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Model Evaluation Report for Corrective Action Unit 98: Frenchman Flat, Nevada National Security Site, Nye County, Nevada

Revision No.: 1

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/s/ Joseph P. Johnston 09/30/2014

Joseph P. Johnston, N-I CO Date

September 2014

Prepared for U.S. Department of Energy under Contract No. DE-AC52-09NA28091.

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MODEL EVALUATION REPORT FOR CORRECTIVE ACTION UNIT 98: FRENCHMAN FLAT, NEVADA NATIONAL SECURITY SITE, NYE COUNTY, NEVADA

Revision No.: 1
September 2014

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Prepared for U.S. Department of Energy under Contract No. DE-AC52-09NA28091.

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Approved by: /s/ Sam Marutzky Date: 09/30/2014

Sam Marutzky, UGTA Project Manager
Navarro-Intera, LLC

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LIST OF ACRONYMS AND ABBREVIATIONS

General Acronyms and Abbreviations

3-D	Three-dimensional
AMS	Accelerator mass spectrometer
amsl	Above mean sea level
atoms/g	Atoms per gram
BN	Bechtel Nevada
CADD	Corrective action decision document
CAI	Corrective action investigation
CAIP	Corrective action investigation plan
CAP	Corrective action plan
CAU	Corrective action unit
CB	Contaminant boundary
CR	Closure report
DOE	U.S. Department of Energy
DOE/NV	U.S. Department of Energy, Nevada Operations Office
DRI	Desert Research Institute
DVRFS	Death Valley Regional Flow System
ECDF	Empirical cumulative distribution function
FFACO	*Federal Facility Agreement and Consent Order*
ft	Foot
GMWL	Global Meteoric Water Line
GPS	Global Positioning System
HDD	Hydrologic data document
HFM	Hydrostratigraphic framework model
HSU	Hydrostratigraphic unit
in.	Inch
ka	Kiloannum
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
LMWL	Local Meteoric Water Line

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

m	Meter
m^2	Square meter
m^2/day	Square meters per day
m^3/day	Cubic meters per day
MCL	Maximum contaminant level
m/day	Meters per day
mg/L	Milligrams per liter
m/m	Meters per meter
mm/yr	Millimeters per year
MWAT	Multiple-well aquifer test
m/yr	Meters per year
N/A	Not applicable
NAD	North American Datum
NDEP	Nevada Division of Environmental Protection
NHA	Northern Hydrologic Alternative
N-I	Navarro-Intera, LLC
NNES	Navarro Nevada Environmental Services, LLC
NNSA/NFO	U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office
NNSS	Nevada National Security Site
NSTec	National Security Technologies, LLC
NTTR	Nevada Test and Training Range
NWIS	National Water Information System
pCi/L	Picocuries per liter
PER	Pre-emptive review
R_c	Cavity radius
RWMC	Radioactive waste management complex
SDWA	*Safe Drinking Water Act*
SEC	Specific electrical conductance
SNJV	Stoller-Navarro Joint Venture
SSR	Sum of squared residuals

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

TD	Total depth
TDS	Total dissolved solids
UGTA	Underground test area
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WP	Working point
%meq/L	Percent milliequivalents per liter
‰	Per mil

List of Acronyms and Abbreviations (continued)

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

AA	Alluvial aquifer
AA1	Alluvial aquifer 1
AA2	Alluvial aquifer 2
AA3	Alluvial aquifer 3
BLFA	Basalt lava-flow aquifer
CHCU	Calico Hills confining unit
CHZCM	Calico Hills zeolitic composite unit
DWT	Densely welded ash-flow tuff
LCA	Lower carbonate aquifer
LCA3	Lower carbonate aquifer thrust plate
LCCU	Lower clastic confining unit
LPCU	Lower Paintbrush confining unit
LTCU	Lower tuff confining unit
LTCU 1	Lower tuff confining unit 1
LVTA	Lower vitric-tuff aquifer
MWT	Moderately welded ash-flow tuff
NWT	Nonwelded ash-flow tuff
OAA	Older alluvial aquifer
OAA 1	Older alluvial aquifer 1
PCU	Playa confining unit
PCU1U	Playa confining unit 1 upper
PCU1L	Playa confining unit 1 lower
PCU2T	Playa confining unit 2
PWT	Partially welded ash-flow tuff
Qai	Intermediate alluvial deposits
Qay	Young alluvial deposits
QT	Quaternary and Tertiary deposits
QTa	Old alluvial deposits

LIST OF ACRONYMS AND ABBREVIATIONS (CONTINUED)

TCU	Tuff confining unit
Th	Calico Hills formation
Thp	Mafic-poor Calico Hills formation
Tm	Timber Mountain group
Tma	Ammonia Tanks tuff
TM-LVTA	Timber Mountain lower vitric-tuff aquifer
Tmr	Rainier Mesa Tuff
Tmrh	Tuff of Holmes Road
Tmrp	Mafic-poor Rainier Mesa tuff
TM-WTA	Timber Mountain welded-tuff aquifer
Tp	Paintbrush group
Tpt	Topopah Spring tuff
TSA	Topopah Spring aquifer
Tw	Wahmonie formation
UCCU	Upper clastic confining unit
UTCU	Upper tuff confining unit
VCU	Volcaniclastic confining unit
VTA	Vitric-tuff aquifer
WCU	Wahmonie confining unit
WTA	Welded-tuff aquifer

List of Acronyms and Abbreviations (continued)

Symbols for Elements and Compounds

C	Carbon
Ca	Calcium
Cl	Chlorine
CO_3	Carbonate
$DI^{14}C$	Dissolved inorganic carbon-14
DO	Dissolved oxygen
^3H	Tritium
HCO_3	Bicarbonate
He	Helium
I	Iodine
K	Potassium
Mg	Magnesium
Na	Sodium
SO_4	Sulfate
Tc	Technetium
$\delta^{13}C$	Delta carbon-13
δD	Delta deuterium
$\delta^{18}O$	Delta oxygen-18

1.0 INTRODUCTION

The *Federal Facility Agreement and Consent Order* (FFACO) (1996, as amended), the governing agreement between the U.S. Department of Energy (DOE) and Nevada Division of Environmental Protection (NDEP), has four stages: corrective action investigation plan (CAIP), corrective action investigation (CAI), corrective action decision document (CADD)/corrective action plan (CAP), and closure report (CR). The Frenchman Flat CAIP stage was completed with the publication of the CAIP in 1999 (DOE/NV, 1999). The CAI stage was completed in 2010 for Frenchman Flat with the successful peer review of the Phase II flow and transport model (N-I, 2010) culminating in NDEP acceptance of the model (Murphy, 2010). Frenchman Flat has been in the CADD/CAP stage since 2011, focusing on model evaluation to ensure that existing models provide adequate guidance for Frenchman Flat regulatory decisions regarding monitoring and institutional controls.

There are five steps in the CADD/CAP stage, as shown in Figure 1-1. In Step 1, specific evaluation targets and data-collection activities were identified (Table 1-1) with an expert elicitation (Chapman and Pohlmann, 2011). This information was included in the CADD/CAP (NNSA/NSO, 2011), which was approved by NDEP in 2011 (Murphy, 2011), completing Step 2. To fulfill Step 3, Wells ER-5-5 and ER-11-2 were drilled, and the following activities were performed: a ground magnetic survey, a limited resurvey of well locations and elevations, water-level measurements, and well hydraulic testing and sampling. As data collection and analysis progressed, meetings were held with the pre-emptive review (PER) committee where interim findings were evaluated and feedback provided. This report is part of Step 4, the model evaluation report required by the CADD/CAP, which supports NDEP Decision 6 in the FFACO strategy.

Model evaluation focused solely on the PIN STRIPE and MILK SHAKE underground nuclear tests' contaminant boundaries (CBs) because they had the largest extent, uncertainty, and potential consequences (NNES, 2010). The CAMBRIC radionuclide migration experiment also had a relatively large CB, but because it was constrained by transport data (notably Well UE-5n), there was little uncertainty, and radioactive decay reduced concentrations before much migration could occur. Each evaluation target and the associated data-collection activity were assessed in turn to determine whether the new data support, or demonstrate conservatism of, the CB forecasts

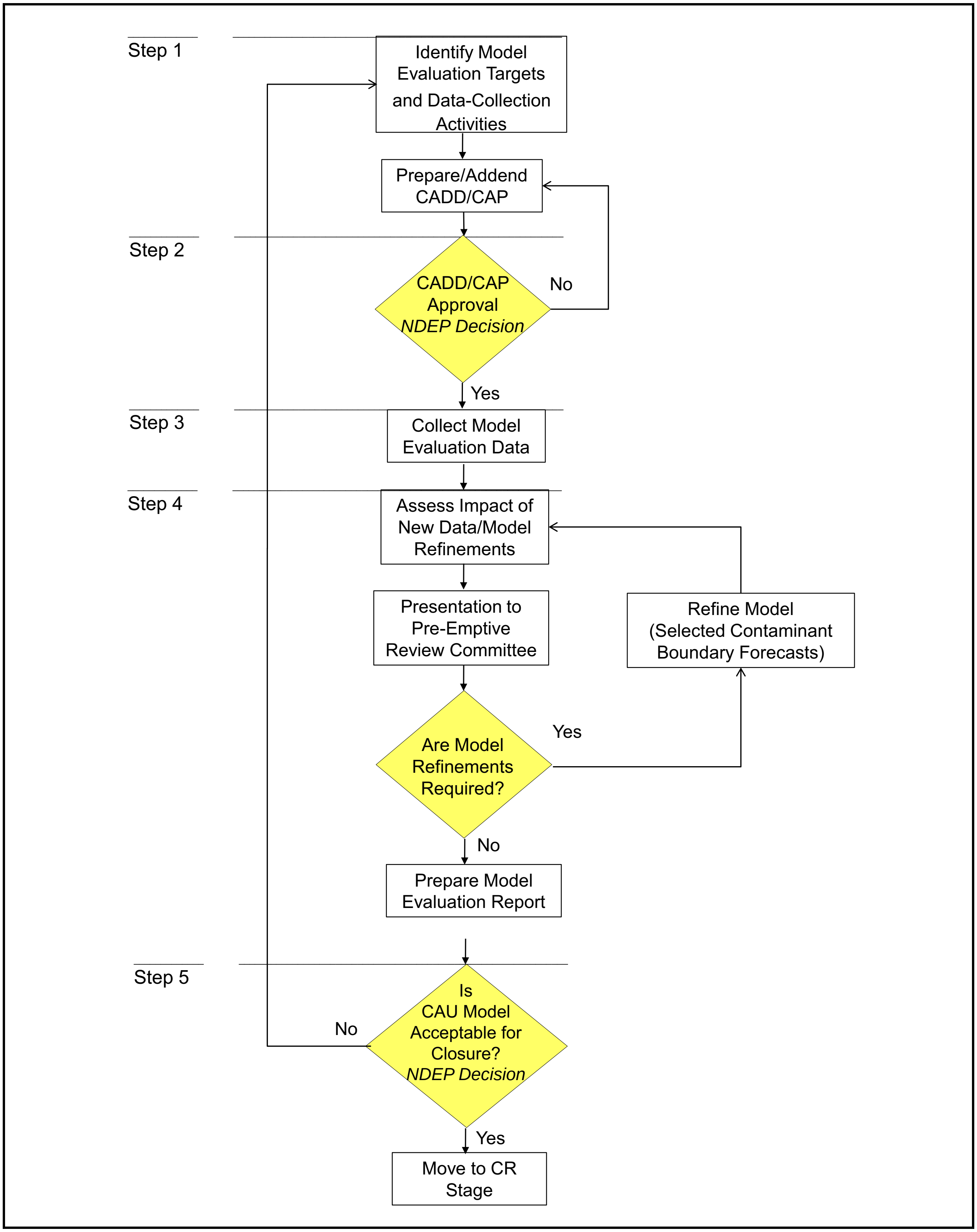


Figure 1-1
Process Flow Diagram for CADD/CAP Model Evaluation Process
Source: NNSA/NSO, 2011

Table 1-1
Summary of Model Evaluation Targets and Data-Collection Activities

Model Evaluation Target	Data-Collection Activity
Internal continuity of TSA	Geologic logging of subsurface rock type, geophysical logging to determine rock type, bed dip, and fracture characteristics. Surface magnetic geophysical survey.
Spatial extent of TSA in the north	Geologic logging of subsurface rock type, geophysical logging to determine rock type, bed dip, and fracture characteristics. Surface magnetic geophysical survey.
Hydraulic conductivity of WTA (TSA)	Constant rate pumping testing.
Continuity of BLFA	Geologic logging of subsurface rock type, geophysical logging to determine rock type, bed dip, and fracture characteristics. Surface magnetic geophysical survey.
Conceptual model of basin drainage to the southeast	Measurement of hydraulic head in new wells and in existing wells as part of a water-level measurement program.
Source release conservative assumptions	Analysis of radionuclides in groundwater samples.
Hydraulic conductivity of BLFA	Constant rate pumping testing.
Flow boundary conditions	Measurement of hydraulic head in new wells and in existing wells as part of a water-level measurement program.
Size of exchange volume	None.
Geochemical age and velocity constraints	Analysis of ^{14}C, stable isotopes, and major ions in groundwater samples.

BLFA = Basalt lava-flow aquifer
C = Carbon
WTA = Welded-tuff aquifer

(NNSA/NSO, 2011, p. 55). The modeling team—in this case, the same team that developed the Frenchman Flat geologic, source term, and groundwater flow and transport models—analyzed the new data and presented the results to a PER committee. Existing site understanding and its representation in numerical groundwater flow and transport models was evaluated in light of the new data and the ability to proceed to the CR stage of long-term monitoring and institutional control.

This report presents a summary of the data-collection activities; the results of the evaluation of model evaluation targets presented in the CADD/CAP; and modeling team and PER committee recommendations for additional data collection in the CADD/CAP stage, model refinements, and whether the corrective action unit (CAU) can proceed to the CR stage. In addition, correspondence between the DOE, National Nuclear Security Administration Nevada Field Office (NNSA/NFO) and NDEP regarding work performed during the CADD/CAP stage are included in Appendix B.

2.0 MODEL EVALUATION DATA-COLLECTION SUMMARY

Data-collection activities designed specifically for the Frenchman Flat model evaluation included performing ground-based magnetic surveys, drilling model evaluation wells, performing hydraulic testing, and analyzing water chemistry. Each of these data-collection activities is summarized below.

2.1 Ground-Based Magnetic Survey of Frenchman Flat

The U.S. Geological Survey (USGS) conducted a ground-based magnetic survey of the northeast portion of Frenchman Flat within the Nevada National Security Site (NNSS), and within the adjacent Nevada Test and Training Range (NTTR) (Phillips et al., 2014). The survey was designed to help address geologic uncertainties related to proposed sites of new wells downgradient and within potential contaminant plumes resulting from the MILK SHAKE and PIN STRIPE underground nuclear tests. Ground magnetic data were collected along 23 separate lines (Figure 2-1).

In the vicinity of MILK SHAKE, groundwater flow and transport model results showed significant sensitivity to the transport properties of the basalt, encountered within the alluvial section near the water table at MILK SHAKE and several other drill holes in the area. Interpretation of the new magnetic data suggests that the basalt extends as a single, large continuous unit much farther to the east and southeast than modeled in the Frenchman Flat BASE hydrostratigraphic framework model (HFM) (BN, 2005), but similar to the BLFA alternative HFM also presented in BN (2005).

At PIN STRIPE, model results were very sensitive to the continuous, unfaulted, saturated Topopah Spring aquifer (TSA) in the area extending eastward from PIN STRIPE as modeled in the Frenchman Flat BASE HFM (BN, 2005). Ground magnetic data were collected east and northeast of PIN STRIPE to evaluate whether northward-striking faults observed in the hills north of PIN STRIPE extend southward below the alluvium that could possibly disrupt the TSA east of PIN STRIPE. However, complex magnetic signatures likely associated with cultural interference such as power lines, variable magnetic intensities, and inclinations of the shallow volcanic rocks in the area precluded reliable recognition of buried faults east of PIN STRIPE.

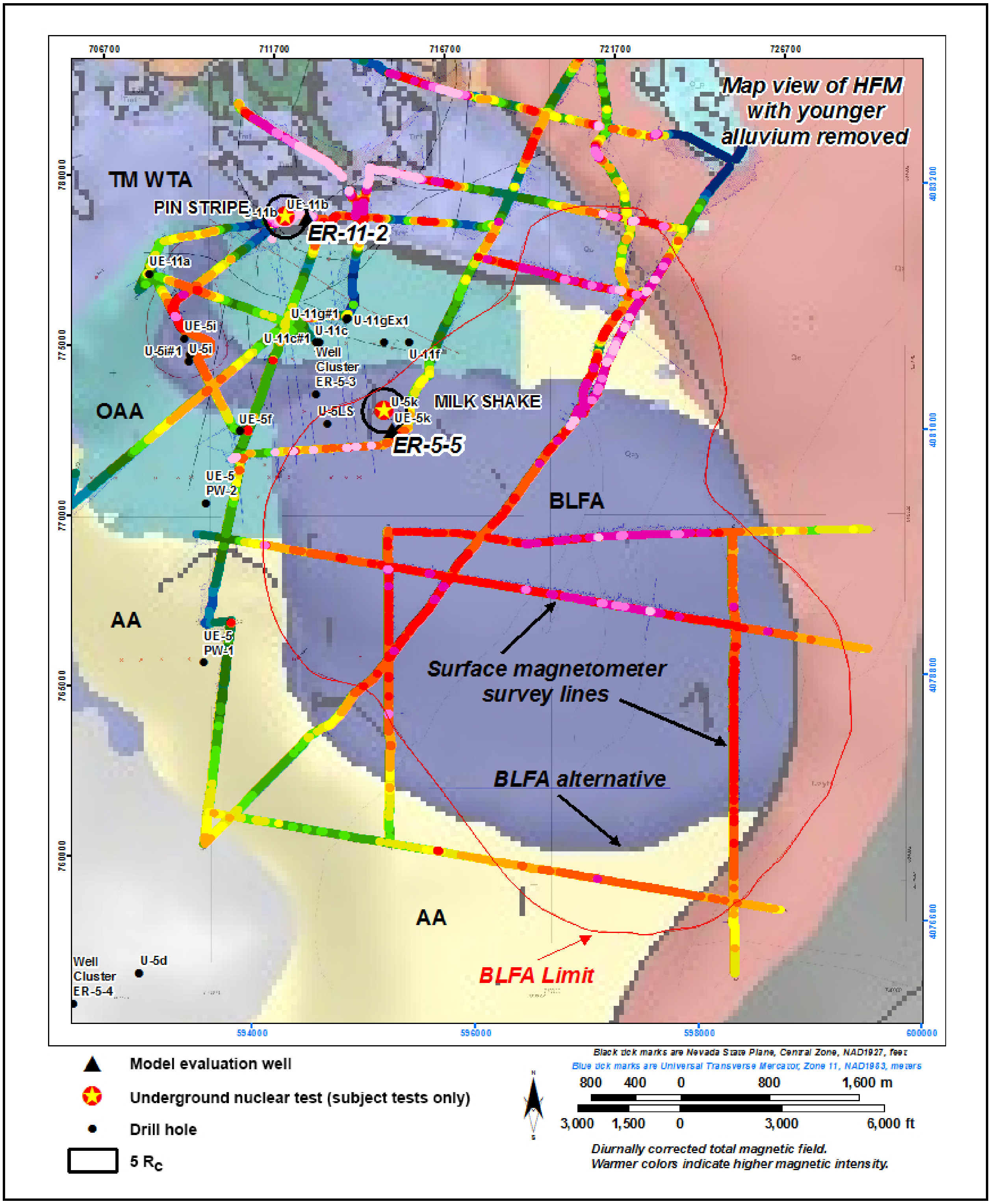


Figure 2-1
Map of Frenchman Flat Showing Locations of Ground Magnetic Survey Lines Colored by Magnetic Intensity Overlain on BLFA Alternative HFM
Source: Modified from Phillips et al., 2014

Note: Cavity radius (R_c) is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

2.2 Model Evaluation Wells

The Frenchman Flat well-drilling program is part of the CADD/CAP for Frenchman Flat CAU 98 (NNSA/NSO, 2011). Two wells, Wells ER-5-5 and ER-11-2, were drilled to support CADD/CAP data-collection objectives downgradient from the MILK SHAKE and PIN STRIPE underground nuclear tests, respectively. The primary purpose of each well was to provide geologic, hydrogeologic, chemical, and radiological data that could be used to test and build confidence in the applicability of the Frenchman Flat CAU groundwater flow and contaminant transport models for their intended purpose; and to address specific issues and uncertainties identified as model evaluation targets, which are listed in Table 4-1 of the CADD/CAP document and included in this report as Table 1-1.

Figure 2-2 shows CB forecasts from the flow and transport report (NNES, 2010) for the MILK SHAKE and PIN STRIPE underground nuclear tests, and the locations of Wells ER-5-5 and ER-11-2. The CB is computed from transport model results and is not a direct measure of groundwater contamination. The CB is created by analyzing transport model Monte Carlo results to give the probability (Daniels and Tompson, 2003; NNES, 2010) of exceeding the *Safe Drinking Water Act* (SDWA) regulatory standards (CFR, 2014). The outlines shown in Figure 2-2 encompass the 5 percent chance or greater of exceeding the maximum contaminant level (MCL) at selected times. At the time of the Frenchman Flat peer review, a transport code error was identified, and an impact assessment was conducted (N-I, 2012a) that showed the effect of the error was to overstate concentrations and the extent of the CBs. The impact assessment showed that Wells ER-5-5 and ER-11-2 are located where the computed probability of exceeding the MCL after 50 years of migration is greater than about 70 percent.

2.2.1 Well ER-5-5

Well ER-5-5 was the first of two wells constructed in Frenchman Flat during the summer of 2012. The primary purpose for drilling Well ER-5-5 was to obtain data to evaluate uncertainty in the conceptual model of flow and transport and its CB forecasts (N-I, 2012b). In particular, the well was intended to produce data that would help characterize the hydrogeology and possible radiological contamination immediately downgradient from the MILK SHAKE underground nuclear test, conducted in Emplacement Hole U-5k in 1968 (DOE/NV, 2000). Well ER-5-5 is sited along the centerline of the model-forecasted CBs approximately 5 R_c, or 195.0 meters (m) (640 feet [ft]), south–southeast from MILK SHAKE (Figure 2-2). The cavity radius was calculated using the maximum of the announced yield range for the test published in DOE/NV (2000) and Equation (1) in

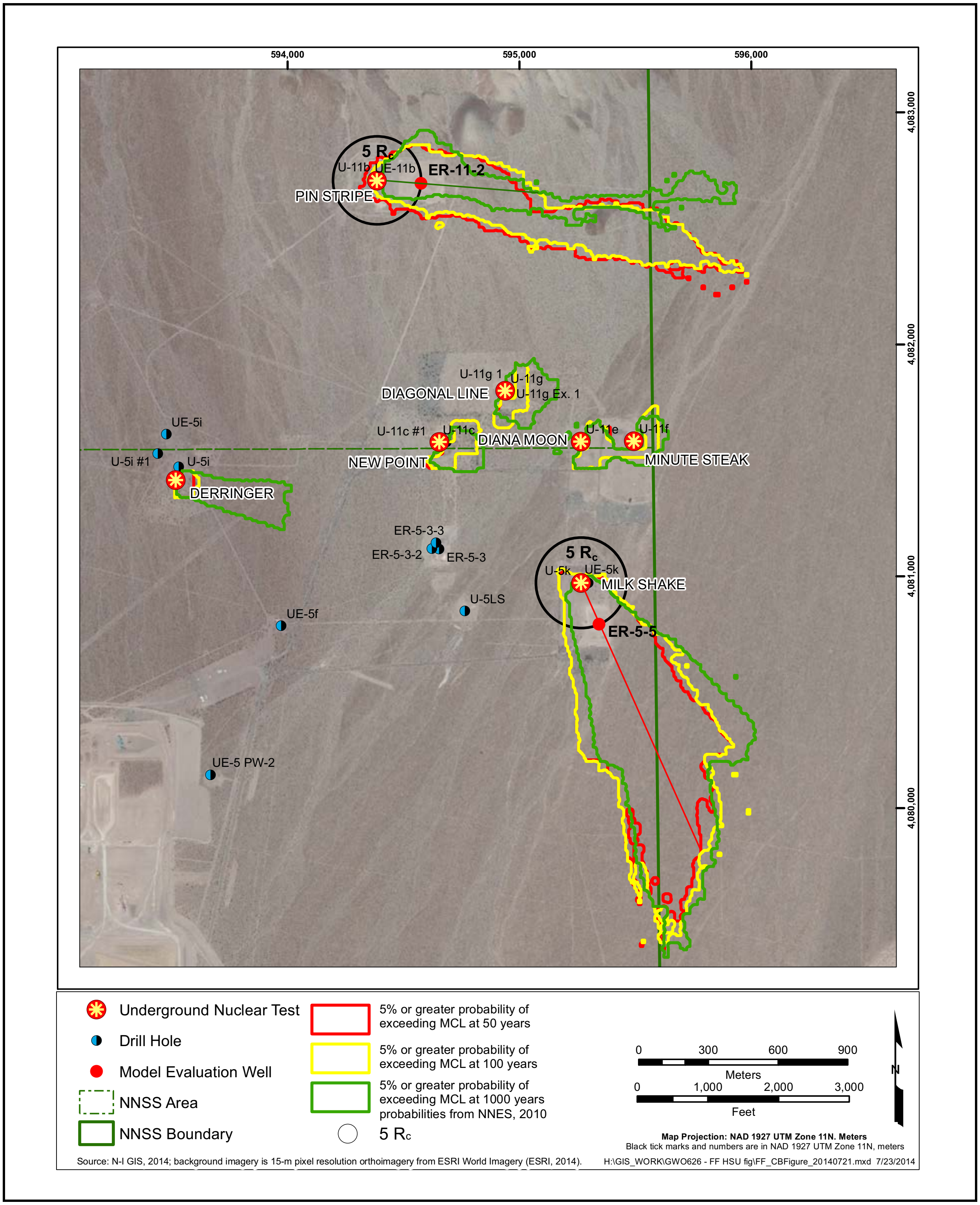


Figure 2-2
Satellite Image of Northern Frenchman Flat Showing Forecast CBs for the Northern Testing Area Underground Nuclear Tests

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

Pawloski (1999). The well was also expected to provide information regarding the nature and hydrologic character in the alluvial section, particularly the intercalated BLFA.

Data collected during construction of Well ER-5-5 include composite drill cuttings samples collected every 3.0 m (10 ft) from 36.6 to 331.3 m (120 to 1,087 ft). Figure 2-3 shows the hydrology and general completion of Well ER-5-5. Open-hole geophysical logging was conducted in the portion of the hole below the surface casing to help verify the geology and assess the hydrologic characteristics of the alluvium and BLFA. However, the log data collected above the depth of 206.7 m (678 ft) were unusable because much of the borehole had been cemented during drilling to stabilize sloughing zones. A complete listing of these data is presented in the completion report for Well ER-5-5 (NNSA/NSO, 2013a).

Well ER-5-5 was drilled entirely within Quaternary–Tertiary alluvium, which contains an intercalated rubblized basalt flow (i.e., BLFA) that was penetrated between the depths of 290.8 and 297.5 m (954 and 976 ft) (Figure 2-4). The stratigraphy, general lithology, and water level were as expected, though the expected BLFA is basalt rubble and not the dense, fractured lava as modeled.

For more information on the drilling and completion of Well ER-5-5, refer to *Completion Report for Model Evaluation Well ER-5-5, Corrective Action Unit 98: Frenchman Flat* (NNSA/NSO, 2013a).

2.2.2 Well ER-11-2

Well ER-11-2 was the second of two Underground Test Area (UGTA) model evaluation wells constructed in Frenchman Flat during the summer of 2012 (NNSA/NSO, 2013b). The primary purpose for drilling Well ER-11-2 was to obtain data to evaluate uncertainty in the conceptual model of flow and transport at PIN STRIPE and its CB forecasts. In particular, the well was intended to produce data that would help characterize the hydrogeology and possible radiological contamination immediately downgradient from the PIN STRIPE underground nuclear test, which was conducted in Emplacement Hole U-11b in 1966 (DOE/NV, 2000). Well ER-11-2 is sited along the centerline of the model-forecasted CBs approximately 5 R_c, or 190.5 m (625 ft), east of PIN STRIPE (Figure 2-2). The cavity radius was calculated using the maximum of the announced yield range for the test published in DOE/NV (2000) and Equation (1) in Pawloski (1999).

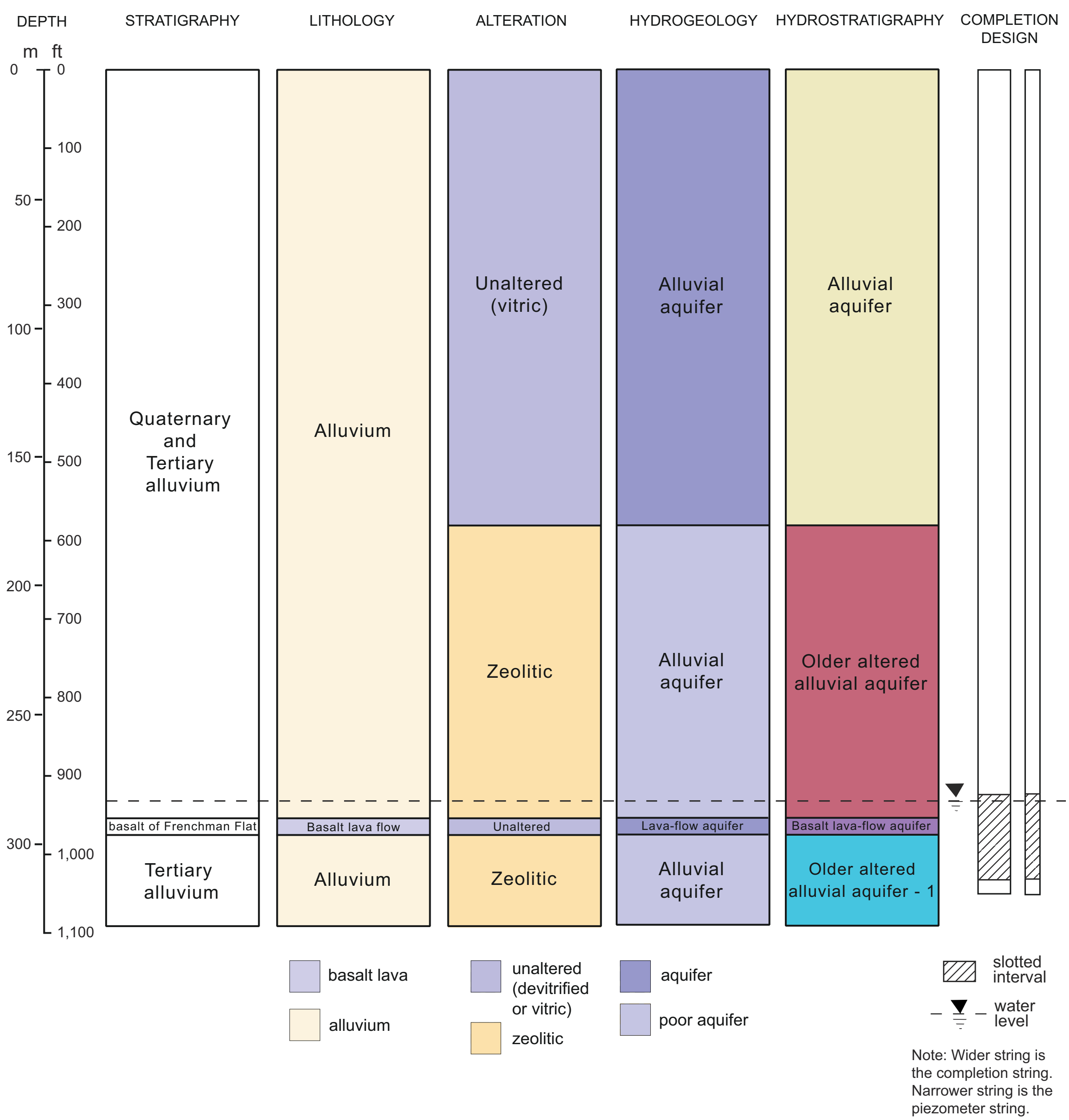


Figure 2-3
Geology and Hydrology of Well ER-5-5
Source: Modified from NNSA/NSO, 2013a

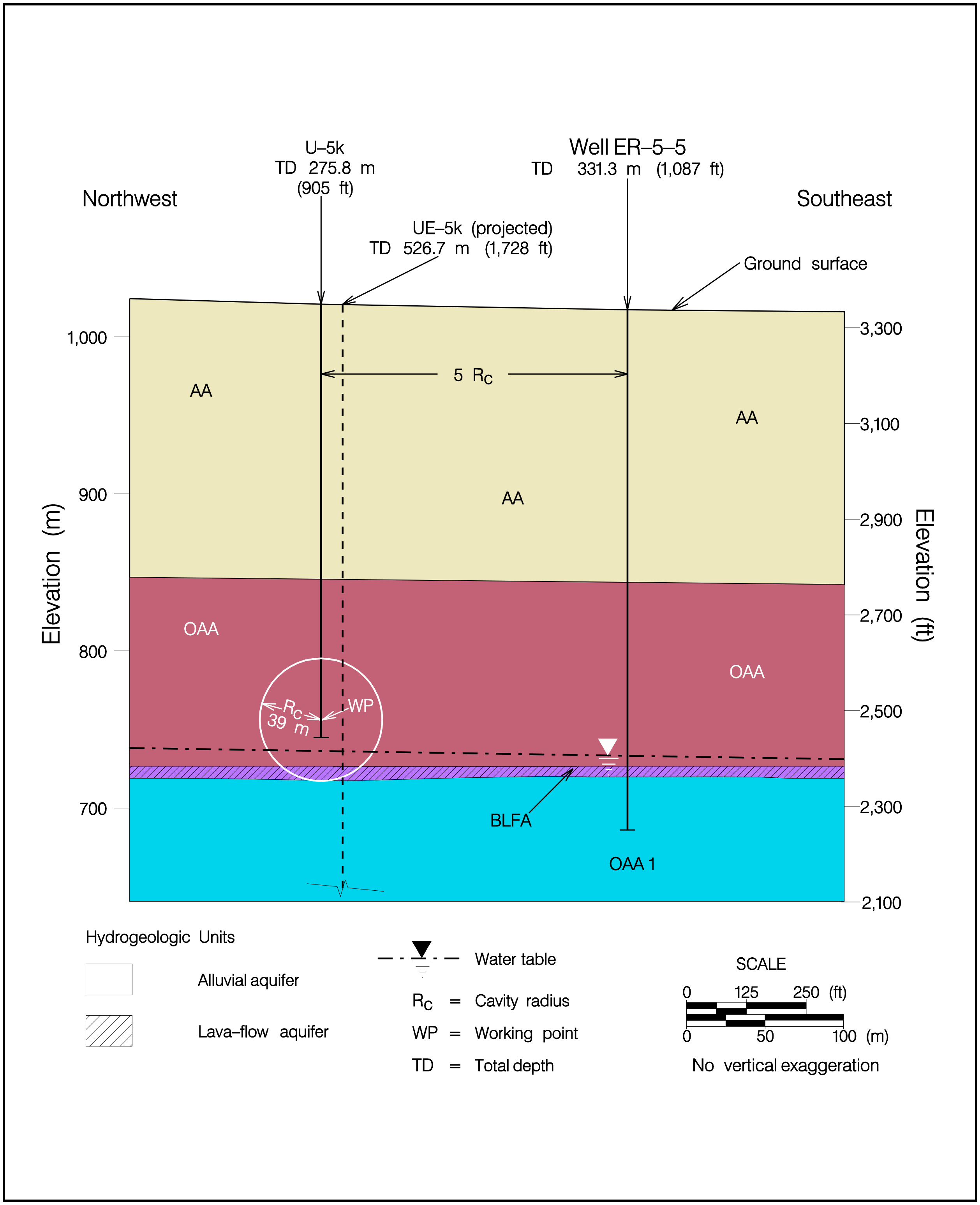


Figure 2-4
Northwest–Southeast Geologic Cross Section through Well ER-5-5
Source: Modified from NNSA/NSO, 2013a
Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

Data collected during and shortly after hole construction include composite drill cuttings samples collected every 3.0 m (10 ft) from 33.5 m (110 ft) to 399.3 m (1,310 ft). Open-hole geophysical logging was conducted to help verify the geology and assess the hydrologic characteristics of the saturated units. A complete listing of these data is presented in the completion report for Well ER-11-2 (NNSA/NSO, 2013b).

The well penetrated 42.7 m (140 ft) of Quaternary and Tertiary alluvium and 356.9 m (1,171 ft) of Tertiary volcanic rock (Figure 2-5). See Table 2-1 for stratigraphic nomenclature. The stratigraphy, general lithology, and the water level were generally as expected at Well ER-11-2, though the stratigraphic section is structurally higher than expected due to faulting disrupting the flow path to the east from PIN STRIPE; however, this uncertainty was identified in the flow and transport report (NNES, 2010).

For more information on the drilling and completion of Well ER-11-2, refer to *Completion Report for Model Evaluation Well ER-11-2, Corrective Action Unit 98: Frenchman Flat* (NNSA/NSO, 2013b).

2.3 Well Testing and Sampling

After drilling, logging, and completing Wells ER-5-5 and ER-11-2, additional data-collection activities in support of the evaluation targets shown in Table 1-1 were conducted. These included (1) water-level monitoring by discrete depth-to-water measurements and pressure transducers over about a 16-month period; (2) well development, including step testing and water-quality (total dissolved solids [TDS], dissolved oxygen [DO], turbidity, specific electrical conductance [SEC], pH, bromide) monitoring at Well ER-5-5; (3) a three-day constant-rate pumping test after well development at Well ER-5-5; (4) bailing at Well ER-11-2 and associated water-quality monitoring (TDS, DO, turbidity, SEC, pH, bromide), because hydrogeologic conditions (saturated hydrostratigraphic units [HSUs] in well; see Section 3.1) could not support pumping; and (5) groundwater sample collection for radiochemical and geochemical analyses at the end of the development and testing operations (N-I, 2013b and c). Samples were analyzed by a commercial laboratory certified through the NDEP Bureau of Safe Drinking Water. These results are presented in N-I (2013b and c). Samples were also analyzed by Lawrence Livermore National Laboratory (LLNL) using non-standard methods that provide significantly lower detection capabilities. These data are used to support specific model-evaluation targets. The data and their interpretation are presented for each relevant target as described in Section 3.0.

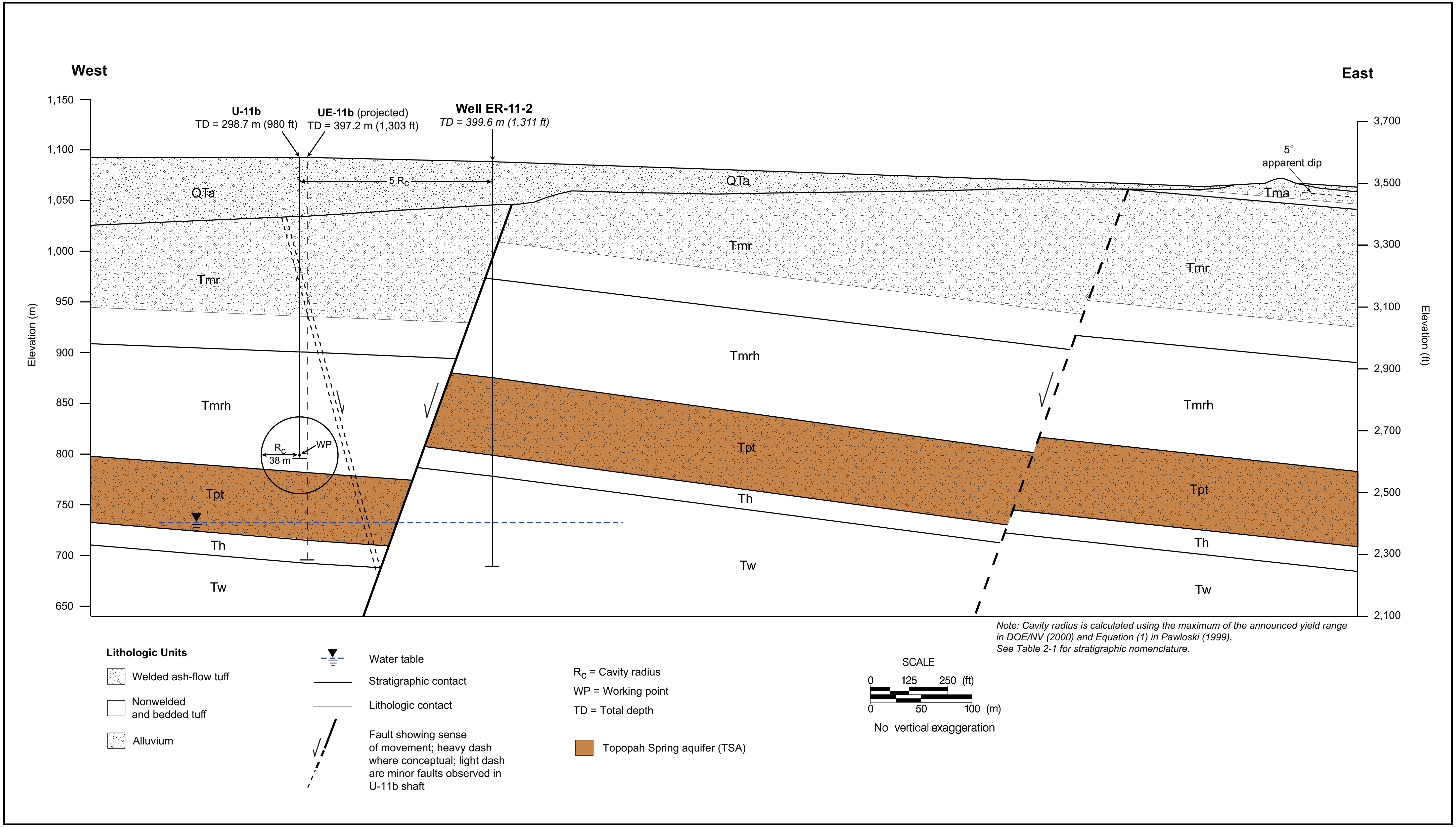


Figure 2-5
West–East Geologic Cross Section through Emplacement Hole U-11b and Well ER-11-2
Source: Modified from NNSA/NSO, 2013b

Table 2-1
Key to Stratigraphic Units and Symbols of the Well ER-11-2 Area

Stratigraphic Unit	Map Symbol
Quaternary and Tertiary deposits	**QT**
young alluvial deposits	Qay
intermediate alluvial deposits	Qai
old alluvial deposits	QTa
Timber Mountain Group	**Tm**
Ammonia Tanks Tuff	Tma
Rainier Mesa Tuff	Tmr
mafic-poor Rainier Mesa Tuff	Tmrp
tuff of Holmes Road	Tmrh
Paintbrush Group	**Tp**
Topopah Spring Tuff	Tpt
Calico Hills Formation	**Th**
mafic-poor Calico Hills Formation	Thp
Wahmonie Formation	**Tw**

Source: NNSA/NSO, 2013b

2.4 Water-Level Measurement Program

The CADD/CAP (NNSA/NSO, 2011, p. 55) includes developing a water-level monitoring program in Frenchman Flat. Water levels have been routinely monitored at the Area 5 Radioactive Waste Management Complex (RWMC) since 1996 and throughout the Frenchman Flat CAU beginning around 2003 (Table 2-2). These established programs constitute an ongoing monitoring program that has resulted in approximately 80 percent more static water-level measurements since the CAI data compilation documented by Stoller-Navarro Joint Venture (SNJV) in 2004 (SNJV, 2004c).

A standardized protocol, as specified in the CADD/CAP (NNSA/NSO, 2011), has been implemented by DOE in accordance with the UGTA Quality Assurance Plan (NNSA/NSO, 2012). This protocol includes a reference-point dataset that was established to ensure high-precision measurements needed to resolve the small water-level differences among the CAU wells. Reference points for water-level measurements include the latitude, longitude, ground-surface elevation, and the measure-point elevation. A review conducted by NSTec (Ortego, 2013a) confirmed that the differential leveling survey completed in 2001 of 14 Frenchman Flat wells reflects the best available survey technology and provides accuracies in the range of 0.01 ft (Table 2-3). Pre-2013 records for nine other Frenchman Flat wells did not have a sufficient survey precision or documentation, and were

Table 2-2
Quarterly Water-Level Monitoring for Wells in Frenchman Flat

Well	Quarterly Monitoring		Measurements Since HDD (SNJV, 2004c)
	Organization	Start	
ER-5-3 deep piezometer	USGS	Q1 2002	38
ER-5-3 main (upper zone)	USGS	Q1 2002	38
ER-5-3 shallow piezometer	USGS	Q1 2002	37
ER-5-3 #2	USGS	Q1 2002	37
ER-5-3 #3	USGS	Q1 2002	37
ER-5-4 main	USGS	Q3 2003	38
ER-5-4 piezometer	USGS	Q3 2003	38
ER-5-4 #2	USGS	Q1 2003	39
ER-5-5	USGS	Q3 2012	19
RNM-1	USGS	Q4 2004	37
RNM-2S	USGS	Q1 2001	40
UE-5n	USGS	Q1 2001	40
WW-5A	USGS	Q1 1992	117
WW-5B	USGS	Q1 2003	35
TW-3	USGS	Q1 2005	33
ER-11-2	USGS	Q2 2014	64 [a]
RNM-2 [b]	USGS	--	0
UE-11a [c]	USGS	--	0
UE-5 PW-1	NSTec	Q1 1996	36
UE-5 PW-2	NSTec	Q1 1996	36
UE-5 PW-3	NSTec	Q1 1996	36

[a] As of 01/01/2014. Well ER-11-2 was instrumented with a transducer, so quarterly electric tape measurements were initiated Q2 2014. Most of the measurements are calibrated electric tape measurements performed by N-I.
[b] The completion for Well RNM-2 has been obstructed since 12/04/2006. The well was checked quarterly until 06/24/2010 to see whether the obstruction is still present.
[c] Water levels were measured in Well UE-11a from 09/30/1965 to 07/26/1996. The well is still monitored quarterly to verify the water level is not above the collapsed bottom.

HDD = Hydrologic data document
N-I = Navarro-Intera, LLC
NSTec = National Security Technologies, LLC
-- = Not started

Table 2-3
Comparison of Ground-Surface Elevation Surveys for Water-Level Monitoring Wells in Frenchman Flat and Vicinity

Well Reporting Name	Land-Surface Elevation [a] (SNJV, 2004c)	Ground-Surface Elevation [b] (SNJV, 2006)	2004 SNJV Survey Surface Elevation [b]	2001 BN Survey [c]	2013 NSTec Survey [d]	Best Available	Differences between Best Available [e]		CADD/CAP Water-Level Measurement Program
	(m amsl)			Ground-Surface Elevation (m amsl)			SNJV, 2004c	SNJV, 2006	
ER 5-3 (3" deep)	1,017.24	1,016.57	1,016.57	--	1,016.54	1,016.54	0.70	0.03	Y
ER 5-3 (3" shallow)	1,017.24	1,016.57	1,016.57	--	1,016.54	1,016.54	0.70	0.03	Y
ER 5-3 (main)	1,017.24	1,016.57	1,016.57	--	1,016.54	1,016.54	0.70	0.03	Y
ER 5-3 #2	1,017.24	1,016.58	1,016.58	--	1,016.56	1,016.56	0.68	0.02	Y
ER 5-3 #3	1,017.24	1,016.58	1,016.58	--	1,016.55	1,016.55	0.69	0.03	Y
ER 5-4 (main)	954.54	954.58	954.58	--	954.54	954.54	0.00	0.04	Y
ER 5-4 (piezometer)	954.54	954.58	954.58	--	954.54	954.54	0.00	0.04	Y
ER 5-4 #2	954.54	954.62	954.62	--	954.56	954.56	-0.02	0.06	Y
RNM-1	955.6	955.66	955.66	955.60	--	955.60	0.00	0.06	Y
RNM-2	953.66	953.63	953.63	953.66	--	953.66	0.00	-0.03	Y (obstructed/infill)
RNM-2S	954.16	954.20	954.20	954.09	--	954.09	0.07	0.11	N
TW-3	1,061.96	--	--	1,061.96	--	1,061.96	0.00	NC	N
UE-11a	1,078.48	--	--	1,078.48	--	1,078.48	0.00	NC	Y (obstructed/infill)
UE-11b	1,093.01	--	--	--	--	1,093.01	0.00	NC	N
UE-5 PW-1	968.73	--	--	--	968.77	968.77	-0.04	NC	Y
UE-5 PW-2	989.54	--	--	989.41	--	989.41	0.13	NC	Y
UE-5 PW-3	1,004.50	--	--	--	1,004.51	1,004.51	-0.01	NC	Y
UE-5c WW upper	980.32	--	--	980.32	--	980.32	0.00	NC	N
UE-5c WW lower	980.32	--	--	980.32	--	980.32	0.00	NC	N
UE-5f	1,006.09	--	--	1,006.09	--	1,006.09	0.00	NC	N
UE-5n	948.95	948.99	948.99	948.85	--	948.85	0.10	0.14	Y
WW-1	944.88	--	--	--	--	944.88	0.00	NC	N
WW-5A	942.97	942.68	942.68	942.63	--	942.63	0.34	0.05	Y
WW-5B	942.83	--	--	942.48	--	942.48	0.35	NC	Y
WW-5C	939.73	939.28	939.28	939.24	--	939.24	0.49	0.04	N
ER-5-5	Not drilled	Not drilled	Not drilled	Not drilled	1,017.20	1,017.20	--	NC	Y
ER-11-2	Not drilled	Not drilled	Not drilled	Not drilled	1,089.12	1,089.12	--	NC	N

[a] Table 8-1 (SNJV, 2004c)
[b] As reported in Table A.1-1 (SNJV, 2006)
[c] Ortego, 2013a
[d] Ortego, 2013b
[e] Negative values indicate best available values are greater than previously published value.

amsl = Above mean sea level
N = No
NC = No change from SNJV (2004c)
Y = Yes
-- = Not applicable

resurveyed during 2013 using the Global Positioning System (GPS) to provide more accurate well site locations (Ortego, 2013b).

Resurvey of the nine wells resulted in modest changes to reference elevations (Table 2-3). Revised reference elevations are compared to the reference elevations reported in the Frenchman Flat HDD (SNJV, 2004c) and the Frenchman Flat flow model report (SNJV, 2006). Overall, best available ground surface elevation measurements are within a few centimeters of those used in the Frenchman Flat models (Table 2-3).

Permanent reference points for data collection were established at each of the water-level monitoring wells. For the majority of wells, angle irons have been welded onto well casings, providing a land-surface reference location. In all cases, diagrams with land surface, reference mark, and measuring point values were completed for each well to clearly document measure points and values. These documents are stored in the UGTA Technical Data Repository, available on the UGTA Field Operations SharePoint Site and used by data-collection staff.

The majority of Frenchman Flat water levels are monitored by the USGS Nevada Water Science Center in support of the UGTA activity. USGS conducts a hydrologic data-collection program at the NNSS and vicinity, which includes an onsite water-level monitoring well network. Typically, water levels in the wells in Frenchman Flat are measured quarterly within a day of two of one another, providing synoptic datasets. These water levels are recorded as depth to water from a reference point using electric tapes that are calibrated annually with a USGS steel reference tape. Table 2-2 lists the wells monitored in Frenchman Flat and vicinity, the start of quarterly data, and the number of new measurements since the Frenchman Flat HDD (SNJV, 2004c).

In addition to the USGS water-level monitoring program, three exploratory boreholes were drilled to the water table in Area 5 of the NNSS in 1992. Wells UE-5 PW-1, UE-5 PW-2, and UE-5 PW-3 are located in a triangular array near the southeast, northeast, and northwest corners, respectively, of the approximately 2.6-square-kilometer Area 5 RWMC. Water levels are currently monitored quarterly by NSTec as part of the operations for the RWMC facility (Table 2-2). Depth to water is measured in the wells using an electric tape, consistent with the methodology employed by USGS. The RWMC water-level measurements are taken on the same day for all three wells, allowing synoptic comparisons. Historically, the RWMC measurements have not been synchronized with the USGS measurement schedule, though the measurement dates sometimes coincide. Coordination between the programs has been initiated to synchronize the measurement schedule in the future, as required in the CADD/CAP (NNSA/NSO, 2011).

Water-level measurements are also made by N-I field staff during data-collection activities such as aquifer tests or groundwater sampling. Measurement methods may include electric tapes or transducers depending on the access to the well and the needs of the data-collection program. N-I uses the same measure points as those documented in the well-specific diagrams used for the quarterly monitoring program.

Water-level data from all of these monitoring programs are compiled and available in the USGS National Water Information System (NWIS) database (USGS, 2014). The NWIS database also includes data comments and reference elevations used for data collection.

3.0 MODEL EVALUATION TARGETS AND RESULTS

Evaluation targets identified in the CADD/CAP (described in Section 1.0) were addressed by data-collection activities summarized in Section 2.0. This section presents the analysis of the data and target evaluation.

3.1 Internal Continuity of TSA

Well ER-11-2 (Section 2.2.2) and a ground-based magnetic survey (Section 2.1) were designed to investigate whether the BASE HFM is overly conservative in representing the TSA as a continuous, well-connected HSU. Specifically, the goals were to investigate the possibility that vertical displacement on north–south-striking normal faults are present that could disrupt a flow path eastward through the TSA. Results from the ground magnetic survey were inconclusive (Section 2.1). The data from Well ER-11-2, however, are unambiguous in establishing the disruption of the TSA east of PIN STRIPE. Well ER-11-2 encountered completely unsaturated TSA approximately 100 m (328 ft) higher than observed at Well UE-11b and PIN STRIPE (Figure 2-5). Geological analysis of the PIN STRIPE area incorporating the new data from Well ER-11-2 strongly suggests that a northward-striking, down-on-the-west normal fault is present between PIN STRIPE and Well ER-11-2. This fault completely disrupts the continuity of the TSA east of PIN STRIPE as hypothesized in the CADD/CAP target description, and juxtaposes the tuff confining unit (TCU) against the TSA along the flow path east of PIN STRIPE, severing the eastward TSA flow path.

3.2 Spatial Extent of TSA in the North

Results from Well ER-11-2 indicate that the TSA is unsaturated and approximately 100 m (328 ft) higher along the modeled flow path east and downgradient of PIN STRIPE, and also that the TCU is juxtaposed against the TSA east of PIN STRIPE. Thus, the amount of saturated TSA is overestimated in the BASE HFM, and the uncertainty of the structural dip of the TSA along the flow path east of PIN STRIPE is rendered irrelevant by the results from Well ER-11-2.

3.3 Hydraulic Conductivity of WTA (TSA)

Hydraulic conductivity of the TSA was an uncertainty that affected forecasted CBs from PIN STRIPE when it was believed that saturated TSA might extend east of Well ER-11-2. As shown in the flow and transport report (NNES, 2010), the hydraulic conductivity of the TSA—which is modeled as a thin, continuous strip of fractured rock along the northern edge of the basin, sandwiched between the lower tuff confining unit (LTCU) on the north and the older alluvial aquifer (OAA) on the south—exercises a strong control on CB extent. The contrast in the CBs between the BASE-USGS alternative (most extensive CB) and the Northern Hydrologic Alternative (NHA) (least extensive CB, with lower hydraulic conductivity TSA) illustrates this issue (see NNES, 2010, Appendix D for further discussion).

However, another key, more impacting uncertainty developed in the transport model report is the potential for the TSA to be disrupted by faulting, as evaluated in Section 3.1. Geologic interpretation of Well ER-11-2 shows that the TSA is above the water table with the saturated TCU below. Thus, this target cannot be evaluated because the TSA is dry at Well ER-11-2. Given the configuration of the geology, this target is no longer of consequence because even if the TSA is saturated farther east, the path is blocked by the TCU just west of Well ER-11-2.

3.4 Continuity of BLFA

Results of the ground magnetic survey (Phillips et al., 2014) suggest that the basalt encountered in several holes in northern Frenchman Flat, designated the BLFA HSU, is likely more extensive and continuous south and east of MILK SHAKE than depicted in the Frenchman Flat BASE HFM (BN, 2005), but is similar to an alternative model also presented in BN (2005) (Figure 2-1, this report). Thus, the ground magnetic survey decreased the uncertainty associated with the lateral extent and continuity of the BLFA, particularly along the modeled flow path from MILK SHAKE.

3.5 Conceptual Model of Basin Drainage to the Southeast

This model evaluation target was addressed by measuring water levels at new wells and as part of a water-level monitoring program (Sections 2.3 and 2.4). Table 4-1 in the CADD/CAP (NNSA/NSO, 2011) describes the conceptual model of basin drainage to the southeast as a low priority model evaluation target focusing on flow directions and velocities.

The conceptual models for groundwater flow in the Frenchman Flat basin have been developed over decades (Winograd and Thordarson, 1975; Laczniak et al., 1996), culminating with the UGTA CAI (SNJV, 2006; NNES, 2010). Dominant features of all conceptual models for the basin are the high hydraulic heads in the CP basin northwest of Frenchman Flat (over 100 m higher than heads in the alluvial basin); the semiperched condition of groundwater in the alluvium and volcanic aquifers as evidenced by the higher heads in these aquifers compared to the regional LCA; and the southeastward thinning of the volcanic section away from the volcanic centers located northwest of Frenchman Flat. These features support key inferences regarding groundwater flow paths in the alluvial and volcanic aquifers. In these aquifers, the dominant flow is horizontal across the Frenchman Flat basin from northwest to southeast, and limited leakage into the LCA occurs as the volcanic units thin and/or are offset by faults associated with the Rock Valley fault system. The vertical gradient in the shallow basin-fill units is approximately an order of magnitude less than the horizontal gradient; however, both gradients are very small.

Despite the multiple sources of evidence supporting the conceptual flow model described here, the groundwater flow directions have not been observed through radionuclide migration and have not been easy to resolve from direct data controls due to the very small differences among measured water levels. Data-collection activities identified in Table 4-2 in the CADD/CAP (NNSA/NSO, 2011) include measurement of hydraulic head at Wells ER-5-5 and ER-11-2 to support this model evaluation target.

3.5.1 Water-Level Analysis

Water-level data collected as part of the monitoring program, documented in Section 2.4, were compiled and analyzed to evaluate whether new data collected at Wells ER-5-5 and ER-11-2 resulted in changes in the interpretation of groundwater elevations or flow paths since the CAI. The focus of this analysis was in the Northern Testing Area of Frenchman Flat because this portion of the CAU model was targeted for evaluation during the CADD/CAP (NNSA/NSO, 2011).

3.5.2 Water-Level Data

The groundwater elevation data were primarily compiled from records maintained by USGS in the NWIS database (Elliott and Fenelon, 2010). The NWIS database includes water-level data collected by USGS, NSTec, and N-I on the NNSS and is the most comprehensive source of data. These data have been compiled and are reported in common units, using well-documented reference and measure-point elevations. Fenelon et al. (2010) independently analyzed NWIS data through 2009. Figure 3-1 shows the USGS interpretation of groundwater flow in the basin-fill materials of Frenchman Flat, indicating that groundwater flow is dominated by southeasterly flow, consistent with the CAI flow and transport models and subsequent CB forecasts.

For the CADD/CAP model evaluation, the hydrograph of each well was examined, and water levels that were not affected by field operations such as drilling, sampling, or aquifer testing were identified. Data qualifiers were used to document water levels not suitable for further calculations. The remaining data reflect static water-level measurements. These data were then corrected for any quantifiable borehole deviation using borehole deviation surveys. Table 3-1 documents the static water levels for wells with new data since the CAI data compilation (SNJV, 2004a). Newly collected water-level data are in good agreement with previously available groundwater data at the majority of well locations.

Water-level measurements have several components of uncertainty. As described in the HDD (SNJV, 2004a), the following six uncertainty factors are summed to produce the total uncertainty for a static water-level average:

- **Accuracy of the Reference Point Elevation.** This is the vertical accuracy of the survey used to measure the elevation of the reference point at the well head.
- **Accuracy of Estimate Static Water-Level Elevation.** This is the standard deviation of the water-level measurements used in the average water level.
- **Accuracy of Depth-to-Water Measurements.** This is the accuracy of the measurement method used to determine depth to water. Averages composed of steel-tape-calibrated electric tape measurements are estimated to be accurate to 0.03 m. The measurement methodology has varied for the Area 5 RWMC, so a more conservative accuracy is estimated for these measurements of 0.06 m.
- **Uncertainty Due to Barometric Effects.** This is the variation in the water level caused by fluctuations in atmospheric pressure. The value 0.15 m was determined by examining a long-term record of 5-minute frequency transducer measurements at Well ER-5-5.
- **Accuracy of Borehole Deviation Correction.** This reflects the resolution and data availability for borehole deviation adjustments.

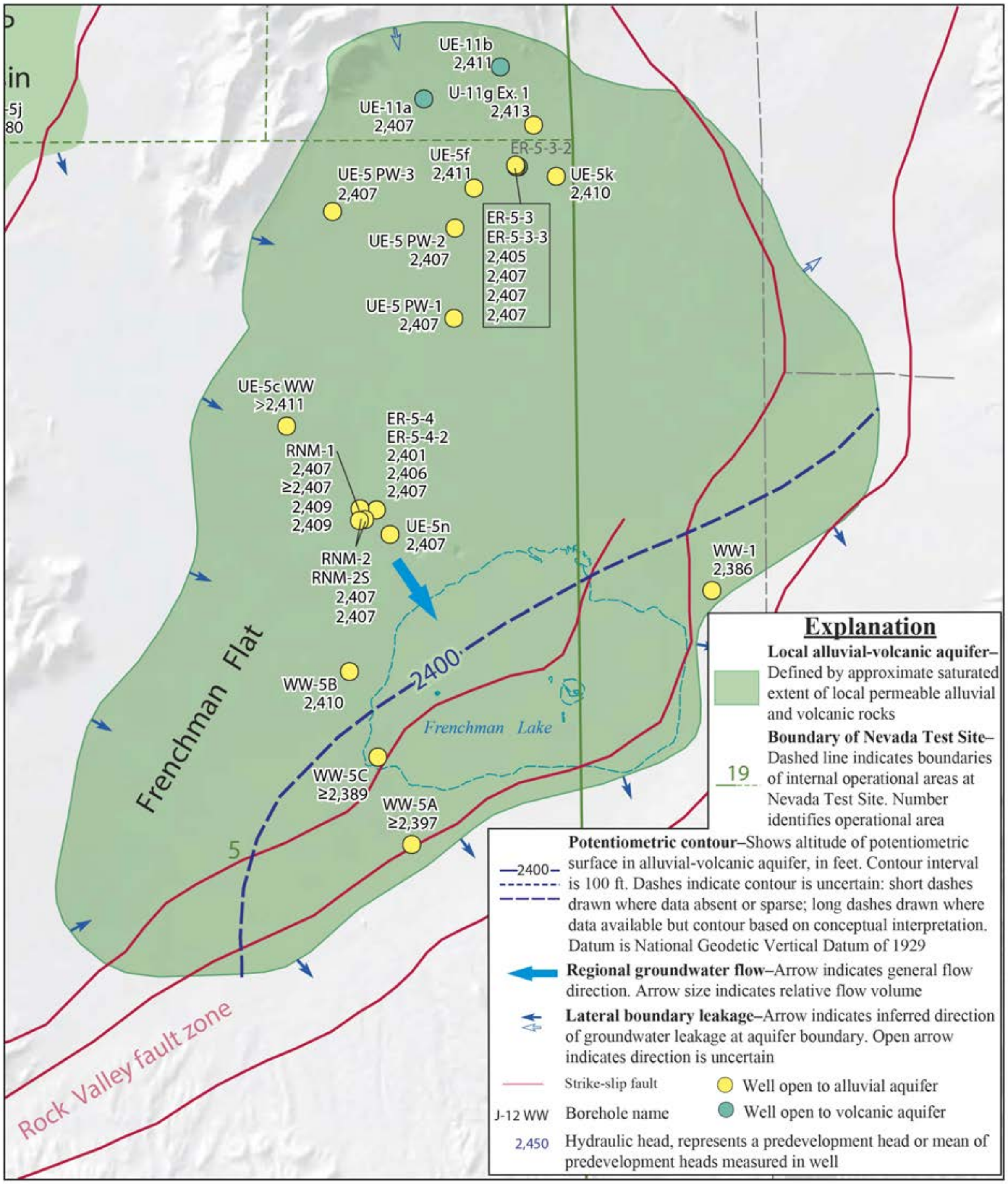


Figure 3-1
USGS Interpretation of Water-Table Elevations in Frenchman Flat Alluvium
Source: Modified from Fenelon et al., 2010

Table 3-1
Summary of Static Head Data and Components of Uncertainty [a]

Well Reporting Name	Number of Static Water-Level Measurements [b]	Static Water Level (m amsl)	Accuracy of the Reference Point Elevation	Accuracy of Estimate Static Water-Level Elevation [c]	Accuracy of Depth-to-Water Measurements	Uncertainty Due to Barometric Effects	Accuracy of Borehole Deviation Correction	Accuracy Due to Data Frequency [d]	Total Uncertainty
		(m)							
ER 5-3 (3" shallow)	50	733.85	0.03	0.05	0.03	0.15	0.001	0.00	0.26
ER 5-3 (3" deep)	8	733.46	0.03	0.03	0.03	0.15	0.001	0.00	0.24
ER 5-3 (Upper Completion)	42	733.86	0.03	0.04	0.03	0.15	0.001	0.00	0.25
ER 5-3 #2	16	729.69	0.03	0.11	0.03	0.15	0.001	0.00	0.32
ER 5-3 #3	50	733.90	0.03	0.05	0.03	0.15	0.001	0.00	0.26
ER 5-4 (main)	45	733.42	0.03	0.06	0.03	0.15	0.001	0.00	0.27
ER 5-4 (piezometer)	44	733.58	0.03	0.06	0.03	0.15	0.001	0.00	0.27
ER 5-4 #2	11	756.29	0.03	0.06	0.03	0.15	0.001	0.00	0.27
ER 5-5	16 [e]	733.72	0.03	0.05	0.03	0.15	0.001	0.00	0.26
ER 11-2	2 [e]	737.36	0.03	0.06	0.03	0.15	0.005	0.10	0.38
RNM-1	37	733.21	0.03	0.05	0.03	0.15	0.75	0.10	1.11
RNM-2	12	733.6	0.03	0.06	0.03	0.15	0.02	0.50	0.79
RNM-2S	64	733.55	0.03	0.07	0.03	0.15	0.02	0.00	0.30
TW-3	59	725.63	0.03	0.18	0.30	0.15	0.03	0.05	0.74
UE-11a	1	733.79	0.07	[f]	0.30	0.15	0.04	0.50	1.06
UE-5 PW-1	40	733.60	0.06	0.06	0.03	0.15	0.03	0.00	0.33
UE-5 PW-2	40	733.68	0.06	0.05	0.03	0.15	0.05	0.00	0.34
UE-5 PW-3	40	733.77	0.06	0.04	0.03	0.15	0.01	0.00	0.29
UE-5n	55	733.68	0.04	0.08	0.03	0.15	0.02	0.00	0.32
WW-5A	214	726.43	0.29	0.63	0.03	0.15	0.02	0.00	1.12
WW-5B	39	732.84	0.30	0.19	0.30	0.15	0.02	0.00	0.96

[a] Only for wells with new data since SNJV (2006).
[b] Through June 2013
[c] Standard deviation
[d] Estimated
[e] Through December 2013
[f] Static head determined from only one measurement

- **Accuracy Due to Data Frequency.** Accuracy due to data frequency was assigned to each static water level based on the analysis reported in SNJV (2004, p. 8-19). These uncertainties account for the temporal distribution of water-level measurements and the likelihood that those values accurately represent aquifer conditions over the measurement time period. It was assigned as follows:
  - 0.0 for many measurements of similar value over a significant time period,
  - between 0.1 and 0.25 m when several measurements were available, but those measurements constituted single measurements or only a few measurements at different time periods,
  - 0.5 m when only one static measurement was available, and
  - 1.0 m for wells having only a single water-level measurement.

Table 3-1 shows the components and total uncertainty in static water levels estimated for each well with new measurements since the CAI. Figure 3-2 shows the static groundwater elevation and uncertainty for wells completed in the alluvial aquifer (AA) or OAA revised with the new data. Overall, the water-level uncertainty is significantly lower throughout Frenchman Flat than before the additional measurements were obtained. This is due to the approximately 80 percent more static water-level measurements since the CAI data analysis (SNJV, 2004a), improved land surface survey data (Section 2.4), and long-term observations of barometric pressure effects.

3.5.3 Comparison of Static Water Levels to CAI Models Used for CB Forecasts

In the CAI modeling reports (SNJV, 2006; NNES, 2010), simulated hydraulic heads are compared to static hydraulic head calibration targets, reflecting predevelopment conditions and estimated measurement uncertainty. Within Frenchman Flat, simulated values were generally in agreement with the CAI static heads presented in SNJV (2006, Appendix A) to within the estimated uncertainties presented in SNJV (2004c) (Figure 3-3). Data reported in Table 3-1 were used to update the static water level and estimated uncertainty in Figure 3-4, while leaving the simulated water levels in the CAI models unchanged. In general, the reduction in uncertainty and the consistency in the water-level data indicate that the models provide a good representation of the current understanding of water levels and associated flow patterns in the Northern and Central Testing Areas. Somewhat larger residuals exist at Wells ER-5-3 #2, WW-5A, and WW-5C.

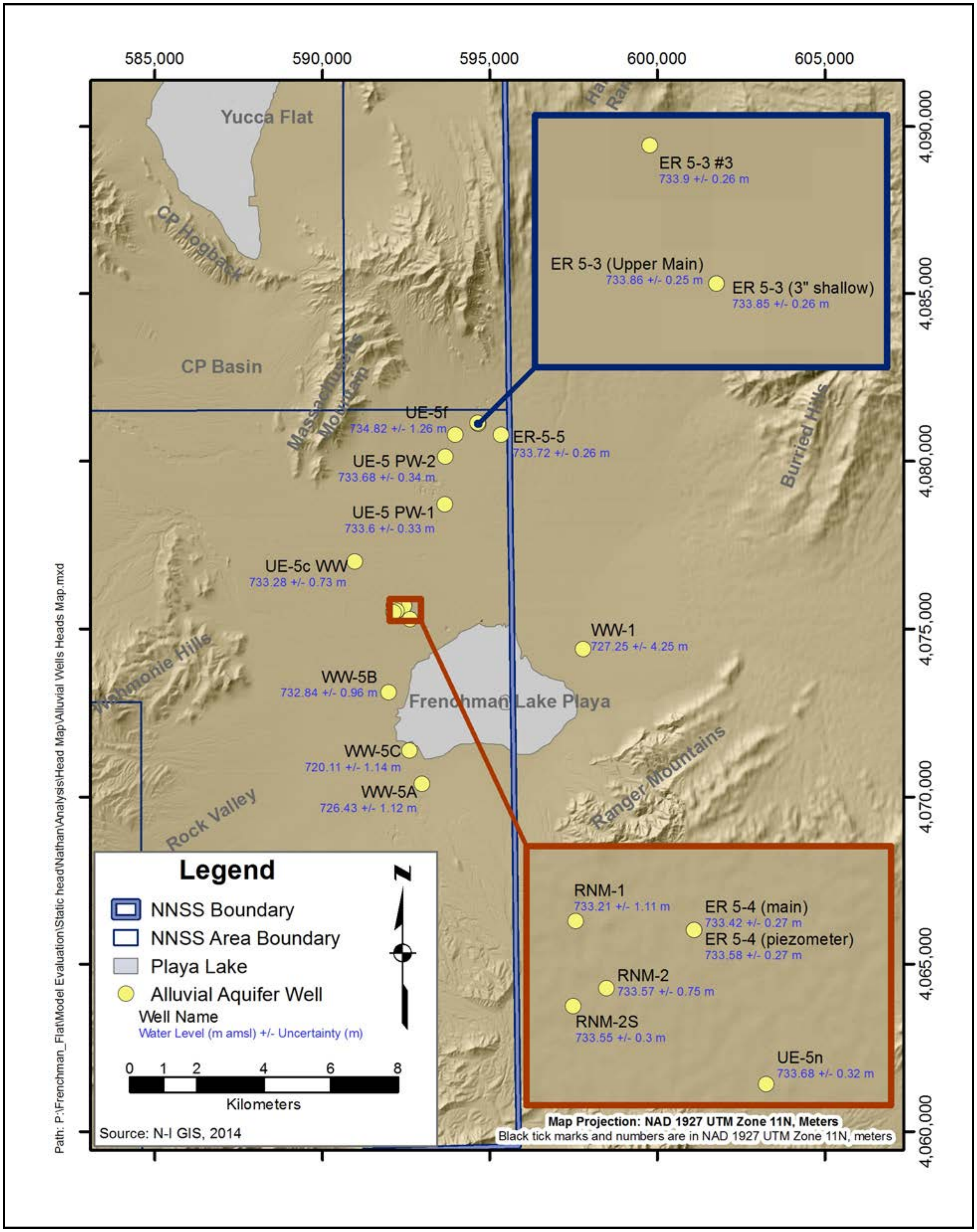


Figure 3-2
Static Hydraulic Head and Total Uncertainty for Wells in OAA and AA

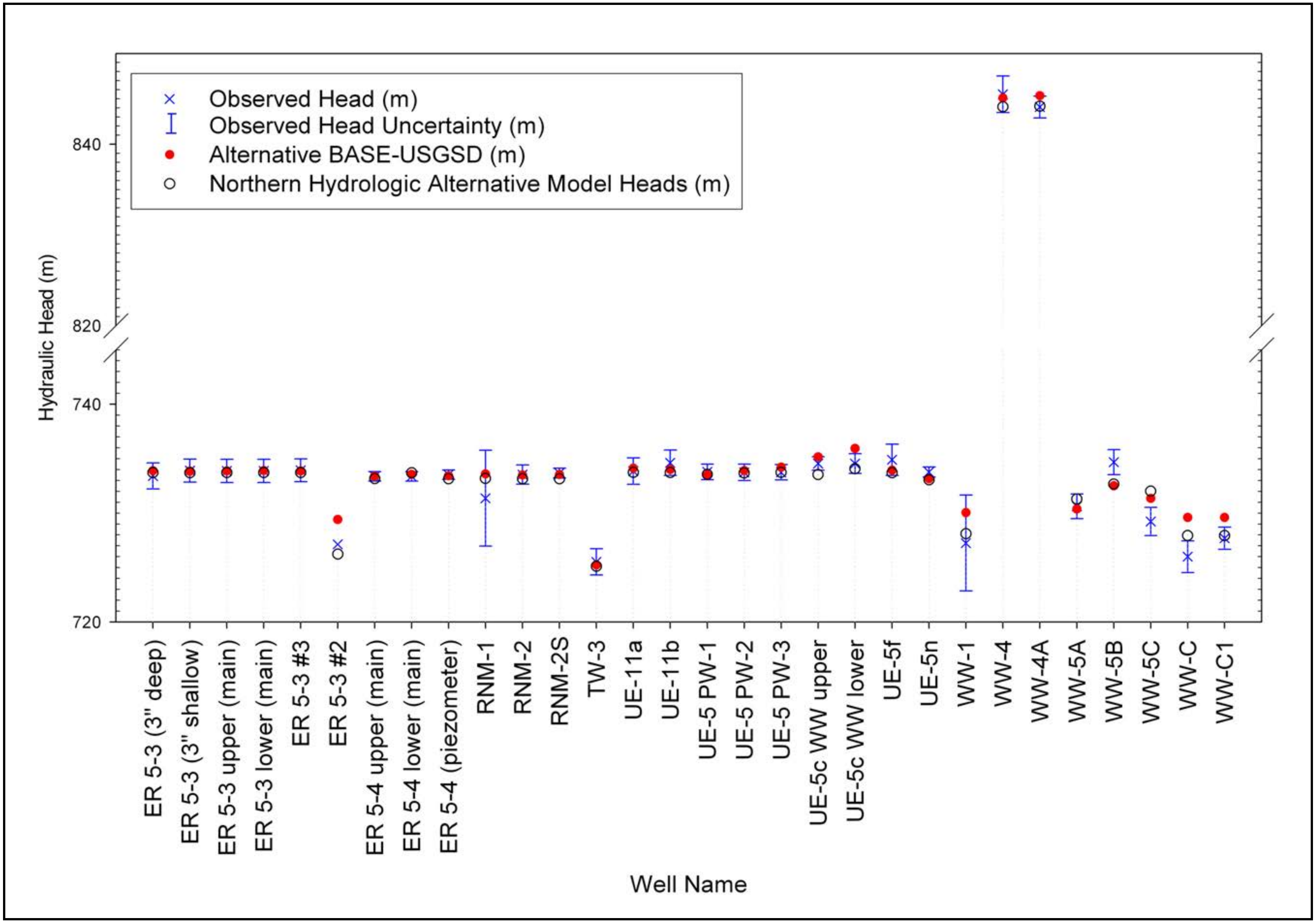


Figure 3-3
CAI Model Hydraulic Head Match to CAI Static Water-Level Data
Source: NNES, 2010

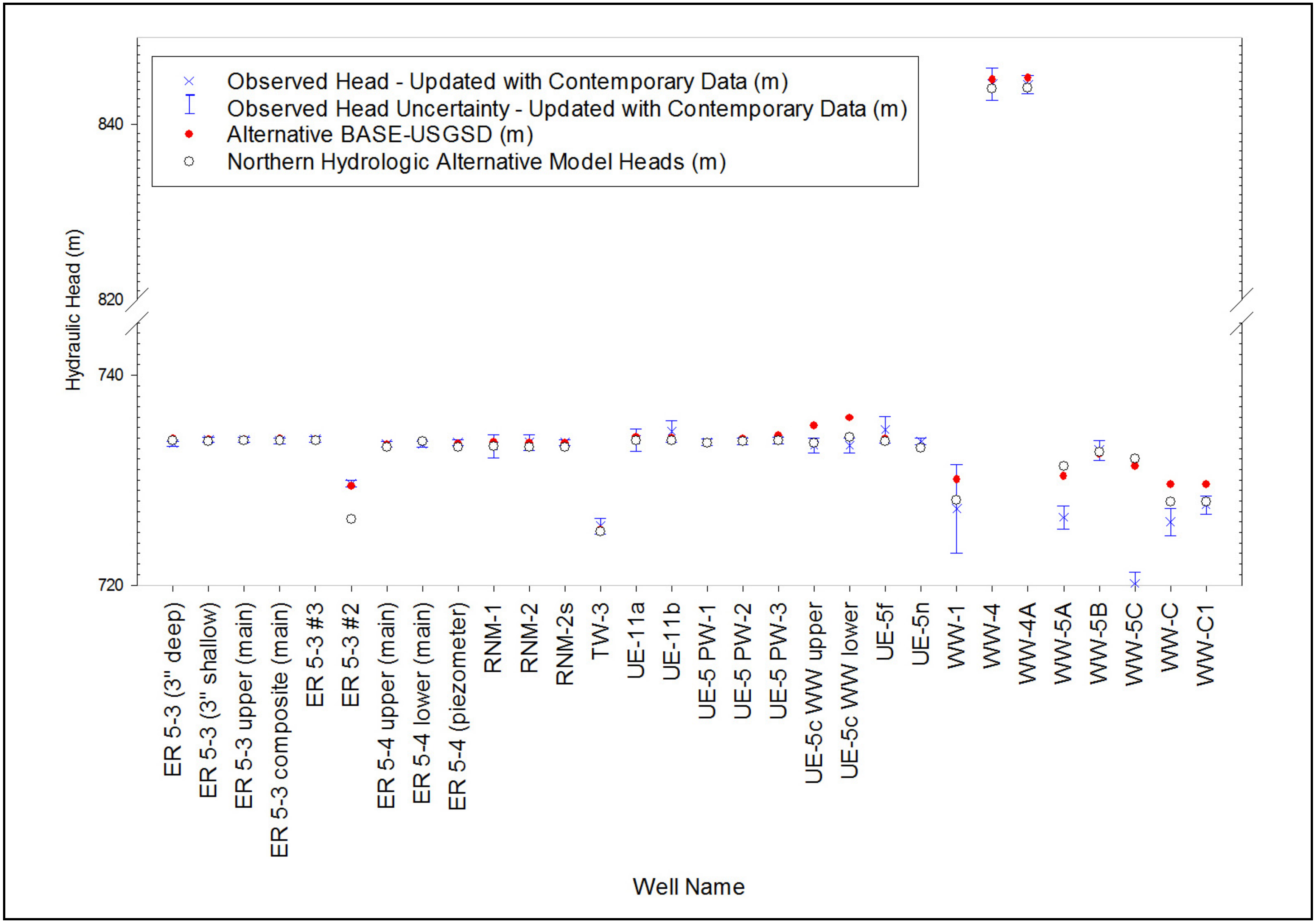


Figure 3-4

CAI Model Hydraulic Head Match to CADD/CAP Static Water-Level Data

Note: When red symbols are not visible, the Alternative BASE-USGSD and NHA model results are nearly identical.

The observed head at Well ER-5-3 #2 (LCA) is well matched by the BASE-USGSD alternative model but underestimated by the NHA model (Figure 3-4). Interestingly, at the time of the CAI model construction and calibration, the best understanding of hydraulic head at Well ER-5-3 #2 was closer to the NHA modeled values (Figure 3-3). Recently collected data indicate that regionally groundwater elevations have been increasing throughout the LCA (Elliot and Fenelon, 2010). In both models, the observed downward head gradient between the alluvium and LCA in northern Frenchman Flat is captured, and the observed magnitude of the measured vertical gradient is bounded by the CAI models.

The simulated hydraulic heads at Wells WW-5A and WW-5C, completed in the alluvium, are higher than the contemporary measured heads at these wells. These wells are located near ongoing withdrawals that were not incorporated into the CAI models, which attempted to simulate predevelopment conditions. A transient analysis demonstrating that continued withdrawals from the water wells in southern Frenchman Flat will not change the CBs in the Central Testing Area is reported in NNES (2010).

3.5.4 New Well Water-Level Data

New groundwater observation Wells ER-5-5 and ER-11-2 provide water-level measurements in portions of the Frenchman Flat CAU where limited data were available. Well ER-5-5 is screened in the BLFA and the OAA (Section 2.2). The static water level observed for the CAI at Well ER-5-5 is approximately 0.15 m lower than water levels observed in these same HSUs at Well Cluster ER-5-3. Well ER-5-5 water levels are consistent with the conceptual and numerical model of the alluvial basin where groundwater flow is to the southeast; therefore, the water level at Well ER-5-5 was expected to be lower than observed at Well Cluster ER-5-3. Although these data were not available at the time of groundwater model calibration, the simulated water level in the NHA model at Well ER-5-5 is 0.03 m lower than the static water level reported in Table 3-1. Similarly, the BASE-USGSD alternative model is in agreement with the new data within 0.16 m (low). In both models, the gradient was overestimated, leading to faster radionuclide migration from MILK SHAKE than the observed hydraulic gradients would indicate. The hydrograph for Well ER-5-5 is shown in Figure 3-5 along with the approximate water-table elevation in Northern Frenchman Flat.

Water levels at Well ER-11-2 (static water level is 737.36 m) are much higher than observed elsewhere in the alluvial basin (see Figures 3-2 and 3-18, and Table 3-1). The elevated water levels at

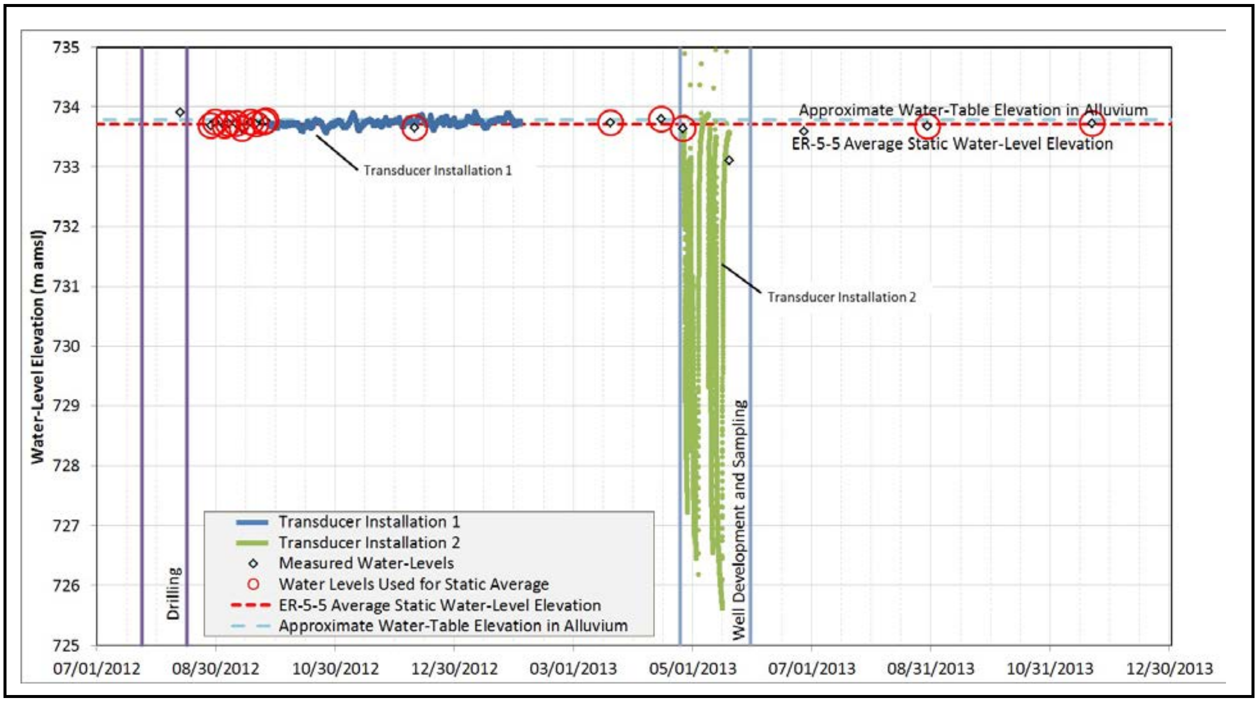


Figure 3-5
Well ER-5-5 Water-Level Elevations

Well ER-11-2 reflect the lithology of the unit, which is bedded tuff, a larger-scale aquitard in the Frenchman Flat basin (SNJV, 2004a and 2006). The Frenchman Flat CAU HFM and subsequent flow and transport models had an aquifer rather than TCU in this position, resulting in lower simulated groundwater elevations than observed at Well ER-11-2 by 3.6 m. The head measurement at Well ER-11-2 is compatible with more southward flow and less eastward flow in the northern part of the basin, consistent with the discontinuous TSA in the vicinity of Well ER-11-2.

3.5.5 Water Levels in the Vicinity of MILK SHAKE

The observed hydrograph for Well ER-5-5 is compared to the hydrographs for the OAA/BLFA completions at Well Cluster ER-5-3 in Figure 3-6. Groundwater elevations are higher in the northernmost location (Well ER-5-3 #3) and decrease to the south (Well UE-5 PW-2). Inspection of Figure 3-6 reveals that water levels collected on the same day are closely tracking one another. For example, all water levels at Well Cluster ER-5-3 are high on the same day. Because these water levels are collected by two different organizations (NSTec and USGS), it is not bias introduced by field staff. In fact, this relationship among the water-level data is observed throughout the semiperched basin of Frenchman Flat. A significant uncertainty component to all contemporary water-level measurements within Frenchman Flat comprises the standard deviation among water-level

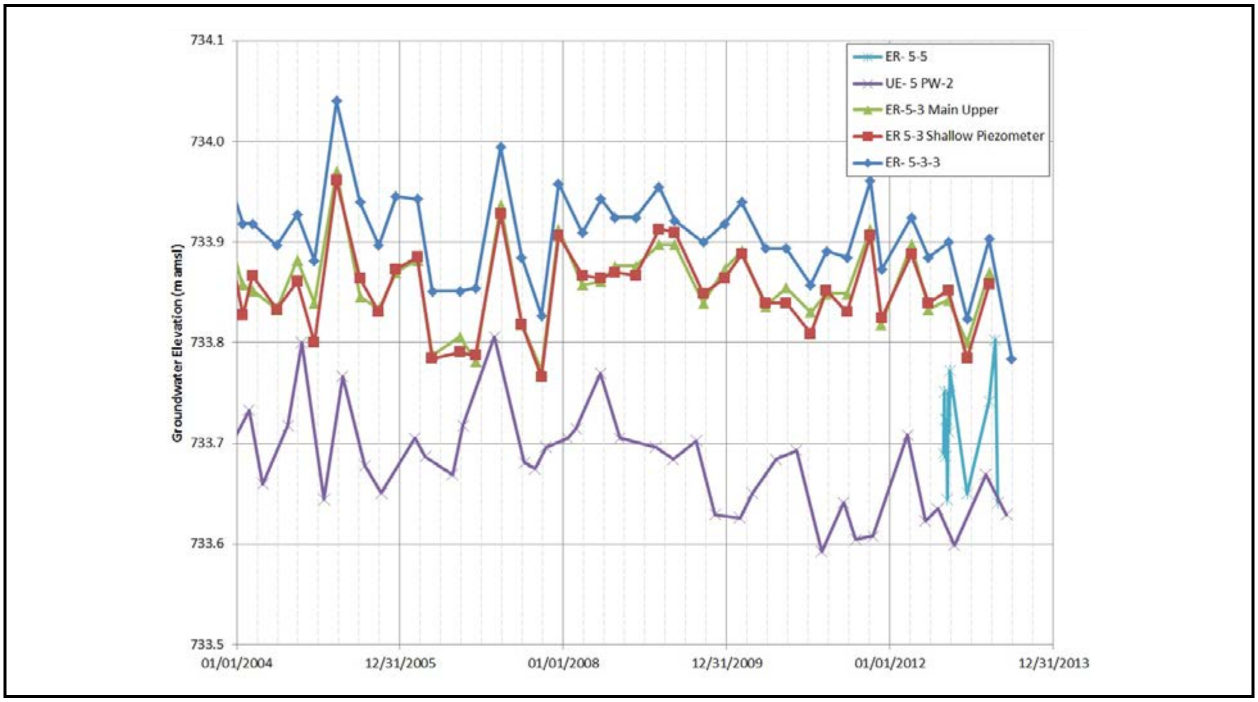


Figure 3-6
Water Levels at Wells in the Vicinity of MILK SHAKE

measurement and barometric uncertainty (Table 3-1). By considering the relationship among water levels collected during synoptic water-level sampling events, the uncertainty in the inferred groundwater gradients can be reduced to better clarify the direction and magnitude of gradients.

To investigate the influence of water-level uncertainty on the local understanding of groundwater flow directions and gradients in the vicinity of MILK SHAKE, a multiple linear regression water-level calculation model was developed using a similar approach to Devlin (2003). This approach assumes that the water table is approximated as a plane, a reasonable assumption throughout the semiperched basin. Uncertainty was evaluated by sampling from triangular distributions representing the static water level and total water-level uncertainty (Table 3-1) for Wells ER-5-3 #3, ER-5-3 Shallow, UE-5 PW-2, and ER-5-5. Using this approach, a regression fit was used to calculate a best-fit horizontal plane that characterized the gradient magnitude and direction of groundwater movement for each realization of the water levels. Solutions reflect a least squares fit of a plane to the sampled water levels. When the total water-level uncertainty is considered without regard to the time-dependent relationship in the measurements, the median of 10,000 Monte Carlo realizations of the groundwater flow direction in the vicinity of MILK SHAKE is 165 degrees clockwise from north, or southeast (Figure 3-7). Well ER-5-5 was drilled 5 R_c and 156 degrees away

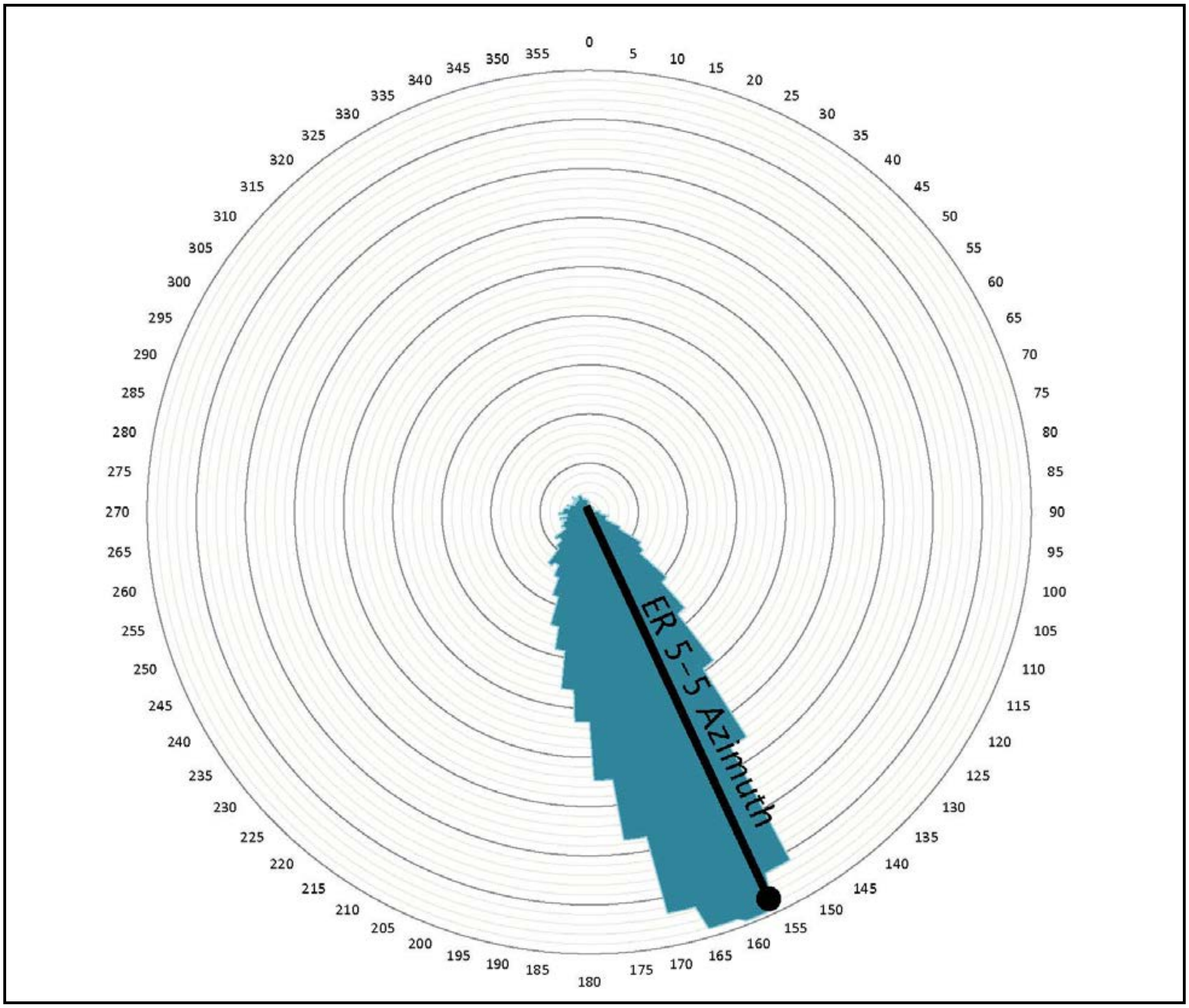


Figure 3-7
Rose Diagram of Best-Fit Plane Average Water-Level Uncertainty (Wells ER-5-5, ER-5-3 Shallow Piezometer, ER-5-3 #3)

from MILK SHAKE, right along the anticipated flow path from MILK SHAKE (Figure 3-7). While the median flow direction calculated from the Monte Carlo realizations reflects a strong clustering of water-level simulations, different trajectories were calculated, allowing for groundwater flow in any direction from MILK SHAKE but with very low probability. When the sum of squared residuals (SSR) is calculated for the best-fit plane, the lowest 5 percent of the SSR corresponds to the median of the 10,000 Monte Carlo simulations and gradients that range from 1×10^{-4} to 4×10^{-4}.

Given the time-dependent trending of water-level measurements, the calculations were repeated using synoptic water-level measurements. Because these measurements remove the background environmental variability (such as barometric pressure), a more precise and accurate understanding of groundwater flow directions is possible. Figure 3-8 shows the gradient magnitude and direction of groundwater movement for each synoptic measurement set. The synoptic data from Wells ER-5-3 #3, ER-5-3 upper piezometer, and UE-5 PW-2 indicate that groundwater is moving to the southeast at approximately 130 degrees from north. When new data from Well ER-5-5 are incorporated into this analysis, the gradient reduces about half an order of magnitude and takes a more southerly orientation by about 35 degrees (Figure 3-8). Estimated flow directions (angular data) and gradients are consistently to the southeast and gradients are clustered (radial axis). These gradients and directions are consistent with the simulations that have the lowest SSR values from the Monte Carlo analysis of the average static water levels and associated uncertainty. The synoptic data provide the highest-quality, most consistent interpretation of the water-level data for Frenchman Flat.

While synoptic data significantly reduce the total uncertainty and better honor the time-dependent trend of water-level measurements, uncertainty is still associated with the measurements. The uncertainty in synoptic water levels reflects the sum of the measurement error (land surface and instrument) and deviation correction. The gradient magnitude and direction of groundwater movement for the uncertainty associated with one synoptic measurement set are shown in Figure 3-9. The measurement method and correction uncertainties are independent of the water-level measurements; therefore, the uncertainty shown in Figure 3-9 is representative of the uncertainty associated with calculated gradient magnitude and direction for each synoptic measurement. The uncertainty associated with averaging water levels, environmental variability, and measurement uncertainty (Figure 3-7) is included for comparison. The basin-scale interpretation of groundwater flow direction and gradients are unchanged as a result of these analyses, in the alluvium of Frenchman Flat groundwater flow is to the southeast.

3.5.6 Summary and Conclusions

Newly collected data at Wells ER-5-5 and ER-11-2 described in Sections 3.5.4 and 3.8, respectively, are in good agreement with the conceptual model of the semiperched groundwater system. At Well ER-5-5, observed heads are similar to other observations in this portion of the basin at Well Cluster ER-5-3 and Well UE-5 PW-2. Local gradient calculations indicate that groundwater flow in the vicinity of MILK SHAKE is 165 degrees from north with a median gradient of 3×10^{-4}. The observed flow direction is bounded by the NHA and BASE-USGSD alternative flow models, and reflected in the CB forecasts. Although observations at Well ER-11-2 are more difficult to compare

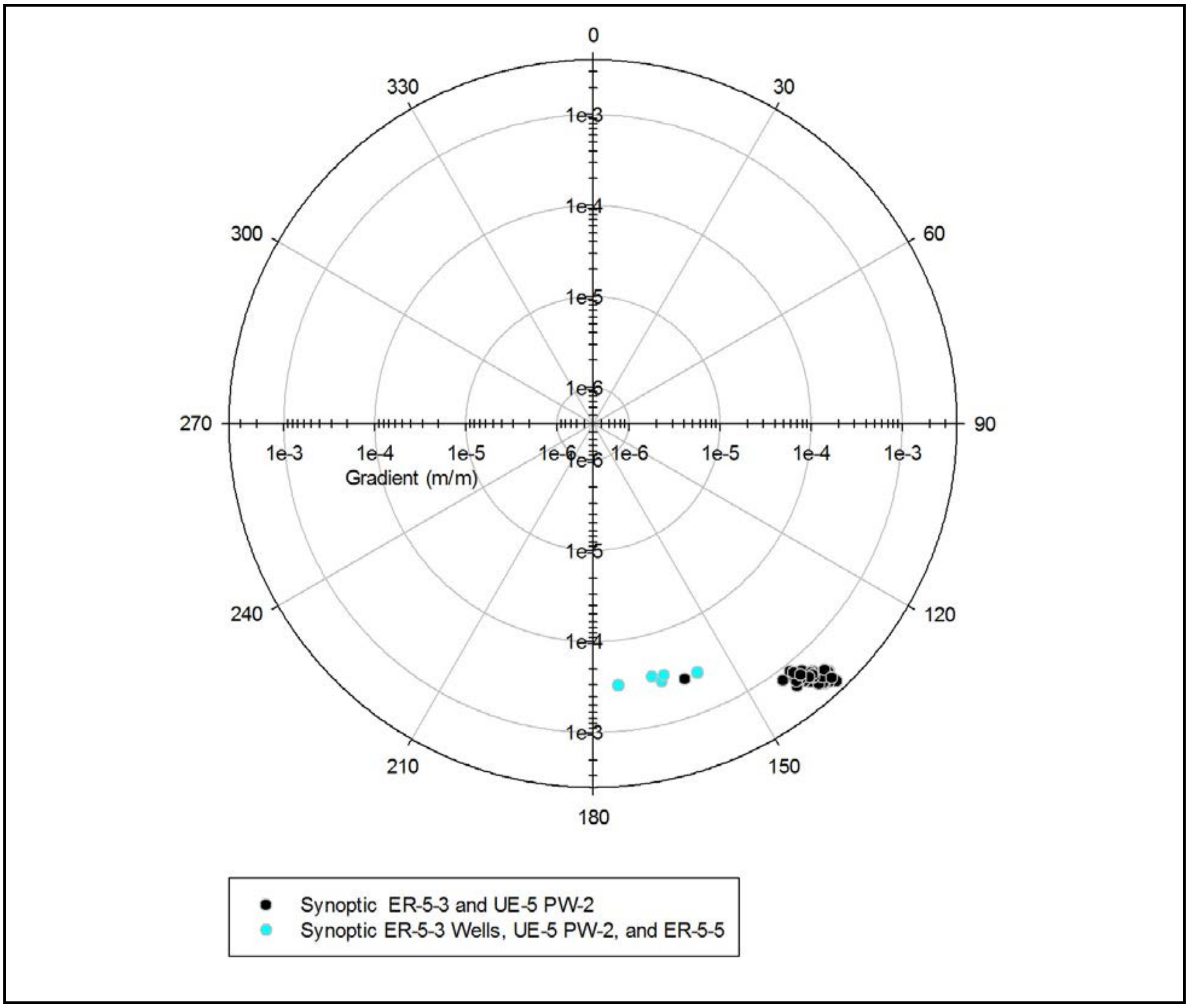


Figure 3-8
Polar Plot of Best-Fit Planes of Synoptic Water-Level Data in the Vicinity of MILK SHAKE

directly to CB results due to the discrepancy between the HFM and observed geology, the groundwater elevation at Well ER-11-2 is a few meters higher than observed in the wells completed in the alluvium HSUs. The water level reflects a transition between the higher heads in the confining units and CP basin and the lower heads in the alluvium. Due to the stratigraphy at the water table, observed heads in CP basin, and limited recharge at Massachusetts Mountain, groundwater flow is directed from north to south in this portion of the basin.

Building on the water-level analysis, the best-fit horizontal planar water-level modeling tool, and simulated water-table elevations by the NHA model, an integrated water-table map has been constructed for Northern Frenchman Flat (Figure 3-10). To do this, the most representative water

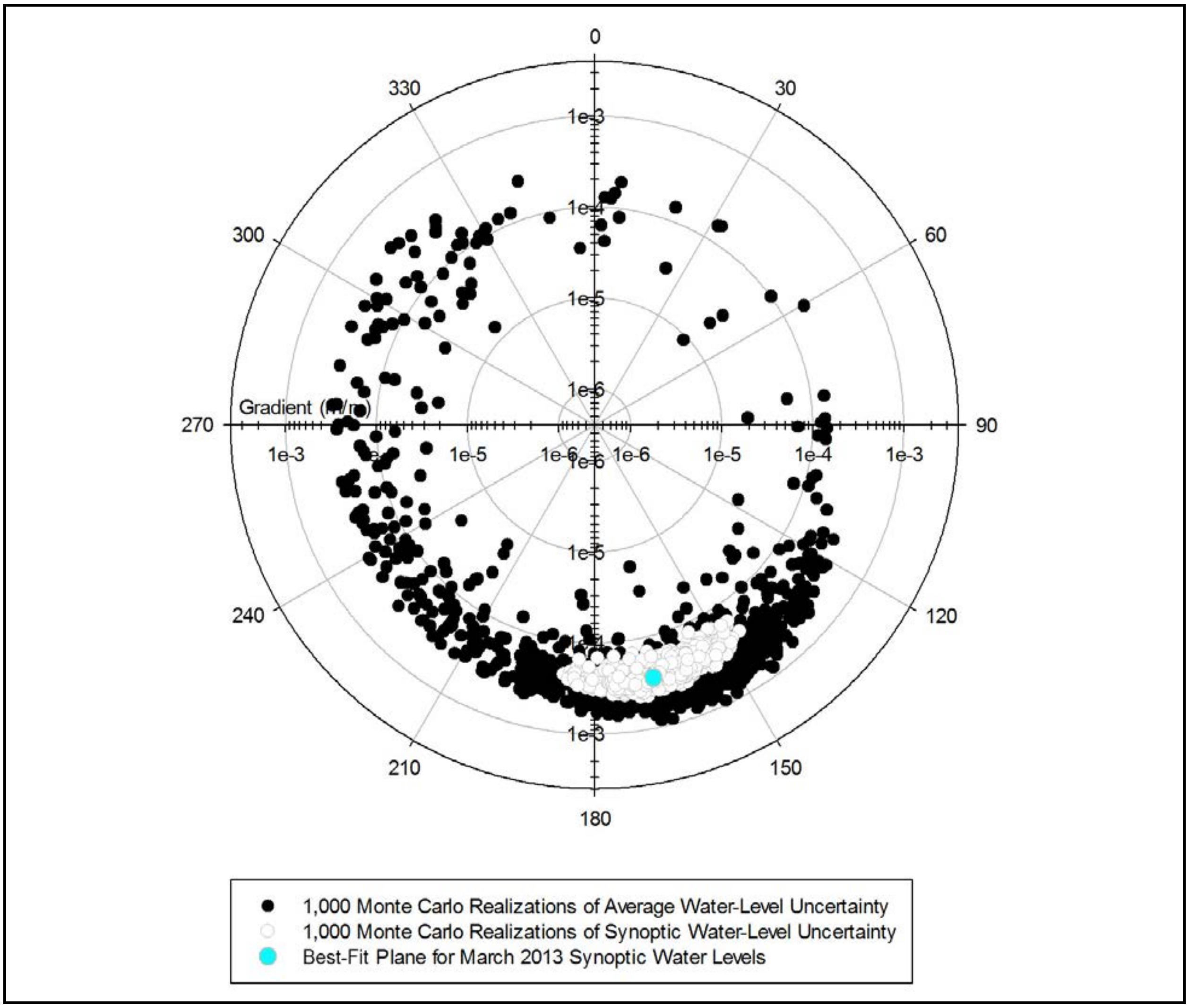


Figure 3-9
Polar Plot of Best-Fit Planes of One Synoptic Water-Level Set and Associated Uncertainty in the Vicinity of MILK SHAKE

level was identified for each well and used as a water-level constraint. In the defined polygons shown in Figure 3-10, synoptic data were used to calculate the direction and magnitude of the groundwater gradient. The median direction and magnitude were then used to further constrain the direction and spacing of the groundwater contours. Finally, the NHA model simulated water levels were used away from well and gradient control to aid in the interpretations of local flow directions. The NHA model was selected because of the good agreement between the observed and simulated flow directions, and the small error at Well ER-5-5 and the updated static water levels. During calibration, the NHA model matched water-level measurements and included properties reflecting the spatial distribution of HSUs; therefore, the model provides several constraints on the extrapolation of the contours. The

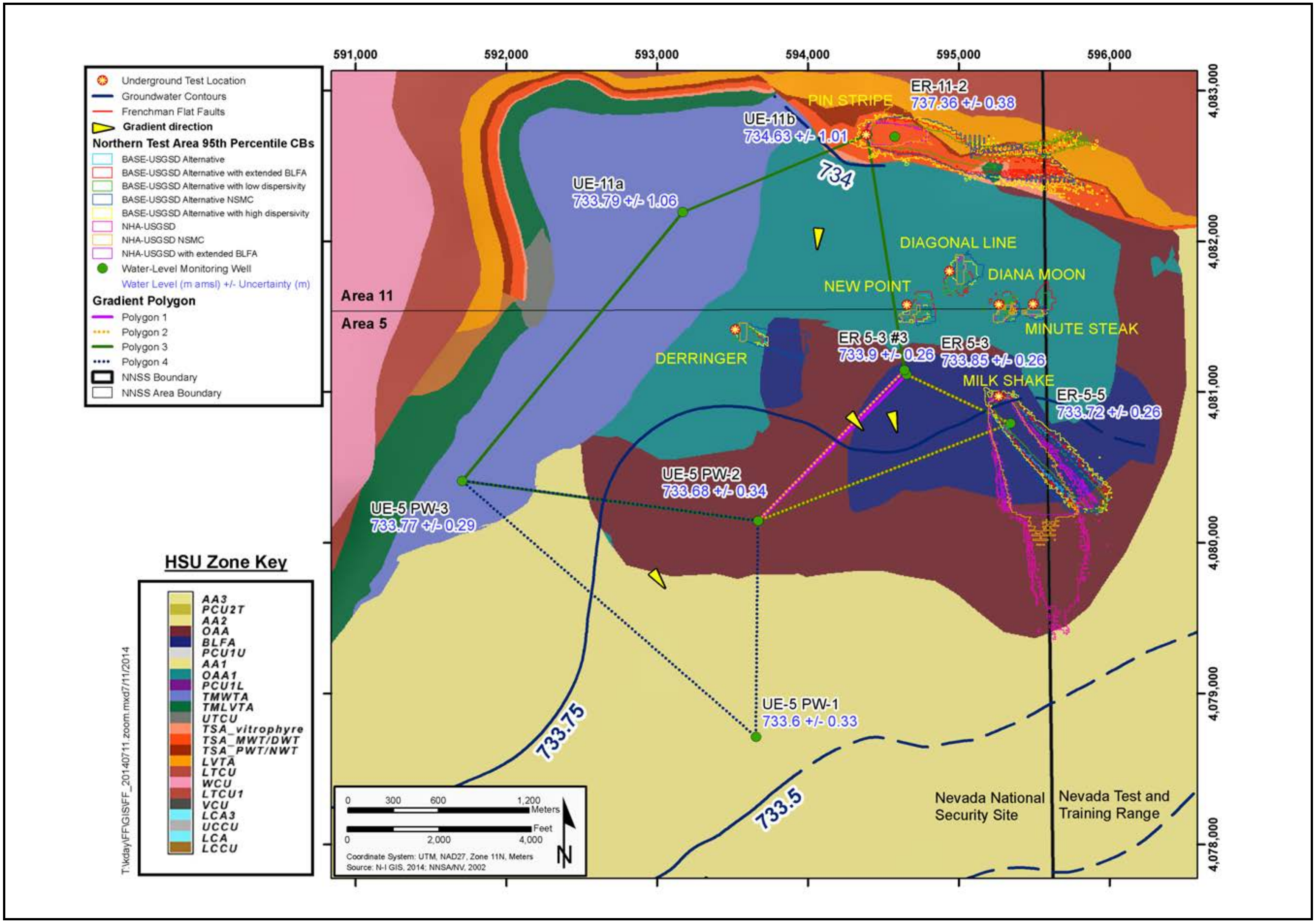


Figure 3-10
Composite Water Table with BASE HFM
Note: HSUs shown at interpreted water-table elevation.

best-fit horizontal plane neglected vertical gradients because observed vertical gradients in the alluvium are approximately an order of magnitude lower than observed horizontal gradients, and flow logging at Well ER-5-3 indicated a significant decrease in flow with depth in the alluvium (NNES, 2010), likely reflecting the significant anisotropy in the hydraulic conductivity tensor. Integrating all of this information indicates that the direction of groundwater flow in the basin is to the south–southeast, as determined during the CAI.

3.6 Source Release Conservative Assumptions

Because DOE classification guidelines require use of maximum announced yield and unclassified inventory (Bowen et al., 2001), this target has been more broadly interpreted as evaluation of the overall release and near-field (5 R_c) transport adjacent to PIN STRIPE and MILK SHAKE via the data-collection activity at Wells ER-5-5 and ER-11-2. This is consistent with the suggestion by Konikow (2010) that because of conceptual and numerical challenges in simulating contaminant transport, computed results should not be expected to match observed concentration variations, even in a single observation well. Rather, major trends and locally averaged values should be considered.

The data-collection activity associated with this model evaluation target was the collection of groundwater samples and analysis of radiologic data from two wells drilled at approximately 5 R_c downgradient from the MILK SHAKE and PIN STRIPE tests (Wells ER-5-5 and ER-11-2, respectively). Radiochemistry measurements were completed for both wells and are evaluated below.

Comparing the CB, a probabilistic result, to field data poses additional challenges. The CB is created by analyzing transport model Monte Carlo results to give the probability (Daniels and Tompson, 2003; NNES, 2010) of exceeding the SDWA regulatory standards (CFR, 2014). Thus, all that can be determined from the CBs at PIN STRIPE and MILK SHAKE is the chance of exceeding the MCL. Wells ER-5-5 and ER-11-2 are located in areas where the total chance of exceeding the SDWA MCL (the sum of contributions from alpha and beta emitters and uranium) is more than 90 percent (NNES, 2010); conversely, the chance of groundwater contamination below the MCL is less than 10 percent. Conceptually, the CB computations suggest that groundwater contamination above MCL is likely to be present at Wells ER-5-5 and ER-11-2. Tritium (^3H), the most abundant radionuclide in the Bowen et al. (2001) inventory, has an MCL of 20,000 picocuries per liter (pCi/L), is reliably detected at very low levels, and is considered the key diagnostic for evaluating transport.

3.6.1 Summary of Well ER-5-5 Data

There are indications that the leading edge of a test-derived radiologic plume, presumably from the MILK SHAKE test, is present at Well ER-5-5. The analytic results for the radionuclides predicted to dominate the CBs in Frenchman Flat (NNES, 2010) are shown in Table 3-2. Ultra-low-level ^{3}H analysis at LLNL determined a ^{3}H activity of 1.1 ± 0.4 pCi/L at this well (Table 3-2). This value is considered above the detection limit (0.8 pCi/L) and above natural background for groundwater at this location. Furthermore, careful examination of noble-gas data provides strong evidence for the presence of the decay product of test-derived ^{3}H, namely helium (^{3}He). The $^{3/4}He$ ratio (relative to air) is 7.8 ± 0.2 at Well ER-5-5. This value is substantially higher than values measured in Frenchman Flat clean wells (Table 3-3). The average of 10 $^{3/4}He$ ratio clean-well samples from Frenchman Flat is 0.7 ± 0.5. The $^{3/4}He$ ratio (relative to air) at Well ER-5-5 is approximately one order of magnitude higher. The higher ratio is the result of the unusually high ^{3}He content in the groundwater at Well ER-5-5 (10^{8} atoms per gram [atoms/g] compared to $10^{6.6\pm0.3}$ atoms/g in Frenchman Flat clean wells).

Table 3-2
Radionuclide Concentrations in Well ER-5-5 Groundwater

Radionuclide	Value	Error	MCL
	(pCi/L)		
^{3}H	1.1 [a]	0.4	20,000
^{14}C	0.1413	0.0005	2,000
^{36}Cl	3.37E-04	4.9E-06	700
^{99}Tc	<0.00086	N/A	900
^{129}I	2.5E-06	2.0E-07	1

[a] 2 sigma detection limit is 0.8 pCi/L.

Cl = Chlorine
I = Iodine
N/A = Not applicable
Tc = Technetium

All other noble-gas indicators appear to be normal at Well ER-5-5. Thus, the high ^{3}He value at Well ER-5-5 is most likely derived from the decay of ^{3}H from the MILK SHAKE test about 200 m away.

There is only one other well at the NNSS that exhibits a ^{3}H and noble-gas signature similar to Well ER-5-5. Well ER-2-1 is located in proximity to three underground saturated nuclear tests in

Table 3-3
^3He and ^4He Concentrations in Clean Wells Located in Frenchman Flat and Well ER-5-5

Location	^3He (atoms/g)	^4He (atoms/g)	$^3He/^4He$ (R/R_a) [a]
WW 5a	4.62E+06	3.16E+12	1.06
WW 5c	3.41E+06	8.67E+12	0.28
WW 5b	3.85E+06	3.90E+12	0.71
ER-5-4	4.10E+06	5.45E+13	0.054
ER-5-4 #2	1.65E+06	1.35E+12	0.89
UE-5c WW	5.18E+06	1.89E+13	0.20
UE-5 PW-3	4.34E+06	2.15E+12	1.46
ER-5-3	3.09E+06	5.20E+12	0.43
ER-5-3 #2	2.42E+07	1.28E+13	1.37
WW 4a	2.42E+06	3.16E+12	0.55
ER-5-5	1.10E+08	1.02E+13	7.83±0.16

[a] R/R_a is $^3He/^4He$ relative to $^3He/^4He$ in ambient air.

Yucca Flat (Figure 3-11). This well contained trace (200 pCi/L) levels of ^3H that can be attributed to the nearby underground nuclear tests. As in the case of Well ER-5-5, the decay of trace level ^3H has led to an elevated $^{3/4}He$ ratio (14.2) relative to clean wells. At both Wells ER-5-5 and ER-2-1, the combination of ^3H activity and $^{3/4}He$ ratio data are a strong indicator for radiologic contamination related to underground nuclear testing.

The ^{14}C activity, though well below its MCL, is significantly higher than background activities in Frenchman Flat groundwater (^{14}C groundwater age at Well ER-5-5 is 64 percent modern carbon compared to 9 percent modern carbon at Well ER-5-3). Due to the long sample hold time (6.4 months compared to the maximum hold time of 2 months identified in the LLNL SOP-UGTA-136 ^{14}C analysis procedure [LLNL, 2013]), these ^{14}C data should be considered unreliable until such a time that the well can be resampled. For samples with ^{14}C activity below 100 percent modern carbon, long hold times lead to carbon dioxide exchange between the sample and air, and an increase in sample ^{14}C activity over time. The long hold time would lead to ^{14}C activities biased high in the Well ER-5-5 sample. Thus, test-derived ^{14}C migration from MILK SHAKE to Well ER-5-5 may be less (and not more) significant than the data suggest. Due to the proximity of Well ER-5-5 to MILK SHAKE and

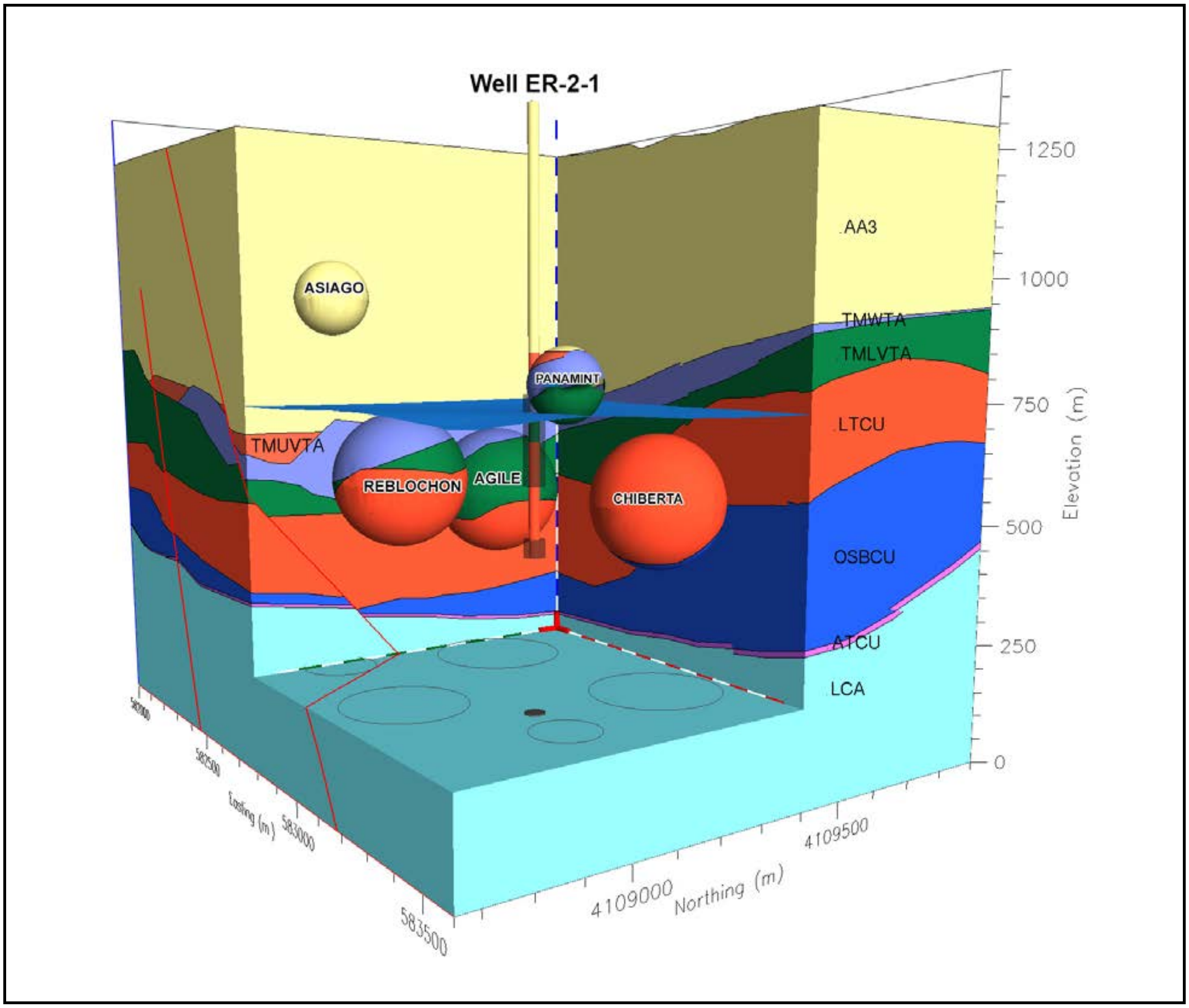


Figure 3-11
Location of Well ER-2-1 That Yielded a ^{3}H and $^{3/4}$He Signature Similar to That Observed at Well ER-5-5

Note: Well ER-2-1 is located 140 to 520 m laterally from three nearby saturated tests. Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

the presence of test-derived ^{3}H water, samples from this well will not be reliable for age dating because of the possibility of test-derived ^{14}C.

The ^{36}Cl, ^{99}Tc, and ^{129}I activities and concentrations are either below LLNL's detection limit or at natural background levels. The ^{36}Cl activity (0.000337 pCi/L) is similar to that observed at Wells ER-5-3 (0.00043 pCi/L) and ER-5-3 #2 (0.00029 pCi/L). The ^{129}I activity is indistinguishable from background (the $^{129/127}$I ratio determined by accelerator mass spectrometer (AMS) [61 × 10^{-14}] is equivalent to the ratio reported for carrier blanks [140 × 10^{-14} and 40 × 10^{-14}]). All radionuclide activities are more than four orders of magnitude below their respective MCLs (Table 3-2).

3.6.2 Conceptual Model of Contaminant Migration from MILK SHAKE to Well ER-5-5

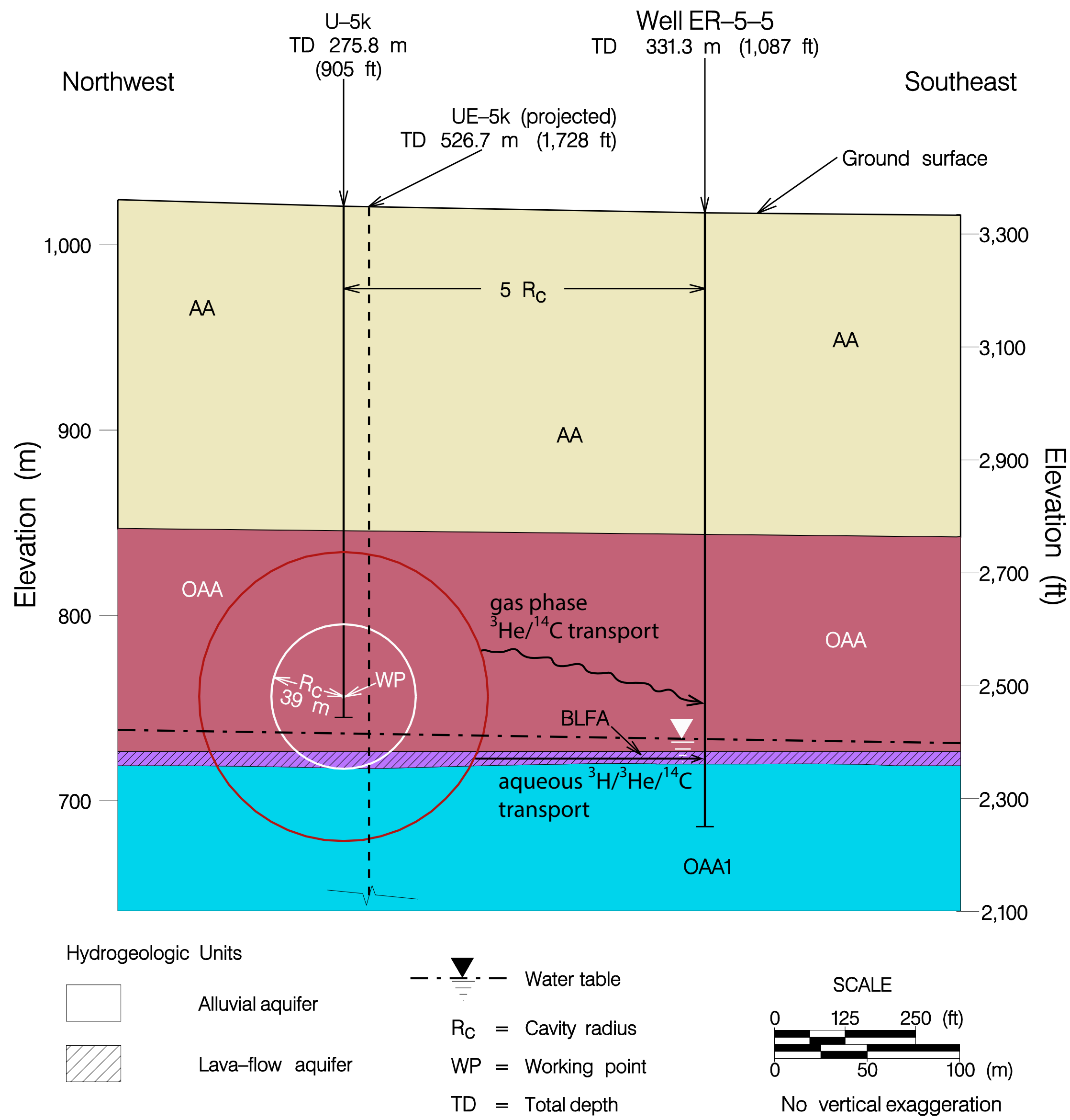
Based on the radiochemical information from Well ER-5-5, contaminants appear to be slowly migrating from MILK SHAKE to the south–southeast. Three independent indicators for radionuclide migration are present at Well ER-5-5. First, low-level ^{3}H data suggest that contaminants are migrating via groundwater flow to Well ER-5-5. Second, the elevated $^{3/4}He$ ratio at Well ER-5-5 is indicative of anthropogenic ^{3}H decay. Based on the half-life of ^{3}H, the elevated $^{3/4}He$ is too high to be attributed to the decay of low-level ^{3}H at Well ER-5-5 alone. Gas-phase transport of ^{3}He from the MILK SHAKE near-field and through the vadose zone is likely contributing to the elevated $^{3/4}He$ at Well ER-5-5. Finally, ^{14}C activities are above natural background levels. Migration of ^{14}C can occur both via groundwater flow and gas-phase transport in the vadose zone. However, due to the long sample hold times, resampling of this well is needed to confirm these ^{14}C activities. Importantly, analysis issues would lead to ^{14}C results that are biased high. Therefore, ^{14}C results represent a conservative estimate of ^{14}C transport. A conceptual representation of contaminant migration at MILK SHAKE is shown in Figure 3-12.

3.6.3 Implications with Respect to Model Evaluation Target

Evaluating the radiologic data at Well ER-5-5 in the context of model results provides perspective regarding the nature of model forecasts. The very low activities measured at Well ER-5-5 demonstrate that model forecasts are conservative in nature. However, the dominant factor controlling the conservative nature of transport forecasts is the hydrologic conceptualization of the MILK SHAKE area and not the source release model. As described in Sections 2.2.1 and 3.7, the dominant hydrologic unit (BLFA) controlling radionuclide transport from MILK SHAKE was conceptualized as a fractured lava-flow aquifer. Data from Well ER-5-5 indicate that the BLFA is not a competent fractured rock aquifer. As a result, contaminant transport from MILK SHAKE is likely to be better represented by slower alluvium-flow velocities rather than faster fracture-flow velocities.

3.6.4 Summary of Well ER-11-2 Data

From the standpoint of test-derived radiologic signatures, there is no definitive indication that radiologic contamination is present at Well ER-11-2. Ultra-low-level ^{3}H analysis does not suggest any anthropogenic ^{3}H at Well ER-11-2 (Table 3-4). Noble-gas sampling and analysis were not successful. Noble-gas measurement of bailed samples from low-permeability rocks is not always reliable due to



Note: The leading edge of a ^3H plume has reached Well ER-5-5. High ^3He is indicative of a combination of saturated groundwater flow and gas-phase transport of the decay product of ^3H. ^{14}C results, though inconclusive, suggest that anthropogenic ^{14}C may have reached Well ER-5-5 at trace concentrations. All radionuclide activities are more than four orders of magnitude below their respective MCLs.

Figure 3-12
Conceptual Model of Radionuclide Migration from the MILK SHAKE Test to Well ER-5-5

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

Table 3-4
Radionuclide Concentrations in Well ER-11-2 Groundwater

Radionuclide	Value	Error	MCL
	(pCi/L)		
^{3}H	0.34 [a]	0.16	20,000
^{14}C	0.2429	0.0009	2,000
^{36}Cl	9.54E-04	1.4E-05	700
^{129}I	2.8E-06	2.0E-07	1

[a] 2 sigma detection limit is 0.32 pCi/L.

the potential for air exchange and sample degassing. Based on the ^{3}H alone, it can be concluded that a radiologic groundwater plume does not exist at Well ER-11-2.

The ^{14}C activity, though well below its MCL, is significantly higher than background activities in Frenchman Flat groundwater (e.g., ^{14}C groundwater age at Well ER-11-2 is 53 percent modern carbon compared to 9 percent modern carbon at Well ER-5-3). However, several factors may have led to the observed ^{14}C activity. First, for samples with ^{14}C activity below 100 percent modern carbon, long hold times (4.3 months for Well ER-11-2 compared to the maximum hold time of 2 months identified in the LLNL SOP-UGTA-136 ^{14}C analysis procedure [LLNL, 2013]) could have led to carbon dioxide exchange between the sample and air, and an increase in sample ^{14}C activity over time. Second, the contribution of drilling fluid and/or atmospheric exchange during sample bailing could have led to higher ^{14}C activities. As a result, ^{14}C measurements of groundwater from Well ER-11-2 are likely biased high. Thus, ^{14}C activities in Well ER-11-2 are likely lower (and not greater) than these data suggest. The present data lead to the conclusion that the ^{14}C activity at Well ER-11-2 are at least four orders of magnitude below its MCL.

The ^{36}Cl and ^{129}I activities are at natural background levels. The ^{36}Cl activity (0.00095 pCi/L) is similar to that observed at Wells ER-5-3 (0.00043 pCi/L) and ER-5-3 #2 (0.00029 pCi/L). Thus, it does not appear that ^{36}Cl at this location is of anthropogenic origin. The ^{129}I activity is indistinguishable from background (the $^{129/127}I$ ratio determined by AMS [64×10^{-14}] is equivalent to the ratio reported for carrier blanks [140×10^{-14} and 40×10^{-14}]). All radionuclide activities are four orders of magnitude or more below their respective MCLs (Table 3-4).

3.6.5 Conceptual Model of Contaminant Migration from PIN STRIPE to Well ER-11-2

Based on the radiochemical information, radiologic contamination resulting from the PIN STRIPE test does not exist at Well ER-11-2. All radionuclides measured at Well ER-11-2 were four orders of magnitude or more below their respective MCLs. While the ^{14}C activity was higher than expected for background ^{14}C at this location, the relatively long sample hold time and artifacts associated with sample gas exchange during bailing tend to bias these results high. Based on the revised hydrogeologic model at PIN STRIPE, it appears unlikely that radionuclides associated with the PIN STRIPE test have a viable path to Well ER-11-2.

3.6.6 Implications with Respect to Model Evaluation Target

Evaluating the radiologic data at Well ER-11-2 in the context of model forecasts provides some perspective regarding the conservative nature of model forecasts. While a direct comparison between measured radionuclide activities and a CB probability map is not possible, the absence of anthropogenic radionuclides at Well ER-11-2 is consistent with the revised interpretation of hydrogeologic conditions at Well ER-11-2. The overestimated transport velocities are a product of the conservative hydrogeologic conceptual model used to forecast these velocities and not the conservative source release model. As described in Section 3.1, the presence of a fault between the PIN STRIPE test and Well ER-11-2 disrupts the continuity of the saturated TSA, which was the presumed conduit for radionuclide migration.

3.7 Hydraulic Conductivity of the BLFA

This uncertainty affects forecasted CBs from MILK SHAKE.

Well development, step testing, and constant rate testing were performed in Well ER-5-5 from April 27 to May 21, 2013. The log-log diagnostic plot of drawdown from the final phase of pumping starting on May 14 is shown in Figure 3-13. The derivative of the observed drawdown shows two apparent drawdown stabilizations, whereas a Theis-like response would show as a single flat line. Several causes for this result are possible, including pumping rate change (not confirmed by data), thermal expansion effects (not confirmed by data), delayed yield (model does not fit), or heterogeneity. The latter explanation, heterogeneity, is most likely based on two considerations: (1) if the observed fluctuations in the ground magnetic survey intensity can be correlated to changes in BLFA characteristics (such as thickness and propensity for fracturing), then an increase in BLFA

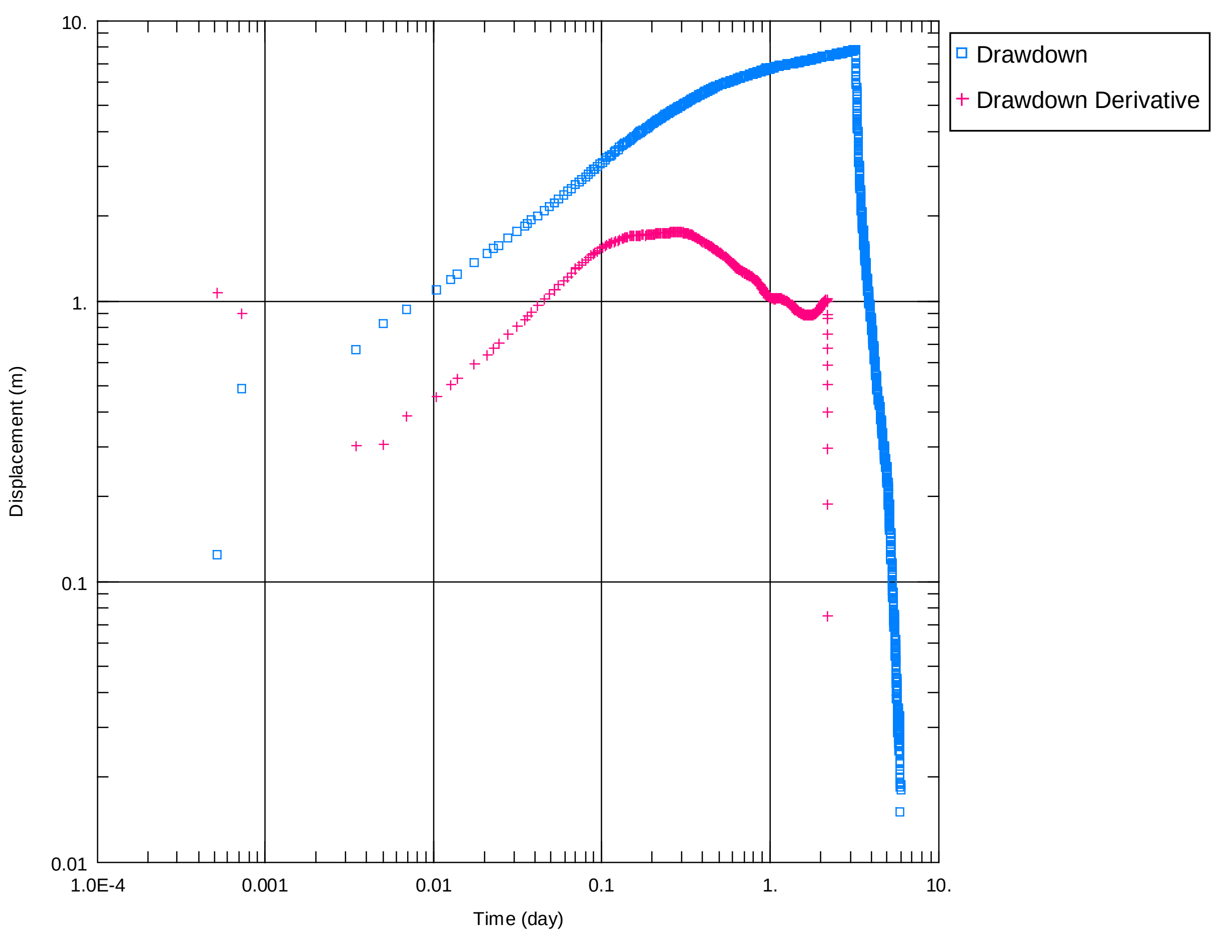


Figure 3-13
Log-Log Diagnostic Plot of Drawdown from Final Pumping Period

transmissivity is possible (Section 2.1); and (2) Well ER-5-5 is located near the transition from OAA to AA, and the latter is conceptualized, from testing at Wells ER-5-4 (AA) and ER-5-3 (OAA), as having a higher hydraulic conductivity, which is also consistent with the observed response.

Estimating transmissivity from the two stabilized pumping responses using the Cooper-Jacob method (Figures 3-14 and 3-15) gives 25 square meters per day (m^2/day) and 47 m^2/day. The recovery data were also analyzed, the same heterogeneity was observed in the data, and similar transmissivity was estimated.

The model evaluation target requires an estimate of hydraulic conductivity, which is transmissivity divided by thickness. However, Butler and Healey (1998) show that for a partially penetrating

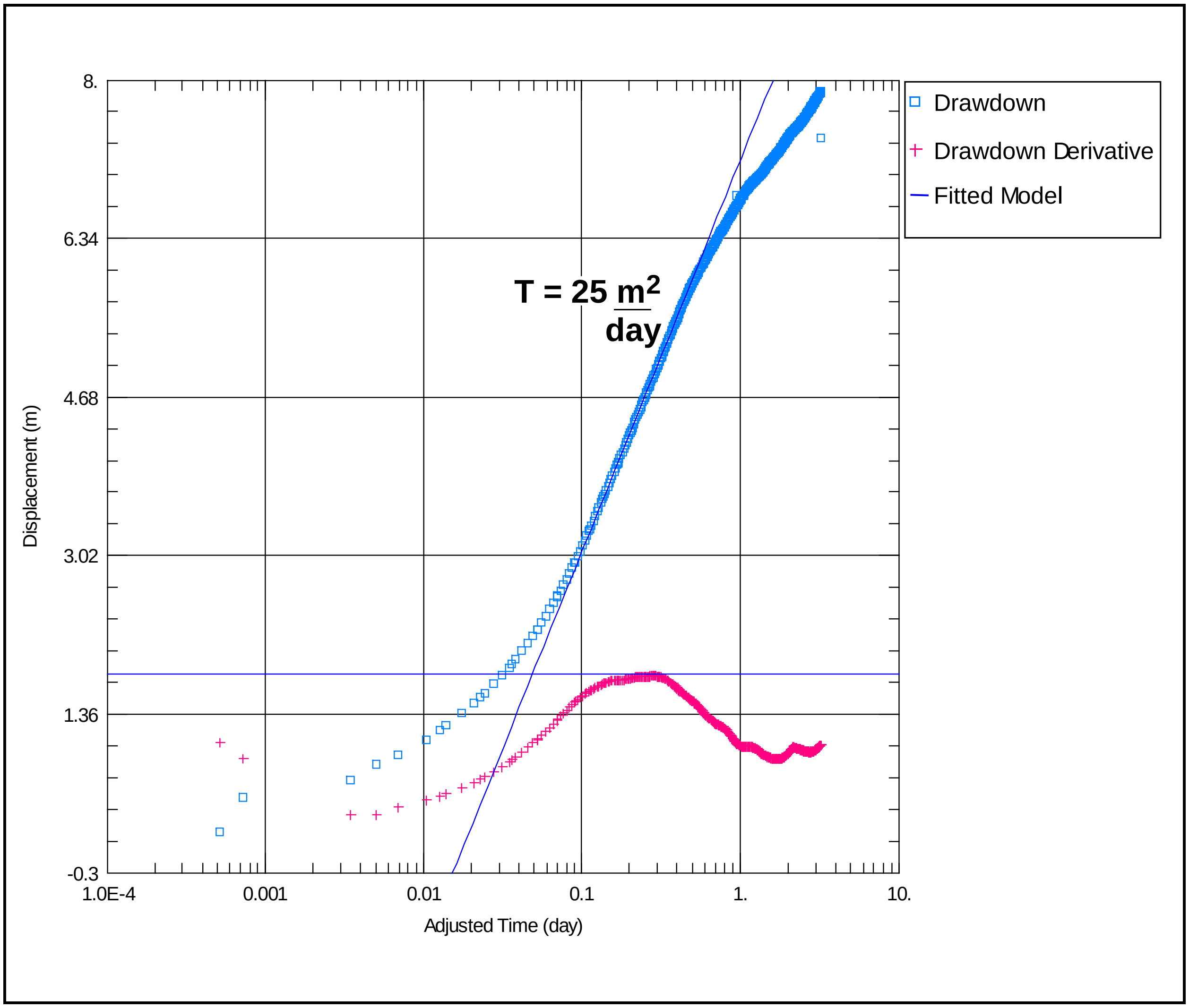


Figure 3-14
Straight-Line Estimate of Transmissivity from First Stabilization

single-well pumping test, total formation thickness is a more appropriate value than the screen interval for converting pumping test transmissivity into hydraulic conductivity. Figure 3-16 shows the geologic section and Well ER-5-5 along with the computed 1 and 2 R_c spheres at the water table, and the water-table-truncated 5 R_c sphere. Two assumptions are used that approximately bound the estimate of hydraulic conductivity:

- The OAA has a low hydraulic conductivity analogous to Well ER-5-3 (SNJV, 2004b); and the BLFA is the primary contributor to transmissivity, and its hydraulic conductivity is estimated as 3.7 meters per day (m/day) (25 m^2/day/6.7 m) and 7 m/day (47 m^2/day/6.7 m).

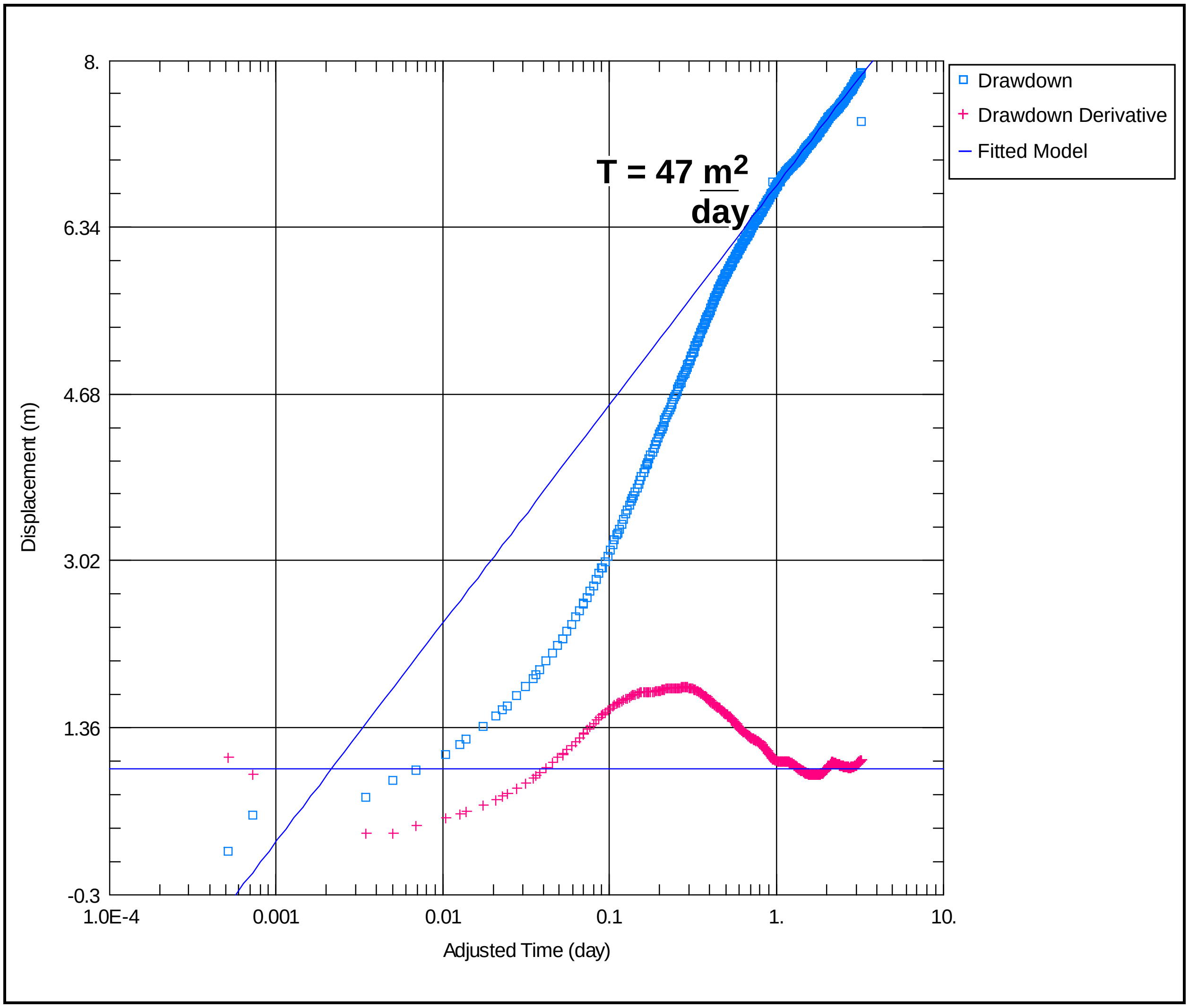


Figure 3-15
Straight-Line Estimate of Transmissivity from Second Stabilization

- Conversely, no obvious difference was noticed between OAA and BLFA when drilling Well ER-5-5, which leads to an interpretation where the entire OAA and BLFA thickness (estimated as 6.7 m of BLFA from Well ER-5-5 and 201 m of OAA from Well UE-5k) act as one unit. This interpretation is supported by the lack of a temperature inflection, indicating concentrated flow in the borehole during pumping. This gives hydraulic conductivity of 0.12 to 0.22 m/day.

Data on the geology and from hydraulic testing do not allow unambiguous interpretation of BLFA hydraulic conductivity. As noted in Section 2.2.1, the BLFA is more rubble-like than a hard fractured rock and may have effective porosity more similar to the OAA, but it is still considered to be a discrete geologic body. Temperature logs did not show the inflection that typically represents discrete inflow, which suggests the BLFA does not have properties significantly different than the OAA.

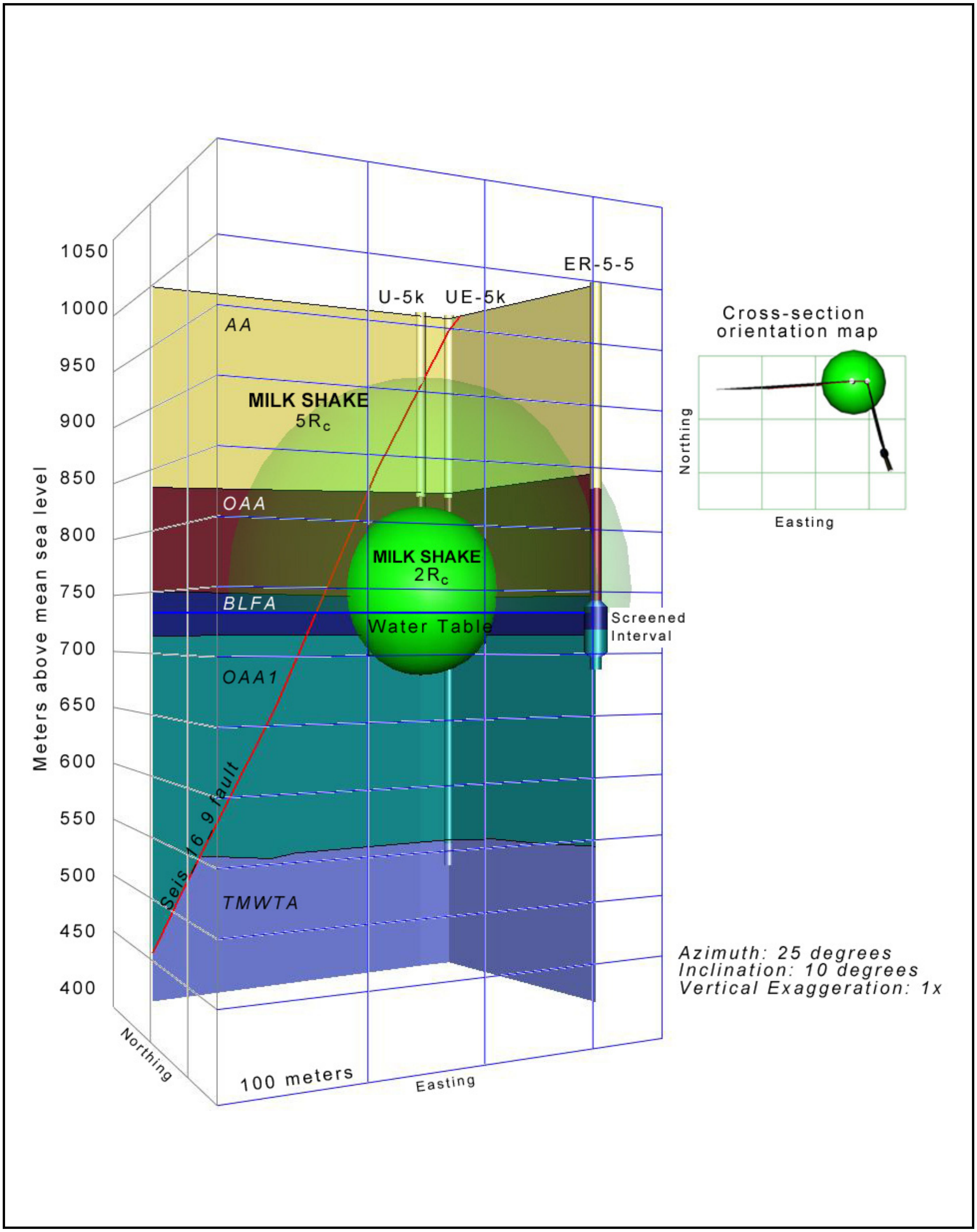


Figure 3-16
Cutaway View of Geology near Well ER-5-5

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

Clouding this observation is that Gillespie (2005) interprets temperatures at nearby Well ER-5-3 #2 as unaffected by groundwater flow with a low geothermal gradient; Well ER-5-5 does not have a very long screen; and inflow to the basin is at the margins and with slow (on the order of 1 meter per year [m/yr] from NNES [2010]) groundwater velocity such that ample time exists for thermal equilibration to occur.

However, as described in Sections 3.5 and 3.6, Well ER-5-5 is interpreted as being at the leading edge of the plume from MILK SHAKE. This information coupled with velocity estimates using Darcy's Law allows for further evaluation of the most plausible interpretation. Darcy velocity was computed with the direction (165 degrees) and hydraulic gradient (3×10^{-4}) determined in Section 3.5 and the four values of hydraulic conductivity estimated here. Adjusting the transport conceptual model of the BLFA to a porous media requires a commensurate porosity, and a value 0.21 from OAA in Well UE-5k is used (Wood, 2007). For comparison, NSTec (2012) used a value of 0.38 for alluvium near the Area 5 RWMC; a lower value produces higher velocities. The composite of all computed CBs at 5 and 95 percent, groundwater velocities, the cylinder estimated to have been purged during sampling at Well ER-5-5, and center-of-mass saturated zone distance traveled since MILK SHAKE's detonation are shown in Figure 3-17. Dispersion was neglected in this computation. In order to help gage the effects of exchange volume uncertainty, two circles are illustrated on Figure 3-17: one at the edge of the saturated cavity (1 R_c) and another at the edge of the saturated exchange volume limit considered in Frenchman Flat (2 R_c). Key points are as follows:

1. The trajectory of groundwater flow estimated from new hydraulic head data agrees well with the simulated results.
2. Well ER-5-5 is located within the 95th percentile line, implying that the MCL was computed to have been exceeded at least 95 out of 100 times 50 years after the test.
3. The 1 and 2 R_c at the water table and the center of mass trajectory estimated from new hydraulic head data show that Well ER-5-5 is on the correct path to intercept groundwater contamination.
4. Center of mass does not move much past the initial test location when the two lowest hydraulic conductivity values are used; this suggests these bounding values are too low.
5. The center of mass is coincident with Well ER-5-5 at the highest velocity. If this were true, given that the initial ^3H concentration is on the order of 10^8 pCi/L in the exchange volume, Well ER-5-5 should be showing much higher ^3H concentration than the 1.1 pCi/L observed. This suggests that the highest hydraulic conductivity value is too high.

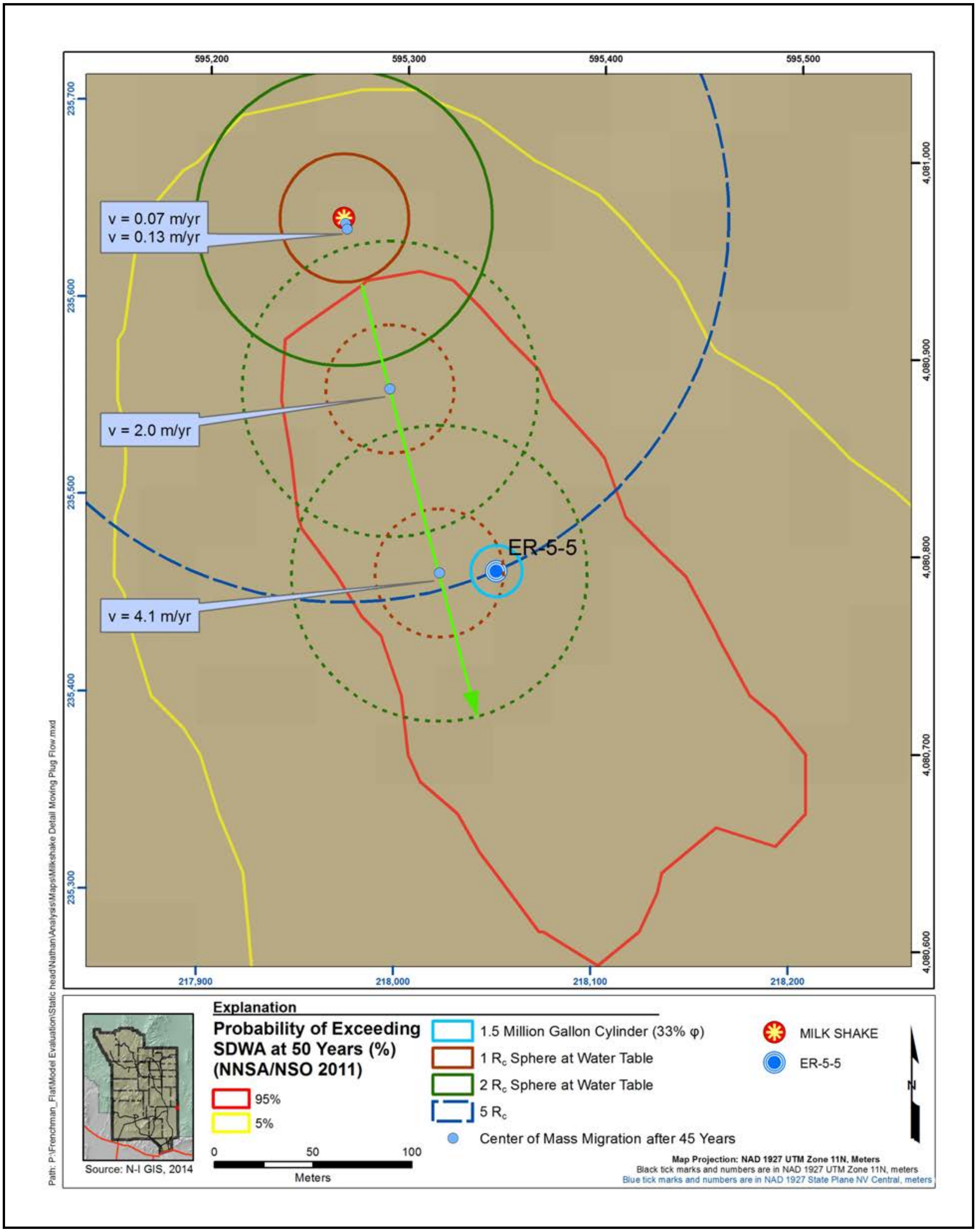


Figure 3-17

Composite CB Forecasts, Exchange Volumes, and Velocities near MILK SHAKE

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

6. The intermediate value (3.7 m/day) results in center of 2 R_c mass travel just short of Well ER-5-5, and is conceptually consistent with the low ^3H observed at Well ER-5-5.

Frenchman Flat computations for all tests used an exchange volume for all radionuclides as large as 2 R_c. A new conceptual model developed for Yucca Flat gives the exchange volume for ^3H as large as 3 R_c (N-I, 2013a). If the ^3H exchange volume is larger than that considered in this analysis, the estimated BLFA hydraulic conductivity and groundwater velocity are both lower—assuming porosity is the same—because less advective groundwater transport is required to move ^3H to Well ER-5-5. Based on the above considerations, it is possible that the BLFA has a hydraulic conductivity on the order of 0.12 m/day. However, the OAA undoubtedly has variable hydraulic properties that affect the assumption that the OAA at Well ER-5-3 is the same as at Well ER-5-5, and the previous analysis may simply represent OAA heterogeneity.

Finally, the overall impact of hydraulic conductivity can be assessed by considering the CBs computed for MILK SHAKE as shown in NNES (2010). The NHA model explicitly conceptualized the BLFA as having a higher hydraulic conductivity, while the BASE-USGS alternative did not. Both alternatives used the same transport parameter distributions; differences will be due to MILK SHAKE hydraulic conductivity as well as other parameter changes. The reference intrinsic permeability (k_o) and depth decay coefficients for the BLFA were 1×10^{-12} m^2 and 2.56×10^{-3} 1/m, respectively, for the BASE-USGSD alternative model (SNJV, 2006); and 1.15×10^{-11} m^2 and 2×10^{-3} 1/m, respectively, for the NHA model (NNES, 2010). It is about 283 m to the water table at Well ER-5-5. The formula for depth decay is as follows (SNJV, 2006):

$$k(z) = k_o * 10^{-z\lambda} \qquad (3\text{-}1)$$

where

$k(z)$ = intrinsic permeability (m^2) at a depth z below land surface
k_o = reference intrinsic permeability (m^2) at land surface
λ = decay coefficient (1/m)

Thus, at the water table, the BLFA intrinsic permeability is 1.9×10^{-13} m^2 and 3.1×10^{-12} m^2 for the BASE-USGS alternative and NHA models, respectively. To convert from m^2 to m/day, these values are divided by 1.2×10^{-12}, giving hydraulic conductivity of 0.16 to 2.6 m/day. The model values are very similar to the range of values estimated from the pumping test (0.12 to 7 m/day).

In conclusion, it is difficult to unambiguously interpret the hydraulic testing results from Well ER-5-5 for the BLFA, but considering the flow direction and radionuclide data, the BLFA has a hydraulic conductivity on the order of 0.12 to 3.7 m/day. Ultimately, because ^{3}H (the direct regulatory data) is much lower than forecasted at the 95 percent probability, it is clear that the radionuclide migration velocity is also smaller than computed (for several possible reasons). The forecasted CBs from MILK SHAKE are conservatively delimited using the fractured rock transport properties.

3.8 Flow Boundary Conditions

Applicable boundary conditions for the model evaluation target named *flow boundary conditions* include the recharge to the semiperched units and the assigned hydraulic heads along the lateral model faces.

3.8.1 CAU Model Summary

During development of the groundwater flow and transport model of Frenchman Flat CAU, a total of seven recharge models were considered, ranging from nearly uniform recharge throughout the model domain to models explicitly considering land elevation and distributed parameter-based watershed infiltration/recharge. Additional uncertainty in recharge was considered during NHA model calibration where recharge was applied in such a way as to direct infiltration from the upland areas to the semiperched system. Models providing more recharge in upland areas along the northern flank of Frenchman Flat and Massachusetts Mountain suggested that hydraulic heads were higher in this area.

Hydraulic heads (specified heads) along the CAU model boundaries were derived by using two regional models; due to the limited extent of the alluvial and volcanic systems and the size of the model, these heads were principally associated with the regional LCA. The UGTA regional model was updated with six different recharge models and five HFMs, providing 30 possible assignments of boundary heads and flux targets. The Death Valley Regional Flow System (DVRFS) model was also used to provide boundary head and boundary flux targets during model construction and calibration. During model calibration, several different approaches were used to refine the boundary conditions, but in all cases these values were strongly dominated by the regional flow system in the LCA and provided limited constraints on the flux through the semiperched aquifers. Water levels collected from exploratory wells drilled for the testing program appeared to have slightly higher heads along the northern flank of the semiperched basin, but these were either no longer available for monitoring or had been monitored very infrequently, resulting in large uncertainties.

3.8.2 Model Evaluation Data

As described in Section 1.0, model evaluation data focused on investigations of the PIN STRIPE and MILK SHAKE CBs, providing very little information related to the flow boundary conditions in the model. Table 1-1 indicates that this model evaluation target will be based on measurement of hydraulic head at Well ER-11-2. Figure 3-18 shows the water-level data collected at Well ER-11-2. The average static water-level data at Well ER-11-2 (Table 3-1), completed along the northern edge of the semiperched basin, is 737.4 m, which is approximately 4 m greater than water levels observed in the Frenchman Flat alluvium in the Northern and Central Testing Areas. While not conclusive, the Well ER-11-2 data are consistent with the conceptual and numerical models of Frenchman Flat, indicating recharge and/or elevated water levels along the northern edge of the semiperched system. Groundwater flow directions calculated from newly collected water-level data throughout Frenchman Flat are in good agreement with recharge areas and higher boundary heads assigned to the northwestern portion of the model domain.

3.9 Size of Exchange Volume

The expert elicitation (Chapman and Pohlmann, 2011) and CADD/CAP (NNSA/NSO, 2011) recognize that Wells ER-5-5 and ER-11-2 do not provide information about this target. Nevertheless, given the new radiologic data available at Wells ER-5-5 and ER-11-2, it is instructive to evaluate the implications of a smaller exchange volume on potential contaminant transport at MILK SHAKE and PIN STRIPE.

As in all unclassified models performed by the UGTA Activity, classification guidelines require the estimation of cavity radii based on the maximum yield reported in DOE/NV (2000). At the MILK SHAKE site, the distance between the working point (WP) and the water table is approximately 21 m while the unclassified maximum cavity radius, estimated from the maximum yield reported in DOE/NV (2000), is 39 m. Thus, the cavity itself intersects the water table and, given that the exchange volume is defined as a multiple of the cavity radius, it will also be saturated, at least in part. Thus, contamination from the MILK SHAKE test is present in the groundwater below the test.

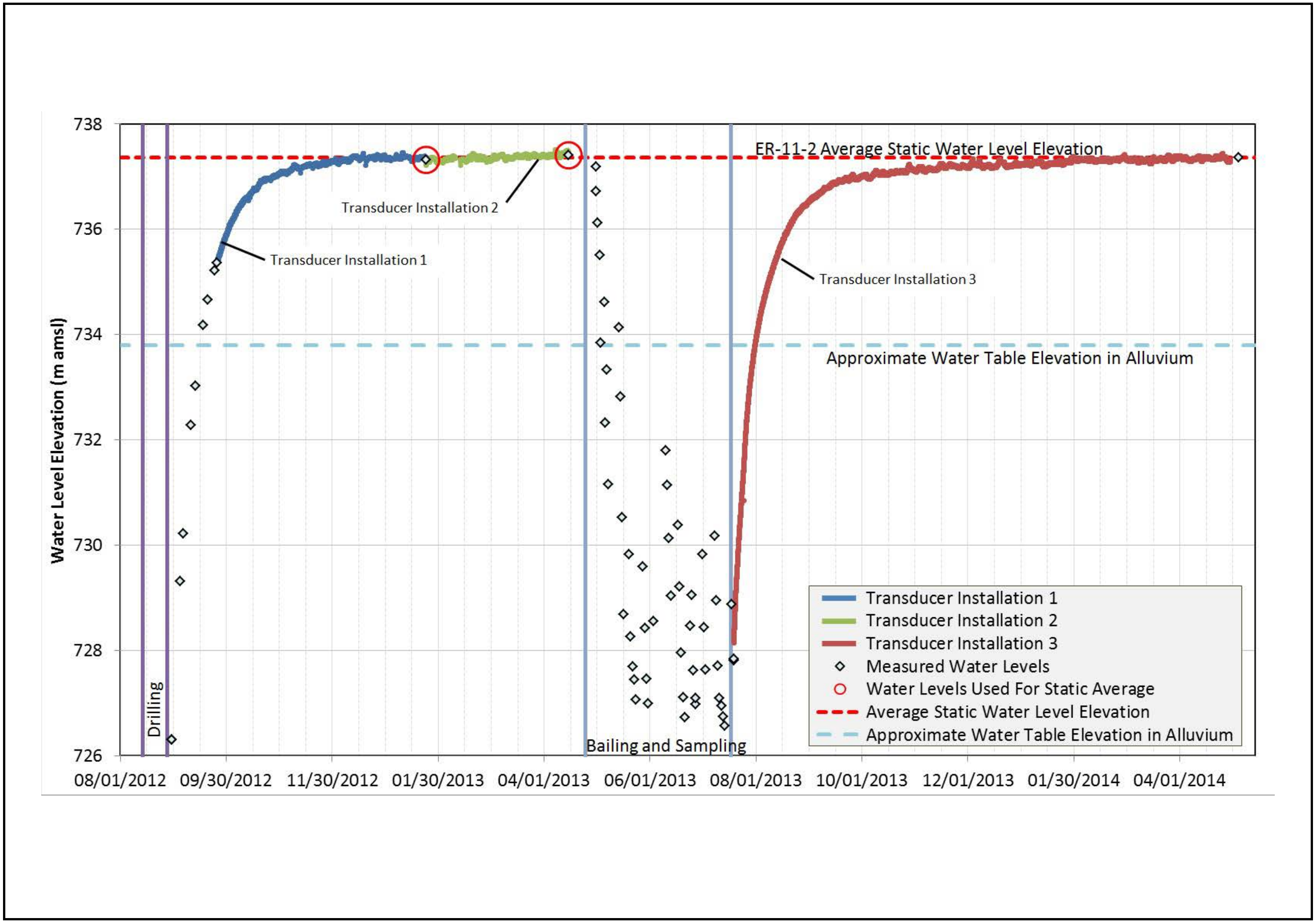


Figure 3-18
Well ER-11-2 Water Levels

Note: May 2014 data were not available at the time of static water-level determination. The value from May 2014 is equal to the static value determined from the data collected before bailing and sampling.

However, as discussed in Sections 2.2.1, 3.6, 3.7, and 3.10, lateral migration of this contamination is limited due to the low flow velocity in the BLFA.

At PIN STRIPE, the greater distance between the WP and the water table suggests that only a small fraction of a 2 R_c exchange volume (estimated from the maximum yield reported in DOE/NV [2000]) intersects the water table. Thus, it is possible that a smaller cavity would lead to the absence of radiologic contamination below the water table. While the absence of contamination at Well ER-11-2 might be explained by such a scenario, the discontinuous TSA and higher head at Well ER-11-2 precludes significant migration of contaminants to Well ER-11-2 regardless of the size of the exchange volume. Given the location of Wells ER-5-5 and ER-11-2, the uncertainty in the size of the exchange volume at MILK SHAKE and PIN STRIPE cannot be reduced. Hydrogeologic considerations at these two sites have the dominant effect on the radiologic observations at the two satellite wells (Figure 3-19).

3.10 Geochemical Age and Velocity Constraints

As described in SNJV (2006), groundwater ages and velocities were estimated using ^{14}C, along with an empirical relationship between ^{14}C and cation concentrations. The cation concentrations reflect the evolution of groundwater chemistry over the flow path and provide a “cation clock” to date the groundwater. The estimated ages were used to compute velocities that were used in NNES (2010) to supplement the water-level dataset during calibration of the NHA model. The estimated groundwater velocities from the geochemical data were also used to evaluate velocities calculated by the CAI groundwater flow models to help differentiate models that were consistent with the available water-level and velocity information.

Appendix F of NNES (2010) investigated the uncertainty in the estimated ages and associated groundwater velocities due to analytical uncertainty, atmospheric ^{14}C variations, misalignment of well pairs relative to true flow directions, ^{14}C sorption onto the sediment and rock matrix, and assumed recharge compositions. The conclusions of that analysis were that, despite these uncertainties, groundwater velocities through the alluvium in Frenchman Flat are very slow, less than 1 m/yr.

New geochemical and isotopic data from Wells ER-5-5 and ER-11-2 included major and minor ions, stable isotopes (delta deuterium [δD], delta deuterium [$\delta^{18}O$], and delta carbon-13 [$\delta^{13}C$]), $^{36}Cl/Cl$ ratios, and ^{14}C from dissolved inorganic carbon-14 (DI^{14}C). Unfortunately, the ^{14}C data from

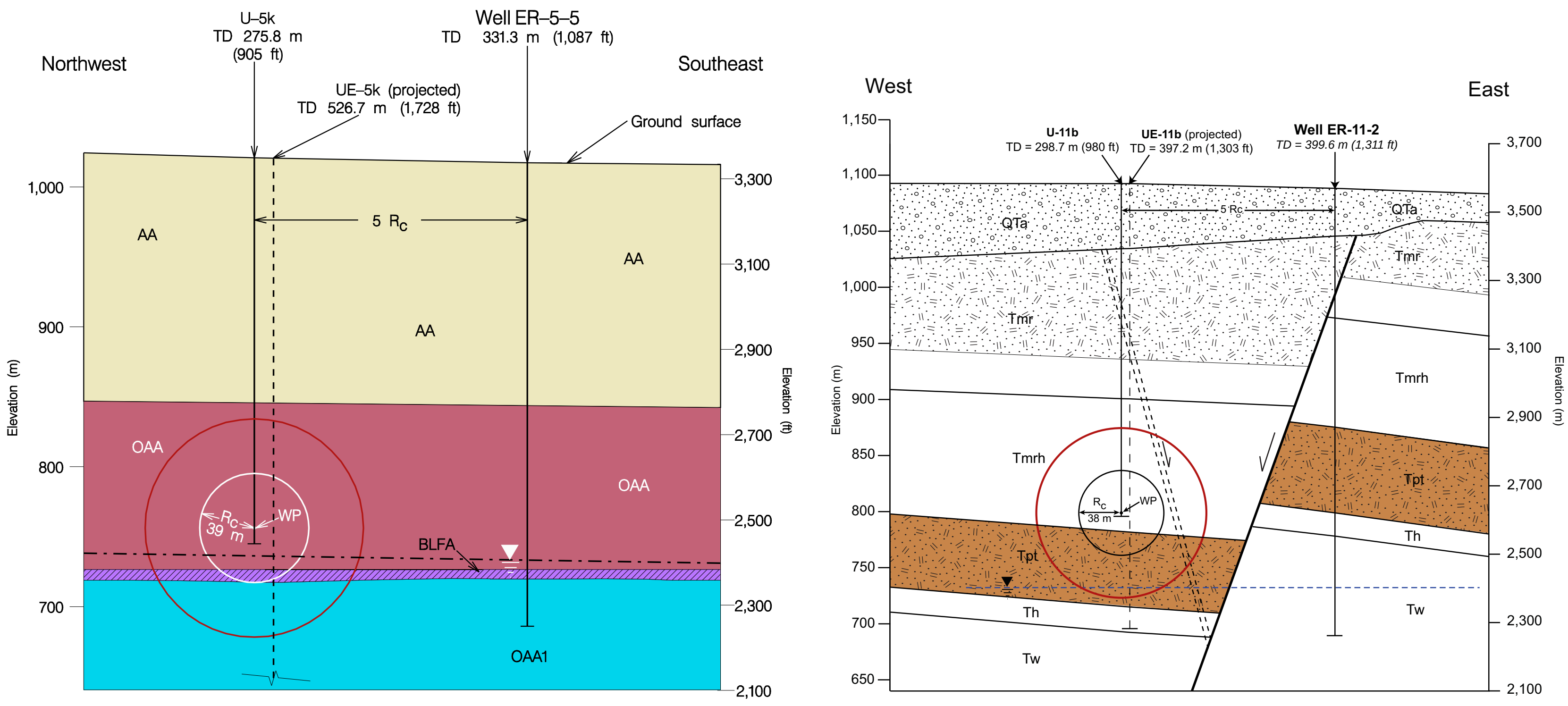


Figure 3-19

MILK SHAKE and PIN STRIPE Exchange Volumes

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

Wells ER-5-5 and ER-11-2 suffered from quality-assurance issues identified during a 2013 interlaboratory study (NNSA/NFO, 2014) and are not considered further in this analysis. However, regardless of the quality-assurance issues with ^{14}C, the exchange volume estimated for test-generated ^{14}C of 3 to 5 R_c may be larger than previously understood due to gas-phase partitioning and diffusion (N-I, 2013a). As a result, groundwater ^{14}C data from Wells ER-5-5 and ER-11-2 might have been affected by the proximity to nearby nuclear tests and therefore are not useful for estimating groundwater age and velocity even in the absence of quality issues. Instead, the groundwater age and velocity constraint evaluation presented in this section relies on indirect evidence from (1) major ions and (2) δD and $\delta^{18}O$ to infer the age and, hence, velocity of the groundwater relative to other groundwater samples from Frenchman Flat that have been quantitatively dated with ^{14}C.

3.10.1 Indirect Age Interpretation Approach (1) – Cation Clock

This subsection presents major-ion data for Wells ER-5-5 and ER-11-2 in the context of similar data from wells used in the CAI phase, and discusses calculations of groundwater age based on empirical relations between sodium (Na^+) and calcium (Ca^{2+}) concentrations and groundwater age developed from groundwater samples that had been dated using groundwater ^{14}C (SNJV, 2006; NNES, 2010).

Major-Ion Data

The major-ion data from Wells ER-5-5 and ER-11-2 are provided in Table 3-5 and are shown with data from other wells in Frenchman Flat and CP basin in Figure 3-20. The charge balances at Wells ER-5-5 and ER-11-2 are -2 percent and -6 percent, respectively.

Figure 3-20 shows that the proportions of anions in Frenchman Flat groundwater vary within a relatively narrow range, with most groundwater having between 60 to 80 percent carbonate or bicarbonate, and 20 to 40 percent sulfate and chloride. Major cation percentages are more variable and reflect relative well locations within the flow system. Groundwater evolves from a mixed Ca/Na water in CP basin (Cane Spring, WW-4, and WW-4a) to an Na-dominated groundwater near Frenchman Lake Playa (WW-5c and WW-5a). Groundwater from Well ER-5-5 resembles groundwater from a composite sample collected from nearby Well ER-5-3 (8-inch. [in.] string), which was dominated by flow from the Timber Mountain welded-tuff aquifer (TM-WTA) with minor contributions of flow from the OAA and BLFA. Major-ion concentrations at Well ER-11-2 resemble groundwater sampled from the same LTCU HSU at Well ER-5-4 #2. Thus, groundwater from both

Table 3-5
Geochemical and Isotopic Data for Wells ER-5-5 and ER-11-2

Analyte	ER-5-5 [a]	ER-11-2 [b]
Major Ions (mg/L) [c]		
Bicarbonate	177	372
Carbonate	<12	<12
Chloride	16	50
Sulfate	41	100
Calcium	7.2	2.8
Magnesium	3.4	0.2
Potassium	7.1	3.5
Sodium	74	190
Charge Balance (%)	-2	-6
Stable Isotopes (‰) [d]		
δD	-109.4	-110.5
$\delta^{18}O$	-14.02	-13.47

[a] ER-5-5 samples were collected on 05/16/2013 (major ions) and 05/11/2013 (stable isotopes).
[b] ER-11-2 samples were collected on 07/12 and 07/13/2013 (major ions), and 07/14/2013 (stable isotopes).
[c] Major-ion concentrations are the average of commercial laboratory field-duplicate results. Only filtered sample results are included when available.
[d] Stable isotope values are the average of laboratory duplicate measurements.

mg/L = Milligrams per liter
‰ = Per mil

Wells ER-5-5 and ER-11-2 are consistent with major-ion chemistry within Frenchman Flat described during the CAI.

Interpretations of Groundwater Age at Wells ER-5-5 and ER-11-2 from the Cation Clock

The age of groundwater at Wells ER-5-5 and ER-11-2 was estimated from the measured Ca^{2+} and Na^{+} concentrations using the cation concentration versus corrected groundwater ^{14}C age relationships from SNJV (2006). The Ca^{2+} and Na^{+} concentrations at the model evaluation wells with the corresponding estimated ^{14}C age dates are shown in Figure 3-21. As described in SNJV (2006), the measured Na^{+} concentrations were adjusted for halite dissolution or variable evaporative concentration by removing the Na^{+} component associated with Cl^{-}, so that Na^{+} increases reflect only silicate weathering and exchange reactions along the flow path. Groundwater ages calculated with the

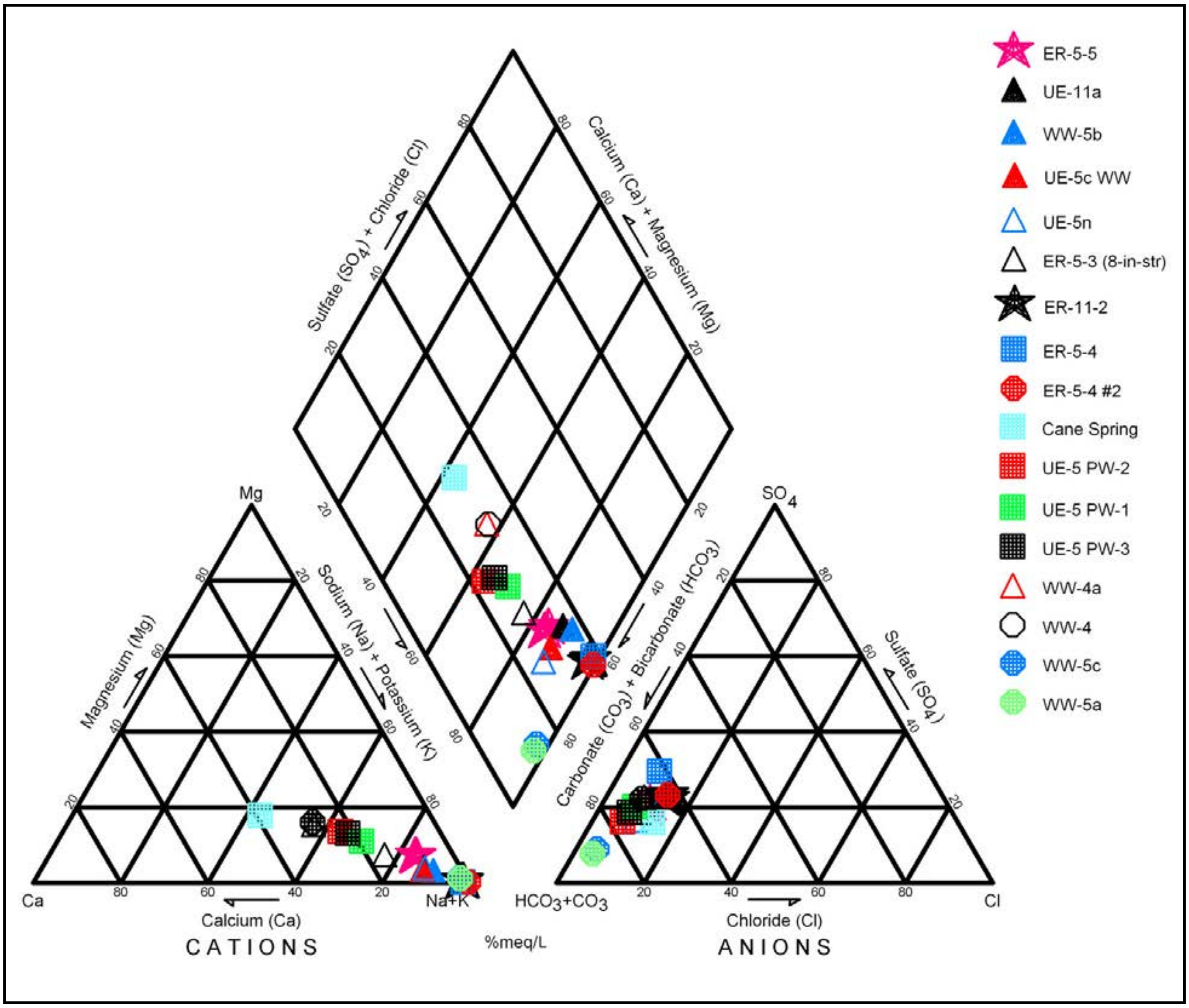


Figure 3-20
Piper Plot Showing the Milliequivalent Proportions of Major Ions in Frenchman Flat Area Wells and Springs

cation clock were 17,838 and 15,933 years at Well ER-5-5 (16,900 years old average) and 23,667 and 26,739 years at Well ER-11-2 (25,200 years old average). The older estimated age at Well ER-11-2 is attributed to the fact that the water was derived from the low-permeability LTCU where flow paths are nearly stagnant, whereas the Well ER-5-5 sample was pumped from a relatively high permeability basalt rubble zone and alluvium where flow is more active. Based on the scatter of the data around their respective trend lines, the uncertainty in the Na^+ and Ca^{2+} ages for Wells ER-5-5 and ER-11-2 are about plus or minus 5,000 years; conversely, the good agreement between Na^+ and Ca^{2+} ages at Wells ER-5-5 and ER-11-2 suggests an uncertainty of about 10 percent of the average age of the sample based on these cation concentrations. The differences between cation-estimated and

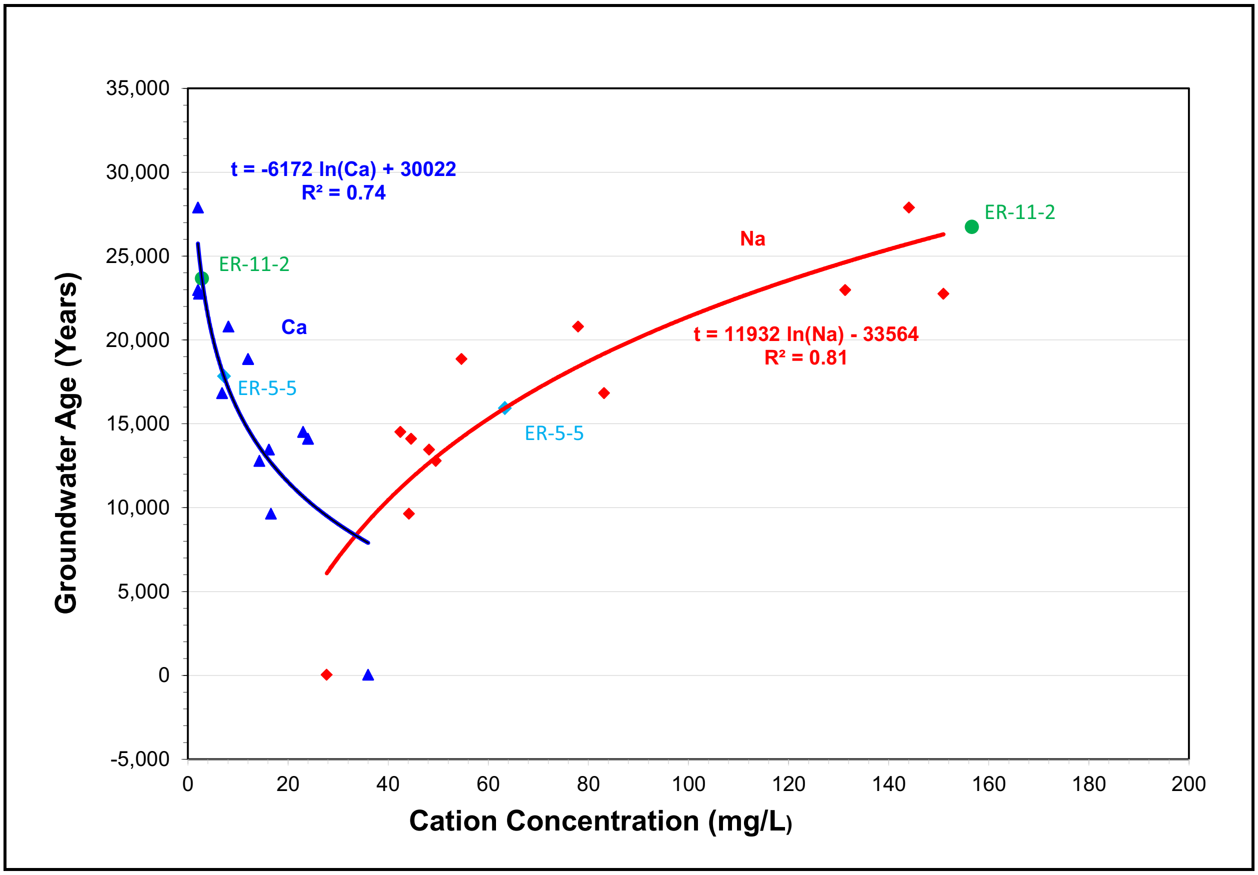


Figure 3-21
Plotting Locations of New Wells ER-5-5 and ER-11-2 Data on the Na^+ versus Corrected ^{14}C Age and Ca^{2+} versus Corrected ^{14}C Age Curves
Source: Modified from SNJV, 2006

^{14}C-estimated groundwater ages are considerably greater and are discussed in NNES (2010). Despite these uncertainties, the groundwater ages of 16,900 and 25,200 years estimated with the cation clock are consistent with previous interpretations (SNJV, 2006) that indicated most of the groundwater in Frenchman Flat was recharged under past pluvial climates that existed before about 10,000 years ago. This result is consistent with the concept that present-day recharge to the system is very low and that flow rates are correspondingly low.

3.10.2 Indirect Age Interpretation Approach (2) – Stable Isotopes

Groundwater inherits its stable isotopic composition at the time of recharge. For δD and $\delta^{18}O$, isotope compositions can vary temporally and spatially, reflecting environmental conditions. In a relatively small area with subdued topography like Frenchman Flat, much of the variability in δD and $\delta^{18}O$ may be due to temporal variability associated with climate fluctuations. This interpretation is evaluated in the following subsections.

δD and δ¹⁸O

Groundwater δD and δ^{18}O from Wells ER-5-5 and ER-11-2 are shown with data from the alluvial and tuff aquifers, perched springs, and precipitation in Figure 3-22. The data from Wells ER-5-5 and ER-11-2 are similar to other measurements within Frenchman Flat and are quite distinct from precipitation or more modern water present at Cane Spring, a perched spring near CP basin.

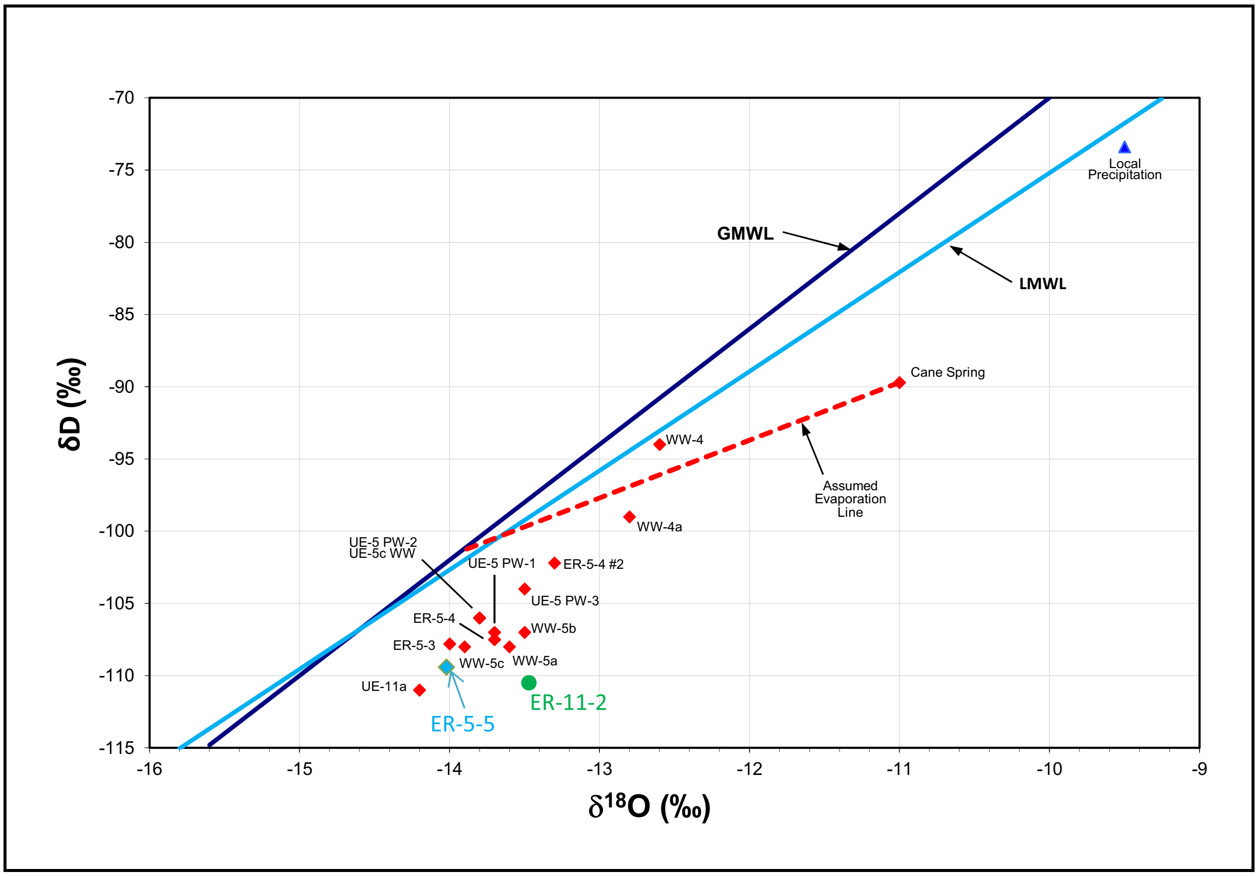


Figure 3-22
Groundwater δD and δ¹⁸O from the Alluvial and Volcanic System in Frenchman Flat and CP Basin along with Average Values of Local Precipitation
Source: SNJV, 2006; Ingraham et al., 1991

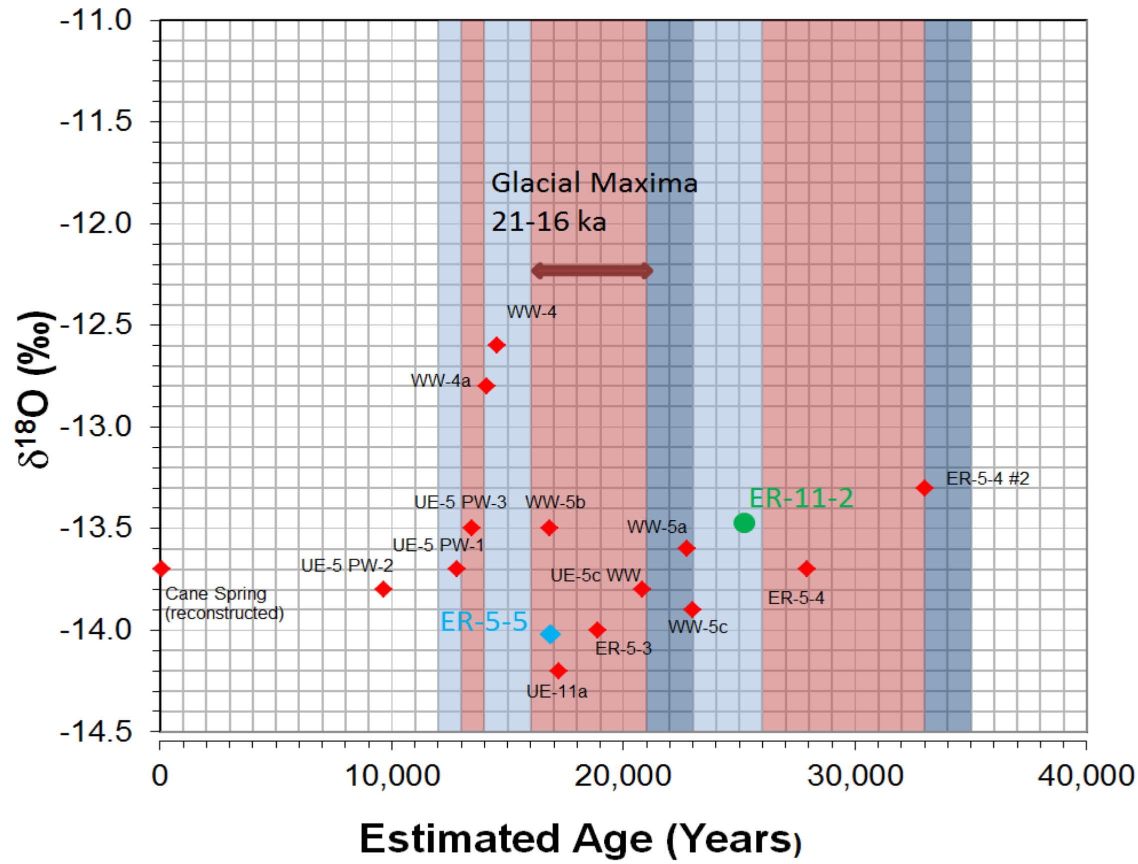
To estimate the isotopic signature of modern groundwater, water sampled from Cane Spring was corrected to account for sampling conditions. The Cane Spring water sample was collected from an adit and was likely to have undergone post-discharge evaporation before sampling (Ingraham et al., 1991). Evaporation would have enriched both δD and $\delta^{18}O$ relative to the original composition. For the low relative humidities typical of Frenchman Flat area, this enrichment progresses along an evaporation line with a slope of about 4. Therefore, to estimate its original composition before it underwent evaporation, its measured composition is projected back toward the Global Meteoric Water Line (GMWL) or Local Meteoric Water Line (LMWL) ($\delta D = 6.87\delta^{18}O - 6.5$). Projecting the Cane Spring composition back to the GMWL along an evaporation line with a slope of 4 gives a δD of -101.4 ‰ and a $\delta^{18}O$ of -13.9 ‰. Similarly, projecting Cane Spring composition back to the LMWL along an evaporation line with a slope of 4 gives a δD of -100.3 ‰ and a $\delta^{18}O$ of -13.7 ‰. Thus, even when the isotopic composition of Cane Spring is adjusted to account for evaporation, the new data from Wells ER-5-5 and ER-11-2 are significantly lighter than modern water from this spring. The δD and $\delta^{18}O$ from Well ER-5-5 are very similar to nearby alluvial and volcanic aquifer wells such as Well ER-5-3 within Frenchman Flat, whereas the δD from Well ER-11-2 is similar to nearby Well UE-11a, (though enriched by about 0.7 ‰ in $\delta^{18}O$).

As first noted by Hershey et al. (2005, p. 12), the fact that most Frenchman Flat groundwater is much lighter than present-day precipitation and plots well below the present-day GMWL or LMWL implies it was recharged under a climate much different from today’s climate. CP basin water is the only water with an isotopic signature similar to local recharge (Hershey et al., 2005).

Because the volcanic and alluvial aquifers in Frenchman Flat constitute a local aquifer system that was probably recharged locally (unlike the groundwater in the LCA, which could have regional inflow from the north or east), it is likely that most of the groundwater was recharged under past pluvial conditions. This suggests that groundwater from Wells ER-5-5 and ER-11-2, which are among the isotopically lightest in the basin, were also recharged under pluvial conditions (i.e., before about 10,000 years ago). In other words, the δD and $\delta^{18}O$ data from Wells ER-5-5 and ER-11-2 also support the concept that the groundwater in Frenchman Flat is very old and recent recharge is very low, consistent with small groundwater velocities within the basin.

Reconstructed History of $\delta^{18}O$ Variations

The $\delta^{18}O$ of precipitation recharge can vary temporally and spatially, depending on the condensation temperature (which varies with season and elevation), and the storm tracks and moisture sources that produced the precipitation that led to infiltration and recharge. In Frenchman Flat, where groundwater



Note:
Shaded regions reflect the reconstructed paleo-climate in southern Nevada (Forester et al., 1999).
Dark blue = very wet; light blue = wet; red = relatively dry.

Figure 3-23
Temporal Variations in δ¹⁸O as Inferred from the Estimated Groundwater Ages
Source: Modified from SNJV, 2006

ages span an approximately 20,000-year range, it is likely that much of the variability in δD and $\delta^{18}O$ arises from temporal variability in storm tracks associated with climate fluctuations. This temporal variability in groundwater δD and $\delta^{18}O$, shown in Figure 3-23, was examined by plotting the groundwater $\delta^{18}O$ values against their ^{14}C ages or cation-clock ages. The new data and age estimates from Wells ER-5-5 and ER-11-2 are consistent with the data originally reported in SNJV (2006). Also shown as shaded regions on the plot are climate fluctuations inferred from the dated vegetation assemblages preserved in packrat middens from southern Nevada (Forester et al., 1999).

In general, it is not possible to correlate changes in $\delta^{18}O$ with every shift in climate inferred from the packrat midden record. However, the occurrence of very light $\delta^{18}O$ (and δD) values from three closely spaced wells in northern Frenchman Flat (Wells ER-5-3, UE-11a, and ER-5-5) in groundwater estimated to be 16,900 to 19,000 years old is consistent with the interpretation from packrat midden data that the glacial maximum which occurred between 16,000 and 21,000 years ago brought relatively cold, dry arctic air to the region at this time (Forester et al., 1999). Arctic air would have significantly lighter $\delta^{18}O$ (and δD) than moisture arriving along other storm tracks, based on studies of the isotopic composition of modern precipitation in the Great Basin (Benson and Klieforth, 1989; Friedman et al., 2002). Thus, the groundwater ages of 16,000 and 17,200 years estimated for Wells ER-5-5 and UE-11a using the cation clock and the ^{14}C age of about 19,000 for Well ER-5-3 (8-in. string) appear to be broadly consistent with timing of the glacial maximum. Groundwater older than the glacial maximum (approximately 20,000 years ago) is less prevalent in the Frenchman Flat basin except in the LTCU (Wells ER-5-4 #2 and ER-11-2) and alluvial wells in the center of the basin (Wells ER-5-4, WW-5c, and WW-5a).

While the reconstructed record of past climate is not definitive proof of the accuracy of the ^{14}C ages or ages estimated from the cation clock, it does offer an explanation of $\delta^{18}O$ and δD variations in this relatively small, local groundwater basin, and it challenges the assumption that $\delta^{18}O$ and δD must be constant along a flow path.

Estimated Groundwater Velocities

As part of the model evaluation, it would have been desirable to use the estimated age date at Wells ER-5-5 and ER-11-2 in conjunction with CAI age interpretations from other wells (SNJV, 2006; NNES, 2010) to calculate groundwater velocities; however, a number of complexities prevent meaningful new interpretations. These include the following:

1. The highly evolved nature of the groundwater in Well ER-11-2 with respect to major-ion chemistry (Figure 3-20) and the relatively unevolved groundwater from alluvial or volcanic wells to the south (e.g., Wells UE-5 PW-2 and ER-5-3 [8-in. string]) indicate that groundwater from the LTCU at Well ER-11-2 is not a major source of the groundwater at these downgradient wells.

2. Inaccuracies in the age dates are as much as plus or minus 5,000 years. Because Well ER-5-5 is only 760 m from Well ER-5-3 and groundwater is moving 0.5 to 1 m/yr, the expected age difference would be 760 to 1,520 years, which cannot be reliably measured.

3. Sampled water at Well ER-5-3 is dominated by the TM-WTA, whereas Well ER-5-5 samples the shallower OAA/BLFA. Very low vertical groundwater gradients indicate that groundwater would be expected to move from the shallower portion of the basin (OAA/BLFA) to the deeper volcanic aquifers (TM-WTA); therefore, the wells would not be expected to be comparable for age relationships because the upgradient well is deeper in the flow system than the downgradient well.

Using the hydraulic head data presented in Section 3.5, an alternative evaluation approach for this target can be implemented with the estimated groundwater flow directions and velocities calculated using the multiple linear regression water-level calculation model in conjunction with Darcy's Law. NSTec (2012) reports such an analysis for the Area 5 RWMC resulting in a groundwater velocity of 0.08 m/yr with a gradient direction of 178 degrees from north (nearly due south). Revised estimates for the RWMC using the new survey elevation data provided in Section 3.5 and available synoptic data since 2003 indicate similarly slow groundwater velocities of 0.06 m/yr with a median gradient direction of 143 degrees from north (southeast). This result is shown on Figure 3-24 along with geochemically based velocities used in the CAI. A larger-scale, more comprehensive analysis was also conducted as follows: (1) using the best estimate of static water-level data and uncertainty (Figure 3-2) to generate 10,000 Monte Carlo realizations of the best-fit plane to determine flow direction and gradient in the area encompassing the geochemically estimated velocities, (2) computing Darcy flux based on the hydraulic gradient and the hydraulic conductivity estimated for the Area 5 RWMC (REECo, 1994), and (3) dividing Darcy flux by the effective porosity for the Area 5 RWMC (NSTec, 2012) to yield groundwater velocity for comparison to the geochemically estimated velocities. The median direction (116 degrees from north) and velocity (0.78 m/yr) for the median gradient of these computations are shown in Figure 3-24 along with the geochemically based velocities used in the CAI. The direction ranged from 113 to 119 degrees between the first and third quartiles of the direction empirical cumulative distribution function (ECDF); the velocity ranged from 0.6 to 0.9 m/yr between the first and third quartiles of the gradient ECDF.

The previous computations are informative because they elucidate the uncertainty arising solely from hydraulic-head measurement. However, the Phase II flow and transport models also considered the uncertainty in hydraulic conductivity and porosity at a larger scale. Combining the AA porosity uncertainty used in the transport modeling, the null-space Monte Carlo AA conductivities for the NHA flow model (NNES, 2010), and the 10,000 realizations of hydraulic gradient and direction described above results in a more comprehensive uncertainty assessment similar to that conducted in the CAI. The NHA model was selected for evaluation because it attempted to honor the

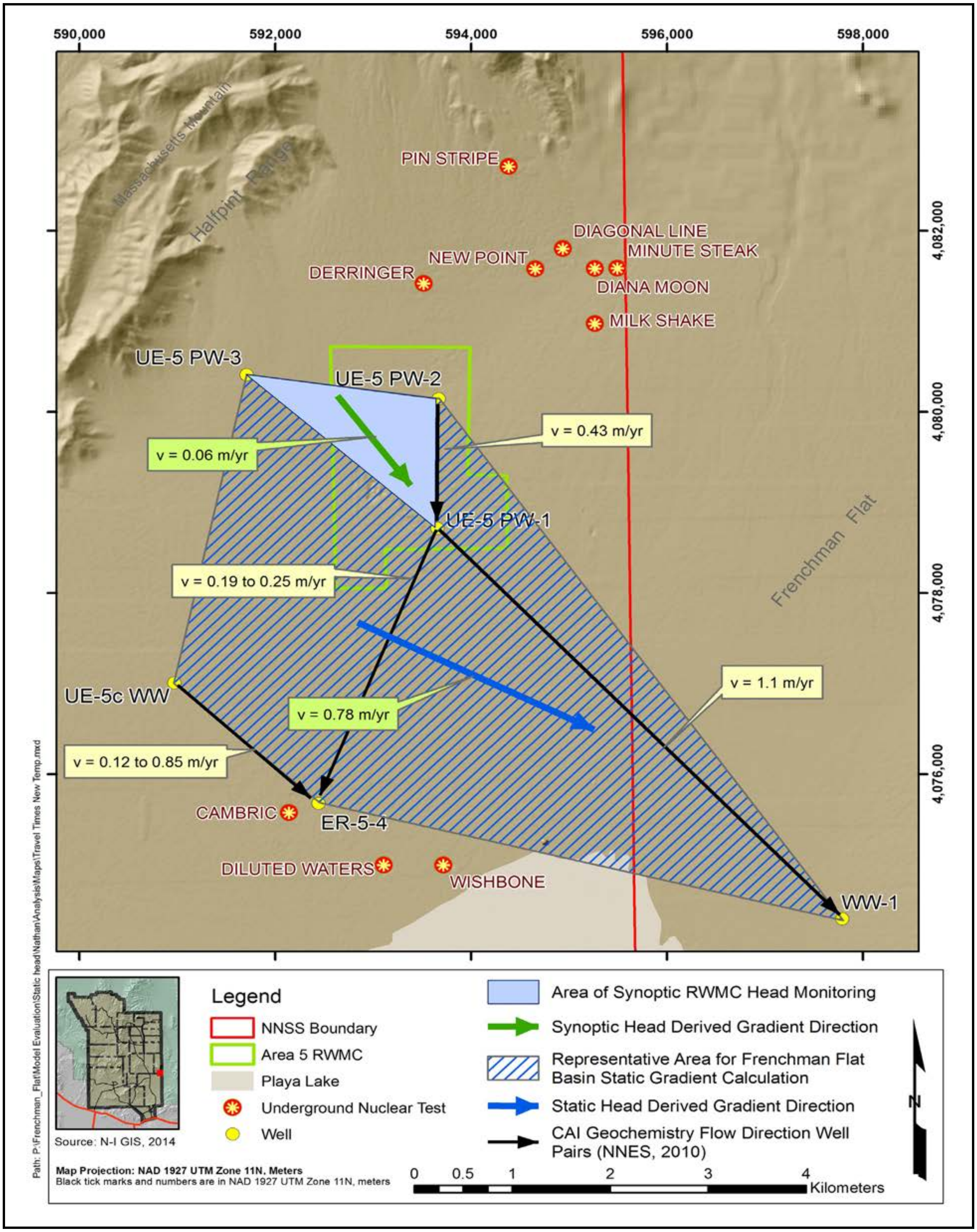


Figure 3-24
Geochemical Velocity Estimates and Best-Fit Plane Gradient Estimates with Calculated Groundwater Velocities

geochemically estimated velocities. The AA hydraulic conductivity is an ECDF, and the porosity distribution is a normal distribution with a mean of 0.33 and a standard deviation of 0.07. Figure 3-25 shows the ECDF of groundwater velocity from this computation along with the velocity estimated at the Area 5 RWMC, the range of the geochemically estimated velocity, and the median velocity accounting only for head measurement uncertainty described previously. A polar plot of velocity and direction is also presented, which shows a strong tendency for a flow direction of about 110 degrees from north and velocity between 0.1 and 1 m/yr. The direction uncertainty reflects the static head measurements and corresponding uncertainty. The velocity uncertainty incorporates both the AA hydraulic conductivity and porosity uncertainty. As anticipated, uncertainty in hydraulic conductivity and porosity results in a larger velocity range than the velocities calculated using the fixed Area 5 RMWC properties.

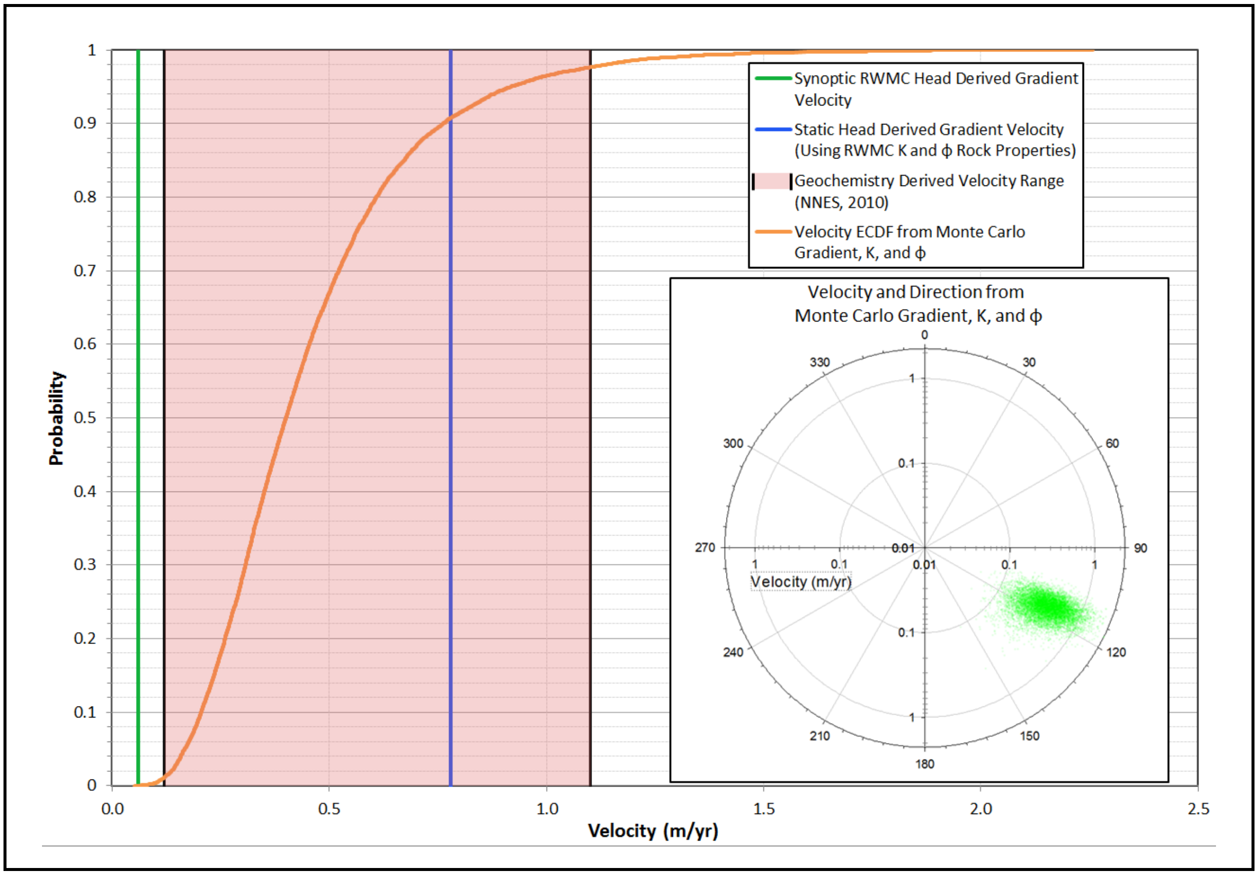


Figure 3-25
Comparison of Geochemical, Synoptic Head, Static Head, and Monte Carlo Synoptic Head Estimated Velocities

New hydraulic head data do not support groundwater flow between well pairs UE-5 PW-2 and UE-5 PW-1 and UE-5 PW-1 and ER-5-4. In the flow and transport analysis (NNES, 2010), the geochemical-estimated flow paths were considered permissible if the age increased between well pairs (NNES, 2010). However, as noted in NNES (2010), the well pairs may be obliquely oriented to the true flow paths so that geochemically estimated velocities cannot be interpreted as unique flow trajectories but rather as an estimate of a component of the velocity vector. Thus, the additional hydraulic head data and the area-based gradient calculations presented here clarified the direction and magnitude of the dominant groundwater velocity in this portion of the CAU.

3.10.3 Summary and Conclusions

Quality concerns regarding carbon isotope measurements for groundwater taken from Wells ER-5-5 and ER-11-2 precluded the use of their ^{14}C data to evaluate conclusions from SNJV (2006) and NNES (2010) that Frenchman Flat groundwater was recharged during a past pluvial period and is moving through the alluvium to the south or southeast at rates of 1 m/yr or less. The analysis during model evaluation of the geochemical age and velocity constraints instead relies on indirect estimates of groundwater age derived using stable isotope concentrations and major cation concentrations of Na^{+} and Ca^{2+} at Wells ER-5-5 and ER-11-2 groundwater. Comparisons of Na and Ca concentrations with a relationship derived between cation concentrations and ^{14}C ages for other nearby wells suggest the age of water in Well ER-5-5 is 16,900 years and at Well ER-11-2 is 25,200 years, in both cases plus or minus 5,000 years. These ages are consistent with the relative depletion in their $\delta^{18}O$ and δD values compared with modern precipitation and recharge that previous analysts (e.g., Hershey et al., 2005) have used to infer the presence of paleo-groundwater.

Hydraulic estimates of groundwater velocity have been estimated using a best-fit plane that honors static groundwater heads, observed hydraulic conductivity values, radionuclide migration, and porosity measurements. In the Northern Testing Area, near MILK SHAKE, groundwater velocity best estimates are between 0.7 and 2 m/yr with an upper bound of 4 m/yr. In the Central Testing Area, velocity estimates ranged from 0.1 to 1.5 m/yr, in good agreement with previously published values (SNJV, 2006; NNES, 2010).

Overall, the new major-ion and stable isotope data from Wells ER-5-5 and ER-11-2 are consistent with a pluvial age for the groundwater in Frenchman Flat advocated by both SNJV (2006) and NNES

(2010). Based on the pluvial origin of the groundwater and hydraulic estimates of groundwater velocity, the new geochemical, water-level, and radiochemical data support the conceptualization of slow (less than 1 m/yr) groundwater flow in central Frenchman Flat basin to the southeast.

3.11 Summary

Data collection described in Table 1-1 has been conducted, and the data analyzed and interpreted. Table 3-6 summarizes the results. Key summary findings relative to the forecasted CBs are as follows:

1. The continuous welded tuff aquifer pathway east from PIN STRIPE does not exist, and the computed CBs do not represent potential transport.
2. Based on multiple lines of evidence, groundwater flow is slow (on the order of 1 m/yr) and generally to the southeast.
3. The BLFA is not a fractured rock, at least in the vicinity of MILK SHAKE, and transport is much slower than forecast. The CBs in NNES (2010) are conservatively represented for MILK SHAKE; if the CB were revised with the new data described here, they would be much smaller than shown in flow and transport report.
4. The very limited extent of the CBs from tests conducted in the OAA (DIANA MOON, for example) is generally consistent with low groundwater velocity.

Well ER-5-5 is located ideally to monitor any future migration.

Table 3-6
Model Evaluation Results Summary

Model Evaluation Target	Results
Internal continuity of TSA	Well ER-11-2 shows TSA is not continuous due to faulting, and the flow path to the east does not exist.
Spatial extent of TSA in the north	Overall spatial extent could not be evaluated by ground magnetic survey due to ground noise and complexity. Well ER-11-2 showed that the eastward saturated extent was less than the base interpretation, but like one of the uncertainties.
Hydraulic conductivity of WTA (TSA)	Well ER-11-2 shows saturated TSA does not exist at this location; eastward pathway is severed, and target cannot be evaluated.
Continuity of BLFA	Continuity is similar to extended case in Phase II HFM.
Conceptual model of basin drainage to the southeast	New data are consistent with conceptual model.
Source release conservative assumptions	Lower-than-expected transport velocity masks this target, but radionuclide data from Well ER-5-5 are consistent with conservative source release assumptions.
Hydraulic conductivity of the BLFA	Results are consistent with the values used in the flow and transport modeling.
Flow boundary conditions	New data are consistent with conceptual model and boundary conditions.
Size of exchange volume	Hydrogeologic conditions dominate source release at PIN STRIPE and MILK SHAKE.
Geochemical age and velocity constraints	Geochemical data are consistent with pluvial-age groundwater and low groundwater velocity. Velocities derived from hydraulic data are less than 1 m/yr, consistent with CAI interpretations.

4.0 Modeling Team Recommendations

The CADD/CAP stage of the UGTA strategy (FFACO, 1996 as amended) requires a model evaluation report (this document) that describes, in addition to the impact of the new data on the flow and transport model, the modeling team's recommendations for model refinements, additional data collection, or advancement to the CR stage (NNSA/NSO, 2011). The focus of data collection and model evaluation was on the PIN STRIPE and MILK SHAKE underground nuclear tests. These tests, in the northern part of Frenchman Flat, included many conservative numerical modeling assumptions due to geologic and parameter uncertainties, which resulted in the largest CBs in northern Frenchman Flat.

4.1 Model Refinements

Analysis of data collected during the model evaluation (Section 2.0) resulted in improved understanding of groundwater conditions in Frenchman Flat and established the suitability of the flow and transport results (Section 3.0) (NNES, 2010). Key conceptual refinements based on the data-collection and evaluation activities include the following:

1. Well ER-11-2 showed the continuous TSA flow path to the east present in all the HFMs is disrupted by a fault-displacing tuff confining unit against the TSA at the water table. Therefore, CB forecasts from PIN STRIPE extending to the east are eliminated from further consideration.

2. Analysis of newly acquired hydraulic head data from Wells ER-5-5 and ER-11-2 and the water-level monitoring program wells shows the CAI groundwater flow models represented flow directions and hydraulic gradients consistent with the data; hydraulic gradients are small and to the southeast. This implies that the flow direction can be reliably estimated and used to support monitoring activities such as locating monitoring wells, interpreting radiological data, and assessing flow velocity.

3. Geologic data from Well ER-5-5 showed that the BLFA, conceptualized as dense fractured lava, is basalt rubble and more properly represented as a porous media for groundwater transport near MILK SHAKE. This refined understanding demonstrates that the approach used in NNES (2010) to forecast CBs at MILK SHAKE was conservative. As a result, the calculated CBs for MILK SHAKE extend farther than now expected.

4. Groundwater samples from Well ER-5-5 showed only mobile radionuclides (^{3}H and ^{14}C) at concentrations much lower than the MCL—about 20,000 times in the case of ^{3}H. At Well ER-5-5, the CAI model forecast from MILK SHAKE indicated a greater than 90 percent chance of exceeding the MCL. Correcting the PlumeCalc transport code (N-I, 2012a) reduced the chance of exceeding the MCL at Well ER-5-5 to about 70 percent, but the water-quality data indicate far less transport than any model forecast. This result is consistent with porous rather than fractured media transport.

Because the flow path to the east of PIN STRIPE is disrupted by faulting, the forecast CBs no longer can extend eastward. Consequently, a refined conceptual model of potential radionuclide migration from PIN STRIPE was developed and is presented in Appendix A. In the refined conceptual model, transport is limited to about 200 m of TSA due south of PIN STRIPE in the next 1,000 years; this is much less than the previous upper-bound plume-size estimates. The CAI flow and transport model's grid resolution is too coarse for meaningful computations; a local-scale model is unlikely to be significantly different than the scoping calculations described in Appendix A; and no further computations are recommended.

4.2 Additional CADD/CAP Data Collection

The modeling team recommends no further data collection in the CADD/CAP phase—the data are sufficient for addressing model uncertainty, and the conceptual model can be used to interpret future monitoring data.

4.3 Advancement to Closure Stage

The results of model evaluation show that the understanding and representation of groundwater flow and transport in Frenchman Flat is generally as described in NNES (2010). All data indicate that groundwater velocity is slow, and observed radionuclide transport is slow and confined to regions near tests (with the exception of the CAMBRIC radionuclide migration experiment). The MILK SHAKE CB has been represented conservatively (i.e., the actual extent of potential groundwater contamination is much less than forecast, but discernible using the available data and models). The hydraulic head and radionuclide data demonstrate that Well ER-5-5 is properly located to monitor future radionuclide migration. Additionally, the refined conceptual model for PIN STRIPE shows less than a few hundred meters of migration southward into the OAA toward a very slow southeasterly flow path. The modeling team considers there to be sufficient confidence in the site conceptual model and its numerical representation to guide the development of a long-term monitoring network and institutional controls. For these reasons, the modeling team recommends advancing Frenchman Flat to the CR stage of the UGTA strategy.

5.0 PER COMMITTEE RECOMMENDATIONS

The CADD/CAP for Frenchman Flat (CAU 98) requires the PER committee's recommendations to the modeling team regarding model refinements, additional data collection, and advancement to the CR stage. Specifically, NNSA/NSO (2011, p. 46-47) states the following:

> *"Step 4 begins with a qualitative and/or quantitative analysis of the new data to assess their impact on the flow and contaminant transport model by the modeling team. The modeling team presents the results of the analysis to the pre-emptive review committee. The presentation will also include the modeling team's preliminary recommendation for model refinements, additional data collection, or advancement to the CR stage.*
>
> *The pre-emptive review committee then provides the modeling team with recommendations for the path forward. If model refinements are required, the refinements are performed; model refinements may involve re-evaluating some, but not all, of the contaminant boundaries.*
>
> *A recommendation for additional data collection will be made if the new data are determined to be insufficient for addressing model uncertainty; model refinement may not be recommended until additional data are collected. A recommendation to proceed to the CR stage will focus on the adequacy of the model for designing a long-term monitoring network for closure and developing effective institutional controls to restrict public access to groundwater."*

5.1 Background

The PER committee consisted of a panel of experts from Desert Research Institute (DRI), LLNL, Los Alamos National Laboratory (LANL), NSTec, and USGS. The committee met multiple times with the modeling team to review various components of the modeling team's analysis of the model evaluation data (i.e., geology, hydraulic testing, static head, and geochemistry/radiochemistry) and their relevance to the model evaluation targets presented in Table 4-1 in the CADD/CAP (NNSA/NSO, 2011). During several of the review presentations, additional work or elaboration on the approaches used to address the model targets were requested by the PER committee. This led to additional work by the modeling team, which was then reviewed by the committee. As a result of this iterative process, the PER committee is now in close agreement with the modeling team that the model evaluation targets were sufficiently addressed to move to closure. Presentations from these meetings and the PER committee's review comments are stored as records in the UGTA Technical Data Repository.

An example of additional work performed during the review process involved a revision of the conceptual model of flow and transport from PIN STRIPE. The modeled eastward transport pathway from PIN STRIPE through the TSA was shown to be disrupted by a fault, as demonstrated by the lack of saturated TSA at Well ER-11-2. Because of this new information, forecasted eastward transport was no longer considered valid. The PER committee requested that the modeling team develop a new conceptual model with some quantitative analysis to illustrate the extent of transport (distance and direction) from PIN STRIPE. The modeling team responded with the new conceptualization (see Appendix A) that indicates the potential for limited southerly transport toward the detachment fault. This conceptualization is supported by the unsaturated WP location, hydraulic heads (gradient and direction), old groundwater ages, geologic interpretations, and hydraulic conductivity estimates at Wells UE-11b and ER-5-3.

As another example of the PER process, many discussions took place regarding the Well ER-5-5 geologic data, geochemistry data, MILK SHAKE CB forecasts, and their mutual interpretation and comparison. Radionuclide concentrations at Well ER-5-5 are well below the MCL, in contrast to CBs that indicate a high probability of detecting radionuclides above the MCL at this well location (NNSA/NSO, 2011, Figure 4-5). Slower-than-forecasted transport is consistent with the reinterpretation of the BLFA near MILK SHAKE as a porous basalt rather than a dense, fractured lava. Hydraulic gradients and hydraulic properties also support the minimal concentrations measured at Well ER-5-5. The static head evaluation supports southeasterly flow, consistent with the MILK SHAKE CB. The PER agrees that the model evaluation data for MILK SHAKE demonstrate conservatism of the CB.

5.2 Recommendation

The Frenchman Flat PER committee agrees there is sufficient confidence in the Frenchman Flat model to advance to the CR stage. No major issues were recognized by the PER committee that require additional data analysis, model refinements, or data collection before closure. In making this recommendation, the committee recognizes that "model" should not imply only the numerical model, but rather the complete understanding of transport as gathered from the data, conceptualization, and numerical modeling. The committee concludes that the current understanding is sufficiently reliable to design a monitoring system and develop effective institutional controls.

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Appendix A

Revised Conceptual Model near PIN STRIPE

A.1.0 INTRODUCTION

In the flow and transport report (NNES, 2010), the CB associated with the PIN STRIPE underground nuclear test followed the thin strip of saturated TSA (Figure A-1) along the northern basin margin. An uncertainty was identified (NNES, 2010, Appendix D) that allowed undocumented buried north–south-striking normal faults to offset the TSA sufficiently to disrupt the flow path.

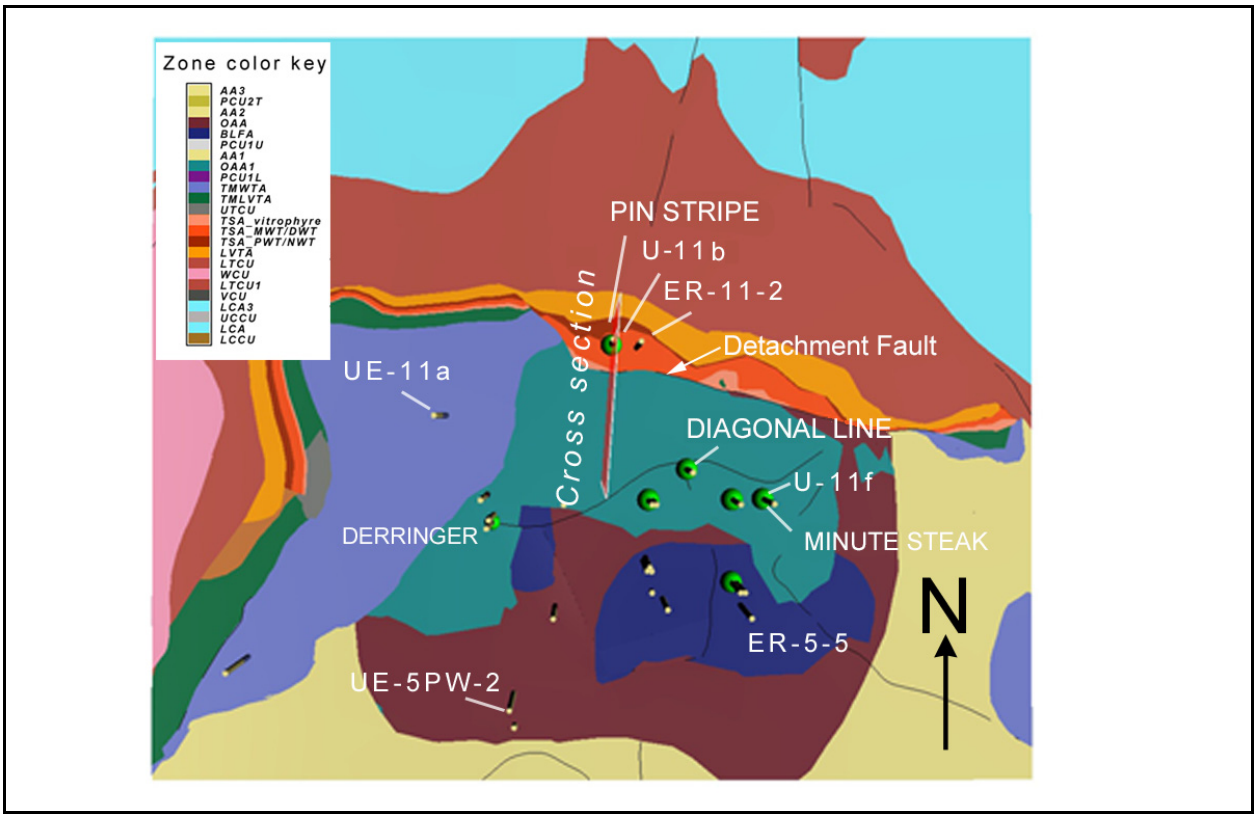

Figure A-1
Phase II Frenchman Flat BASE HFM Sliced at the Water Table

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

Well ER-11-2 demonstrated that this uncertainty was justified (Sections 2.2.2 and 3.1). As a result, the conceptual model of flow and transport from PIN STRIPE requires refinement. The local geology and hydrology were reviewed to develop this conceptual model as well as its uncertainties as described in this appendix.

A.1.1 Local Geology

A notable feature south of PIN STRIPE is a detachment fault detected during the Phase II CAI by the three-dimensional (3-D) seismic investigations (BN, 2005). The seismic data were used to determine the location of the fault as modeled in the HFM. Figure A-2 illustrates this geometry along the north–south cross-section line shown in Figure A-1. This interpretation places the detachment fault as far north as the data are believed to allow. However, the position of the fault could be interpreted to be as much as 150 m south of the location shown here. The PIN STRIPE 1 and 2 R_c are also shown, as are the emplacement (Well U-11b) and exploratory holes (Well UE-11b) and the water table—the detachment fault is about 200 m south. The detachment fault is interpreted to become listric with depth and does not go through to the LCA (BN, 2005). Well ER-5-3 #2 encountered the TSA at a depth of about 870 m (NNSA/NSO, 2005) versus about 310 m for Well UE-11b (Dixon et al., 1965), and the TSA is interpreted as present some distance southward into the basin at a much greater depth.

Well UE-11b was drilled to 396 m, and logged by Dixon et al. (1965); the Topopah Spring Member (since elevated to geologic formation status) lithology is described as shown in Table A-1; the HSU is referred to as the TSA (BN, 2005). The water table was logged at a depth of 358 m below ground surface. None of the vitrophyre, about 4 m of the densely welded section, and all (15 m) of the partially to nonwelded TSA intervals are saturated. Similar TSA lithology exists at Wells ER-5-3 #2 (Table A-2) and ER-11-2 (Table A-3). Note that Dixon et al. do not use the term “moderately welded tuff” because it was not introduced into NNSS interpretations until the early 1980s. Additionally, the TSA is thought to thin southward as shown by the decreasing thickness from Wells ER-11-2/UE-11b to ER-5-3 #2 (Tables A-1 through A-3).

The hydrologic characteristics of the TSA on Pahute Mesa are related to its geologic properties by the conceptual model shown in Figure A-3, modified from Winograd (1971); no vitrophyre is present in Figure A-3, but a vitrophyre is conceptualized as a fractured rock. Using this conceptual model, the bulk of the saturated rock (PWT to NWT) immediately under PIN STRIPE is thought to have low fracture intensity and a relatively high porosity. Following the conceptual model in Figure A-3, the TSA HSU was divided by lithology at Well UE-11b as shown in Figure A-2; for instance, the vitrophyre is labeled *TSA-vitrophyre*. Because the lithology is related to the deposition of a welded tuff, the relationship between the lithology and the relative proportions are extrapolated away from Well UE-11b to conform to the dip of the TSA.

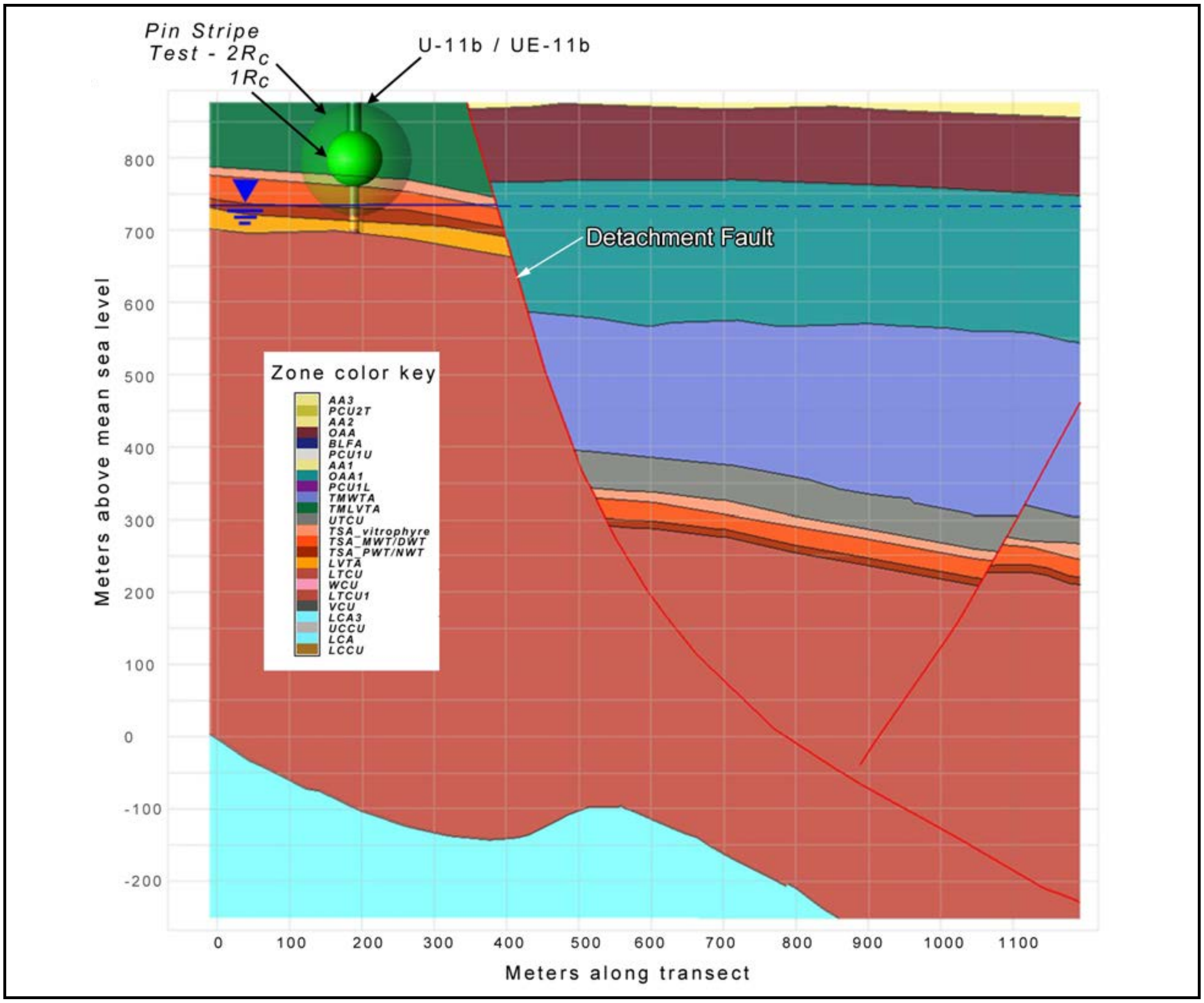

Figure A-2
North–South HFM Cross Section through PIN STRIPE

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

Table A-1
TSA Lithology in Well UE-11b

Depth Interval (m)	Thickness (m)/% Total	Geologic Description
310.9–320	9.1/13	Vitrophyre, ash-flow, densely welded.
320–362.7	42.7/64	Tuff, ash-flow, densely welded, lithophysal, devitrified. Highly fractured zones were observed between 338.3 and 350.5 m depth. Unit probably contains lithophysal cavities and zones of fracturing. The contact to the unit below is gradational, with decreasing welding downward.
362.7–377.9	15.2/23	Tuff, ash-flow, partially to nonwelded.

Source: Dixon et al., 1965

Table A-2
TSA Lithology in Well ER-5-3 #2

Depth Interval (m)	Thickness (m)/% Total	Geologic Description
872.3–881.2	8.8/25	Densely welded ash-flow tuff, vitrophyric.
881.2–890	8.8/combined with next interval	Moderately to densely welded ash-flow tuff. Conspicuous fractures.
890–906.8	12.2/58	Moderately to densely welded ash-flow tuff.
906.8–914.4	6.1/17	Partially welded ash-flow tuff.

Source: NNSA/NSO, 2005

Table A-3
TSA Lithology at Well ER-11-2

Depth Interval (m)	Thickness (m)/% Total	Geologic Description
213.4–227.1	13.7/17	Vitrophyric ash-flow tuff.
227.1–265.2	38.1/46	Densely welded ash-flow tuff.
265.2–280.4	22.9/27	Moderately welded ash-flow tuff.
280.4–288	8/10	Partially welded to nonwelded and weakly zeolitic at the base of the interval below 280.4 m.

Source: NNSA/NSO, 2013

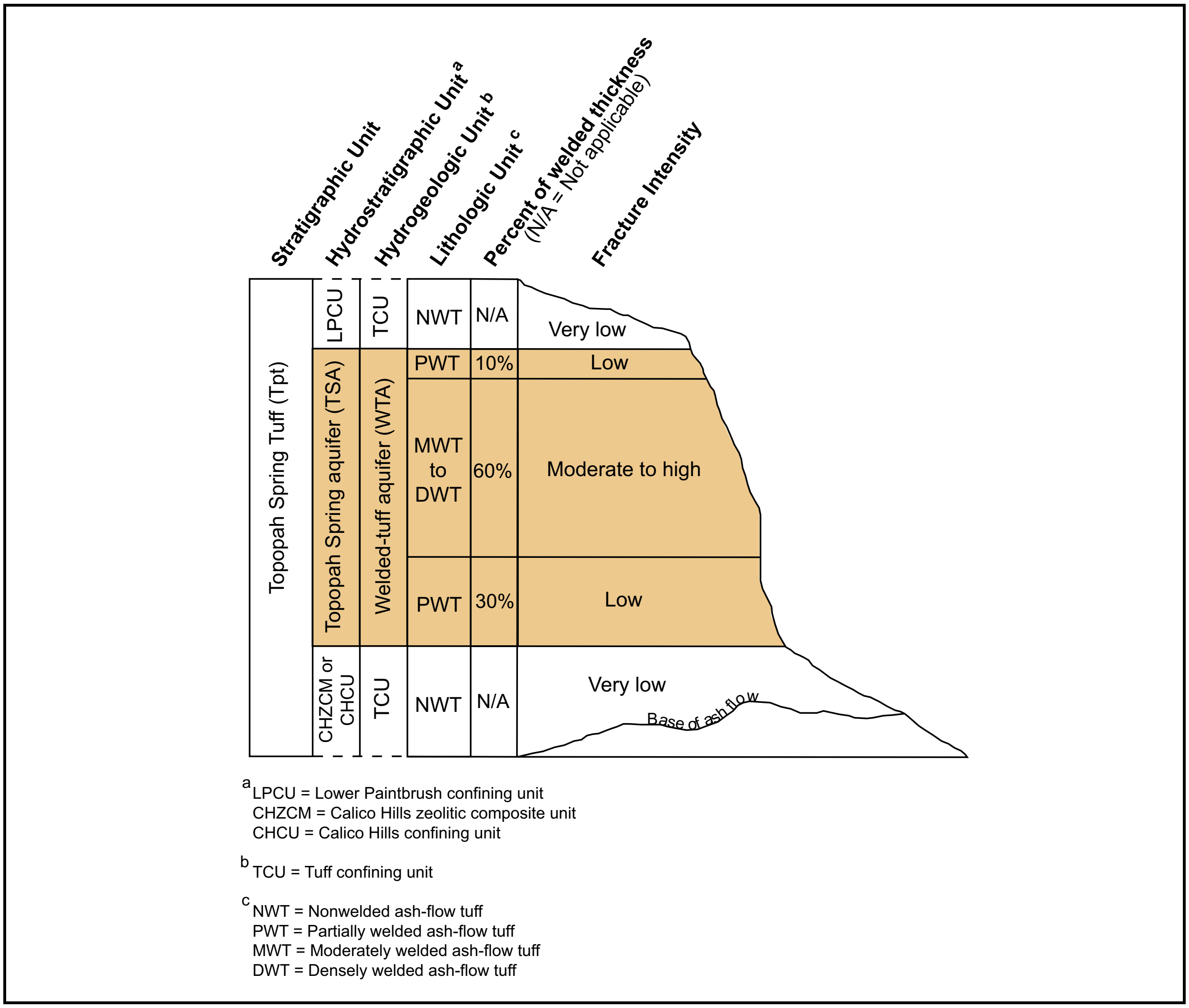

Figure A-3
Hydrogeologic Conceptual Model of the TSA
Source: Drellack (2010); as modified in N-I (2012)

Small faults were logged in the U-11b emplacement shaft as reported by Wood (2007), which includes data from Barnes (1966). These small faults were not included in the HFM because they did not have sufficient offset to have significance at the CAU scale, but they are included in this analysis of local conditions (Figure A-4).

Sweetkind and Drake (2007) noted that damage zones tend to scale with fault offset in volcanic rocks in Yucca Flat, and damage zones associated with large-offset faults (greater than 100 m) are many tens of meters wide, whereas damage zones associated with smaller offset (less than 10 m) faults are generally only a meter or two wide. Zeolitized tuff develops moderate-sized damage zones whereas vitric nonwelded, bedded, and air-fall tuff have very minor damage zones, often consisting of the fault zone itself as a deformation band, with minor fault effect to the surrounding rock mass.

Prothro et al. (2009) also studied faults at the NNSS and observed the following: (1) more recently active faults probably form permeable fault zones where they cut stronger rocks such as welded tuff and lava; (2) faults that intersect TCU form zones of enhanced permeability, relative to TCU protolith, although of less absolute permeability than those in welded tuff and lava; and (3) within weaker hydrogeologic units—such as AA, playa confining unit (PCU), and vitric-tuff aquifer (VTA)—these faults will typically not form zones of enhanced permeability and may form zones of reduced permeability relative to the protolith.

SNJV (2006) summarized the understanding of the role of faults in poorly consolidated sediments (AA and OAA) and presented the conceptual model that faults are low-hydraulic conductivity features because of the associated damage zones.

Thus, the conceptual model of fault damage is as follows:

- Fault damage becomes larger with larger fault displacement.
- Weak rock such as AA and VTA has hydraulic conductivity reduced by faulting.
- DWT/MWT has an increased hydraulic conductivity damage zone with potential for a lower permeability fault core.
- TCU also has a higher hydraulic conductivity, relative to its very low intact properties, as a result of faulting.

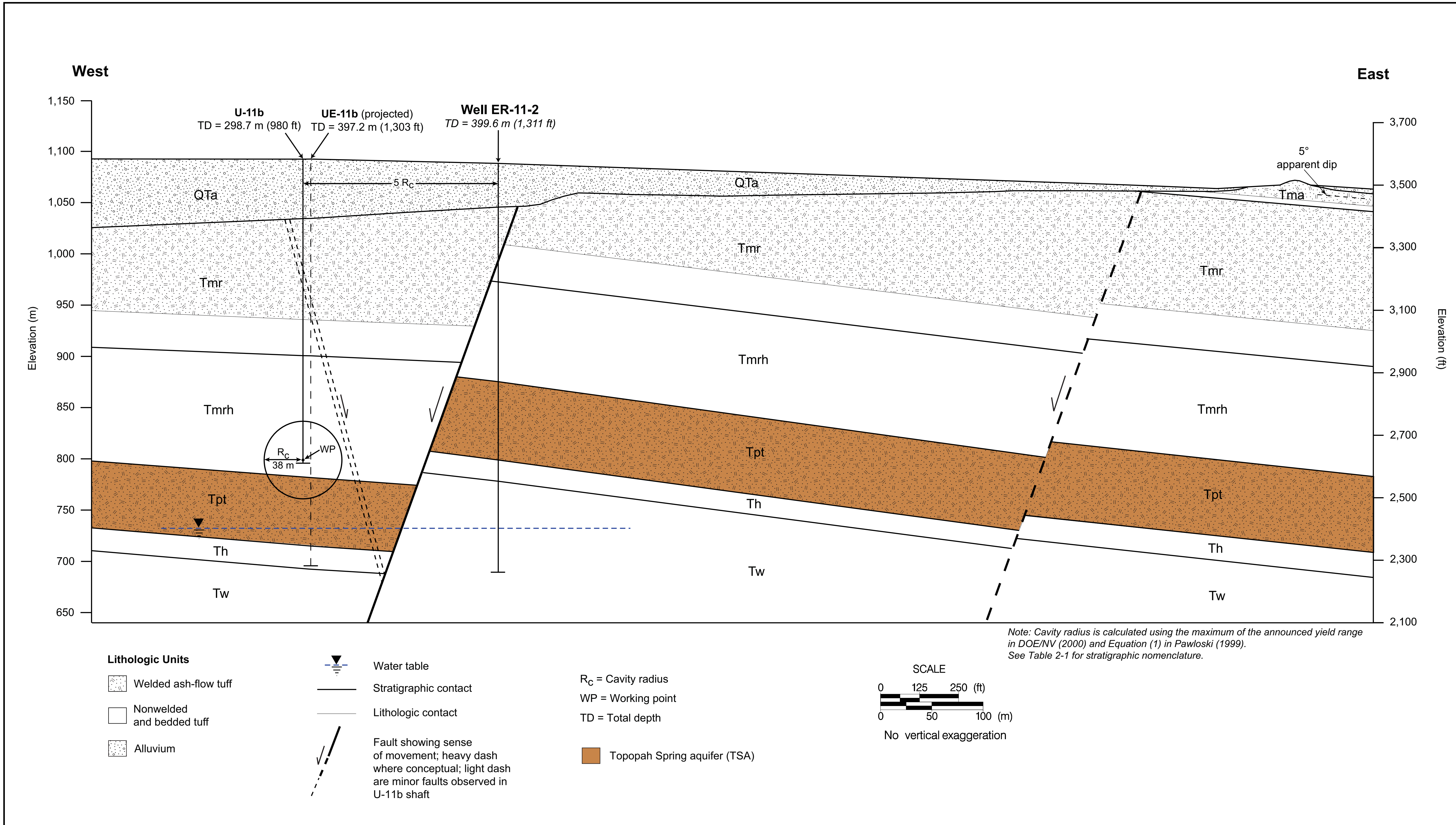

Figure A-4
West–East Geologic Cross Section through Emplacement Hole U-11b and Well ER-11-2
Source: Modified from NNSA/NSO, 2013

A.1.2 Local Hydrology

Several hydrologic factors provide conceptual constraint on groundwater flow direction near PIN STRIPE, including the following:

- Massachusetts Mountain receives modern recharge in all the recharge models considered in SNJV (2006) and NNES (2010), and is higher to the north—and, to a lesser degree, to the west—providing driving force to the south and east.
- Hydraulic head in CP basin is about 100 m higher than in Frenchman Flat proper, and water is thought to leak eastward across the Cane Spring fault, providing some driving force to the east (SNJV, 2006).
- Higher head at Well ER-11-2 than observed in nearby OAA and volcanic aquifer wells precludes groundwater flow to the east.
- Land surface, a general control on the water table of an unconfined aquifer (Hubbert, 1940), trends to the southeast.

These hydrologic factors are illustrated on Figure A-5. Based on these considerations, and the fact that the LTCU precludes flow to the north and east from PIN STRIPE, it is concluded that flow should be southward from PIN STRIPE.

Groundwater flow direction was estimated using a multiple regression approach (Section 3.5) with hydraulic head from Wells ER-5-5, ER-5-3 #3, ER-5-3 shallow piezometer, UE-5 PW-2, UE-5 PW-3, UE-11a, and UE-11b at 184 degrees (0 degrees is north) with a standard deviation of 32 degrees. The hydraulic gradient is 2.6×10^{-4} with standard deviation 1.4×10^{-4}. This represents an average in gradient direction and magnitude over the area bounded by the wells. The static head estimated for Well UE-11b is higher than head at Well ER-5-3, and another way to conceptualize the gradient is that the bulk of that change occurs in the TSA between Well UE-11b and the detachment fault (Figure 3-10). This conceptualization might result in a higher gradient for about 400 m (the saturated width of the TSA), but then the gradient would be even lower in the OAA without the influence of Well UE-11b.

The detachment fault creates a potentially complex flow path near PIN STRIPE, with the TSA juxtaposed against the OAA and the TM-WTA and TSA displaced downward about 400 m (Figure A-2). The closest data available on hydraulic head relationships between aquifers in Frenchman Flat is from the completions at Well ER-5-3. The shallow piezometer at

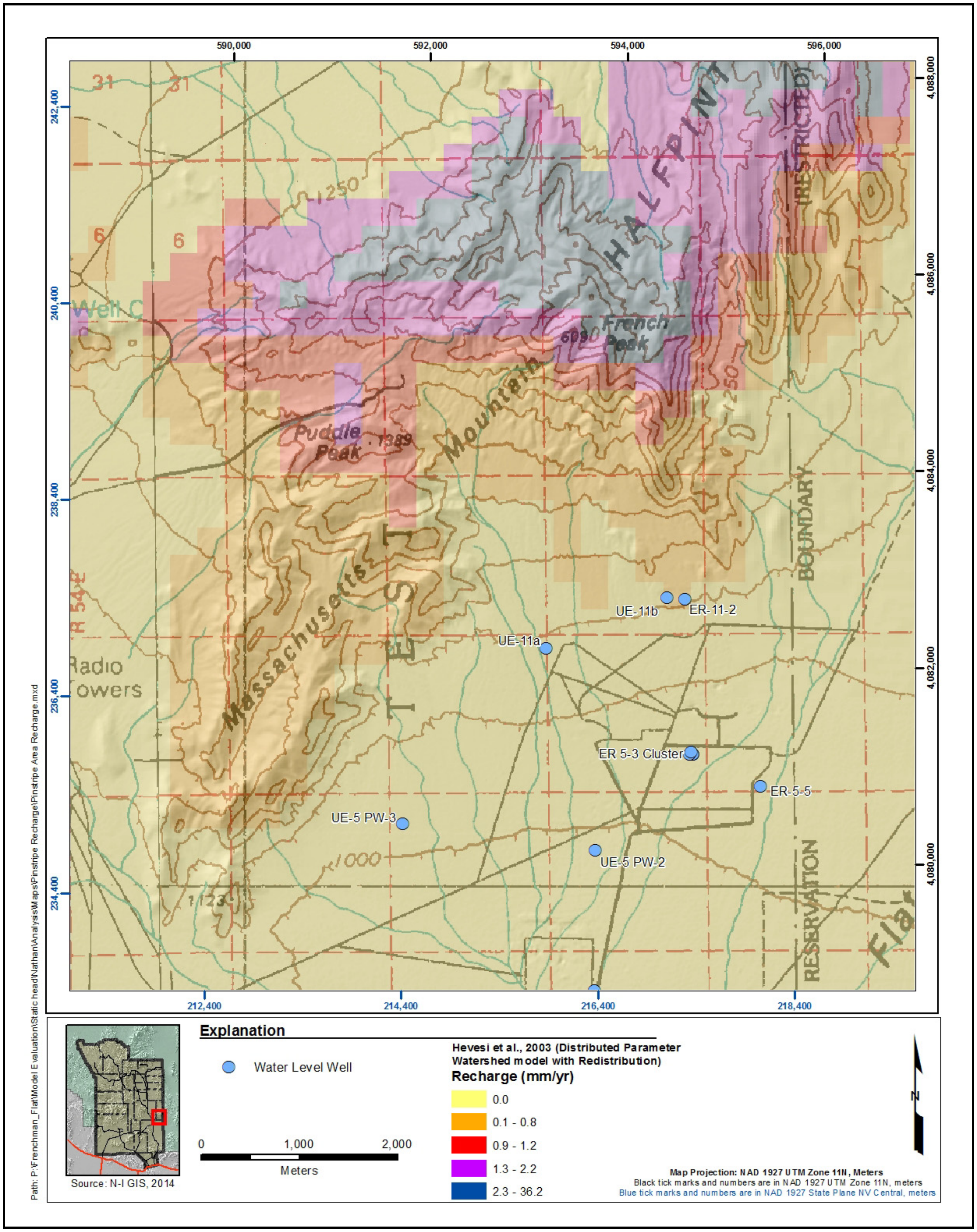

Figure A-5
Topography and USGSD Recharge Model in Northern Frenchman Flat

Well Cluster ER-5-3 monitors the OAA and BLFA, and the deep piezometer monitors the TM-WTA. The complete dataset (as of April 2014) from NWIS is shown in Figure A-6 and demonstrates a consistent downward head difference from the OAA/BLFA to the TM-WTA of about 0.35 m (vertical gradient of 1×10^{-3} between piezometer well screen centers). These data suggest that a downward head gradient could exist at the detachment fault.

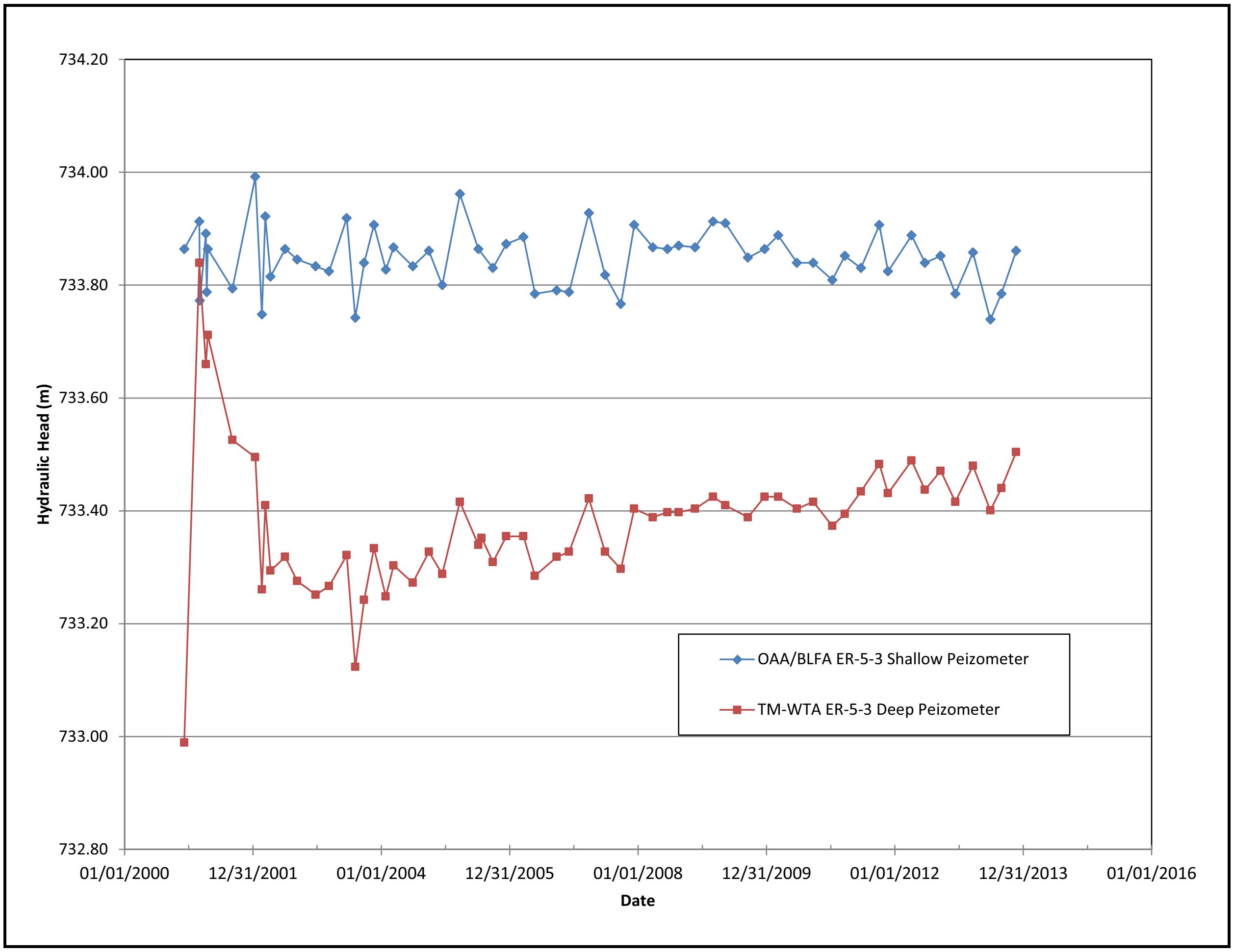

Figure A-6
Hydraulic Head in Well ER-5-3 Shallow and Deep Piezometers

After drill pipe was set in Well UE-11b, water levels were observed to rise and were monitored (Elliott and Fenelon, 2010). These data were interpreted as a slug test and the results presented in NNES (2010). The hydraulic conductivity of the TSA was estimated at 0.14 m/day. Butler and Healey (1998) show that slug tests are prone to underestimating hydraulic conductivity without proper well development; because the “test” involved drill pipe, such development likely did not occur at Well UE-11b. About 4 m of densely welded, potentially, fractured tuff and 15 m of nonwelded to partially welded, likely, unfractured tuff was tested; the former is thought to have little permeability unless fractured, whereas the latter has primary permeability (Peters et al., 1984). The location of the water table in the welding transition zone creates interpretation ambiguity as to what part of the TSA is represented by the "test"; this is evaluated by assuming the results reflect different lithologies. For comparison, the RNM-2S multiple-well aquifer test (MWAT) (SNJV, 2004a) gave an AA hydraulic conductivity of 0.3 m/day, and the Well Cluster ER-5-3 MWAT (SNJV, 2004b) gave an OAA hydraulic conductivity of 0.034 m/day (vertical to horizontal anisotropy ratio of 0.13).

In order to compute transport velocity, groundwater flow rate must be estimated. Flow through a line L perpendicular to streamlines is as follows:

$$Q = T\, i\, L \qquad \text{(A-1)}$$

where
- Q = flow in cubic meters per day (m^3/day)
- T = transmissivity in m^2/day
- i = hydraulic gradient in meters per meter (m/m)

As conceptualized in Figure A-2, the PWT to NWT is more or less completely saturated and constant thickness to the south, resulting in a constant transmissivity. Assuming the hydraulic conductivity represents only the NWT and PWT and is homogenous at the scale of potential radionuclide groundwater migration from PIN STRIPE gives a transmissivity of 2 m^2/day (0.14 m/day $\times$ 15 m of saturated thickness) along this path. This results in a flow rate of 5.4×10^{-4} m^3/day per unit length. Dividing by saturated thickness gives a flow per unit area of 3.6×10^{-5} m/day. Equivalently, the Darcy flux (volume per unit area) is given by the following equation:

$$J = -K\, i \qquad \text{(A-2)}$$

where
- J = flux in m/day
- K = hydraulic conductivity in m/day
- i = hydraulic gradient in m/m

Substituting the hydraulic gradient and hydraulic properties gives a Darcy flux of 3.6×10^{-5} m/day, the equivalent result from Equation (A-1). This flow rate can be used to estimate transport velocity for the NWT to PWT.

The geometry is more complicated for the MWT to DWT because as the TSA dips southward into the water table, the conceptual model (Figures A-2 and A-3) suggests that the saturated thickness—and hence cross-sectional area—of the DWT goes up. The MWT to DWT saturated thickness is about 4 m at Well UE-11b, 24 m about 100 m south, and 43 m at the detachment fault—increasing transmissivity (cross-sectional area) by factors of 6 and 10. The NHA (NNES, 2010) conceptualization is that recharge on the mountains to the north travels some distance laterally to the northern saturated edge of the basin. This limits the amount of water that can flow southward; thus, as MWT to DWT transmissivity goes up to the south, Darcy flux and gradient must go down. The reduction in Darcy flux is from the fixed flow rate being spread over increasing cross-sectional area as the TSA dips into the water table. The reduction in hydraulic gradient can be verified by examining Equation (A-1). When Q is fixed, which is the conceptualization of recharge inflow at the edge of the basin near PIN STRIPE, and transmissivity increases as the TSA dips into the water table, then the hydraulic gradient must decrease proportionally to the transmissivity increase. At Well UE-11b, transmissivity is (assuming the hydraulic conductivity represents only DWT) 0.56 m^2/day (4-m saturated thickness $\times$ the hydraulic conductivity). This gives a Q of 1.5×10^{-4} m^3/day, or a Darcy flux of 3.6×10^{-5} m/day (the same as for the PWT to NWT). Using the midpoint of the southward flow path 100 m from Well UE-11b, where the saturated MWT to DWT is 24 m, to represent the entire path velocity gives a Darcy flux of 6×10^{-6} m/day.

Applying Equation (A-2) to the OAA gives a flux of 8.8×10^{-6} m/day for the OAA.

In order to estimate approximate transport distances, velocity must be computed from Darcy flux by dividing by effective porosity. Two bulk density samples were taken from Well UE-5k (Wood, 2007) that when converted into porosity gives 0.21 and 0.23 for the OAA. No Frenchman Flat core porosity data exist for the TSA. Instead, TSA core data from Yucca Mountain as compiled by Flint (1998) were used. Mean matrix porosities across all wells for the densely welded TSA zone PV3, moderately welded TSA zone PV2, and nonwelded basal tuff zone BT1 were 0.04, 0.16, and 0.28, respectively. Standard deviation for the densely welded TSA zone PV3, moderately welded TSA zone PV2, and nonwelded basal tuff zone BT1 were 0.094, 0.28, and 0.11, respectively—the welded zones showed considerable variability. Potential transport in the fractured TSA is complicated by fracture-matrix interaction; the full spectrum of behavior encompasses fracture transport only (fastest) to combined fracture-matrix (slowest) transport. It is also complicated by the porosity range between MWT to DWT. Assuming dense TSA fracturing (observed in part of Well UE-11b, Table A-1) coupled with the low hydraulic gradient and slow velocities (less than 1 m/yr, Section 3.10) results in conditions favorable for full matrix participation allowing the use of matrix porosity to estimate velocity. No other information exists to directly evaluate this assumption.

Considering the potential transport velocity associated with the TSA lithological variations approximately bounds potential migration by going from a high-porosity to a low-porosity condition (which is not equivalent to fracture transport)—the effect of rate-limited fracture-matrix transport cannot be evaluated with existing data, but is interpreted to be minimal due to low groundwater velocities (Section 3.10). Velocity by TSA lithology is 0.055, 0.083, and 0.048 m/yr for the DWT, MWT, and NWT, respectively. The similarity in DWT and NWT velocity is because the cross-sectional area increase along the DWT flow path, which offsets its lower porosity. These velocities result in 55, 83, and 48 m, respectively, of travel in the 1,000-year regulatory period. More relevantly, ^{3}H—which composes about 95 percent of the 1994 inventory (Bowen et al., 2001) and drives the CB (NNES, 2010)—decays to low activity in 200 years. Transport distances during this 200-year time frame are 11, 17, and 10 m for the DWT, MWT, and NWT, respectively. Under this condition, it may not be possible to meaningfully identify transport associated with any TSA lithology via groundwater monitoring.

Potential downward flow velocity in the OAA (without considering vertical to horizontal anisotropy) using the observed head differences from Well ER-5-3 is 0.015 m/yr, or 15 m in the 1,000-year regulatory period, or about 3 m in the 200 years it will take for ^{3}H to decay to low activity.

Uncertainty exists in the hydraulic gradient, direction, porosity, hydraulic conductivity, and the distance between PIN STRIPE and the location of the detachment fault. Porosity uncertainty is further complicated, as previously discussed, by potentially rate-limited, mass transfer between the fracture system and the matrix in the fractured TSA. At plus two standard deviations, the hydraulic gradient is double the estimated value, yielding a proportional increase in groundwater velocity (0.11, 0.17, and 0.10 m/yr for DWT, MWT, and NWT; 110-, 170-, and 100-m travel distance in 1,000 years, respectively). Because the porosity standard deviation is much larger than the mean for the DWT and MWT, no statistically based uncertainty evaluation can be done; groundwater velocity at the mean value of NWT porosity is 0.048 m/yr, and at plus and minus one standard deviation of porosity velocity is 0.03 and 0.08 m/yr, respectively. Considering this range of porosity and plus two standard deviations of hydraulic gradient, these values are 0.07 and 0.16 m/yr. Assumptions required in developing these estimates of groundwater velocity included full fracture-matrix interaction, representativeness of hydraulic gradient computations, and comparability of porosity data from similar tuffs at Yucca Mountain. For bounding computations of potential radionuclide transport the maximum estimated velocity value of 0.17 m/yr is rounded to 0.2 m/yr.

A.1.3 Flow Path Conceptualizations

The local hydrogeology discussed previously was used to formulate three different conceptual flow paths as described below.

A.1.3.1 Flow Path A

This conceptual flow path has flow southward toward the detachment fault and down the detachment fault into the TM-WTA (Figure A-2). This flow path has the following components:

- Central tendency estimates of horizontal flow velocities southward are similar for all TSA lithologies and do not have radionuclides reaching the detachment fault within 1,000 years.
- Upper-bound estimates of horizontal flow velocities southward are required to get transport to the detachment fault within 1,000 years.
- The OAA will have reduced hydraulic conductivity along the fault plane, and it has a low intact hydraulic conductivity as well as shown by hydraulic testing at Well ER-5-3 (SNJV, 2004b), resulting in a vertical groundwater velocity so low (15 m in 1,000 years) that transport to the TM-WTA is unlikely.
- At Well ER-11-2, the TCU can be interpreted as having low hydraulic conductivity by the slow hydraulic responses even though it is relatively near a fault with about 100 m of displacement. Thus, even if the TCU is damaged by the detachment fault and its hydraulic conductivity enhanced, the absolute magnitude will still be low as conceptualized by Prothro et al. (2009), making transport to the TM-WTA unlikely.
- If radionuclides managed to reach the TM-WTA, its depositional extent is limited (BN, 2005) and it does not connect to the LCA preventing ready exit from the slow alluvial/volcanic flow system.

The flow path is judged improbable because of the low horizontal and vertical velocities.

A.1.3.2 Flow Path B

This conceptual flow path is southward toward the detachment fault and potentially laterally across the fault into the OAA. Like Flow Path A, this path is only realized if transport velocities are high enough to reach the fault within 1,000 years, which can occur at upper-bound velocity estimates for the densely welded component of TSA flow by invoking a higher hydraulic gradient, lower porosity or incomplete matrix participation in transport. Taking the saturated 2 R_c exchange volume radius at the water table, using the maximum velocity of 0.2 m/yr over 1,000 years (resulting in 200 m of transport), and moving it 200 m in the estimated flow direction and plus and minus one standard deviation in direction yields an upper-bound estimate of potentially contaminated TSA groundwater in 1,000 years shown in Figure A-7. For comparison, the 3 R_c exchange volume considered in N-I (2013) is also shown.

A.1.3.3 Alternative C

In this alternative, groundwater is conceptualized as essentially stagnant. A conceptual model uncertainty is in the role of saturated fracture flow on transport—the water table is located near the bottom of the welded zone in the transition to NWT with the conceptually more fractured portion becoming saturated southward. The low flow velocity in the TSA may be practically indistinguishable from zero as previously discussed, and when combined with the conceptual model of a ^{3}H exchange volume up to 3 R_c in size (N-I, 2013) as shown in Figure A-7, it would be hard to discriminate between Flow Path B and Alternative C. Neither alternative results in much more contamination of the TSA other than the test exchange volume.

A.1.4 Summary

The refined conceptual model near the PIN STRIPE underground nuclear test has the following elements:

- TCU to the east and north essentially prevents groundwater flow in those directions.
- Recharge on the mountains and leakage from CP basin suggest groundwater flow also cannot be strongly westward or northward.
- Flow to the east is also precluded by the higher head at Well ER-11-2.

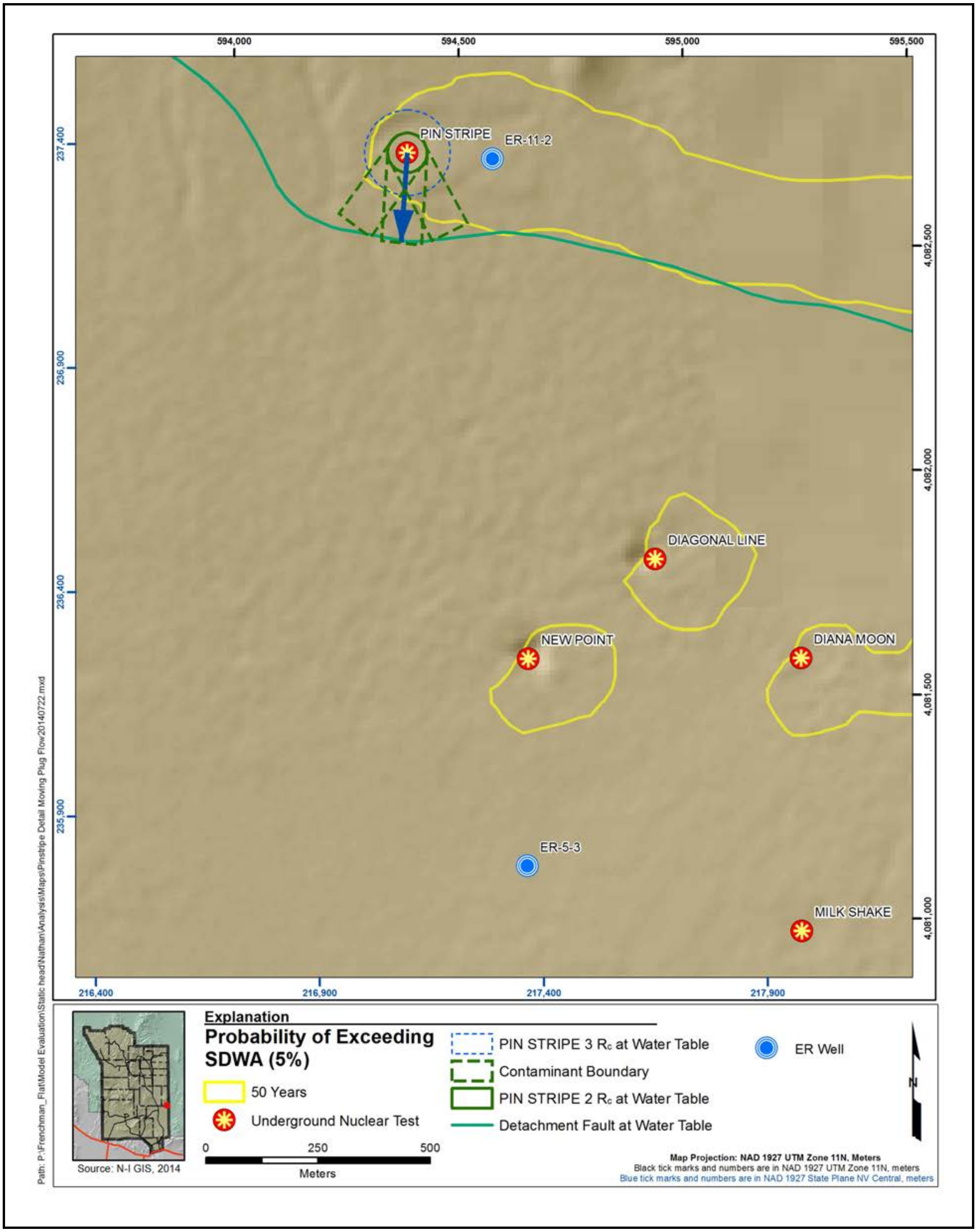

Figure A-7
Diagram of Conceptual Extent of Contamination from PIN STRIPE

Note: Cavity radius is calculated using the maximum of the announced yield range in DOE/NV (2000) and Equation (1) in Pawloski (1999).

- Recharge on the mountains, southeast-trending land surface, and water-level observations suggest flow should be approximately south.

- Low recharge, small horizontal hydraulic gradients, and old groundwater ages suggest very limited inflow to the Frenchman Flat basin.

- Low (less than 0.2 m/yr) horizontal groundwater velocities are estimated in all saturated tuff lithologies in the TSA under PIN STRIPE.The conceptual model of an ash-flow tuff is that a DWT is fractured. Very little of this DWT is saturated in the exchange volume, potentially limiting outflow.

- The potential TSA flow path is truncated about 200 m south by a detachment fault, which juxtaposes older altered alluvium against the TSA.

The preferred interpretation (Flow Path B) is that radionuclides will be transported slowly southward in the TSA, and invoking upper-bound uncertainties will reach the detachment fault within 1,000 years and cross laterally into the OAA through the detachment fault where groundwater flow will still be very slow (less than 1 m/yr).

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Appendix B

Correspondence between NNSA/NFO and NDEP Regarding CADD/CAP Stage Activities

B.1.0 DESCRIPTION

In addition to the data collection activities designed to address the model evaluation targets, work was performed during the CADD/CAP stage to meet the model acceptance conditions specified by NDEP and included in Appendices A and B of the CADD/CAP (NNSA/NSO, 2011). This appendix presents the series of correspondence between NNSA/NFO and NDEP that shows how these conditions have been satisfied.

B.1.1 Resurvey of Well-Head Elevations

The correspondence in Attachment B-1 describe activities that support establishment of a long-term groundwater monitoring program that includes resurveying well-head elevations; developing a standardized protocol for measurements; measuring water levels over a short interval; and monitoring water levels on an established, routine schedule. The focus of the correspondence is on the partial resurvey of Frenchman Flat that was completed during the CADD/CAP stage. Survey results and comparison to earlier results are presented.

B.1.2 Peer Review Issue Responses

The correspondence in Attachment B-2 present the approaches and associated results used to address the issues identified by the formal Frenchman Flat Peer Review Committee. Three items were not directly satisfied but will be addressed when monitoring indicates a need for an action.

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Attachment B-1

Correspondence Regarding Request for Approval That Requirements Have Been Met to Re-Survey Frenchman Flat Wells

Boehlecke to Murphy, January 29, 2014
(9 Pages)

Murphy to Boehlecke, February 11, 2014
(2 Pages)

Boehlecke to Andres, June 20, 2014
(34 Pages)

Andres to Boehlecke, July 03, 2014
(2 Pages)

Department of Energy
National Nuclear Security Administration
Nevada Field Office
P.O. Box 98518
Las Vegas, NV 89193-8518

JAN 29 2014

Tim Murphy, Chief
Bureau of Federal Facilities
Division of Environmental Protection
2030 East Flamingo Road, Suite 230
Las Vegas, NV 89119-0818

REQUEST FOR APPROVAL THAT REQUIREMENTS HAVE BEEN MET TO RE-SURVEY WELLS IN CORRECTIVE ACTION UNIT (CAU) 98: FRENCHMAN FLAT

This letter is in response to the Nevada Division of Environmental Protection (NDEP) letter of November 30, 2010 to the National Nuclear Security Administration Nevada Field Office (NNSA/NFO) that approved the CAU 98: Frenchman Flat, Flow and Transport Model, requiring that actions be documented in the Corrective Action Decision Document/Corrective Action Plan (CADD/CAP) and that actions taken be communicated to NDEP via interim documents/correspondence. These actions required re-surveying of well-head elevations for wells in Frenchman Flat prior to the establishment of a long-term monitoring program. Attached with this letter is a memorandum addressing NNSA/NFO's approach to the re-survey, and discussion on how NNSA/NFO believes this request has been fulfilled.

As stated within the Summary and Conclusion section of the memorandum, based on expert recommendation, NFO had nine (9) wells resurveyed. NFO believes the accuracy of the fourteen (14) other wells can't be improved and therefore supports the recommendation that these not be resurveyed.

If NDEP agrees with this approach, and that the re-survey work that has been completed, NNSA/NFO requests NDEP approval that the intent of the current language in the Frenchman Flat CADD/CAP has been met, and requests NDEP's guidance on the documentation required for acceptance of these conclusions.

/s/ Robert F. Boehlecke

Robert F. Boehlecke, Manager
Environmental Management Operations

EMO:10325.CD

Enclosure:
As stated

cc via e-mail:
C. D. Andres, NDEP
J. T. Fraher, DTRA/CXTS
N-I Central Files
NSTec Correspondence Control
K. S. Knapp, NFO
Bimal Mukhopadhyay, NFO
W. R. Wilborn, NFO
FFACO Group, NFO
NNSA/NFO Read File

Memorandum

Date: August 21, 2013

From: Greg Ruskauff/Frenchman Flat CAU Lead

Subject: Frenchman Flat CADD/CAP Survey Requirement Data Review

In a letter written on November 17, 2010, the National Nuclear Security Administration Nevada Site Office (NNSA/NSO) requested the acceptance of the Frenchman Flat flow and transport model and acknowledged the establishment of a long-term groundwater monitoring program that would include the following:

1. Resurveying well-head elevations
2. Developing a standardized protocol for measurements
3. Measuring water levels over a short interval
4. Monitoring water levels on an established, routine schedule

The planned approach for implementing these activities was incorporated into the Corrective Action Decision Document/ Corrective Action Plan (CADD/CAP), and the NNSA/NSO letter is in Appendix A of that document.

CADD/CAP Statements of Work (July 2011)

The currently existing water-level measurement program is described in Section 4.5.3 of the CADD/CAP as a data-collection activity. This section also includes a statement describing the proposed work for the wells in Frenchman Flat:

> "This work <u>will</u> (emphasis added) begin with a high precision resurvey of the wells in Frenchman Flat to precisely determine the coordinates and ground-surface elevation at each well location. In addition, a permanent data point on each of the well casings will be established as a reference for future measurements."(p.55)

A review of the status of the data requirements to support the NNSA/Nevada Field Office mission is presented in the following text, including a discussion of the overall accuracy of the water-level monitoring program and a proposal for further action.

Survey Evaluation Results

The CADD/CAP scope of work was modified so that an initial evaluation of survey data could be conducted. The Navarro-Interra Corrective Action Unit (CAU) Lead felt it was important to understand the current data quality and lessons learned from past survey efforts. National Security Technologies (NSTec) has delivered their report (including 90 pages of scanned survey notes) and found that:

> "Mike Keogh, current supervisor of the NSTec Survey group, reviewed the survey notes from the 14 Frenchman Flat well sites resurveyed in 2001. He confirmed that the differential leveling method was used to establish the bench mark altitudes at bench marks listed in Table 1 of the referenced USGS September 21, 2001 memorandum [Graves, 2001]. This method is still the best survey method to measure elevations with elevation accuracies in the range of 0.01 feet (~1/8 of an inch). There are no new methods or improved survey instruments that would improve elevation accuracy of these wells at this time.

Mr. Keogh also reviewed the most recent survey records of the 9 other Frenchman Flat wells of interest listed below and found that elevations of record at these sites were not established using the differential leveling method. Elevations at these well sites were typically measured at ground level outside the outer most casing or the top of the upper most, smallest casing, using GPS or trigonometric leveling methods. However, there are no documents or survey notes relative to monuments used to measure elevations during the surveys of these 9 wells. The elevation information is believed to be in the 0.1 - 0.2 foot range, but this would have to be confirmed with resurvey using GPS." (p. 1-2)

Further investigation of the nine other wells (ER-5-3, ER-5-3#2, ER-5-3#3, ER-5-4, ER-5-4#2, ER-5-5, ER-11-2, UE-5 PW-1, and UE-5 PW-3) revealed insufficient survey documentation, necessitating their resurvey (currently pending in August 2013). The locations of the two sets of wells are shown in Figure 1.

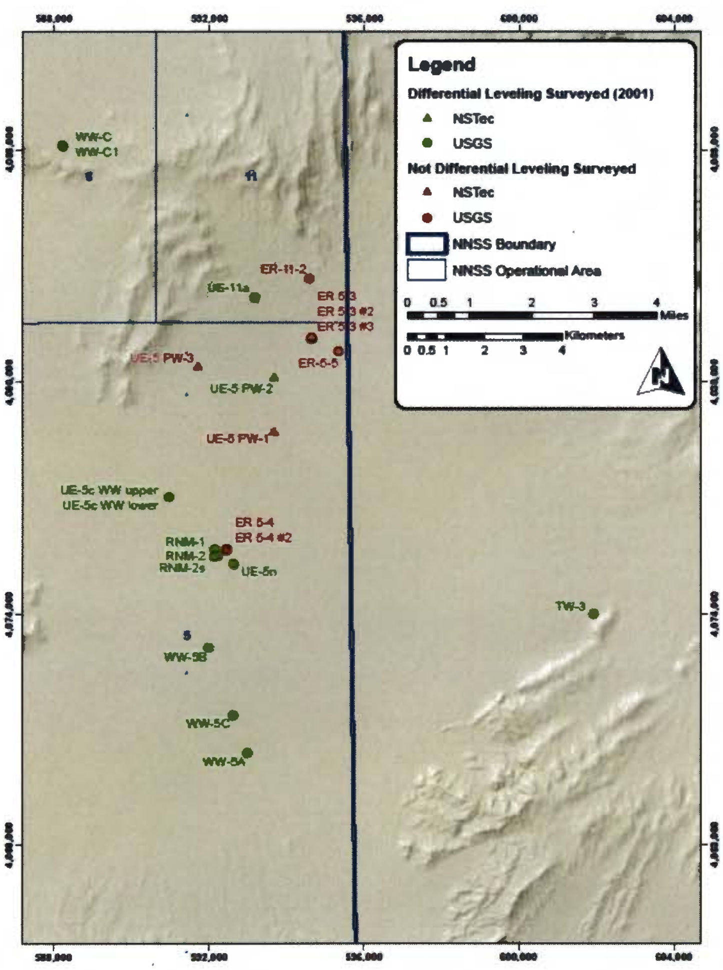

Figure 1 Well Location, Survey Data Status, Measuring Agency (N-I GIS, 2013)

Measurement Protocol

Both the U.S. Geological Survey (USGS) and NSTec have stated that they have a standard protocol for performing depth-to-water (DTW) measurements. No further documentation has been requested, but is presumed to be available.

Measurement Period

Data monitored by NSTec's Radiological Waste Management Complex (RWMC) show the DTW for the three pilot wells is typically taken on the same day. Comparing data collection dates in the National Water Information System (NWIS) suggests that, similarly, data are collected by the USGS over the course of one or two days. Data collection from the pilot wells (approximately quarterly) is not synchronized with the collection done by USGS (also approximately quarterly). However, given the quarterly measurements over the last decade, long-term trends have clearly been established, and there is no need to completely synchronize the two efforts.

Water-Level Measurement Frequency

In Appendix A of the CADD/CAP, the NNSA/NSO's letter to the Nevada Division of Environmental Protection (NDEP) requesting model acceptance states that a long-term water-level monitoring program will be implemented. However, a *de facto* program already exists at the USGS and NSTec pilot wells associated with RWMC quarterly monitoring. Table 1 lists the wells being monitored in Frenchman Flat. Figure 2, from the NWIS, clearly shows the consistency and frequency of USGS data collection for ER-5-4 Main, which is representative of the other wells the USGS has been monitoring in Frenchman Flat. Figure 3 shows the data from the RWMC and also illustrates the consistency and frequency of NSTec data collection.

Table 1. Wells Monitored for Water Levels and the Responsible Contractors

Well	Contractor
UE-5 PW1	NSTec
UE-5 PW2	NSTec
UE-5 PW3	NSTec
WW-5A	USGS
WW-5B	USGS
WW-5C	USGS
UE-5n	USGS
UE-5c WW	USGS
RNM-2S	USGS
RNM-2	USGS
RNM-1	USGS
ER-5-4#2	USGS
ER-5-4 peizometer	USGS
ER-5-4 main	USGS
ER-5-3#3	USGS
ER-5-3#2	USGS
ER-5-3 shallow peizometer	USGS
ER-5-3 main	USGS
ER-5-3 deep peizometer	USGS

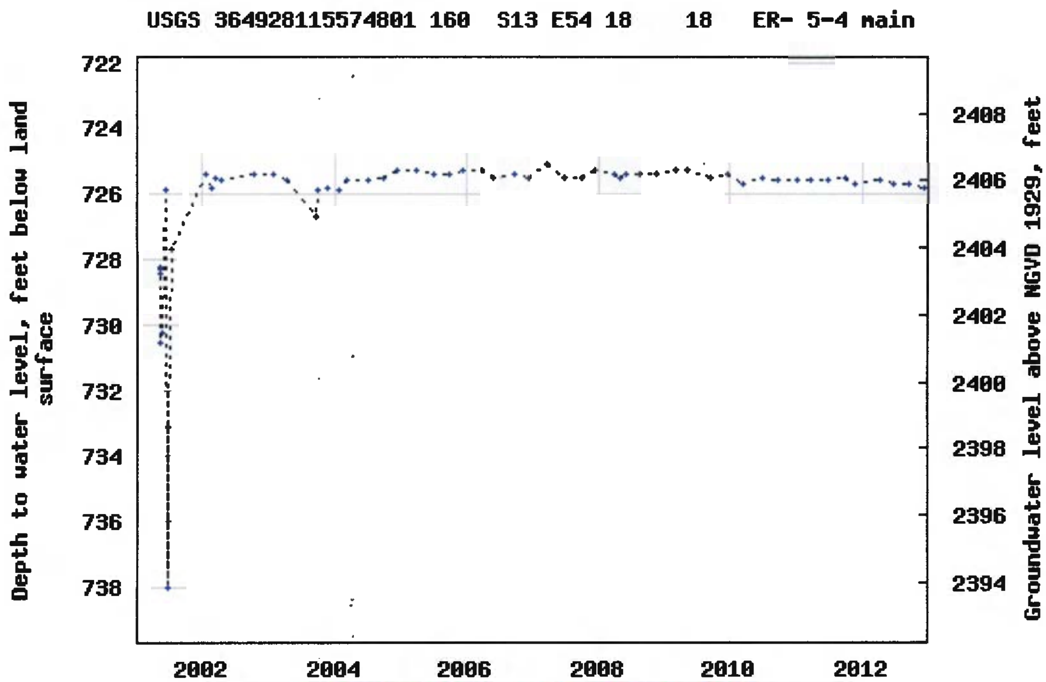

Figure 2. Water-level Data from NWIS for ER-5-4 Main [http://nevada.usgs.gov/doe_nv/sitepage_temp.cfm?site_id=364928115574801]

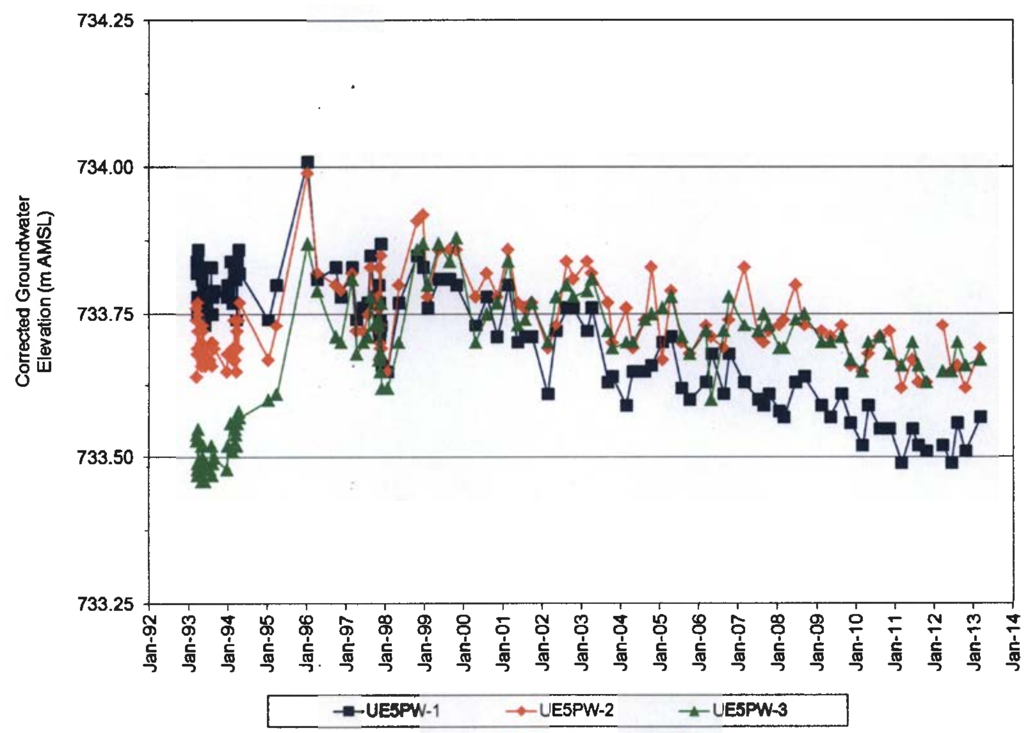

Figure 3. Water-level Data from Area 5 RWMC Pilot Wells (Hudson, 2013)

Overall Water-Level Measurement Accuracy

Water levels in Frenchman Flat are quite similar due to the low hydraulic gradient, making interpretations challenging. The accuracy of the land-surface elevation is only one of the factors limiting the interpretation of water levels. Additional factors include borehole deviation and changes in water density due to temperature (Elliot and Fenelon, 2010). Bright et al. (2001) analyzed these factors for water levels in Frenchman Flat and found that corrections in Frenchman Flat basin were less than 0.2 meters (m) (0.65 feet [ft]). NSTec monitored the pilot wells associated with the RWMC and applied corrections for Wells UE5PW-1, UE5PW-2, and UE5PW-3 of -0.08, -0.12, and -0.02 m (-0.27, -0.68, and -0.06 ft), respectively (Bechtel Nevada, 2005). The largest observed difference in head between the pilot wells was approximately 0.07 m (0.25 ft) for wells about a mile apart.

The following comments about water-level accuracy are from the 2005 Bechtel Nevada report:

> "It should be emphasized that the error in the deviation logs may be equal to or greater than the differences in the uncorrected water table elevations. For example, data from the manufacturer and operator of the deviation tool (Century Geophysics Corporation) indicate that the error in the corrected depth provided by this tool is ±0.15 m (±0.5 ft). This error is as large as the difference observed between water table elevations. In addition, estimated errors arising from the use of a water level measurement tape are on the order of ±0.03 m (±0.1 ft), and the error associated with surveying of casing elevations is probably somewhat less. Because of these uncertainties, it is only reasonable to conclude that differences in water table elevations are within the error of measurement." (p. 4-15)

The USGS does not correct water levels for borehole deviation if the magnitude of the correction is less than 0.5 ft (Elliott and Fenelon, 2010):

> "Corrections less than 0.5 ft were not applied to water levels because at depths exceeding 1,000 ft for water levels in many wells on the NTS the uncertainty in the deviation correction can be as great or greater than the magnitude of the correction." (p.4)

Elliot and Fenelon (2010) also comment on the general accuracy of DTW measurements:

> "Periodic water-level measurements in the water-level database primarily were made by USGS or private contracting agencies working at the NTS using calibrated electric tapes, calibrated electric-cable units (also known as iron-horse and wire-line devices), and less commonly, a steel tape, fluid-density geophysical log, airline, float recorder, pressure transducer, and pressure gage. Most water-level measurements prior to 1996 were made with an electric-cable unit (Garber and Koopman, 1968), whereas more recent measurements typically were made using electric tapes. The tapes and cable units are calibrated annually at different water-level depths with a USGS steel reference tape. At the time of measurement, a correction factor is applied to the depth-to-water reading based on the annual calibration. Post-1995 measurements using electric tapes generally are more accurate (±0.1 ft) than older measurements using electric-cable units or other methods (±0.5–1 ft)" (p.4)

In the Phase II Hydrologic Data Document (SNJV, 2004), the estimated uncertainty in water levels due to measurement accuracy (0.03 m/0.1 ft), barometric effects (0.3 m/1 ft), and borehole deviation (0.02 m/0.06 ft) totaled 0.35 m for the Frenchman Flat wells-- a number considerably greater than even the lowest survey accuracy thought to exist (as much as 0.2 ft) in Frenchman Flat. In 2004, Stoller-Navarro Joint Venture (SNJV) personnel measured elevation via the Global Positioning System (GPS) and took

DTW measurements. These data were reported by SNJV (2006). Even though there were minor changes in land-surface elevation from these differential GPS measurements, it was concluded that "the new ground-surface elevation data do not change any of the discussion found in the Frenchman Flat hydrologic data document regarding flow direction in these three aquifers." (p. A-4) If there is an error in land surface, it is systematic; inferred flow directions remain the same.

Summary and Conclusions

NNSA/NSO's letter to NDEP requesting model acceptance states that a long-term, water-level monitoring program will be implemented; however, a *de facto* program already exists at the USGS (selected wells) and NSTec (the pilot wells associated with the RWMC) quarterly monitoring.

It is the professional opinion of NSTec personnel that the survey accuracy of 14 of the wells cannot be improved. Insufficient survey documentation exists for nine of the wells, necessitating their being resurveyed. Given the ability to measure, at best, ±0.1 ft differences, the uncertainty inherent in the corrections, in the overall uncertainty in water levels, and in the low groundwater velocity does not warrant performing a high-resolution resurvey. Future trends can still be accurately defined because of this capability to measure so precisely. The USGS and NSTec have been measuring water levels in Frenchman Flat quarterly since the early 2000s, using procedures they have standardized. Therefore, a program has already been established. The requirement in the CADD/CAP can reasonably be satisfied with current work that can be supplemented with the resurvey of nine wells. The CAU Lead recommends reviewing these facts with NDEP and, with their concurrence, developing a path forward that documents this conclusion. This could be done with a Record of Technical Change or other clear statement of NDEP approval. The current water-level monitoring program also needs to continue as stated in the CADD/CAP.

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Navarro-Intera Geographic Information Systems. 2012. ESRI ArcGIS Software.

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NEVADA DIVISION OF ENVIRONMENTAL PROTECTION
protecting the future for generations

STATE OF NEVADA
Department of Conservation & Natural Resources
DIVISION OF ENVIRONMENTAL PROTECTION

Brian Sandoval, Governor
Leo M. Drozdoff, P.E., Director
Colleen Cripps, Ph.D., Administrator

ERD.140211.0003

February 11, 2014

Mr. Robert F. Boehlecke
Manager
Environmental Management Operations
National Nuclear Security Administration
Nevada Field Office
P.O. Box 98518
Las Vegas, Nevada 89193-8518

RE: Request for Approval That Requirements Have Been Met to Re-Survey Wells in Corrective Action Unit (CAU) 98: Frenchman Flat
Federal Facility Agreement and Consent Order

Dear Mr. Boehlecke:

The Nevada Division of Environmental Protection, Bureau of Federal Facilities staff (NDEP) has received and reviewed the above-referenced letter and enclosure. The NDEP is aware that the CAU 98: Frenchman Flat Corrective Action Decision Document/Corrective Action Plan (CADD/CAP) required actions that were described in Section 4.5.3, Water-Level Measurement Program, of the CADD/CAP.. As part of this program, a high precision re-survey of the wells in Frenchman Flat was to be completed prior to the establishment of a long-term monitoring program.

The above-referenced letter included a memorandum addressing the NNSA/NFO's approach to the re-survey and a discussion on how the NNSA/NFO believes this requirement has been fulfilled. While the NDEP is in agreement that the accuracy of fourteen (14) of twenty-three (23) Frenchman Flat wells cannot be improved through re-surveying, the following three questions/comments were generated from the review of the letter and memorandum:

1. For the nine (9) wells that were re-surveyed, a comparison should be included listing the "old" and "new" measurements.

2. It should be stated how the requirement of "a permanent data point on each of the well casings will be established as a reference for future measurements" was completed. This requirement is listed in the last sentence of the first paragraph in Section 4.5.3 of the Frenchman Flat CADD/CAP.

3. After review of a draft of the memorandum in August 2013, the NDEP made the following comment which was not addressed in the final memorandum attached to the above-referenced letter: In regards to the **Water-Level Measurement Frequency** section on Page 3, the reader has to look very closely at Figures 2 and 3 to observe the sampling frequency, which appears to be quarterly for the USGS wells and twice a year for the NSTec wells. It was stated in a meeting on February 6, 2014 with NNSA/NFO and NDEP personnel that the text would be revised and the figures would be landscaped and placed on separate pages to increase the clarity.

The NDEP requests that after the above questions/comments are addressed, the NNSA/NFO resubmit the above-referenced letter with an amended memorandum.

If you have questions regarding this matter, please contact Chris Andres of my staff at (702) 486-2850 ext. 232.

Sincerely

/s/ Chris Andres for

T. H. Murphy
Chief
Bureau of Federal Facilities

THM/CDA

ec: EM Records, AMEM, Las Vegas, NV (1 electronic copy, 1 hard copy)
N-I Central Files, MS NSF 156, Las Vegas, NV

cc: FFACO Group, PSG, NNSA/NFO, Las Vegas, NV
J. T. Fraher, DTRA/CXTS, Kirkland AFB, NM
NSTec Correspondence Control. MS NLV008, Las Vegas, NV
W. R. Wilborn, ERP, NNSA/NFO, Las Vegas, NV
K.S. Knapp, EMOS, NNSA/NFO, Las Vegas, NV
Bimal Mukhopadhyay, EMO, NNSA/NFO, Las Vegas, NV

Department of Energy
National Nuclear Security Administration
Nevada Field Office
P.O. Box 98518
Las Vegas, NV 89193-8518

JUN 20 2014

Christine Andres, Chief
Bureau of Federal Facilities
Division of Environmental Protection
2030 East Flamingo Road, Suite 230
Las Vegas, NV 89119-0818

REQUEST FOR APPROVAL THAT REQUIREMENTS HAVE BEEN MET TO RE-SURVEY WELLS IN CORRECTIVE ACTION UNIT (CAU) 98: FRENCHMAN FLAT

In correspondence dated February 11, 2014, the Nevada Division of Environmental Protection (NDEP), Bureau of Federal Facilities staff provided three questions/comments concerning the re-survey of nine (9) wells in Frenchman Flat. The National Nuclear Security Administration Nevada Field Office (NNSA/NFO) has addressed each of the three concerns as indicated below:

1. For the nine (9) wells that were re-surveyed, a comparison should be included listing the "old" and "new" measurements. *Refer to the United States Geological Survey (USGS) memo, Attachment 1, for the comparison.*

2. It should be stated how the requirement of "a permanent data point on each well casing will be established as a reference for future measurements" was completed. This requirement is listed in the last sentence of the first paragraph in Section 4.5.3 of the Frenchman Flat Corrective Action Decision Document/Corrective Action Plan (CADD/CAP). *Refer to the USGS memo, Attachment 1, for how a permanent data point was established.*

3. After review of the draft memorandum in August 2013, the NDEP made the following comment which was not addressed in the final memorandum attached to the above-referenced letter: In regards to the **Water-Level Measurement Frequency** section Page 3, the reader has to look very closely in Figures 2 and 3 to observe the sampling frequency, which appears to be quarterly for the USGS wells and twice a year for the National Security Technologies (NSTec) wells. It was stated in a meeting on February 6, 2014 with NNSA/NFO and NDEP personnel that the text would be revised and the figures would be landscaped and placed on separate page to increase the clarity. *Refer to the Navarro-Intera (N-I) memo, Attachment 2, that contains the revised text and figures that are more legible and easier for the reader to discern the sampling frequency.*

If NDEP agrees that the re-survey work has been completed and documentation of the work is acceptable, NNSA/NFO requests NDEP approval that the intent of the current language in the Frenchman Flat CADD/CAP has been met.

Please direct comments and questions to Bill Wilborn, of my staff at (702) 295-3188.

/s/ Wilhelm R. Wilborn

for Robert F. Boehlecke, Manager
Environmental Management Operations

EMO:10619.CD
ADM 16.1.5.6

Enclosures:
As stated

cc w/encl. via email:
J. T. Fraher, DTRA/CXTS
N-I Central Files
NSTec Correspondence Control
K. S. Knapp, NFO
W. R. Wilborn, NFO
FFACO Group, NFO
NNSA/NFO Read File

Attachment 1

United States Department of the Interior
U. S. GEOLOGICAL SURVEY
Nevada Water Science Center
160 North Stephanie Street
Henderson, NV 89074-8829
(702) 564-4608

MEMORANDUM

June 18, 2014

TO: Bill R. Wilborn, UGTA Activity Lead, Environmental Management Operations, National Nuclear Security Administration, Nevada Field Office

CC: Kathryn Knapp, UGTA Task Manager, Environmental Management Operations, National Nuclear Security Administration, Nevada Field Office

FROM: Steve Reiner, Hydrologist, USGS, Henderson, Nevada

Nicole DeNovio, PhD, Associate Hydrogeochemist / Hydrogeologist, Golder Associates Inc.

SUBJECT: FY2013, Frenchman Flat Well Re-Survey. Well Sites ER-5-3, ER-5-3-2, ER-5-3-3, ER-5-4, ER-5-4-2, ER-5-5, ER-11-2, UE-5 PW#1 and UE-5 PW#3.

Establishment of permanent data points as references for future water-level measurements and determining the effects of establishing these permanent data points on previously collected and calculated water-level measurements, Frenchman Flat, Nevada National Security Site.

During September 2013, permanent data points were established by NSTec as references for future well measurements at nine well sites in Frenchman Flat (Attachment 1). At seven well sites (ER-5-3, ER-5-3-2, ER-5-3-3, ER-5-4, ER-5-4-2, ER-5-5, and ER-11-2), a location on the wellhead was selected as a permanent reference point representing land-surface elevation. A 7/8-inch angle iron was welded on the wellhead at this permanent reference point and the angle iron elevation surveyed using global positioning system leveling.

At two well sites in Frenchman Flat (UE-5 PW#1 and UE-5 PW#3), a location near the wellhead was selected as a permanent reference point representing land-surface elevation. A location on the well head was not selected as a permanent reference point because the wellheads were located inside of enclosed structures. The permanent reference point was surveyed using global positioning system leveling.

The northing and easting of the permanent reference points were reported by NSTec in State Plane coordinates (1927) and the datum for their elevations is the National Geodetic Vertical Datum of 1929. Per surveyor calculations, northing and easting errors range from 0.003 to 0.051 foot and elevation errors range from 0.005 to 0.076 foot.

Previous horizontal locations for the nine well sites were compared to results from the September 2013 survey (Attachment 2, table 1). The maximum change in horizontal location as a result of the 2013 survey was 2.5 feet.

The surveyed land-surface elevations of the newly established permanent reference points were used to recalculate measuring point heights, water levels below land surface, and water-level altitudes for National Water Information System (NWIS) data previously collected at the nine well sites (Attachment 2, table 2). Changes in water-surface altitude ranged from -0.04 to 0.81 feet compared to previous reference elevation values used in NWIS.

Land-surface elevations used for the Corrective Action Investigation (CAI) of Frenchman Flat were initially summarized by Stoller-Navarro Joint Venture in the Hydrologic data document in 2004. These values were updated when new land-surface data became available in 2006 (SNJV, 2006) and used to establish the calibration data set for the CAI groundwater flow model (SNJV, 2006 and NNES, 2010). Attachment 3, Table 1 provides a comparison of the ground-surface surveys and the differences between the best available reference elevation data and previously published CAI documents. The improved 2013 survey data do not substantively influence the CAI interpretations of groundwater flow directions or the magnitude of groundwater gradients.

Diagrams describing the location and elevation of the measuring point, reference point, and land surface elevation for wells at the nine well sites were compiled to clarify the recalculations and avoid future inconsistencies (Attachment 1). These diagrams and spreadsheets of pre- and post-survey measurements and calculations can be found on the UGTA Document Center/Technical Data Repository (DC/TDR) under document UGTA-4-1027, which was uploaded to the DC/TDR March 21, 2014.

References

Navarro Nevada Environmental Services, LLC. 2010. Phase II Transport Model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada, Rev. 1, N-I/28091--004, S-N/99205--122. Las Vegas, NV.

Stoller-Navarro Joint Venture. 2004. Phase II Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 98: Frenchman Flat, Nevada, Rev. 0, S-N/99205--032. Las Vegas, NV.

Stoller-Navarro Joint Venture. 2006. Phase II Groundwater Flow Model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada, S-N/99205--074. Las Vegas, NV.

ATTACHMENT 1: WELL DIAGRAMS

USGS well name: ER- 5-3 main (upper zone)   **USGS site number:** 365223115561701

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
773,577.871	713,137.224	36°52'23.12695" N	115°56'16.74717" W

Source: NSTec survey, September 2013

Photo of well head, north side, February 2014

	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	3.37	3,338.47	01/14/2002-present
Reference point	0.0	3,335.10	09/30/2013-present
Land surface	--	3,335.10	03/16/2000-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 3-inch inch stainless steel tubing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

Reference point description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-3 deep piezometer **USGS site number:** 365223115561702

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
773,577.871	713,137.224	36°52'23.12695" N	115°56'16.74717" W

Source: NSTec survey, September 2013

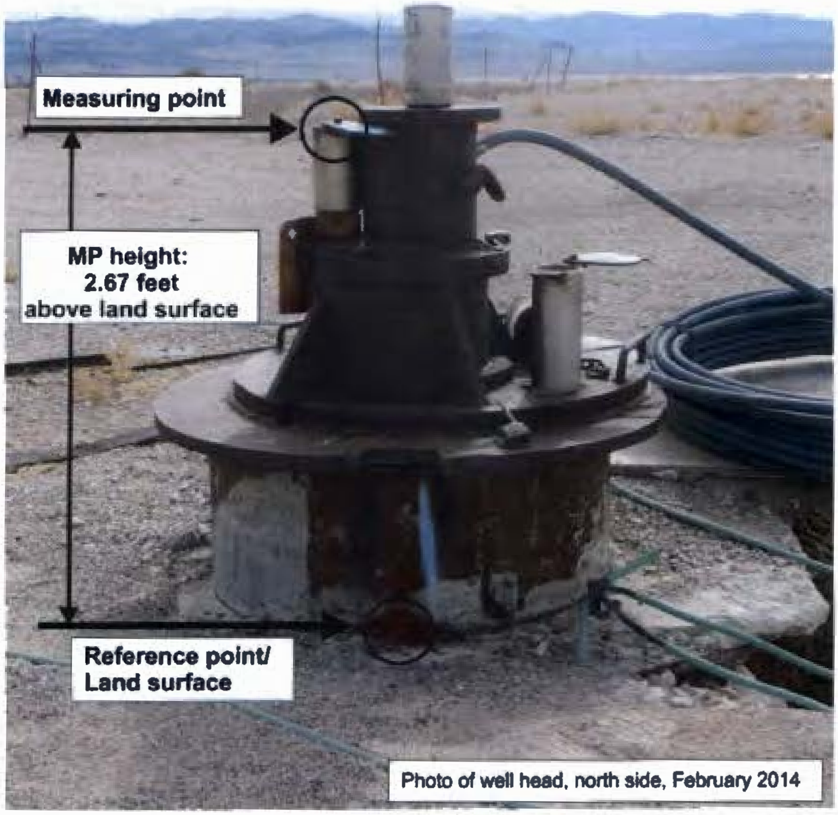


Photo of well head, north side, February 2014

	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	2.67	3,337.77	03/02/2001-present
Reference point	0.0	3,335.10	09/30/2013-present
Land surface	--	3,335.10	03/16/2000-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 2.875-inch stainless steel casing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

Reference point description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-3 shallow piezometer **USGS site number:** 365223115561703

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
773,577.871	713,137.224	36°52'23.12695" N	115°56'16.74717" W

Source: NSTec survey, September 2013

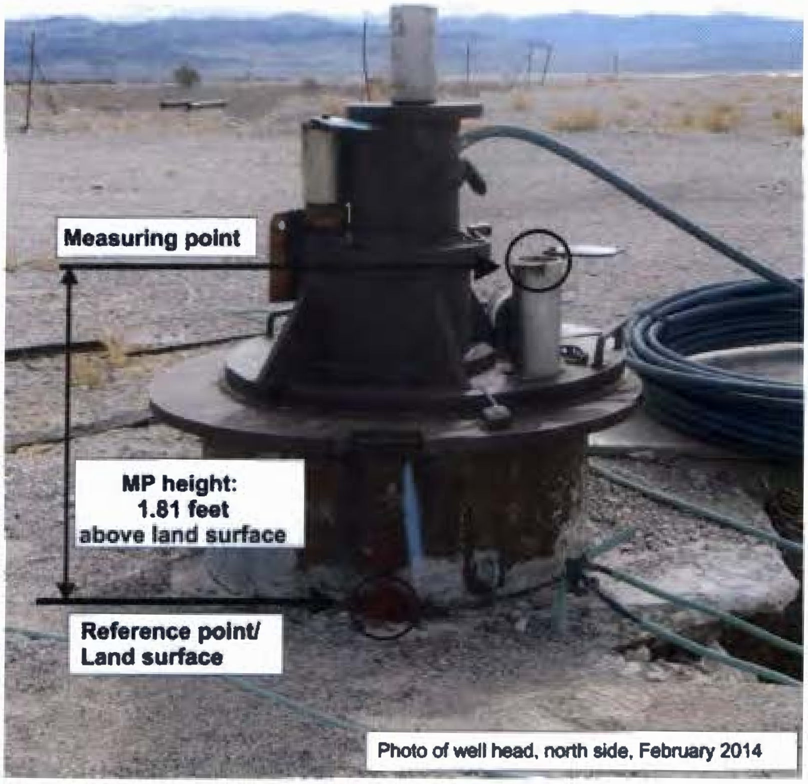


Photo of well head, north side, February 2014

	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	1.81	3,336.91	12/06/2000-present
Reference point	0.0	3,335.10	09/30/2013-present
Land surface	--	3335.10	03/16/2000-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 2.875-inch stainless steel casing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

Reference point description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-3-2 **USGS site number:** 365223115561801

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
773,585.773	713,036.918	36°52'23.21266" N	115°56'17.98088" W

Source: NSTec survey, September 2013

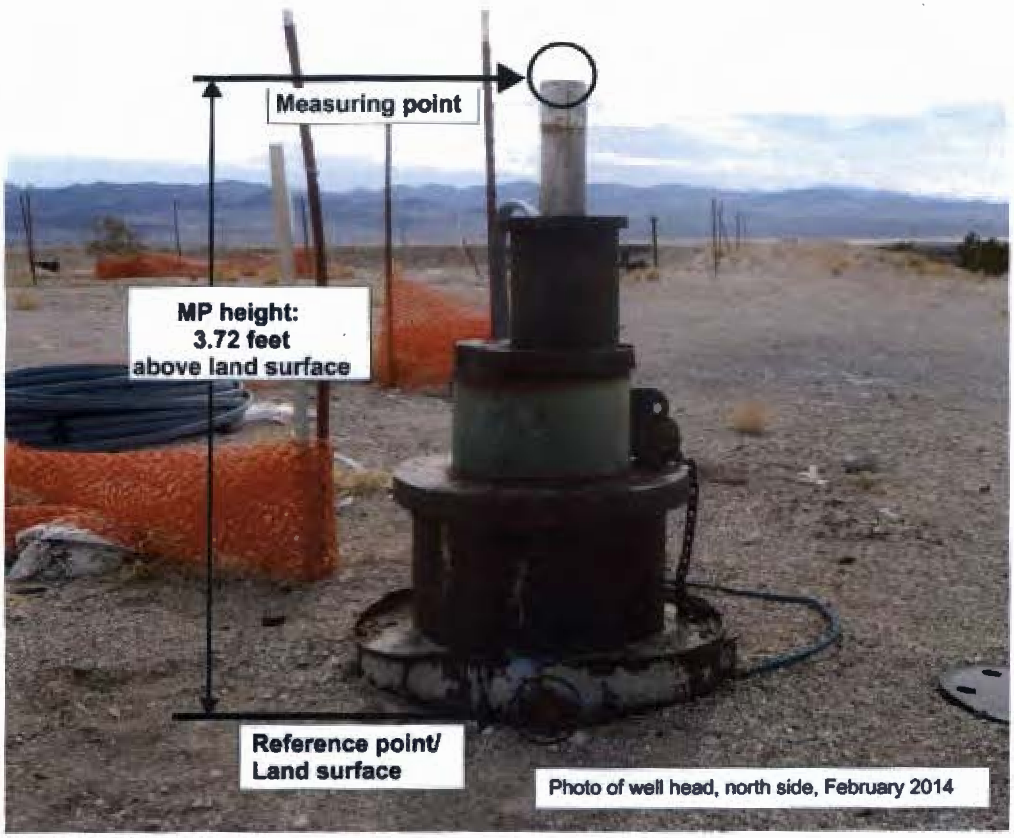


Photo of well head, north side, February 2014

	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	3.72	3,338.89	05/18/2001-present
Reference point	0.0	3,335.17	09/30/2013-present
Land surface	--	3,335.17	05/19/2000-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 2.875-inch stainless steel tubing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

Reference point description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-3-3 **USGS site number:** 365223115561704

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
773,667.871	713,094.100	36°52'24.02013" N	115°56'17.26944" W

Source: NSTec survey, September 2013

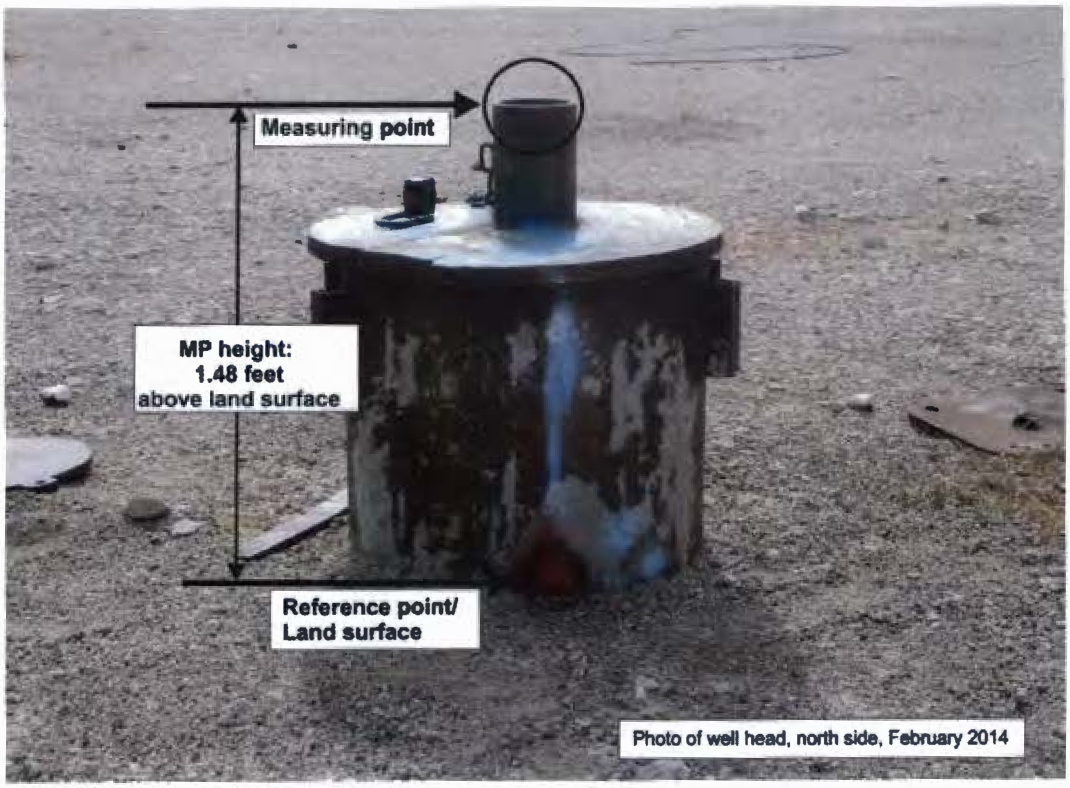


Photo of well head, north side, February 2014

	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	1.48	3,336.62	02/21/2001-present
Reference point	0.0	3,335.14	09/30/2013-present
Land surface	--	3,335.14	02/06/2001-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 2.875-inch carbon steel casing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

Reference point description: 1-inch angle iron welded onto the 16-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the16-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-4 main **USGS site number:** 364928115574801

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
755,749.170	705,818.635	36°49'27.37699" N	115°57'48.43179" W

Source: NSTec survey, September 2013

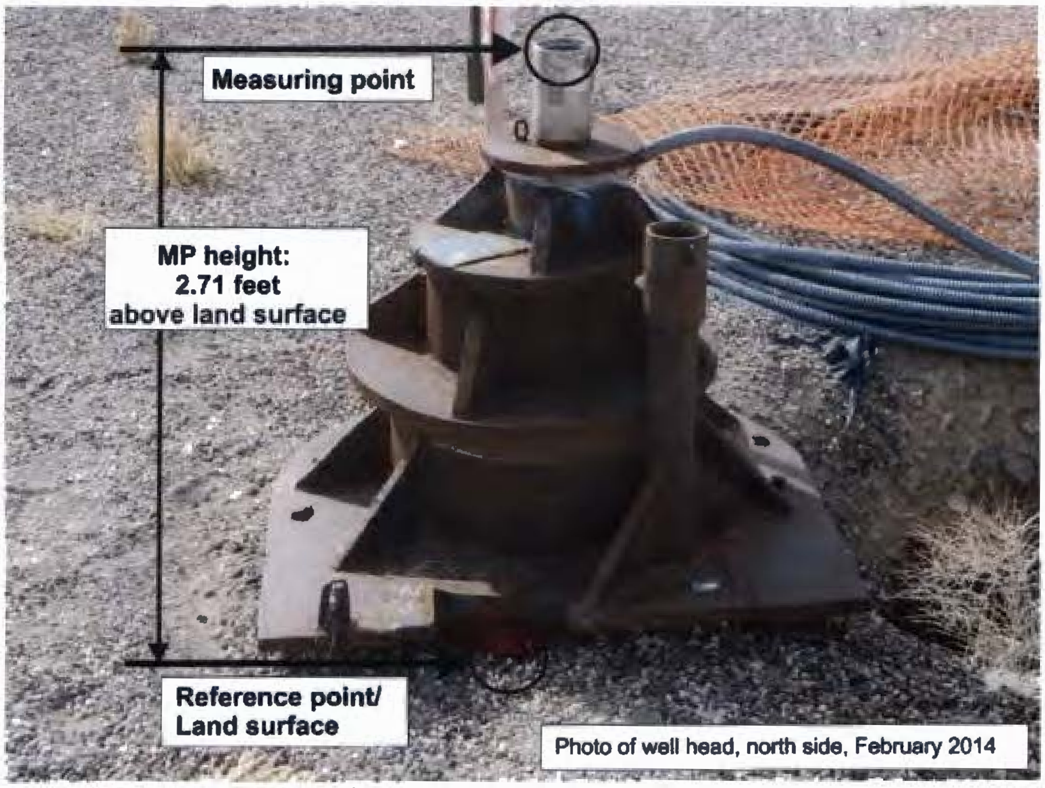


Photo of well head, north side, February 2014

	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	2.71	3,134.41	09/29/2003-present
Reference point	0.0	3,131.70	09/30/2013-present
Land surface	--	3,131.70	03/31/2001-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 3-inch stainless steel tubing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

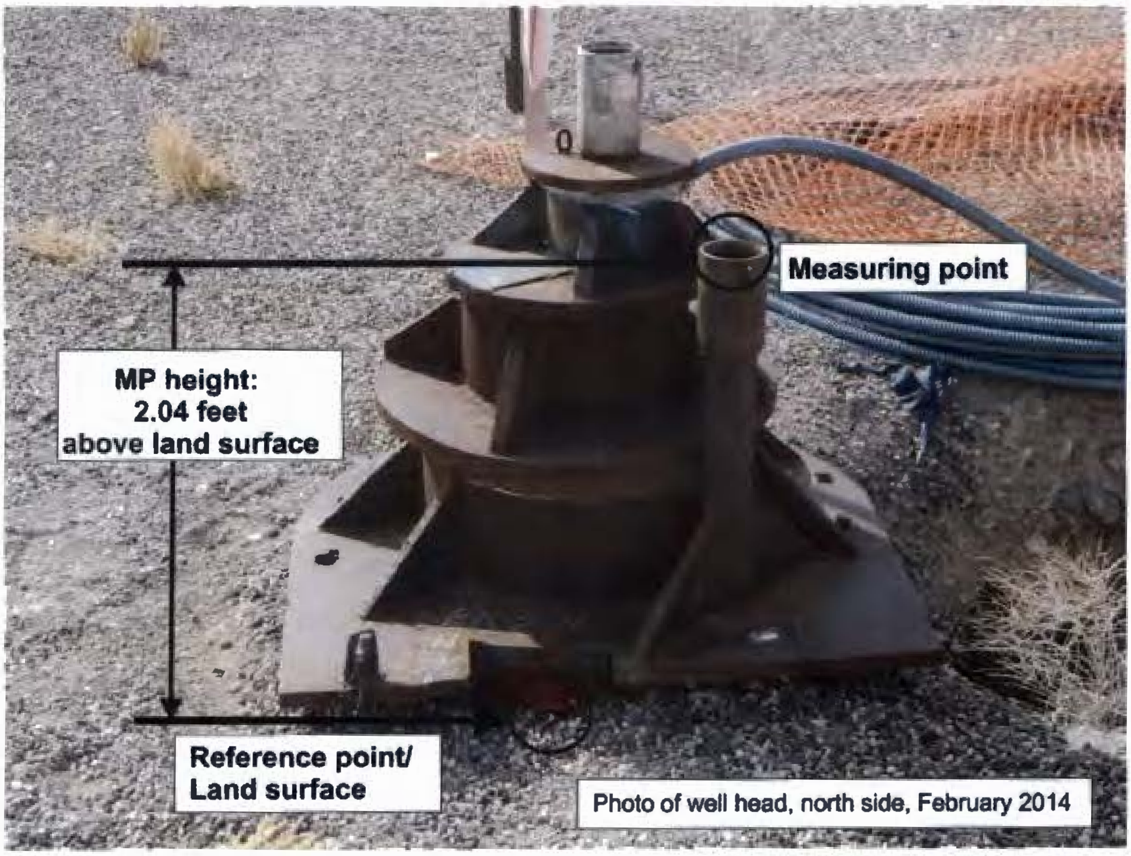
Reference point description: 1-inch angle iron welded onto the 36-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 36-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-4 piezometer **USGS site number:** 364928115574802

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
755,749.170	705,818.635	36°49'27.37699" N	115°57'48.43179" W

Source: NSTec survey, September 2013



	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	2.04	3,133.74	05/06/2001-present
Reference point	0.0	3,131.70	09/30/2013-present
Land surface	--	3,131.70	03/31/2001-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 3.6-inch steel coupling on 2.875-inch carbon steel casing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

Reference point description: 1-inch angle iron welded onto the 36-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 36-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-4-2 **USGS site number:** 364927115574801

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
755,649.031	705,818.348	36°49'26.38682" N	115°57'48.44438" W

Source: NSTec survey, September 2013

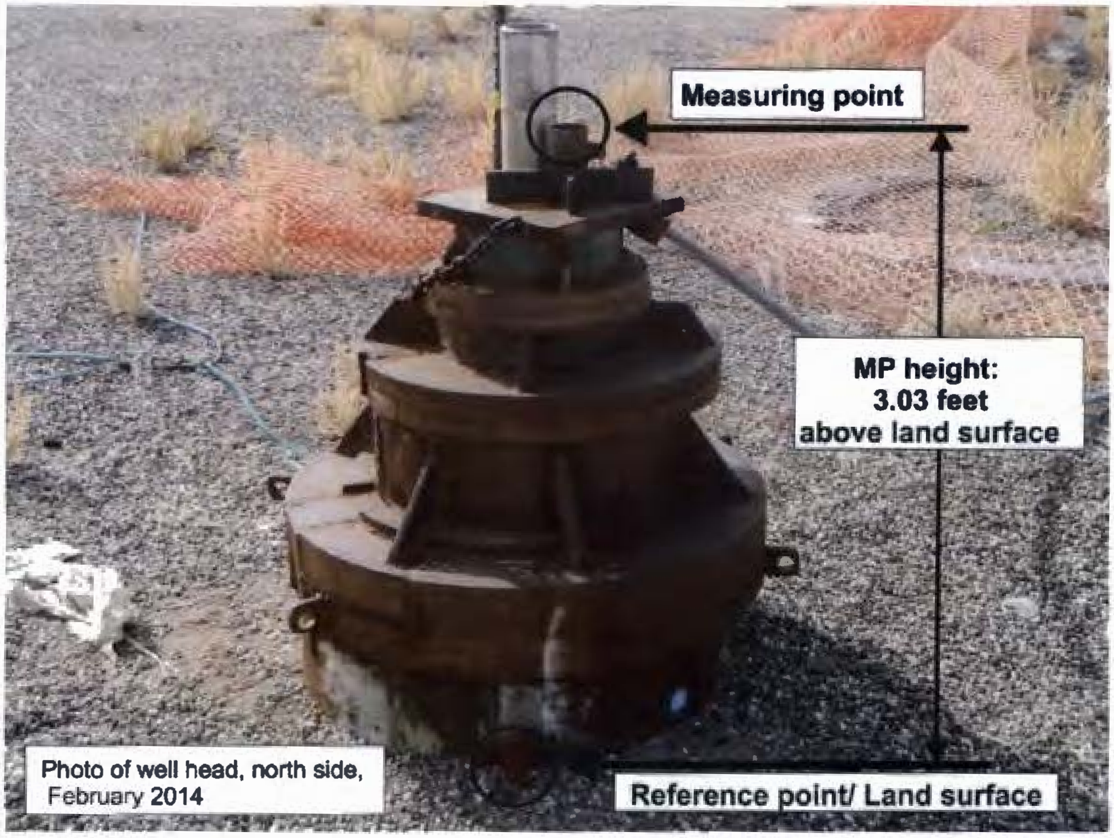


Photo of well head, north side, February 2014

	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	3.03	3,134.80	03/12/2003-present
Reference point	0.0	3,131.77	09/30/2013-present
Land surface	--	3,131.77	09/18/2002-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 2.375-inch carbon steel tubing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

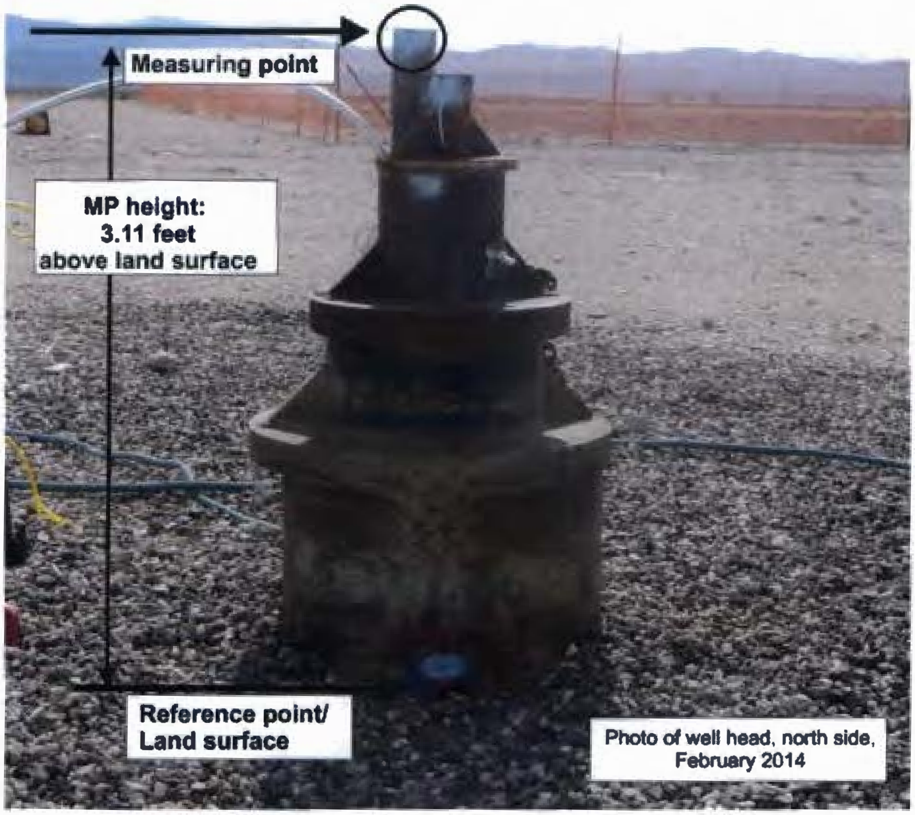
Reference point description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 30-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER- 5-5 piezometer **USGS site number:** 365212115554901

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
772,504.875	715,397.112	36°52'12.34568" N	115°55'49.03681" W

Source: NSTec survey, September 2013



	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	3.11	3,340.38	08/28/2012-present
Reference point	0.0	3,337.27	09/30/2013-present
Land surface	--	3,337.27	08/12/2012-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 2.875- inch carbon steel casing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

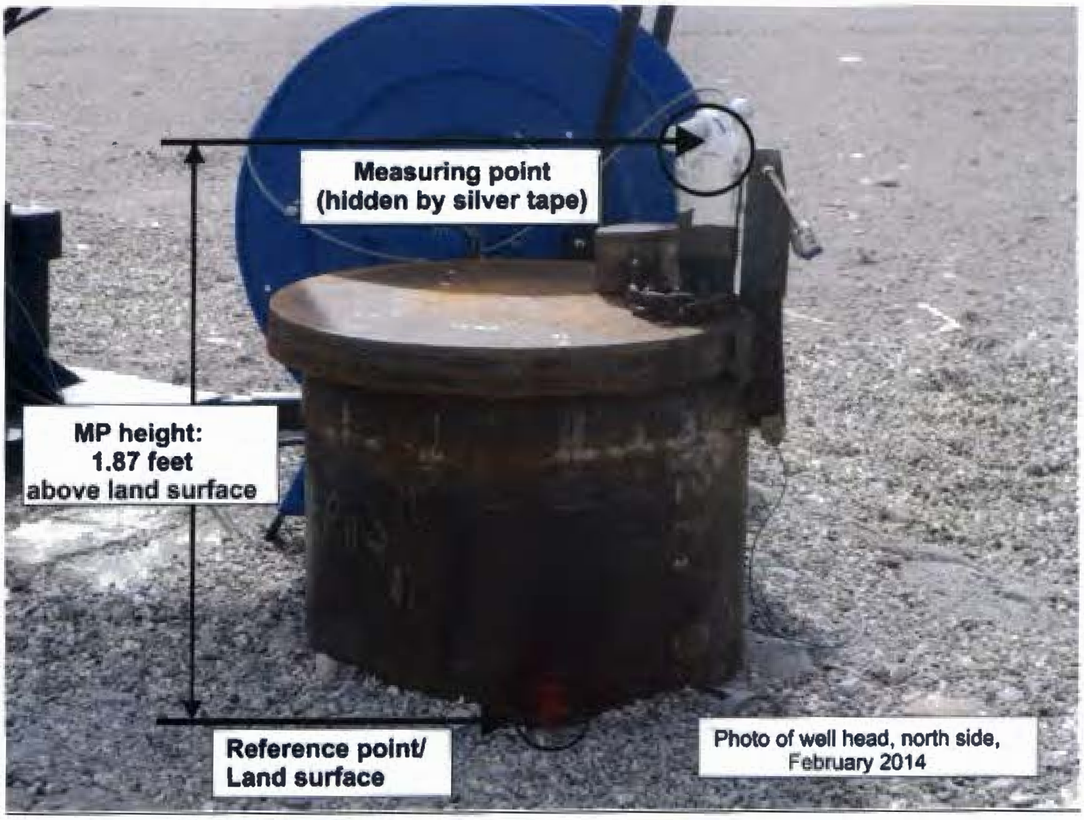
Reference point description: 1-inch angle iron welded onto the 20-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

Land surface description: 1-inch angle iron welded onto the 20-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: ER-11-2 **USGS site number:** 365314115561901

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
778,754.768	712,899.115	36°53'14.33427" N	115°56'19.19170" W

Source: NSTec survey, September 2013



	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	1.87	3,575.09	08/28/2012-present
Reference point	0.0	3,573.22	09/30/2013-present
Land surface	--	3,573.22	08/23/2012-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 2.375-inch carbon steel casing, north side. Measuring point height established by USGS in January 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates.

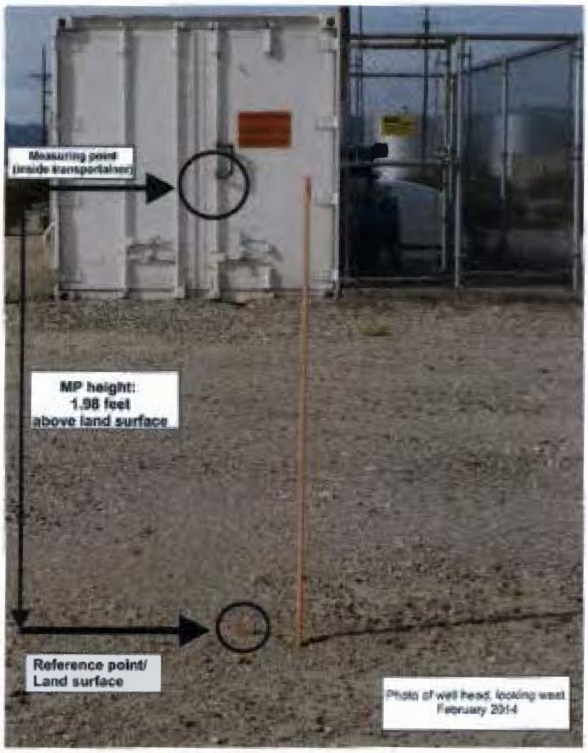
Reference point description: 1-inch angle iron welded onto the 20-inch conductor casing, north side. Reference point established and elevation surveyed in September 2013.

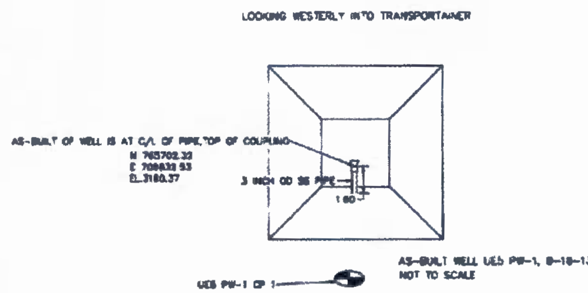
Land surface description: 1-inch angle iron welded onto the 20-inch conductor casing, north side. Land surface established and elevation surveyed in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates.

USGS well name: UE-5PW-1 **USGS site number:** 365105115565801

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
765,702.32	709,832.53	36°51'05.50023" N	115°56'58.14564" W

Source: NSTec survey, September 2013 (see figure below).





	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	1.98	3,180.37	03/02/1993-present
Reference point	0.0	3,178.39	09/30/2013-present
Land surface	--	3,178.39	09/29/1992-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 3-inch outer diameter stainless steel pipe, center line. Wellhead is located inside locked transportainer. Measuring point height established by NSTec in February 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates. A distance of 1.60 feet was measured from the transportainer floor to the measuring point in September 2013.

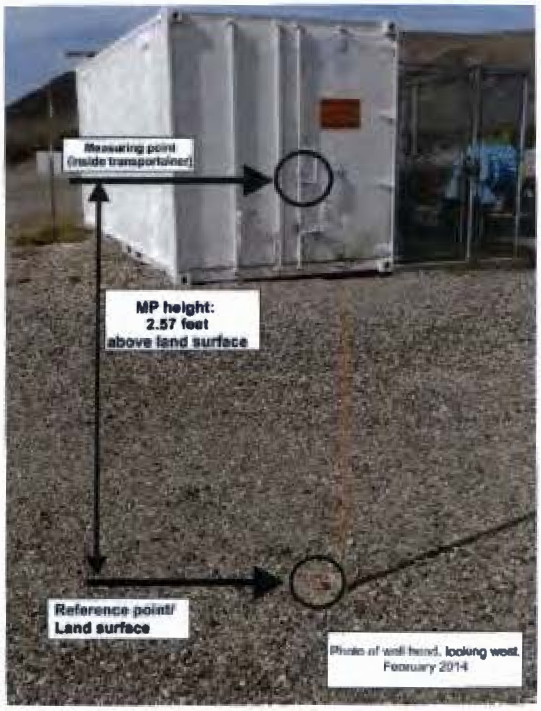
Reference point description: Top of nail driven in wooden stake located about 50 feet west of the well. Reference point is located outside of locked transportainer. Reference point established and elevation surveyed by NSTec in September 2013. NSTec name for the reference point is "UE-5PW-1 CP-1".

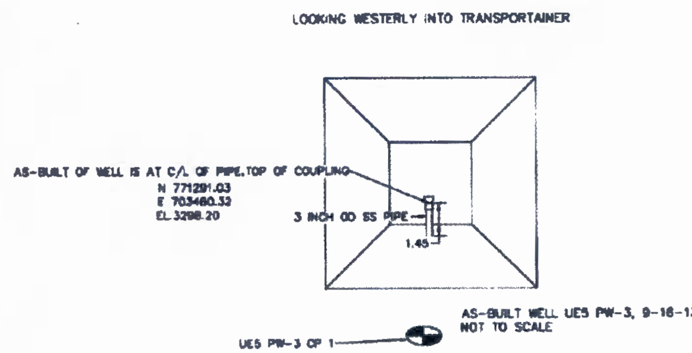
Land surface description: Top of nail driven in wooden stake located about 50 feet west of the well. Land surface established and elevation surveyed by NSTec in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates. NSTec name for reference point is "UE-5 PW-1 CP-1".

USGS well name: UE-5PW-3 **USGS site number:** 365201115581601

U.S. State Plane Coordinate System (1927): Zone 2702		North American Datum of 1927	
Northing (feet)	Easting (feet)	Latitude (degrees-minutes-seconds)	Longitude (degrees-minutes-seconds)
771,291.03	703,460.32	36°52'01.22808" N	115°58'16.04553" W

Source: NSTec survey, September 2013





	Height above land surface (feet)	Elevation (feet) (NGVD29)	Effective dates
Measuring point	2.57	3,298.20	03/02/1993-present
Reference point	0.0	3,295.63	09/30/2013-present
Land surface	--	3,295.63	01/05/1993-present

Vertical datum: National Geodetic Vertical Datum of 1929 (NGVD29)

Measuring point description: Top of 3-inch outer diameter stainless steel pipe, center line. Wellhead is located inside locked transportainer. Measuring point height established by NSTec in February 2014. Measuring point height was used in depth-to-water calculations for measurements collected during the effective dates. A distance of 1.45 feet was measured from the transportainer floor to the measuring point in September 2013.

Reference point description: Top of nail driven in wooden stake located about 35 feet west of the well. Reference point is located outside of locked transportainer. Reference point established and elevation surveyed by NSTec in September 2013. NSTec name for reference point is "UE-5 PW-3 CP-1".

Land surface description: Top of nail driven in wooden stake located about 35feet west of the well. Land surface established and elevation surveyed by NSTec in September 2013. Land-surface elevation applies to all depth-to-water calculations for measurements collected during the effective dates. NSTec name for reference point is "UE-5 PW-3 CP-1".

ATTACHMENT 2: TABLES SHOWING HORIZONTAL LOCATION AND WATER-SURFACE ALTITUDE CHANGE IN FRENCHMAN FLAT AND VICINITY

Table 1. Changes in horizontal location as a result of the September 2013 Frenchman Flat well survey

			Pre-2013 Frenchman Flat survey data		Post-2013 Frenchman Flat survey data		
Well site	**USGS site ID**	**Well name**	**US State Plane 1927 Northing (US survey feet)**	**US State Plane 1927 Easting (US survey feet)**	**US State Plane 1927 Northing (US survey feet)**	**US State Plane 1927 Easting (US survey feet)**	**Change in horizontal location (feet)**
ER-5-3	365223115561701	ER-5-3 main (upper zone)	733577.8	713137.0	773577.871	713137.224	0.23
ER-5-3	365223115561702	ER-5-3 deep	733577.8	713137.0	773577.871	713137.224	0.23
ER-5-3	365223115561703	ER-5-3 shallow	733577.8	713137.0	773577.871	713137.224	0.23
ER-5-3-2	365223115561801	ER-5-3-2	733586.1	713036.7	773585.773	713036.918	0.39
ER-5-3-3	365223115561704	ER-5-3-3	773668.0	713093.7	773667.871	713094.100	0.42
ER-5-4	364928115574801	ER-5-4 main	755751.3	705819.9	755749.170	705818.635	2.48
ER-5-4	364928115574802	ER-5-4 piezometer	755751.3	705819.9	755749.170	705818.635	2.48
ER-5-4-2	364927115574801	ER-5-4-2	755651.2	705819.6	755649.031	705818.348	2.50
ER-5-5	365212115554901	ER-5-5 piezometer	772505.1	715396.9	772504.875	715397.112	0.31
ER-11-2	365314115561901	ER-11-2	778755.2	712898.9	778754.768	712899.115	0.48
UE-5 PW-1	365105115565801	UE-5 PW-1	765702.33	709831.50	765702.32	709832.53	1.03
UE-5 PW-3	365201115581601	UE-5 PW-3	771290.83	703459.75	771291.03	703460.32	0.60

Pre-2013 Frenchman Flat Survey State Plane coordinates for ER wells compiled from USDOE well completion reports. Pre-2013 Frenchman Flat Survey State Plane coordinates for UE-5 PW wells compiled from Raytheon Services Nevada well completion diagrams.

Table 2. Changes in water-surface altitude as a result of the September 2013 Frenchman Flat well survey

			Pre-2013 Frenchman Flat survey data			Post-2013 Frenchman Flat survey data			
Well site	**USGS site ID**	**Well name**	**Measuring point height (feet)**	**Land surface altitude (feet)**	**Measuring point altitude (feet)**	**Measuring point height (feet)**	**Land surface altitude (feet)**	**Measuring point altitude (feet)**	**Change in water-surface altitude (feet)**
ER-5-3	365223115561701	ER-5-3 main (upper zone)	3.43	3,334.30	3,337.73	3.37	3,335.10	3,338.47	0.74
ER-5-3	365223115561702	ER-5-3 deep	2.89	3,334.30	3,337.19	2.67	3,335.10	3,337.77	0.58
ER-5-3	365223115561703	ER-5-3 shallow	1.83	3,334.30	3,336.13	1.81	3,335.10	3,336.91	0.78
ER-5-3-2	365223115561801	ER-5-3-2	3.78	3,334.30	3,338.08	3.72	3,335.17	3,338.89	0.81
ER-5-3-3	365223115561704	ER-5-3-3	1.52	3,334.60	3,336.12	1.48	3,335.14	3,336.62	0.50
ER-5-4	364928115574801	ER-5-4 main	2.71	3,131.70	3,134.41	2.71	3,131.70	3,134.41	0.00
ER-5-4	364928115574802	ER-5-4 piezometer	2.08	3,131.70	3,133.78	2.04	3,131.70	3,133.74	-0.04
ER-5-4-2	364927115574801	ER-5-4-2	3.02	3,131.70	3,134.72	3.03	3,131.77	3,134.80	0.08
ER-5-5	365212115554901	ER-5-5 piezometer	3.17	3336.90	3,340.07	3.11	3337.27	3,340.38	0.31
ER-11-2	365314115561901	ER-11-2	1.98	3,573.00	3,574.98	1.87	3,573.22	3,575.09	0.11
UE-5 PW-1	365105115565801	UE-5 PW-1	2.11	3178.24	3,180.35	1.98	3,178.39	3,180.37	0.02
UE-5 PW-3	365201115581601	UE-5 PW-3	2.35	3295.62	3,297.97	2.57	3,295.63	3,298.20	0.23

Water-surface altitude changes range from -0.04 feet (ER-5-4 piezometer), to 0.81 feet (ER-5-3-2). With the exception of two wells, all changes resulted in higher water-surface altitudes. Change in ER-5-4 piezometer resulted in a lower water-surface altitude and there was no change in water-surface altitude for well ER-5-4 main.

ATTACHMENT 3: TABLE SHOWING COMPARISON OF GROUND-SURFACE ELEVATION SURVEYS FOR WATER-LEVEL MONITORING WELLS IN FRENCHMAN FLAT AND VICINITY

Attachment 3, Table 1
Comparison of Ground-Surface Elevation Surveys for Water-Level Monitoring Wells in Frenchman Flat and Vicinity

Well Reporting Name	Land-Surface Elevation [a]	Ground-Surface Elevation [b]	2004 SNJV Survey Surface Elevation [b]	2001 BN Survey [c]	2013 NSTec Survey [d]	Best Available	Differences between Best Available	
	(m amsl)			Ground-Surface Elevation (m amsl)			SNJV, 2004	SNJV, 2006
ER 5-3 (3" deep)	1,017.24	1,016.57	1,016.57	--	1,016.54	1,016.54	0.70	0.03
ER 5-3 (3" shallow)	1,017.24	1,016.57	1,016.57	--	1,016.54	1,016.54	0.70	0.03
ER 5-3 (main)	1,017.24	1,016.57	1,016.57	--	1,016.54	1,016.54	0.70	0.03
ER 5-3 #2	1,017.24	1,016.58	1,016.58	--	1,016.56	1,016.56	0.68	0.02
ER 5-3 #3	1,017.24	1,016.58	1,016.58	--	1,016.55	1,016.55	0.69	0.03
ER 5-4 (main)	954.54	954.58	954.58	--	954.54	954.54	0.00	0.04
ER 5-4 (piezometer)	954.54	954.58	954.58	--	954.54	954.54	0.00	0.04
ER 5-4 #2	954.54	954.62	954.62	--	954.56	954.56	-0.02	0.06
RNM-1	955.6	955.66	955.66	955.60	--	955.60	0.00	0.06
RNM-2	953.66	953.63	953.63	953.66	--	953.66	0.00	-0.03
RNM-2S	954.16	954.20	954.20	954.09	--	954.09	0.07	0.11
TW-3	1,061.96	--	--	1,061.96	--	1,061.96	0.00	NC
UE-11a	1,078.48	--	--	1,078.48	--	1,078.48	0.00	NC
UE-11b	1,093.01	--	--	--	--	1,093.01	0.00	NC
UE-5 PW-1	968.73	--	--	--	968.77	968.77	-0.04	NC
UE-5 PW-2	989.54	--	--	989.41	--	989.41	0.13	NC
UE-5 PW-3	1,004.50	--	--	--	1,004.51	1,004.51	-0.01	NC
UE-5c WW upper	980.32	--	--	980.32	--	980.32	0.00	NC
UE-5c WW lower	980.32	--	--	980.32	--	980.32	0.00	NC
UE-5f	1,006.09	--	--	1,006.09	--	1,006.09	0.00	NC
UE-5n	948.95	948.99	948.99	948.85	--	948.85	0.10	0.14
WW-1	944.88	--	--	--	--	944.88	0.00	NC
WW-5A	942.97	942.68	942.68	942.63	--	942.63	0.34	0.05
WW-5B	942.83	--	--	942.48	--	942.48	0.35	NC
WW-5C	939.73	939.28	939.28	939.24	--	939.24	0.49	0.04
ER-5-5	Not drilled	Not drilled	Not drilled	Not drilled	1,017.20	1,017.20	--	NC
ER-11-2	Not drilled	Not drilled	Not drilled	Not drilled	1,089.12	1,089.12	--	NC

[a] Table 8-1 (SNJV, 2004)
[b] As reported in Table A.1-1 (SNJV, 2006)
[c] Ortego, 2013a
[d] Ortego, 2013b

amsl = Above mean sea level
BN = Bechtel Nevada
m = Meter
NSTec = National Security Technologies, LLC
SNJV = Stoller-Navarro Joint Venture

N = No
NC = No change from SNJV (2004)
Y = Yes
-- = Not applicable

References:

Ortego, P., National Security Technologies, LLC. 2013a. Personal communication to G. Ruskauff (N-I) regarding the summary report of research on past Frenchman Flat elevation surveys, 1 April. Las Vegas, NV.

Ortego, P., National Security Technologies, LLC. 2013b. Personal communication to G. Ruskauff (N-I) regarding resurvey of nine Frenchman Flat wells, 27 September. Las Vegas, NV.

Stoller-Navarro Joint Venture. 2004. *Phase II Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 98: Frenchman Flat, Nevada*, Rev. 0, S-N/99205--032. Las Vegas, NV.

Stoller-Navarro Joint Venture. 2006. *Phase II Groundwater Flow Model of Corrective Action Unit 98: Frenchman Flat, Nevada Test Site, Nye County, Nevada*, Rev. 0, S-N/99205--074. Las Vegas, NV.

Attachment 2

Navarro-Intera

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Phone: (702) 295-2033 Fax: (702) 295-2025

June 18, 2014

Greg Ruskauff/Frenchman Flat CAU Lead

Frenchman Flat CADD/CAP Survey Requirement Data Review

The NNSA/NSO letter requesting acceptance of the Frenchman Flat flow and transport model dated November 17, 2010 (included as Appendix A in the CADD/CAP), identifies establishing a long-term groundwater monitoring program that includes the following:

1. Resurveying of well head elevations,
2. Developing a standardized protocol for measurements,
3. Measurement of water levels over a short interval, and
4. Routine monitoring of water levels on an established schedule.

The planned approach to fulfill these statements was incorporated into the CADD/CAP.

CADD/CAP Statements of Work (July 2011)

Data collection activities are described in Section 4.5. Section 4.5.3 identifies the currently existing water-level measurement program as a data collection activity. Section 4.5.3 also states that:

> *This work will* (emphasis added) *begin with a high precision resurvey of the wells in Frenchman Flat to precisely determine the coordinates and ground-surface elevation at each well location. In addition, a permanent data point on each of the well casings will be established as a reference for future measurements.*

A review of the status of data needs in support of the NNSA/NFO is presented in the following text, along with a discussion of overall accuracy of the water-level monitoring program and a proposal for further action.

Survey Evaluation Results

The CADD/CAP scope of work was modified to conduct an initial evaluation of survey data because the CAU lead felt it was important to understand the current data quality and lessons learned from past survey efforts. NSTec has delivered their report (including 90 pages of scanned survey notes), and found that:

Mike Keogh, current supervisor of the NSTec Survey group, reviewed the survey notes from the 14 Frenchman Flat well sites resurveyed in 2001. He confirmed that the differential leveling method was used to establish the bench mark altitudes at bench marks listed in Table 1 of the referenced USGS

September 21, 2001 memorandum. This method is still the best survey method to measure elevations with elevation accuracies in the range of 0.01 feet (~1/8 of an inch). There are no new methods or improved survey instruments that would improve elevation accuracy of these wells at this time.

Mr. Keogh also reviewed the most recent survey records of the 9 other Frenchman Flat wells of interest listed below and found that elevations of record at these sites were not established using the differential leveling method. Elevations at these well sites were typically measured at ground level outside the outer most casing or the top of the upper most, smallest casing, using GPS or trigonometric leveling methods. However, there are no documents or survey notes relative to monuments used to measure elevations during the surveys of these 9 wells. The elevation information is believed to be in the 0.1 - 0.2 foot range, but this would have to be confirmed with resurvey using GPS.

Further investigation of the 9 other wells (ER-5-3, ER-5-3#2, ER-5-3#3, ER-5-4, ER-5-4#2, ER-5-5, ER-11-2, UE-5 PW-1, and UE-5 PW-3) revealed insufficient survey documentation, necessitating their resurvey (pending in August). The locations of the two sets of wells are shown in Figure 1.

Navarro-Intera

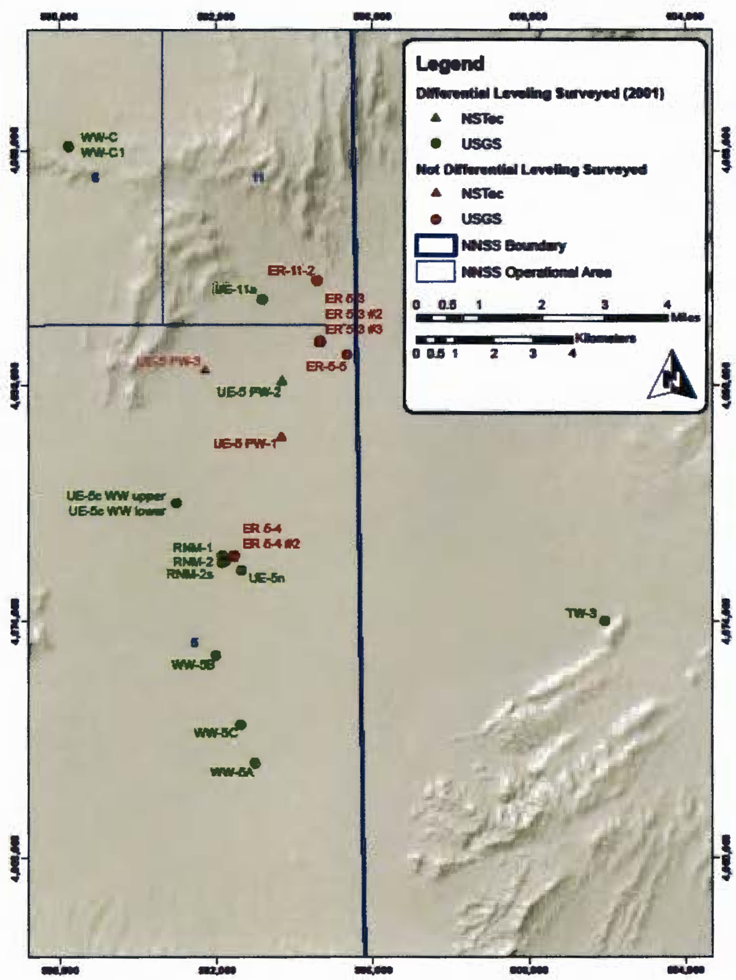

Figure 1 Well location, survey data status, measuring agency

<u>Measurement Protocol</u>

Both the USGS and NSTec have stated that they have a standard protocol for performing depth to water measurement. No further documentation has been requested, but is presumed to be available.

<u>Measurement Period</u>

Data provided by NSTec Radiological Waste Management Complex (RWMC) monitoring show the three pilot wells depth to water are typically taken on the same day. Comparing data collection dates in NWIS suggests that, similarly, data are collected by the USGS over the course of 1 or 2 days. Data collection from the pilot wells is not synchronized with the collection done by USGS. However, given the quarterly measurements over the last decade long-term trends have clearly been established, and there is no need to completely synchronize the two efforts.

Navarro-Intera

Water-Level Measurement Frequency

Appendix A, NNSA/NSO's letter request for model acceptance to NDEP, states that a long-term water-level monitoring program will be implemented. However, a *de facto* one already exists from both the USGS and NSTec (the pilot wells associated with the RWMC) quarterly monitoring. Table 1 lists the wells being monitored in Frenchman Flat. Figure 2, from NWIS (58 data points between May 4, 2001 and March 20, 2013); clearly show the consistency and frequency of USGS data collection for ER-5-4 main, which is representative of the other wells the USGS has been monitoring in Frenchman Flat. Figures 3a and 3b (125 data points between March 22, 1993 and March 4, 2013) shows the data from the RWMC, by decade with six month major intervals, and also illustrates the consistency and frequency of NSTec data collection.

Table 1. Wells being monitoring for water levels and responsible contractor

Well	Contractor
UE-5 PW1	NSTec
UE-5 PW2	NSTec
UE-5 PW3	NSTec
WW-5A	USGS
WW-5B	USGS
WW-5C	USGS
UE-5n	USGS
UE-5c WW	USGS
RNM-2S	USGS
RNM-2	USGS
RNM-1	USGS
ER-5-4#2	USGS
ER-5-4 peizometer	USGS
ER-5-4 main	USGS
ER-5-3#3	USGS
ER-5-3#2	USGS
ER-5-3 shallow peizometer	USGS
ER-5-3 main	USGS
ER-5-3 deep piezometer	USGS

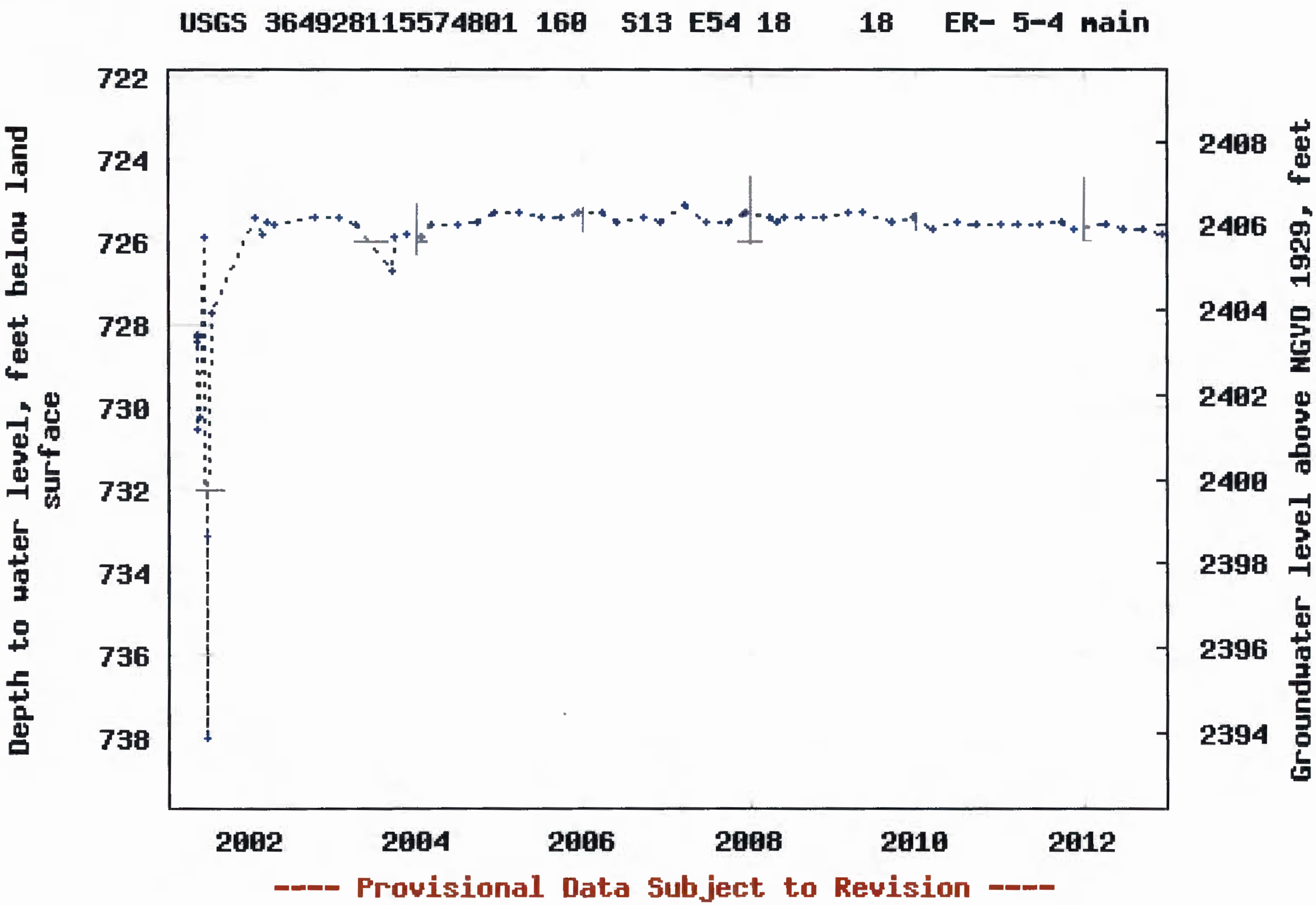

Figure 2 Water-level data from NWIS for ER-5-4 main

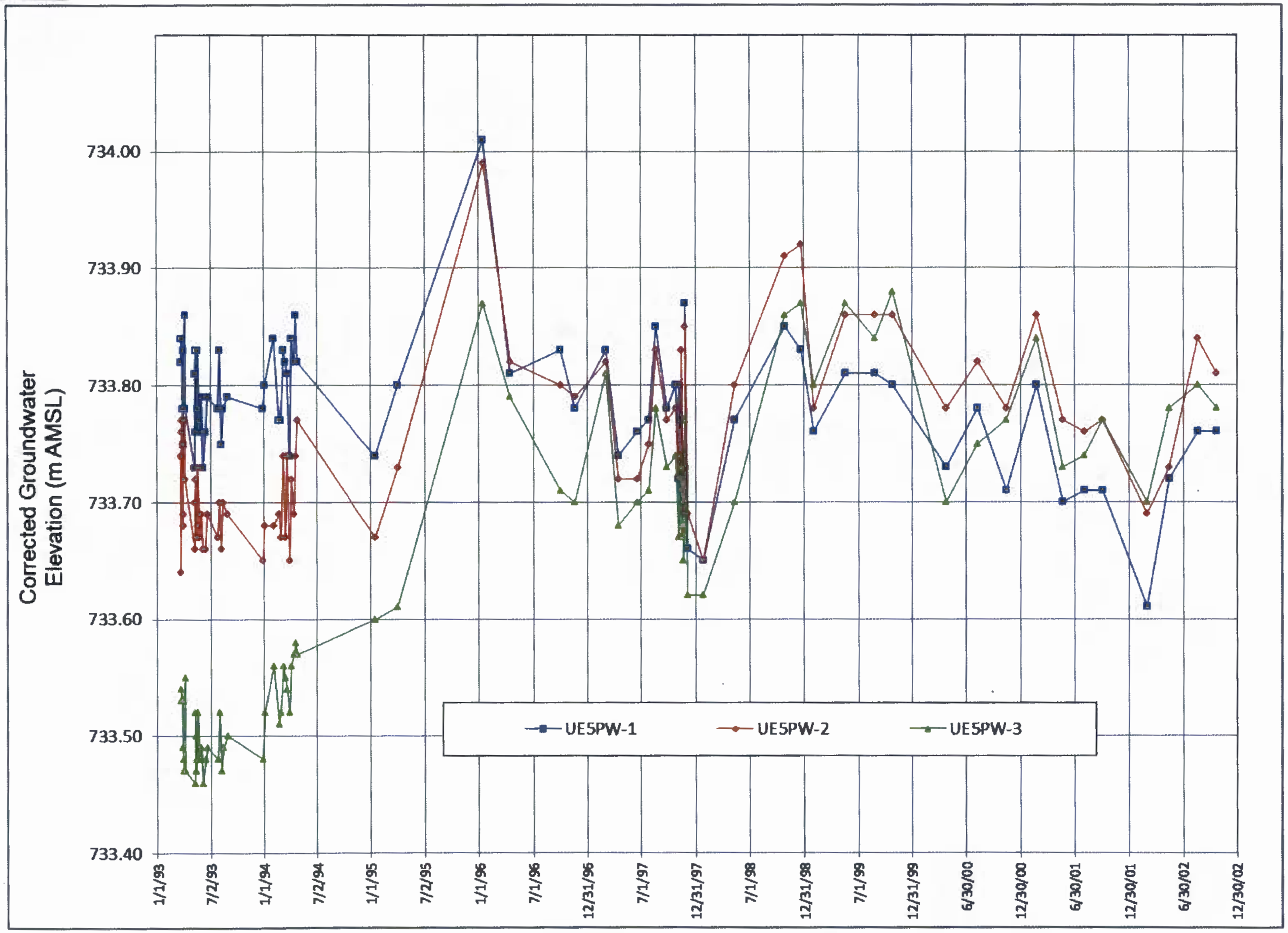

Figure 3a Water-level data from Area 5 RWMC Pilot Wells, January 1, 1993 through December 31, 2002

Navarro-Intera

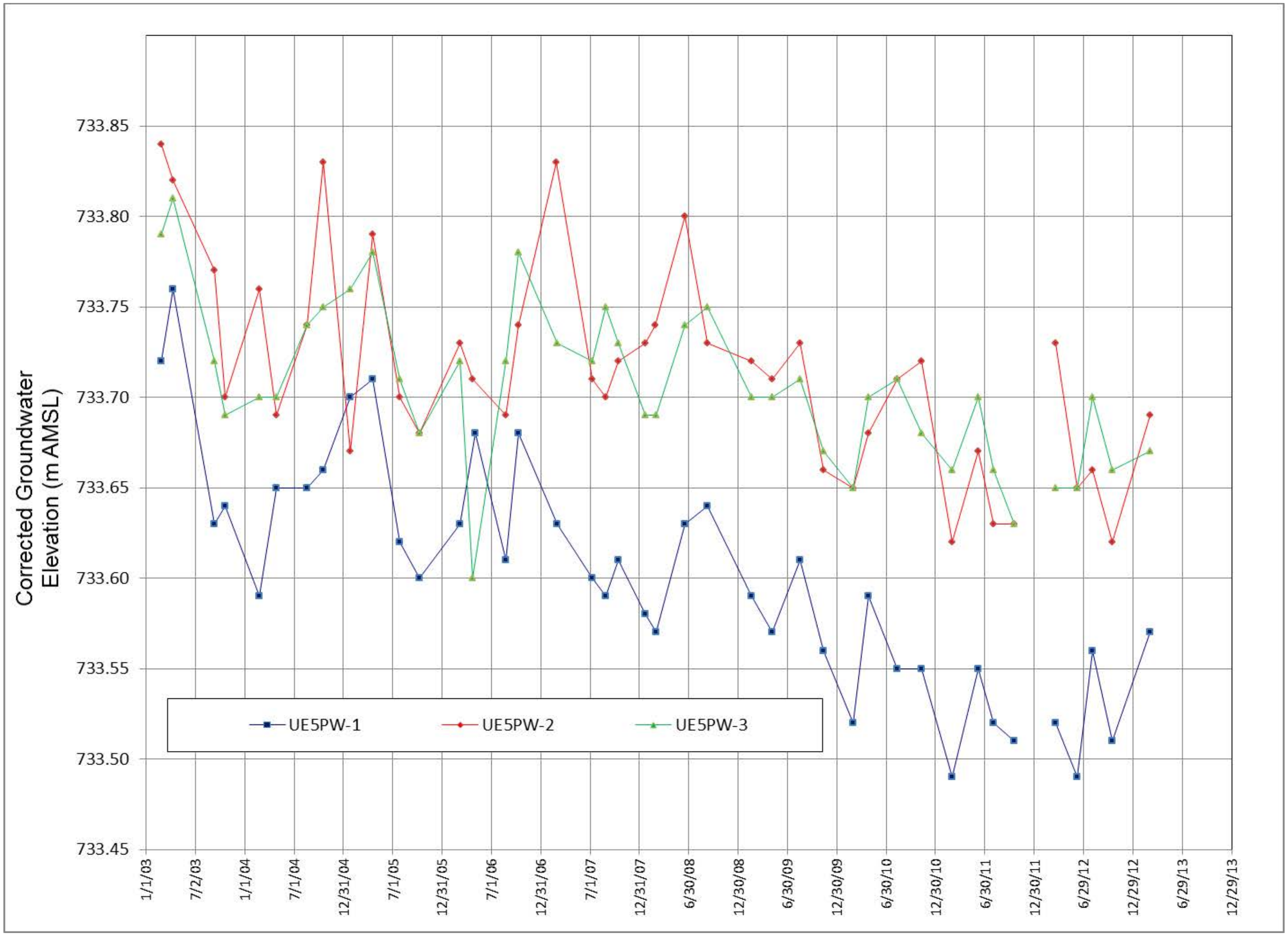

Figure 3b Water-level data from Area 5 RWMC Pilot Wells, January 1, 2003 through December 31, 2013

Navarro-Intera

Overall Water-Level Measurement Accuracy

Water levels in Frenchman Flat are quite similar due to low hydraulic gradient, making interpretations challenging. Accuracy of land-surface elevation is only one of the factors limiting the interpretation of water levels. Additional factors include borehole deviation and changes in water density due to temperature (Elliot and Fenelon, 2010). Bright et al. (2001) analyzed these factors for water levels in Frenchman Flat, and found that corrections in Frenchman Flat basin were less than 0.2 m (0.65 ft). NSTec monitors the pilot wells associated with the Radioactive Waste Management Complex, and applies corrections for Well UE5PW-1, UE5PW-2, and UE5PW-3 of -0.08, -0.12, and -0.02 m (-0.27, -0.68, and -0.06 ft) (Bechtel Nevada, 2005), respectively. The largest observed difference in head between the pilot wells is about 0.07 m (0.25 ft) for wells about a mile apart.

Bechtel Nevada (2005) makes the following comments about water-level accuracy:

> *It should be emphasized that the error in the deviation logs may be equal to or greater than the differences in the uncorrected water table elevations. For example, data from the manufacturer and operator of the deviation tool (Century Geophysics Corporation) indicate that the error in the corrected depth provided by this tool is ±0.15 m (±0.5 ft). This error is as large as the difference observed between water table elevations. In addition, estimated errors arising from the use of a water level measurement tape are on the order of ±0.03 m (±0.1 ft), and the error associated with surveying of casing elevations is probably somewhat less. Because of these uncertainties, it is only reasonable to conclude that differences in water table elevations are within the error of measurement.*

The USGS does not correct water-levels for borehole deviation if the magnitude of the correction is less than 0.5 ft (Elliott and Fenelon, 2010):

> *Corrections less than 0.5 ft were not applied to water levels because at depths exceeding 1,000 ft for water levels in many wells on the NTS the uncertainty in the deviation correction can be as great or greater than the magnitude of the correction.*

Elliot and Fenelon (2010) also comment on the general accuracy of depth-to-water measurements:

> *Periodic water-level measurements in the water-level database primarily were made by USGS or private contracting agencies working at the NTS using calibrated electric tapes, calibrated electric-cable units (also known as iron-horse and wire-line devices), and less commonly, a steel tape, fluid-density geophysical log, airline, float recorder, pressure transducer, and pressure gage. Most water-level measurements prior to 1996 were made with an electric-cable unit (Garber and Koopman, 1968), whereas more recent measurements typically were made using electric tapes. The tapes and cable units are calibrated annually at different water-level depths with a USGS steel reference tape. At the time of measurement, a correction factor is applied to the depth-to-water reading based on the annual calibration. Post-1995 measurements using*

electric tapes generally are more accurate (±0.1 ft) than older measurements using electric-cable units or other methods (±0.5–1 ft).

In the Phase II Hydrologic Data Document (SNJV, 2004) the estimated uncertainty in water levels due to measurement accuracy (0.03 m/0.1 ft), barometric effects (0.3 m/1 ft), and borehole deviation (0.02 m/0.06 ft) totaled 0.35 m for the Frenchman Flat wells; a number considerably greater than even the lowest survey accuracy thought to exist (as much as 0.2 ft) in Frenchman Flat. In 2004 SNJV measured elevation via GPS and took depth to water measurements. This data was reported in SNJV (2006) and even though there were minor changes in land surface elevation from these differential GPS measurements, it was concluded that "the new ground-surface elevation data do not change any of the discussion found in the Frenchman Flat hydrologic data document regarding flow direction in these three aquifers." If there is an error in land surface it is systematic, and thus inferred flow directions remain the same.

Summary and Conclusions

NNSA/NSO's letter request for model acceptance to NDEP states that a long-term water-level monitoring program will be implemented; however, a *de facto* one already exists from both the USGS (selected wells) and NSTec (the pilot wells associated with the RWMC) quarterly monitoring.

It is NSTec's professional opinion that the survey accuracy of 14 of the wells cannot be improved. Insufficient survey documentation exists for 9 of the wells necessitating their resurvey. Given the ability to measure, at best, ±0.1 ft differences, the uncertainty inherent in the corrections themselves, overall uncertainty in water levels, and low groundwater velocity it is not warranted to perform a high-resolution resurvey – future trends can still be accurately defined with this accuracy. The USGS and NSTec have been measuring water levels, using procedures they have standardized, in Frenchman Flat quarterly since the early 2000s, thus a program has already been established. This requirement in the CADD/CAP can reasonably be seen to be satisfied with current work supplemented with the resurvey of 9 wells. The CAU lead recommends reviewing these facts with NDEP and with their concurrence develop a path forward that documents this conclusion – this could be done with a record of technical change or other clear statement of NDEP approval. The current water-level monitoring program also needs to continue as stated in the CADD/CAP.

References

Bechtel Nevada. 2005. *Site Characterization and Monitoring Data from Area 5 Pilot Wells, Nevada Test Site, Nye County, Nevada*, DOE/NV/11718--1067. Prepared for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office. Las Vegas, NV.

Bright, D.J., S.A. Watkins, and B.A. Lisle. 2001. Analysis of Water Levels in the Frenchman Flat Area, Nevada Test Site, USGS Water-Resource Investigations Report 00-4272. Denver, CO: U.S. Geological Survey.

Elliott, P.E., and Fenelon, J.M. 2010, Database of groundwater levels and hydrograph descriptions for the Nevada Test Site area, Nye County, Nevada, 1941–2010: U.S. Geological Survey Data Series 533, 16 p.

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

Stoller-Navarro Joint Venture. 2004. *Phase II Hydrologic Data for the Groundwater Flow and Contaminant Transport Model of Corrective Action Unit 98: Frenchman Flat, Nye County, Nevada*, S-N/99205--032, Rev. 0. Prepared for the U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office. Las Vegas, NV.

Stoller-Navarro Joint Venture. 2006. *Groundwater Flow Model of Corrective Action Units 101 and 102: Central and Western Pahute Mesa, Nevada Test Site, Nye County, Nevada*, Rev. 0, S-N/99205--076. Las Vegas, NV.

U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office. 2011. *Corrective Action Decision Document/Corrective Action Plan for Corrective Action Unit 98: Frenchman Flat Nevada National Security Site, Nevada*, DOE/NV--1455. Las Vegas, NV.

ndep
NEVADA DIVISION OF ENVIRONMENTAL PROTECTION
protecting the future for generations

STATE OF NEVADA
Department of Conservation & Natural Resources
DIVISION OF ENVIRONMENTAL PROTECTION

Brian Sandoval, Governor
Leo M. Drozdoff, P.E., Director
Colleen Cripps, Ph.D., Administrator

ERD.140707.0001

July 03, 2014

Mr. Robert F. Boehlecke
Manager
Environmental Management Operations
National Nuclear Security Administration
Nevada Field Office
P.O. Box 98518
Las Vegas, Nevada 89193-8518

RE: Request for Approval That Requirements Have Been Met to Re-Survey Wells in Corrective Action Unit (CAU) 98: Frenchman Flat
Federal Facility Agreement and Consent Order

Dear Mr. Boehlecke:

The Nevada Division of Environmental Protection, Bureau of Federal Facilities staff (NDEP) has received and reviewed the above-referenced letter and enclosures dated June 20, 2014. The NDEP is aware that the CAU 98: Frenchman Flat Corrective Action Decision Document/Corrective Action Plan (CADD/CAP) required actions that were described in Section 4.5.3, Water-Level Measurement Program, of the CADD/CAP. As part of this program, a high precision re-survey of the wells in Frenchman Flat was to be completed prior to the establishment of a long-term monitoring program.

The above-referenced letter included attachments addressing the NNSA/NFO's approach to the re-survey and a discussion on how the NNSA/NFO believes this requirement has been fulfilled and addresses comments from the NDEP's February 11, 2014 letter. The NDEP agrees the re-survey work has been completed and documentation of the work is acceptable. The NDEP also agrees the intent of the current language in the Frenchman Flat CADD/CAP, Section 4.5.3 has been met. Therefore, construe this letter as approval that requirements have been met to re-survey wells in CAU 98.

If you have questions regarding this matter, please contact me at (702) 486-2850 ext. 232.

Sincerely

/s/ Chris Andres

Christine Andres
Chief
Bureau of Federal Facilities

THM/CDA

ec: EM Records, AMEM, Las Vegas, NV (1 electronic copy, 1 hard copy)
N-I Central Files, MS NSF 156, Las Vegas, NV

cc: FFACO Group, PSG, NNSA/NFO, Las Vegas, NV
J. T. Fraher, DTRA/CXTS, Kirkland AFB, NM
NSTec Correspondence Control. MS NLV008, Las Vegas, NV
W. R. Wilborn, ERP, NNSA/NFO, Las Vegas, NV
K.S. Knapp, EMOS, NNSA/NFO, Las Vegas, NV
Bimal Mukhopadhyay, EMO, NNSA/NFO, Las Vegas, NV

Attachment B-2

Correspondence Regarding External Peer Review Comment Status for Frenchman Flat CAU

Boehlecke to Andres, September 16, 2014
(5 Pages)

Andres to Boehlecke, September 17, 2014
(2 Pages)

Department of Energy
National Nuclear Security Administration
Nevada Field Office
P.O. Box 98518
Las Vegas, NV 89193-8518

SEP 16 2014

Christine Andres, Chief
Bureau of Federal Facilities
Division of Environmental Protection
2030 East Flamingo Road, Suite 230
Las Vegas, NV 89119-0818

STATUS OF ATTACHMENT B EXTERNAL REVIEW COMMENTS FOR CORRECTIVE ACTION UNIT (CAU) 98: FRENCHMAN FLAT, NEVADA NATIONAL SECURITY SITE

In response to NNSA/NSO's November 17, 2010, letter (Appendix A; NNSA/NSO, 2011) requesting NDEP acceptance of the Frenchman Flat flow and transport model (including as Attachment B *External Peer Review Team Report: Comments and Responses by the Underground Test Area Subproject [UGTA] of the Nevada Site Office*), NDEP wrote on November 30, 2010, (Appendix B; NNSA/NSO, 2011) that it accepted the model subject to a condition that "all planned actions in Attachment B of the above-referenced document be identified in the Frenchman Flat Corrective Action Decision Document/Corrective Action Plan. The results of all of these actions must be documented and presented to the NDEP via interim documents, letters, or presentations during the CADD/CAP stage." The attached table shows how the issues and actions from Attachment B have been resolved in the model evaluation report provided to you on August 8, 2014, or with other documentation.

NNSA/NFO believes all the planned actions associated with the issues in Attachment B have been satisfied with the exception of the following items based on discussions with NDEP (the rationale and proposed actions are also given):

1. **Issue Six:** No regional-scale climate models were assessed during the CADD/CAP. This work was not pertinent to evaluating the confidence in the groundwater flow and transport model as sufficient for establishing a monitoring system and institutional controls at this time. NNSA/NFO proposes that by continued execution of the UGTA strategy (FFACO, 1996, as amended) that any such assessment of regional-scale climate change will occur when monitoring indicates a need for this action.

2. **Issue Six:** No sensitivity analysis of the effects of discrete sets of plausible seismic events has been considered in consultation with NDEP during the CADD/CAP. This was not pertinent to evaluating the confidence in the groundwater flow and transport model as sufficient for establishing a monitoring system and institutional controls at this time. NNSA/NFO proposes that by continued execution of the UGTA strategy (FFACO, 1996, as amended) that any such assessment of seismic events will occur when monitoring indicates a need for this action.

3. **Issue Eight:** A refined model of water-level response to pumping near Frenchman Lake playa was not developed. This was because it is not an evaluation task relevant to establishing a monitoring system and institutional controls at this time. Additionally, modeling analysis showed that projecting the current pumping rates from the production wells for the regulatory period does not impact groundwater contamination from the CAMBRIC ditch and, by extension, DILUTED WATERS and WISHBONE. With the refined understanding of the low groundwater flow and transport velocities developed during the model evaluation NNSA/NFO believes that, other than continued water-level surveillance, no further work is necessary on this issue at this time.

NNSA/NFO requests NDEP approval that the actions associated with Attachment B have been sufficiently documented and presented.

References:

Federal Facility Agreement and Consent Order 1996 (as amended March 2010). Agreed to by the State of Nevada; U.S. Department of Energy, Environmental Management; U.S. Department of Defense; and U.S. Department of Energy, Legacy Management. Appendix VI, which contains the Underground Test Area Strategy, was last modified June 2014, Revision No. 5.
U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office, 2014.

Corrective Action Decision Document/Corrective Action Plan for Corrective Action Unit 98: Frenchman Flat Nevada National Security Site, Nevada, DOE/NV--1455, Las Vegas, NV.

Please direct comments and questions to Bill R. Wilborn, of my staff, at (702) 295-3188.

/s/ Robert F. Boehlecke

Robert F. Boehlecke, Manager
Environmental Management Operations

EMO:10804.CD

As stated

cc w/encl. via e-mail:
E. A. Jacobson, NDEP
N-I Central Files

cc w/o encl. via e-mail:
Mark McLane, NDEP
J. T. Fraher, DTRA/CXTS
NSTec Correspondence Control, M/S NLV008
W. R. Wilborn, NFO
FFACO Group, NFO
NFO Read File

Attachment B: Peer Review Issues	Action	Response Documentation
Issue One: Evaluation and use of water-level gradients from the Pilot Wells at the Area 5 Radioactive Waste Management Complex in model calibration.	Update the RWMC pilot well head data, and evaluate during CADD/CAP.	Section 3.5 of the Model Evaluation Report discusses the pilot wells (Table 3-1; Figures 3-2, 3-3, 3-4, and 3-10). Additionally, Section 3.10 shows (Figure 3-24) computed groundwater flow directions using the pilot wells (Figure 3-24).
Issue Two: Re-evaluation of the use of geochemical age-dating data to constrain model calibrations.	Groundwater age information will be interpreted recognizing data uncertainties, but this information will continue to be assessed in CADD/CAP and CR studies.	Section 3.10 of the Model Evaluation Report explicitly documents the assessment of groundwater age and associated uncertainties at the model evaluation wells.
Issue Three: Development of water budgets for the alluvial and upper volcanic aquifer system in Frenchman Flat.	Continuing studies for the CADD/CAP and CR stages will attempt to use parameters and assumptions that are more representative of the expected case including assumptions for inflow terms.	The groundwater velocity computations in Section 3.7 of the Model Evaluation Report use properties from the test and the hydraulic gradients computed from new and existing data. Appendix A uses best available data for all PIN STRIPE conceptual computations. These computations are representative of expected conditions including inflow.
Issue Four: Consideration of modeling approaches in which calculated groundwater flow directions near the water table are not predetermined by model boundary conditions and areas of recharge, all of which are very uncertain.	The core of the problem is the level of confidence in model estimation of flow directions, a question that will be emphasized in the model evaluation of the CADD/CAP stage.	Section 3.5 of the Model Evaluation Report comprehensively evaluated groundwater flow directions using new data since 2006, and also determined that the flow models are consistent with the new groundwater elevation data. Section 3.7 showed that the direction estimated with new data is consistent with that simulated near MILK SHAKE. Considerably more confidence in groundwater flow direction determined by data now exists.
Issue Five: Evaluation of local-scale variations in hydraulic conductivity on the calculation contaminant boundaries.	The potential for local-scale variations in permeability will be considered in evaluations of new data collected during the CADD/CAP stage.	Section 3.7 of the Model Evaluation Report discusses OAA and BLFA heterogeneity.

Issue Six: Evaluation of the effects on non-steady state flow conditions on calculated contaminant boundaries including the effects of long-term declines in water levels, climate change and disruption of the groundwater system by potential earthquake faulting along either of the two major controlling fault zones in the flow system, the Cane Springs and Rock Valley faults.	NNSA/NFO agrees that the potential effects of non-steady state flow should be considered and will implement a water-level monitoring program during model evaluations for the CADD/CAP with continuation into the CR stage.	The quarterly monitoring conducted by the USGS and NSTec satisfies this requirement.
	With respect to climate change, the UGTA subproject will continue to follow the scientific literature on anthropogenic driving forces for climate change particularly for the topic of abrupt climate change which could affect climate assumptions during the next 1,000 years. The UGTA subproject, in consultation with NDEP, will periodically assess progress in development of regional scale models for the arid southwest United States and reassess the need for further studies during the CADD/CAP and CR stages.	NNSA/NFO proposes that by continued execution of the UGTA strategy (FFACO, 1996, as amended) that any such assessment of regional-scale climate change will occur when monitoring indicates a need for this action.
	Sensitivity analysis of the effects of discrete sets of plausible seismic events will be considered in consultation with NDEP during future studies (CADD/CAP or CR stages).	NNSA/NFO proposes that by continued execution of the UGTA strategy (FFACO) (1996, as amended) that any such assessment of seismic events will occur when monitoring indicates a need for this action.
Issue Seven: Consideration of the use of less-complex modeling approaches.	NNSA/NFO will provide information to NDEP on changes in modeling approaches in future briefings, and these changes will be described in CAU-specific model documents submitted for NDEP review. The first descriptions of the refined modeling approaches will be in the CADD/CAP document for Frenchman Flat and in the Phase II modeling for the western and center Pahute Mesa. These descriptions will be developed in consultation and agreement with the NDEP.	Section 3.5 and 3.7, and Appendix A of the Model Evaluation Report illustrate simpler approaches to groundwater velocity, direction, and conservative radionuclide transport.
Issue Eight: Evaluation the large change in water levels in the vicinity of the Frenchman Flat playa and development of a conceptual model to explain these water-level changes.	This issue will be evaluated in two stages. First, the existing data will be assessed during the CADD/CAP stage to ensure the water level measurements and resulting water-level differences are not in error. This will be combined with continued long-term monitoring of water levels for all wells (see response to Issue nine).	Section 3.5 of the Model Evaluation Report fulfills this obligation.

	Second, if the large changes in water levels are verified as part of CADD/CAP water-level monitoring studies, the potential effects of local structure will be evaluated and local models of geologic structure revised, if required.	With the refined understanding of the low groundwater flow and transport velocities developed during the model evaluation NNSA/NFO believes that, other than continued water-level surveillance, no further work is necessary on this issue at this time.
Issue Nine: Development of a long-term groundwater level monitoring program for Frenchman Flat with regular monitoring of water levels at key monitoring wells.	A groundwater level monitoring program for Frenchman Flat is planned to begin with the installation of the first two model evaluation wells. This program will include: 1. Re-surveying of well head elevations, 2. Developing a standardized protocol for measurement of water levels, 3. Resurveying of water levels in all wells in Frenchman Flat during a short interval (days to weeks) to minimize possible effects of barometric pressure, water temperature, and earth tides on water levels, and 4. Routine monitoring of water levels on an established schedule. The details and schedule for this monitoring program will be described in the CADD/CAP document.	With a partial resurvey of the wells and the existing USGS and NSTec water-level programs, this obligation is fulfilled. Documentation of all monitoring wells and the best available reference data are provided in the June 20, 2014, memo and in Section 2.4 of the Model Evaluation Report.

September 17, 2014

Mr. Robert F. Boehlecke
Manager
Environmental Management Operations
National Nuclear Security Administration
Nevada Field Office
P.O. Box 98518
Las Vegas, Nevada 89193-8518

RE: STATUS OF ATTACHMENT B EXTERNAL REVIEW COMMENTS FOR CORRECTIVE ACTION UNIT (CAU) 98: FRENCHMAN FLAT, NEVADA NATIONAL SECURITY SITE

Dear Mr. Boehlecke:

The Nevada Division of Environmental Protection, Bureau of Federal Facilities staff (NDEP) has received and reviewed the above-referenced letter and enclosure dated September 16, 2014. The NDEP is aware that it accepted the Frenchman Flat flow and transport model subject to a condition that "all planned actions in Attachment B of the *External Peer Review Team Report: Comments and Responses by the Underground Test Area Subproject of the Nevada Site Office*, be identified in the Frenchman Flat Corrective Action Decision Document/Corrective Action Plan" (CADD/CAP). Furthermore, "the results of all of these actions must be documented and presented to the NDEP via interim documents, letters or presentations during the CADD/CAP stage".

The NDEP agrees the requirements placed on all the planned actions associated with the issues in Attachment B have been satisfied with the exception of the three issues identified in the above -referenced letter. The NDEP however concurs with the rationale and proposed actions that are given for those three issues and will hold the National Nuclear Security Administration /Nevada Field Office responsible to address and complete these actions if the need arises. Therefore, construe this letter as approval that the actions associated with Attachment B have been sufficiently documented and presented.

If you have questions regarding this matter, please contact me at (702) 486-2850 ext. 232.

Sincerely

/s/ Chris Andres

Christine Andres
Chief
Bureau of Federal Facilities

CDA/MM

ec: EM Records, AMEM, Las Vegas, NV (1 electronic copy, 1 hard copy)
N-I Central Files, MS NSF 156, Las Vegas, NV
Mark McLane, NDEP

cc: FFACO Group, PSG, NNSA/NFO, Las Vegas, NV
J. T. Fraher, DTRA/CXTS, Kirkland AFB, NM
NSTec Correspondence Control. MS NLV008, Las Vegas, NV
W. R. Wilborn, ERP, NNSA/NFO, Las Vegas, NV

Appendix C

NDEP Comments

(9 Pages)

NEVADA ENVIRONMENTAL MANAGEMENT OPERATIONS ACTIVITY
DOCUMENT REVIEW SHEET

1. Document Title/Number: Final Model Evaluation Report for Corrective Action Unit (CAU) 98: Frenchman Flat, Nevada National Security Site, Revision 0, July 2014.	2. Document Date: July 30, 2014
3. Revision Number: 0	4. Originator/Organization: Navarro-INTERA LLC
5. Responsible DOE NNSA/NFO Activity Lead: Bill Wilborn	6. Date Comments Due: August 31, 2014
7. Review Criteria: Complete Document	
8. Reviewer/Organization Phone No.: Nevada Division of Environmental Protection	9. Reviewer's Signature:

10. Comment Number/Location	11. Type[a]	12. Comment	13. Comment Response	14. Accept/Reject
1) Section 3.5.2, page 3-7	M	Top bullet "Accuracy Due to Data Frequency": Please include the basis for the values that were assigned for the approximate uncertainty for the wells.	A reference was added in the Model Evaluation Report to the FF Hydrologic Data Document where these concepts were developed. Page 8-19 first full paragraph (SNJV, 2004) provides an extensive explanation of these values. The first sentence after the bullet will be replaced with the following text: "Accuracy due to data frequency was assigned to each static water level based on the analysis reported in SNJV (2004, p. 8-19). These uncertainties account for the temporal distribution of water-level measurements and the likelihood that those values accurately represent aquifer conditions over the measurement time period."	

[a] Comment Types: M = Mandatory, S = Suggested.
[b] This comment was generated by the document authors and reviewed by NDEP.
[c] This comment was generated by NDEP after receipt of the Boehlecke to Andres letter dated September 16, 2014 (Appendix B; Attachment B-2).
Return Document Review Sheets to NNSA/NFO Environmental Management Operations Activity, Attn: QAC, M/S NSF 505

10. Comment Number/Location	11. Type[a]	12. Comment	13. Comment Response	14. Accept/Reject
2) Section 3.5.2, page 3-7	M	First paragraph below top bullet: "Table 3-1 shows the components and total uncertainty in static water levels **determined** for each well ... " These are estimated values for data frequency and Table 3-1 indicates that in a footnote. Please use "estimated" instead of "determined".	Revised text to "estimated."	
3) Section 3.5.3, page 3-7	M	Second paragraph, third sentence that is continued on top of page 3-11: "Recently collected data indicate that regionally groundwater elevations have been increasing throughout the LCA (Elliot and Fenelon, 2010)." What impact does this information have on this model evaluation?	There is no impact at this time because the alluvial/volcanic system is effectively isolated from the LCA by the LTCU at the bottom and sides of the alluvial basin. No effects of this rise are noticeable in the alluvium, which shows gradual decline in water levels that are most noticeable near active water supply wells. No change to text.	

[a] Comment Types: M = Mandatory, S = Suggested.
[b] This comment was generated by the document authors and reviewed by NDEP.
[c] This comment was generated by NDEP after receipt of the Boehlecke to Andres letter dated September 16, 2014 (Appendix B; Attachment B-2).
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10. Comment Number/Location	11. Type[a]	12. Comment	13. Comment Response	14. Accept/Reject
4) Section 3.5.4, page 3-11	M	Second paragraph, first sentence: "Water levels at Well ER-11-2 are much higher than observed elsewhere in the alluvial basin (see Figure 3-18)." Figure 3-18 only shows information for Well ER-11-2 with no comparison to other well data in the alluvial basin. Is there another figure showing this comparison, or are there other values for the well data in the alluvial basin elsewhere in this report to see how much higher the water levels are for Well ER-11-2? Please clarify this section.	Figure 3-18 illustrates the approximate water table elevation in the alluvium (horizontal dashed blue line at approximately 733.8 m). This line is consistent (value, color, etc.) with the Approximate Water-Table Elevation line shown on Figure 3-5. To improve the clarity of the statement, the static water level for ER 11-2 was added to the text and reference added to Table 3-1 where all static water level values are listed and to Figure 3-2, which shows only the values for the OAA/AA wells. Note that the point of Figure 3-18 is to show the magnitude of the difference between the AA water levels and those observed at ER-11-2 (about 4 m), and other figures and tables provide the supporting data in greater detail. The composite water table map shown in Figure 3-10 posts the ER-11-2 water-level data with the water levels observed at nearby wells. Related to this comment, the dashed line on Figure A-2 has been lowered slightly to represent the groundwater elevation difference observed between ER-11-2 and wells located in the OAA.	
5) Section 3.5.5, page 3-12	M	First paragraph, fourth sentence: "..., all water levels are high on the same day." This is not the case for Well UE-5 PW-2 and Well ER-5-5 shown on the figure. Please indicate in the text which wells have water levels collected on the same day.	The text will be modified as follows: "For example, all water levels **at Well Cluster ER-5-3** are high on the same day."	

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6) Section 2.2, page 2-3	M	Third paragraph, fourth sentence: On page 2-3, section 2.2, first paragraph, last sentence, the impact assessment based on the transport code error is mentioned with the statement that "showed the effect of the error was to overstate concentrations and extent of the CBs." How would the information presented in this paragraph be modified based on the impact assessment results?	As shown in the impact analysis the chance of exceeding the SDWA MCL at ER-5-5 is on the order of 70% even with the code error that overstated concentrations. While this was stated in the text, it was not clear that this result was associated with the impact analysis and not the original result. The sentence on page 2-3 was moved to follow the sentence describing the code error and impact assessment and was preceded with "***The impact assessment showed that..***."	
7) Section 3.8, page 3-34	M	"Applicable boundary conditions for this uncertainty include ..." Please indicate what uncertainty is being discussed.	The text will be modified as follows: "Applicable boundary conditions **for the model evaluation target named *flow boundary conditions*** include the recharge to the semiperched units and the assigned hydraulic heads along the lateral model faces."	
8) Section 3.11, page 3-51, Table 3-6	M	Third model evaluation target, results: "... shows saturated TSA does not exist ..." Please add, does not exist **at this location** (bold used to show what text should be added).	The text, "at this location" was added as specified.	
9) Section 4.3, page 4-2	M	First paragraph, third sentence: "... (i.e., the actual extent of potential groundwater contamination is much less than forecast, but identifiable using available data and models)... " Please clarify the portion of this sentence concerning identifiable. For example, is the meaning that the actual extent of potential groundwater contamination is identifiable?	The intended meaning is that the direction, approximate velocity, transport mode (porous), and overall potential for groundwater contamination are discernible or apparent. That is, uncertainty does not so cloud the interpretation that no conclusions can be drawn. The text was changed to "discernible."	

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10) Appendix A, Section A.1.2, page A-8	M	Second paragraph, last sentence: Please clarify "dipping deeper into the potentiometric surface". In the first sentence on page A-12 it states, "TSA dips southward into the water table." Is this what is meant on page A-8? If so, for consistency please use the water table phrase. Also "... which would reduce the hydraulic gradient and velocity." The increase in saturated thickness mentioned on page A-12 would impact the velocity, however it is not clear how it leads to a reduction in horizontal hydraulic gradient. Please clarify this section.	The point made by the text does not require this sentence, and it was deleted. A similar point is made on page A-12 that is more relevant to the computations. Relating to this comment, the text on page A-12 was modified by inserting, after the sentence ending, "…Darcy flux and gradient must go down." in the first paragraph the text "The reduction in Darcy flux is from the fixed flow rate being spread over increasing cross-sectional area as the TSA dips into the water table. The reduction in hydraulic gradient can be verified by examining Equation (A-1). When *Q* is fixed, which is the conceptualization of recharge inflow at the edge of the basin near PIN STRIPE, and transmissivity increases as the TSA dips into the water table, then the hydraulic gradient must decrease proportionally to the transmissivity increase."	

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11) Appendix A, Section A.1.2, page A-11	M	First sentence below equation (A-1): "resulting in constant transmissivity ...” Does constant imply that hydraulic conductivity is homogeneous and the aquifer has constant thickness? Please clarify.	The key point is that the PWT and NWT are completely saturated south of the working point, and if the hydraulic conductivity and thickness is constant (conceptualized, not known), then the transmissivity of these two lithologic units is also constant southwards. It is implied in the computation that the hydraulic test properties are homogeneous at the scale of the computation. The text “and constant thickness” was inserted after “completely saturated”. An explicit statement of this assumption was added, and the text now reads, “Assuming the hydraulic conductivity represents only the NWT and PWT **and is homogenous at the scale of potential radionuclide groundwater migration from PIN STRIPE** gives…”	
12) Appendix A, Section A.1.2, page A-11	M	Next to last sentence on page: Because the same data are used in equations (A-1) and (A-2), the Darcy flux would be the same. Why are both calculations shown?	Both computations are shown to illustrate equivalent answers via two variations on Darcy’s Law. The first highlights the total flow rate *Q*, and the second flux. Both forms are used in the discussion. No changes to text.	

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13) Appendix A, Section A.1.2, page A-13	M	Third paragraph, fourth sentence: Please check the value for velocity with minus one standard deviation in porosity because it is the same value as the mean.	Related to this comment a systematic error was discovered in the computation of the velocity for the MWT, beginning in the first paragraph and affecting the third paragraph as noted. Also minor round-off inconsistencies were corrected. <u>First Paragraph:</u> The groundwater velocity is 0.083 m/yr (MWT) and 0.048 m/yr (NWT) (changed on 5th line), resulting in 83 and 48 m of travel in 1,000 years (changed on 8th line), and in 200 years the transport distance is 17 m (changed on 11th line and 10 m [rounded from 9.6 m]). <u>Third Paragraph:</u> The DWT, MWT, and NWT velocities with 2 sigma hydraulic gradient are 0.11 m/yr, 0.17 m/yr, and 0.10 m/yr and DWT travel distance for DWT is 110 m (changed on line 6). The sentence beginning, “Because the porosity…” is meant to discuss the range in groundwater velocity in the NWT at the expected gradient. The 0.03 m/yr presented as representing mean conditions is corrected to 0.048 m/yr as given in paragraph 1. As noted there is an error in the plus and minus 1 sigma porosity computations, the correct results in this sentence are 0.03 and 0.08 for the plus and minus 1 sigma porosity, respectively. In the sentence beginning, “Considering this range of porosity…” the velocity at plus 2 sigma hydraulic gradient and ± 1 sigma porosity were corrected to 0.07 and 0.16 m/yr. In the third paragraph, the word “porosity” was deleted on line 4 and “nearly” on line 5 – they are incorrect and confusing.	

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14) Appendix A, Section A.1.3.1, page A-14	M	Please clarify the entire section concerning horizontal and vertical flow velocities. For example, bullets one and two appear to be concerned with horizontal velocity, bullet three is vertical velocity and the last sentence in the section appears to include both horizontal and vertical.	The first two bullets discuss horizontal velocities; to make the meaning clearer, the word “horizontal” was inserted before “flow velocities” in each sentence. For the third bullet, the word “vertical” was inserted before “groundwater velocity” for clarity. In the final sentence of the section, the words “horizontal and vertical” were inserted before “velocities.”	
15) Appendix A, Section A.1.4; page A-15	M	Fifth bullet: " ... small hydraulic gradients ... " Please clarify hydraulic gradients (horizontal, or vertical or both).	The word “horizontal” was inserted before “hydraulic” for clarity.	
16) Appendix A, Section A.1.4; page A-15	M	Sixth bullet: "Low (0.05 m/yr.) groundwater velocities ... " Please add **"horizontal"** groundwater velocities if this is the appropriate meaning.	Horizontal is the appropriate meaning. Additionally, responding to comment 13 changes the velocity to 0.2 m/yr. The sentence now reads, “Low (0.2 m/yr) **horizontal** groundwater velocities are estimated…”	
17) Figure 2-1 caption, Section 2.1; page 2-1, Section 3.4; page 3-2, Section 6; page 6-4[b]	M	Replace Phillips et al. (2011) reference with Phillips et al. (2014): Phillips, J.D., B.L. Burton, E. Curry-Elrod, and S. Drellack. 2014. *A Ground-Based Magnetic Survey of Frenchman Flat, Nevada National Security Site and Nevada Test and Training Range, Nevada: Data Release and Preliminary Interpretation*. Open-File Report 2014-1187. Henderson, NV: U.S. Geological Survey. Phillips et al. (2014) is a USGS Open-File Report rather than a written communication.	Reference has been replaced.	
18) Figure A-2[b]	M	Well names are not UGTA standard.	The well name nomenclature was corrected. For instance, “U11-b” was changed to “U-11b.”	
19) Page A-15[b]	M	The plus or minus one standard deviation on the second line should refer to direction, not porosity.	Changed “porosity” to “direction.”	

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20) Page A-13 [b]	M	The value of 0.1 m/yr on line 6 of the third paragraph on page A-13 is for the DWT with plus 2 standard deviation hydraulic gradient; the value of 0.2 m/yr is an erroneous additional doubling.	The sentences, "A two standard deviation gradient…" and "Reduction in porosity…" were deleted. For clarity the following text was inserted, "Assumptions required in developing these estimates of groundwater velocity included full fracture-matrix interaction, representativeness of hydraulic gradient computations, and comparability of porosity data from similar tuffs at Yucca Mountain. For bounding computations of potential radionuclide transport the maximum estimated velocity value of 0.17 m/yr is rounded to 0.2 m/yr."	
21) Section A.1.2, pages A-13, and A-17 [b]	M	Change 5.5 x 10^{-4} to 5.4 x 10^{-4} on page A-11, para. 2, line 7; and 0.2 m/y to less than 0.2 m/yr (page A-17, bullet 3) to be consistent with calculation briefs/checks.	Revisions completed.	
22) Section 3.5.2, page 3.6, Table 3.1 and Section 3.5.3, page 3-9, Figure 3-3 [c]	M	The reference for the table is NNES (2010), and while similar plots are provided in that reference the data are not. What is the source of the data and uncertainty shown in Figure 3-3?	The titles for Figure 3-3 and 3-4 were inadvertently switched; the text that describes them is correct. Titles were corrected. Figure 3-3 is directly from NNES (2010), and the target data for this figure (CAI data used for calibration) are described in SNJV (2006) Appendix A and the uncertainty is described in SNJV (2004c). Text was added in Section 3.5.3 (Line 4) after "the CAI static heads" to read "presented in SNJV (2006, Appendix A)". Also, text was added in Section 3.5.3 (line 4) after "and estimated uncertainty" to read "presented in SNJV (2004c)".	

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