations, the aquifer test can be interpreted as a “bailed” slug test. Although slug tests require an “instantaneous” initial aquifer stress (step function), the short pumping duration on each cycle can be considered as relatively instantaneous bailing. Slug tests also require an initial SWL. If previous pump cycling has occurred for the purpose of well development before the test, it is ideal to start the slug test after the most amount of well recovery has occurred in order to reduce previous pumping effects on the head response. In her multi-well analysis report for Well ER-3-3, included in Appendix E of this report,

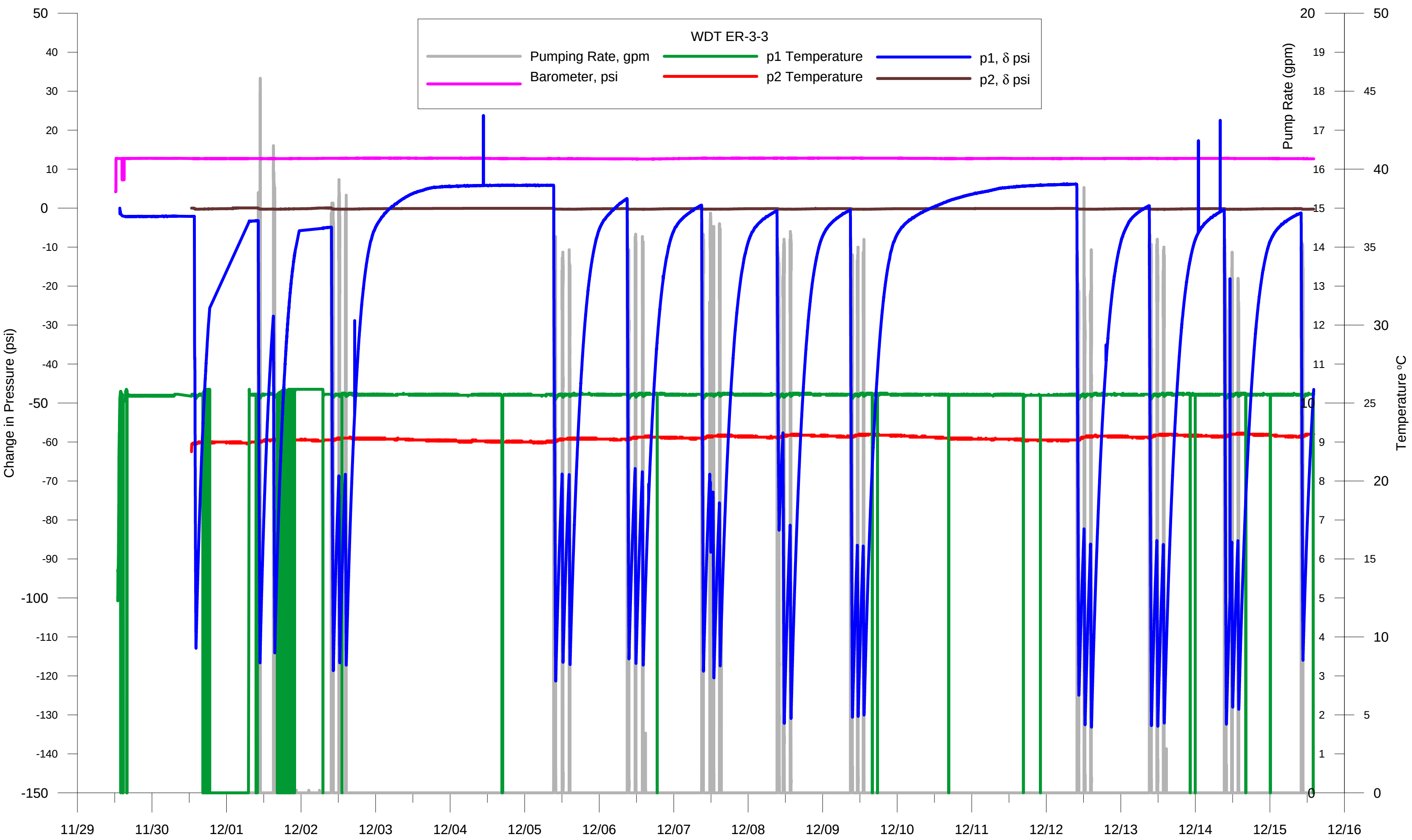

Figure 5-6
PXD Pressure Response, Temperature, and Barometric Pressure during WDT of Well ER-3-3

Tracie Jackson of USGS analyzed a slug test using the data immediately following the first pumping cycle on December 5, 2016, after a long period of well recovery starting on December 2, 2016. Using the Bouwer and Rice (1976) method, Jackson obtained a hydraulic conductivity estimate of 0.01 feet per day (ft/day) (0.003 meters per day [m/day]). To evaluate whether any increase of hydraulic conductivity occurred due to further well development by the cyclic pumping, the initial pumping cycle on December 12, 2016, was used for a slug test analysis, following a recovery period from December 9, 2016. Figure 5-7 shows the results of the slug test analysis using the method of Bouwer and Rice (1976) analyzed in AQTESOLV (Duffield, 2007), with an estimated hydraulic conductivity of 0.0018 m/day (0.0059 ft/day). Although it is within the same range as the USGS value, the result is less, indicating that no increase in hydraulic conductivity occurred in response to the additional pumping. Also, recovery from the later pumping interval was likely affected by superposition of previous pump cycles, slowing recovery and thus resulting in the lower hydraulic conductivity value.

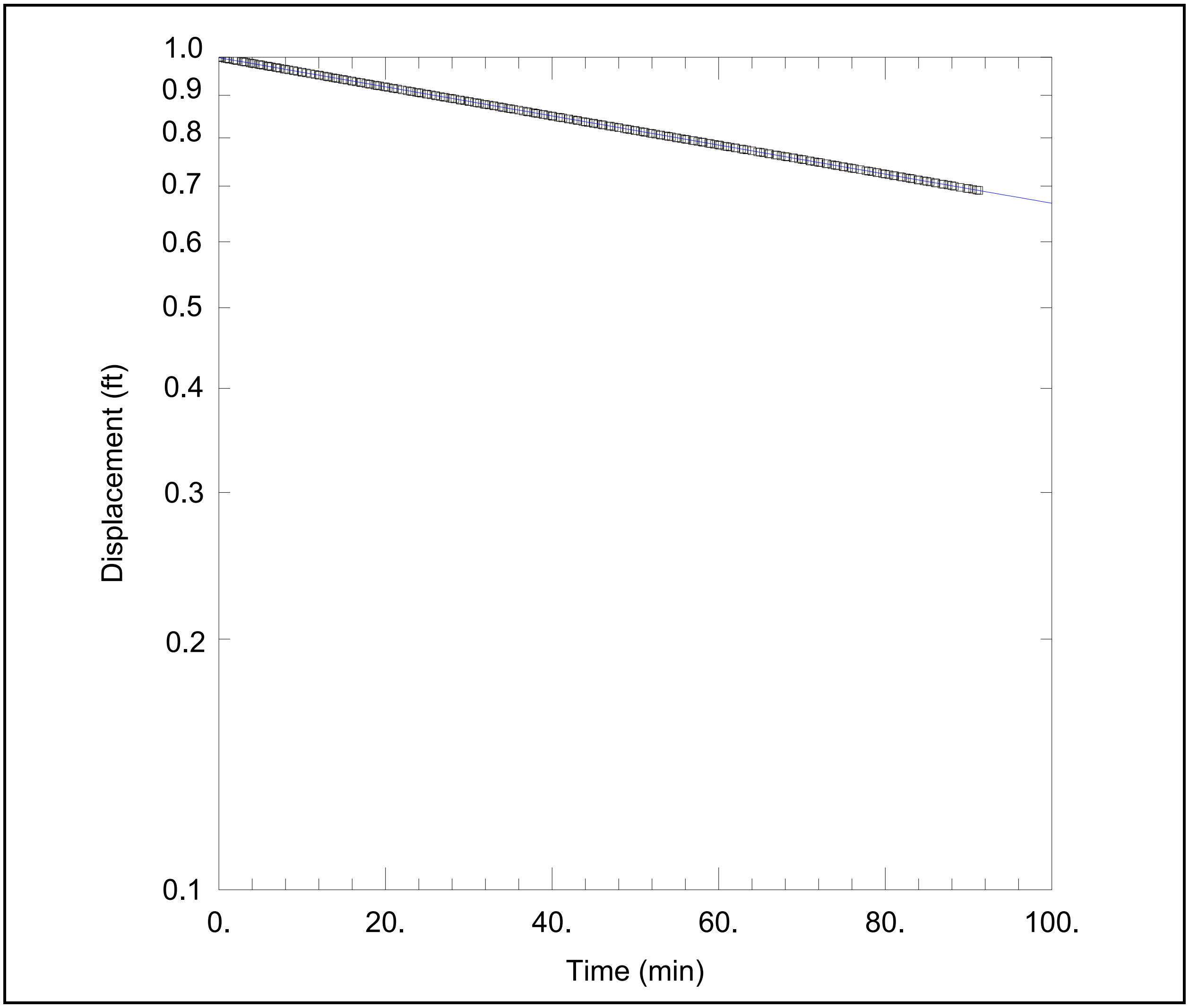

Figure 5-7
Bouwer and Rice (1976) Slug Test Interpretation of Recovery Data after Initial Pumping Cycle of Well ER-3-3 p1 Piezometer on 12/12/2016

6.0 GROUNDWATER CHEMISTRY

This section presents new chemistry data for Wells ER-3-3 and ER-4-1, and an evaluation of the data with respect to groundwater from other wells in the vicinity. Comprehensive groundwater chemistry evaluations for Yucca Flat are presented in *Geochemical and Isotopic Evaluation of Groundwater Movement in Corrective Action Unit 97: Yucca Flat/Climax Mine, Nevada Test Site, Nevada* (SNJV, 2006). This section integrates the new data from Wells ER-3-3 and ER-4-1, as well as additional sampling of other Yucca Flat UGTA wells that are open to the same HSU intervals, primarily the LCA. The wells included in this evaluation are shown on the sampling location map of Yucca Flat (Figure 6-1).

6.1 Sample Collection and Analysis

Groundwater samples were collected following Navarro sampling procedures and desktop instructions. The *NNSS Integrated Sampling Plan and Water-Level Monitoring Implementation Strategy* (Navarro, 2016e) specifies the analyte suites to be collected for each laboratory depending on the well location type. Details of the sampling activities associated with WDT activities at Wells ER-3-3 and ER-4-1 are presented in Sections 6.2 and 6.3, respectively. The analytical results are also included in these sections.

6.2 Well ER-3-3

Before the start of WDT activities, the PXDs were removed from the p1 and p2 piezometers. Depth-discrete bailer samples were then collected from the p1 piezometer at a depth of 3,010 ft bgs and from the p2 piezometer at a depth of 2,320 ft bgs. These samples were analyzed for standard tritium by ALS Laboratory Group (ALS). Table 6-1 shows the results of the p1 piezometer sampling, and Table 6-2 shows the results of the p2 piezometer sampling.

GWC samples were collected from Well ER-3-3 at the wellhead sampling port on December 15, 2016, after the cyclic pumping of the well was completed. The well was pumped cyclically for 12 days with a production rate of 12 to 14 gpm. A total of 9,416 gal had been purged from the well before sampling. Table 6-3 shows the GWC sample results from ALS, and Table 6-4 shows the

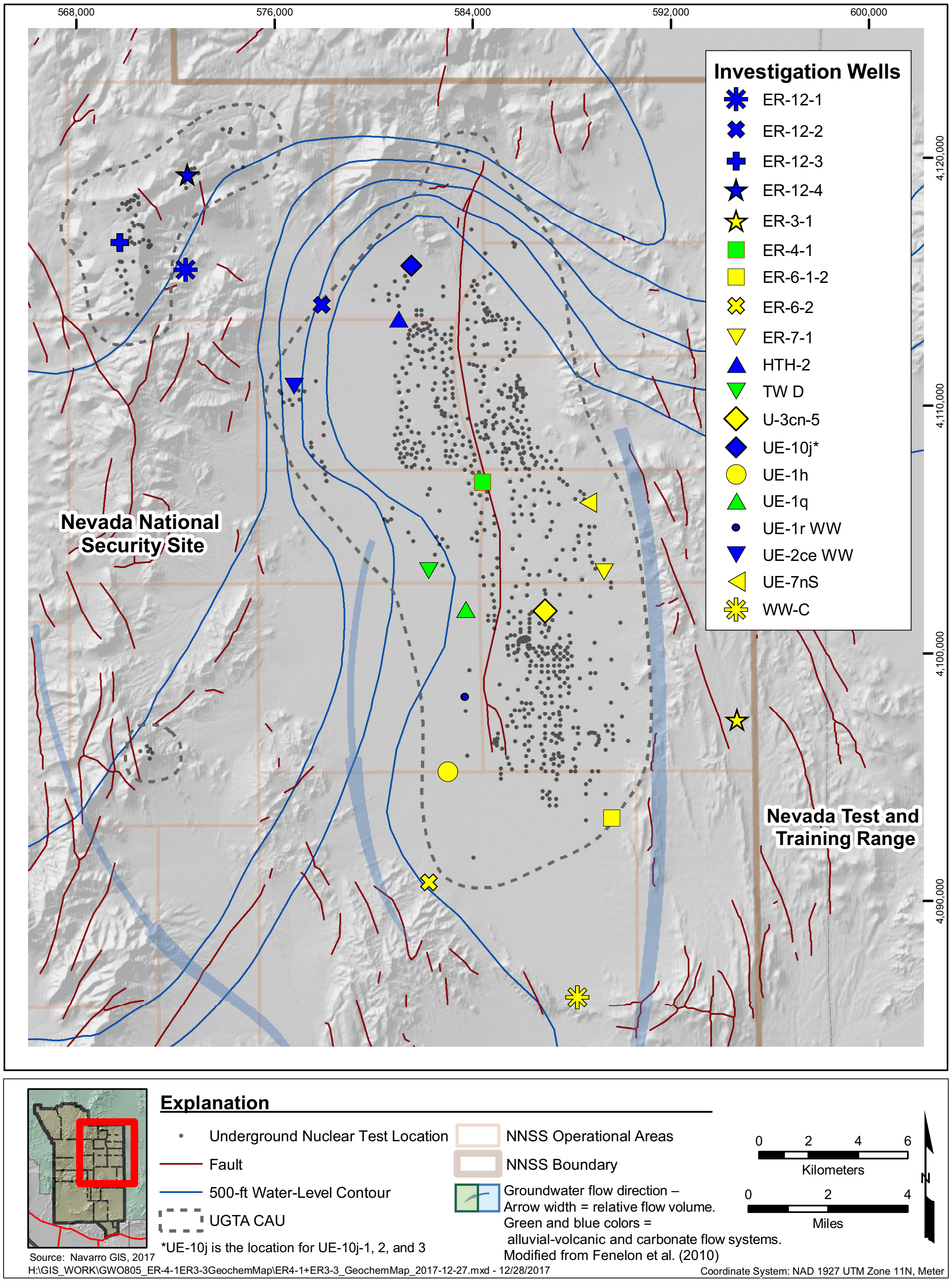

Figure 6-1
Sampling Locations

Table 6-1
Analytical Results from ALS for Tritium Depth-Discrete Bailer Samples Collected from p1 Piezometer before Development at Well ER-3-3

Analyte	Analytical Method [a]	Detection Limit	Depth-Discrete Bailer Sample 430-110916-1 Depth 3,010 ft bgs		Depth-Discrete Bailer Duplicate QC Sample 430-110916-2 Depth 3,010 ft bgs	
		MDC [b] (pCi/L)	Result (pCi/L)	Error (pCi/L)	Result (pCi/L)	Error (pCi/L)
Tritium	EPA 906.0 [c]	320, 300	-30 U	190	30 U	180

Source: Navarro, 2017a

[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.
[b] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.
[c] EPA, 1980

EPA = U.S. Environmental Protection Agency
MDC = Minimum detectable concentration
pCi/L = Picocuries per liter
QC = Quality control

U = Compound was analyzed for but was not detected (“Non-detect”).

Table 6-2
Analytical Results from ALS for Tritium Depth-Discrete Bailer Samples Collected from p2 Piezometer before Development at Well ER-3-3

Analyte	Analytical Method [a]	Detection Limit	Depth-Discrete Bailer Sample 430-110916-3 Depth 2,320 ft bgs		Depth-Discrete Bailer Duplicate QC Sample 430-110916-4 Depth 2,320 ft bgs	
		MDC (pCi/L)	Result (pCi/L)	Error (pCi/L)	Result (pCi/L)	Error (pCi/L)
Tritium	EPA 906.0 [b]	310	-50 U	180	30 U	190

Source: Navarro, 2017a

[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.
[b] EPA, 1980

U = Compound was analyzed for but was not detected (“Non-detect”).

Table 6-3
Analytical Results from ALS for GWC Samples Collected at Well ER-3-3 after WDT
(Page 1 of 2)

Analyte	Analytical Method [a]	Detection Limit [b]	Wellhead Composite Samples 430-121516-1 430-121516-1F		Wellhead Composite Duplicate QC Samples 430-121516-2 430-121516-2F	
Metals (mg/L)						
			Total	**Filtered**	**Total**	**Filtered**
Aluminum	SW-846 6010 [c]	0.2	6.5 J	--	13 J	--
Arsenic		0.01	0.024		0.024	
Barium		0.1	0.028 J		0.071 J	
Cadmium		0.005	0.005 U		0.005 U	
Calcium		1	15		36	
Chromium		0.01	0.021		0.024	
Iron		0.1	5		9.2	
Lead		0.003	0.018		0.029	
Lithium		0.01	0.09		0.098	
Magnesium		1	3.6		7	
Manganese		0.01	0.11		0.27	
Potassium		1	14		13	
Selenium		0.005	0.0059		0.0086	
Silicon		0.05	44		55	
Silver		0.01	0.01 U		0.01 U	
Sodium		1	100		100	
Strontium		0.01	0.089		0.16	
^{238}Uranium	SW-846 6020 [c]	0.0001	0.0041		0.0037	
Inorganics (mg/L unless otherwise noted)						
			Total	**Filtered**	**Total**	**Filtered**
Bromide	EPA 300.1 [d]	0.2	--	0.08 J	--	0.1 J
Chloride		1, 0.2		8.6		9
Fluoride		0.1		2.2		2.1
Sulfate		5, 1		52		56
Alkalinity (as $CaCO_3$)	EPA 310.1 [e]	20	170	--	200	--
Bicarbonate Alkalinity (as $CaCO_3$)		20	130		120	
Carbonate Alkalinity (as $CaCO_3$)	EPA 310.1 [e]	20	35	--	83	--
pH (SU)	EPA 150.1 [e]	0.1	9.5 J-		9.5 J-	
Specific Conductivity (μmhos/cm)	EPA 120.1 [e]	1	590		580	

Table 6-3
Analytical Results from ALS for GWC Samples Collected at Well ER-3-3 after WDT
(Page 2 of 2)

Analyte	Analytical Method [a]	Detection Limit [b]	Wellhead Composite Samples 430-121516-1 430-121516-1F		Wellhead Composite Duplicate QC Samples 430-121516-2 430-121516-2F	
Radiological Indicator Parameters (pCi/L)						
		MDC [f]	Result	Error	Result	Error
Tritium	EPA 906.0 [g]	310	-90 U	180	-70 U	180
Gross Alpha	EPA 900.0 [g]	1.8, 2.8	5.6	1.6	13.1	3.1
Gross Beta		2, 2.5	19.6 J	3.5	19.8 J	3.6
^{238}Plutonium	HASL 300 [g]/ Pu-10-Rc	0.045, 0.033	-0.01 U	0.022	-0.003 U	0.023
$^{239/240}$Plutonium	HASL 300 [g]/ Pu-10-Rc	0.016, 0.017	0.012 U	0.022	0.006 U	0.023
Gamma Spectroscopy	EPA 901.1 [g]	Varies by Nuclide	ND	Varies by Nuclide	ND	Varies by Nuclide
^{14}Carbon	EPA EERF C-01 [h]	410, 390	-70 U	240	-100 U	230
^{36}Chlorine	EPA 902.0 [g]	2.8, 3.1	0.8 U	1.7	0.4 U	1.8
^{129}Iodine	EPA 902.0 [g]	0.64, 0.74	0.21 U	0.4	-0.33 U	0.46
^{90}Strontium	EPA 905.0 [g]	0.23, 0.26	0.18 U	0.15	0.25 U	0.17
^{99}Technetium	HASL TCW-02	7.5, 7.2	1.7 U	4.5	1.6 U	4.4

Source: Navarro, 2017a

[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.
[b] Detection limit varies by instrument and dilution of sample. Where more than one detection limit is given, they apply to the samples in the order presented.
[c] EPA, 2017
[d] EPA, 1997
[e] EPA, 1983
[f] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.
[g] EPA, 1980
[h] EPA, 1984

$CaCO_3$ = Calcium carbonate
EERF = Eastern Environmental Radiation Facility
HASL = Health and Safety Laboratory

F = Filtered
J = Result is estimated.
J- = Estimated bias low.
ND = No gamma spectroscopy nuclides detected above detection limits.
U = Compound was analyzed for but was not detected (“Non-detect”).
-- = No result.

Table 6-4
Analytical Results from LLNL for GWC Samples Collected at Well ER-3-3 after WDT

Analyte	Analytical Method	Detection Limit	Wellhead Composite Samples 430-121516-3 430-121516-3F	
Inorganics (mg/L)				
			Total	**Filtered**
Bromide	SOP-UGTA-120	TBD	--	Pending
Chloride				
Fluoride				
Sulfate				
Organics (mg/L)				
Total Inorganic Carbon	SOP-UGTS-116	TBD	--	Pending
Environmental Tracers				
		MDC [a]	**Result**	**Error**
Stable Isotopes ($^{2}H/^{1}H$)	SOP-UGTA-128	NA	-107 per mil	0.2
Stable Isotopes ($^{18}O/^{16}O$)			-13.79 per mil	NA
Noble Gases				
Noble Gases	SOP-NGMS-122	TBD	Pending	--
Radiological Indicator Parameters (pCi/L)				
		MDC [a]	**Result**	**Error**
Tritium	SOP-NGMS-121	TBD	Pending	Pending
^{13}Carbon	SOP-UGTS-116			
^{14}Carbon	SOP-UGTS-136		0.0198	0.0016
^{36}Chlorine	SOP-UGTS-115		Pending	Pending

Source: Navarro, 2017a

[a] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.

NA = Not available
TBD = To be determined

F = Filtered
-- = No result

analytes sampled for and analyzed by Lawrence Livermore National Laboratory (LLNL); all results, except for the stable isotopes, are pending.

6.3 Well ER-4-1

Before the start of WDT activities, the PXD was removed from the p1 piezometer. Depth-discrete bailer samples were then collected from the p1 piezometer a depth of 2,045 ft bgs; these samples were analyzed for standard tritium by General Engineering Laboratories (GEL). Table 6-5 shows the results of the sampling.

Table 6-5
Analytical Results from GEL for Tritium Depth-Discrete Bailer Samples Collected from p1 Piezometer before Development at Well ER-4-1

Analyte	**Analytical Method [a]**	**Detection Limit**	**Depth-Discrete Bailer Sample 431-010517-1 Depth 2,045 ft bgs**		**Depth-Discrete Bailer Duplicate QC Sample 431-010517-2 Depth 2,045 ft bgs**	
		MDC [b] (pCi/L)	**Result (pCi/L)**	**Error (pCi/L)**	**Result (pCi/L)**	**Error (pCi/L)**
Tritium	EPA 906.0 [c]	219, 218	733	207	648	194

Source: Navarro, 2017a

[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.
[b] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.
[c] EPA, 1980

Before and during the 10-day constant-rate test, three low-level tritium samples were collected at the wellhead sampling port and analyzed by GEL. The production rate during the three sampling events was approximately 70 gpm. Approximately 700,400 gal, 1,117,000 gal, and 1,614,000 gal of water was purged before collection of these samples, respectively. Analytical results are shown in Table 6-6.

GWC samples were collected from Well ER-4-1 at the wellhead sampling port on February 17, 2017, after the step-rate and constant-rate tests were completed. The well was pumped and step-rate tests occurred over a period of 15 days; production rate during the step-rate tests ranged from 17 to 90 gpm. During the 10-day constant-rate test, the production rate was 70 to 71 gpm. A total of 1,732,160 gal had been purged from the well before sampling. Table 6-7 shows the GWC sample

Table 6-6
Analytical Results from GEL for Low-Level Tritium Samples Collected during WDT at Well ER-4-1

Wellhead Sample	Analyte	Analytical Method [a]	MDC (pCi/L)	Result (pCi/L)	Error (pCi/L)
431-020617-1	Low-Level Tritium	EPA 906.0 [b]	2.78	-1.54 U	1.54
431-021217-1			2.81	0.307 U	1.63
431-021617-1			3.01	0.12 U	1.74

Source: Navarro, 2017a

[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.
[b] EPA, 1980

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

results from GEL, and Table 6-8 shows the analytes sampled for and analyzed by LLNL; all results, except for the stable isotopes (O-18/16), are pending.

6.4 Review of Analytical Results

The following subsections presents major-ion, stable-isotope, and naturally occurring RN data for the samples collected from Wells ER-3-3 and ER-4-1, and other wells in the vicinity. The wells included all of the LCA wells in Yucca Flat except WW-C-1 data that are nearly identical to WW-C, and ER-6-1-1 data that are nearly identical to ER-6-1-2. The laboratory results are presented in Table 6-3 for ER-3-3 and in Table 6-7 for Well ER-4-1. For this review, the data from ER-3-3 were not included due to indications from the field measured water-quality parameters that well development was not complete. The major-ion, stable-isotope ($\delta^{18}O$, δD, and $\delta^{13}C$), and natural radiochemistry (^{14}C [pmc] and $^{36}Cl/Cl$) data for Well ER-4-1, as well as the 19 other LCA wells in Yucca Flat, are summarized in Table 6-9. These results and all others presented within this section are stored in the UGTA Chemistry Database (Navarro, 2017b). For the UGTA (ER) wells, results for the pumped wellhead samples collected during WDT operations are used for the evaluation; these samples are considered most representative of the formation water. The average is presented when multiple results are available for a single analyte and well.

Table 6-7
Analytical Results from GEL for GWC Samples Collected at Well ER-4-1 after WDT
(Page 1 of 2)

Analyte	Analytical Method [a]	Detection Limit	Wellhead Composite Samples 431-021717-1 431-021717-1F		Wellhead Composite Duplicate QC Samples 431-021717-2 431-021717-2F	
Metals (mg/L)						
			Total	**Filtered**	**Total**	**Filtered**
Aluminum	SW-846 6010 [b]	0.2	0.2 U	--	0.2 U	--
Arsenic		0.03	0.03 U		0.03 U	
Barium		0.005	0.0874		0.087	
Cadmium		0.005	0.005 U		0.005 U	
Calcium		0.2	83.7		83.8	
Chromium		0.005	0.005 U		0.005 U	
Iron		0.1	0.211		0.208	
Lead		0.002	0.000697 J		0.000644 J	
Lithium		0.05	0.258		0.261	
Magnesium		0.3	42.4		42.5	
Manganese		0.01	0.00499 J		0.00491 J	
Potassium		0.15	12.6		12.6	
Selenium		0.005	0.005 U		0.005 U	
Silicon		0.1	23.4		23.4	
Silver		0.005	0.005 U		0.005 U	
Sodium	SW-846 6010 [b]	0.3	73.3	--	67	--
Strontium		0.005	0.403		0.4	
^{238}Uranium	SW-846 6020 [b]	0.0002	0.00612		0.00612	
Inorganics (mg/L unless otherwise noted)						
			Total	**Filtered**	**Total**	**Filtered**
Bromide	EPA 300.1 [c]	0.2	--	0.153 J	----	0.146 J
Chloride		1		25.3		24.8
Fluoride		0.1		0.44		0.454
Sulfate		2		52.3		50.9
Alkalinity (as $CaCO_3$)	EPA 310.1 [d]	4	504	--	515	--
Bicarbonate Alkalinity (as $CaCO_3$)		4	504		515	
Carbonate Alkalinity (as $CaCO_3$)	EPA 310.1 [d]	4	1.45 U	--	1.45 U	--
pH (SU)	EPA 150.1 [d]	0.1	7.2		7.35	
Specific Conductivity (µmhos/cm)	EPA 120.1 [d]	1	1,020		1,020	

Table 6-7
Analytical Results from GEL for GWC Samples Collected at Well ER-4-1 after WDT
(Page 2 of 2)

Analyte	Analytical Method [a]	Detection Limit	Wellhead Composite Samples 431-021717-1 431-021717-1F		Wellhead Composite Duplicate QC Samples 431-021717-2 431-021717-2F	
Radiological Indicator Parameters (pCi/L)						
		MDC [e]	**Result**	**Error**	**Result**	**Error**
Tritium	EPA 906.0 [f]	216, 218	1.16 U	125	-24 U	124
Tritium (Low-level)	HASL 300 3H-02 and EPA 906.0 [f]	2.84, 2.83	0.517 U	1.66	-0.67 U	1.6
Gross Alpha	EPA 900.0 [f]	2.75, 2.98	17.4	4.33	16.5	4.25
Gross Beta		1.59, 1.68	12.8	2.56	12.9	2.62
^{238}Plutonium	HASL 300 [f]/ Pu-10-Rc	0.0625, 0.0513	-0.0119 U	0.0219	-0.00831 U	0.0201
$^{239/240}$Plutonium	HASL 300 [f]/ Pu-10-Rc	0.0786, 0.0605	-0.00807 U	0.0336	-0.022 U	0.0194
Gamma Spectroscopy	EPA 901.1 [f]	Varies by Nuclide	ND	Varies by Nuclide	ND	Varies by Nuclide
^{214}Lead		22.2	41.1	18.2		
^{214}Bismuth		14.6	30.9	14.8		
^{14}Carbon	EPA EERF C-01 [g]	347	6.92 U	199	195 U	210
^{36}Chlorine	EPA 902.0 [f]	20.1, 18.9	0.745 U	11.8	-2.61 U	11
^{129}Iodine	EPA 902.0 [f]	0.618, 0.92	-0.25 U	0.355	-0.141 U	0.491
^{90}Strontium	EPA 905.0 [f]	0.963, 0.952	-0.239 U	0.449	-0.598 U	0.446
^{99}Technetium	HASL TCW-02	5.04, 5.12	0.888 U	2.9	2.76 U	3.07

Source: Navarro, 2017a

[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.
[b] EPA, 2017
[c] EPA, 1997
[d] EPA, 1983
[e] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.
[f] EPA, 1980
[g] EPA, 1984

F = Filtered
J = Result is estimated.
ND = No gamma spectroscopy nuclides detected above detection limits, except ^{214}Lead and ^{214}Bismuth.
U = Compound was analyzed for but was not detected (“Non-detect”).
-- = No result

Table 6-8
Analytical Results from LLNL for GWC Samples Collected at Well ER-4-1 after WDT

Analyte	Analytical Method	Detection Limit	Wellhead Composite Samples 431-021717-3 431-021717-3F		Wellhead Composite Duplicate QC Samples 431-021717-4 431-021717-4F	
Inorganics (mg/L)						
			Total	**Filtered**	**Total**	**Filtered**
Bromide	SOP-UGTA-120	TBD	--	Pending	--	Pending
Chloride						
Fluoride						
Sulfate						
Organics (mg/L)						
Total Inorganic Carbon	SOP-UGTS-116	TBD	--	Pending	--	Pending
Environmental Tracers						
			Result		**Result**	
Stable Isotopes ($^{2}H/^{1}H$)	SOP-UGTA-128	NA	Pending		Pending	
Stable Isotopes ($^{18}O/^{16}O$)			-13.77 per mil		-13.16 per mil	
Noble Gases						
Noble Gases	SOP-NGMS-122	TBD	Pending	Pending	Pending	Pending
Radiological Indicator Parameters (pCi/L)						
		MDC [a]	**Result**	**Error**	**Result**	**Error**
Tritium	SOP-NGMS-121	TBD	Pending	Pending	Pending	Pending
^{13}Carbon	SOP-UGTS-116					
^{14}Carbon	SOP-UGTS-136		0.0344	0.0022		
^{36}Chlorine	SOP-UGTS-115		Pending	Pending		

Source: Navarro, 2017a

[a] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.

F = Filtered
-- = No result

Table 6-9
Summary of Major-Ion Chemistry, Stable Isotopes, and Naturally Occurring Radiochemistry

Well	pH	Temp (°C)	HCO_3 (mg/L)	Cl (mg/L)	SO_4 (mg/L)	Ca (mg/L)	Na (mg/L)	Mg (mg/L)	K (mg/L)	SiO_2 (mg/L)	Sr (ppb)	$\delta^{18}O$	δD	$\delta^{13}C$	^{14}C (pmc)	$^{36}Cl/Cl$
Upgradient Wells																
UE-10j-1	6.43	32.7	552	23.9	79	107	68	45	13	41	470	-13.55	-104.1	-3.63	7.5	2.41E-13
UE-10j-2	6.73	32.3	403	16	67	68	43	30	8	36	320	-13.15	-101.5	-5.73	11.4	3.91E-13
UE-10j-3	7.08	32.1	322	12.8	59	60	37	27	7	32	270	-12.83	-100.1	-7.71	12.6	4.45E-13
WW-2	7.4	34.6	202	7.4	20	30	28	15	7	56	105	-13.47	-103	-11.2	10	---
UE-2ce WW	7.15	32.9	368	59	33	74	48	33	24	47	160	-12.9	-100	-5.3	---	---
ER-12-1	7.73	25	221	17.2	343	34	37	64	4	20	210	-12.5	-94	-9.6	10.8	7.80E-13
ER-12-2	8.23	35.2	300	6.8	27	5	114	1.8	3	22	323	-13.7	-101.1	-5.55	1.5	6.90E-13
ER-12-3	8.02	30.6	120	6	26	17.4	29.8	17.4	2.8	25.3	1,000.4	-14.5	-106	-5.7	3	5.39E-13
ER-12-4	7.9	26	84.5	8.9	13	8.65	29.5	8.65	3.98	15.8	51.8	-13.8	-101.15	-7.05	6.9	5.70E-13
Medial Wells																
ER-4-1	6.8	32.1	621	25.1	52	84	70	42	13	50	402	-13.50	-104.7	-2.81	4.19	---
TW-D	7.9	23.9	238	7.3	30	12	84	5	8	40	112	-14.2	-108	-5.5	2.8	7.24E-13
UE-1q	7.8	27.7	197	10.5	24	24	39	14	7	51	140	-14.47	-108	-5.5	7.7	7.90E-13
Downgradient Wells																
U-3cn#5	7.26	44.7	263	32	36	32	56	19	9	56	227	-14.08	-104.3	-6.8	3.2	4.08E-13
ER-6-1#2	7.7	39.3	244	11	34	33	44	13	8	33	213	-14.10	-105.8	-6.2	2.4	4.33E-13
ER-7-1	7.68	49.4	241	11.4	34	34	47	14	7	33	230	-14.00	-106	-6.25	5.3	3.77E-13
UE-7nS	7.59	34.6	167	27	1	20	58	4	5	21	70	-14.00	-106	-2	--	--
UE-1h	8.2	25.3	270	43.4	3	13	101	9	24	11	185	-13.75	-104.5	-11.2	18	1.61E-13
ER-6-2	7.61	34.9	373	18.9	58	58	63	20	11	31	337	-14.05	-106	-4.3	1.6	2.00E-13
WW-C	7.01	34.6	544	35.9	66	67	127	30	15	35	704	-13.97	-106.9	-4	0.6	1.76E-13
UE-1r WW	7.8	--	251	7	13	20	--	9	--	--	--	--	--	--	--	--
ER-3-1	6.65	41.4	584	42	67	91	139	34	18	35	917	-14.13	-108.9	-2.32	0.7	1.31E-13

Source: Navarro, 2017b

-- = No result

ppb = Parts per billion
SiO_2 = Silicon dioxide
Sr = Strontium

6.4.1 Major Ions

The dissolved constituents in groundwater provide a record of the minerals encountered as water moves through an aquifer; therefore, the major-ion characteristics of groundwater can provide insight on groundwater source areas and flow directions. A Piper diagram illustrating the relative major-ion concentrations in groundwater is presented in Figure 6-2 from the data in Table 6-9. The data included new analytical results from Well ER-4-1, as well as Well ER-3-3 presented for completeness, though suspect due to poor well development. The new data were plotted alongside an existing set of analyses from LCA wells in the vicinity for comparison to the region, taken from SNJV (2006). The major ions consist of calcium (Ca^{2+}), potassium (K^{+}), magnesium (Mg^{2+}), sodium (Na^{+}), chloride (Cl^{-}), sulfate (SO_4^{2-}), bicarbonate (HCO_3^{-}), and carbonate (CO_3^{2-}). The Piper diagram presents relative concentrations in percent milliequivalents per liter (%meq/L) and is used to classify various groundwater chemistry types (or facies) and illustrate the relationships that may exist between water samples. The relative concentrations of cations and anions are presented in the left and right triangles, respectively, and are projected onto the central diamond to present the combined major-ion chemistry (Figure 6-2). The symbol colors are selected to improve visualization of sampling locations that plot close to one another.

The Piper diagram shows that HCO_3^{-} dominates the anions in the study area groundwaters. Only one sample (ER-12-1) shows elevated levels of sulphate (63 percent) with lesser bicarbonate (32 percent) and minor chloride (5 percent). Most likely the sulfate came from pyrite oxidation at the nearby Gold Meadows stock (granite), which is similar to Climax Stock and possibly connected with it at depth. Overall, the relative concentrations of cations are substantially more variable (Figure 6-2) than that of anions; the cations present show either a mix of the three major cation groups (Mg, Ca, and Na+K), with each ranging from 20 to 40 percent, or Na + K in excess of 66 percent. The mixed group is consistent with water evolution in the limestone and dolomitic rocks of the LCA (SNJV, 2006). The water with predominant Na +K is most likely sourced from volcanic rocks, either from groundwater upgradient or recharge through overlying deposits. Four samples show Na and K to be the predominant cation, greater than 66 percent. The groundwaters vary from an $Na+K-HCO_3$ type (greater than 50 percent Na+K as the dominant cations and greater than 50 percent HCO_3 as the dominant anion) to an $Ca+Mg-HCO_3$ type (relatively equal concentrations of the four cations are present). The data plot along a trend on the Piper plot that may correspond to the groundwater geochemical evolution along a flowpath.

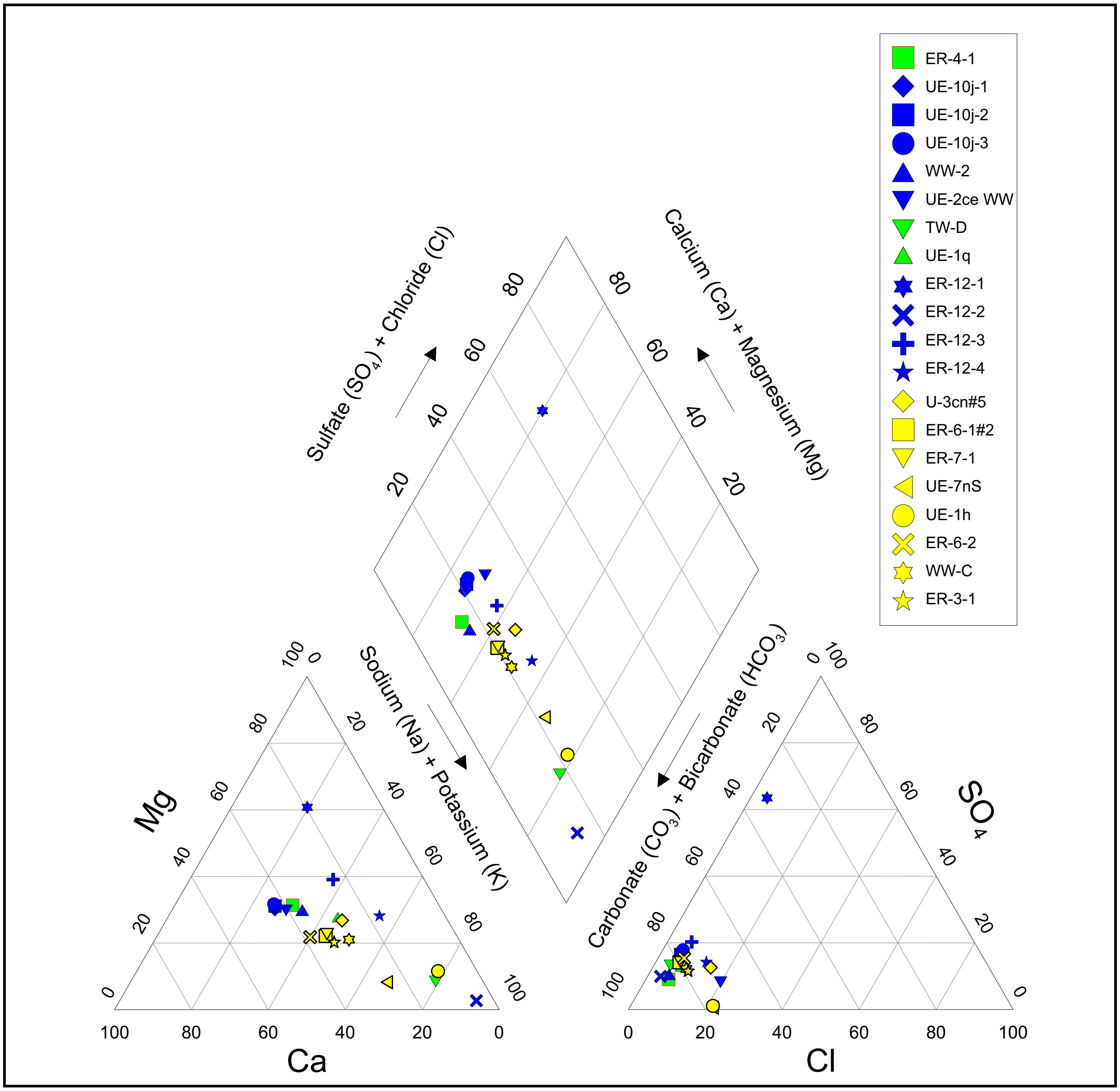

Figure 6-2
Piper Diagram Illustrating Groundwater Major-Ion Chemistry of Well ER-4-1 and Wells in the Vicinity

The Well ER-4-1 (green square) sample plotted on the Piper diagram as a Ca+Mg-HCO_3 water, 38 percent Ca, 31 percent Mg, and 31 percent (Na+K) (Figure 6-2). The Well ER-3-3 samples were not plotted due to the uncertainty as to whether complete well development had been achieved.

6.4.2 Stable Isotopes

The stable isotopes of hydrogen ($^2H/^1H$ or $D/^1H$) and oxygen ($^{18}O/^{16}O$) are intrinsic to the water molecule and therefore behave conservatively in most groundwater systems. In the water cycle, these isotopes are fractionated between the liquid and vapor phases during evaporation and condensation processes. Once precipitation has infiltrated to the water table, the stable isotope values are unaffected by water-rock interaction at temperatures below approximately 100 °C (Criss, 1999). These isotopes are therefore used along with Cl as conservative tracers for evaluating groundwater origin and flow paths. Hydrogen and oxygen isotopes are conventionally reported as delta (δ) values representing per mil variations in the isotope ratio of the sample relative to a reference standard.

A plot of delta deuterium (δD) versus $\delta^{18}O$, presented in Figure 6-3, shows that the results for Well ER-4-1 plots along the trend of the other LCA wells, parallel to the trend of the global meteoric water line (GMWL), but with relatively lower δD values with respects to the GMWL. Residual waters fractionated off of the meteoric water line get heavier, but the trend is to right of the GMWL with relatively lighter δD with respects to GMWL and relatively heavier $\delta^{18}O$ with respects to GMWL, with most fractionation processes (e.g., hyper-evaporation in enclosed basins; see Craig [1961]). For reference, the GMWL defined by Craig (1961) and the local meteoric water line (LMWL) defined by Ingraham et al. (1990) are included on Figure 6-3. The meteoric water lines represent the observed correlations in $\delta^{18}O$-δD values of precipitation samples from around the world and from the NNSS, respectively. The GMWL is defined by the equation $\delta D = 8\delta^{18}O + 10$ (Craig, 1961), while the LMWL is defined by the equation $\delta D = 6.87\delta^{18}O - 6.5$ (Ingraham et al., 1990).

The symbol colors and shapes correspond those on the map (Figure 6-1) and the Piper diagram (Figure 6-2). All samples plot below the present-day GMWLs or LMWLs, suggesting that the groundwater is mostly fossil groundwater unrelated to present precipitation (Merlivat and Jouzel, 1979).

The stable isotope composition of Well ER-4-1 groundwater is quite similar to that in other LCA samples, although they are within the typical measurement uncertainty ($\delta D = \pm 2$ per mil and $\delta^{18}O = \pm 0.2$ per mil) of most other nearby sampling locations.

The stable isotopes of carbon ($\delta^{13}C$) found in groundwater are related to the $\delta^{13}C$ values encountered in the Earth's carbon cycle. The $\delta^{13}C$ value is influenced by carbon dissolved in groundwater

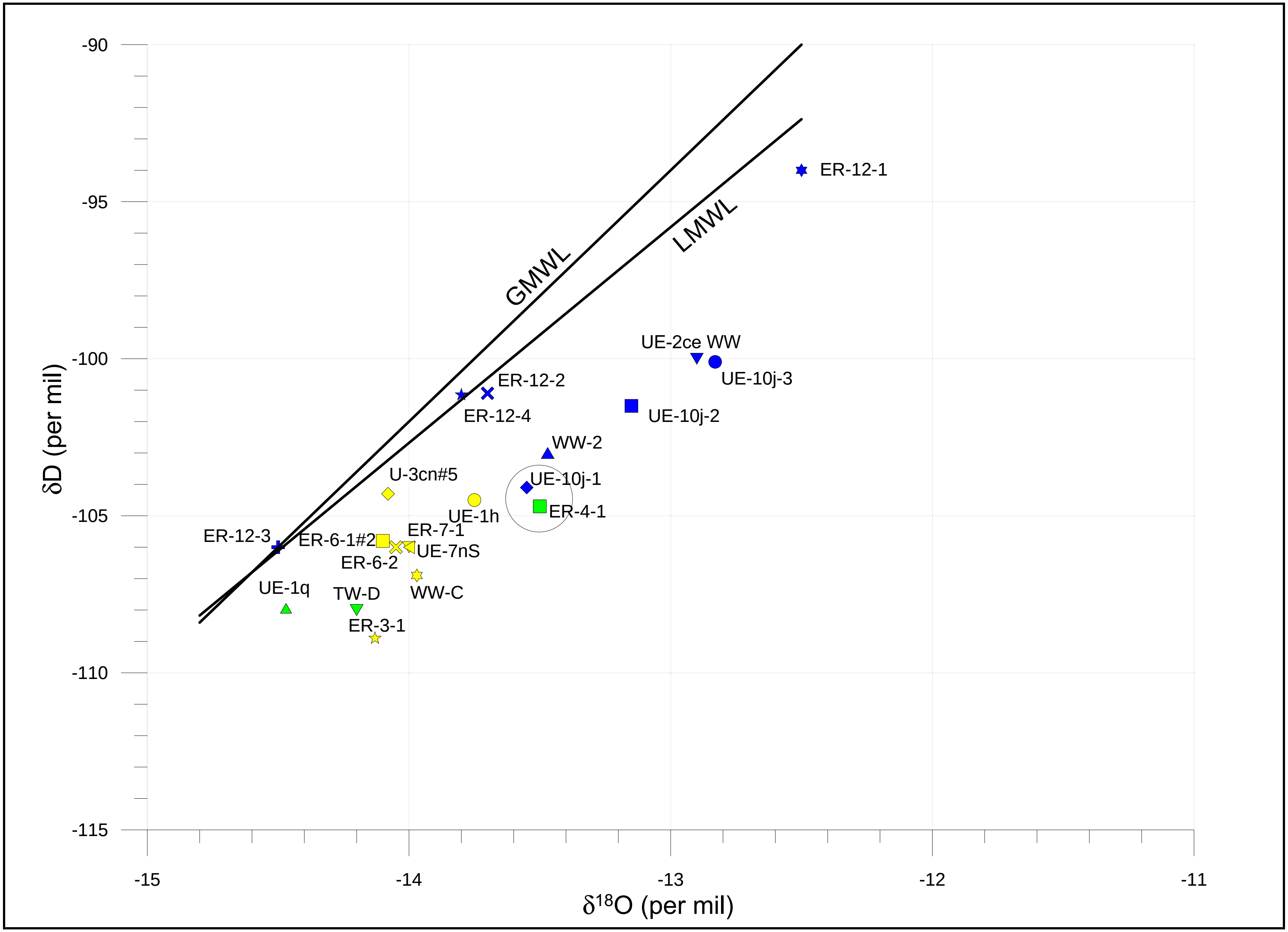

Figure 6-3
Delta Deuterium (δD) versus $\delta^{18}O$
Note: Symbol color represents general map location as shown in Figure 6-1.

reflecting possible interactions with carbon dioxide (CO_2) in the atmosphere, with carbon from organic matter, or with carbon from rock minerals, as well as exchange with calcite and dolomite from limestone and dolomite rocks. The atmospheric CO_2 isotopic composition is a mixture of volcanic and organic carbon inputs. Organic carbon inputs include both fossil fuel emissions as well as terrestrial biota, both with a $\delta^{13}C$ of around -26 per mil due to the preferential uptake (fractionation) of ^{12}C in photosynthesis (thus lowering the $\delta^{13}C$ value) (Fauer, 1986). The $\delta^{13}C$ of volcanic gas ranges from -18 to +3, but on average is higher than sources of organic carbon (Fauer, 1986). Currently, the $\delta^{13}C$ of the atmosphere is a mixture of these two sources, with a value of approximately -8.0 per mil (NOAA, 2017). This composition has decreased from a pre-Industrial-Revolution estimate of -6.5 per mil due to fossil fuel emissions, with the observed recent decrease from a value of -7.6 per mil as recently as 1992 (Keeling, 1995). The $\delta^{13}C$ of carbonate rocks averages near the carbonate Pee Dee Belemnite $\delta^{13}C$ standard of 0.0, with a common typical average value of -1.0 used as an assumed endpoint in many mixing models. A common hypothesis for groundwater evolution posits that atmospheric CO_2 in recharge (with $\delta^{13}C = -8$) encounters (mixes with) organic matter (with $\delta^{13}C = -28$) in the vadose zone, and then becomes part of a system closed to CO_2 below the water table. The water may eventually encounter carbonate rocks (limestone and dolomite), and thus may exchange isotopes with carbonate rock ($\delta^{13}C = 0$) (Kendall et al., 1992).

A plot of $\delta^{13}C$ versus HCO_3 is presented in Figure 6-4. Most (12) of the data plot within a range of $\delta^{13}C$ from -8 to -4, which is consistent with atmospheric recharge mixing with limestone (Bullen and Kendall, 1998). Three values plot below -8, suggesting that there is at least some mixing with organic matter. In general, higher bicarbonate (alkalinity) levels correspond to higher $\delta^{13}C$ values, suggesting that higher bicarbonate in the water corresponds to more dissolution of, or exchange with, limestone, with its commonly assumed higher $\delta^{13}C$ value of -1.

6.4.3 Radionuclides

The results from ALS of tritium and RN analyses of samples from Well ER-3-3 are summarized in Tables 6-1 through 6-4. As of the time of this report, samples from LLNL were pending analysis. Bailer samples from piezometer p1, monitoring the LCA HSU, and p2, monitoring the LTCU Tertiary volcanic HSU—both before WDT activities—showed no detection for tritium (Tables 6-3 and 6-4,

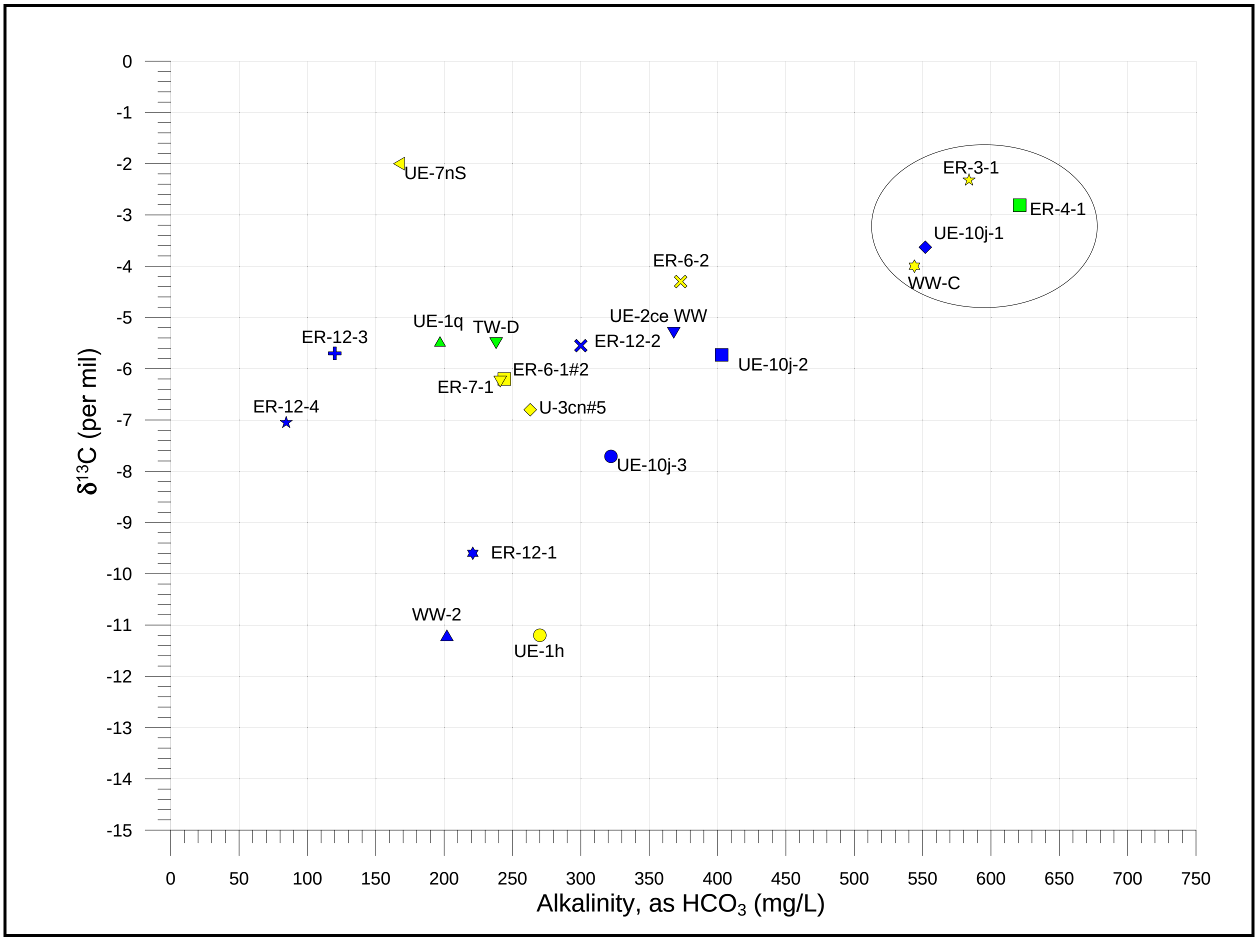

Figure 6-4
Plot of $\delta^{13}C$ versus HCO_3

Note: Symbol color represents general map location as shown in Figure 6-1.

respectively). RN results from the main completion, m1, monitoring the LCA during WDT activities, were non-detect, with the exception of gross alpha.

The results from GEL of tritium and RN analyses of samples from Well ER-4-1 are summarized in Tables 6-5 through 6-7. As of the time of this report, samples from LLNL were pending analysis. A bailer sample from piezometer p1, monitoring the LTCU Tertiary volcanic HSU before WDT activities, had a tritium result of 733 pCi/L (Table 6-5). RN results from the main completion, m1, monitoring the LCA during (Table 6-6, tritium only) and after (Table 6-7) WDT activities, were non-detect, with the exception of gross alpha, gross beta, and the natural radiogenic isotopes ^{214}Pb and ^{214}Bi.

7.0 Environmental Compliance

This section discusses fluid and waste management during WDT activities at Wells ER-3-3 and ER-4-1.

7.1 Fluid Management Plan

Guidelines for managing fluids generated during well drilling, development, testing, and sampling of UGTA wells are provided in the UGTA Fluid Management Plan (FMP) (NNSA/NSO, 2009). The well-specific fluid management strategy letters for Wells ER-3-3 (Navarro, 2016a) and ER-4-1 (Navarro, 2016b), as required by the UGTA FMP and approved by the Nevada Division of Environmental Protection (NDEP), address specific fluid management strategies employed at the wells for fluid-generating activities relating to WDT. During well development, testing, and sampling operations, tritium samples were collected daily to meet the requirements stated in the FMP and in accordance with the Navarro ER-3-3 and ER-4-1 Field Activity Work Packages (Navarro, 2016c and d).

7.1.1 Fluid Containment and Disposition

7.1.1.1 Well ER-3-3

Two onsite infiltration basins (Sumps #1 and #2) were constructed to contain fluids and drill cuttings during operations at Well ER-3-3. Sump #1 is lined with an approximate 1.5-million-gal capacity for drilling fluid containment. A second unlined sump (Sump #2) with an estimated 500,000-gal capacity was to be used only in the event fluid storage capacity was not sufficient; Sump #2 was not used during WDT activities. The sumps are approximately 10 ft deep from the floor of the sump to the drill pad surface.

The FMP (NNSA/NSO, 2009) and the Well ER-3-3 FMP strategy letter (Navarro, 2016a) establish concentrations for specified parameters below which purged fluids may be discharged either to an unlined containment basin or infiltration area, or directly to the ground surface. Purged fluids were discharged into Sump #1. Fluid volumes produced from the well were monitored using a calibrated flowmeter. Approximately 9,416 gal of groundwater was pumped from the well during WDT activities. The FMP confirmatory sampling results (Table 7-1) met the FMP criteria for fluid discharge to an unlined sump.

Table 7-1
Analytical Results from ALS for FMP Samples Collected at Well ER-3-3 after WDT

Analyte	Analytical Method [a]	Detection Limit	Sample Numbers 430-121516-4 430-121516-4F		Duplicate QC Sample Numbers 430-121516-5 430-121516-5F	
			Total	Dissolved [b]	Total	Dissolved [c]
Metals (mg/L)						
Arsenic	SW-846-6010 [d]	0.01	0.024	0.02	0.021	0.021
Barium		0.1	0.025 J	0.003 J	0.023 J	0.0025 J
Cadmium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Chromium		0.01	0.02	0.013	0.02	0.013
Lead		0.003	0.01	0.003 U	0.011	0.003 U
Selenium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Silver		0.01	0.01 U	0.01 U	0.01 U	0.01 U
Mercury	SW-846-7470 [d]	0.0002	0.0002 U	0.0002 U	0.0002 U	0.0002 U
Radiological Indicator Parameters (pCi/L)						
		MDC [e]	Result	Error	Result	Error
Tritium	EPA 906.0 [f]	310	150 U	190	-170 U	180
Gross Alpha	EPA 900.0 [f]	2.4, 2.7	2.7 U	1.7	4.2 U	2.2
Gross Beta		2.9, 2.6	8.1	2.4	8.4	2.3

Source: Navarro, 2017a

[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.
[b] Dissolved sample designated 430-121516-4F.
[c] Dissolved sample designated 430-121516-5F.
[d] EPA, 2017
[e] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.
[f] EPA, 1980

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

The volumes of fluids produced during WDT activities at Well ER-3-3 are presented in Table 7-2, the Fluid Disposition Reporting Form. At the completion of WDT operations on September 1, 2016, an estimated total of 36 cubic meters (m^3) (9,416 gal) of purged water had been discharged into Sump #1.

Table 7-2
Well ER-3-3 Fluid Disposition Reporting Form

Site Identification: ER-3-3
Site Location: Nevada National Security Site
Site Coordinates: (UTM NAD 27, Zone 11) N 4,102,139.02 m; E 583,443.27 m
Well Classification: ER Hydrogeologic Investigation Well
Navarro Project No: UN17-485

Report Date: August 31, 2017
NNSA/NFO UGTA Activity Lead: Bill Wilborn
Navarro Project Manager: Ken Rehfeldt
Navarro Site Representative: Dawn Peterson
Navarro Field Environmental Specialist: Mark Heser

Well Construction Activity	Activity Duration		#Ops. Days [a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes (m^3)		Infiltration Area [c] (m^3)	Other [d] (m^3)	Fluid Quality Objective Met?
	From	To				Solids [b]	Liquids	Solids [b]	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	02/21/2016	02/24/2016	2	499.87	289.38	183.68	154.81	N/A	N/A	N/A	N/A	Yes
Phase I: Saturated-Zone Drilling	02/24/2016	03/15/2016	7	473.32	519.93	79.06	1,726.38	N/A	662.19	NA	N/A	Yes
Phase II: Well Development	12/02/2016	12/15/2016	10	N/A	N/A	N/A	35.81	N/A	N/A	N/A	N/A	Yes
Phase II: Aquifer Testing	-	-	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cumulative Production Totals to Date:			19	973.2	809.31	262.75	1,917.00	N/A	662.19	0	N/A	Yes

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

[b] Solids volume estimates include calculated added volume (50%) attributed to rock bulking factor.

[c] Discharge to an NDEP approved infiltration area as defined in the Well-Specific Fluid Management Strategy Letter for ER-3-3.

[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; m^3 = Cubic meter

Total Facility Capacities (at 8 ft fluid level): Sump # 1 = 3,879 m^3 Sump #2 = 1,306 m^3 Infiltration Area (assuming very low/no infiltration) = N/A

Remaining Facility Capacity (Approximate) as of 12/15/2016: Sump #1 = 3,685 m^3 (95%) Sump #2 = 1,306 m^3 (100%)

Current Average Tritium activity for FMP samples collected from Sump #1 was <310 pCi/L.

Notes: None

Navarro Authorizing Signature/Date /s/ Jeffrey Wurtz 11-27-17

7.1.1.2 Well ER-4-1

Two onsite infiltration basins (Sumps #1 and #2) were constructed to contain fluids and drill cuttings during operations at Well ER-4-1. Sump #1 is lined with an approximate 1.5-million-gal capacity for drilling fluid containment. A second unlined sump (Sump #2) with an estimated 500,000-gal capacity was used because fluid storage capacity in Sump #1 was not sufficient. The sumps are approximately 10 ft deep from the floor of the sump to the drill pad surface.

The FMP (NNSA/NSO, 2009) and the Well ER-4-1 FMP strategy letter (Navarro, 2016b) establish concentrations for specified parameters below which purged fluids may be discharged either to an unlined containment basin or infiltration area, or directly to the ground surface. Purged fluids were discharged into Sump #1. Approximately 1,732,160 gal of groundwater was pumped from the well during WDT activities.The FMP confirmatory sampling results (Table 7-3) met the FMP criteria for fluid discharge to an unlined sump.

Table 7-3
Analytical Results from GEL for FMP Samples Collected at Well ER-4-1 after WDT
(Page 1 of 2)

Analyte	Analytical Method [a]	Detection Limit	Sample Numbers 431-021717-5 431-021717-5F		Duplicate QC Sample Numbers 431-021717-6 431-021717-6F	
			Total	Dissolved [b]	Total	Dissolved [c]
Metals (mg/L)						
Arsenic	SW-846-6010 [d]	0.03	0.03 U	0.03 U	0.03 U	0.03 U
Barium		0.005	0.0868	0.0872	0.0852	0.0863
Cadmium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Chromium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Lead		0.002	0.002 U	0.002 U	0.002 U	0.002 U
Selenium		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Silver		0.005	0.005 U	0.005 U	0.005 U	0.005 U
Mercury	SW-846-7470 [d]	0.0002	0.000168 J	0.000164 J	0.000157J	0.00015 J

Table 7-3
Analytical Results from GEL for FMP Samples Collected at Well ER-4-1 after WDT
(Page 2 of 2)

Analyte	Analytical Method [a]	Detection Limit	Sample Numbers 431-021717-5 431-021717-5F		Duplicate QC Sample Numbers 431-021717-6 431-021717-6F	
			Total	Dissolved [b]	Total	Dissolved [c]
Radiological Indicator Parameters (pCi/L)						
		MDC [e]	Result	Error	Result	Error
Tritium	EPA 906.0 [f]	220, 222	-2.72 U	127	-46.2 U	126
Gross Alpha	EPA 900.0 [f]	2.95, 2.99	9.66	3.36	10.6	3.62
Gross Beta		1.97, 1.83	11.2	2.53	13.1	2.7

Source: Navarro, 2017a

[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.
[b] Dissolved sample designated 431-021717-5F.
[c] Dissolved sample designated 431-021717-6F.
[d] EPA, 2017
[e] MDC varies by matrix, instrument, and count rates. Where more than one detection limit is given, they apply to the samples in the order presented.
[f] EPA, 1980

J = Estimated value.
U = Compound was analyzed for, but was not detected (“Non-detect”).

The volumes of fluids produced during WDT activities at Well ER-4-1 are presented in Table 7-4, the Fluid Disposition Reporting Form. At the completion of WDT operations on February 17, 2017, an estimated total of 6,556.23 m^3 (1,732,160 gal) of purged water had been discharged into Sump #1 and Sump #2.

7.1.2 Tritium Monitoring

7.1.2.1 Well ER-3-3

In accordance with Section 4.2, “Other Well-Site Activities,” of the FMP (NNSA/NSO, 2009) and the approved strategy letter, grab samples for tritium analysis were collected from depth-discrete bailer samples from both the p1 and p2 piezometers, and from the wellhead sampling port on a daily basis once the pump was started. Samples were stored on site and delivered daily to Navarro Radiological Services (Building 23-310) for tritium analysis using a liquid scintillation counter. All samples were processed and analyzed by Navarro personnel in accordance with Navarro procedures. The tritium results indicate that tritium levels were consistently below the *Safe Drinking Water Act* (SDWA) limit

Table 7-4
Well ER-4-1 Fluid Disposition Reporting Form

Site Identification: ER-4-1
Site Location: Nevada National Security Site
Site Coordinates: (UTM NAD 27, Zone 11) N 4,106,917.22 m; E 584,398.13 m
Well Classification: ER Hydrogeologic Investigation Well
Navarro Project No: UN17-480

Report Date: August 31, 2017
NNSA/NFO UGTA Activity Lead: Bill Wilborn
Navarro Project Manager: Ken Rehfeldt
Navarro Site Representative: Dawn Peterson
Navarro Field Environmental Specialist: Mark Heser

Well Construction Activity	Activity Duration		#Ops. Days [a]	Well Depth (m)	Import Fluid (m^3)	Sump #1 Volumes (m^3)		Sump #2 Volumes (m^3)		Infiltration Area [c] (m^3)	Other [d] (m^3)	Fluid Quality Objective Met?
	From	To				Solids [b]	Liquids	Solids [b]	Liquids	Liquids		
Phase I: Vadose-Zone Drilling	03/23/2016	03/25/2016	2	320.39	206.70	137.00	273.43	N/A	N/A	N/A	N/A	Yes
Phase I: Saturated-Zone Drilling	03/25/2016	04/14/2016	9	604.74	996.93	142.40	2,912.09	N/A	N/A	NA	N/A	Yes
Phase II: Well Development and Aquifer Testing	01/17/2017	02/17/2017	25	N/A	N/A	N/A	1,887.96	N/A	4,668.27	N/A	N/A	Yes
Cumulative Production Totals to Date:			36	925.13	1,203.63	279.40	5,073.48	N/A	4,668.27	N/A	N/A	Yes

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

[b] Solids volume estimates include calculated added volume (50%) attributed to rock bulking factor.

[c] Discharge to an NDEP approved infiltration area as defined in the Well-Specific Fluid Management Strategy Letter for ER-4-1.

[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; m^3 = Cubic meter

Total Facility Capacities (at 8 ft fluid level): Sump # 1 = 3,879 m^3 Sump #2 = 1,306 m^3 Infiltration Area (assuming very low/no infiltration) = N/A

Remaining Facility Capacity (Approximate) as of 02/21/2017: Sump #1 = 1,024.3 m^3 (26.4%) Sump #2 = 1,306 m^3 (100%)

Current Average Tritium activity for FMP samples collected from Sump #1 was <220 pCi/L.

Notes: None

Navarro Authorizing Signature/Date /s/ Jeffrey Wurtz 11-27-17 of 20,000 pCi/L (CFR, 2017). As shown in Table 7-5, tritium analyses for the discharge samples from Well ER-3-3 were all below the method detection limit. The Navarro tritium analysis result from the p2 bailer sample is inconsistent with the analytical laboratory result (non-detect) given in Table 6-2.

Table 7-5
Final Tritium Results for WDT Operations at Well ER-3-3
(Page 1 of 2)

Sample Number	Navarro Tritium Analysis Results (pCi/L)	MDA (pCi/L)	Sample Description
ER-3-3-110916-1	515	1,613	Collected from p1 bailer at 3,010 ft bgs
ER-3-3-110916-2	4,382	2,039	Collected from p2 bailer at 2,320 ft bgs
ER-3-3-113016-1	0	1,748	Collected from m1, pump intake at 1,979.44 ft bgs
ER-3-3-120116-1	16	1,697	Collected from m1, pump intake at 1,979.44 ft bgs; 1st purge of day
ER-3-3-120116-2	0	1,692	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-120216-1	0	1,832	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day
ER-3-3-120216-2	0	1,759	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-120216-3	0	2,050	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-120516-1	0	3,040	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day
ER-3-3-120516-2	0	1,927	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-120516-3	0	1,847	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-120616-1	277	1,921	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day
ER-3-3-120616-2	330	1,668	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-120616-3	518	1,698	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-120716-1	210	1,681	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day
ER-3-3-120716-2	180	1,573	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-120716-3	28	1,602	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-120816-1	248	1,594	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day

Table 7-5
Final Tritium Results for WDT Operations at Well ER-3-3
(Page 2 of 2)

Sample Number	Navarro Tritium Analysis Results (pCi/L)	MDA (pCi/L)	Sample Description
ER-3-3-120816-2	6	1,635	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-120816-3	671	1,657	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-120916-1	172	1,992	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day
ER-3-3-120916-2	41	1,673	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-120916-3	0	1,586	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-121216-1	779	1,563	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-121316-1	0	1,594	Collected from m1, pump intake at 1,979.44 ft bgs; 3rd purge of day
ER-3-3-121416-1	0	1,696	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day
ER-3-3-121416-2	115	1,629	Collected from m1, pump intake at 1,979.44 ft bgs; 2nd purge of day
ER-3-3-121516-1	666	1,550	Collected from m1, pump intake at 1,979.44 ft bgs 1st purge of day; before GWC sampling

MDA = Minimum detectable activity

7.1.2.2 Well ER-4-1

In accordance with Section 4.2, “Other Well-Site Activities,” of the FMP (NNSA/NSO, 2009) and the approved strategy letter, grab samples for tritium analysis were collected from depth-discrete bailer sample from the p1 piezometer, and from the wellhead sampling port on a daily basis once the pump was started. Samples were stored on site and delivered daily to Navarro Radiological Services (Building 23-310) for tritium analysis using a liquid scintillation counter. All samples were processed and analyzed by Navarro personnel in accordance with Navarro procedures. The tritium results indicate that tritium levels were consistently below the SDWA limit of 20,000 pCi/L (CFR, 2017). As shown in Table 7-6, tritium analyses for the discharge samples from Well ER-4-1 ranged from 0 to 1,873 pCi/L. The analytical laboratory result for tritium from the m1 completion (Table 6-7) was non-detect.

Table 7-6
Final Tritium Results for WDT Operations at Well ER-4-1
(Page 1 of 3)

Sample Number	Navarro Tritium Analysis Results (pCi/L)	MDA (pCi/L)	Sample Description
ER-4-1-010517-1	1,227	1,407	Collected from p1 bailer at 2,045 ft bgs; highly turbid; opaque brown
ER-4-1-011317-1	1,873	1,528	Collected from m1, pump intake at 2,088 ft bgs; turbid
ER-4-1-011717-1	0	1,542	Collected from m1, pump intake at 2,088 ft bgs; slight gray tint, trace of scale, strong organic odor
ER-4-1-011717-2	0	1,857	Collected from m1, pump intake at 2,088 ft bgs; light red stain, faint odor
ER-4-1-011817-1	0	1,873	Collected from m1, pump intake at 2,088 ft bgs; red stain, minor sediment
ER-4-1-011817-2	0	1,637	Collected from m1, pump intake at 2,088 ft bgs; high turbidity
ER-4-1-011917-1	85	1,498	Collected from m1, pump intake at 2,088 ft bgs; very clear, very slight odor
ER-4-1-011917-2	781	1,565	Collected from m1, pump intake at 2,088 ft bgs; pale pink tinge
ER-4-1-012017-1	166	1,499	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012117-1	0	1,516	Collected from m1, pump intake at 2,088 ft bgs; clear, slight sulfur odor
ER-4-1-012217-1	0	1,513	Collected from m1, pump intake at 2,088 ft bgs; clear, trace of sediment
ER-4-1-012217-2	0	1,527	Collected from m1, pump intake at 2,088 ft bgs; light tint, trace of sediment
ER-4-1-012217-3	225	1,725	Collected from m1, pump intake at 2,088 ft bgs; red tint, turbid
ER-4-1-012317-1	0	1,550	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012317-2	329	1,460	Collected from m1, pump intake at 2,088 ft bgs; clear; test at 50 gpm
ER-4-1-012317-3	0	1,581	Collected from m1, pump intake at 2,088 ft bgs; clear; test at 70 gpm
ER-4-1-012317-4	27	1,666	Collected from m1, pump intake at 2,088 ft bgs; slightly turbid; test at 90 gpm
ER-4-1-012417-1	0	1,465	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012517-1	5	1,468	Collected from m1, pump intake at 2,088 ft bgs; clear

Table 7-6
Final Tritium Results for WDT Operations at Well ER-4-1
(Page 2 of 3)

Sample Number	Navarro Tritium Analysis Results (pCi/L)	MDA (pCi/L)	Sample Description
ER-4-1-012517-2	0	1,463	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012517-3	0	1,465	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012617-1	262	1,482	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012617-2	192	1,501	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012617-3	90	1,535	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012717-1	20	1,479	Collected from m1, pump intake at 2,088 ft bgs; clear, slight sulfur odor
ER-4-1-012717-2	131	1,510	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-012717-3	0	1,497	Collected from m1, pump intake at 2,088 ft bgs; light red tint, trace of sediment, slight sulfur odor
ER-4-1-020117-1	0	1,589	Collected from m1, pump intake at 2,088 ft bgs; clear, slight sulfur odor
ER-4-1-020117-2	0	1,688	Collected from m1, pump intake at 2,088 ft bgs; light red tint, trace of sediment, slight sulfur odor
ER-4-1-020217-1	506	1,410	Collected from m1, pump intake at 2,088 ft bgs; clear, trace of sediment, slight sulfur odor
ER-4-1-020617-1	0	1,425	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-020717-1	0	1,480	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-020817-1	256	1,430	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-020917-1	26	1,504	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-021017-1	558	1,492	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-021117-1	202	1,492	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-021217-1	0	1,477	Collected from m1, pump intake at 2,088 ft bgs; clear

Table 7-6
Final Tritium Results for WDT Operations at Well ER-4-1
(Page 3 of 3)

Sample Number	Navarro Tritium Analysis Results (pCi/L)	MDA (pCi/L)	Sample Description
ER-4-1-021317-1	370	1,483	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-021417-1	268	1,462	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-021517-1	0	1,467	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-021617-1	0	1,438	Collected from m1, pump intake at 2,088 ft bgs; clear
ER-4-1-021717-1	550	1,472	Collected from m1, pump intake at 2,088 ft bgs; clear

7.2 Waste Management

Navarro was responsible for environmental compliance and waste management at the Wells ER-3-3 and ER-4-1 sites. Waste generated during WDT operations consisted of hydrocarbon and sanitary wastes. Sanitary waste generated during the well development operations was routinely collected by National Security Technologies, LLC (NSTec) and disposed of at the Area 23 solid waste landfill.

The waste drum used at the ER-3-3 and ER-4-1 well sites was previously used at the ER-EC-1 site during groundwater sampling. Approximately 20 gal of solid hydrocarbon waste was generated from a generator oil spill, and servicing and flushing of the electric submersible pumps. The waste included kitty litter impacted by CL-5 pump oil, hydraulic fluid, and absorbent pads. The waste was characterized using process knowledge and monitoring results. The hydrocarbon waste was removed from the Well ER-4-1 site and transported by Navarro personnel to Building 6-909 for interim storage until disposal by NSTec. The waste was ultimately disposed of at the U-10c industrial waste landfill in Area 9. Table 7-7 is a summary of the waste type, volume, and disposition of the waste stream.

Table 7-7
Final Waste Disposition for Wells ER-3-3 and ER-4-1 Well Development, Testing, and Sampling Operations

Container ID #	Start Date	Container Size	Container Type	Contents	Characterization	Disposition	Status/ Comments
ER-EC-1-01	07/13/2016	55 gal	Open-top steel drum	Hydrocarbon Solids: absorbent pads, absorbent	Non-Haz, Non-Rad Hydrocarbon	Area 9 - U10c	Completed LVF received 07/10/2017

Total Waste Containers
Lab Analytical waste: 0 Pads/debris: 1 Used oil (liquid): 0
Total number of 5-gal waste containers: 0
Total number of 55-gal waste containers: 1

ID = Identification
LVF = Load Verification Form

Note: The 55-gal open-top steel drum waste container was previously used at the ER-EC-1 well site, then used at both ER-3-3 and ER-4-1 well sites.

8.0 OBSERVATIONS AND CONCLUSIONS

Wells ER-3-3 and ER-4-1 were constructed to evaluate possible RNs in groundwater from nearby UGTs, to provide hydrogeologic information to support refinement of the Yucca Flat HFM (BN, 2006), and to provide supplemental data to the Yucca Flat groundwater flow and contaminant transport model (N-I, 2013) to help address priority concerns and recommendations of the Yucca Flat External Peer Review Team. In addition to providing water-level and geochemical sampling data, the wells were developed and tested to provide information on aquifer parameters. This report provides a summary of the analysis of single-well tests, and provides an overview to USGS MWAT analyses provided Appendices E and F of this report for Wells ER-3-3 and ER-4-1, respectively.

In Well ER-3-3, piezometer p1 (screened alongside the main completion, m1, in the LCA) and piezometer p2 (screened across the overlying TMWTA, TMLVTA, and LTCU) were fitted with 500-psi transducers for aquifer testing. Only piezometer p1 showed any response to the pumping periods. The well was not able to sustain a minimum pump rate required for safe operation, requiring the pump to be shut off at intervals. Instead of a constant-rate test, the well was cyclically pumped while monitoring water-quality parameters to assess the extent of well development. The well was not sufficiently developed. With an assumption that pumping represented relatively instantaneous bailing of the well with each pump cycle, recovery from single pump intervals were analyzed as slug tests. As part of their report, USGS analyzed an early pump cycle as a slug test, choosing the initial pumping interval on December 5, 2016, that followed a long period of recovery, and obtaining a value of 0.00305 m/day (0.01 ft/day). To evaluate whether additional pumping cycles increased the hydraulic conductivity, Navarro analyzed the initial pumping interval on December 12, 2016, and obtained a hydraulic conductivity value of 0.00179 m/day [0.0059 ft/day], indicating that additional pumping did not increase the value. However, recovery from the later pumping interval was likely affected by superposition of previous pump cycles, slowing recovery and thus resulting in the lower hydraulic conductivity value.

In Well ER-4-1, the m1 main completion (pumping and monitoring the LCA) and piezometer p1 (screened in the overlying LTCU) were fitted with 500-psi transducers for aquifer testing. Only the main completion, m1, showed any response to the pumping periods. Well ER-4-1 had two main WDT periods:, a step test conducted from January 18 to January 27, 2017; and a constant-rate test from February 7 through February 17, 2017.

The step testing in Well ER-4-1 was used to purge the well, including intervals where the pump was shut off then on again with a high pump rate. Several pump rates were used until water-quality parameters indicated that the well was developed. As a result, the stepped rates were not used to determine well losses from inefficiencies considered to be due to a non-developed well.

In Well ER-4-1, a constant pump rate of 70 gpm was sustained for the entire 10-day constant-rate pump test. Analysis of the data using the Cooper and Jacob (1946) semi-log straight line method revealed multiple slopes for the duration of the test. The elapsed time at each break in slope was used to determine the radius of the effective cone of depression (radius of minimum detectable drawdown) at the time of the change, possibly reflecting the effect of a hydrologic barrier at that distance. Four slopes were evaluated to determine transmissivity. The early initial slope resulted in the highest transmissivity of 27.6 m^2/day, a conductive response that may include wellbore storage effects. The first change in slope, a barrier response, occurred at approximately 200 minutes of elapsed time, corresponding to transmissivity of 1.6 m^2/day at a radius of 29 m. The second change in slope occurred at approximately 400 minutes of elapsed time, which marked a return to a conductive response at a radius of 41 m, corresponding to a transmissivity of 13.8 m^2/day. The third and final change in slope occurred at approximately 2,000 minutes of elapsed time, a return to a less conductive response at a radius of 92 m, corresponding to a transmissivity of 5.1 m^2/day.

Samples were collected from Wells ER-3-3 and ER-4-1 and analyzed for major ions, stable isotopes, and RNs, to be compared with other wells in the vicinity for consistency with the overall trends discerned from the regional geochemistry. Data from ER-3-3 were not included in this review due to indications from the field measured water-quality parameters that well development was not complete. The major-ion results for ER-4-1 plotted on the Piper diagram as a Ca+Mg+Na+K-HCO_3 water, and most closely resembled results from the UE-10j wells, WW-2, ER-6-2, ER-12-3, and UE-2ce WW. Results of the analysis of deuterium and 18-O plotted consistently with the results from other Yucca Flat wells, parallel to the GMWL and LMWL, but with enrichment in 18-O, which indicate typical fractionation trends. Of note, the results of Well ER-4-1 are similar to results from UE-10j-1, WW-2, and UE-1h. Results of the analyses of $\delta^{13}C$ and HCO_3 plot in a region of high alkalinity (HCO_3 as alkalinity) and high relative enrichment in ^{13}C along with Wells ER-3-1, ER-4-1, UE-10j-1 and WW-C. The trends generally indicate that wells along the Yucca Fault are most similar to one another than to wells more proximal to their locations but away from the fault. Additional geochemical analysis of Yucca Flat aqueous geochemistry is in preparation as part of Corrective Action Decision Document/Corrective Action Plan model evaluation in FY 2018.

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Appendix A

Detailed Lithology Logs for Wells ER-3-3 and ER-4-1

Table A-1
Lithologic Log for Well ER-3-3
(Page 1 of 8)

Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
0-505.97 (0-1,660)	505.97 (1,660)	DA	**Alluvium, From 0-120 ft:** Drilled under NSTec supervision; no samples were collected by Navarro. Lithology inferred from surface exposures, collected cuttings below 120 ft bgs, and geophysical logs. **From 120-1,150 ft:** cuttings consist of loose, medium to coarse sand-size fragments of welded and nonwelded tuff, lavas, and minor (2-5%) carbonates (dolomite) and clastics (siltstone). Matrix (overall color): yellow (10YR 7/6) > yellowish brown (10YR 5/6); Most fragments are sub-rounded to rounded with minor flattened pieces. Weakly to moderately reactive with HCl (minor caliche?). **From 1,150-1,420 ft:** Tuffaceous Alluvium, moderately > poorly indurated, caliche coating/matrix; Matrix color: pinkish white (7.5YR 8/2) > brownish yellow (10YR 6/6); Approximately 98% volcanic fragments, (1-2%) carbonate/clastics, and the remainder is caliche and silica? Crystal fragments (loose and in clayey matrix), sanidine, quartz (mostly term., some dipyramidal, minor pink tint), plagioclase, mafics (preserved only in volcanic fragments); 50% coarse sand > gravel size (angular > rounded) and 50% silt/sand-size (ash, loose crystal fragments), strong to moderate reaction with HCl; **From 1,420-1,500 ft:** Tuffaceous Alluvium; Matrix (overall): light brown (7.5YR 6/4) > light yellowish brown (10YR 6/4) > pinkish white (7.5YR 8/2) > light olive brown (2.5Y 5/4); carbonate/clastic fragments <1%, gradually increasing (with depth) caliche/clayey (altered matrix) coating; **From 1,500-1,660 ft:** Tuffaceous Alluvium; carbonate/clastics increasing to between (2-4%); Geophysical logs (GR and SGR) indicate a clear break at 1,660 ft bgs marking the alluvium/bedrock contact, abundant cement fragments from 120-130 ft and no sample from 330-380 ft.	Quaternary/Tertiary Alluvium (QTa)
505.97-585.22 (1,660-1,920)	79.25 (260)	DA	**Nonwelded to Partially Welded Ash-flow Tuff:** crystal-rich, vitric/partially altered; Matrix color: reddish gray (5R 6/1) > reddish gray (2.5YR 6/1) > light gray (5YR 7/1); Phenocrysts: (15-20%), sanidine (mod. chatoyant), quartz (terminated, some dipyramidal, clear, rare pink tint, rare resorbed texture), plagioclase, rare sphene?, Mafics (1%): biotite (black>bronze, unoxidized>oxidized?), rare pyroxene?, oxide (magnetite?); Pumice (7-15%): white (5YR 8/1) > pinkish white (5YR 8/2), vitric > relict vitric texture, some plucked/vapor phase corroded; Lithics (2-5%): welded tuff, light red (10R 7/6) > pale red (7.5YR 7/4), lava? red (7.5YR 5/8), basalt very dark gray (N 3/1) > dark gray (N 4/1); glass shards black (N 2.5/1), minor to moderate contamination from 1,660-1,730 ft.	Timber Mountain Ammonia Tanks Tuff (Tma)

Table A-1
Lithologic Log for Well ER-3-3
(Page 2 of 8)

Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
585.22-594.36 (1,920-1,950)	9.14 (30)	DA	**bedded and reworked tuff:** crystal-rich, vitric/partially altered; Matrix color: reddish yellow (5YR 7/6) > reddish yellow (7.5YR 6/8) > dark gray (7.5YR 4/1) > pinkish white (7.5YR 8/2); Phenocrysts (10-15%): quartz (terminated, rare dipyramidal, mostly clear, rare pink tint), sanidine (mod. chatoyant), plagioclase, Mafics (≤1%): biotite (black>bronze, unoxidized>oxidized), oxides (magnetite); Pumice (≥10%): white (7.5YR 8/1) > pinkish white (2.5YR 8/2), vitric>vapor phase corroded>altered (with relict vitric texture); Lithics (5-7%): welded tuff/lava reddish brown (5YR 5/4) > reddish yellow (5YR 6/6); beds(?) with abundant glass shards and bubbles black (N 2.5/1) > reddish black (2.5YR 2.5/1), very poor recovery over this interval.	Timber Mountain Ammonia Tanks bedded tuff (Tmab)
594.36-621.79 (1,950-2,040)	27.43 (90)	DA	**Nonwelded to Partially Welded Ash-flow Tuff:** crystal-rich, mafic-poor, devitrified, vapor phase mineralized/altered, poorly to mod. indurated; Matrix color: light reddish brown (2.5YR 6/4) > reddish brown (2.5YR 4/4) > light red (10R 7/6) > pale red (10R 7/3); Phenocryst (10-15%?): sanidine (rare chatoyant), quartz (terminated, rare>minor dipyramidal, rare pink tint), plagioclase, Mafics (1%): biotite (black/unoxidized, euhedral), magnetite; Pumice (10-15%): white (7.5YR 8/1) > pinkish white (5YR 8/2), mostly 1-2 mm, relict vitric/vapor phase altered; Lithics: (3-5%?), welded tuff red (2.5YR 5/6) > pale red (2.5YR 7/2); volcanic glass (shards?) black (5YR 2.5/1), contamination (10-20%?) including alluvium and nonwelded/bedded tuff (Tma?).	Timber Mountain Rainier Mesa mafic-poor Tuff (Tmrp)
621.79-664.46 (2,040-2,180)	42.67 (140)	DA	**Partially to Moderately Welded Ash-flow Tuff (Breccia Zone):** crystal-rich, mafic-poor, devitrified, partially altered (silica/limonite), vapor phase mineralized; Matrix color: reddish brown (5YR 5/4) > light reddish brown (5YR 6/4) > pinkish gray (5YR 7/2), ~(10-15%) of cuttings are yellowish red (5YR 5/8 to 4/4) and red (10R 4/6); Phenocrysts (10-15%): sanidine (rare chatoyant), quartz (terminated, rare dipyramidal, rare pink tint), plagioclase, Mafics (≤1%): biotite (black, unoxidized, euhedral>fragments), oxides (magnetite?); Pumice: (10-15%): white (7.5YR 8/1) > pinkish white (5YR 8/2) > light gray (7.5YR 7/1), relict vitric texture, minor to mod. flattening; Lithics (1-3%): welded tuff red (2.5YR 5/6) > pale red (2.5YR 7/2), lava/basalt black (N 2.5/1) > dark reddish gray (5R 3/1); Possible Breccia/Fault zone shows both angular breccia and rounded/ground material cemented, with open space. Open space coated/filled with drussy quartz, limonite(?), and unknown minerals. Contamination varies from (10-20%) possibly higher, mixed alluvium and tuffs. specially noticeable from 2,090-2,180. Casing was set at 2,039 ft.	Timber Mountain Rainier Mesa mafic-poor Tuff (Tmrp)

Table A-1
Lithologic Log for Well ER-3-3
(Page 3 of 8)

Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
664.46-679.70 (2,180-2,230)	15.24 (50)	DA	**Densely Welded Ash-flow Tuff:** crystal-rich, mafic-poor, devitrified, partially altered (silica/limonite), vapor phase mineralized; Description as listed above (from 2,040-2,180 ft); Pumice flattening between 4:1 to 6:1 or greater.	Timber Mountain Rainier Mesa mafic-poor Tuff (Tmrp)
679.70-691.90 (2,230-2,270)	12.19 (40)	DA	**Moderately to Partially Welded Ash-fall Tuff:** crystal-rich, mafic-poor, devitrified, vapor phase mineralized: Matrix color: reddish brown (2.5YR 5/3) > light reddish brown (2.5YR 6/4) > red (2.5YR 5/8); Phenocrysts (10-15%): sanidine (rare chatoyant), quartz (terminated, rare dipyramidal, clear), plagioclase, Mafics (≤1%): biotite (black, unoxidized), oxides (magnetite), trace hornblende(?); Pumice (10-15%): white (10R 8/1) > light gray (5YR 7/1), devitrified/vapor phase altered with relict vitric textures, mostly 1-2 mm - rare to 5 mm; Lithics (3-5%): welded tuff/lava red (2.5YR 5/6) > pale red (2.5YR 7/2); rare/unknown mineral (analcime?) (<1-2%) white (N9) > light pink (10R 8/2) - fracture/void filling?, minor cement contamination (up to 5%?).	Timber Mountain Rainier Mesa mafic-poor Tuff (Tmrp)
691.90-719.33 (2,270-2,360)	27.43 (90)	DA	**Partially to Nonwelded Ash-flow Tuff:** crystal-rich, mafic-poor, devitrified>partially vitric, minor alteration (argillic/zeolitic); Matrix color: light reddish brown (5YR 6/4) > light red (2.5YR 6/6) becoming mottled (2,295-2,360) light red (10R 7/6) > pale red (10R 7/4) and white (7.5YR 8/1) > white (N9) interbedded with pale red (10R 6/3) > light reddish brown (2.5YR 6/4); Phenocrysts (5-15%): sanidine, quartz (term., rare>minor dipyramidal, clear, rare pink tint), plagioclase, Mafics (1%): biotite (black/unoxidized?), Mn oxides, magnetite(?); Pumice (5-15%): light gray (5YR 7/1)>white (10R 8/1)> white (N9) > pink (2.5YR 8/4), mostly 1-2 mm - rare to 5 mm, near base of interval (2,270-2,295) some pumice have glassy core; Lithics (1-5%): welded tuff/lava red (10R 4/6) > weak red (7.5YR 5/4) > weak red (2.5YR 4/2), volcanic glass black (5YR 2.5/1) grading down into black 7.5YR 2.5/1) > black (10G 2.5/1);cement contamination variable (1-5%?).	Timber Mountain Rainier Mesa mafic-poor Tuff (Tmrp)

Table A-1
Lithologic Log for Well ER-3-3
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
719.33-752.86 (2,360-2,470)	33.53 (110)	DA	**bedded tuff and Nonwelded Ash-flow Tuff:** crystal-moderate, vitric>altered (argillic/zeolitic); Matrix color: light brown (7.5YR 6/4) > pink (7.5YR 7/4) > very pale brown (10 YR 8/3) interbedded with white (N9) > white (2.5YR 8/1) porcelainous ash-fall beds; Phenocrysts (5-10%): sanidine, quartz (terminated, dipyramidal, clear), plagioclase, Mafics (<u><</u>0.5%): biotite (black, unoxidized), Mn oxides (spots,?), white ash-fall beds (0%) phenocrysts; Pumice (10-20%): white (N9) > pinkish white (2.5YR 8/2) > pale yellow (2.5Y 8/2) rare, alteration (zeolitic/argillic) increasing with depth; Lithics: (1%), welded tuff/lava red (7.5R 4/8) typically very small (<u><</u>1 mm), volcanic glass black (5YR 2.5/1); One, possibly more, fine (porcelainous) ash beds (weakly silicified), some material appears bedded/reworked and have a higher phenocryst content, distinctive "peppered" appearance from pale matrix with very small black spots.	tuff of Holmes Road (Tmrh)
752.86-771.14 (2,470-2,530)	18.29 (60)	DA/DB4	**bedded and reworked:** crystal-poor, altered (zeolitic/argillic/silicification?); Matrix color: light brown (7.5YR 6/4 to 6/3) > brown (7.5YR 5/3) > reddish brown (7.5YR 6/6); Phenocrysts (3-5%): sanidine, plagioclase, quartz (<1% terminated, rare dipyramidal), Mafics (1%): Mn oxide (spots), biotite (black, unoxidized, euhedral), hornblende (?, greenish black), magnetite (?); Pumice (10-15%): white (N9) > white (2.5Y 8/1) > pale yellow (5Y 8/4), pumice mostly 1-2 mm, some relict vitric texture; Lithics (2-3%): welded tuff/lava red (10R 4/8) > light red (7.5YR 6/6) and rare very dark gray (N 3/1), most lithics <2 mm, volcanic glass black (5GY 2.5/1) - very small (<u><</u>1 mm); some fragments appear to be altered (silica/opal [?]) fine ash beds. Overall, beds weakly to moderately indurated and pervasively altered, many fragments have a waxy to vitreous luster and some relict vitric textures preserved. From 2,460-2,540 ft heavy cement contamination (10-20%) and pyroclastic material from uphole (Tmr?), overall 20-40% contamination.	Pre-Timber Mountain Tuff - Post-Wahmonie Tuff, undivided (Tm/Tw)
771.14-781.81 (2,530-2,565)	10.67 (35)	DA	**Nonwelded Ash-flow Tuff and bedded tuff:** crystal-poor, mafic-rich(?), pervasively altered (zeolitic/argillic); Matrix color (mottled): pale yellow (2.5Y 7/3 to 7/4) > very pale brown (10YR 7/4) with bands/spots of red (7.5R 4/6) > light red (7.5YR 6/6); Phenocrysts (3-5%): sanidine (rare chatoyant), quartz (terminated, rare dipyramidal, clear), Mafics (1-2%): biotite (black, unoxidized, euhedral), pyroxene (?, granular), Mn oxides, magnetite (?); Pumice (10-15%+?): pale yellow (5Y 8/3 to 8/4) > pale yellow (2.5Y 8/2) > red (7.5R 4/6), some relict vitric texture, blocky to flattened (?); Lithics (1-2%): welded tuff/lava red (7.5R 5/6) > pale red (7.5R 6/3) and rare basalt (?) black (N 2.5/1); Overall distinctive appearance with pale yellow mass and red bands/spots. Possible bedding/change noted on geophysical logs (Density, Resistivity, GR, and Caliper).	Pre-Timber Mountain Tuff - Post-Wahmonie Tuff, undivided (Tm/Tw)

Table A-1
Lithologic Log for Well ER-3-3
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
781.81-801.62 (2,565-2,630)	19.81 (65)	DA	**Nonwelded to Partially Welded Ash-flow Tuff:** crystal-rich, mafic-rich (?), altered (vapor phase, quartzo-feldspathic [?]); Matrix (spotted) color: weak red (7.5R 5/4 to 5/3) > pale red (7.5R 6/2 to 6/3) and red (7.5R 4/8 to 5/6) spots and larger patches, by 2,610 ft 50% of sample is dominantly red and by 2,620 ft 70%; Phenocrysts (3-5%): sanidine, quartz (terminated, clear), Mafics (<1-2%): biotite (black>golden, unoxidized euhedral>fragment, books/sheets), magnetite (oxidized), hornblende (?); Pumice (5-10%): white (7.5R 8/1) > light pink (7.5R 8/2) > white (N9), mostly 1-2 mm, blocky>minor flattening, vapor phase corroded cavities many with relict vitric texture; Lithics (1-3%): lava (aphanitic?) very dusky red (7.5R 2.5/2), welded tuff/lava red (7.5R 4/6) > reddish brown (2.5YR 4/4), rare basalt (vesicular) dusky red (7.5R 3/3), vesicle in basalt filled with clusters of black acicular crystals; Rare to minor preserved (altered) ash-shards and bubbles. Hematite (?) coating on surfaces of fragments indicating open space, base picked from strong geophysical log (Density, Resistivity, GR, and Caliper) response, spots (5-25%) increasing downward. Zone of intense oxidation and bleaching, possible fault or breccia zone with some vapor phase corrosion.	Pre-Timber Mountain Tuff - Post-Wahmonie Tuff, undivided (Tm/Tw)
801.62-806.20 (2,630-2,645)	4.57 (15)	DB4	**bedded tuff:** bedded tuff: crystal-poor, mafic-rich, altered (vitric to partially zeolitic, vapor phase; Matrix (mottled - salt & pepper) color: (overall) gray (5YR 5/1), made up of white (7.5YR 8/1) and black (7.5YR 2.5/1) > very dark brown (10YR 2/2); Phenocrysts (5-7%): felsic (plagioclase?), Mafics (2-5%): biotite (black, unoxidized, euhedral>fragment, books/sheets, some biotite has “birds-eye” texture and sooty appearance), hornblende (?, dark grayish green 5G 3/2); Pumice (5-10%): white 5YR 8/1) > gray (5YR 5/1), pumice content uncertain due to poor cuttings; Lithics (<1%): volcanic (?) yellowish brown (10YR 5/6) high uncertainty; Abundant glass shards and partially vitric pumice (very dark brown (10YR 2/2) > black [7.5YR 2.5/1]) possibly up to 20-30%? Zone located primarily based on geophysical logs (Resistivity, Density, and Caliper). Cuttings are not representative of interval (60-70%) contamination?	Wahmonie Formation (Tw)

Table A-1
Lithologic Log for Well ER-3-3
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
806.20-816.86 (2,645-2,680)	10.67 (35)	DA	**bedded tuff and Nonwelded Ash-flow Tuff:** mafic-rich, pervasively altered (zeolitic); Matrix color: pale yellow (5Y 7/3) > pale yellow (5Y 8/2) > very pale brown (10YR 8/3), ash bed (porcelainous) pinkish white (7.5YR 8/2), approximately 5% of sample from 2,670-2,680 ft; Phenocrysts (3-7%): sanidine, plagioclase, quartz (?, trace), Mafics: (1-3%), biotite (black>golden, euhedral/fragment, books/sheets), hornblende (dark grayish green 5G 3/2), magnetite (?); Pumice (5-10%): pale yellow (2.5Y 7/4) > white (5Y 8/1) > pale yellow (5Y 7/4 to 8/3), mostly 1-2 mm, rare relict vitric texture; Lithics: (<1%), volcanic; Small patches (pumice?) of olive yellow (5Y 6/6) sometime appear associated with phenocrysts? Altered/oxidation layer possibly related to pumice?	Tunnel formation, undifferentiated (Tn)
816.86-830.58 (2,680-2,725)	13.72 (45)	DA/DB4	**bedded tuff and Nonwelded Ash-flow Tuff:** crystal-poor, mafic-poor, pumice-rich, pervasively altered (zeolitic), oxidized; Matrix color: dusky red (10R 3/4) > weak red (10R 4/4) > pale red (10R 6/4); Phenocrysts (2-3%): feldspar (sanidine?), Mafics (≤1%): biotite (?, black), magnetite (partially oxidized); Pumice (20-40%): white (N9) > pinkish white (2.5YR 8/2), very small (≤1 mm) and blocky, rare relict vitric texture, vapor phase corroded (?); Lithics: (≤1%): volcanic, basalt (vesicular, trace); Matrix color changes from 2,645-2,725 ft possibly indicate bedding(?), Geophysical Logs (Density, Resistivity, GR, and Caliper) indicate a break, base of Tn.	Tunnel formation, undifferentiated (Tn)

Table A-1
Lithologic Log for Well ER-3-3
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
830.58-859.54 (2,725-2,820)	28.96 (95)	DA/DB4	**bedded tuffs and volcanoclastic sediments: From 2,725-2,790 ft:** crystal-poor, lithic-rich, altered (matrix, argillic); Matrix (bedded tuff) color: white (5Y 8/1) > white (N8) > white (2.5Y 8/1), Matrix (sediments) color: dark reddish brown (2.5YR 3/4) > dark red (2.5YR 3/6) > dark reddish brown (2.5YR 2.5/4); Phenocrysts (bedded tuff) (2-5%): sanidine, plagioclase (?), Mafics (1-2%): biotite (black, euhedral, books), hornblende (?, pyroxene), magnetite (?); Pumice: (20-40%?): white (N9) > light bluish gray (5PB 8/1), very small ($\leq$1 mm) and rarely larger; Lithics: (2-7%+?), volcanic, clastic, and carbonate, distinctive dark greenish gray (5GY 4/1) > dark greenish gray (5G 4/1) to grayish green (5G 5/2) siltstone, alters/oxidizes to a light olive brown (2.5Y 5/4) (rare) and rare red (7.5R 4/6) spots/patches, all lithics have a matrix coating of white or dark reddish brown material; Sediments: interbeded siltstone and sandstone (size) material; Siltstone: very fine grained, fissile/thin bedded, Sandstone: fine sand-size crystal fragments (feldspars) with red (7.5R 4/6) > dusky red (7.5R 3/4) matrix; Lithics (2-5%): clastic (including distinctive siltstone mentioned above), volcanic (?); **From 2,790-2,820 ft:** crystal-poor, lithic-rich, altered (matrix, argillic); Matrix color: dark reddish brown (2.5YR 3/4) > dark red (2.5YR 3/6) > dark reddish brown (2.5YR 2.5/4); Phenocrysts: as above; Lithics (10-20%): carbonates/clastics gray (2.5Y 6/1) > dark olive gray (5Y 3/2) > light gray (2.5Y 7/1), most lithics are coarse sand to gravel size, are subrounded with at least one broken face, and matrix coating on unbroken surfaces.	Older Tunnel Beds (Ton)
859.54-909.83 (2,820-2,985)	50.29 (165)	DA/DB4	**Colluvium and Nonwelded Ash-flow Tuff, minor bedded tuff (?):** altered (argillic): Matrix color: red (2.5YR 5/6) > dark reddish brown (2.5YR 3/4); Colluvium: dominantly carbonate/clastic material (~3-10 mm), gray (2.5Y 6/1) > light gray (2.5Y 7/1), rare quartzite white (N9) and siltstone light gray (5Y 7/2), cemented/incorporated in clay to fine ash (?); fragments are subangular>subrounded; From 2,830-2,900 ft distinct change in cuttings: cuttings are much smaller (~1-4 mm) and palmate to flat chips with sharp edges (typical of drilled/spalled material with no visible matrix material on any fragments. Small rare pieces of clay (?) dark greenish gray (5BG 4/1). Possibly a slide block of Paleozoic material? Samples are heavily contaminated (50%) with volcanics from uphole.	Paleocolluvium/older tuffs (Tlc/To)

Table A-1
Lithologic Log for Well ER-3-3
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Depth Interval m (ft)	**Thickness m (ft)**	**Sample Type** [a]	**Lithologic Description** [b]	**Stratigraphic Unit (map symbol)**
909.83-973.20 (2,985-3,192.9)	63.37 (207.9)	DA	**Dolomite and minor interbedded Limestone:** Matrix color (Dolomite): gray (2.5Y 6/1) > light gray (2.5Y 7/1) > dark olive gray (5Y 3/2), Matrix color (Limestone): gray (N4); Dolomite: recrystallized (fine>medium grain), minor>moderate brecciation(?), veining (calcite?), fracturing, with incipient clay alteration along fractures/bedding planes, rock has weak reaction with HCl when scratched, Limestone is fine grained to micritic with minor to rare pyrite, thin to platty fragments (some larger fragments exhibit conchoidal or horsetail patterns); Approximately 10% of material is composed of brecciated material (rotated (?) clasts supported by fine to coarse grained calcite (or dolomite after calcite), additional fragments appear to be made up of ground material and small clasts with apparent bedding planes, bedding planes have “sooty” bluish black (10B 2.5/1) material (Mn oxide or carbon??) coating portions of open (?) surfaces. Fine to coarse grained pyrite is visible on some of these surfaces and within the matrix. Fragments show moderate to strong reaction with HCl.	Paleozoic rocks (Pz)

[a] Lithologic samples collected from interval during drilling and logging operations and used for lithologic interpretation. **DA** = drill cuttings that represent lithologic character of interval; **DB4** = drill cuttings that are not wholly representative of interval.
[b] 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.

HCl = Hydrochloric acid
unox. = Unoxidized
ox. = Oxidized

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
0-187.45 (0-615)	187.45 (615)	DA	**Alluvium, From 0-120 ft:** Drilled under NSTec supervision; no samples were collected by Navarro. Lithology inferred from surface exposures, collected cuttings below 120 ft bgs, and geophysical logs. **From 120-615:** cuttings consist of loose, medium to coarse sand size fragments of Tertiary Volcanics (Nonwelded to Welded Tuffs, bedded tuffs, and lavas), rare to minor (2-5%) clastics (siltstone) and carbonates (dolomite and limestone), and loose felsic (sanidine, plagioclase, quartz) crystal fragments. Interbedded(?) zones with clay/caliche coatings, Moderate > Strong reaction with HCl, mostly subangular > sub-rounded followed by angular/platty. Fine silt and ash washed away during drilling/processing. From 610-620, cuttings are heavily contaminated (DB4).	Quaternary/Tertiary Alluvium (QTa)
187.45-207.26 (615-680)	19.81 (65)	DB4/DA	**Nonwelded to Partially Welded Ash-flow Tuff:** crystal-rich, vitric; Matrix color: light reddish brown (2.5YR 6/3) > light reddish brown (5YR 6/3) grading into dominantly pink (7.5YR 7/4); Phenocrysts: (15-30%), sanidine (common chatoyant), quartz (terminated, dipyramidal, clear), plagioclase, sphene (rare>minor?), Mafics (1%): biotite (black, unox), magnetite; Pumice: Percentage uncertain due to drilling/cuttings collection, pink (7.5YR 7/4), vitric; Lithics (1-2%): welded tuff/lava, high uncertainty due to contamination from alluvium; heavy contamination (70-80%) from 620-650 and from 650-680 contamination significant (40-60%). Geophysical logs (GR, Density, Resistivity) used to determine location of contact.	Timber Mountain Ammonia Tanks Tuff (Tma)
207.26-231.65 (680-760)	24.38 (80)	DB4/DA	**bedded and reworked tuff:** crystal-rich, pumice-rich, vitric; Matrix color: pinkish gray (7.5YR 6/2) > brown (7.5YR 5/3); Phenocrysts (15-30%): sanidine (chatoyant), quartz (terminated, dipyramidal, mostly clear), plagioclase, sphene(?), Mafics (1-2%): biotite (black, unox), magnetite (unox.>partially ox.), pyroxene(?); Pumice (5>10%): white (N9) > light gray (N 7/1) > mottled light gray (N 7/1) and weak red (2.5YR 4/2) > mottled light gray (N 7/1), brown (7.5YR 4/2) and black (N 2.5), vitric, fibrous > tubular texture, some white pumice have vitreous > pearlescent surface; Lithics (1-2%): welded tuff/lava and volcanic glass black (N 2.5/1); cuttings are (40-50%) contamination and are not entirely representative of interval, from 730-744 abundant loose felsic crystal fragments, from 740-760 appears to be a reworked bed.	Timber Mountain Ammonia Tanks bedded tuff (Tmab)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
231.65-249.94 (760-820)	18.29 (60)	DA	**Nonwelded to Moderately Welded Ash-flow Tuff:** crystal-rich, mafic-rich, devitrified, vapor phase alteration; Matrix color: light brown (7.5YR 6/4) grading into reddish brown (2.5YR 5/3) > weak red (10R 5/3) > pale red (10R 6/2); Phenocryst (15-20%?): sanidine (minor chatoyant), quartz (terminated, dipyramidal, clear), plagioclase, Mafics (1≤2%): biotite (black, euhedral/fragments, unox.), magnetite (?), rare pyroxene (?, greenish black); Pumice (10-15%): light red (2.5YR 7/6) > pale red (10R 6/2) > pinkish white (10R 8/2) and white (N8-N9) > pink (7.5YR 8/3), relict vitric texture > partially vitric, some vapor phase corroded; Lithics: (1%?), welded tuff/lava, volcanic glass black (N 2.5), small 1-2 mm or smaller; pumice flattening increasing with depth, mafic content varies widely.	Timber Mountain Rainier Mesa mafic-rich Tuff (Tmrr)
249.94-252.98 (820-830)	3.05 (10)	DA	**Moderately to Densely Welded Ash-flow Tuff:** crystal-rich, mafic-rich, devitrified > partially vitric; Matrix color: pinkish gray (5YR 6/2) > reddish gray (5YR 5/2) grading into light reddish brown (5YR 6/3) > reddish brown (5YR 5/3) with black (N 2.5) vitric portions (fiamme?); Phenocrysts (10-25%): sanidine (minor chatoyant), quartz (terminated, rare dipyramidal, clear), plagioclase, Mafics (1-3%): biotite (black, unox., euhedral books > fragments), pyroxene (greenish black (10GY 2.5/1); Pumice: (10-15%): pink (7.5YR 8/3) > reddish yellow (7.5YR 7/6) and white (N8-N9), vapor phase corroded/altered, flattened, rare relict vitric texture; Lithics (<1%): welded tuff/lava.	Timber Mountain Rainier Mesa mafic-rich Tuff (Tmrr)
252.98-268.22 (830-880)	15.24 (50)	DA	**Densely Welded Ash-flow Tuff (vitrophyre):** crystal-rich, mafic-rich, vitric; Matrix color: very dark gray (5Y 3/1) > black (N 2.5) > very dark gray (10YR 3/1); Phenocrysts (15-25%): sanidine, quartz (terminated, dipyramidal, clear), plagioclase, Mafics (2-3%): biotite (black, euhedral books/fragments, unox.), magnetite, pyroxene (?); Pumice (?): possible pumice - small (1 mm?) gray (10YR 5/1), actual percentage indeterminate in vitric - densely welded section; Lithics (1-3%): welded tuff/lava, sand size (1-≤2 mm); very minor incipient crystallization (devitrification) beginning at ~860 and increasing with depth.	Timber Mountain Rainier Mesa mafic-rich Tuff (Tmrr)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
268.22-271.27 (880-890)	3.05 (10)	DA	**Densely to Moderately Welded Ash-flow Tuff:** crystal-rich, mafic-rich, partially vitric > devitrified; Matrix color: weak red (2.5YR 5/2) > reddish brown (2.5YR 5/3); Phenocrysts (7-15%): sanidine (minor chatoyant), quartz (terminated, minor dipyramidal, clear), plagioclase, Mafics (2%): biotite (black, euhedral/fragments, unox.), oxides (magnetite?); Pumice (10-15%): pinkish white (5YR 8/2), rare red (2.5YR 5/6) and light reddish gray (2.5YR 7/1), vapor phase corroded, some vapor phase alteration/mineralization, increasing vitric texture from 890 ft down; Lithics (1-2%): welded tuff; contamination (20-30%), primarily from the vitrophyre, Geophysical log (Density) primary basis used to determine zone.	Timber Mountain Rainier Mesa mafic-rich Tuff (Tmrr)
271.27-289.56 (890-950)	18.29 (60)	DA/DB4 > DA	**Moderately to Partially Welded Ash-flow Tuff:** mafic-poor, partially vitric > devitrified, vapor phase altered/mineralized; Matrix color: light reddish brown (2.5YR 6/3-6/4) > reddish brown (2.5YR 5/4); Phenocrysts (5-10%): sanidine, quartz (terminated, rare dipyramidal, clear), plagioclase, Mafics (1%): biotite (black, fragments-very small, unox.), magnetite(?); Pumice (10-15%): pinkish white (5YR 8/2) > light reddish brown (2.5YR 6/3), rarely white (N8), vitric to vapor phase corroded/mineralized, rare dark reddish brown (5YR 3/3) coating on some pumice, pumice 2-5 mm (ave. ~2-3 mm); Lithics (≤1%): volcanic(?), ≤1 mm; from 890-950 abundant loose felsic crystal fragments (possibly contamination from above?), contamination variable (40-10%) - mostly from vitrophyre, rare botryoidal silica (≤1%) from 910-950, zone determined from pumice flattening and Geophysical log (Density).	Timber Mountain Rainier Mesa mafic-poor Tuff (Tmrp)
289.56-353.57 (950-1,160)	64.01 (210)	DA > DA/DB4	**Partially to Nonwelded Ash-flow Tuff with minor bedded tuff:** mafic-poor, vitric > partially devitrified; **From 950-1,100:** Matrix color: (as in 890-950 above); Phenocrysts: (as in 890-950 above); Pumice: (as in 890-950 above), except pumice from 2-10 mm (average ~4-5 mm); Lithics: (as in 890-950 above); common shard casts, dark reddish brown (5YR 3/3) > black (N 2.5) glass shards and fragments, from 1,000-1,040 strongly altered zone (possible paleosol?), Matrix color: mottled dark red (10R 3/6) and red (7.5R 4/8) with reddish yellow (5YR 7/6) spots on a base that ranges from pale red (10R 7/4) > pale red (10R 6/2); **From 1,100-1,160:** Nonwelded Ash-flow Tuff to bedded tuff: vitric; Matrix color: reddish brown (5YR 5/3) > dark reddish gray (5YR 4/2); Phenocrysts (5-10%): sanidine, quartz (terminated, dipyramidal, clear), plagioclase(?), Mafics (1-≤2%): biotite (black, fragments); Pumice 10-15%): white (5YR 8/1) > white (N 8); Lithics (2-3%): welded tuff/lava weak red (7.5R 5/3) > dusky red (7.5R 3/2); contamination (20-40%) from Nonwelded Tmrp.	Timber Mountain Rainier Mesa mafic-poor Tuff (Tmrp)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
353.57-385.57 (1,160-1,265)	32.00 (105)	DA/DB4 > DA	**bedded tuff and Nonwelded Ash-flow Tuff:** pumice-rich, vitric; **From 1,160-1,205:** bedded tuff: vitric, pumice-rich, moderately indurated; Matrix color: reddish brown (2.5YR 5/3) > light reddish brown (2.5YR 6/4) grading down to > light reddish brown (5YR 6/3) > light gray (10YR 7/2), distinctive mottled appearance with white pumice; Phenocrysts (7-10%): sanidine (very rare chatoyant), quartz (terminated, clear), plagioclase(?), Mafics (≤1%): biotite (black, fragments, unox.), Mn oxides (spots,?), trace pyroxene(?); Pumice (15-30%): white (N9-N8) > very pale brown (10YR 8/2), vitric, fibrous/tubular (woody) texture, some vapor phase corrosion, very small to larger (≤1-10 mm) pumice; Lithics: (1-3%), welded tuff/lava very dusky red (5R 2.5/3) > reddish black (7.5R 2.5/1) > black (N 2.5), distinctive due to larger size (2-4 mm), most lithics very fine sand size (≤1 mm), welded tuff/lava light red (7.5R 6/6) > red (10R 5/6), volcanic glass (shards, bubble fragments), very fine (≤1 mm) black (N 2.5/1) > dark reddish brown (5YR 3/3); contamination (20-30%) from 1,160-1,180 decreasing with depth. **From 1,205-1,265:** Nonwelded Ash-flow Tuff: vitric, crystal-moderate, mafic-rich, moderately indurated; Matrix color: very pale brown (10YR 8/3-8/2) > pale yellow (2.5Y 8/2), distinctive "peppered" appearance; Phenocrysts (5-10%): sanidine, quartz (terminated, trace dipyramidal, clear), Mafics (2-3%): biotite (black, euhedral/fragments(?), unox., typically ≤1 mm rarely to 2 mm), Mn oxide (spots and granular clumps); Pumice (20-30%): very pale brown (10YR 8/4), reddish yellow (7.5YR 8/6), reddish yellow (5YR 7/6), and yellowish red (5YR 5/6), relict pumice mostly removed by vapor phase corrosion, ~30-40% of pumice show incipient alteration rims, commonly vapor phase corroded, typically 1-3 mm; Lithics (1-2%): welded tuff/lava weak red (10R 5/2), very dusky red (10R 2.5/2), and black (N 2.5/1), from 1,250-1,265 slight increase in abundance to 3-5% and size from 2-4 mm.	tuff of Holmes Road (Tmrh)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
385.57-475.49 (1,265-1,560)	89.92 (295)	DA/DB4	**bedded and reworked:** crystal-moderate to crystal-poor, altered (zeolitic) > partially vitric, moderately to poorly indurated; **From 1,265-1,470:** bedded and reworked tuff (interbedded), crystal-poor to moderate, altered (zeolitic) > partially vitric; Matrix color: brown (7.5YR 5/3) > reddish brown (5YR 5/3) grading to light brown (7.5YR 6/3) > brown (7.5YR 5/4) > pale brown (10YR 6/3); Phenocrysts (3-7%): sanidine, plagioclase, quartz (trace), very rare sphene(?), trace apatite (??, yellow 5Y 7/8), Mafics (≤1-2%): biotite (black, euhedral/fragments, unox.>ox.), Mn oxide (spots, dendrites), hornblende (?, greenish black), magnetite (?); Pumice (10-15%): white (N9) > pinkish white (7.5Y 8/2) > pale yellow (5Y 8/2-8/3), pumice mostly ≤1-3 mm, altered (zeolitic), relict vitric texture (minor), some vapor phase corroded; Lithics (1-3%): welded tuff/lava weak red (7.5R 5/4) > dusky red (7.5R 3/4) and minor light gray (10R 7/1) > reddish gray (10R 6/1), most ≤1 mm occasionally 3 mm+, many loose with little to no matrix, lithics with no matrix may be contamination from above, possible lithic-rich (10-15%) zones from 1,340-1,360(?) and 1,440-1,470(?); contamination from uphole (primarily Tmrh) varies from (15-30%), rare fragments with bluish white (5B 9/1) silica on matrix. **From 1,470-1,560:** bedded tuff: crystal-poor, altered (zeolitic, pervasive), moderately well indurated; Matrix color: very pale brown (10YR 8/3 -8/4) > pale yellow (2.5Y 8/2) > very pale brown (10YR 7/3); Phenocrysts (2-5%): sanidine, plagioclase, trace quartz, trace sphene(?), Mafics (1-2%): biotite (black/brown, euhedral/fragments, unox.>ox.), Mn oxide (spots), hornblende(?); Pumice (5-15%): white (5Y 8/1), pale yellow (5Y 8/3 -8/4), very pale brown (10Y 8/2), typically <1-4 mm+, some rare silicification(?) around pumice; Lithics (2-5%): welded tuffs/lava dark reddish gray (10R 3/1) > dusky red (10R 3/3) > reddish gray (10R 5/1), very fine sand size lithics pale red (7.5R 6/4), lithics are in matrix or have matrix coating, larger lithics may be in zones where fine (pale red) lithics appear evenly distributed in matrix; contamination most significant from 1,470-1,480 (30-40%).	Pre-Timber Mountain Tuff - Post Wahmonie Tuff, undivided (Tm/Tw)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
475.49-481.58 (1,560-1,580)	6.10 (20)	DB4	**bedded tuff:** crystal-rich, mafic-rich, altered (zeolitic/argillic) > partially vitric(?); Matrix color (mottled): pale yellow (2.5Y 7/3 to 7/4) > pale yellow (2.5Y 8/3-8/4) > light gray (2.5YR 7/2) > light brownish gray (2.5Y 6/2); Phenocrysts (7-15%): sanidine, plagioclase (?), quartz (rare), Mafics (3-7%): biotite (black/golden, euhedral/fragments, unox.>ox.), hornblende, magnetite (?), phenocrysts sometimes concentrated in matrix fragments - possibly reworked bed(?) interbedded with pumice-rich beds, strong brown (7.5YR 5/8) stains appear to be associated with some magnetite grains; Pumice (3-15%): pale yellow (2.5Y 8/2-8/3), white (N9), pink (7.5YR 8/3), pumice ≤1 mm, rarely to 2-3 mm(?), some pumice-rich fragments swell and crumble when wet; Lithics (1-2%): welded tuff/lava reddish gray (7.5R 6/1), very fine sand size (≤1 mm); significant contamination (40-50%), cuttings not representative of interval, Geophysical logs (GR, SGR, Density, and Resistivity) used to determine contacts.	Wahmonie Formation (Tw)
481.58-516.64 (1,580-1,695)	35.05 (115)	DA	**Nonwelded Ash-flow Tuff and bedded tuff:** mafic-rich, altered (zeolitic); Matrix color: very pale brown (10YR 7/4) > brown (10YR 5/3), light reddish brown (2.5YR 6/4) > grayish brown (2.5Y 5/2) > white (2.5Y 8/1), distinctive “peppered” appearance; Phenocrysts (5-7%): sanidine, plagioclase, rare quartz, Mafics (3-5%?): hornblende (greenish black), biotite (black>bronze, euhedral/fragment., unox.>ox.), magnetite (ox.); Pumice (3-7%): white (N9) > white (7.5YR 8/1) > pale brown (10YR 8/2) > pinkish white (7.5YR 8/2), pumice very small (≤1 mm); Lithics (3-7%): welded tuff/lava, fine > very fine (1-2 mm?) rarely larger (4 mm+); possible significant contamination from 1,580-1,590 and 1,670-1,695.	Crater Flat Group, undivided (Tc)
516.64-550.16 (1,695-1,805)	33.53 (110)	DB4/DA > DA	**bedded tuff:** crystal-poor, altered (zeolitic, pervasive); Matrix color: pale yellow (5Y 8/4) > pale yellow (2.5Y 8/3) and light olive brown (2.5Y 5/4) > yellowish brown (10YR 5/4); Phenocrysts (1-3%): sanidine, plagioclase(?), Mafics (none noted): Mn oxide (spots, dendrites); Pumice (10-15%): olive yellow (2.5Y 6/6), pale yellow (2.5Y 7/4), rare yellow (5Y 8/6), some pumice show signs of vapor phase corrosion, mostly sub-rounded; Lithics (2-5%?): welded tuff/lava dark reddish brown (5YR 2.5/2), dusky red (7.5R 3/4), black (N 2.5/1), rare weak red (7.5R 5/4) - typically very small (≤1 mm), other lithics from 2-5 mm, possible lithic-rich intervals from 1,760-1,775 and 1,795-1,805; contamination (20-30%) from 1,695-1,740 ft bgs decreasing to (20%) or less by 1,805.	Grouse Canyon bedded tuff (Tbgb)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
550.16-600.46 (1,805-1,970)	50.29 (165)	DB4 > DA	**bedded tuff and Nonwelded Ash-flow Tuff:** crystal-poor, altered (zeolitic/argillic) > devitrified(?); Matrix color (mottled/banded?): pale brown (10YR 6/3) > very pale brown (10YR 7/3) and light brown (7.5YR 6/3) > pinkish gray (7.5YR 6/2) interbedded with red (10R 4/6-5/6) > dark red (10R 3/6); Phenocrysts (3-7%): sanidine, quartz (rare>minor), Mafics: (<1-2%), biotite (black>golden, euhedral/fragments., unox.>partially ox.), pyroxene, magnetite; Pumice (10-30%): white (7.5YR 8/1) > pinkish white (2.5YR 8/1) > pink (2.5YR 8/3) > pale yellow (5Y 8/3) > yellow (2.5Y 8/6), pumice typically 1-2 mm, rarely 3 mm+, translucent/waxy appearance; Lithics: (1-3%), welded tuff/lava dusky red (10R 3/4) > weak red (10R 4/3) > pale red (10R 6/4), mostly <1 mm some 2-3 mm, lithic percentage and description only included lithics in matrix or having a matrix coating; significant contamination (40-60%) from 1,805-1,840 ft bgs decreasing to <20%, second zone of significant contamination from 1,920-1,930.	Tunnel Formation, Member 4, undifferentiated (Tn4)
600.46-667.51 (1,970-2,190)	67.06 (220)	DA	**bedded tuff and Nonwelded Ash-flow Tuff:** crystal-poor, altered (zeolitic/argillic) > devitrified(?); Matrix color (mottled): red (10R 4/6) > dark red (10R 3/6) > reddish brown (2.5YR 5/4) and pale yellow (2.5Y 8/2) > very pale brown (10YR 7/4), white (2.5YR 8/1), possibly beds with differing color/alteration; Phenocrysts (3-7%): sanidine, plagioclase, quartz (rare), Mafics (≤1%): pyroxene(?), magnetite, biotite (?, very rare); Pumice (5-30%): white (5Y 8/1) > pinkish white (2.5YR 8/2) > red (7.5R 5/8), from ~2,030 becoming dominantly pale yellow (5Y 8/2-8/4) and rare yellow (5Y 8/6), some pumice have distinctive Mn oxide clots, size varies from ≤1-5 mm+, some relict vitric texture; Lithics: (3-7%): welded tuff/lava very dusky red (7.5R 2.5/3), black (N 2.5/1), reddish gray (2.5YR 6/1), size ranges from ≤1-3 mm+; rare molds of glass shards, contamination (15-30%).	Tunnel Formation, Member 3, undifferentiated (Tn3)
667.51-694.94 (2,190-2,280)	27.43 (90)	DA	**bedded tuff:** crystal-poor, altered (zeolitic/argillic), moderately to poorly indurated; Matrix color: dark red (10R 3/6) > red (7.5R 2.5/2) > red (7.5R 5/6); Phenocrysts (3-7%): sanidine, quartz, plagioclase(?), Mafics (≤1%): biotite (?, very small/fine, black, fragments), pyroxene(?), magnetite; Pumice (5-20%): pinkish white (10R 8/2) > light red (7.5R 7/6), white (7.5R 8/1), pumice typically very small (≤1 mm, rarely 2 mm+: Lithics (1-3%): welded tuff/lava very dusky red (7.5R 2.5/2), black (N 2.5/1), and light red (7.5R 6/6); bed has distinctive color and sandy (very fine) texture with rare silty (ash?) layers, from 2,230-2,280 appearance of alternating dusky red and light red layers.	Tunnel Formation, Member 3, bed A (Tn3A)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
694.94-749.81 (2,280-2,460)	54.86 (180)	DA/DB4	**bedded tuffs and Nonwelded Ash-flow Tuff:** crystal-poor, pumice-rich, altered (zeolitic/argillic); Matrix color (mottled): red (2.5YR 5/8) > reddish brown (2.5YR 5/4) and pink (5YR 7/4) > pale yellow (2.5Y 8/3); Phenocrysts (5-7%): sanidine, plagioclase, quartz, Mafics (<1-2%): biotite (pale brown>bronze), hornblende(?); Pumice: (10-20%): white (N9) to variegated white (N9) and red (2.5YR 5/8) with rare yellow (5Y 7/8), some relict vitric texture; Lithics: (1-3%): lava/welded tuff, rare clastic(?); significant contamination from uphole and within unit.	tunnel bed2 (Ton2)
749.81-832.10 (2,460-2,730)	82.30 (270)	DB4	**bedded tuff and Nonwelded Ash-flow Tuff:** crystal-poor, pumice-rich, mafic-poor, altered (zeolitic/argillic), poorly indurated; Matrix color: reddish brown (2.5YR 5/4-4/4) > light reddish brown (2.5YR 7/4); Phenocrysts (1-3%): sanidine, plagioclase(?), Mafics (≤1% - trace): biotite(?) (fragments); Pumice (15%): very pale brown (10YR 8/2) and white (N9-N8), variably altered (zeolitic/argillic); Lithics (≤1%): welded tuff/lava(?); from 2,470-2,560, ~10% of sample is a silicified(?) crystal-rich tuff, significant contamination, difficult to distinguish Ton1 from Ton2, hole experienced sloughing/fill related issues, Geophysical log (run down to ~2,510) used to determine contact between Ton2 - Ton1, from 2,700-2,730, ~10-20% contamination with cement.	tunnel bed1 (Ton1)
832.10-858.93 (2,730-2,818)	26.82 (88)	DB4 > DA/DB4	**Paleocolluvium, bedded tuff, and tuffaceous sediments (Interbedded):** altered (argillic): **From 2,730-2,790:** Matrix (clay) color: red (10R 5/6) > reddish brown (2.5YR 5/4) and minor pink (10R 8/3); Colluvium: fragments of altered tuff light red (10R 7/6) > pinkish white (5YR 8/2) > very pale brown (10YR 8/2), carbonates light bluish gray (10B 7/1) > gray (7.5YR 5/1), and loose felsic crystal fragments: crystal fragments are euhedral > subrounded and frosted to clear; contamination is ~(60-80%?), cuttings are not wholly representative of the interval. **From 2,790-2,810:** bedded tuff and Nonwelded Ash-flow Tuff(?): altered (argillic, pervasive); Matrix color: pale red (10R 6/4) > weak red (10R 5/4) > red (2.5YR 5/6); Phenocrysts (5-10%): sanidine. plagioclase(?), Mafics (<1%): biotite (black>golden, euhedral/fragments), thin ash beds with no phenocrysts; Pumice (10-20%): white (N9) > pinkish white (2.5YR 8/2), pervasive alteration, rare relict vitric texture; Lithics (≤1%): welded tuff/lava pale red (7.5R 6/3) rare dark reddish gray (7.5R 4/1); contamination (10-20%) mostly volcanics from uphole. **From 2,810-2,818:** Paleocolluvium, bedded tuff, and tuffaceous sediments: Paleocolluvium: fragments of altered tuffs, carbonates, and loose felsic crystal fragments: Colors and description as in 2,730-2,790 description; contamination (20-40%) or which 10-20% is cement/float shoe fragments, samples may not be representative of interval.	Paleocolluvium/older tuffs (Tlc/To)

Table A-2
Lithologic Log for Well ER-4-1
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Depth Interval m (ft)	Thickness m (ft)	Sample Type [a]	Lithologic Description [b]	Stratigraphic Unit (map symbol)
858.93-925.13 (2,818-3,035)	66.14 (217)	DA	**Limestone:** fine > medium grained, minor alteration and recrystallization: **From 2,818-2,890:** Interbedded Limestones: (1) massive to thick bedded limestone: Matrix color: black (N 2.5) > very dark gray (N 3); fine > medium grained, minor argillic/hematitic alteration along fractures, minor fracturing, calcite mineralization and rare pyrite: (2) very thin bedded/laminated limestone: Matrix color: gray (7.5YR 5/1-6/1) > pinkish gray (7.5YR 6/2); very fine grained > micritic, limonite staining along bedding/laminations, laminations ~1 mm to thicker beds(?); all fragments show moderate to strong reaction with HCl; cuttings show 2 major size groupings (~1-3 mm and ~5-15 mm+); contamination varies from 40% and decreasing to 20% around 2,280 and returning to ~40% at 2,290. **From 2,890-2,940:** Limestone and Limestone/Breccia: Matrix color (Limestone): gray (7.5YR 5/1) > light gray (7.5YR 7/1) with dark grayish brown (10YR 4/2) > dark grayish brown (2.5Y 4/2) > dark gray (2.5Y 4/1); Matrix color (Limestone/Breccia): brownish yellow (10YR 6/6) > yellowish brown (10YR 5/8) > pale yellow (2.5Y 7/3) and light gray (10YR 7/1) > gray (10YR 6/1); fine grained > recrystalized, minor veins with calcite mineralization, spary/coarse calcite fragments, limonite and hematite staining and mineralization (including open space filling, gouge?), very rare chalcedony; contamination varies from 60-20% (mixture of limestone and volcanics), cuttings decreasing in size with increasing depth, possible fault/breccia zone from 2,900-2,940. **From 2,940-3,035:** contamination (80-90%) primarily volcanics from above, material appears to be re-drilled cuttings,90% of cuttings are <2 mm in size.	Paleozoic (undivided) (Pz)

[a] Lithologic samples collected from interval during drilling and logging operations and used for lithologic interpretation. **DA** = drill cuttings that represent lithologic character of interval; **DB4** = drill cuttings that are not wholly representative of interval.

[b] 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.

Appendix B

Descriptions of Measurement Equipment Used and Submersible Pump Performance Curves

B.1.0 DESCRIPTIONS OF MEASUREMENT EQUIPMENT USED AND SUBMERSIBLE PUMP PERFORMANCE CURVES

This appendix contains descriptions of the measurement equipment used for collecting the WDT data in this report. In addition, the performance curves for the submersible pumps used for WDT activities at Wells ER-3-3 and ER-4-1 are provided.

B.1.1 Measurement Equipment

In addition to the description of the measurement equipment, this appendix also provides basic information about the methods used to process the data to create the graphs presented in this report.

B.1.2 DTW Measurements

DTW measurements are made with a calibrated e-tape equipped with a conductivity sensor. Incidental DTW measurements may also be recorded with instruments such as PXDs and other downhole logging tools run on wirelines.

DTW measurements (Section 3.3) were primarily made during the installation and removal of PXDs using calibrated e-tapes. DTW can also be reported on other logs such as water-chemistry parameter/temperature logs and flow logs; however, these other measurements do not provide the same degree of accuracy as the calibrated e-tapes. Formal measurements with e-tapes were made in accordance with the Navarro *Field Instruction for Underground Test Area Activity Well Development, Hydraulic Testing, and Groundwater Sampling* (N-I, 2012). These measurements were reported on the UGTA Depth-to-Water-Level Data Forms and Pressure Transducer Data Forms. The following subsection describes the e-tape and wirelines used by Navarro.

B.1.2.1 Solinst E-Tapes

Navarro uses Solinst e-tapes of varying lengths for DTW measurements. The specific e-tape used for a measurement is selected according to the best fit for the specific need. The equipment number of the e-tape used is recorded on the UGTA Depth-to-Water-Level Data Forms. The e-tapes are calibrated every two years against a reference steel tape maintained by USGS, and a calibration factor is determined to correct all measurements to a common reference for comparability.

B.1.3 Wirelines

Navarro has a variety of Comprobe, Mt. Sopris, and Century wireline winch units with varying cable lengths that are used to install PXDs and to run depth-discrete bailers downhole. Depth measurement is provided by a cable-length measurement wheel/counter mechanism. Although the wireline measurements are not calibrated, they do provide a good approximation of depth.

B.1.4 Barometers

Barometric pressure at Wells ER-3-3 and ER-4-1 was measured using Viasala PTB110 barometers. The barometers are housed with the datalogger near the wellhead in a weatherproof enclosure that is vented to the atmosphere. The pressure sensor outputs an analog millivolt signal and is accurate to ± 0.3 hectopascal at 20 ºC. The barometer is used to take a single barometric pressure measurement when formal DTW measurements are taken. When PXDs are used in the wells to monitor total pressure below the water level, a pressure reading from the barometer at the wellhead is recorded each time a PXD pressure reading is recorded. The barometers are factory-calibrated every two years.

B.1.5 Pressure Transducers

INW Model PT12 PXDs were used below the water level for automated recording of total pressure in wells and the groundwater temperature at the PXD. The INW PT12 PXDs are digital with a static accuracy of ± 0.06 percent of full-scale pressure. The PXDs are factory-calibrated every two years. The pressure values are absolute (as psia). The groundwater temperature, as monitored by the PXD, is recorded in degrees ºC with an accuracy of ± 0.5 ºC.

B.1.5.1 PXD Installation and Removal Procedures

PXD installations in a piezometer or main well completion are preceded by a DTW measurement with a calibrated e-tape. The DTW is measured, referenced to the ground surface, and recorded on a DTW data form. During PXD installations, depths and corresponding PXD pressures and temperatures are recorded at five stations on a PXD data form. The first station measurement is taken in the air just above the measured water surface, and the fifth station measurement is taken at or near the final PXD set depth. The remaining three-station measurements are taken below the measured water surface and are roughly equally spaced between the measured water surface and the final PXD depth. During PXD removal, the order of measurement is reversed. Depths are recorded from the wireline counter installed on the PXD cable reel and referenced to the top of the casing. These measurements are used to check the linearity of the PXD response and to calculate a density conversion factor for the water column above the PXD. Once the PXD is removed, the DTW is measured and recorded.

The PXD installation depth is calculated using the DTW measurement and the PXD pressure at the installation depth attributable to water pressure. The PXD pressure at the set depth minus the PXD pressure in the air above the water surface is multiplied by the density conversion factor for groundwater at the temperature as measured by the PXD to give the PXD depth below the SWL. The PXD depth below SWL is then added to the measured DTW to determine the PXD installation depth. The installation depth of the PXD is verified by calculating the removal depth. When water levels and water temperature are relatively stable, there is generally good agreement between the calculated installation depth and calculated removal depth.

B.1.6 Production Flowmeter

The production rate at Wells ER-3-3 and ER-4-1 was measured using a Foxboro IMT25 Transmitter and Foxboro 8004A Magnetic Flow Tube (4 in.). The meter uses a pulse signal to transmit production rate data to a datalogger and a 4-20 analog signal to transmit production rate data to the VSC. The meter is accurate to 0.25 percent of the flow rate being measured at flow velocities greater than or equal to 2.0 feet per second. The meter is factory-calibrated every two years.

B.1.7 Water-Chemistry Instrumentation

Measurement of temperature, pH, DO, SEC, and turbidity of grab samples was accomplished using a Hydrolab Quanta Multiprobe. A Horiba F-53 pH/ION Meter (pH + bromide) was used to measure bromide in the grab samples. Water-chemistry parameters (pH, DO, SEC, temperature, and turbidity) were also measured continuously on a side stream from the wellhead discharge using a Hydrolab Quanta Multiprobe with a flow-through cell. Flow rate to the flow-through cell was controlled in the range of 1 to 3 gpm and was measured using an appropriately sized Kobold flowmeter.

B.1.8 Datalogger and Data Collection

Campbell Scientific CR1000 dataloggers were used for recording data (e.g., PXD pressure data, groundwater temperature, barometric pressure, and flow rates). The CR1000 is a fully programmable datalogger that uses digital communication (e.g., RS-485, SDI-12 protocol) with digital sensors or makes analog measurements (precision voltage measurement, pulse counter) for analog sensors. The analog sensors measure voltage across a precision resistor. The dataloggers are powered by external, deep-cycle batteries that are typically recharged using solar cells. The data collected are referenced to a specific date and time.

To avoid excessive data collection by the dataloggers, two programming protocols were used. The first protocol stored PXD data on a fixed time interval for all parameters. The second protocol was applied to the PXD and was driven by the amount of pressure change measured. When pressure changes were occurring rapidly, such as at times of initial drawdown or recovery, triggers set in the datalogger by Navarro field personnel initiated the collection of data at rapid intervals. When pressure changes were not changing rapidly, triggers set in the datalogger signaled the datalogger to decrease the frequency of sampling. Field personnel determined data-collection intervals based on the amount of pressure change observed during monitoring and based on the noise level experienced with preceding PXD measurements. Each data record includes the trigger number.

B.1.9 Datalogger Data Presentation

The datalogger data were imported into Microsoft Excel spreadsheets for review and processing. The following data presentation conventions were used:

- Time for data collected by CR1000 dataloggers is in calendar day, hours:minutes:seconds. This format is compatible with Microsoft Excel time formats.
- The WDT operations time data were collected in Pacific Standard Time (PST).
- The LTWLM time data were collected in PST.
- The graphs illustrate data collection timelines and present the gross features of the monitoring and testing data. Detailed evaluation of the data is supported through the inclusion of the raw data files.

- The PXD data are initially presented as the pressure recorded by the datalogger corresponding to the raw data in the data files. These data may be processed to various measures of head or head change (e.g., feet or meters) using density-conversion factors.
- The PXD pressure measurements are reported as psia.
- Barometric pressure was measured as absolute pressure in mBar. The barometric data are shown on graphs in units of mBar and scaled to the corresponding PXD pressure. The conversion was made using 1 mBar = 0.0145037738 psi. The accompanying digital versatile disc (DVD) includes the original data files with barometric pressure in mBar.

Due to changing temperature with depth and/or differences in water quality with depth, the water density varies with time (changing temperature distribution) and depth in the water column. The data on water density in this report are presented in terms of the conversion factor for pressure in psi to the vertical height of the water column in feet. The density conversion factors were computed for the water column above the PXD using installation calibration information.

B.1.10 Downhole Logging and Data Presentation

The distribution of various parameters (i.e., temperature, pressure, and water chemistry) with depth was logged using an Idronaut I-CHEM probe downhole tool. The Idronaut tool was run in the piezometer at ER-3-3 and in the main completion at ER-4-1. Measurements were made under ambient (nonpumping) conditions (i.e., no groundwater production). These measurements are used to provide the groundwater quality with depth.

B.1.10.1 Water-Chemistry Logging

Personnel from DRI conducted water-chemistry logging using an I-CHEM tool. The I-CHEM tool is a 16-bit, high-resolution digital probe capable of measuring pressure (0 to 1,000 decibar); temperature (1 to 50 °C); conductivity (0 to 6,400 microsiemens per centimeter [µS/cm]); DO (0 to 50 parts per million [ppm], 0 to 500 percent saturation); and pH (0 to 14 SU) in groundwater wells with up to 3,300 ft of head and in wells as small as 48 mm (1.9-in.) diameter. The I-CHEM tool can be used under both stressed and ambient conditions. Inflections in the profile of measured parameters are indicative of the mixing of groundwater within the well and are used to select stations for thermal flowmeter measurements and the depths at which to collect depth-discrete bailer samples. The tool is factory calibrated; the calibration is verified in the field, both before and after use.

B.1.10.2 Downhole Log Data Presentation

The data files received from DRI are included in Appendix E on the DVD included with this report. For this report, the DRI log data were uploaded into LogPlot and presented in completion diagrams.

B.1.11 Radiologic Monitoring

Tritium activities were evaluated with respect to background activities, analytical error, and the FMP discharge criteria (see the fluid management strategy letters [Navarro, 2016a and b]). During continuous pumping activities, daily samples were collected and analyzed for tritium activity in accordance with the requirements of the FMP (NNSA/NSO, 2009). The samples were analyzed using a Packard liquid-scintillation counter located in Mercury, Nevada, at Building 23-310. All samples were processed and analyzed by Navarro personnel in accordance with the "Radiation Services" RBMS desktop instruction (Navarro, 2017). A table of the results of analyses is given in Section 4.1.2.2.

B.1.12 Pump Performance Curves

The pump performance curve for the pump installed in ER-3-3 is provided in Figure B-1, and the pump performance curve for the pump installed in ER-4-1 is provided in Figure B-2.

Baker Hughes Incorporated

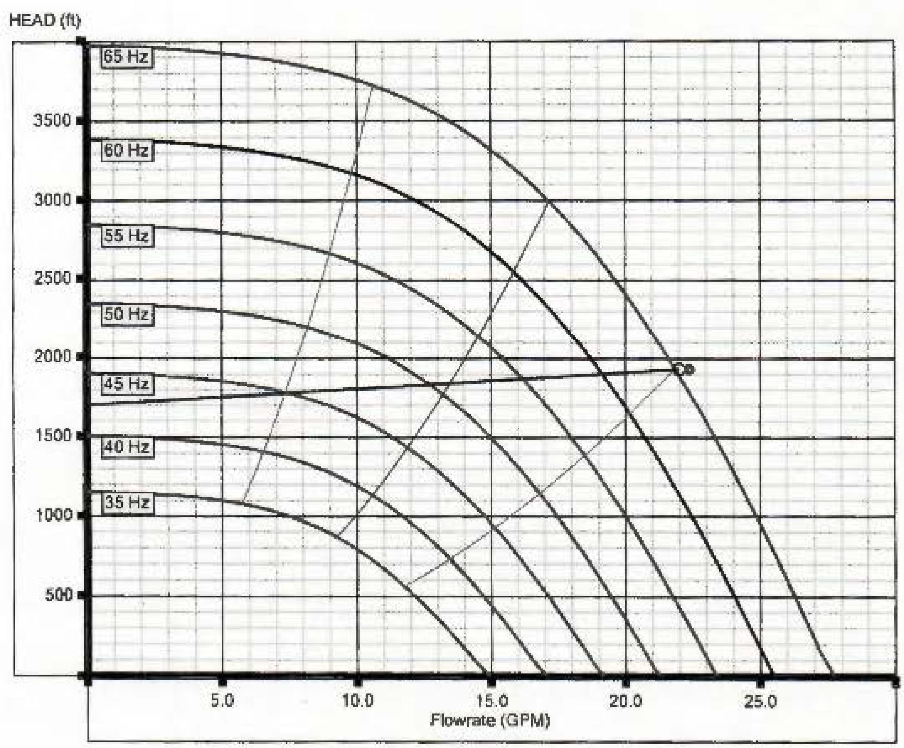
(918) 341-9600 200W Stuart Roosa Dr, Claremore, OK 74017

BAKER HUGHES

Project:	UGTA FY 2016	**Pump:**	149-338DC550
Customer:	NSTech	**Seal:**	338DSFB3
Well:	New Redesign for new well w/ existing equipment	**Motor:**	375MSP 44HP 615V/ 53A (60 Hz)
Engineer:	Dave Patti	**Cable:**	#4 CPNF 5kV ,1970ft
		MLE:	#6 MLE-KHT 5kV ,30.0ft
		Controller:	VSD 2250-VT 260kVA 480V/ 313A
		Sensor:	none

Case:
149 DC550 (rev) 20-30 GPM 2000'Setting 9-20-16

149-338DC550



AutographPC™ V9.5 File:9-20-16 NST 20-30 GPM Redesign .apcx

Figure B-1
Well ER-3-3 Pump Performance Curve

Actual Pump Curve

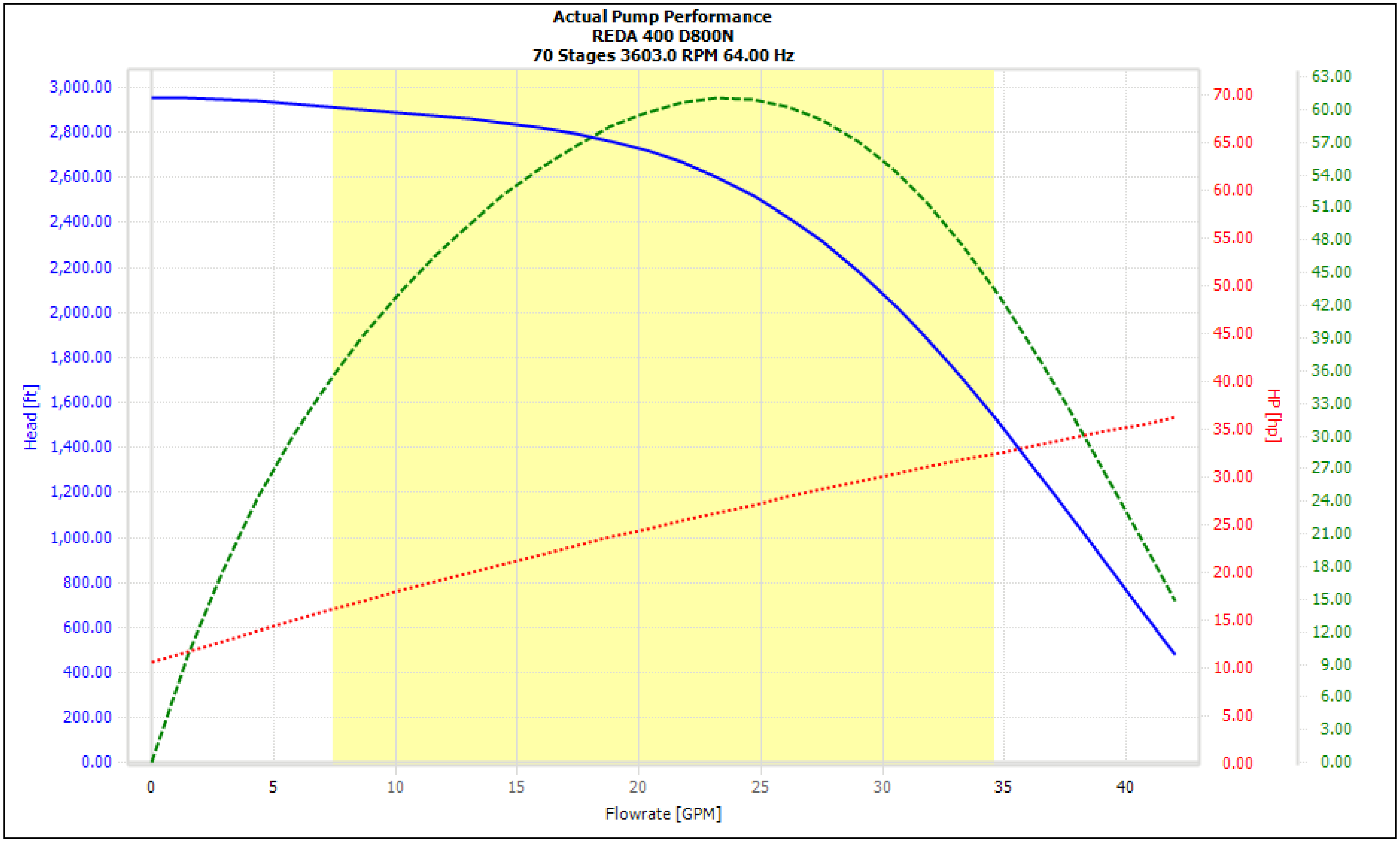


Figure B-2
Well ER-4-1 Pump Performance Curve

B.2.0 REFERENCES

N-I, see Navarro-Intera, LLC.

NNSA/NSO, see U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office.

Navarro. 2016a. Written communication. Subject: *Final Well Specific Fluid Management Strategy for UGTA Well ER-3-3, Nevada National Security Site,* 1 February. Las Vegas, NV.

Navarro. 2016b. Written communication. Subject: *Final Well Specific Fluid Management Strategy for UGTA Well ER-4-1, Nevada National Security Site,* 25 March. Las Vegas, NV.

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Navarro-Intera, LLC. 2012. *Field Instruction for the Underground Test Area Activity Well Development, Hydraulic Testing, and Groundwater Sampling*, Rev. 1, N-I/28091--028-REV. 1. Las Vegas, NV.

U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office. 2009. *Underground Test Area Project Waste Management Plan,* Rev. 3, DOE/NV–343-Rev. 3; *Attachment 1 Fluid Management Plan for the Underground Test Area Project*, Rev. 5; DOE/NV--370-Rev. 5. Las Vegas, NV.

Appendix C

Wells ER-3-3 and ER-4-1 Grab Sample Water-Quality Data

Table C-1
Well ER-3-3 Water-Quality Data

Date	Time	Temperature (°C)	SEC (µmhos/cm)	pH (SU)	DO (mg/L)	Turbidity (NTU)	Bromide (mg/L)	Production Rate (gpm)
12/01/2016	10:40	19.98	410	8.91	2.66	240	1.69	12.53
12/01/2016	15:26	20.61	431	9.84	3.01	793	0.594	15.13
12/02/2016	10:13	19.49	482	9.78	3.60	742	0.397	14.20
12/02/2016	12:18	20.01	484	9.77	3.77	1,006	0.387	14.30
12/02/2016	14:23	20.50	491	9.89	3.28	2,000	0.397	13.20
12/05/2016	09:50	20.45	515	10.26	2.36	2,000	0.230	13.21
12/05/2016	12:10	21.34	539	10.44	2.32	1,458	0.231	13.27
12/05/2016	14:26	21.42	551	10.50	1.67	1,358	0.267	13.60
12/06/2016	09:28	20.15	509	10.20	2.76	2,000	0.404	12.53
12/06/2016	11:41	21.47	505	9.86	2.46	877	0.329	13.93
12/06/2016	14:02	21.45	510	9.99	2.18	1,131	0.345	13.47
12/07/2016	09:27	20.24	507	9.82	2.67	753	0.409	14.07
12/07/2016	12:47	21.29	495	9.88	2.14	1,204	0.791	13.71
12/07/2016	14:50	21.77	510	9.95	2.82	962	0.669	13.93
12/08/2016	09:48	19.02	508	9.97	2.52	858	0.397	12.91
12/08/2016	11:27	20.74	506	9.85	1.95	786	0.392	13.53
12/08/2016	13:38	21.70	503	9.67	1.62	846	0.348	14.13
12/09/2016	09:25	21.13	514	9.84	1.96	2,000	0.384	11.80
12/09/2016	11:15	21.89	505	9.73	2.42	656	0.278	12.10
12/09/2016	13:10	22.40	514	9.76	1.83	557	0.274	13.20
12/12/2016	10:10	21.06	540	9.64	1.70	364	0.244	12.50
12/12/2016	12:19	21.97	536	9.78	0.80	246	0.192	13.00
12/12/2016	14:22	22.50	552	9.74	1.78	209	0.236	11.80
12/13/2016	09:30	20.01	487	9.56	2.20	394	0.233	12.80
12/13/2016	11:40	22.08	472	9.63	3.20	185	0.076	13.80
12/13/2016	13:45	22.14	476	9.63	2.50	168	0.084	13.70
12/14/2016	09:48	20.93	466	9.80	2.31	660	0.307	12.00
12/14/2016	11:45	21.16	459	9.70	2.45	393	0.238	13.00
12/14/2016	13:45	21.41	457	9.62	1.89	323	0.281	12.10
12/15/2016	10:25	19.44	480	10.05	2.32	316	0.169	13.00

Table C-2
Well ER-4-1 Water-Quality Data
(Page 1 of 3)

Date	Time	Temperature (°C)	SEC (µmhos/cm)	pH (SU)	DO (mg/L)	Turbidity (NTU)	Bromide (mg/L)	Production Rate (gpm)
Step-Rate Test								
01/13/2017	14:25	18.83	907	7.12	1.91	42.5	4.48	17.00
01/17/2017	09:40	21.25	752	8.39	1.91	25.5	2.02	32.04
01/17/2017	11:20	25.60	878	6.88	2.01	24.9	1.03	34.02
01/17/2017	13:26	28.51	923	6.64	3.16	5,999 [a]	0.579	33.89
01/17/2017	14:33	30.59	923	6.6	2.34	959	0.638	34.20
01/17/2017	15:30	31.72	921	6.72	2.63	420	0.712	33.51
01/18/2017	11:46	19.81	913	6.96	4.54	648	0.518	51.69
01/18/2017	12:45	29.82	918	6.82	3.00	816	0.706	47.70
01/18/2017	13:45	31.01	914	6.76	2.99	988	0.732	47.19
01/18/2017	14:45	30.99	917	6.76	4.18	2,000	0.979	41.98
01/19/2017	09:23	31.60	1,017	6.85	2.03	18.7	0.411	29.80
01/19/2017	11:15	31.46	1,021	6.87	2.40	17.3	0.752	41.91
01/19/2017	12:15	31.05	1,019	6.92	3.49	107	0.819	50.19
01/19/2017	13:15	31.29	1,020	6.94	2.61	93.6	0.883	58.58
01/19/2017	14:15	31.44	1,023	6.95	2.79	118	1.27	66.83
01/20/2017	08:40	32.24	1,009	6.99	2.48	12.1	1.16	49.18
01/20/2017	12:34	31.49	1,010	6.94	2.57	32.4	1.81	49.81
01/20/2017	13:35	31.01	1,010	6.97	2.56	29.4	2.55	47.90
01/21/2017	09:30	31.59	992	7.00	2.71	14.3	2.44	56.53
01/21/2017	11:22	31.09	1,003	6.98	2.92	32.9	3.30	49.26
01/21/2017	13:18	31.35	997	6.96	2.68	15.7	2.60	58.13
01/21/2017	15:04	31.47	996	6.97	2.60	50.5	2.64	49.27
01/22/2017	08:10	31.99	1,002	7.01	2.63	13.9	2.53	56.26
01/22/2017	10:25	31.53	994	6.96	2.91	12.7	2.68	50.20
01/22/2017	12:25	31.72	995	6.91	2.88	24.4	2.77	69.70
01/22/2017	14:25	31.53	997	6.89	3.63	541	2.92	89.70
01/23/2017	09:15	31.84	979	6.85	2.43	14.4	0.736	44.62
01/23/2017	10:50	32.13	982	6.91	4.66	130	0.770	49.61
01/23/2017	11:50	32.24	985	6.95	2.48	23.4	0.753	49.63
01/23/2017	12:50	31.10	980	6.96	3.71	102	0.836	70.26
01/23/2017	14:50	31.60	981	6.96	4.15	187	0.662	90.33
01/24/2017	10:35	32.15	968	6.82	2.80	8.8	0.346	50.34
01/24/2017	12:05	31.97	975	6.83	2.35	7.9	0.485	49.90

Table C-2
Well ER-4-1 Water-Quality Data
(Page 2 of 3)

Date	Time	Temperature (°C)	SEC (µmhos/cm)	pH (SU)	DO (mg/L)	Turbidity (NTU)	Bromide (mg/L)	Production Rate (gpm)
01/25/2017	11:15	31.89	969	6.82	2.88	9.7	0.615	50.80
01/25/2017	12:50	31.77	964	6.93	4.13	5.6	0.709	70.13
01/25/2017	13:50	32.11	969	6.84	3.26	6.9	0.749	70.00
01/25/2017	14:20	31.18	968	6.88	3.13	33.3	0.887	69.93
01/25/2017	15:20	31.95	968	6.88	2.68	11.5	1.050	70.30
01/26/2017	07:55	31.37	953	7.06	4.13	9.4	0.539	69.20
01/26/2017	09:55	32.05	955	6.92	2.81	6.3	0.558	49.05
01/26/2017	14:25	32.14	962	6.97	2.86	4.3	0.640	50.27
01/27/2017	07:52	31.42	955	6.98	2.82	6.2	0.460	69.33
01/27/2017	09:11	31.47	953	6.89	2.80	6.6	0.685	69.70
01/27/2017	11:10	32.00	956	6.91	2.79	75.4	0.583	70.10
01/27/2017	11:56	31.91	948	7.06	4.37	12.1	0.586	70.10
01/27/2017	13:27	31.89	954	6.92	3.42	40.2	0.611	89.90
01/27/2017	15:00	31.86	953	6.90	3.43	68.5	0.598	89.90
02/01/2017	11:06	29.91	957	6.78	2.71	0.0	0.958	50.90
02/01/2017	13:11	31.71	956	6.80	3.00	0.0	0.998	50.20
02/01/2017	15:06	31.43	957	6.81	2.61	77.4	1.020	70.30
02/02/2017	07:40	32.37	953	6.85	2.74	5.6	1.060	80.60
Constant-Rate Test								
02/06/2017	11:40	25.93	1,052	6.74	2.41	9.1	0.460	73.03
02/06/2017	14:30	29.94	1,050	6.75	2.48	34.2	0.458	71.33
02/07/2017	10:00	28.90	1,020	6.82	2.85	34.6	0.425	70.26
02/07/2017	12:00	29.76	1,018	6.87	2.32	4.70	0.546	71.20
02/07/2017	14:00	31.40	1,016	6.86	2.63	0.60	0.410	71.06
02/07/2017	15:00	30.79	1,022	6.87	2.64	0.00	0.531	70.90
02/08/2017	09:15	31.32	1,010	6.86	1.73	8.00	0.211	70.20
02/08/2017	11:11	31.69	1,011	6.88	2.47	8.50	0.146	71.60
02/08/2017	13:11	31.00	1,015	6.92	3.90	7.70	0.157	70.50
02/08/2017	15:00	31.09	1,014	6.82	1.55	7.40	0.732	70.80
02/09/2017	09:25	30.85	990	6.87	2.17	3.30	0.230	70.90
02/09/2017	11:28	30.81	996	6.93	2.31	3.10	0.303	71.30
02/09/2017	13:30	30.78	998	6.96	2.43	2.00	0.176	70.70
02/09/2017	15:00	31.44	993	6.92	2.61	3.30	0.284	71.60
02/10/2017	09:00	31.41	948	6.89	2.10	8.80	0.187	71.40

Table C-2
Well ER-4-1 Water-Quality Data
(Page 3 of 3)

Date	Time	Temperature (°C)	SEC (μmhos/cm)	pH (SU)	DO (mg/L)	Turbidity (NTU)	Bromide (mg/L)	Production Rate (gpm)
02/10/2017	11:00	31.14	958	6.92	2.48	8.90	0.164	70.60
02/10/2017	13:00	30.71	955	6.93	2.98	10.60	0.148	70.90
02/10/2017	15:00	30.14	954	6.87	1.83	7.50	0.154	70.60
02/11/2017	08:45	31.07	929	6.83	2.46	4.30	0.129	70.70
02/11/2017	10:45	30.74	917	6.92	3.56	4.50	0.095	71.60
02/11/2017	12:45	31.11	919	6.83	3.05	5.60	0.118	70.00
02/11/2017	14:45	31.02	928	6.85	2.95	4.10	0.092	70.70
02/12/2017	08:20	31.32	918	6.87	2.62	6.40	0.020	70.70
02/12/2017	10:20	31.51	920	6.92	3.35	1.10	0.021	71.20
02/12/2017	12:20	31.76	922	6.83	2.38	0.90	0.030	71.60
02/12/2017	14:20	32.04	923	6.85	2.56	0.00	0.024	70.70
02/12/2017	15:00	32.17	925	6.85	2.67	0.00	0.028	71.00
02/13/2017	09:00	31.95	925	6.86	3.16	3.30	0.484	71.50
02/13/2017	11:00	32.06	926	6.84	2.87	2.90	0.480	71.70
02/13/2017	13:00	32.36	928	6.87	3.24	3.10	0.494	70.90
02/13/2017	15:00	32.48	926	6.84	2.78	2.40	0.482	71.80
02/14/2017	09:00	31.94	929	6.87	2.75	1.60	0.668	71.40
02/14/2017	11:10	32.06	927	6.88	2.98	1.80	0.579	71.30
02/14/2017	13:00	32.44	929	6.90	3.32	1.50	0.611	71.70
02/14/2017	15:00	32.70	930	6.89	3.37	1.00	0.581	70.70
02/15/2017	09:00	32.23	928	6.78	2.71	0.90	0.531	71.30
02/15/2017	11:00	32.54	930	6.78	2.64	0.80	0.565	70.70
02/15/2017	13:00	32.65	929	6.77	2.62	1.00	0.552	71.10
02/15/2017	15:00	32.51	930	6.76	2.46	0.80	0.532	71.30
02/16/2017	09:00	32.15	931	6.75	2.45	0.60	0.596	71.30
02/16/2017	11:00	32.28	933	6.76	2.55	0.70	0.595	70.90
02/16/2017	13:00	31.94	930	6.75	2.13	0.70	0.582	71.30
02/16/2017	15:00	31.81	931	6.74	3.14	0.80	0.577	71.70
02/17/2017	08:27	32.14	928	6.77	2.74	0.60	0.351	70.30
02/17/2017	11:42	31.48	932	6.77	2.89	0.90	0.314	71.60

[a] Water-quality instrument records turbidity values up to 2,000 NTU; if turbidity values are greater than 2,000 NTU, the instrument defaults to 5,999 NTU.

Appendix D

Wells ER-4-1 and ER-3-3 Electronic Data Files Generated during WDT Activities

D.1.0 WELLS ER-3-3 AND ER-4-1 ELECTRONIC DATA FILES

This appendix contains the electronic data file index for WDT activities at Wells ER-3-3 and ER-4-1. The electronic data files are provided in this appendix on the DVD included with this report. These files represent various original data files or minimally processed files.

D.1.1 Baker Hughes Data Files

The Baker Hughes files, pump specifications, and pump curves are included as original information obtained from Baker Hughes and NSTec.

D.1.2 DRI Data Files

The DRI I-CHEM Tool logs are included as original recorded data.

D.1.3 Navarro Data Files

The Navarro data files include hydraulic head; groundwater temperature at the PXDs; barometric pressure collected at Wells ER-3-3 and ER-4-1 before, during, and after testing; and the production rate data at Wells ER-3-3 and ER-4-1. The data files are included as Microsoft Excel workbooks.

Appendix E

USGS ER-3-3_m1 Aquifer Test of Lower Carbonate Aquifer

(22 Pages)

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Nevada Water Science Center
160 North Stephanie
Street Henderson, NV
89074

MEMORANDUM

March 30, 2017

To: Devon Galloway, Groundwater Specialist
USGS, Western Region Water Mission Area

From: Tracie R. Jackson, Hydrologist
USGS, Nevada Water Science Center, Henderson, Nevada

Subject: AQUIFER TEST PACKAGE—Drawdown estimation and analysis of the *ER-3-3 m1* aquifer test of the lower carbonate aquifer, Yucca Flat, Nevada National Security Site

This memorandum documents the analysis of the *ER-3-3 m1* single-well aquifer test in Yucca Flat at the Nevada National Security Site (NNSS). Original goals of the analysis were to estimate the transmissivity of the lower carbonate aquifer (LCA) at well *ER-3-3 m1*, and to estimate drawdowns in observation wells from a multiple-well aquifer test in well *ER-3-3 m1*.

The multiple-well aquifer test at well *ER-3-3 m1* was reduced to a single-well aquifer test because excessive drawdown occurred in the well even at the lowest rate of pumping (10 gal/min). A network of 27 observation and background wells in Rainier Mesa, Yucca Flat, and Frenchman Flat (Figure 1; Table 1) were instrumented with pressure transducers by a private contractor, Navarro, and the U.S. Geological Survey (USGS). Water levels were monitored for potential drawdowns related to well development and aquifer testing in well *ER-3-3 m1*. A limited amount of groundwater (about 9,500 gallons) was withdrawn from the LCA during well development and testing. Drawdown was not observed in observation wells distant from the pumping well, resulting in the interpretation of the multiple-well aquifer test as single well.

Borehole ER-3-3 has two main completions and three piezometers. The lower and upper main completions are designated *ER-3-3 m1* and *ER-3-3 m2*, respectively. The deep, intermediate, and shallow piezometers are designated *ER-3-3 p1*, *ER-3-3 p2*, and *ER-3-3 p3*, respectively. The lower main completion, *ER-3-3 m1*, was pumped for aquifer testing. Piezometers *ER-3-3 p1* and *ER-3-3 p2* were used as observation wells during aquifer testing. Piezometer *ER-3-3 p3* was not monitored because the well is filled with mud. The well completion diagram is provided in Appendix B.

Drawdowns were estimated at 16 distant observation wells using water-level models. Distant observation wells are defined as wells located beyond the pumping well site at ER-3-3. Water-level models were used because potential drawdowns could be masked by environmental water-level fluctuations. No drawdown was estimated at distant observation wells. Water-level model analyses and estimated drawdown results for distant observation wells are discussed in Appendix A.

ER-3-3 is located within the central corridor of underground nuclear testing in Yucca Flat. The borehole is 533 ft southwest of WAGTAIL (U-3an), a large underground nuclear test (UGT) conducted within the saturated zone with an announced yield of 20 to 200 kilotons (U.S. Department of Energy, 2015). The *ER-3-3 m1* aquifer test was conducted by Navarro from November to December of 2016 to target the LCA, which is a regional carbonate aquifer that extends from UGT locations in Yucca Flat toward groundwater discharge areas downgradient of the NNSS boundary.

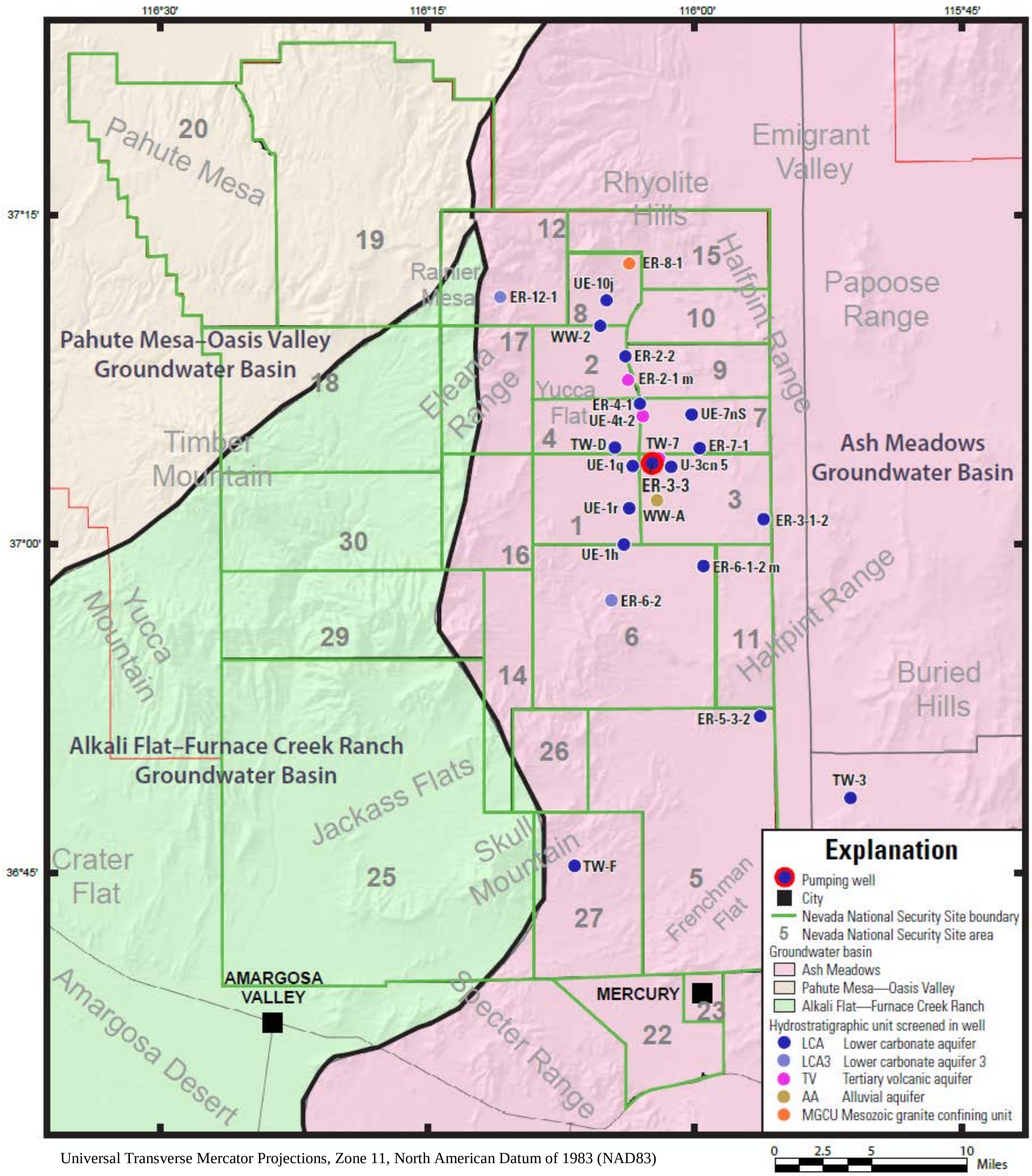

Figure 1. Location of *ER-3-3 m1* pumping well and network of observation and background wells instrumented during aquifer testing. Hydrostratigraphic unit definitions from Prothro and others (2009).

Table 1. Well location and construction data for pumping, observation, and background wells monitored during well ER-3-3 m1 development and testing, Nevada National Security Site.

[**Well Name** refers to the name of the well in the National Water Information System (NWIS) database, where the **bold** part of the name is shown on Figure 1; **Latitude** and **Longitude** are in decimal degrees and referenced to North American Datum of 1983 (NAD 83); **Ground surface altitude** is the altitude of the well in ft amsl, feet above National Geodetic Vertical Datum of 1929 (NGVD 29); **Depth to static water level** is the water-level depth in the well in ft bgs, feet below ground surface; **Top of open interval** and **Bottom of open interval** correspond to the depth of the top and bottom of the open interval (i.e., interval that includes well screen, and gravel pack or open hole].

Well Name	Site Identifier	Lat.	Long.	Ground surface altitude, ft	Depth to static water level, ft bgs	Top of open interval, ft bgs	Bottom of open interval, ft bgs	Radial distance from pumping well, ft
Pumping Well								
ER- 3-3 m1	370349116021902	37.06	-116.04	4,054	1,645	2,630	3,193	0
Observation Wells								
ER- 2-1 main (shallow)	370725116033901	37.13	-116.06	4,216	1,725	1,642	2,177	23,526
ER- 2-2 o2	370831116035001	37.14	-116.06	4,273	2,410[a]	2,008	3,457	29,450
ER- 3-1-2 (shallow)	370116115561302	37.02	-115.94	4,407	2,014	2,208	2,310	33,861
ER- 3-3 p1	370349116021904	37.06	-116.04	4,054	1,645[b]	2,630	3,193	0
ER- 3-3 p2	370349116021905	37.06	-116.04	4,054	1,653[b]	2,203	2,507	0
ER- 3-3 p3	370349116021906	37.06	-116.04	4,054	1,444[b]	118	1,940	0
ER- 4-1 m1	370625116030001	37.11	-116.05	4,158	1,769	2,812	3,035	16,119
ER- 4-1 p1	370625116030002	37.11	-116.05	4,158	1,052	118	2,375	16,119
ER- 5-3-2	365223115561801	36.87	-115.94	3,335	945	4,674	5,683	75,196
ER- 6-1-2 main	365901115593501	36.98	-115.99	3,935	1544	1,775	3,200	31,818
ER- 6-2	365740116043501	36.96	-116.08	4,231	1780	1,746	3,430	38,974
ER- 7-1	370424115594301	37.07	-116.00	4,246	2394	1,775	2,500	12,892
ER-12-1 (1641-1846 ft)	371106116110401	37.18	-116.19	5,817	1,519	1,641	1,846	61,350
TW- 3	364830115512601	36.81	-115.86	3,484	1,104	165	1,860	106,851
TW- 7	370353116020201	37.06	-116.03	4,058	1,646	41	2,272	1,467
TW- D	370418116044501	37.07	-116.08	4,150	1,723	1,700	1,950	11,551
U - 3cn 5	370320116012001	37.06	-116.02	4,009	1,619	2,832	3,030	4,708
UE- 1h	370005116040301	37.00	-116.07	3,995	1,552	2,134	3,358	24,252
UE- 1q (2600 ft)	370337116033002	37.06	-116.06	4,081	1,655	2,459	2,600	6,118
UE- 1r WW	370142116033301	37.03	-116.06	4,042	1,616	2,319	4,182	14,172
UE- 4t 2 (1564-1754 ft)	370556116025406	37.10	-116.05	4,141	868	1,564	1,754	13,150
UE- 7nS	370556116000901	37.10	-116.00	4,367	1,968	1,707	2,205	16,375
UE-10j (2232-2297 ft)	371108116045303	37.19	-116.08	4,574	2,156	2,232	2,297	46,193
WW- 2 (3422 ft)	370958116051512	37.17	-116.09	4,470	2,052	2,700	3,422	40,055
WW- A (1870 ft)	370142116021101	37.04	-116.04	4,006	1,599	1,555	1,870	9,715
Background Wells								
ER- 8-1 (recompleted)	371248116032102	37.21	-116.06	4,820	2,293	1,947	2,863	54,752
TW- F (3400 ft)	364534116065902	36.76	-116.12	4,143	1,734	3,142	3,392	113,086

[a]Estimated steady-state water level at well *ER-2-2 o2*. Available water levels for this well are nonstatic.
[b]Estimated water levels at wells *ER-3-3 p1*, *ER-3-3 p2*, and *ER-3-3 p3* are for periodic measurements on January 4, 2017.

Hydrogeology

Yucca Flat is underlain by three types of aquifers: alluvial, volcanic, and carbonate rock. The alluvial aquifers are underlain by a thick sequence of volcanic aquifers and volcanic confining units. Alluvial and volcanic aquifers contribute limited flow to the underlying carbonate aquifer through a volcanic confining unit that acts as a flow barrier (Winograd and Thordarson, 1975).

Alluvial deposits form thin, localized aquifer systems in the Yucca Flat basin. Alluvial aquifers comprise poorly sorted gravels and sands derived from Tertiary volcanic and Paleozoic sedimentary rocks (Slate and others, 1999). Alluvial deposits increase in thickness from the margins to the center of the basin (Bechtel Nevada, 2006), and are unsaturated throughout most of Yucca Flat. However, alluvial aquifers have saturated thicknesses of up to 2,000 ft in areas along the central corridor of Yucca Flat (Fenelon and others, 2012). Observation well *WW-A* is screened in the alluvial aquifer (Figure 1), and borehole ER-3-3 intersects 1,680 ft of partially saturated alluvial deposits (see well completion diagram in Appendix B).

Volcanic rocks form localized and regionally extensive aquifer systems throughout Yucca Flat. The majority of volcanic rocks were erupted during the Miocene from within the southwestern Nevada volcanic field (Winograd and Thordarson, 1975), which is located to the north and west in the Pahute Mesa—Oasis Valley and Alkali Flat—Furnace Creek Ranch groundwater basins (Figure 1). Regionally extensive volcanic aquifers comprise moderately to densely welded ash-flow tuffs. Localized volcanic aquifers comprise fractured vitric ash-fall tuffs and rhyolitic lava flows. Volcanic aquifers typically have saturated thicknesses that range between 1,000 and 2,500 ft (Fenelon and others, 2012). Observation wells *TW-7*, *UE-4t 2*, and *ER-3-3 p2* are screened in volcanic aquifers (Figure 1 and 2).

A thick, regionally extensive volcanic confining unit forms a hydraulic barrier between the volcanic aquifers and underlying carbonate aquifer throughout most of the Yucca Flat basin. The volcanic confining unit comprises nonwelded ash-flow tuff, bedded tuff, and reworked tuffaceous sediments that are commonly zeolitized (Winograd and Thordarson, 1975). The saturated thickness of the volcanic confining unit typically ranges between 1,000 and 2,500 ft (Fenelon and others, 2012). The volcanic confining unit is absent in the western part of Yucca Flat, where volcanic aquifers directly overlie the lower carbonate aquifer. Borehole ER-3-3 intersects about 620 ft of the volcanic confining unit overlying the lower carbonate aquifer in the central part of Yucca Flat (see well completion diagram in Appendix B).

Carbonate aquifers form localized and regionally extensive aquifer systems. The regional lower carbonate aquifer (LCA), occurs throughout Yucca Flat and large areas of southern Nevada. The LCA comprises a thick sequence of Paleozoic limestones and dolostones, and has a saturated thickness of more than 15,000 ft in some areas. Pumping well *ER-3-3 m1* and the piezometer screened adjacent to the main completion (*ER-3-3 p1*) are open to 208 ft of the LCA (see well completion diagram in Appendix B), and the majority of observation wells are screened in the LCA (Figure 1).

Data Collection

Pumping for the aquifer test at well *ER-3-3 m1* occurred from 11/30/2016 13:40 to 12/15/2016 10:36. During the test, a straddle packer was installed across *ER-3-3 m2* to isolate the LCA in *ER-3-3 m1*. Discharge rates during pumping ranged from 1 to 16 gal/min, and averaged 10 gal/min. A constant-rate test could not be done because pumping rates of 10 gal/min induced excessive drawdown (hundreds of feet of water-level decline) in the well.

Data were collected before, during, and after well development and aquifer testing. Continuously measured data include water levels, water temperature, and barometric pressure at the pumping, observation, and background wells (Table 1), and pumping rates in the pumping well. Water levels and temperature were measured using an INW PT12 pressure transducer, which has a pressure accuracy of ± 0.05% of the pressure range. INW PT12 pressure transducers installed in distant observation wells and background wells had a pressure range of 0 to 30 psia, whereas pressure transducers installed in the pumping well and observation wells at borehole ER-3-3 had a pressure range of 0 to 2000 psia. The INW PT12 pressure transducer also has a temperature range of 0º to 55ºC (32º to 131ºF) with a temperature accuracy of ± 0.5ºC. Barometric pressure was measured using a PTB110 barometer, which has an accuracy of ± 0.3 hPa at 20ºC (68ºF). A CR1000 Campbell Scientific datalogger collected water levels, water temperature, and barometric pressure every 10 minutes or if a change greater than 0.05 psi occurred. The Foxboro 8002A series flowmeter was used to measure pumping rates, which has a flow rate range of 13 to 250 gal/min and a flow rate accuracy of 0.029%. The pumping schedule for well *ER-3-3 m1* is shown in Figure 2.

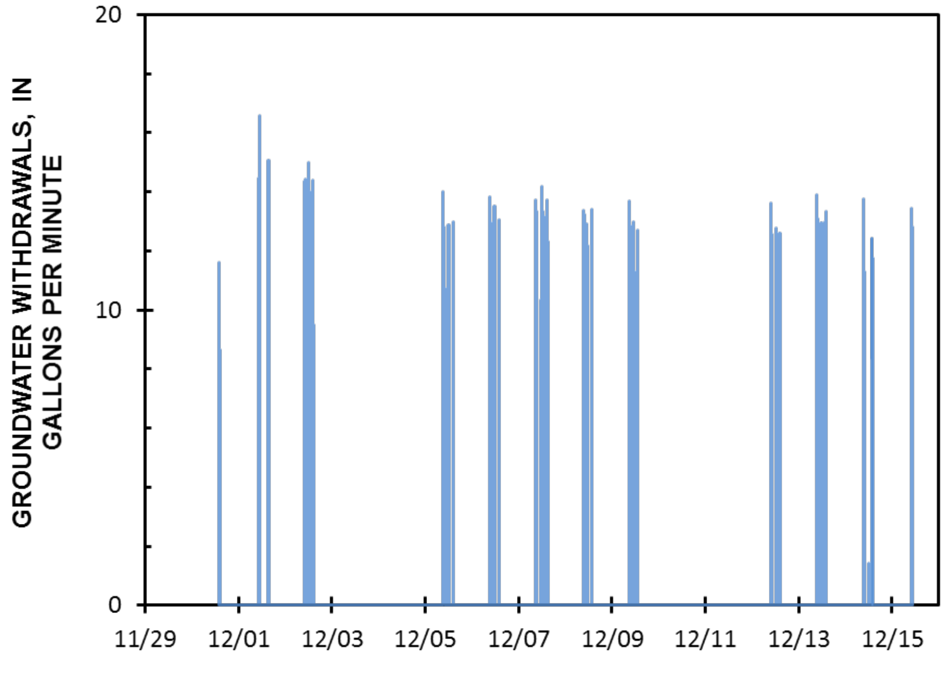

Figure 2. Pumping schedule of well *ER-3-3 m1* during aquifer testing at Yucca Flat, November—December 2016.

Estimated Drawdowns

Drawdowns only were detected in observation wells at the pumping well site. *ER-3-3 p1*, open to the LCA in the pumped interval, had drawdowns that exceeded 200 ft (Figure 3). *ER-3-3 p2*, open to welded and vitric tuffs above the pumped interval, had drawdowns of less than 1 ft (Figure 4). No drawdowns were estimated at observation wells not located at the pumping well site. Water-level model analyses and estimated drawdown results for distant observation wells are discussed in Appendix A.

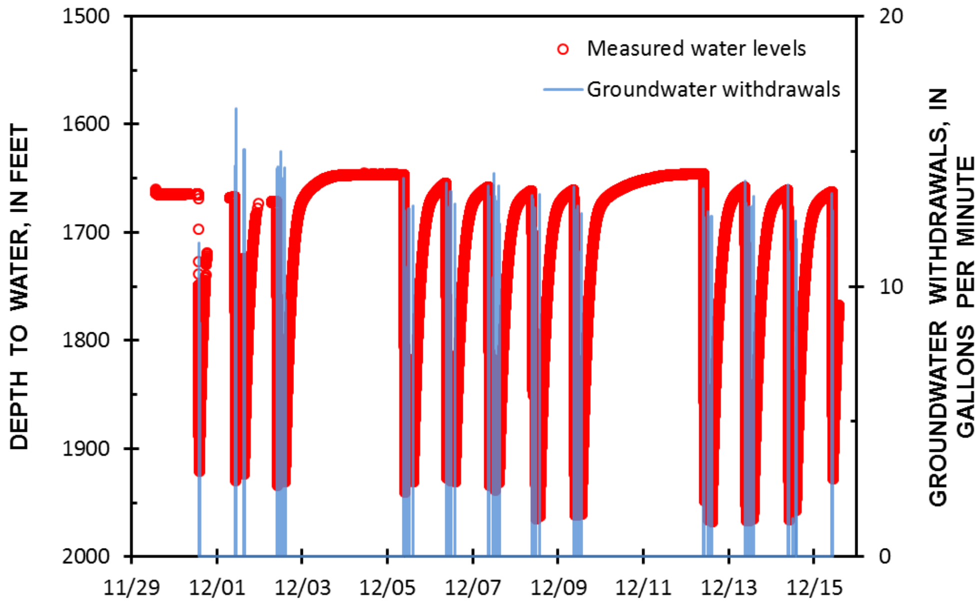

Figure 3. Depth-to-water in *ER-3-3 p1* and groundwater withdrawal rates in *ER-3-3 m1* during aquifer testing.

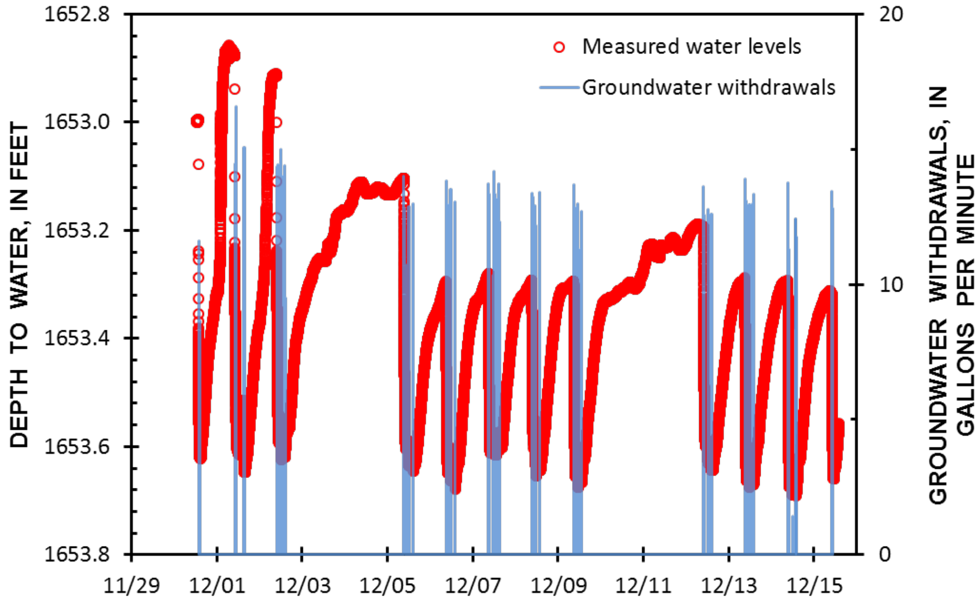

Figure 4. Depth-to-water in *ER-3-3 p2* and groundwater withdrawal rates in *ER-3-3 m1* during aquifer testing.

Aquifer Test Analysis

Drawdown in piezometer *ER-3-3 p1* was interpreted as a slug test with the Bouwer and Rice method (Bouwer and Rice, 1976). The Bouwer and Rice method was selected because excessive drawdown occurred in the well even at the lowest rate of pumping (10 gal/min), causing water levels to draw down below the pump intake. Pumping in the well can be interpreted as a series of slug tests, where the well was "bailed" and water levels recovered (Figure 3). The Bouwer and Rice method is appropriate for the analysis because the method can be applied to confined aquifers (Bouwer, 1989). Piezometer *ER-3-3 p1* is open to a confined part of the LCA, and the Bouwer and Rice method yields superior estimates of hydraulic conductivity compared to other confined analytical slug-test solutions for partially penetrating wells (Brown and others, 1995). However, unlike a typical slug test, the wellbore contains a pump string, where the volume of the pump string is removed in the analysis by computing an effective casing diameter of the well (see slug test analysis in Appendix B for details).

The estimated hydraulic conductivity of the LCA is 0.01 ft/d (Figure 5). The period of analysis for estimating transmissivity spans from 12/05/16 10:01 to 12/05/16 12:05. Estimated hydraulic conductivity from this 2.1 hour (0.09 day) period of analysis is similar to other recovery periods. Using the interval of the well screen open to the LCA as the aquifer thickness (L = 80 ft), the estimated transmissivity of the LCA is 1 ft^2/d.

Two factors likely contribute to the low transmissivity estimated for the LCA at ER-3-3: the majority of the open interval is screened across confining units and the well screen is partially clogged with drilling mud. The open interval at *ER-3-3 m1* is screened in about 105 ft of nonwelded tuff, 250 ft of paleocolluvium, and 208 ft of Paleozoic dolomite. The nonwelded tuff and paleocolluvium are assumed to have little to no contribution to the total estimated transmissivity because these rocks are low permeability confining units (Fenelon and others, 2012). The Paleozoic dolomite is assumed to contribute significantly to the total estimated transmissivity; however, only 80 ft of the well screen is hydraulically connected to the dolomite. A well screen length of 80 ft was selected, even though *ER-3-3 p1* is open to 208 ft of the LCA, because the well screen was emplaced in about 128 ft of drilling mud.

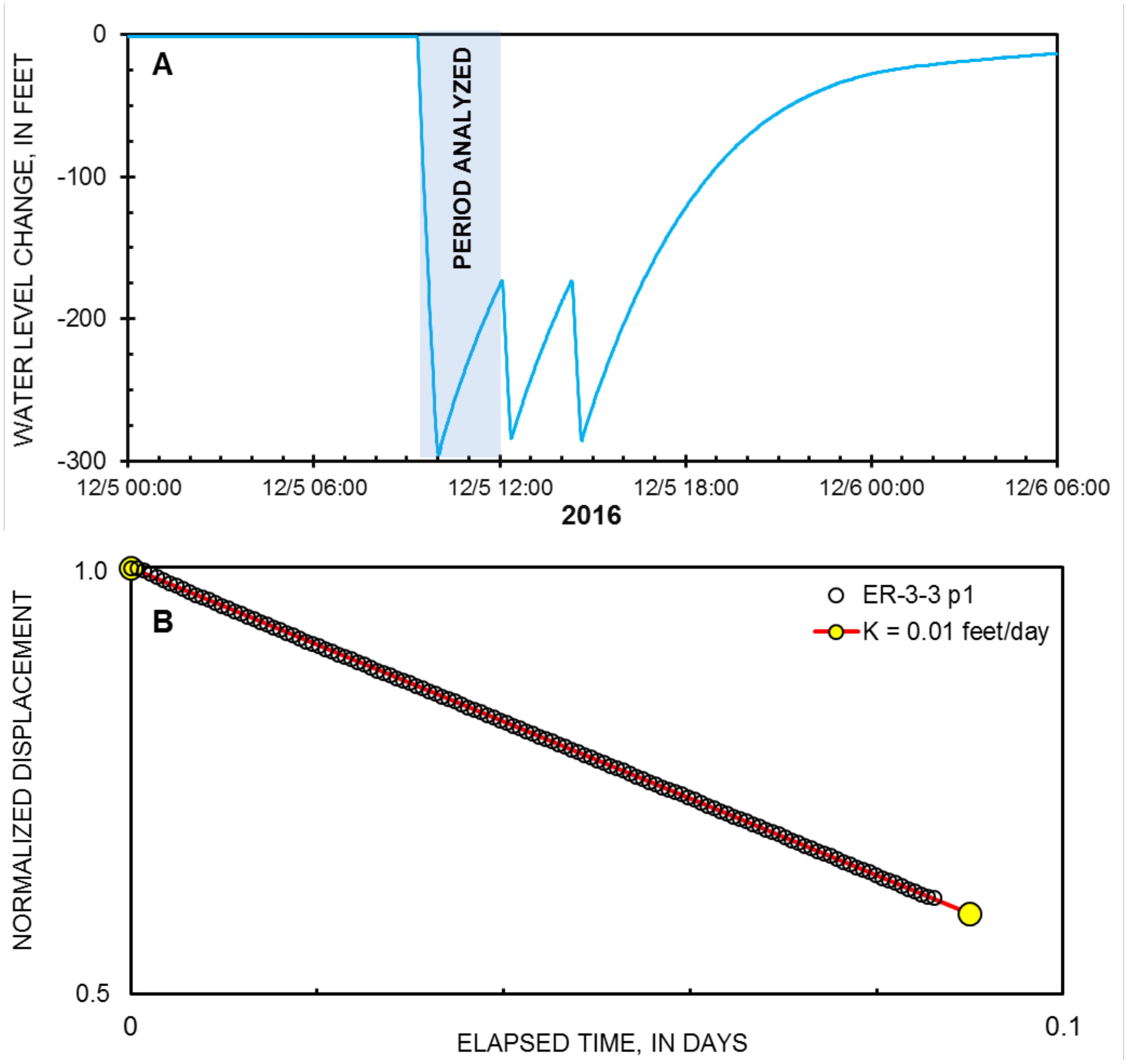

Figure 5. (**A**) Period of analysis for estimating transmissivity spanning from 12/05/16 10:01 to 12/05/16 12:05 (2.1 hours); and (**B**) Normalized drawdowns and straight-line approximation in well *ER-3-3 p1* during pumping in well *ER-3-3 m1*.

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Appendix A. Estimated Drawdowns in Distant Observation Wells

Appendix A contains the estimated drawdown analysis of 16 distant observation wells monitored during the *ER-3-3 m1* aquifer test. The first part of this appendix discusses data collection and the water-level modelling methodology used to estimate drawdown. The water-level modelling discussion is followed by 16 hydrographs showing water-level model results. Hydrographs compare measured and synthetic water-level change, and show residuals, estimated drawdown, and groundwater withdrawals during aquifer testing at well *ER-3-3 m1*. Hydrographs are presented for observation wells distant from the pumping well, where no drawdown was detected.

Data Collection

Water levels were analyzed for drawdown from pumping well *ER-3-3 m1* at 16 observation wells: *ER-2-1 m*, *ER-2-2*, *ER-3-1-2*, *ER-5-3-2*, *ER-6-1-2 m*, *ER-6-2*, *ER-7-1*, *TW-D*, *TW-7*, *U-3cn 5*, *UE-1h*, *UE-1q*, *UE-7nS*, *UE-10j*, *WW-2*, and *WW-A*. These wells are closest to borehole ER-3-3, are screened across a range of hydrostratigraphic units, and exist in opposing quadrants from the pumping well (Figure 1). The selection of distant observation wells analyzed for drawdown was sufficient to understand hydraulic connections within the LCA and between the LCA and volcanic-rock aquifers.

Water levels in observation wells *UE-1r*, *UE-4t 2*, *ER-3-3 p3*, *ER-4-1 m1*, and *ER-4-1 p1* were removed from the analysis. Continuous water-level measurements in *UE-1r* began 5 days prior to well *ER-3-3 m1* development and aquifer testing, which did not provide a sufficient antecedent period for estimating small drawdown that would otherwise be masked by environmental noise. Continuous water-level data in well *UE-4t 2* had an anomalously rising trend during well development and testing that is not representative of the aquifer system. Because the pressure transducer in *ER-4-1 m1* was removed during well *ER-3-3 m1* development and aquifer testing, this well was not used in the drawdown analysis. Well *ER-4-1 p1* recently was drilled and water levels currently are recovering following well construction; therefore, water levels are not representative of the aquifer system. Water levels were not measured in *ER-3-3 p3* during the period of aquifer testing in *ER-3-3 m1* because the piezometer is filled with drilling mud.

Drawdown Estimation Using Water-Level Models

Drawdowns from pumping well *ER-3-3 m1* were estimated by modeling water levels in observation wells as described by Halford and others (2012). Water-level modeling was used to estimate drawdown because environmental (non-pumping) water-level fluctuations of more than 0.2 ft could potentially mask drawdown from pumping in observation wells. Potential drawdown was differentiated from environmental fluctuations by modeling synthetic water levels that simulated environmental water-level fluctuations and the pumping signal.

Environmental water-level fluctuations were simulated using time series of barometric pressure, earth and gravity tides, and water levels from background wells *TW-F* and *ER-8-1*. The background wells are assumed to be close enough to the observations wells to be affected by similar environmental fluctuations, yet distant enough to be unaffected by pumping from aquifer testing. Water levels from background wells were critical because they were affected by tidal potential–rock interaction, barometric pressure, and seasonal climatic trends. These effects also are assumed present in the observation wells.

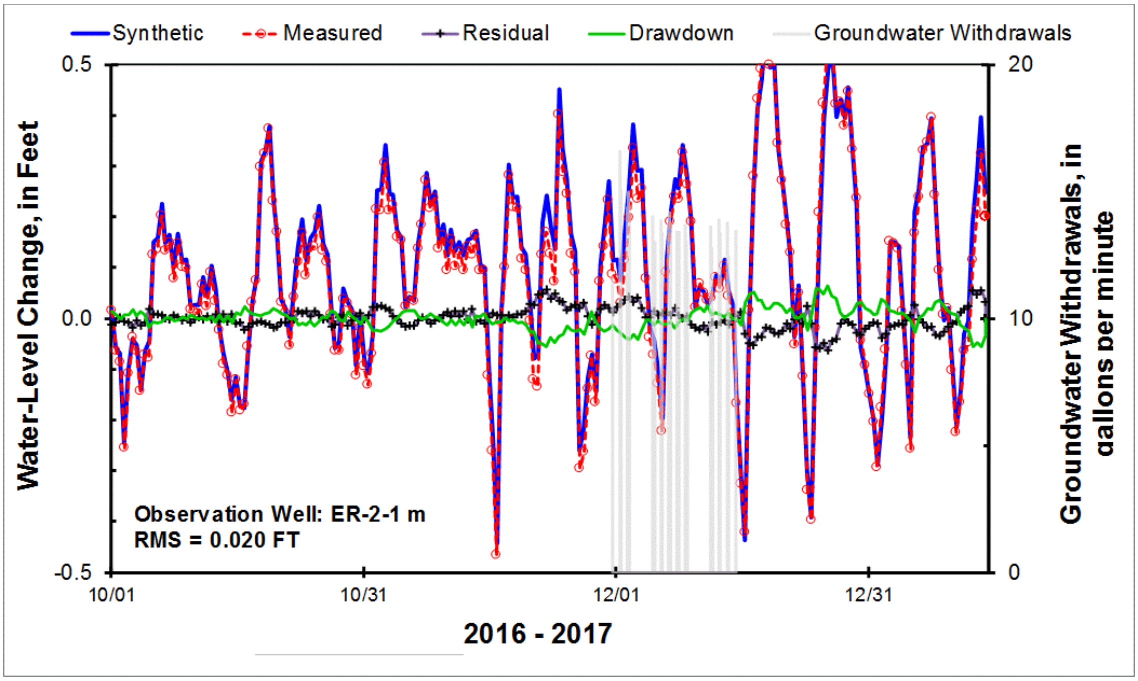
Responses from pumping well *ER-3-3 m1* were modeled with a Theis transform of the pumping signal, where multiple pumping rates were simulated by superimposing multiple Theis (1935) solutions. Theis transforms serve as simple transform functions, where step-wise pumping records are translated into approximate water-level responses. Numerical experiments have confirmed that superimposed Theis transforms closely approximate water-level responses through hydrogeologically complex aquifers (Garcia and others, 2013).

Synthetic water levels were fit to measured water levels by minimizing the Root-Mean-Square (RMS) error of differences between synthetic and measured water levels (Halford and others, 2012). Amplitude and phase were adjusted in each time series used to simulate environmental water-level fluctuations (barometric pressure, water levels in background wells, and earth and gravity tides). Transmissivity and the storage coefficient were adjusted in the Theis transform.

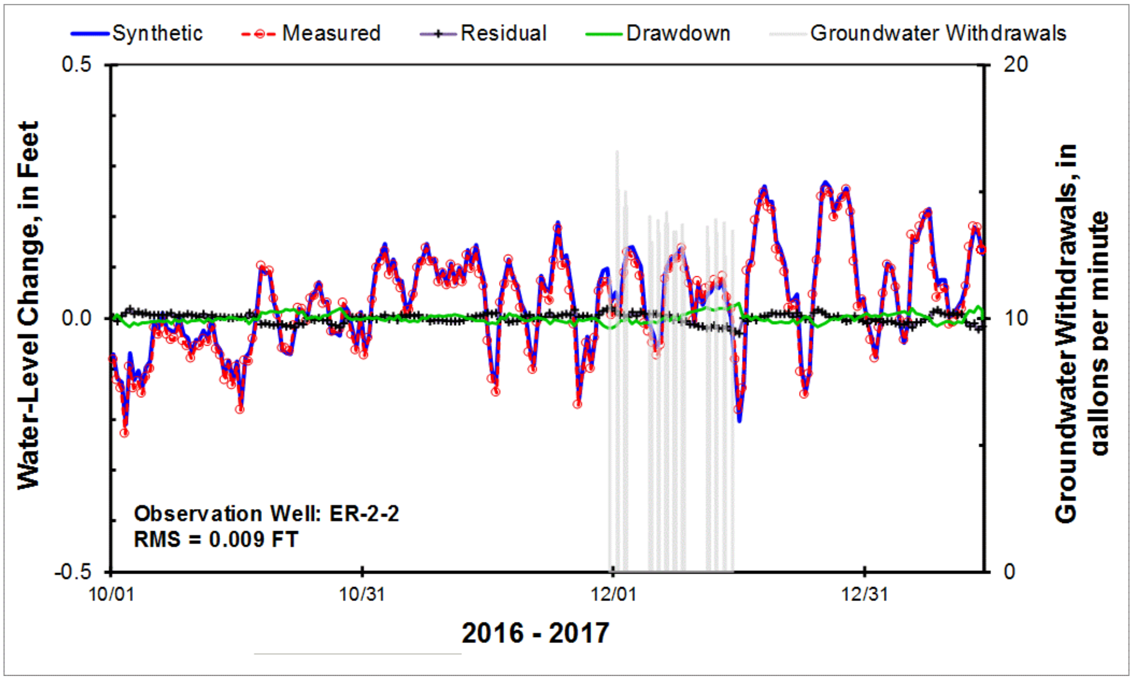
Drawdown estimates are the summation of Theis transforms minus residual differences between synthetic and measured water levels (Halford and others, 2012). The summation of all Theis transforms is the direct estimate of the pumping signal. Residuals represent all unexplained water-level fluctuations. These fluctuations primarily are random during non-pumping periods, but can contain unexplained components of the pumping signal during pumping periods.

All synthetic water levels in the water-level models represented summed time series of earth tides, gravity tides, barometric pressure, background water levels, and pumping responses. Earth and gravity tides were computed functions based on well-established theoretical equations (Harrison, 1971). Barometric pressure typically was measured at the well being analyzed and/or at the background well. Pumping responses were simulated with Theis transforms that used simplified pumping schedules in *ER-3-3 m1*. Pumping in well *ER-3-3 m1* was approximated using 198 simplified pumping steps. These simplified steps were sufficient to calculate the pumping response in observation wells with the Theis transform models. Total withdrawal during the period of well development and testing was less than 10,000 gallons (~1,337 ft^3).

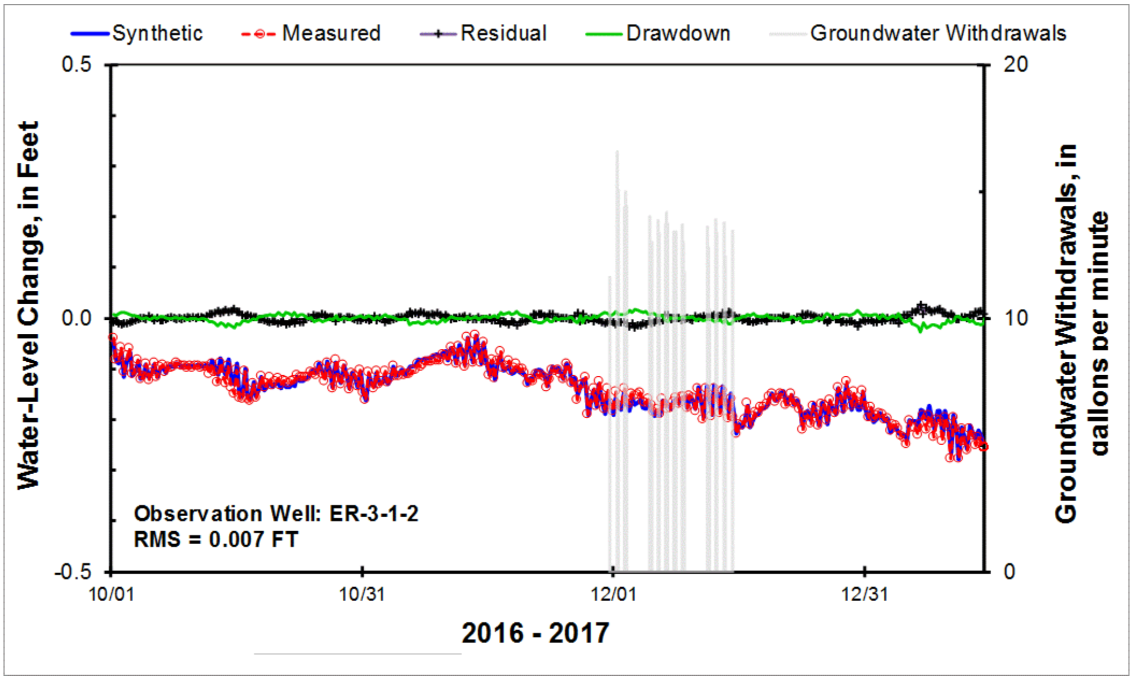
Water levels were modeled from October 1, 2016 to January 15, 2017 to estimate drawdowns at 16 distant observation wells monitored before, during, and after the aquifer test. Synthetic water levels matched measured water levels with RMS errors between 0.003 and 0.020 ft in observation wells. Drawdown was not detected in any distant observation well, as shown in the hydrographs below. Worksheets showing fitting parameters, measured and synthetic water levels, and drawdown estimates for analyzed wells are in individual Excel files in Appendix B.



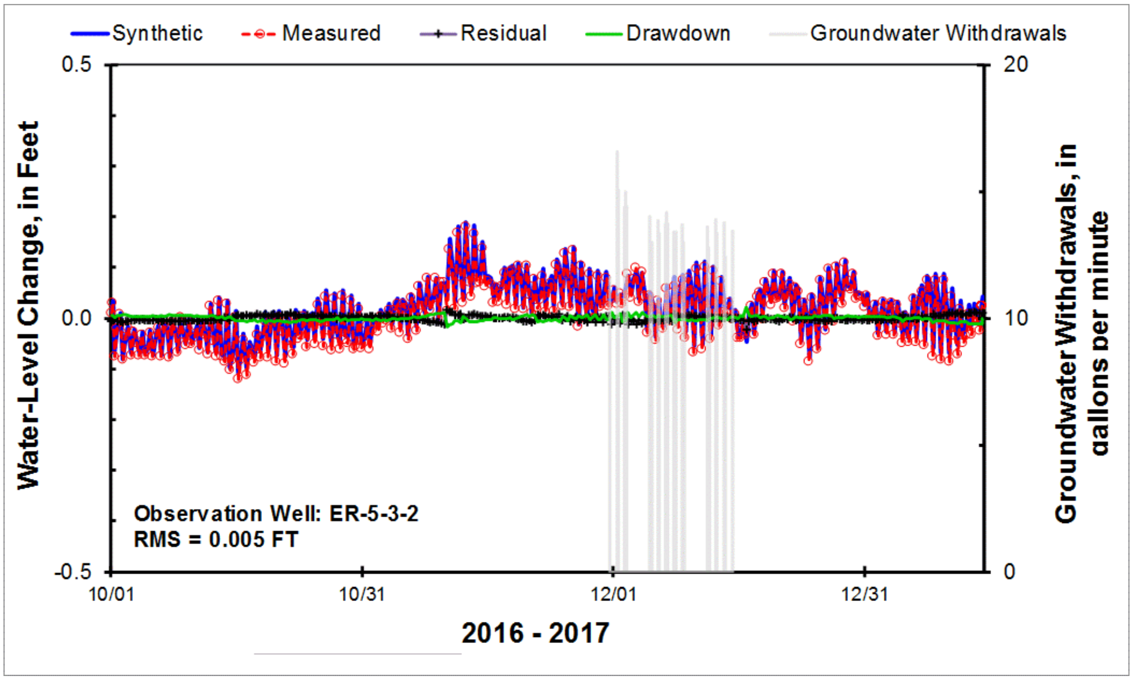
Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: ER-2-1 m
RMS = 0.020 FT
0.5
0.0
-0.5
20
10
0
10/01
10/31
12/01
12/31
2016 - 2017



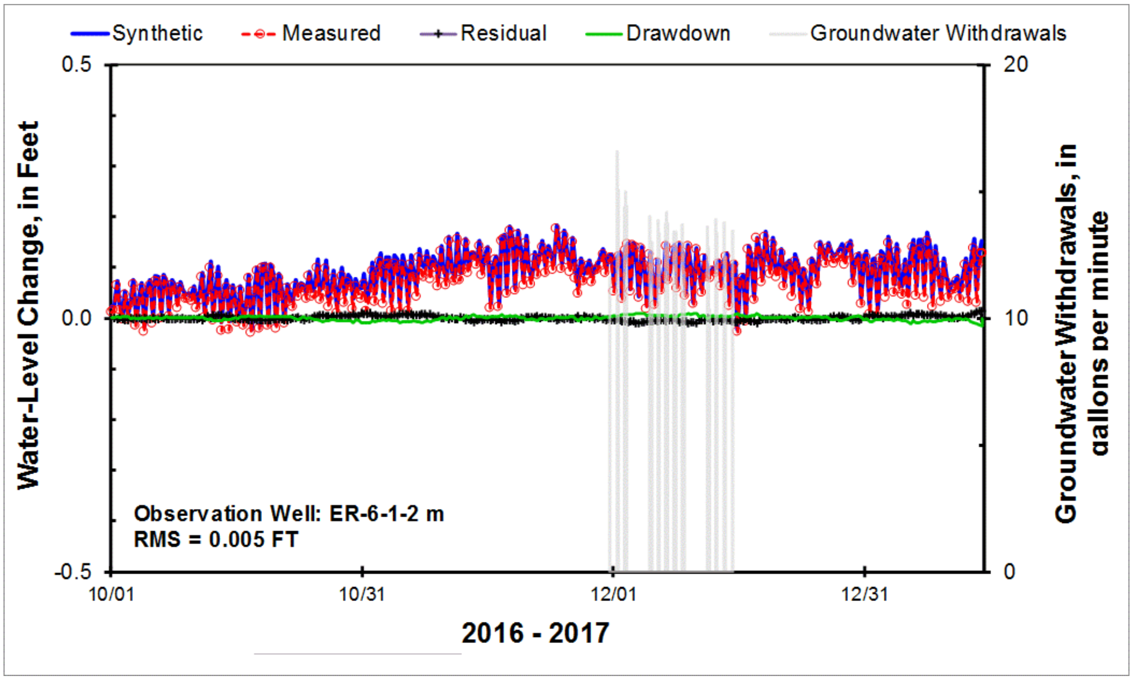
Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: ER-2-2
RMS = 0.009 FT
0.5
0.0
-0.5
20
10
0
10/01
10/31
12/01
12/31
2016 - 2017

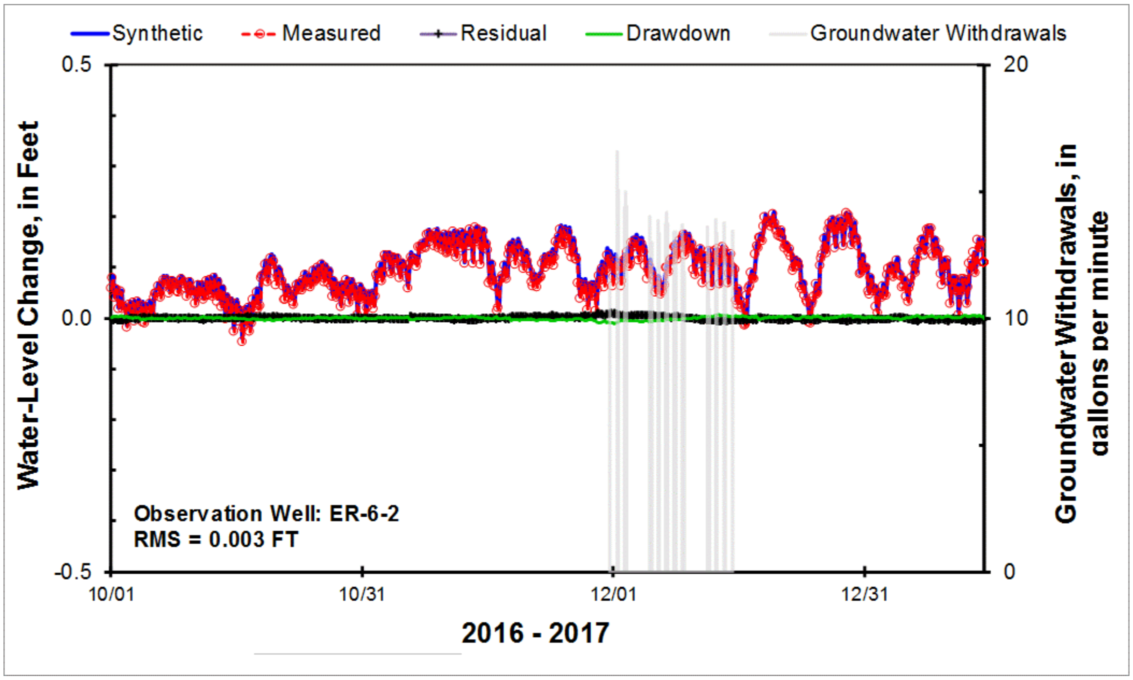


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
20
10
0
Observation Well: ER-3-1-2
RMS = 0.007 FT
10/01
10/31
12/01
12/31
2016 - 2017



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
20
10
0
Observation Well: ER-5-3-2
RMS = 0.005 FT
10/01
10/31
12/01
12/31
2016 - 2017


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
20
10
0
Observation Well: ER-6-1-2 m
RMS = 0.005 FT
10/01
10/31
12/01
12/31
2016 - 2017


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
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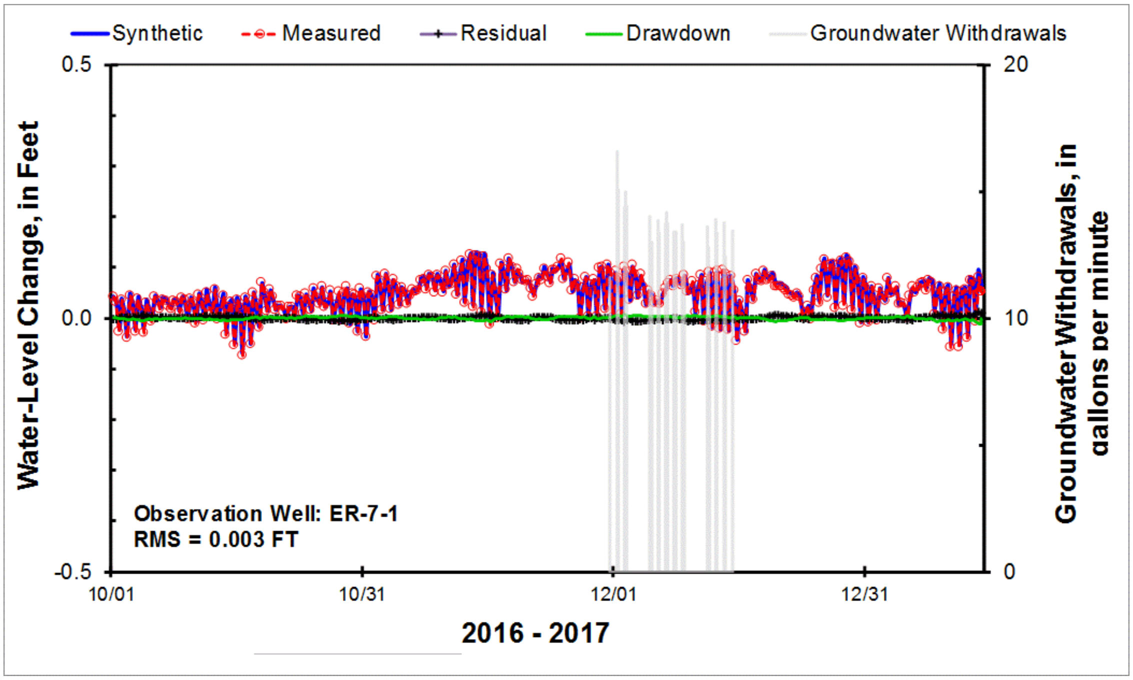
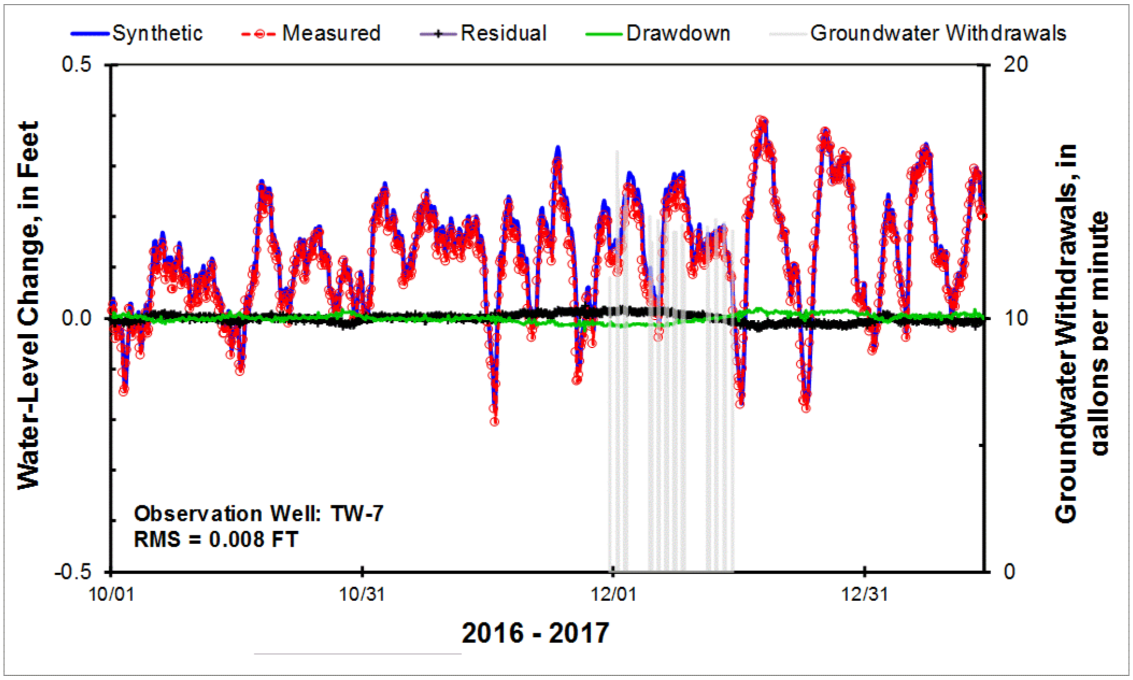
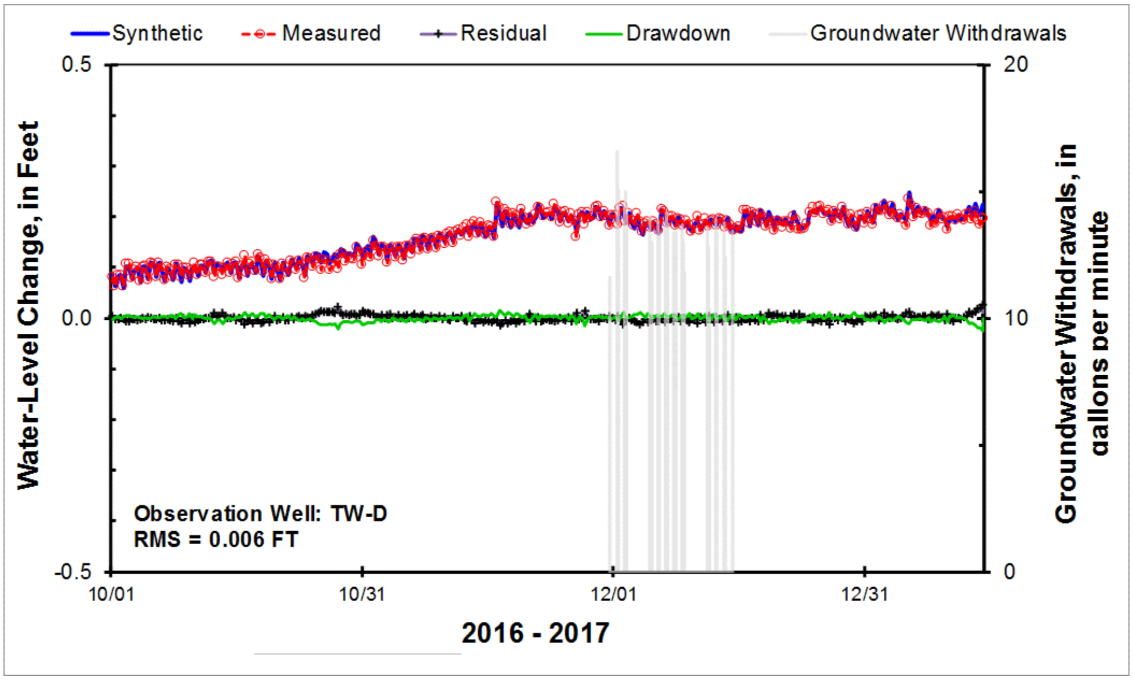
0.0
-0.5
20
10
0
Observation Well: ER-6-2
RMS = 0.003 FT
10/01
10/31
12/01
12/31
2016 - 2017

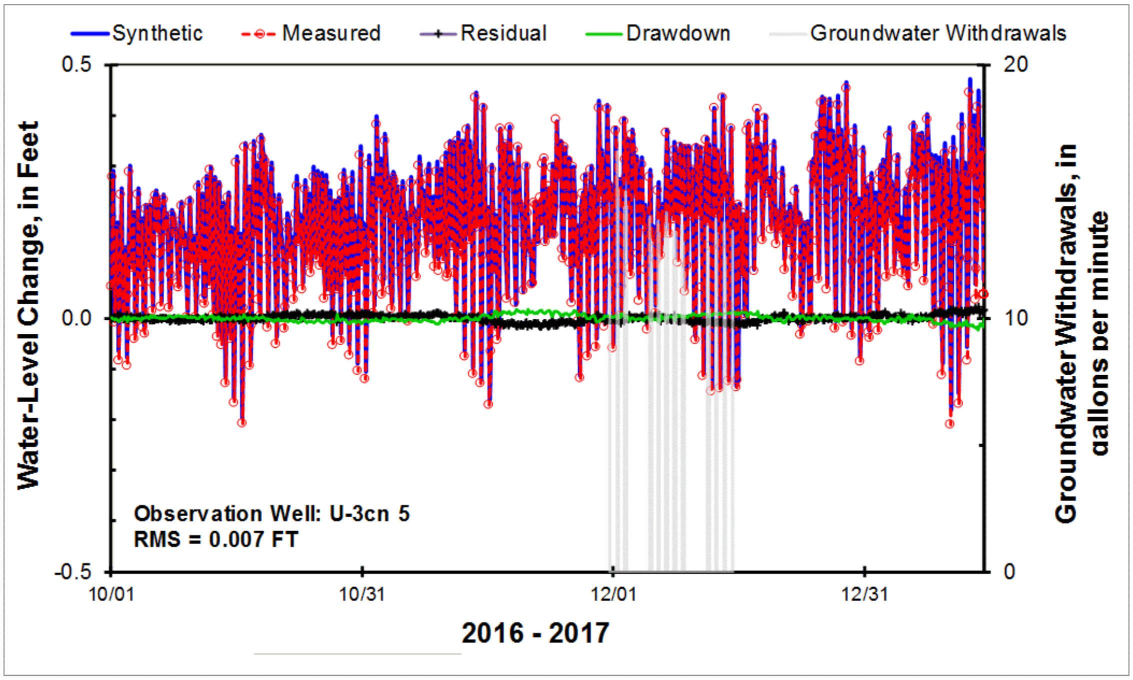


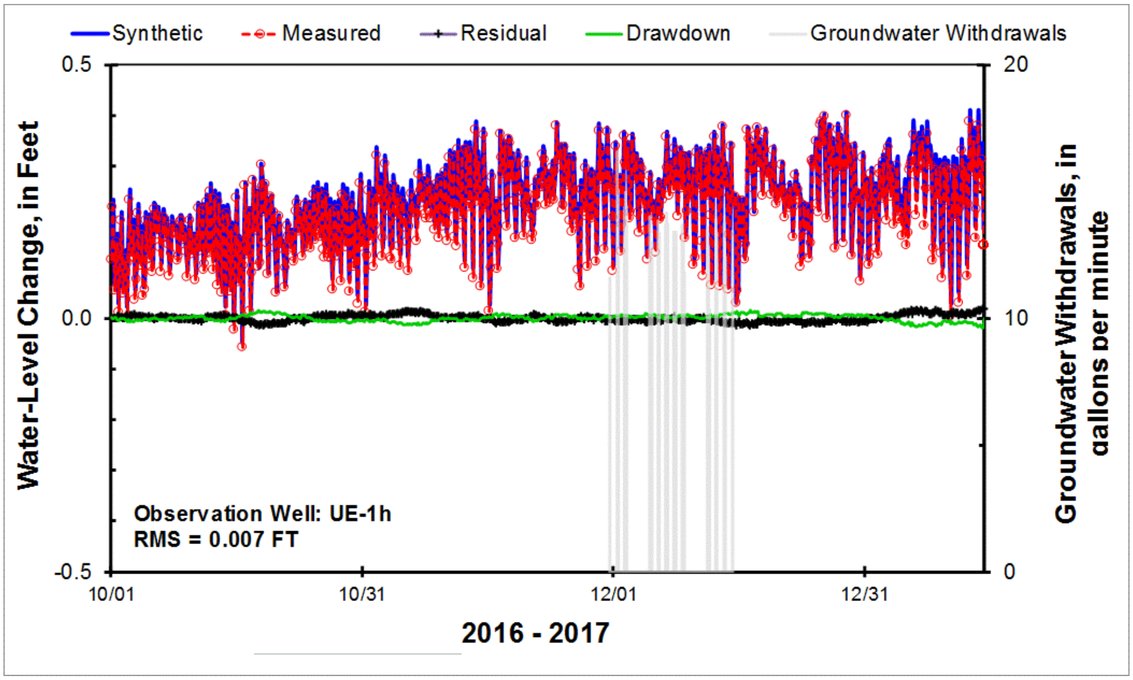
Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
20
10
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: ER-7-1
RMS = 0.003 FT
10/01
10/31
12/01
12/31
2016 - 2017

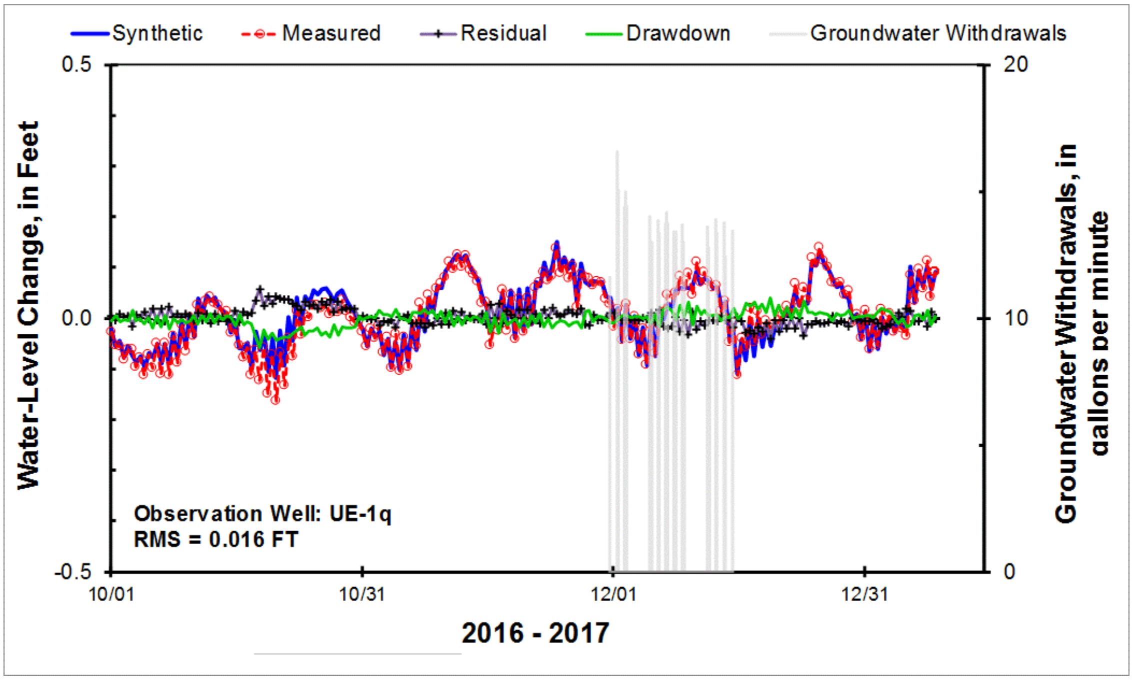


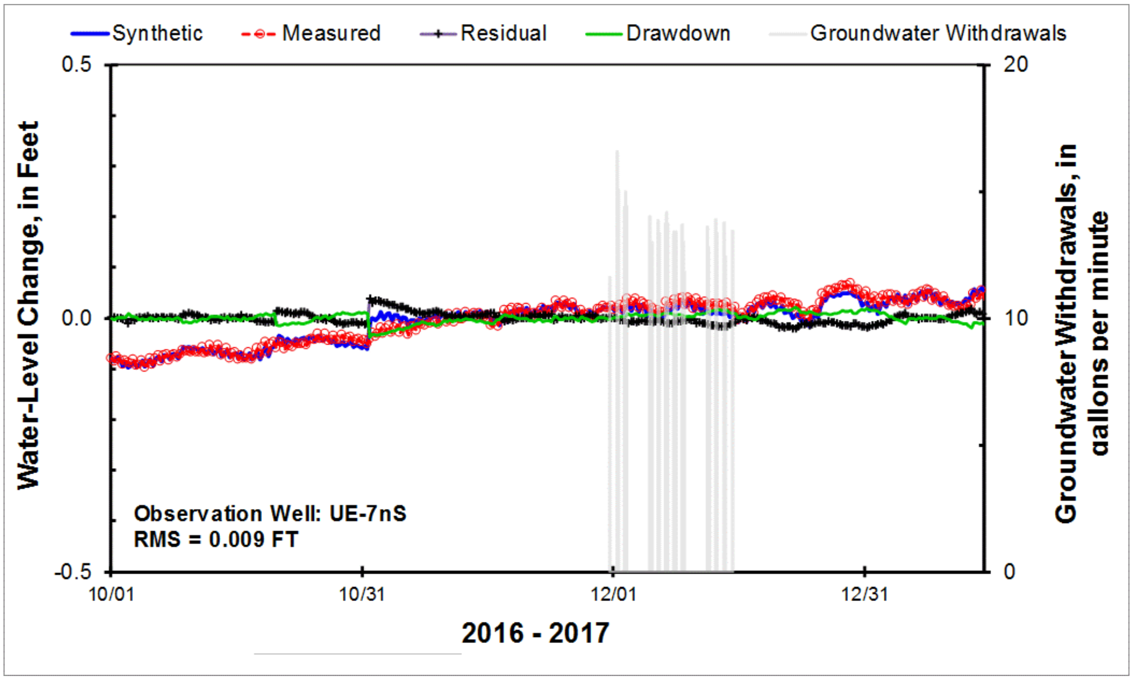
Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
20
10
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: TW-7
RMS = 0.008 FT
10/01
10/31
12/01
12/31
2016 - 2017


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
20
10
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: TW-D
RMS = 0.006 FT
10/01
10/31
12/01
12/31
2016 - 2017

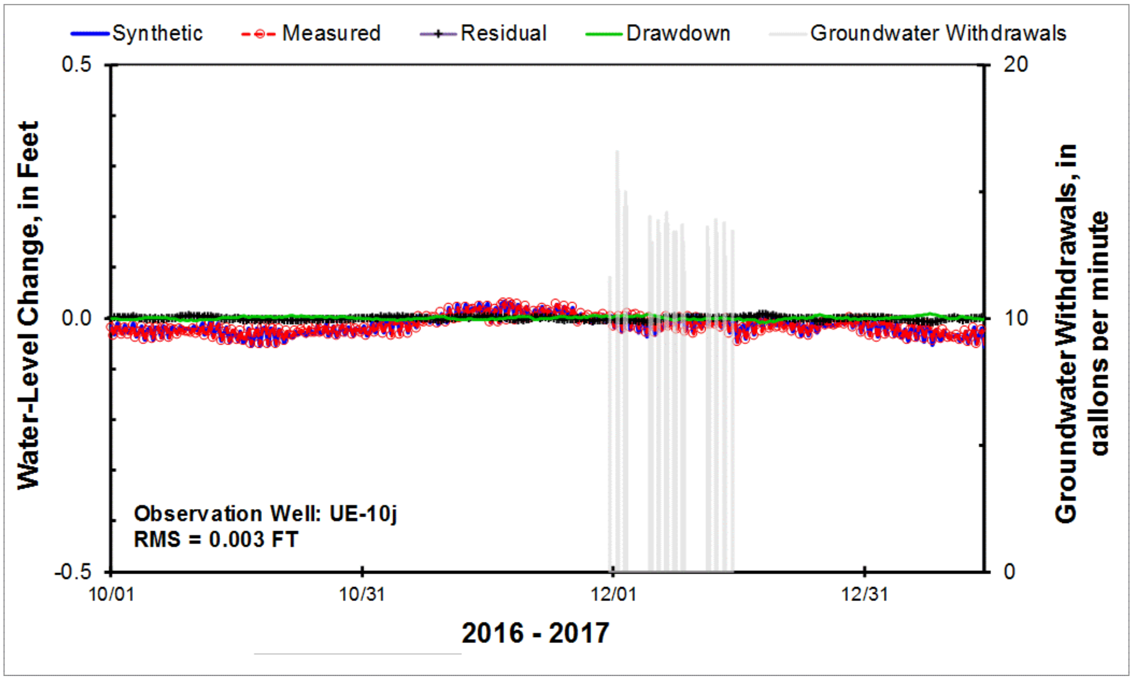

Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
20
10
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: U-3cn 5
RMS = 0.007 FT
10/01
10/31
12/01
12/31
2016 - 2017


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
20
10
0
Observation Well: UE-1h
RMS = 0.007 FT
10/01
10/31
12/01
12/31
2016 - 2017

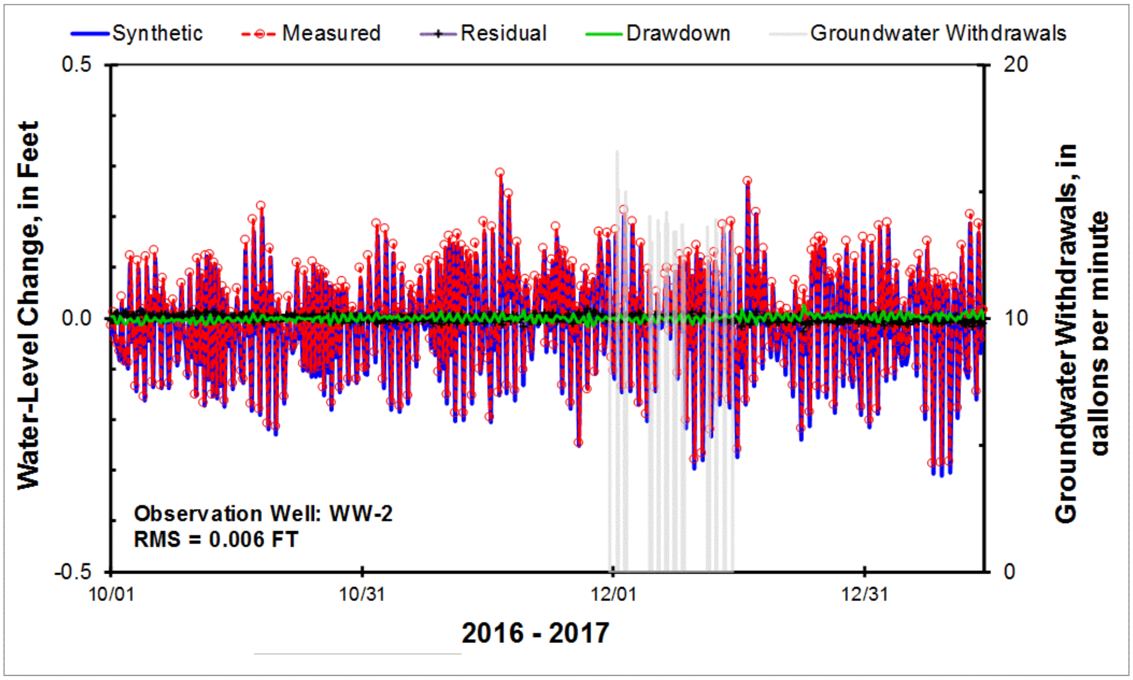

Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
20
10
0
Observation Well: UE-1q
RMS = 0.016 FT
10/01
10/31
12/01
12/31
2016 - 2017



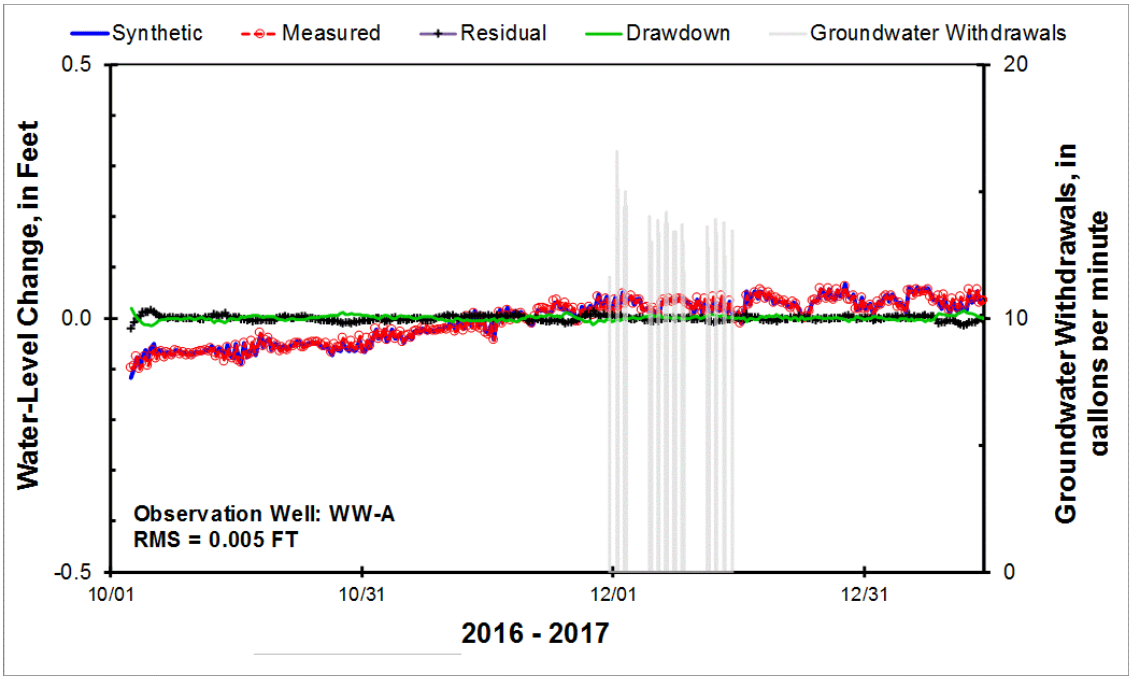
Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
20
10
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: UE-7nS
RMS = 0.009 FT
10/01
10/31
12/01
12/31
2016 - 2017



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
20
10
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: UE-10j
RMS = 0.003 FT
10/01
10/31
12/01
12/31
2016 - 2017



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
20
10
0
10/01
10/31
12/01
12/31
2016 - 2017
Observation Well: WW-2
RMS = 0.006 FT



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
20
10
0
10/01
10/31
12/01
12/31
2016 - 2017
Observation Well: WW-A
RMS = 0.005 FT

Appendix B. Water-Level Models, Slug Test Analysis, and Supporting Datasets

Water-level models, the slug test analysis, and supporting datasets are in the compressed (zip) file, AppendixB. The zip file contains 4 directories: (1) *CleanData*; (2) *SlugTest*; (3) *WellCompletionDiagram*; and (4) *WLM*.

The *CleanData* directory contains time series data used to estimate drawdowns and aquifer transmissivity. Time series data include observation-, pumping-, and background-well water levels and barometric pressure, and pumping rates for ER-3-3 m1. Raw data were obtained from Navarro. For each of the observation and background wells, a Microsoft© Excel workbook contains hourly averages of water level and barometric pressure data. Bad values (values equal to 99999 or 0) were removed from the time series data prior to averaging.

The *SlugTest* directory contains a macro-enabled Microsoft© Excel workbook that was used to estimate the transmissivity of the lower carbonate aquifer at ER-3-3. The COMPUTATION worksheet contains formulas used to compute aquifer hydraulic conductivity and transmissivity using the Bouwer and Rice (1976) method. The DEFAULT PROPERTIES and SETTINGS worksheet contains a reference table of extreme and likely ranges of hydraulic conductivity for different aquifer materials. The OUTPUT worksheet is used to input well construction information for computing hydraulic properties, and shows a semi-log displacement-time plot for the Bouwer and Rice analysis of the *ER-3-3 m1* aquifer test. The DATA worksheet is used to input water-level data for computing hydraulic properties. The EFFECTIVE DIAMETER worksheet contains the computation of the effective casing diameter.

The *WellCompletionDiagram* directory contains a Portable Document File (PDF) showing the well completion of borehole ER-3-3. Well completion diagram was modified from Navarro (written communication, 2017).

The *WLM* directory contains 16 water-level models (macro-enabled Microsoft© Excel workbooks) for water-level records from the 16 observation wells located away from the pumping site. Water-level models were generated using a Microsoft© Excel add-in, SeriesSEE (Halford and others, 2012). Each Microsoft Excel workbook has three worksheets: DATA, Series, and WLmodel. The DATA tab contains the time-series data used in the water-level model. Data include time series of water levels from the observation well and background well(s), barometric pressure at the observation and (or) background well(s), and pumping data. The Series tab contains the time series used in the water-level model. Time series include moving averages of water levels and barometric pressure in background wells, Theis transforms of pumping in well ER-3-3, and time series of gravity tides (in microgals) and solid Earth tides (dry dilation in ppb). Measured, synthetic, residuals, and estimated drawdown time series also are included in this worksheet. The WLmodel tab shows the parameters used in the water-level model, a plot of measured versus synthetic water levels and residuals, and the overall RMSE.

Appendix F

USGS ER-4-1_m1 Multiple-Well Aquifer Test of Lower Carbonate Aquifer

(27 Pages)

United States Department of the Interior

U.S. GEOLOGICAL SURVEY
Nevada Water Science Center
160 North Stephanie Street
Henderson, NV 89074

MEMORANDUM

June 1, 2017

To: Devin Galloway, Groundwater Specialist, Water Science Field Team, USGS, Water Mission Area, Indianapolis, Indiana

From: Tracie R. Jackson, Hydrologist
USGS, Nevada Water Science Center, Henderson, Nevada

Subject: AQUIFER TEST PACKAGE—Drawdown estimation and analysis of the *ER-4-1 m1* multiple-well aquifer test of the lower carbonate aquifer, Yucca Flat, Nevada National Security Site

This memorandum documents the analysis of the *ER-4-1 m1* multiple-well aquifer test in Yucca Flat at the Nevada National Security Site (NNSS). Goals of the analysis were to estimate the transmissivity of the lower carbonate aquifer (LCA) at well *ER-4-1 m1* and to estimate drawdowns in observation wells from a multiple-well aquifer test in well *ER-4-1 m1*. The drawdowns estimated at observations wells documented in this text are not used to interpret hydraulic properties, but can be used to calibrate numerical groundwater-flow models.

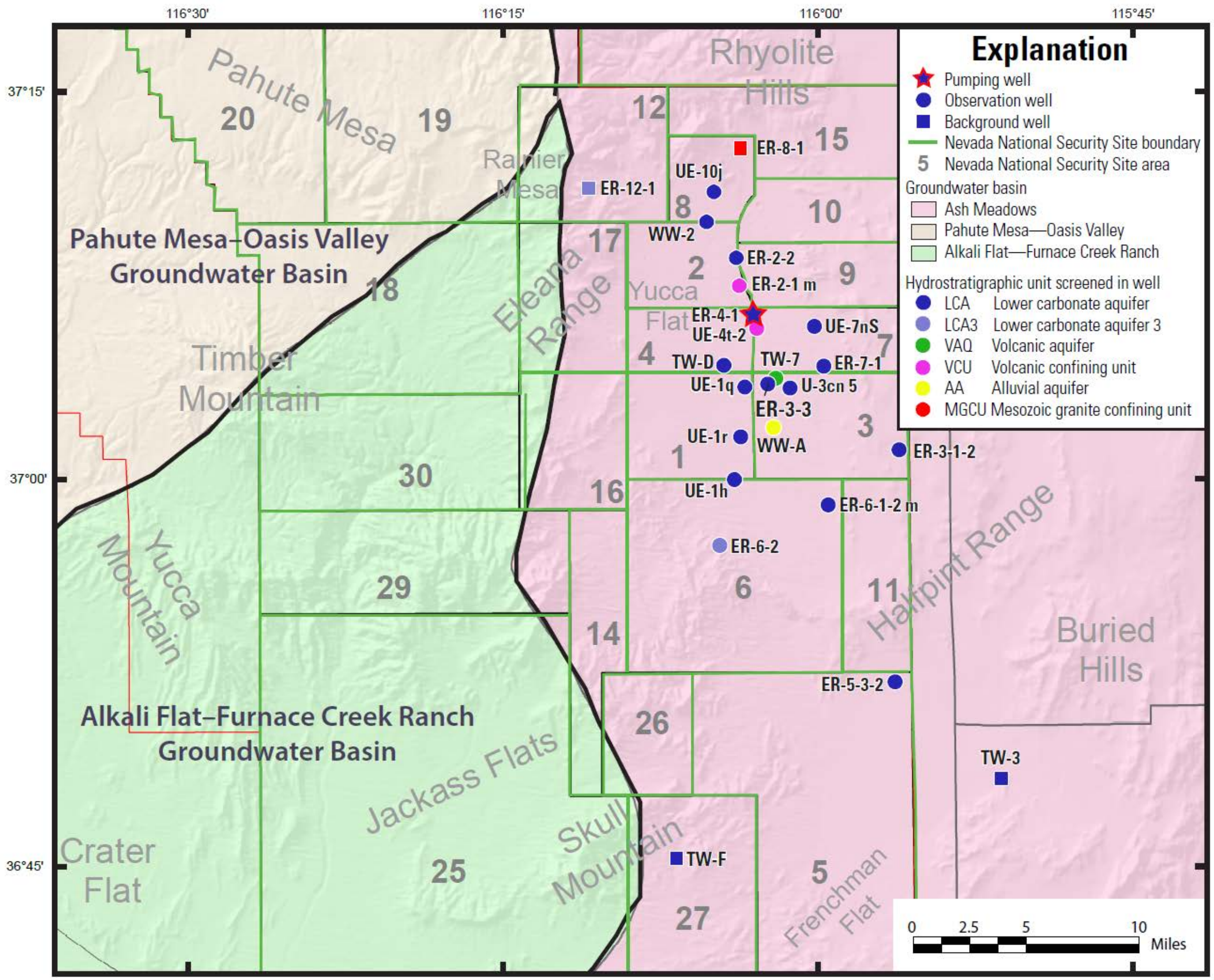
The *ER-4-1 m1* multiple-well aquifer test of the LCA was conducted by a private contractor, *Navarro*, from January 13, 2017 to February 17, 2017. The LCA is a regional carbonate aquifer that extends from Yucca Flat to groundwater discharge areas downgradient of the NNSS boundary. Borehole ER-4-1 is within the central corridor of underground nuclear testing in Yucca Flat.

A network of 27 pumping, observation, and background wells in Rainier Mesa, Yucca Flat, and Frenchman Flat (Figure 1; Table 1) were instrumented with pressure transducers by *Navarro* and the U.S. Geological Survey (USGS). Water levels were monitored continuously for potential drawdowns related to well development and aquifer testing in well *ER-4-1 m1*. About 1.7 million gallons of groundwater was withdrawn from the LCA in well ER-4-1 m1 during well development and testing.

Drawdowns were estimated at 17 observation wells using water-level models as described by Halford and others (2012). Water-level models were used because of the potential for drawdowns to be masked by environmental water-level fluctuations. Drawdown was detected in six wells: *ER-6-1-2 m*, *ER-7-1*, *U-3cn 5*, *UE-7nS*, *UE-10j*, and *WW-2*. Drawdown was not detected in 11 wells: *ER-2-1 m*, *ER-2-2*, *ER-3-1-2*, *ER-5-3-2*, *ER-6-2*, *TW-7*, *TW-D*, *UE-1h*, *UE-1q*, *UE-1r*, and *WW-A*. Hydrographs including estimated drawdowns, synthetic water levels from water-level models, measured water levels and residual (measured minus synthetic water levels) in the 17 observation wells as well as pumping rate time series are shown in Appendix A. The water-level models, aquifer test analysis, and supporting datasets are provided in Appendix B.

Description of Well Network

The 27 well sites monitored by *Navarro* and the USGS during *ER-4-1 m1* aquifer testing are located in the eastern part of the Nevada National Security Site (Figure 1). Wells monitored are categorized as pumping, observation, or background wells. Observation wells are instrumented to record potential water-level changes during well development and aquifer testing in well *ER-4-1 m1*. Background wells are assumed to be unaffected by well development and aquifer testing and are used to monitor background water-level changes used in water level modeling for estimated drawdown analyses. Table 1 provides location and well construction information for the pumping well, 22 observation wells, and 4 background wells.



Universal Transverse Mercator Projections, Zone 11, North American Datum of 1983 (NAD83)

Figure 1. Location of *ER-4-1 m1* pumping well and network of observation and background wells instrumented during aquifer testing. Hydrostratigraphic unit definitions from Prothro and others (2009).

Table 1. Well location and construction data for pumping, observation, and background wells monitored during well *ER-4-1 m1* development and testing, Nevada National Security Site.

[**Well Name** refers to the name of the well in the USGS National Water Information System (NWIS) database (https://nwis.waterdata.usgs.gov/nwis), where the **bold** part of the name is shown on Figure 1 and used in the text of this document; **Site Identifier** is a unique, 15-digit, U.S. Geological Survey site identification number; **Latitude** and **Longitude** are in decimal degrees and referenced to North American Datum of 1983 (NAD 83); **Ground surface altitude** is the altitude of the well in feet above National Geodetic Vertical Datum of 1929 (NGVD 29); **Depth to static water level** is the water-level depth in the well, in feet below ground surface (ft bgs); **Top of open interval** and **Bottom of open interval** correspond to the depth of the top and bottom of the open interval (interval can include well screen and gravel pack and/or open hole)].

Well Name	Site Identifier	Latitude	Longitude	Ground surface altitude, ft	Depth to static water level, ft bgs	Top of open interval, ft bgs	Bottom of open interval, ft bgs
Pumping Well							
ER- 4-1 m1	370625116030001	37.1069	-116.0500	4,158	1,769	2,812	3,035
Observation Wells							
ER- 2-1 main (shallow)	370725116033901	37.1253	-116.0628	4,216	1,725	1,642	2,177
ER- 2-2 o2	370831116035001	37.1419	-116.0639	4,273	2,410[a]	2,008	3,457
ER- 3-1-2 (shallow)	370116115561302	37.0192	-115.9367	4,407	2,014	2,208	2,310
ER- 3-3 p1	370349116021904	37.0636	-116.0386	4,054	1,667	2,630	3,193
ER- 3-3 p2	370349116021905	37.0636	-116.0386	4,054	1,653	2,203	2,507
ER- 3-3 p3	370349116021906	37.0636	-116.0386	4,054	1,444	118	1,940
ER- 4-1 p1	370625116030002	37.1069	-116.0500	4,158	1,052	118	2,375
ER- 5-3-2	365223115561801	36.8731	-115.9392	3,335	945	4,674	5,683
ER- 6-1-2 main	365901115593501	36.9839	-115.9939	3,935	1,544	1,775	3,200
ER- 6-2	365740116043501	36.9611	-116.0772	4,231	1,780	1,746	3,430
ER- 7-1	370424115594301	37.0733	-115.9961	4,246	2,394	1,775	2,500
TW- 7	370353116020201	37.0650	-116.0339	4,058	1,646	41	2,272
TW- D	370418116044501	37.0744	-116.0758	4,150	1,723	1,700	1,950
U - 3cn 5	370320116012001	37.0594	-116.0233	4,009	1,619	2,832	3,030
UE- 1h	370005116040301	37.0014	-116.0683	3,995	1,552	2,134	3,358
UE- 1q (2600 ft)	370337116033002	37.0603	-116.0592	4,081	1,655	2,459	2,600
UE- 1r WW	370142116033301	37.0283	-116.0592	4,042	1,616	2,319	4,182
UE- 4t 2 (1564-1754 ft)	370556116025406	37.0989	-116.0483	4,141	868	1,564	1,754
UE- 7nS	370556116000901	37.0986	-116.0033	4,367	1,968	1,707	2,205
UE-10j (2232-2297 ft)	371108116045303	37.1856	-116.0825	4,574	2,156	2,232	2,297
WW- 2 (3422 ft)	370958116051512	37.1661	-116.0886	4,470	2,052	2,700	3,422
WW- A (1870 ft)	370142116021101	37.0369	-116.0372	4,006	1,599	1,555	1,870
Background Wells							
ER- 8-1 (recompleted)	371248116032102	37.2133	-116.0567	4,820	2,293	1,947	2,863
ER-12-1 (1641-1846 ft)	371106116110401	37.1847	-116.1850	5,817	1,519	1,641	1,846
TW- 3	364830115512601	36.8083	-115.8581	3,484	1,104	165	1,860
TW- F (3400 ft)	364534116065902	36.7594	-116.1175	4,143	1,734	3,142	3,392

[a]Estimated steady-state water level at well ER-2-2 o2. Available water levels for this well are nonstatic.

Hydrogeology

Yucca Flat is underlain by three types of aquifers: alluvial, volcanic, and carbonate rock. The alluvial aquifers are underlain by a thick sequence of volcanic aquifers and confining units. Alluvial and volcanic aquifers contribute limited flow to the underlying carbonate aquifer because of a volcanic confining unit that acts as a flow barrier (Winograd and Thordarson, 1975).

Alluvial deposits form thin, localized aquifer systems in the Yucca Flat basin. Alluvial aquifers comprise poorly sorted gravels and sands derived from Tertiary volcanic and Paleozoic sedimentary rocks (Slate and others, 1999). Alluvial deposits increase in thickness from the margins to the center of the basin (Bechtel Nevada, 2006), and are unsaturated throughout most of Yucca Flat. However, alluvial aquifers have saturated thicknesses of up to 2,000 ft in areas along the central corridor of Yucca Flat (Fenelon and others, 2012). Observation well *WW-A* is the only well screened in the alluvial aquifer (Figure 1). Borehole ER-4-1 intersects 620 ft of unsaturated alluvial deposits (see well completion diagram in Appendix B).

Volcanic rocks form localized and regionally extensive aquifer systems throughout Yucca Flat. The majority of volcanic rocks were erupted during the Miocene from within the southwestern Nevada volcanic field (Winograd and Thordarson, 1975), which is located to the north and west in the Pahute Mesa—Oasis Valley and Alkali Flat—Furnace Creek Ranch groundwater basins (Figure 1). Regionally extensive volcanic aquifers comprise moderately to densely welded ash-flow tuffs. Localized volcanic aquifers comprise fractured vitric ash-fall tuffs and rhyolitic lava flows. Volcanic aquifers typically have saturated thicknesses of less than 500 ft (Fenelon and others, 2012). Observation wells *TW-7*, *ER-3-3 p2*, and *ER-3-3 p3* are screened in volcanic aquifers (Figure 1).

A thick, regionally extensive volcanic confining unit forms a hydraulic barrier between the volcanic aquifers and underlying carbonate aquifer throughout most of the Yucca Flat basin. The volcanic confining unit comprises nonwelded ash-flow tuff, bedded tuff, and reworked tuffaceous sediments that are commonly zeolitized (Winograd and Thordarson, 1975). The saturated thickness of the volcanic confining unit typically ranges between 500 and 2,000 ft (Fenelon and others, 2012). The volcanic confining unit is absent in the western part of Yucca Flat, where volcanic aquifers directly overlie the lower carbonate aquifer. Wells *ER-2-1 m*, *ER-4-1 p1*, and *UE-4t* 2 are screened in the tuff confining unit.

Carbonate aquifers form localized and regionally extensive aquifer systems. The LCA3 is a localized carbonate aquifer in parts of Rainier Mesa and central Yucca Flat (Figure 1). The regional lower carbonate aquifer (LCA) occurs throughout Yucca Flat and large areas of southern Nevada. The LCA comprises a thick sequence of Paleozoic limestones and dolostones, and has a saturated thickness of more than 15,000 ft in some areas. Pumping well *ER-4-1 m1* is open to 223 ft of the LCA (see well completion diagram in Appendix B), and the majority of observation wells are screened in the LCA (Figure 1).

Data Collection

Data were collected before, during, and after well development and aquifer testing. Continuously measured data include water levels, water temperature, and barometric pressure at the pumping, observation, and background wells (Table 1), and pumping rates in the pumping well. Water levels and temperature were measured using an INW PT12 pressure transducer, which has a pressure accuracy of ± 0.05% of the pressure range. INW PT12 pressure transducers installed in distant observation wells and background wells had a pressure range of 0 to 30 psia, whereas pressure transducers installed in the pumping well and observation wells at borehole ER-4-1 had a pressure range of 0 to 2000 psia (accuracy of about 2.36 ft). The INW PT12 pressure transducer also has a temperature range of 0º to 55ºC (32º to 131ºF) with a temperature accuracy of ± 0.5ºC. Barometric pressure was measured using a PTB110 barometer, which has an accuracy of ± 0.3 hPa at 20ºC (68ºF). A CR1000 Campbell Scientific datalogger was used to measure and record water levels, water temperature, and barometric pressure every 10 minutes or if a water-level change greater than 0.05 psi occurred. The Foxboro 8002A series flowmeter, which has a flow rate range of 13 to 250 gal/min and a flow rate accuracy of 0.029%, was used to measure pumping rates.

Water levels were analyzed for drawdown at 17 observation wells (Table 2). These wells are screened across a range of hydrostratigraphic units, and exist in opposing azimuthal quadrants from the pumping well (Figure 1). The horizontal distance between pumping and observation wells ranged from less than 1 to 17.2 miles (0.5 to 91,076 feet) (Table 2). The selection of observation wells analyzed for drawdown was sufficient to understand hydraulic connections between ER-4-1, screened in the LCA, and observation wells screened in the LCA, alluvial aquifer, and volcanic aquifer.

Water levels in observation wells *ER-3-3 p1*, *ER-3-3 p2*, *ER-3-3 p3*, *ER-4-1 p1*, and *UE-4t 2* were not used in the drawdown analysis. Continuous water-level data in *p1*, *p2* and *p3* within borehole ER-3-3 have a two-month data gap (November–January) immediately prior to well development and aquifer testing, which precluded drawdown estimates in these wells. Water levels in well *ER-4-1 p1* currently are recovering following well construction, and are not representative of hydrologic conditions in the aquifer system. Continuous water-level data in well *UE-4t 2* had an anomalous rising trend during well development and testing that is not representative of hydrologic conditions in the aquifer system. The rising trend is formation equilibration as water in the wellbore equilibrates to low-transmissivity air-fall and bedded tuffs in the open interval of the well due to nearby nuclear testing (Halford and others, 2005; Elliott and Fenelon, 2010). Other wells screened in the tuff confining unit, such as wells ER-2-1 m, have equilibrated to the formation and water levels are representative of aquifer conditions.

The constant-rate aquifer test of well *ER-4-1 m1* lasted about 243 hours and was conducted from 2/07/2017 09:34 to 2/17/2017 12:07 (Table 3). The discharge rate during the constant rate test averaged 71 gal/min with a total groundwater withdrawal of more than 1 million gallons. An additional 0.7 million gallons were pumped from *ER-4-1 m1* for purposes of testing the pump function, well development and step-drawdown testing between 1/13/2017 and 2/06/2017, prior to the constant-rate test. Therefore, total withdrawal during well development and testing was 1.7 million gallons. Well development and aquifer testing of well *ER-4-1 m1* are summarized in Table 3, and shown in Figure 2. Raw pumping data and a simplified pumping schedule are in the

CleanData directory of Appendix B. All pumping is included in drawdown analyses where drawdown is estimated using water-level models.

Table 2. Distance and bearing of observation wells from pumping well *ER-4-1 m1* during multiple-well aquifer testing, January–February 2017.

[**Well name:** name of well in USGS National Water Information System database, where **bold** part of name is used in text of this document;
Horizontal distance from pumping well: horizontal distance, in feet, from pumping well *ER-4-1 m1*;
Bearing relative to pumping well: true bearing, in degrees (referenced to 0°N), from pumping well *ER-4-1 m1* to observation well.
Analyzed for drawdown?: Observation wells analyzed for drawdown or not analyzed for drawdown are denoted with a “Yes” or “No”, respectively.]

Well Name	Horizontal distance from pumping well, in feet	Bearing relative to pumping well	Analyzed for drawdown?
ER- 2-1 main (shallow)	7,642	331°	Yes
ER- 2-2 o2	13,367	342°	Yes
ER- 3-1-2 (shallow)	45,976	134°	Yes
ER- 3-3 p1	16,119	168°	No
ER- 3-3 p2	16,119	168°	No
ER- 3-3 p3	16,119	168°	No
ER-4-1 p1	0.5	270°	No
ER- 5-3-2	91,076	159°	Yes
ER- 6-1-2 main	47,689	160°	Yes
ER- 6-2	53,673	188°	Yes
ER- 7-1	19,915	128°	Yes
TW- 7	15,974	163°	Yes
TW- D	14,024	212°	Yes
U - 3cn 5	18,958	156°	Yes
UE- 1h	38,792	188°	Yes
UE- 1q (2600 ft)	17,195	189°	Yes
UE- 1r WW	28,738	185°	Yes
UE- 4t 2 (1564-1754 ft)	2,972	171°	No
UE- 7nS	13,940	103°	Yes
UE-10j (2232-2297 ft)	30,140	342°	Yes
WW- 2 (3422 ft)	24,298	333°	Yes
WW- A (1870 ft)	25,750	172°	Yes

Table 3. General pumping schedule of well *ER-4-1 m1* during well development and aquifer testing in Yucca Flat, January-February, 2017.

[**Start date/time and End date/time**: Start and end date and time (Pacific Standard Time) of pumping from *Navarro* daily well development and testing reports.
Pumping duration: Time, in minutes, that pump was turned on.
Discharge rate: Approximate discharge, to the nearest gallons per minute, of the pumping well between the start and end time. Value estimated from *Navarro* daily well development and testing reports. Hyphens indicate a range of pumping rates during step-drawdown testing.
Total discharge: Approximate discharge, to the nearest gallon, of the pumping well between the start and end time. Value based upon data collected from in-line flowmeter.]

Start date/time	End date/time	Aquifer-test description	Pumping duration	Discharge rate	Total discharge
01/13/2017 14:22	01/13/2017 14:24	Pump function test	2	17	25
01/17/2017 09:30	01/17/2017 09:49	Well development	19	31	580
01/17/2017 11:07	01/17/2017 11:25	Well development	18	35	635
01/17/2017 12:40	01/17/2017 15:32	Well development	172	37	6,055
01/18/2017 11:42	01/19/2017 09:31	Step drawdown test	589	50-70-42-30	42,349
01/19/2017 10:47	01/19/2017 14:54	Step drawdown test	367	40-50-59-67	12,850
01/19/2017 15:02	01/19/2017 15:06	Step drawdown test	4	61	206
01/19/2017 15:47	01/20/2017 09:01	Step drawdown test	1,094	50	50,649
01/20/2017 09:46	01/20/2017 09:55	Step drawdown test	9	50-24-40	202
01/20/2017 10:07	01/20/2017 10:19	Step drawdown test	12	50-23	276
01/20/2017 11:44	01/20/2017 14:09	Step drawdown test	265	50-95-48-110-48-70	7,482
01/20/2017 14:37	01/21/2017 09:35	Step drawdown test	1,198	57	65,239
01/21/2017 11:11	01/21/2017 11:40	Step drawdown test	29	84-50	1,563
01/21/2017 11:53	01/22/2017 08:15	Step drawdown test	1,222	49-30-55-78-55	65,028
01/22/2017 09:13	01/23/2017 09:16	Step drawdown test	1,443	50-70-90-45	73,507
01/23/2017 10:17	01/24/2017 07:13	Step drawdown test	1,256	50-70-90-45	65,168
01/24/2017 08:56	01/24/2017 12:43	Step drawdown test	227	50-70-50-70-50	11,734
01/25/2017 10:43	01/26/2017 07:54	Step drawdown test	1,330	50-70	87,372
01/26/2017 08:53	01/26/2017 09:56	Step drawdown test	63	48-37-27-65-49	2,961
01/26/2017 10:28	01/26/2017 10:36	Step drawdown test	8	50-27-50	285
01/26/2017 11:56	01/27/2017 07:53	Step drawdown test	1,197	46-65-50-70	77,204
01/27/2017 09:00	01/27/2017 15:20	Step drawdown test	500	60-70-90-80-90	28,991
02/01/2017 10:43	02/01/2017 14:08	Step drawdown test	325	50-70-90-50-65-90	12,575
02/01/2017 14:39	02/02/2017 07:57	Step drawdown test	1,038	90-50-70-90-80	85,050
02/06/2017 10:08	02/06/2017 10:28	Step drawdown test	20	80-39	1,066
02/06/2017 11:33	02/06/2017 11:46	Step drawdown test	13	39-73-40-74	718
02/06/2017 13:12	02/06/2017 14:38	Step drawdown test	86	70-39-71	4,796
02/07/2017 09:34	02/17/2017 12:07	Constant-rate test	14,553	71	1,027,594

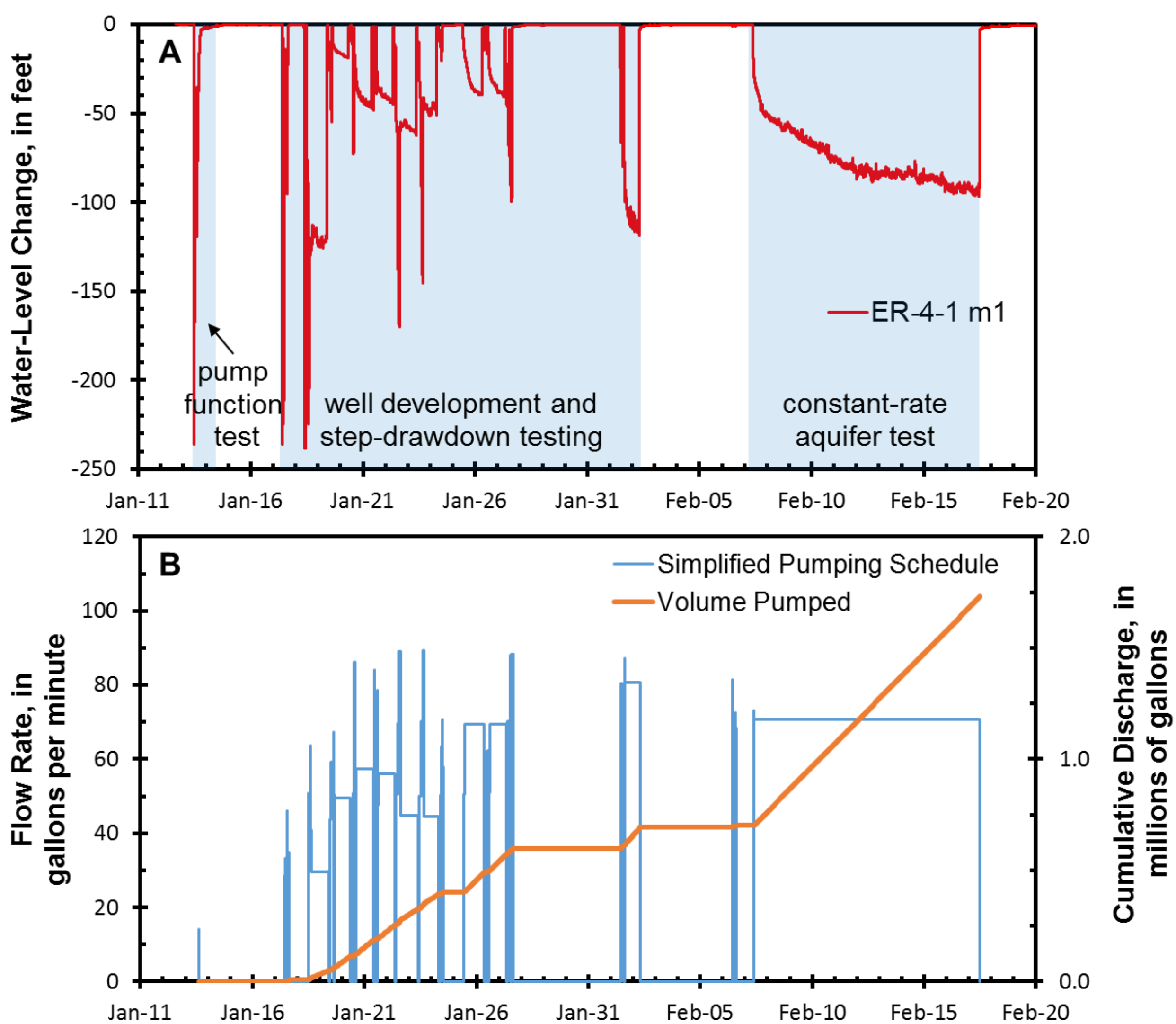


Figure 2. (**A**) Water levels in and (**B**) flow rate and cumulative discharge from well *ER-4-1 m1* during pump function testing, well development, step-drawdown testing and aquifer testing January 13–February 17, 2017. Pumping Data were binned into 204 pumping steps for use in the Theis transform model.

Drawdown Estimation Using Water-Level Models

Drawdowns from pumping well *ER-4-1 m1* were estimated in observation wells using a water-level modelling approach described by Halford and others (2012). Water-level modeling was used to estimate drawdown because environmental (non-pumping) water-level fluctuations of more than 0.2 ft masked drawdown from pumping in observation wells. Drawdown was differentiated from environmental fluctuations by fitting measured water levels to a synthetic water-level curve. The synthetic curve is the sum of simulated environmental water-level fluctuations and the pumping signal.

Environmental water-level fluctuations were simulated using time series of barometric pressure, earth and gravity tides, and water levels from background wells *ER-8-1*, *ER-12-1*, *TW-3*, and *TW-F*. The background wells are assumed to be close enough to observations wells to be affected by similar environmental fluctuations, yet distant enough to be unaffected by pumping from aquifer testing. Water levels from background wells were critical because they were affected by tidal potential–rock interaction, barometric pressure, and seasonal or long-term climatic trends. These effects also are assumed present in the observation wells.

Responses from pumping well *ER-4-1 m1* were modeled with a Theis transform of the pumping signal, where multiple pumping rates were simulated by superimposing multiple Theis (1935) solutions. Theis transforms serve as simple transform functions, where step-wise pumping records are translated into approximate water-level responses. Numerical experiments have confirmed that superimposed Theis transforms closely approximate water-level responses through hydrogeologically complex aquifers (Garcia and others, 2013).

Synthetic water levels were fit to measured water levels by minimizing the Root-Mean-Square (RMS) error of differences between synthetic and measured water levels (Halford and others, 2012). Amplitude and phase were adjusted in each time series used to simulate environmental water-level fluctuations (barometric pressure, water levels in background wells, and earth and gravity tides). Transmissivity and the storage coefficient were adjusted in the Theis transform model.

Synthetic water levels in the water-level models represented summed time series of earth tides, gravity tides, barometric pressure, recharge responses, and pumping responses. Earth and gravity tides were computed functions based on well-established theoretical equations (Harrison, 1971). Barometric pressure typically was measured at the well being analyzed and/or at the background well. Pumping responses were simulated with Theis transforms that used 204 simplified pumping steps in *ER-4-1 m1* (Figure 2). These simplified steps were sufficient to calculate the pumping response in observation wells with Theis transforms. Total withdrawal during the period of well development and testing was 1.7 million gallons.

Drawdown estimates are the summation of Theis transforms minus residual differences between synthetic and measured water levels (Halford and others, 2012). The summation of all Theis transforms is the direct estimate of the pumping signal. Residuals represent all unexplained water-level fluctuations. These fluctuations primarily are random during non-pumping periods, but can contain unexplained components of the pumping signal during pumping periods.

Drawdown detection was classified as detected or not detected (Table 4) based on the signal-to-noise ratio. Signal and noise are defined herein as the maximum drawdown occurring in an observation well during an aquifer test and the RMS error, respectively. Drawdown was classified as detected where the signal-to-noise ratio was greater than or equal to 10 and recovery was observed. Drawdown was classified as not detected where the signal-to-noise ratio was less than or equal to 5, indicating drawdown (if any) could not be reliably differentiated from the noise. Drawdown would have been classified as ambiguous if the signal-to-noise ratio was between 6 and 9; however, computed signal-to-noise ratios did not occur in this range and no drawdowns were classified as ambiguous.

Table 4. Estimated drawdowns in observation wells from the *ER-4-1 m1* aquifer test in Yucca Flat, January, 2017-February, 2017.

[**Estimated maximum drawdown:** Maximum drawdown was estimated by matching measured water levels in the observation well to a synthetic curve of non-pumping (environmental) and pumping responses. NA indicates results not available.
RMS error: Root-mean-square error between measured and synthetic water levels in water-level model.
Signal-to-noise ratio: ratio of estimated maximum drawdown (signal) to RMS error (noise).
Drawdown detection: Drawdown detection is classified as not detected, detected, or not analyzed (NA). Drawdown is not detected where the signal-to-noise ratio is ≤5, indicating drawdown cannot be reliably differentiated from the noise in the dataset. Drawdown is detected definitively where the signal-to-noise ratio is ≥10 and correlation between environmental fluctuations and pumping signals is unlikely.]

Well name	Estimated maximum drawdown (feet)	RMS Error (feet)	Signal-to-noise ratio	Drawdown detection
ER- 2-1 main (shallow)	< 0.03	0.013	2	Not detected
ER- 2-2 o2	< 0.02	0.007	3	Not detected
ER- 3-1-2 (shallow)	< 0.02	0.006	3	Not detected
ER- 3-3 p1 [a]	NA	NA	NA	NA
ER- 3-3 p2 [a]	NA	NA	NA	NA
ER- 3-3 p3 [a]	NA	NA	NA	NA
ER- 4-1 p1 [b]	NA	NA	NA	NA
ER- 5-3-2	< 0.02	0.008	3	Not detected
ER- 6-1-2 main	0.06	0.002	30	Detected
ER- 6-2	< 0.02	0.004	5	Not detected
ER- 7-1	0.06	0.003	20	Detected
TW- 7	< 0.01	0.004	3	Not detected
TW- D	< 0.02	0.004	5	Not detected
U - 3cn 5	0.13	0.006	22	Detected
UE- 1h	< 0.01	0.004	3	Not detected
UE- 1q (2600 ft)	< 0.01	0.002	5	Not detected
UE- 1r WW	< 0.02	0.006	3	Not detected
UE- 4t 2 (1564-1754 ft) [c]	NA	NA	NA	NA
UE- 7nS	0.08	0.002	40	Detected
UE-10j (2232-2297 ft)	0.04	0.002	20	Detected
WW- 2 (3422 ft)	0.02	0.002	10	Detected
WW- A (1870 ft)	< 0.01	0.002	5	Not detected

[a] Water levels have a two-month data gap (November–January) prior to well development and aquifer testing, which precluded drawdown estimates in these wells.
[b] Water levels not used in drawdown analysis because levels were recovering following well construction and are not representative of hydrologic conditions in the aquifer system.
[c] Water levels not used in drawdown analysis because data show an anomalous rising trend during well development and testing that is not representative of hydrologic conditions in the aquifer system.

Estimated Drawdowns

Water levels were modeled from October 30, 2016 to April 1, 2017 to estimate drawdowns at 17 observation wells monitored before, during, and after the aquifer test. Synthetic water levels matched measured water levels with RMS errors between 0.002 and 0.013 ft in observation wells. Estimated drawdowns were classified as either detected or not detected (Table 4).

Estimated drawdown analysis results are shown in Figure 3. Drawdowns were detected in 6 wells: *ER-6-1-2 m*, *ER-7-1*, *U-3cn 5*, *UE-7nS*, *UE-10j*, and *WW-2*. Drawdowns were not detected in 11 wells: *ER-2-1 m*, *ER-2-2*, *ER-3-1-2*, *ER-5-3-2*, *ER-6-2*, *TW-7*, *TW-D*, *UE-1h*, *UE-1q*, *UE-1r*, and *WW-A*. Hydrographs showing estimated drawdowns in all observation wells are provided in Appendix A. Worksheets showing fitting parameters, measured and synthetic water levels, and drawdown estimates for analyzed wells in Table 4 are in individual Microsoft Excel workbooks in the WLM directory of Appendix B.

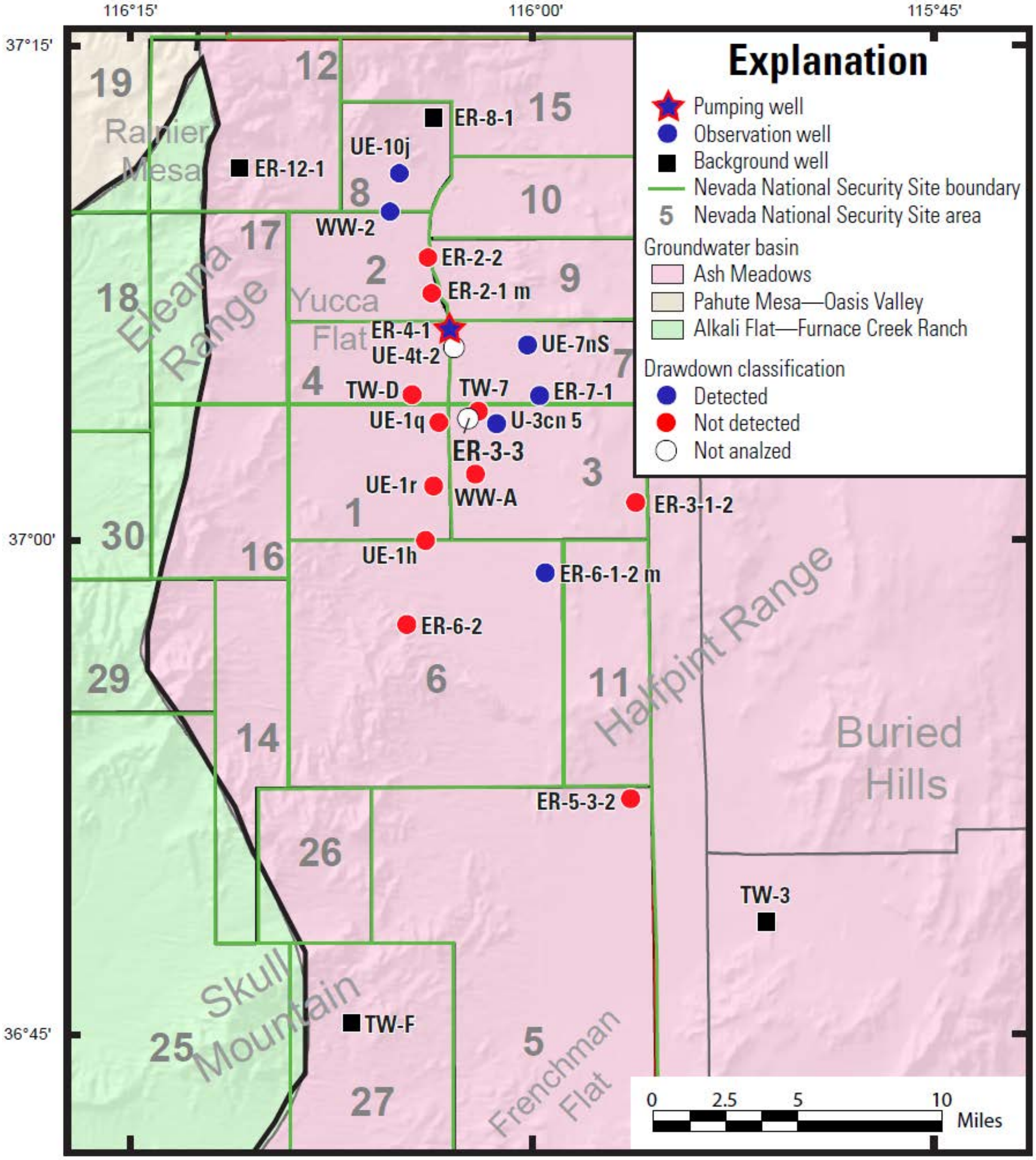


Figure 3. Estimated drawdown results for observation wells from the *ER-4-1 m1* aquifer test in Yucca Flat, January, 2017-February, 2017.

Aquifer Test Analysis

Estimated transmissivity of the LCA differs near and far from borehole ER-4-1. Drawdowns in the pumping well *ER-4-1 m1* were interpreted using the Cooper-Jacob method (Cooper and Jacob, 1946). The period of analysis for estimating transmissivity spans the 10-day constant-rate aquifer test from February 7–17, 2017. On the semi-log drawdown-time plot (Figure 4), a break in slope occurs about 6 hours into the constant-rate test (25,000 gallons pumped). The estimated early-time transmissivity of the LCA is 250 ft^2/d, which is representative of LCA transmissivity near borehole ER-4-1. The estimated late-time (1,000,000 gallons pumped) transmissivity of the LCA is 56 ft^2/d, which is representative of LCA transmissivity farther from borehole ER-4-1. This result is counter-intuitive to estimated drawdown results. Estimated drawdowns were detected up to 9 miles from the pumping well at observation well *ER-6-1-2* (Table 4), suggesting that the LCA transmissivity is high farther from borehole ER-4-1. The cause of the low estimated late-time transmissivity of the LCA is unknown.

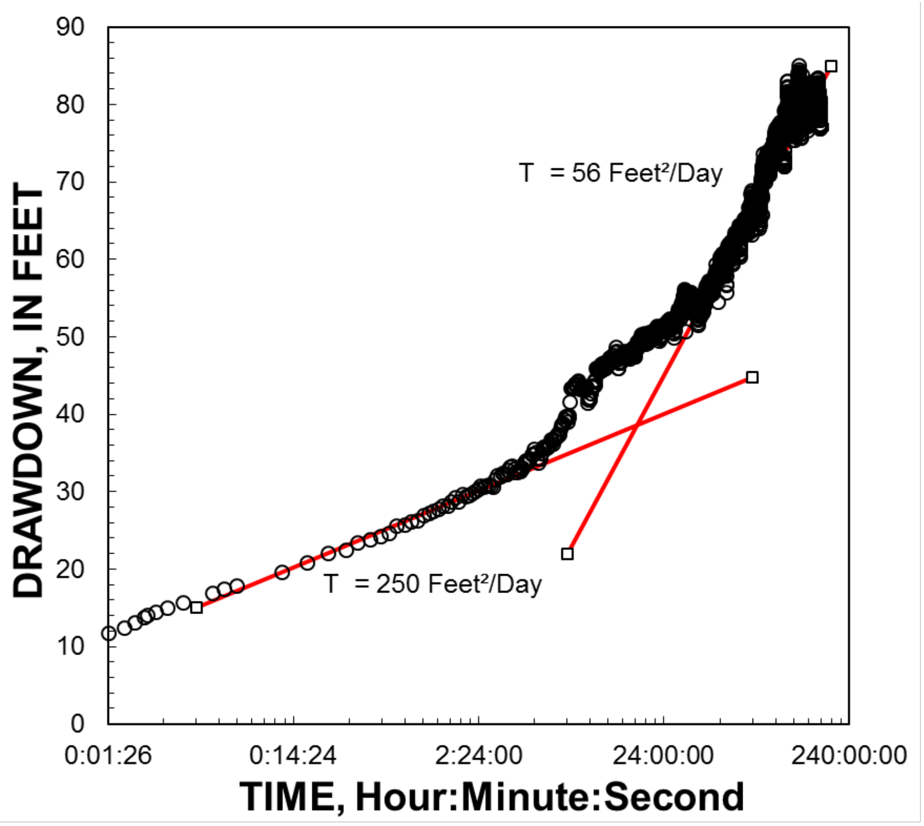


Figure 4. Semi-log drawdown-time plot and straight-line approximations for estimating early-time or near-field (250 ft^2/d) and late-time or far-field (56 ft^2/d) transmissivity at well *ER-4-1 m1* during the constant-rate aquifer test, February 7-17, 2017.

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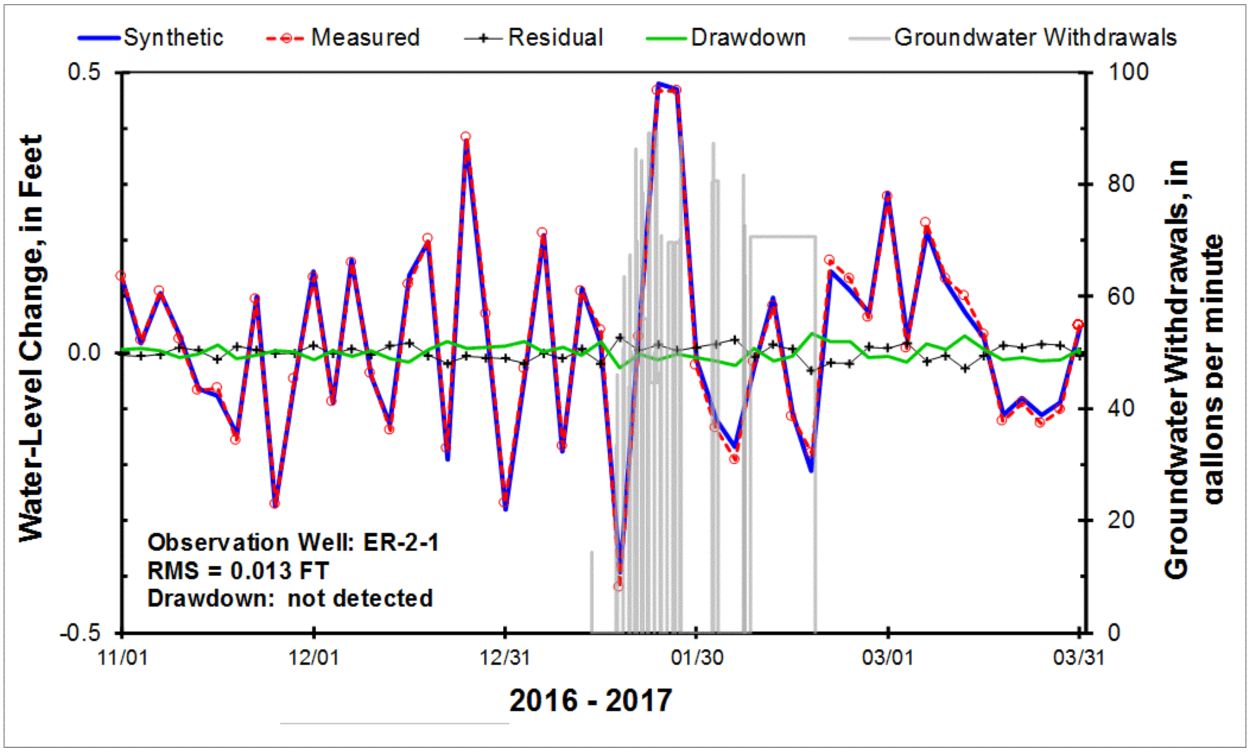
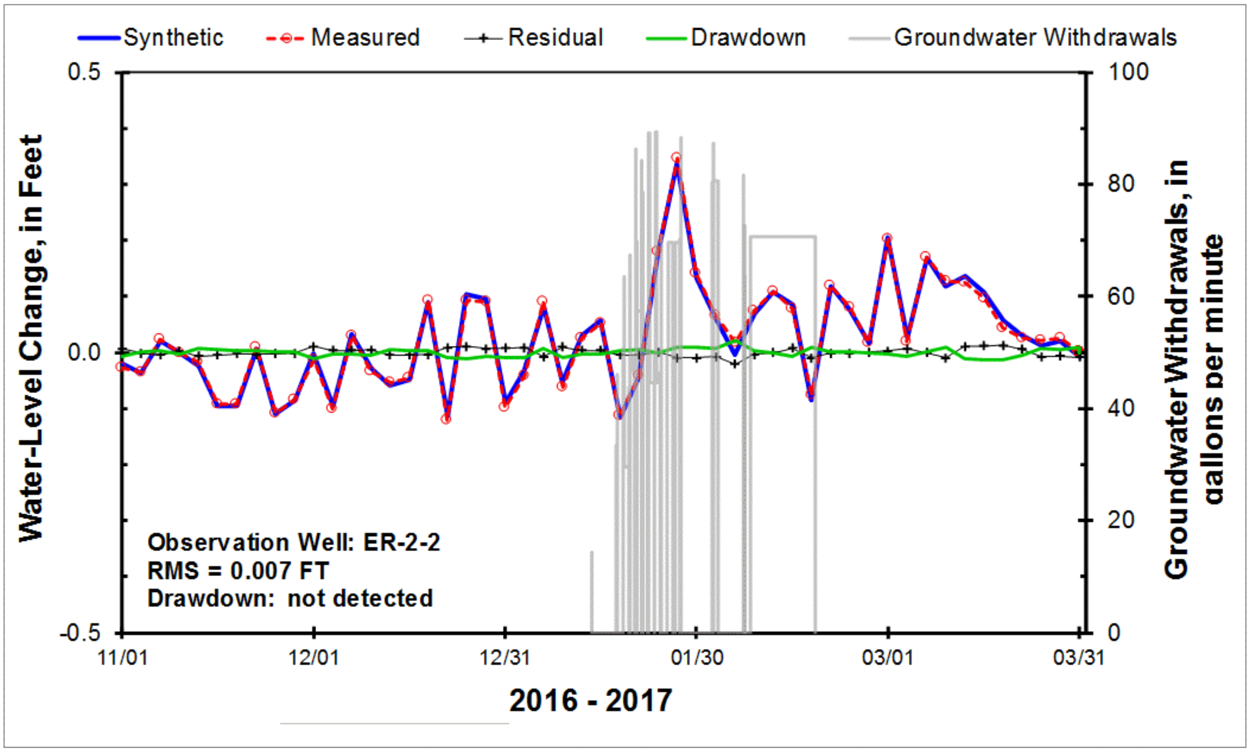
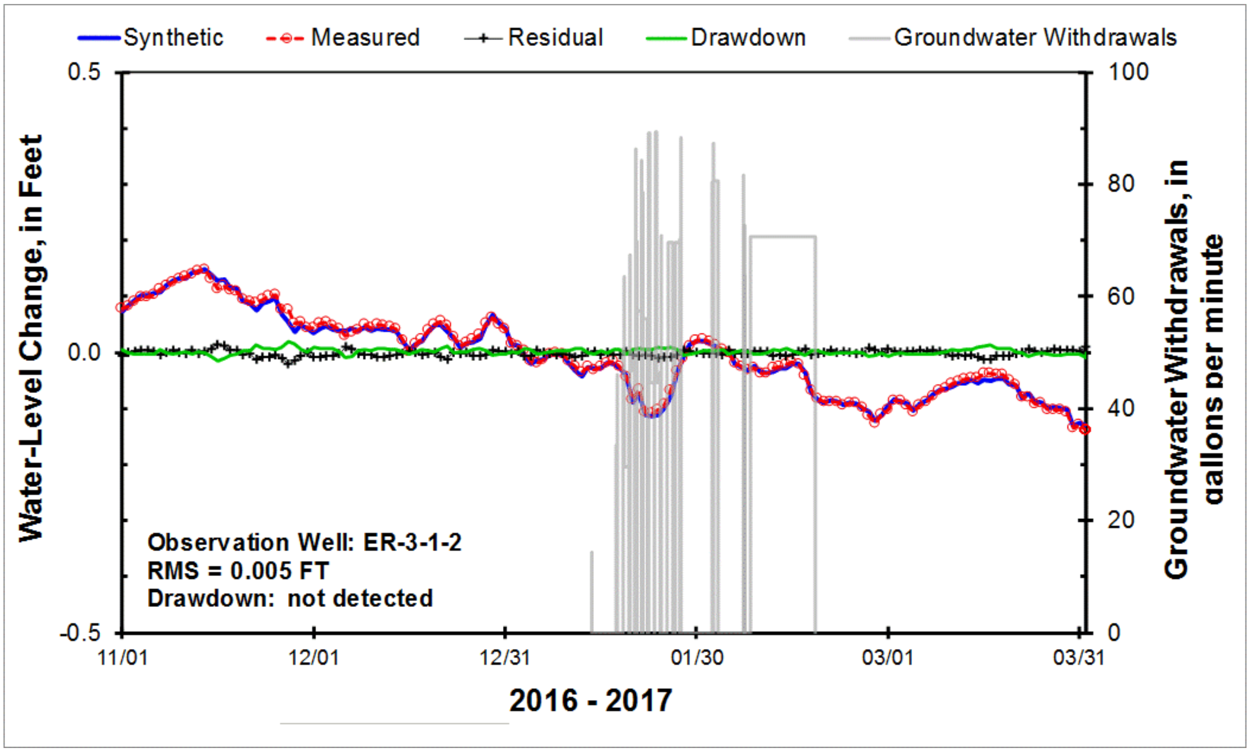
Appendix A. Estimated Drawdowns in Observation Wells

Appendix A contains hydrographs showing estimated drawdown analysis results of 17 observation wells monitored during the *ER-4-1 m1* aquifer test. Hydrographs compare measured and synthetic water-level change, and show residuals, estimated drawdown, and groundwater withdrawals during aquifer testing at well *ER-4-1 m1*. Hydrographs presented for the 17 observation wells have estimated drawdowns classified as either detected or not detected, where the detection classification is provided on each hydrograph.




Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
100
80
60
40
20
0
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017
Observation Well: ER-2-2
RMS = 0.007 FT
Drawdown: not detected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Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
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0.0
-0.5
100
80
60
40
20
0
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017
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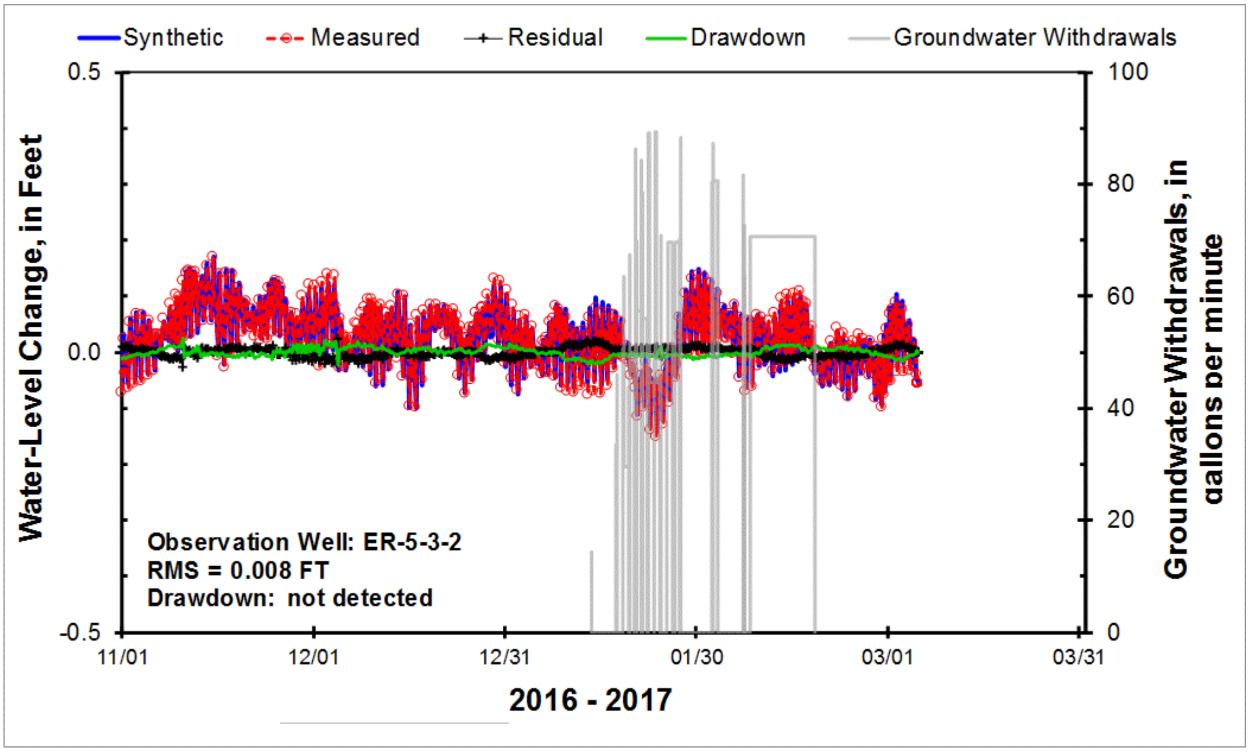
RMS = 0.005 FT
Drawdown: not detected



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: ER-5-3-2
RMS = 0.008 FT
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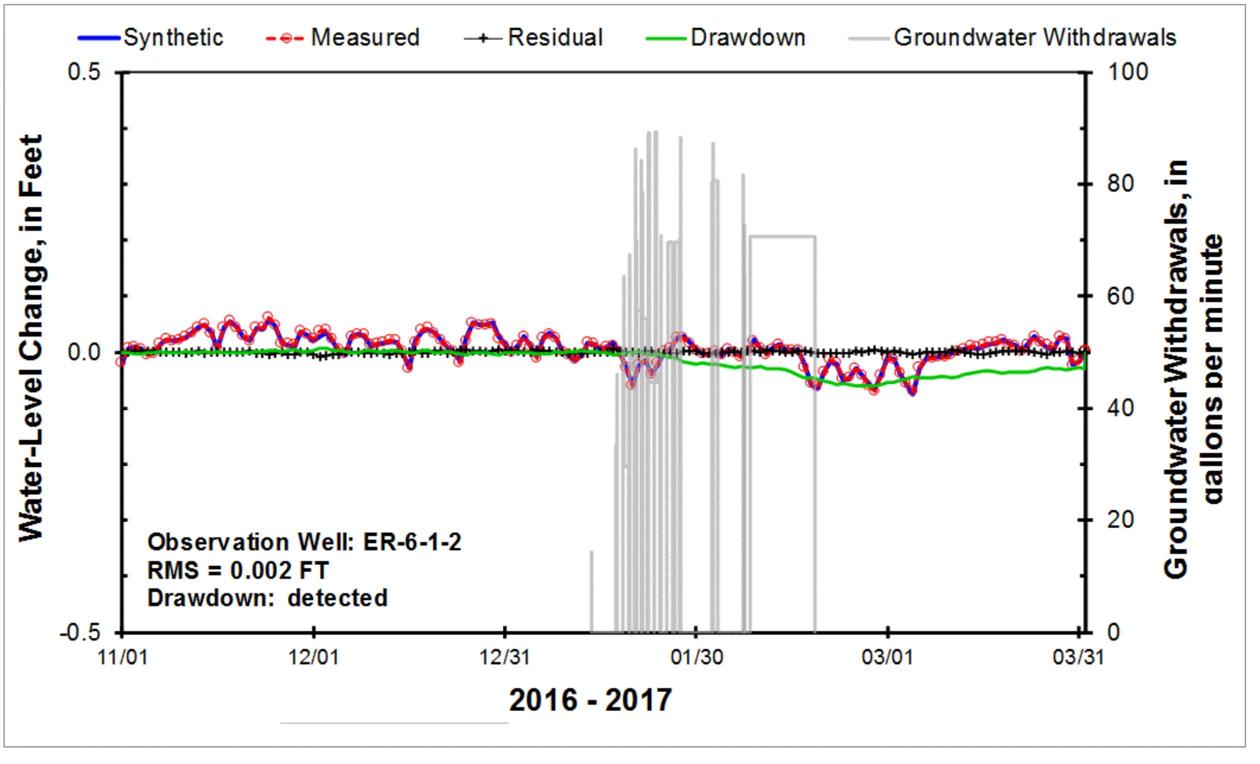
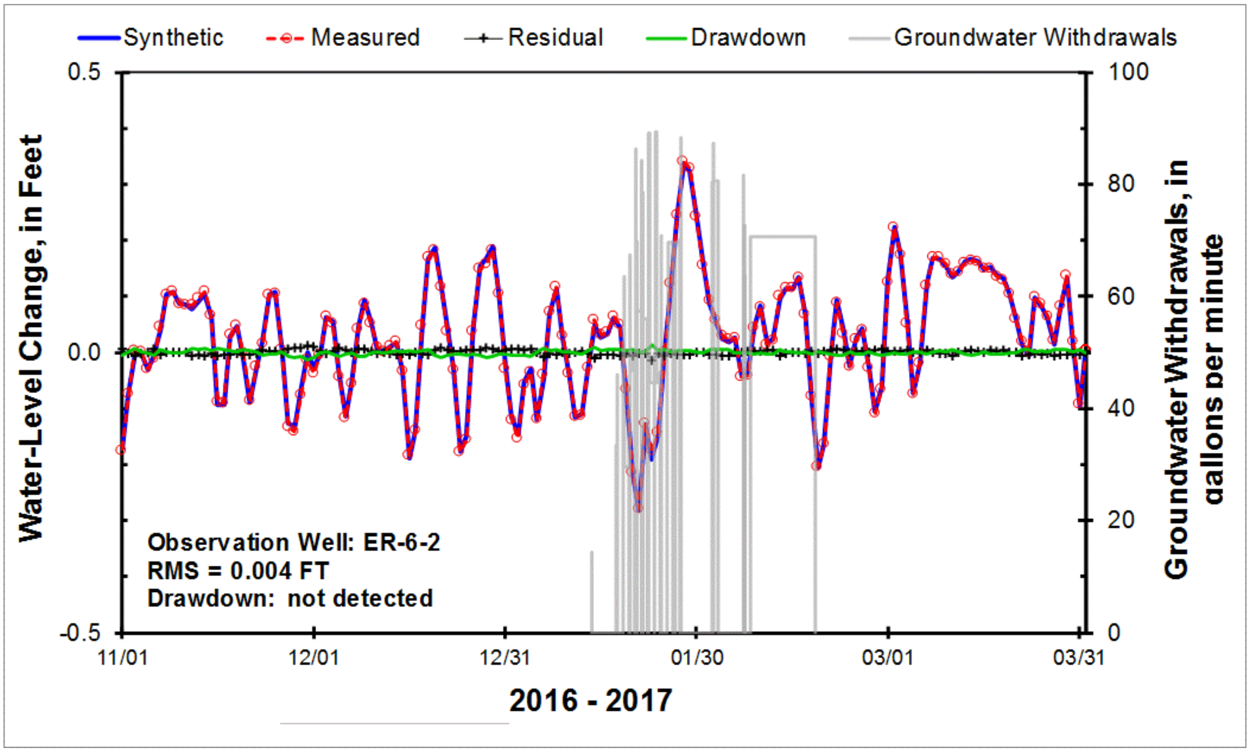
03/01
03/31
2016 - 2017



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: ER-6-1-2
RMS = 0.002 FT
Drawdown: detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017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Residual
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Groundwater Withdrawals
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60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
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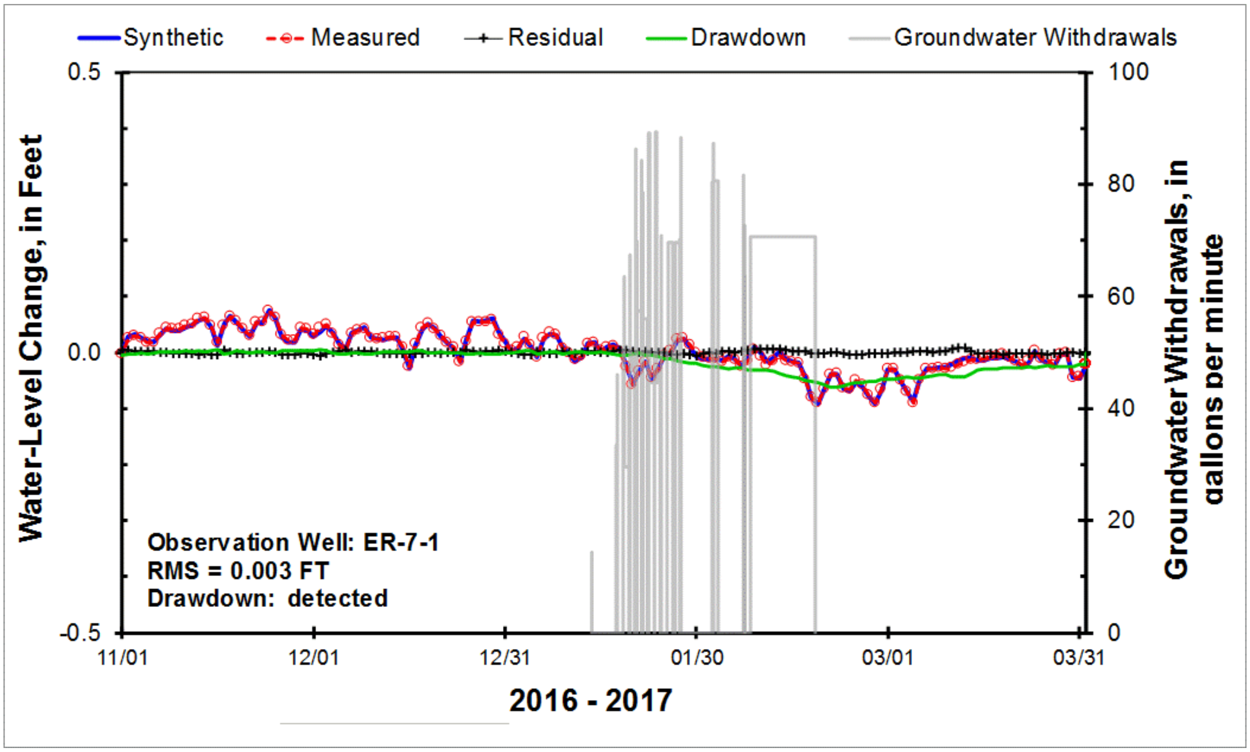
12/31
01/30
03/01
03/31
2016 - 2017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Residual
Drawdown
Groundwater Withdrawals
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100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
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Drawdown: detected
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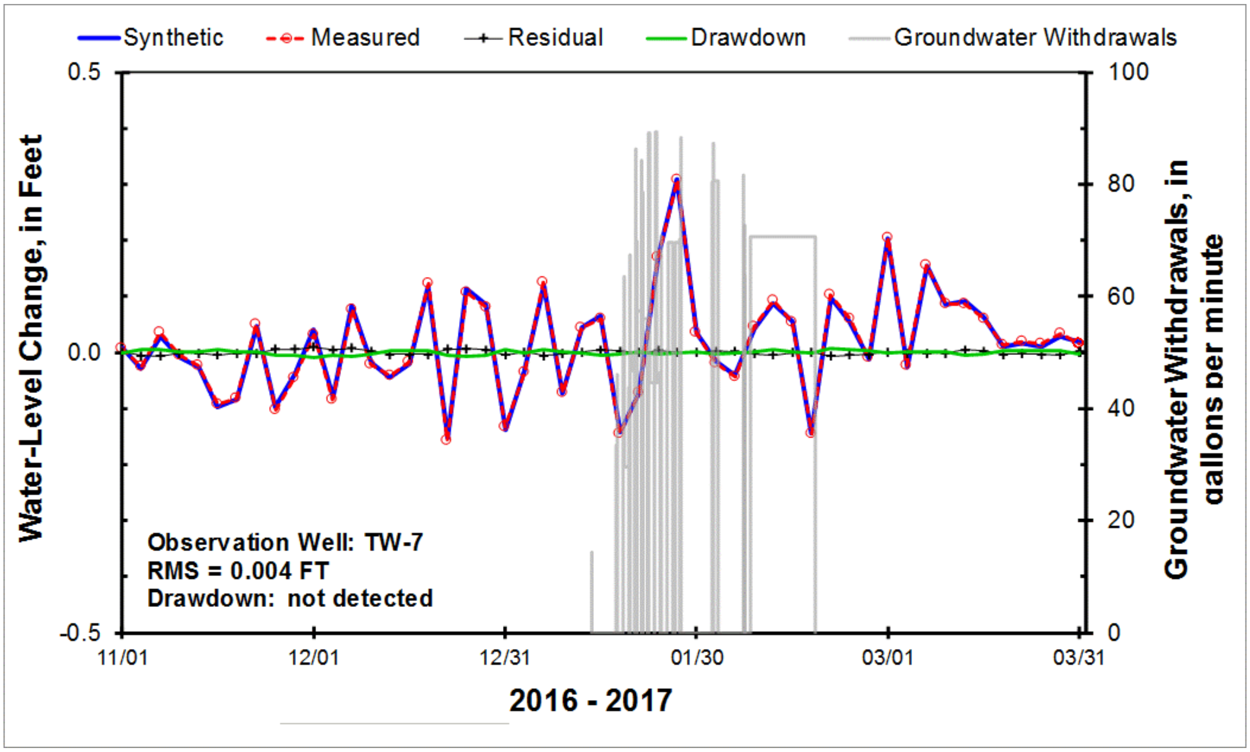
12/01
12/31
01/30
03/01
03/31
2016 - 2017



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
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-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
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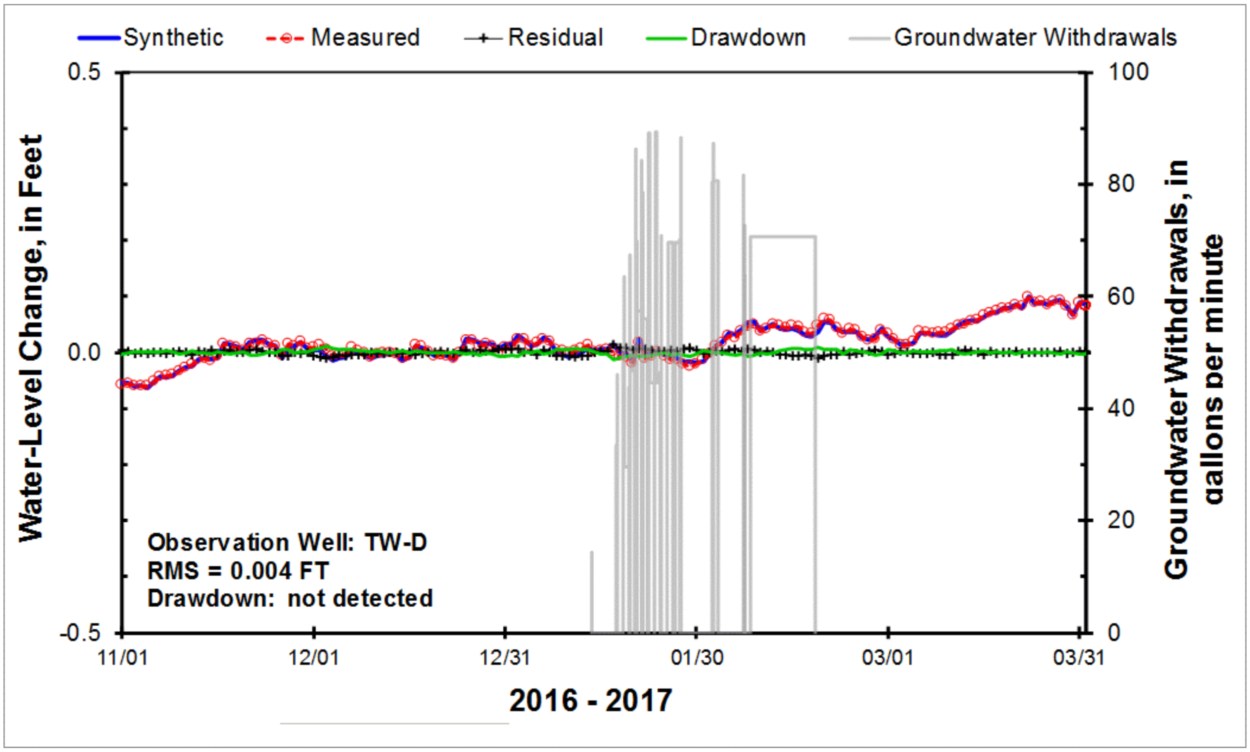
Drawdown: not detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
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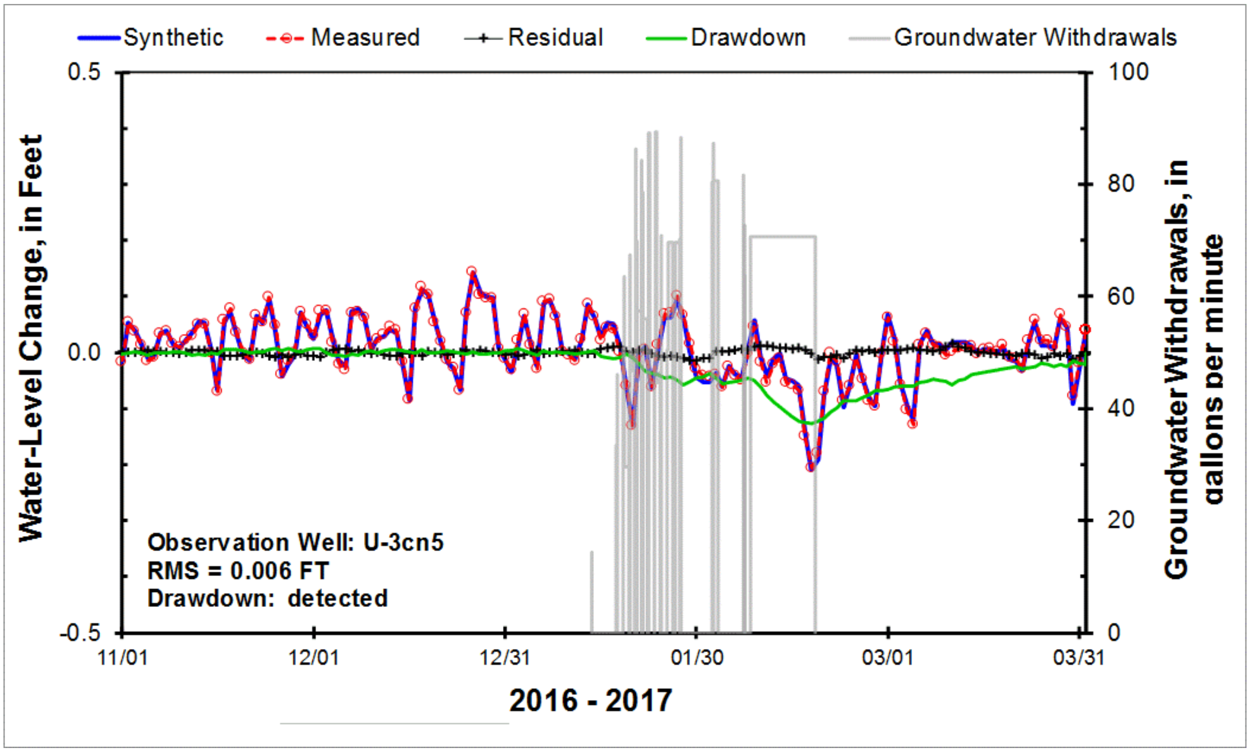
0.0
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: TW-D
RMS = 0.004 FT
Drawdown: not detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017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Residual
Drawdown
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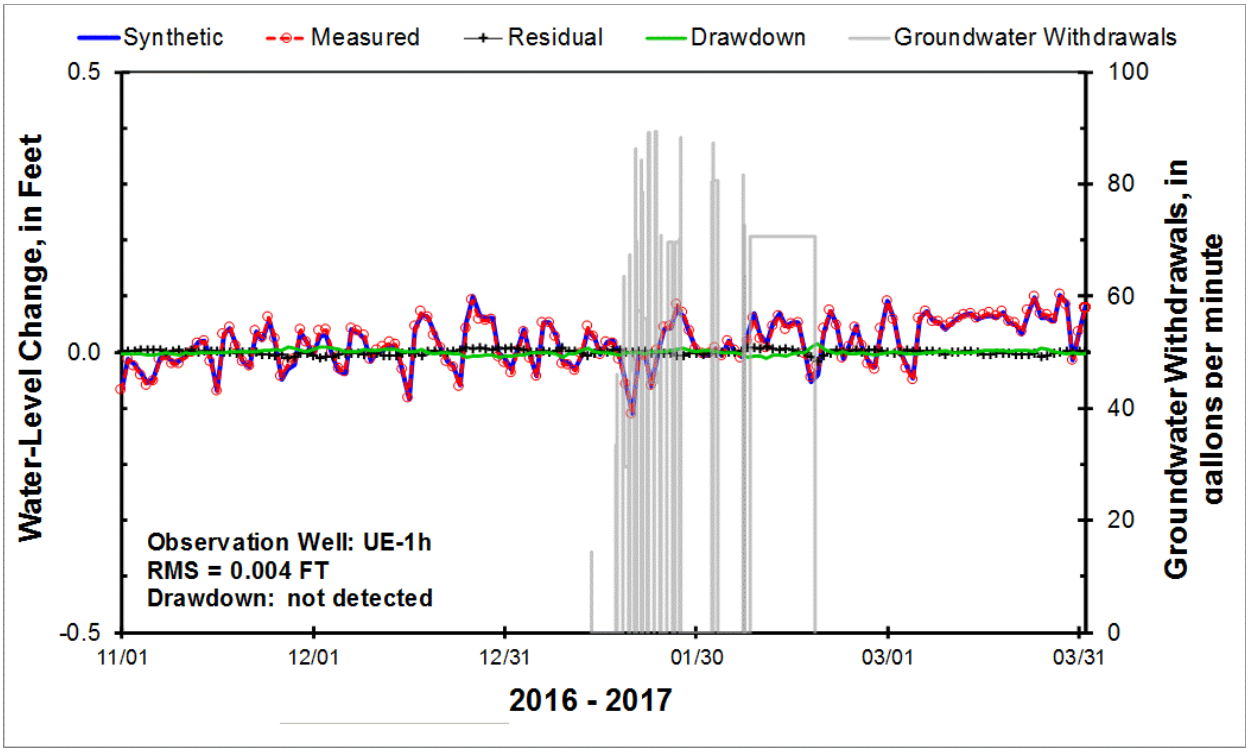
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: U-3cn5
RMS = 0.006 FT
Drawdown: detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017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Drawdown
Groundwater Withdrawals
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0.0
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
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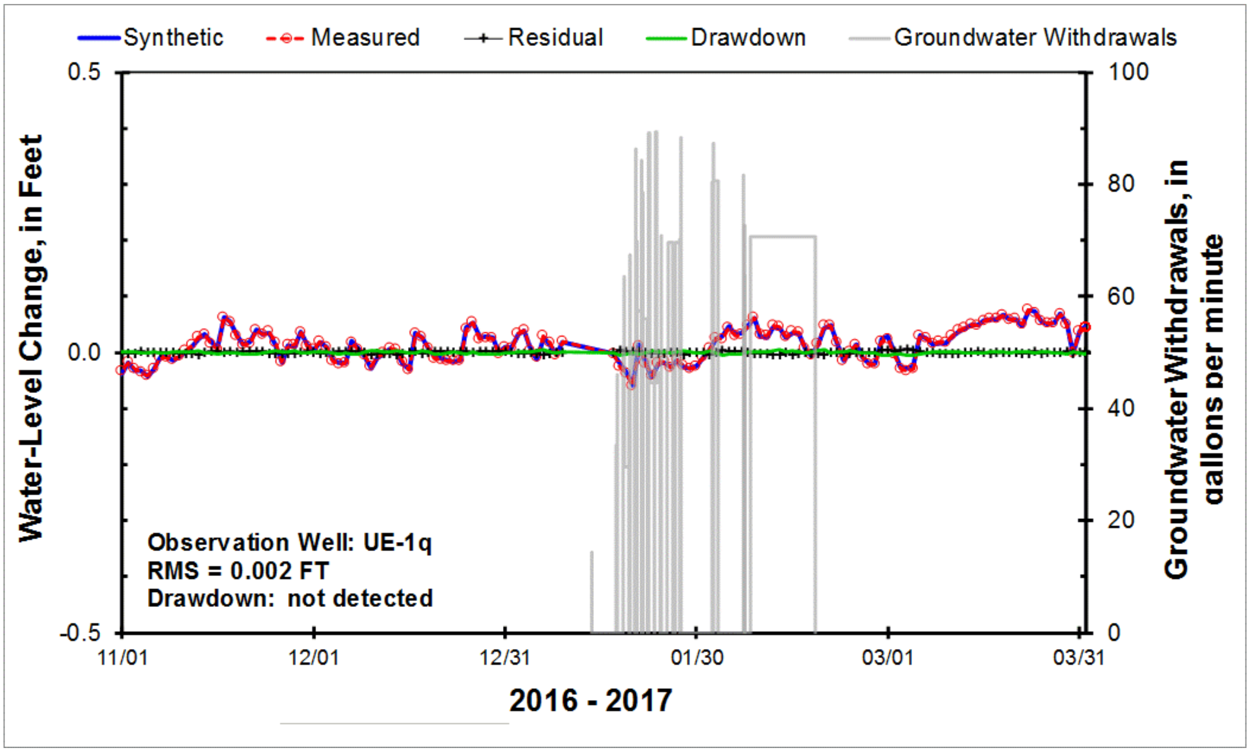
RMS = 0.004 FT
Drawdown: not detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017



Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
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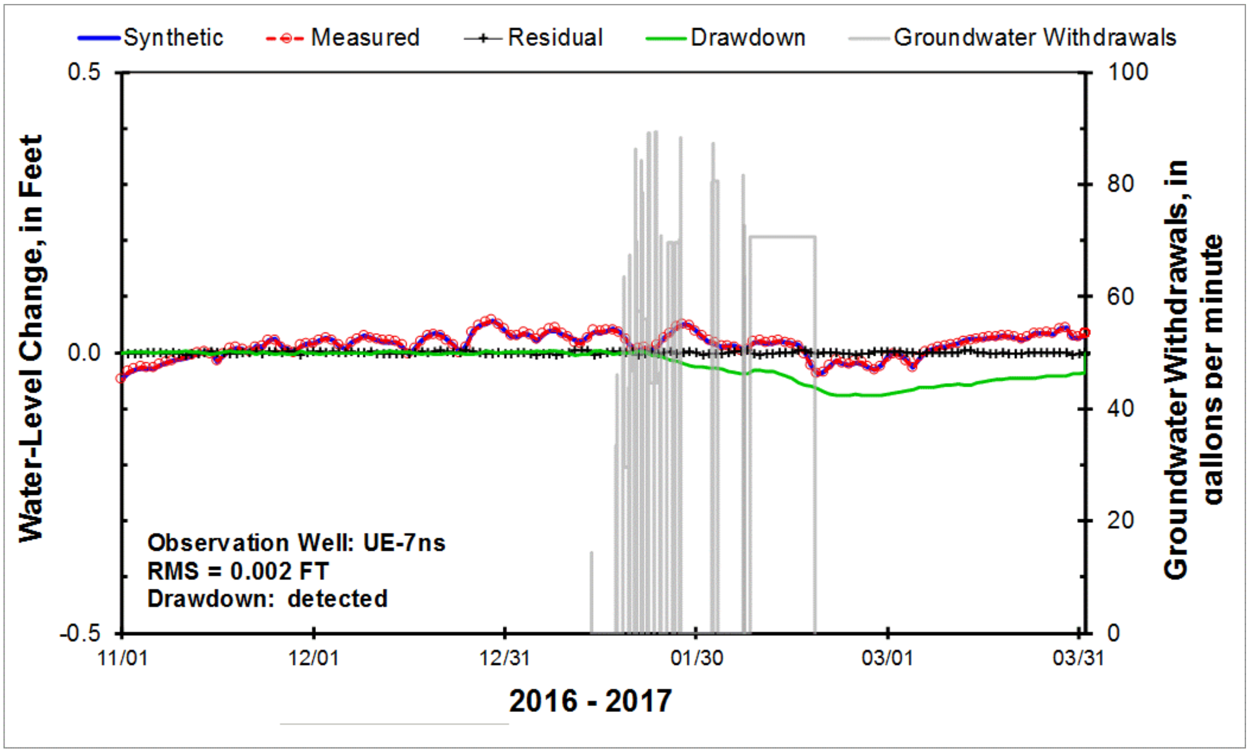
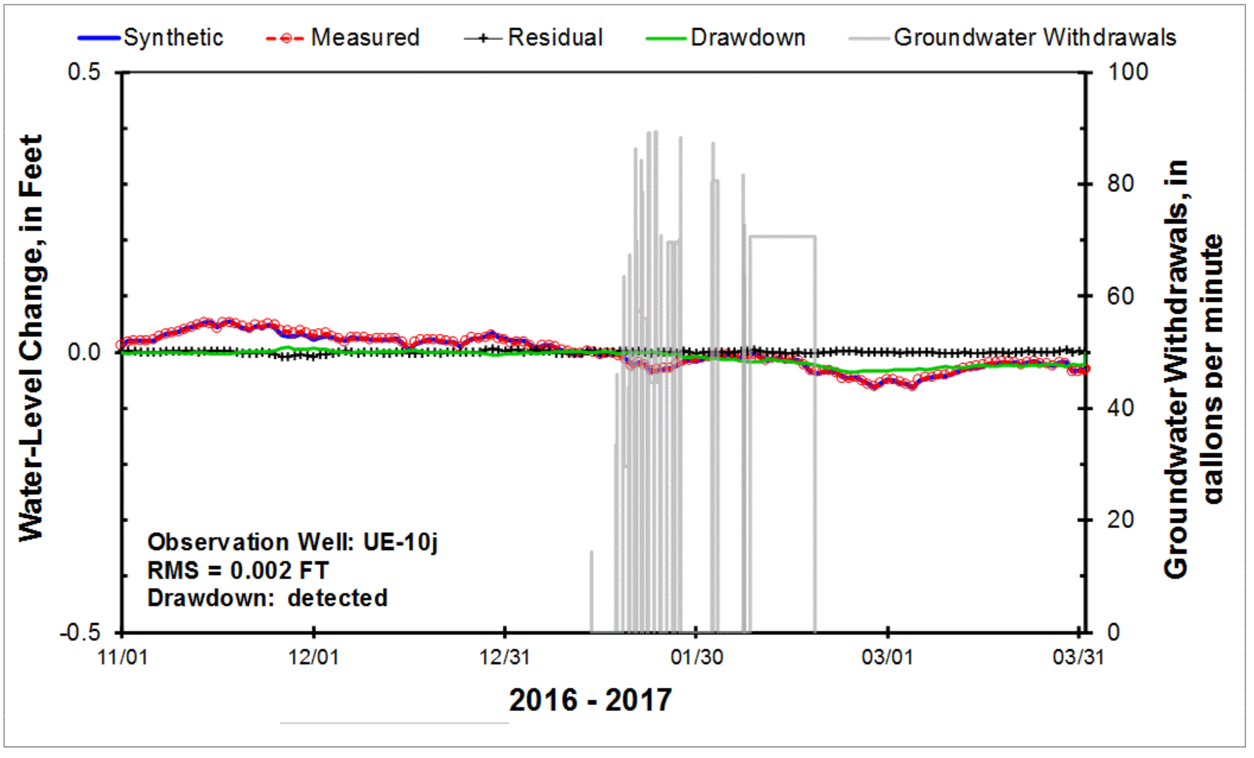
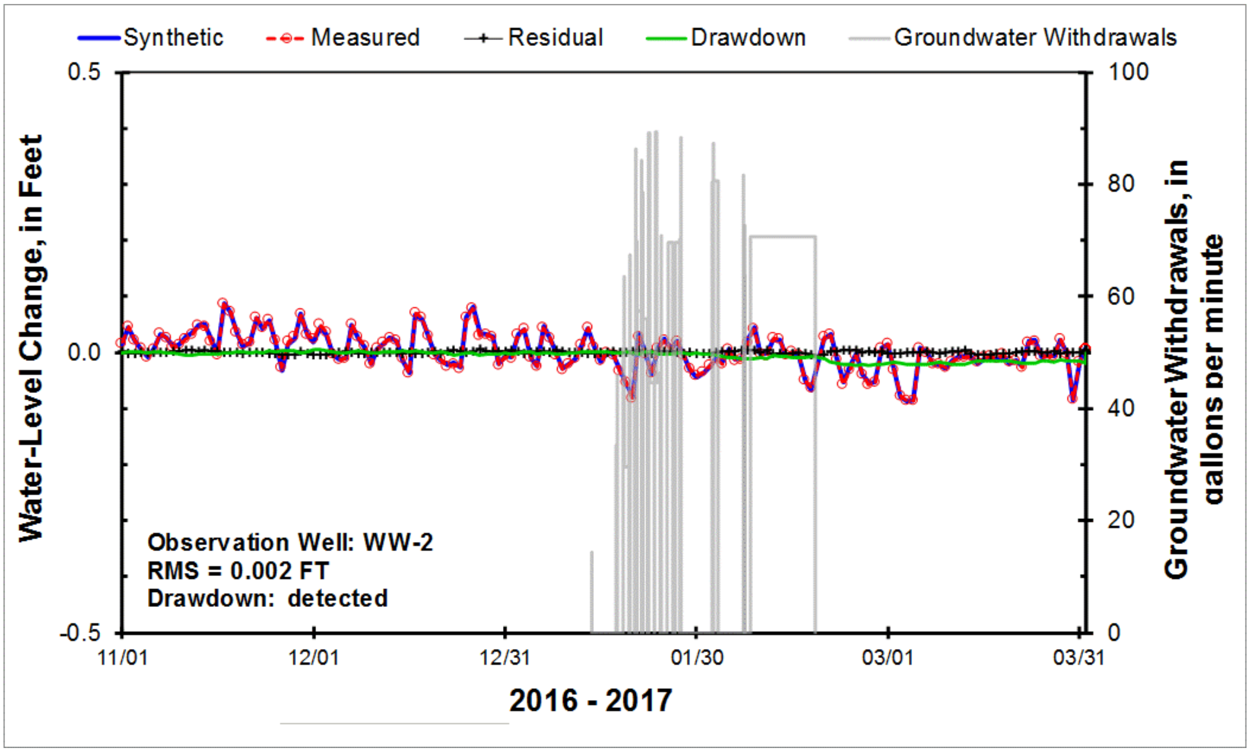
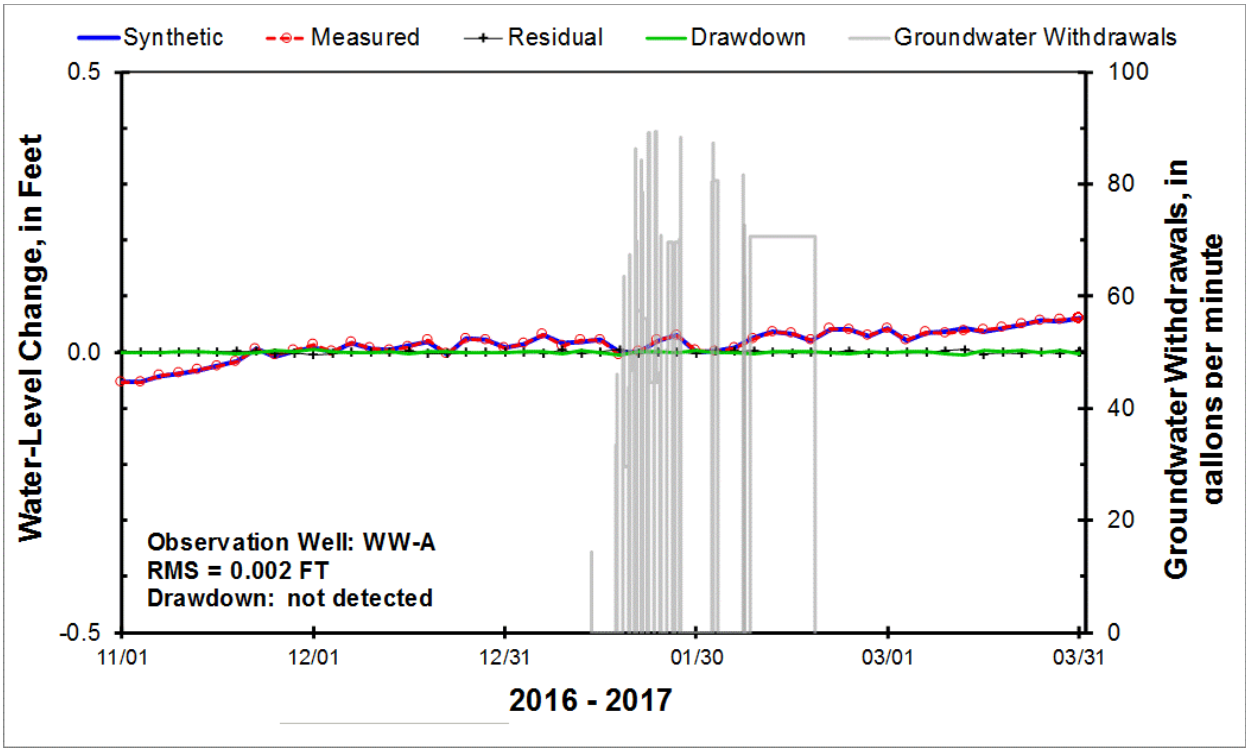
0.0
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: UE-1q
RMS = 0.002 FT
Drawdown: not detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
100
80
60
40
20
0
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017
Observation Well: UE-7ns
RMS = 0.002 FT
Drawdown: detected


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
0.5
0.0
-0.5
100
80
60
40
20
0
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017
Observation Well: UE-10j
RMS = 0.002 FT
Drawdown: detected


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: WW-2
RMS = 0.002 FT
Drawdown: detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017


Synthetic
Measured
Residual
Drawdown
Groundwater Withdrawals
0.5
0.0
-0.5
100
80
60
40
20
0
Water-Level Change, in Feet
Groundwater Withdrawals, in gallons per minute
Observation Well: WW-A
RMS = 0.002 FT
Drawdown: not detected
11/01
12/01
12/31
01/30
03/01
03/31
2016 - 2017

Appendix B. Water-Level Models, Aquifer Test Analysis, and Supporting Datasets

The water-level models, aquifer test analysis, and supporting datasets are in the compressed (zip) file, AppendixB_ER-4-1m1_AQtestPackage_2017. The zip file contains four directories: (1) *AquiferTest*; (2) *CleanData*; (3) *WellCompletionDiagram*; and (4) *WLM*.

The *AquiferTest* directory contains a macro-enabled Microsoft© Excel workbook that was used to estimate the transmissivity of the lower carbonate aquifer at ER-4-1. The DATA worksheet contains input data: continuous water-level data (in feet above the pressure transducer); and computed water-level change (drawdown). The COMPUTATION worksheet contains formulas used to compute aquifer hydraulic conductivity and transmissivity using the Cooper and Jacob (1946) method. The DEFAULT PROPERTIES and SETTINGS worksheet contains a reference table of extreme and likely ranges of hydraulic conductivity for different aquifer materials. The OUTPUT worksheet is used to input well construction information for computing hydraulic properties. The OUTPUT worksheet also shows a semi-log drawdown-time plot for the Cooper-Jacob analysis of the *ER-4-1 m1* aquifer test.

The *CleanData* directory contains cleaned up time-series data used to estimate drawdowns and aquifer transmissivity. Time series data include observation-, pumping-, and background-well water levels and barometric pressure for 26 wells, and pumping rates for *ER-4-1 m1*. Raw data (not provided) for all wells, except *ER-12-1*, were obtained from *Navarro*. For each of the observation and background wells, a Microsoft© Excel workbook contains hourly averages of water level and barometric pressure data. Bad values (values equal to 99999 or 0) were removed from the raw time-series data prior to averaging.

The *WellCompletionDiagram* directory contains a Portable Document File (PDF) showing the well completion of borehole ER-4-1. Well completion diagram was obtained from *Navarro* (written communication, 2017).

The *WLM* directory contains 17 water-level models (macro-enabled Microsoft© Excel workbooks) used to estimate drawdowns at 17 observation wells during aquifer testing at well *ER-4-1 m1*. Water-level models were generated using a Microsoft© Excel add-in, SeriesSEE (Halford and others, 2012). Each Microsoft Excel workbook has three worksheets: DATA, Series, and WLmodel. The DATA worksheet contains the time-series data used in the water-level model. Data include time series of water levels from the observation well and background well(s), barometric pressure at the observation well, and pumping data. The Series worksheet contains the time series used in the water-level model. Time series include moving averages of background water levels and barometric pressure, Theis transforms of pumping in well *ER-4-1 m1*, and time series of gravity tides (in microgals) and solid Earth tides (dry dilation in ppb). Measured, synthetic, residuals, and estimated drawdown time series also are included in this worksheet. The WLmodel worksheet shows the parameters used in the water-level model, a plot of measured versus synthetic water levels and residuals, and the overall RMS error.

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