LMS/SHL/S09338

2012 Groundwater Monitoring Report Project Shoal Area Subsurface Corrective Action Unit 447

March 2013

Approved for public release; further dissemination unlimited

U.S. DEPARTMENT OF ENERGY | Legacy Management

Available for sale to the public from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
Telephone: 800.553.6847
Fax: 703.605.6900
E-mail: orders@ntis.gov
Online Ordering: *http://www.ntis.gov/help/ordermethods.aspx*

Available electronically at *http://www.osti.gov/bridge*

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

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
Phone: 865.576.8401
Fax: 865.576.5728
Email: reports@adonis.osti.gov

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors.

LMS/SHL/S09338

2012 Groundwater Monitoring Report
Project Shoal Area Subsurface
Corrective Action Unit 447

March 2013

Approved for public release; further dissemination unlimited

This page intentionally left blank

Contents

Abbreviations iii
Executive Summary v
1.0 Introduction 1
2.0 Site Location and Background 1
2.1 Summary of Corrective Action Activities 1
3.0 Geologic and Hydrologic Setting 4
4.0 Monitoring Program and Objectives 4
4.1 Radioisotopic Monitoring 7
4.2 Radioisotopic Results 8
4.3 Hydraulic Head Monitoring 11
4.4 Hydraulic Head Results 11
5.0 Site Inspection and Supplemental Site Activities 15
5.1 Enhanced Analytical Suite and Sampling Network 15
5.2 HC-4 Extended Purge with Sampling 16
5.3 HC-8 Infiltration Testing 17
5.4 Seismograph Station Monitoring Results 18
5.5 Rain Gage Monitoring Results 18
6.0 Summary and Recommendations 18
7.0 References 20

Figures

Figure 1. Location of the Project Shoal Area 2
Figure 2. Well Locations, Shoal, Nevada 5
Figure 3. Cross Section A–A′ Depicting Monitoring Well and Shear Zone Location, Project Shoal Area, Nevada 6
Figure 4. Time-Concentration Plot of Tritium at Well HC-4 10
Figure 5. Hydrographs for Wells West of the Shear Zone 14
Figure 6. Hydrographs for Wells East of the Shear Zone 14
Figure 7. Hydrographs for Wells in Fourmile Flat 15
Figure 8. Well HC-4 Tritium Concentrations vs. Gallons Purged 17
Figure 9. Precipitation Data, August 8 Through September 13, 2012 19

Tables

Table 1. Radioisotopic and Chemical Sampling Results 2009 through 2012 9
Table 2. Uranium Isotopic Sampling Results, 2009 Through 2012 12
Table 3. Well Construction Details and September 2012 Head Data for Wells at the PSA 13

Appendixes

Appendix A Well Purge Data, Carbon-14 Calculation Data, Water Chemistry and Stable Isotope Data, and Carbon-14 Age Data
Appendix B Analytical Data: 2007 through Present
Appendix C Hydraulic Head Data: 1996 through Present
Appendix D Annual Water Level Changes in Wells West of Shear Zone: July 2007 through July 2012
Appendix E Single-Seismograph-Station Earthquake Reconnaissance at the Shoal Site
Appendix F NDEP Correspondence with Record of Review and Response to Comments

Abbreviations

AEC	U.S. Atomic Energy Commission
amsl	above mean sea level
bgs	below ground surface
BSZ	bottom of open interval/screen zone
CADD	Corrective Action Decision Document
CAP	Corrective Action Plan
CAU	Corrective Action Unit
DIC	dissolved inorganic carbon
DOC	dissolved organic carbon
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FFACO	Federal Facility Agreement and Consent Order
ft	feet
LM	Office of Legacy Management
MCL	maximum contaminant level
MDC	minimum detectable concentration
µg/L	micrograms per liter
µmhos/cm	micromhos per centimeter
MV	monitoring/validation
NA	not applicable
NDEP	Nevada Division of Environmental Protection
NR	not run
pCi/L	picocuries per liter
PM	particle motion
PSA	Project Shoal Area
RDL	required detection limit
s.u.	standard unit
SCM	site conceptual model
TOC	top of casing
TSZ	top of open interval/screen zone
TVD	true vertical depth

This page intentionally left blank

Executive Summary

The Project Shoal Area (PSA) in Nevada was the site of a 12-kiloton underground nuclear test in 1963. Although the surface of the site has been remediated, investigation of groundwater contamination resulting from the test is still in the corrective action process. Annual sampling and hydraulic head monitoring are conducted at the site as part of the subsurface corrective action strategy. Analytical results from the 2012 monitoring are consistent with those of the previous years, with tritium detected only in well HC-4. The tritium concentration in groundwater from well HC-4 remains far below the U.S. Environmental Protection Agency-established maximum contaminant level of 20,000 picocuries per liter. Concentrations of total uranium and gross alpha were also detected during this monitoring period, with uranium accounting for nearly all the gross alpha activity. The total uranium concentrations obtained from this monitoring period were consistent with previous results and reflect a slightly elevated natural uranium concentration, consistent with the mineralized geologic terrain. Isotopic ratios of uranium also indicate a natural source of uranium in groundwater, as opposed to a nuclear-test-related source. Water level trends obtained from the 2012 water level data were consistent with those of previous years.

The corrective action strategy for the PSA is currently focused on revising the site conceptual model (SCM) and evaluating the adequacy of the current monitoring well network. Some aspects of the SCM are known; however, two major concerns are the uncertainty in the groundwater flow direction and the cause of rising water levels in site wells west of the shear zone. Water levels have been rising in the site wells west of the shear zone since the first hydrologic characterization wells were installed in 1996. While water levels in wells west of the shear zone continue to rise, the rate of increase is less than in previous years. The SCM will be revised, and an evaluation of the groundwater monitoring network will be conducted when water levels at the site have stabilized.

This page intentionally left blank

1.0 Introduction

This report presents the 2012 groundwater monitoring results collected by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) at the Project Shoal Area (PSA) Subsurface Corrective Action Unit (CAU) 447 in Churchill County, Nevada. Responsibility for the environmental site restoration of the PSA was transferred from the DOE Office of Environmental Management to LM on October 1, 2006. The environmental restoration process and corrective action strategy for CAU 447 are conducted in accordance with the *Federal Facility Agreement and Consent Order (FFACO)* (NDEP 1996, as amended) and all applicable Nevada Division of Environmental Protection (NDEP) policies and regulations. The corrective action strategy for the site includes monitoring in support of future site closure. This report summarizes the results from the groundwater monitoring program during fiscal year 2012.

2.0 Site Location and Background

The PSA is south of U.S. Highway 50, approximately 30 miles southeast of Fallon, in Churchill County, Nevada (Figure 1). The Project Shoal underground nuclear test was performed on October 26, 1963, as part of the Vela-Uniform program sponsored jointly by the U.S. Department of Defense and the U.S. Atomic Energy Commission (AEC). The test consisted of detonating a 12-kiloton nuclear device in granitic rock at a depth of approximately 1,211 feet (ft) below ground surface (bgs) (AEC 1964). A cavity created by the test collapsed shortly after the detonation and formed a rubble chimney (Pohll et al. 1998). The radius of the cavity is reported to be 85 ft (26 meters) (Hazleton-Nuclear Science Corporation 1965).

Site deactivation and post-shot drilling activities began on October 28, 1963. Re-entry drilling indicated that the Shoal rubble chimney extended approximately 356 ft above the shot point (Hazleton-Nuclear Science Corporation 1965). A radioactive materials survey conducted at the site in 1970 indicated that there were no radiological levels that exceeded background for the area (AEC 1970). The decontamination and restoration activities were minimal, because no large areas of surface radiological contamination were found during or following the test. During this effort the emplacement shaft was covered with a concrete slab, and the particle motion (PM), exploratory core holes, and U.S. Bureau of Mines boreholes on the site were plugged and abandoned (AEC 1970).

2.1 Summary of Corrective Action Activities

Surface and subsurface contamination resulted from the underground nuclear test at PSA. To address these areas of contamination, surface and subsurface CAUs were identified, and the areas of contamination were addressed through separate corrective action processes. The surface CAU included three Corrective Action Sites that consisted of a mud pit with drilling mud impacted by petroleum hydrocarbons; a muckpile of granite that remained from excavation of the emplacement shaft; and housekeeping areas that consisted of approximately 20 rusted and empty oil cans. Remediation of surface CAU 416 was completed in 1998 and is summarized in the *Closure Report for CAU No. 416, Project Shoal Area* (DOE/NV 1998). NDEP approved the Closure Report on February 13, 1998, stating that no post-closure monitoring is required, and no land use restrictions apply at CAU 416 (NDEP 1998).

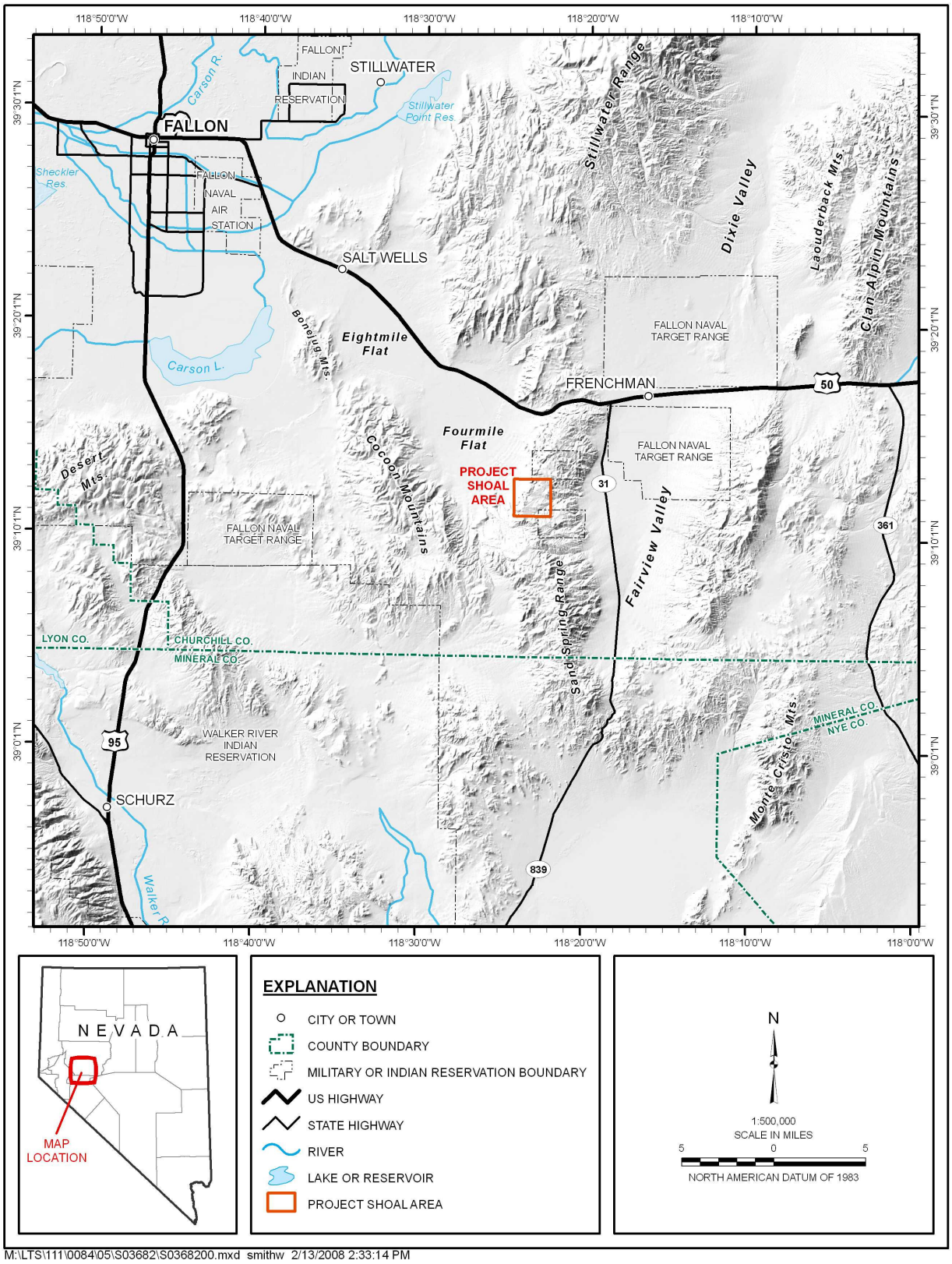


Figure 1. Location of the Project Shoal Area

The corrective action process for the subsurface has not been completed, and there is currently no known technology to remediate the remaining subsurface radioactive contamination at the site. The original corrective action strategy for the subsurface used a groundwater flow and transport model developed by Desert Research Institute to help evaluate data and select a corrective action alternative. The model results were used to determine a contaminant boundary and establish a restricted region surrounding the site. The contaminant boundary (Figure 2) is a probabilistic forecast of the maximum extent over 1,000 years of radionuclide transport where test-related radionuclides in groundwater outside the boundary have a 5 percent or less likelihood of exceeding the radiological standards of the Safe Drinking Water Act. NDEP approved the contaminant boundary as the compliance boundary in their letter dated January 19, 2005 (NDEP 2005). The corrective action alternative selected for the site includes monitoring with institutional controls and is presented in the Corrective Action Decision Document/Corrective Action Plan (CADD/CAP; DOE/NNSA 2006).

As part of the original corrective action strategy, three monitoring/validation (MV) wells (MV-1, MV-2, and MV-3) were installed in 2006 for the dual purpose of monitoring for contaminant migration and evaluating the flow and transport model results. The site conceptual model (SCM) is being reevaluated to address inconsistencies with the numerical model predictions and monitoring well data. Concerns with the model stem from two observations. First, the horizontal component of groundwater flow predicted by the model was primarily toward the north-northeast, whereas horizontal gradients inferred from water levels measured in site wells do not support the modeled flow direction. Second, the model incorrectly assumed that the groundwater flow system is in a steady state; in fact, water levels west of the shear zone have been rising approximately 1 to 2 ft per year during the time they have been monitored, beginning with the installation of the HC wells in the late 1990's. Water levels were not monitored at the site, except for the adjacent valleys, prior to the installation of the HC wells and later MV wells. Pursuant to the FFACO (NDEP 1996, as amended), LM began implementing a new corrective action strategy for the site in 2009.

On November 24, 2009, LM submitted an initial Short-Term Data Acquisition Plan to NDEP, detailing data collection activities that included a surface geophysical program and enhanced groundwater monitoring. The completed geophysical program included seismic and electromagnetic surveys. As part of the evaluation of data obtained from the surveys, a technical exchange meeting was conducted in March 2011 with the geophysicists who performed the surveys (Lee Liberty from Boise State University and Jim Hasbrouck from Hasbrouck Geophysics), Desert Research Institute, and NDEP to discuss the results and potential site conceptual models. During the meeting it was agreed that further understanding of the groundwater flow system was needed for the enhancement of potential SCMs and that a new Short-Term Data Acquisition Plan was necessary to outline future activities at the site. The Surface Geophysics Report recommended that geophysical data be evaluated further and compared to existing data to assess and enhance any potential SCMs (DOE 2011b). The technical exchange and Surface Geophysics Report provided the basis for developing the new Data Acquisition Plan that was submitted to NDEP in October 2011.

The 2011 data acquisition plan includes further review of available reports and assembling a detailed information resource tool that includes a summary of pertinent technical data. Analytical, hydrologic, and geologic data obtained from the evaluation of historical reports will be reviewed with existing data and collected geophysical data to help identify geologic structures that might be influencing groundwater flow at the site. These data will be assembled for three-

dimensional visualization. Revisions to the SCM and enhancements to the monitoring well network will be provided to NDEP in an addendum to the CADD/CAP (DOE/NNSA 2006).

3.0 Geologic and Hydrologic Setting

The PSA is in the northern portion of the Sand Springs Range in west-central Nevada's Churchill County. The Sand Springs Range is the southern extension of the Stillwater Range, a north-northeast-trending fault block range that traverses Churchill County. The Sand Springs Range rises to an elevation of approximately 6,751 ft above mean sea level (amsl) and is flanked by Fourmile Flat to the west and Fairview Valley to the east (Figure 1). The Shoal site is in Gote Flat at an elevation of approximately 5,250 ft amsl and is within an area that is part of the Cretaceous-age Sand Springs granitic batholith.

The Sand Springs batholith is composed of granodiorite and granite, aplite, and pegmatite dikes; andesite dikes; rhyolite dikes; and rhyolitic intrusive breccia. Internal deformation of the Sand Springs granite is largely by high-angle normal faults and fractures distributed between two dominant structural trends that strike approximately N 50° W and N 30° E and are vertical to steeply dipping. Several dikes of varying composition predominantly follow the same two orientations and intrude along these lines of preexisting weakness. These orthogonal-type sets of faults and fractures appeared early in the history of the Sand Springs granite and affected much of the subsequent structural and chemical evolution of this large intrusion (Beal et al. 1964).

The water table beneath the site (near surface ground zero and west of the shear zone) occurs at depths ranging from approximately 965 to 1,090 ft bgs, and groundwater moves primarily through fractures in the granite. Recharge occurs by infiltration of precipitation on the mountain range, and regional discharge occurs in the adjacent valleys. A shear zone, located about 1,500 ft east of surface ground zero (Figure 2 and Figure 3), is interpreted as a barrier to groundwater flow due to disparate head levels in wells separated by the shear zone (Carroll et al. 2001). Groundwater within Fairview Valley to the east has been used for ranching, seasonal residential purposes, and military purposes within the last 5 years.

4.0 Monitoring Program and Objectives

The primary objectives of the monitoring program are (1) "detection monitoring" to identify any migration of radiologic contamination from the test cavity and (2) "system monitoring" to obtain hydraulic head data for monitoring the overall stability (quasi-steady state) of the hydrogeologic system. The monitoring program and objectives were established in the CADD/CAP, and the program was initiated after NDEP approved the CADD/CAP and wells MV-1, MV-2, and MV-3 were installed in 2006. Enhancements were made to the monitoring program after the numerical model could not be verified against data obtained from the MV wells (MV-1, MV-2, and MV-3). The enhancements are documented in short-term data acquisition plans that were completed in 2009 and 2011 to support the CADD/CAP and provide interim guidance documents until an addendum to the CADD/CAP can be completed. The *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites* (LMS/PLN/S04351) is used to guide the quality assurance/quality control of the annual sampling and monitoring program.

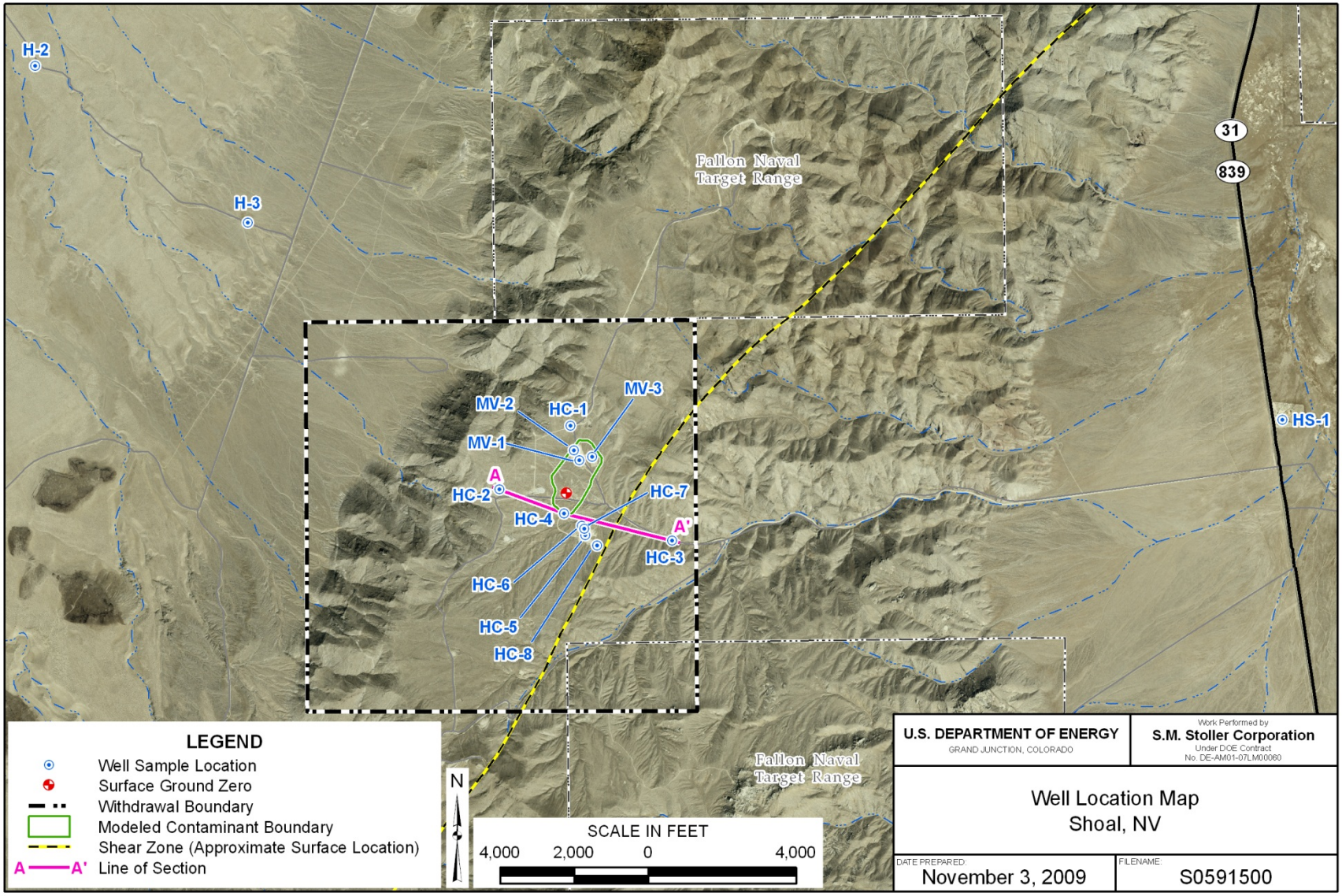


Figure 2. Well Locations, Shoal, Nevada

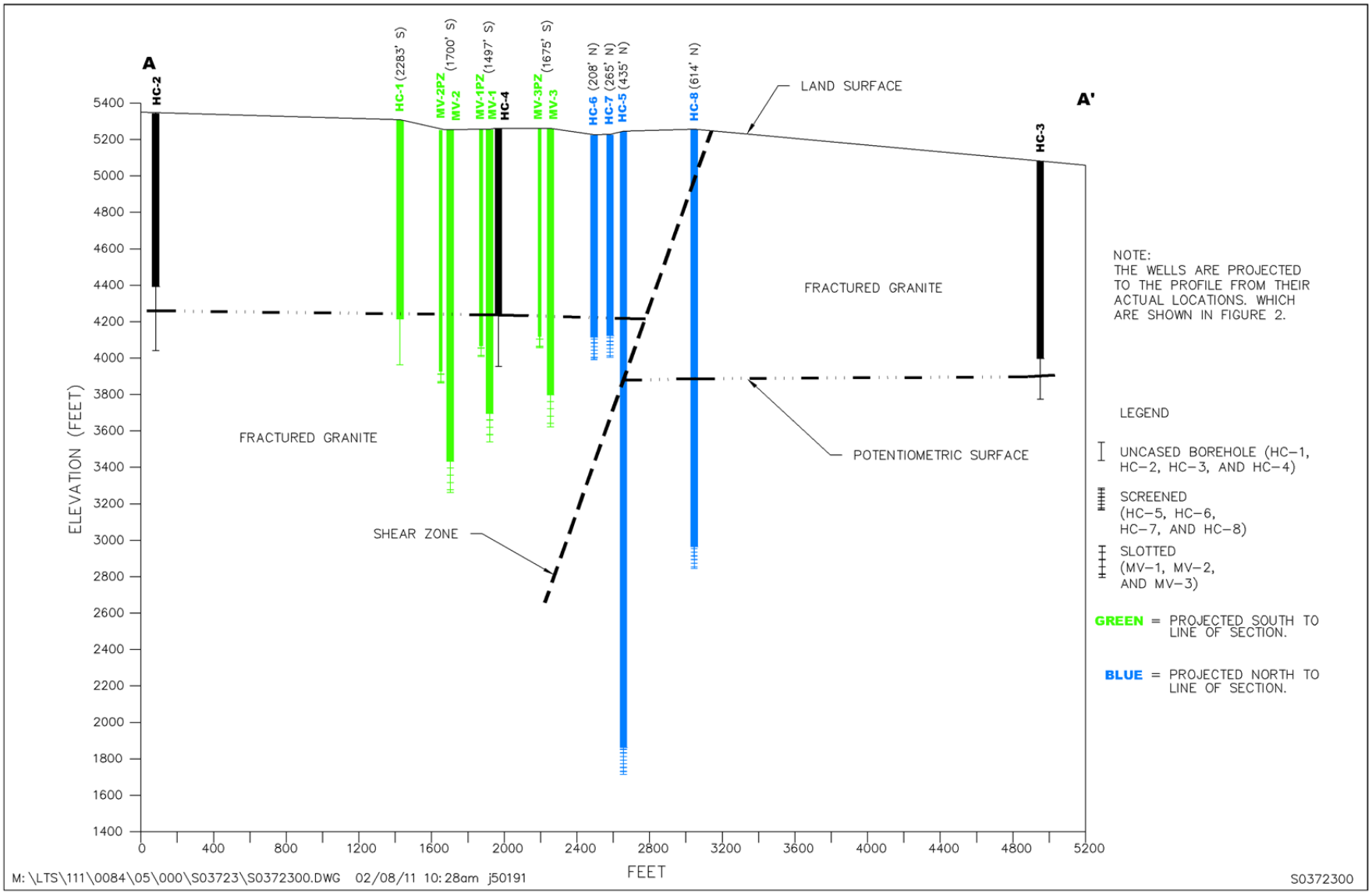


Figure 3. Cross Section A–A' Depicting Monitoring Well and Shear Zone Location, Project Shoal Area, Nevada

The corrective action strategy is focused on revising the SCM and evaluating the adequacy of the current monitoring well network. Aspects of the SCM are currently known; however, two major concerns are the uncertainty in the groundwater flow direction and the cause of the rising water levels in site wells that are west of the shear zone. Water levels have been rising in the site wells west of the shear zone since the first wells were installed in 1996. LM continues to evaluate site data to enhance the SCM and monitor water levels as part of the ongoing groundwater monitoring program at the site. The 2012 monitoring program was enhanced to include supplemental activities that were specified in the Short-Term Data Acquisition Plan (DOE 2011a). Results from the monitoring program are provided below, and results from the supplemental activities are provided in Section 5.0.

4.1 Radioisotopic Monitoring

Groundwater samples were collected from wells MV-1, MV-2, MV-3, HC-1, HC-2, HC-3, HC-4, HC-5, HC-6, HC-7, and HC-8 during the May 2012 sampling event. Monitoring wells MV-1, MV-2, MV-3, HC-4, HC-5, HC-7, and HC-8 were purged prior to sampling using dedicated submersible pumps. At least one well casing volume was removed, and field parameters (temperature, pH, and specific conductance) were allowed to stabilize before samples were collected. Well HC-7 was an exception because the well was purged overnight and a total of approximately seven well casing volumes (2,200 gallons) of water were removed before samples were collected (Appendix A; Table A–1). Samples were collected from wells HC-1, HC-2, HC-3, and HC-6 using a depth-specific bailer because these wells are not completed with dedicated submersible pumps. The analytical results obtained from the annual sampling were validated in accordance with the *Environmental Procedures Catalog* (LMS/PRO/S04325), "Standard Practice for Validation of Laboratory Data." A copy of the Data Validation Package is maintained in the LM records and is available on request. The final set of field parameters and well purge volumes are presented in Appendix A.

Groundwater samples collected as part of the annual monitoring event were analyzed for tritium, uranium isotopes, gross alpha, and mass concentrations of uranium as specified in the Short-Term Data Acquisition Plans (DOE 2009 and 2011a), which enhanced the monitoring network defined in the CADD/CAP (DOE/NNSA 2006). The Short-Term Data Acquisition Plans also reduced the frequency for analyzing samples for carbon-14 (^{14}C) and iodine-129 (^{129}I) to every 5 years beginning after the 2010 sampling event (DOE 2009 and 2011a). However, samples were analyzed for ^{14}C as part of the supplemental activities conducted during this annual monitoring event. Tritium is the analyte selected as an indicator of contaminant migration from the cavity due to its mobility and abundance in the first 100 years of the post-shot monitoring period. However, because of tritium's short half-life, monitoring of ^{14}C and ^{129}I is also conducted in support of long-term post-closure monitoring. Gross alpha is included in the analytical suite because elevated concentrations of gross alpha have been detected in the past at the PSA. The U.S. Environmental Protection Agency (EPA)-established maximum contaminant level (MCL) for gross alpha is exclusive of uranium and radon. Including uranium and uranium-isotopic analyses as part of the analytical suite provides data to demonstrate that the elevated concentrations of gross alpha are from natural sources. Radon is not included in the analytical suite because it volatilizes during analysis and is an insignificant contributor to gross alpha.

The CADD/CAP established regulatory levels for site groundwater of 20,000 picocuries per liter (pCi/L) tritium, 2,000 pCi/L ^{14}C, and 1 pCi/L ^{129}I (DOE/NNSA 2006). These levels are not to be exceeded outside the compliance boundary, which is the modeled contaminant boundary

(Figure 2). The EPA-established MCLs for gross alpha and uranium are 15 pCi/L and 30 micrograms per liter (µg/L), respectively. These constituents are believed to be naturally elevated in groundwater in the region. The LM required detection limit (RDL) for tritium is 400 pCi/L, which is slightly higher than the limit of 300 pCi/L established in the CADD/CAP. A record of technical change was submitted to NDEP to change the RDL to 400 pCi/L in the CADD/CAP. The laboratory radiochemical minimum detectable concentration (MDC) reported with these data is an a priori estimate of the detection capability of a given analytical procedure, not an absolute concentration that can or cannot be detected.

4.2 Radioisotopic Results

Table 1 presents a summary of analytical results for ^{14}C, ^{129}I, tritium, uranium, and gross alpha that were obtained from the recent sampling events conducted in 2009 through 2012. Analytical results obtained from when the CADD/CAP monitoring program began in 2007 through the present are provided in Appendix B. A time-concentration plot for well HC-4 (Figure 4) presents tritium results obtained from the CADD/CAP monitoring program and sampling events performed by the EPA and Desert Research Institute before the CADD/CAP monitoring program was initiated in 2007. Well HC-4 was installed in 1996 and is the only well that has had detections of tritium above the laboratory's MDC using conventional laboratory methods. The presence of tritium in this well is attributed to its proximity to the nuclear detonation (Figure 2). This interpretation of the tritium source is supported by the elevated levels of ^{14}C detected in samples collected from well HC-4 compared to levels in samples from the other monitoring wells (Table 1 and Appendix A, Table A–2). The elevated concentration of ^{14}C in this well is likely the result of its migration in the gas phase near the water table, as part of the CO_2 molecule, where it dissolved into groundwater in the upper saturated zone near the detonation.

Samples collected from well HC-4 during the May 2012 sampling event were the only samples with tritium detected above the laboratory's MDC. Tritium levels in well HC-4 (Figure 4) were typically above laboratory MDCs from the mid-1990s until 2006, though some duplicate analyses were below MDCs. Tritium levels have been trending lower and were below the laboratory MDC for the 2005 and 2007 sampling events (Figure 4). Of the two samples analyzed in 2008 (one by the EPA and one by Paragon), results were above the MDC for one sample and below the MDC for the other. Since 2008, tritium results have increased from a concentration that was below the laboratory MDC in 2007 to concentrations above the MDC, ranging from 434 pCi/L in 2009 to 803 pCi/L in 2012. The variation in tritium concentrations in this well is likely related to the different volumes of groundwater removed during the sampling events. The highest tritium concentration of 1,130 pCi/L was from a sample collected in 1997 by Desert Research Institute after approximately 1,100 gallons of groundwater were removed during an aquifer test. The volume of groundwater removed from well HC-4 was increased during the 2012 sampling event to 700 gallons (1 well volume), which resulted in a tritium concentration of 803 pCi/L, higher than results from previous lower purge volume samples. From 2007 through 2011 the well purge volumes for this well ranged from 200 to 420 gallons. These volumes were less than one well volume because of a misunderstanding in the well configuration. The samplers assumed that the 5.5-inch casing diameter at the surface extended to the total depth of the borehole. However, the 5.5-inch casing only extends to 1,013 ft bgs, with open 8-inch borehole from 1,013 to 1,303 ft bgs. The assumed smaller radius for the entire well resulted in a purge volume calculation less than one well volume. The well purge volumes are not available for samples collected by EPA prior to 2007, with the exception of the sample collected by Desert Research Institute in 1997.

Table 1. Radioisotopic and Chemical Sampling Results 2009 through 2012

Monitoring Location	Date	Carbon-14 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)	Uranium (µg/L)	Gross Alpha (pCi/L)
MV-1	2/26/2009	<RDL (1.95E-02)	<RDL (10.5E-11)	<350	21	12.6
	3/11/2010	<RDL (1.93E-02)	<RDL (7.8E-11)	<300	21	11.3
	3/22/2011	NA	NA	<350	25	16.6
	3/22/2011[c]	NA	NA	<360	25	14.3
	5/25/2012	NA	NA	<300	22	14.3
MV-2	2/26/2009	<RDL (2.13E-02)	NR	<360	24	12
	3/11/2010	<RDL (3.31E-02)	<RDL16.5 (E-11)	<300	21	13.8
	3/22/2011	NA	NA	<350	23	9.92
	5/24/2012	NA	NA	<300	22	10.6
MV-3	2/26/2009	<RDL (8.37E-03)	<RDL (10.7E-11)	<360	3.8	<1.5
	3/12/2010	<RDL (1.29E-02)	<RDL (6.5E-11)	<300	4.2	2.63
	3/22/2011	NA	NA	<350	5.8	4.98
	5/25/2012	<RDL (1.06E-02)	NA	<300	7	2.72
HC-1	2/26/2009	<RDL (2.01E-02)	NR	<360	1.4	<1.4
	3/24/2010	<RDL (3.18E-02)	<RDL (11.9E-11)	<310	3.3	4.93
	3/22/2011	NA	NA	<360	1.6	2.19
	5/23/2012	<RDL (1.23E-02)	NA	<300	1.1	<0.75
HC-2	3/24/2010	<RDL(1.90E-02)	<RDL (2.5E-11)	<300	140	63.8
	3/22/2011	NA	NA	<360	120	197
	5/22/2012	NA	NA	<300	110	64.5
HC-3	3/24/2010	<RDL (2.37E-02)	<RDL (541E-11)	<300	4.3	2.57
	3/22/2011	NA	NA	NA	NA	NA
	5/23/2012	<RDL (1.45E-02)	NA	<300	2	0.283
HC-4	2/26/2009	<RDL (3.20)	<RDL (0.6E-11)	434	2.0	<1.4
	3/11/2010	<RDL (2.93)	<RDL (38.7E-11)	544	6.4	1.79[b]
	3/23/2011	NA	NA	554	8.9	3.82
	5/24/2012[c]	NA	NA	774	46	16.7
	5/24/2012	<RDL (2.50)	NA	803	46	22.9
HC-5	3/11/2010	<RDL (5.11E-03)	<RDL (1.1E-11)	<300	0.48	<1.5
	3/23/2011	NA	NA	<360	0.45	<2.1
	5/23/2012	<RDL (3.70E-03)	NA	<300	0.49	0.349
HC-6	3/24/2010	<RDL (1.14E-02)	<RDL (5.6E-11)	<300	35	25.7
	3/23/2011	NA	NA	<360	37	20.4
	5/23/2012	<RDL (1.16E-02)	NA	<300	38	14.1
HC-7	3/11/2010	<RDL (5.31E-03)	<RDL (3.0E-11)	<300	7.4	5.77
	3/23/2011	NA	NA	<360	13	10.6
	5/23/2012	NA	NA	<300	41	23.9
HC-8	3/10/2010	<RDL (9.63E-03)	<RDL (1.3E-11)	<300	0.25	<1.3
	3/23/2011	NA	NA	NA	NA	NA
	5/25/2012	NA	NA	<300	0.2	0.454

[b] Indicates the sample was filtered.
[c] Indicates a duplicate sample.
<RDL = below required detection limit with laboratory result in parentheses; RDL is 5 pCi/L for ^{14}C, 0.1 pCi/L for ^{129}I, 300 pCi/L for tritium, 50 µg/L for uranium, and 4 pCi/L for gross alpha (DOE/NNSA 2006)
NR = not run, because sample bottle was broken during shipment to the laboratory
NA = not applicable (samples not collected or samples not analyzed)

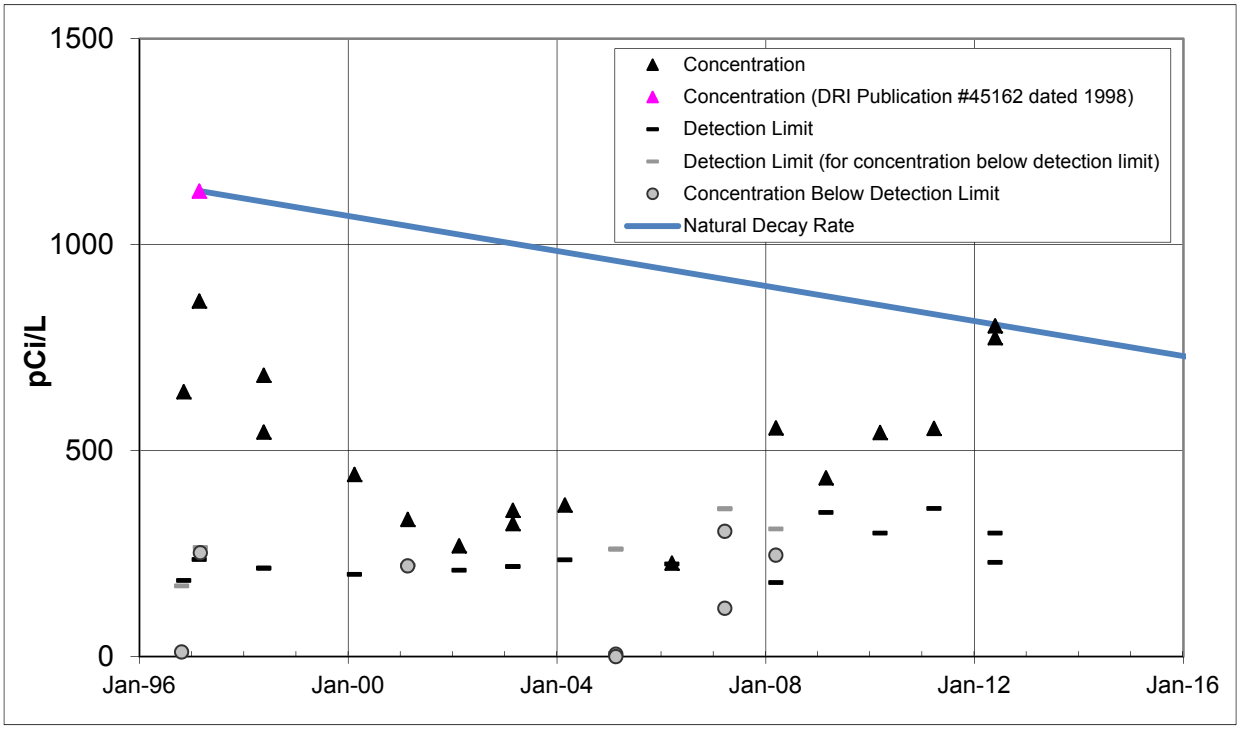


Figure 4. Time-Concentration Plot of Tritium at Well HC-4

The tritium concentrations observed in 2012 are more consistent with the natural decay rate of tritium when projected forward from the highest concentration in 1997 (Figure 4) though several more sampling events at a consistent purge volume will be needed to confirm the trend. Section 5.0 presents additional information that supports the hypothesis that tritium concentrations in this well are affected by the volume of groundwater purged.

Samples collected from wells MV-1 and MV-2 in 2007 (Appendix B, Table B–1) had detectable gross alpha and uranium mass concentrations above the EPA-established MCLs of 15 pCi/L and 30 µg/L, respectively. Concentrations in samples collected from these wells in 2008 declined below the EPA-established MCLs and have remained relatively constant since then with the exception of the sample collected from well MV-1 in 2011 that detected gross alpha (16.6 pCi/L) above the EPA-established MCL of 15 pCi/L. Analytical results obtained from the 2012 sampling event (Table 1) indicate that gross alpha and uranium mass concentrations were detected above the EPA-established MCL in the samples collected from wells HC-2, HC-4, and HC-7. Historically, samples collected from well HC-2 have had concentrations of gross alpha and uranium above the EPA-established MCLs, and this trend continued in 2012. The concentration of gross alpha detected in the sample collected from well HC-2 decreased from the result obtained in 2011 and is consistent with the result obtained in 2010. The increased concentration in gross alpha observed in 2011 is attributed to the use of a different bailer than was used during the 2010 and 2012 sampling events. Several attempts were required to get the bailer to fill in 2011, increasing turbidity of the sample. Analytical results obtained from samples collected from wells HC-4 and HC-7 indicate an increase in gross alpha and uranium concentrations from previous sampling events. These increases may be attributed to an increase in the volume of groundwater removed from the wells during sampling (Appendix A; Table A–1). Uranium was also detected above the EPA-established MCL in the sample collected from well HC-6, which is consistent with the historical trend. The analytical results for gross

alpha and uranium that were obtained from the 2012 sampling event are consistent with the previous results, with the exception of samples collected from wells HC-4 and HC-7.

Bevans et al. (1998) demonstrated that ambient groundwater in the region surrounding the site is elevated in concentrations of gross alpha and uranium. The elevated uranium concentrations are attributed to leaching from granitic bedrock and associated sediments. If the gross alpha values obtained from samples collected from wells HC-2, HC-4, and HC-7 (Table 1) are adjusted by subtracting activities of ^{234}U and ^{238}U shown in Table 2, values are less than zero, indicating that uranium accounts for all or nearly all gross alpha activity in these samples (refer to example below for adjusted results). Isotopic ratios of uranium further support the interpretation of a natural source of uranium in groundwater rather than a nuclear-test-related source. Natural uranium-bearing systems typically have $^{234}U/^{238}U$ activity ratios near 1 (Cowart and Osmond 1977), which is indicative of secular equilibrium between the two isotopes. Table 2 indicates that most ratios observed in the samples range from 0.91 to 2.77—consistent with a natural uranium source. In contrast, average estimates of radionuclides resulting from nuclear tests at the Nevada National Security Site suggest a residual source term with a $^{234}U/^{238}U$ activity ratio of 56.25 (Smith 2001).

Example Calculation: Gross Alpha (pCi/L) – ^{234}U (pCi/L) – ^{238}U (pCi/L) = Adjusted Result

HC-2:	*64.5 – 38.1 – 36.2 = -9.8*
HC-4:	*22.9 – 14.2 – 14.8 = -6.1*
HC-7:	*23.9 – 16.1 – 13.9 = -6.1*

Note: Adjusted gross alpha results can be <0 due to laboratory measurement uncertainty.

4.3 Hydraulic Head Monitoring

Monitoring of the groundwater flow system was performed by measuring hydraulic head in the onsite wells/piezometers (MV-1 through MV-3 and HC-1 through HC-8) and offsite wells (H-2 and H-3) (Figure 2). Heads were recorded every 3 hours by transducers installed in these wells/piezometers. Water levels were measured manually, and transducers were downloaded in May as part of the annual sampling and in September as part of a scheduled monitoring event and site inspection. The manual water level measurements were collected prior to conducting activities that would disturb ambient water level conditions. The manual water level measurements were used to convert the transducer data to groundwater elevations.

4.4 Hydraulic Head Results

Table 3 presents well construction information and the most recent hydraulic head data, obtained in September 2012. Hydrographs of hydraulic head data obtained from site wells and piezometers from when the CADD/CAP monitoring program was initiated in 2007 are shown in Figure 5, Figure 6, and Figure 7. Head data collected using a water level tape appear as individual symbols, and data collected with transducers appear as lines due to the recording frequency of every few hours. The hydrographs are grouped according to the location of the open interval of each well relative to the north-northeast-trending shear zone that transects the site. Monitoring locations west of the shear zone include the MV-1, MV-2, and MV-3 wells and piezometers and wells HC-1, HC-2, HC-4, HC-6, and HC-7 (Figure 5). Head levels east of the shear zone are monitored by wells HC-3, HC-5, and HC-8 (Figure 6). Monitoring locations in Fourmile Flat (west of the site) include the H-2 and H-3 wells (Figure 7). The hydrograph for the MV-2 piezometer was added to Figure 5 this year and it currently is the highest water level at the

site. The water level in this piezometer was recovering very slowly after its installation and water was added in several stages until it began to take water, resulting in the current slowly declining water level that is not indicative of the head level in the formation at its screened interval. Once the water level stops declining and stabilizes, or begins to rise, the water level may then be representative of the formation at its screened interval. However, it may always be suspect due to the lack of fractures and low permeability of the MV-2 piezometer open interval.

Table 2. Uranium Isotopic Sampling Results, 2009 Through 2012

Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	$^{234}U/^{238}U$
MV-1	2/26/2009	8.75	6.98	1.25
	3/11/2010	9.06	7.64	1.19
	3/22/2011	10.8	8.89	1.21
	3/22/2011[b]	10.4	8.77	1.19
	5/25/2012	8.14	6.81	1.20
MV-2	2/26/2009	8.64	6.7	1.29
	3/11/2010	9.66	8.32	1.16
	3/22/2011	10.1	8.65	1.17
	5/24/2012	7.9	7.01	1.13
MV-3	2/26/2009	1.33	0.998	1.33
	3/12/2010	1.7	1.42	1.20
	3/22/2011	2.55	2.2	1.16
	5/25/2012	2.49	2.3	1.08
HC-1	2/26/2009	0.572	0.385	1.49
	3/24/2010	1.24	1.05	1.18
	3/22/2011	0.9	0.609	1.48
	5/23/2012	0.401	0.35	1.15
HC-2	3/24/2010	45.1	45.3	0.996
	3/22/2011	45.2	45.3	0.998
	5/22/2012	38.1	36.2	1.05
HC-3	3/24/2010	1.16	1.21	0.96
	3/22/2011	NA	NA	NA
	5/23/2012	0.678	0.668	1.01
HC-4	2/26/2009	0.654	0.722	0.91
	3/11/2010	2.27[a]	1.95[a]	1.16[a]
	3/23/2011	2.69	2.86	0.941
	5/24/2012[b]	14.4	15.1	0.95
	5/24/2012	14.2	14.8	0.96
HC-5	3/11/2010	0.295	0.173	1.71
	3/23/2011	0.264	0.117	2.26
	5/23/2012	0.227	0.126	1.80
HC-6	3/24/2010	14.4	12.2	1.18
	3/23/2011	15.4	13.5	1.14
	5/23/2012	14.4	12.2	1.18
HC-7	3/11/2010	3.43	3.08	1.11
	3/23/2011	5.9	4.78	1.23
	5/23/2012	16.1	13.9	1.16
HC-8	3/10/2010	0.187	0.101	1.85
	3/23/2011	NA	NA	NA
	5/25/2012	0.153	0.0553	2.77

[a] Indicates the sample was filtered.
[b] Indicates a duplicate sample.
NA = not applicable (samples not collected or samples not analyzed)

Table 3. Well Construction Details and September 2012 Head Data for Wells at the PSA

Well/Piezometer	TOC Elevation (ft amsl)	Water Depth (ft)[a]	Date	Elevation Water (ft amsl)[b]	Elevation TSZ (ft amsl)	Elevation BSZ (ft amsl)	Screen Length (ft)
MV-1	5,257.54	990.86	9/14/2012	4,266.68	3,684.81	3,531.00	153.81
MV-1 PZ	5,257.30	974.47	9/14/2012	4,282.83	3,919.80	3,859.80	60.00
MV-2	5,266.62	1,000.27	9/14/2012	4,266.35	3,446.75	3,275.98	170.77
MV-2 PZ	5,266.51	971.75[c]	9/14/2012	4,294.76[c]	4,078.82	4,019.32	59.50
MV-3	5,261.50	972.11	9/14/2012	4,289.39	3,797.91	3,626.75	171.16
MV-3 PZ	5,261.17	971.61	9/14/2012	4,289.56	4,120.75	4,060.72	60.03
HC-1	5,309.21	1,061.44	9/14/2012	4,268.98	4,236.01	3,997.12	238.89
HC-2	5,347.12	1,083.49	9/14/2012	4,264.07	4,392.12	4,124.12	268.00
HC-3	5,081.52	1,180.52	9/14/2012	3,921.00	3,918.52	3,898.02	20.50
HC-4	5,260.90	1,007.75	9/14/2012	4,256.95	4,247.90	3,957.90	281.00
HC-5	5,247.37	1,368.72	9/14/2012	3,878.65	1,862.37	1,716.77	145.60
HC-6	5,228.68	966.04	9/14/2012	4,263.53	4,112.70	3,996.38	116.32
HC-7	5,229.72	966.15	9/14/2012	4,263.80	4,123.25	4,006.12	117.13
HC-8	5,259.91	1,370.80	9/13/2012	3,889.67	2,965.51	2,848.99	116.52
H-2	4,017.06[d]	110.02	9/13/2012	3,907.04	3,377.06	3,237.06	140.00
H-3	4,232.30[d]	325.65	9/13/2012	3,906.65	3,919.30	3,762.30	157.00

[a] Depth-to-water measurements not corrected for borehole deviation. Depth-to-water measurements were collected prior to performing activities that disturb ambient water level conditions.
[b] Corrected for borehole deviation.
[c] Indicates the water level and/or groundwater elevation have not recovered from bailing.
[d] Indicates land surface elevation because TOC elevations are not available.
BSZ = (bottom of open interval; screened, perforated, or open hole)
NM = Not measured
TOC = top of casing (well/piezometer)
TSZ = (top of open interval; screened, perforated, or open hole)
Elevation Water (true vertical depth [TVD] corrected), Water Depth (not TVD corrected)

Water levels in onsite wells west of the shear zone (detonation side) continued to rise from 0.94 ft in MV-2 to 2.10 ft in MV-1PZ (July 2011 to July 2012). The increase was more than the previous year for most wells, reversing the declining rate of rise that had been observed since 2007 when the water level monitoring program began. Water levels in wells west of the shear zone at the site are 300 to 400 ft higher than those in wells east of the shear zone and in wells west of the site in Fourmile Flat. Refer to Appendix C for hydraulic head data from 1996 to the present. Refer to Appendix D for a table showing annual water level changes in wells west of the shear zone from July 2007 through July 2012.

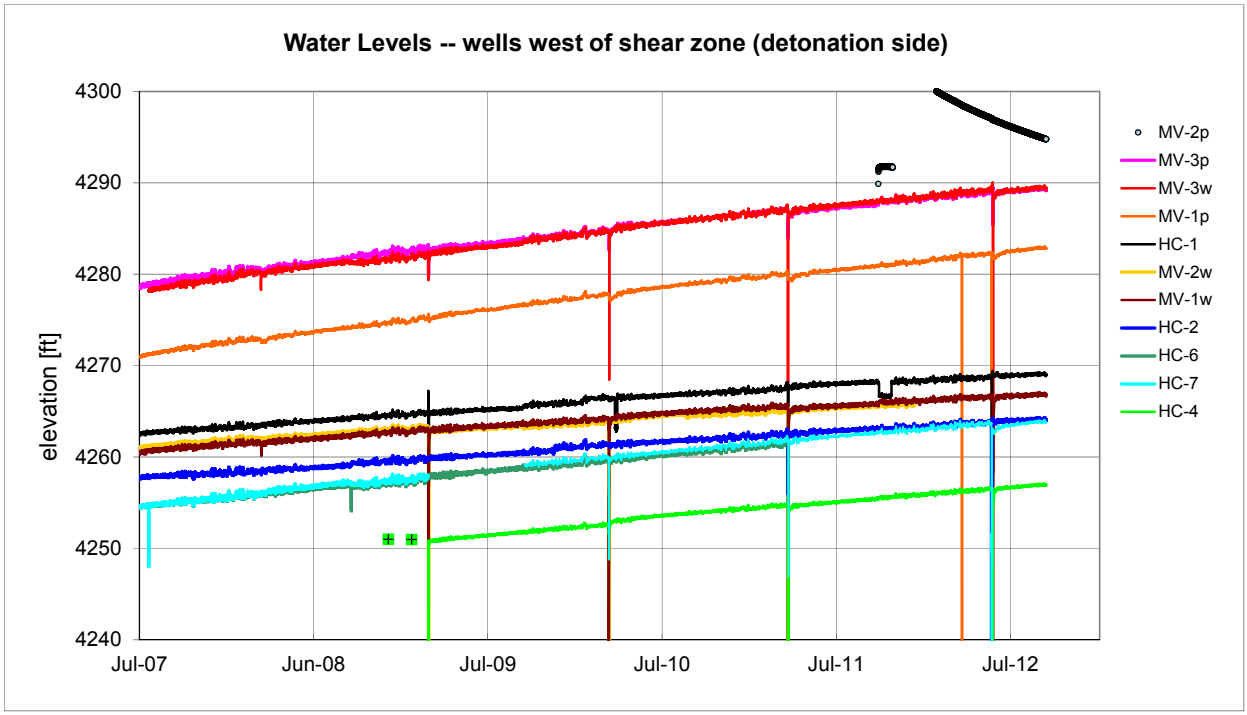


Figure 5. Hydrographs for Wells West of the Shear Zone

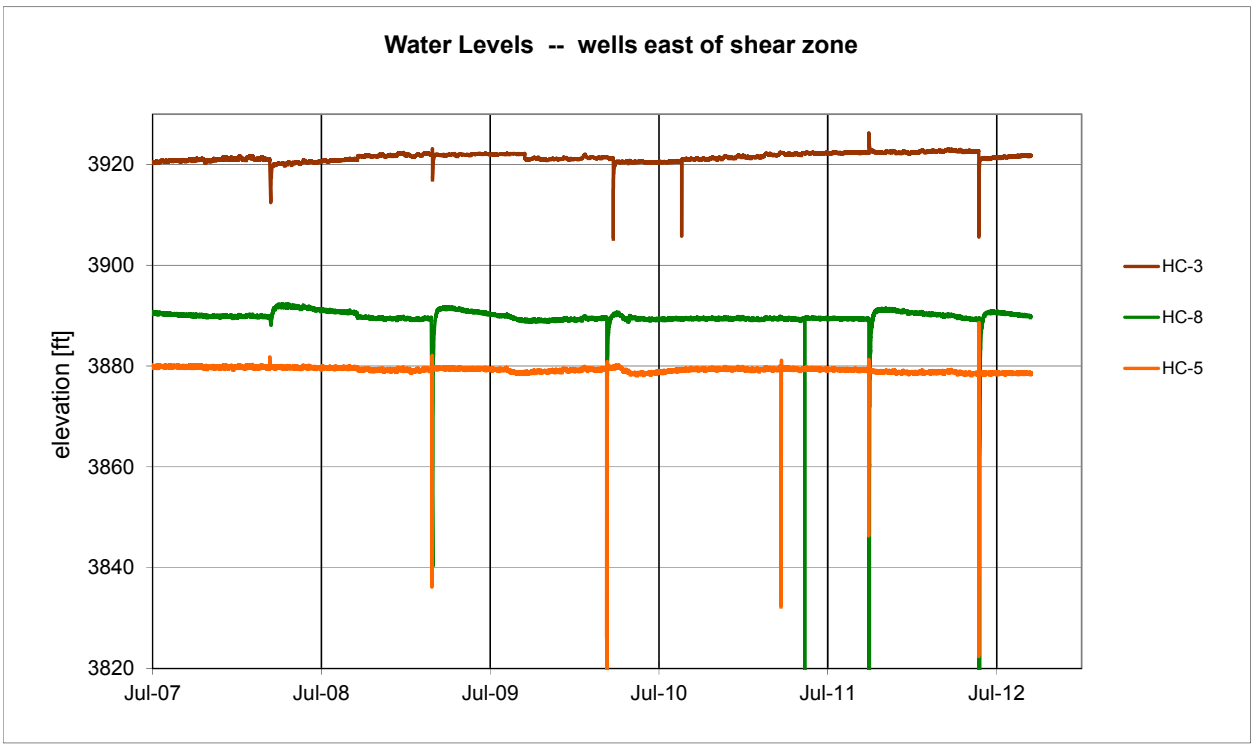


Figure 6. Hydrographs for Wells East of the Shear Zone

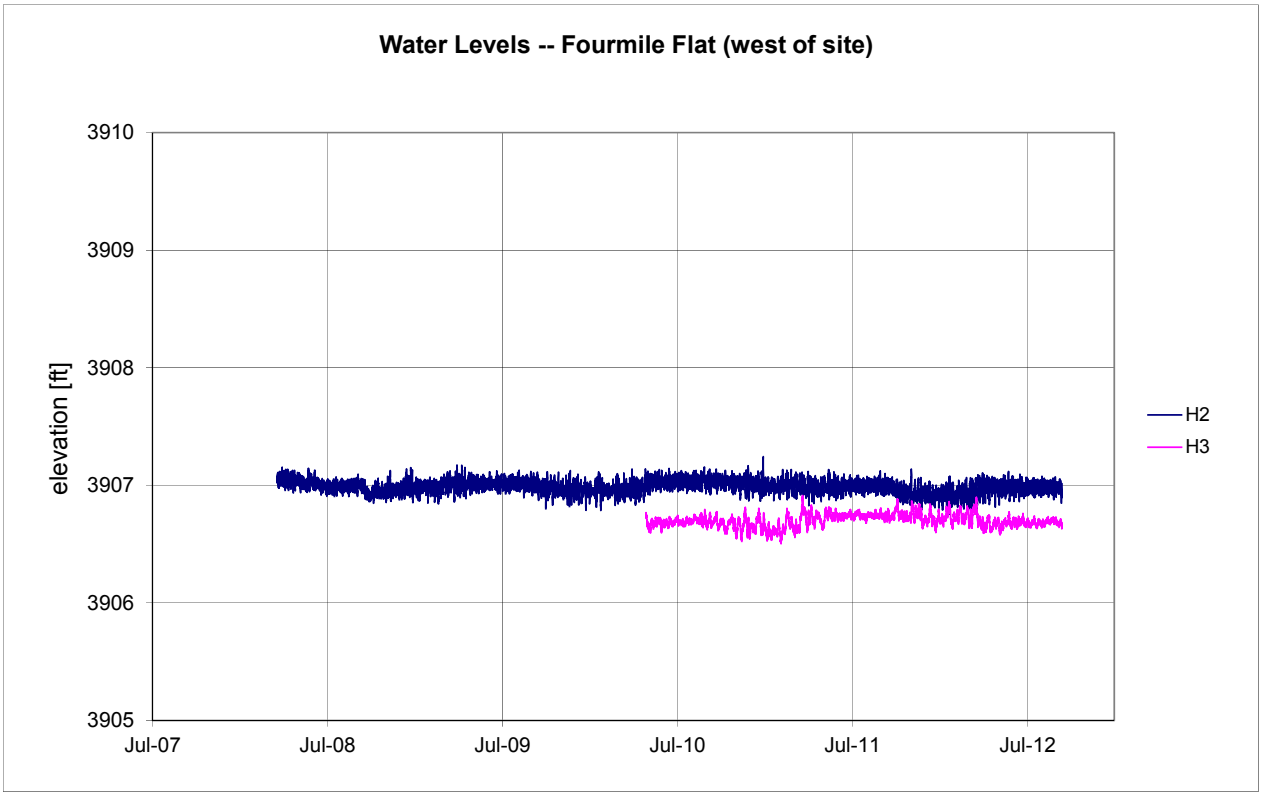


Figure 7. Hydrographs for Wells in Fourmile Flat

5.0 Site Inspection and Supplemental Site Activities

A site inspection was conducted as part of the fall monitoring event that included measuring water levels, downloading transducers and recently installed rain gage, and inspecting the recently installed seismograph station, roads, wellheads, and monument at surface ground zero for signs of damage. The seismograph station, rain gage, roads, wellheads, and monument were all in good condition at the time of the inspection. Supplemental activities performed during this annual monitoring period included an enhanced analytical suite, inclusion of selected piezometers (MV-1PZ and MV-3PZ) to the sampling network, extended purge with additional sampling of well HC-4, additional infiltration testing near well HC-8, and installation of a surface seismograph station and rain gage at the site. Results from the supplemental activities are provided in the following sections.

5.1 Enhanced Analytical Suite and Sampling Network

This sampling event was enhanced by including additional locations that are not typically sampled (the MV-1PZ and MV-3PZ piezometers) and by adding analyses for major ions for all sampled locations in an effort to provide water chemistry data to help delineate site structures. The 3D visualization of faults and dikes along with hydrograph data from wells and piezometers suggest there may be faults at the site that significantly influence groundwater flow. These interpretations would be supported if wells in different fault blocks have different water chemistry and wells in the same fault block have similar water chemistry. Additionally, samples were analyzed for stable isotopes of oxygen and hydrogen, and carbon-13 (^{13}C) and ^{14}C to age

date the water. Refer to Table A–3 in Appendix A for a summary of the water chemistry, stable isotope data, and last set of field parameters (pH, temperature, and specific conductance) obtained from the annual sampling event. The analysis of ^{14}C in dissolved organic carbon (DOC) is believed to provide a more reliable age date of water than dissolved inorganic carbon (DIC) analysis. The DOC fraction in groundwater is less susceptible to reactions within the aquifer, and as a result, the DOC age dates are thought to be more accurate than those based on DIC measurements (Burr et al. 2001). Ages from DOC ^{14}C analysis are typically younger than those from analysis of DIC and this relationship was evident in the results from the Shoal samples. Refer to Table A–4 in Appendix A for a summary of the ^{13}C and ^{14}C results from DOC and DIC with the apparent age dates obtained from the annual sampling event.

Current site conceptual models are based on the concept that older water is present at deeper depths and younger water is present at shallower depths in the saturated zone due to the contribution from more recent infiltration. The age date results are generally consistent with this conceptual model with the exception of the DOC age date from well HC-5. The DOC derived apparent age for water from HC-5 is one of the youngest (3,411 years) whereas the DIC derived age is the oldest (21,710 years). Well HC-5 is the deepest well at the site with an open interval over 1,000 ft deeper than the next deepest well and over 2,000 ft deeper than most site wells (Table 3). This geometry is consistent with the older DIC derived age date but not the DOC age date. The lighter oxygen and hydrogen isotopic results (Appendix A; Table A–3) from the HC-5 sample also indicate that the water is from precipitation during an older cooler climate. At this time it is uncertain why there is such variability between the two age dates, but discussions with personnel on the Underground Test Area Project indicate that this is not uncommon and that they are currently working with a laboratory to develop a procedure for the ^{14}C DOC method. A more thorough analysis of the major ion and stable isotope results will be included with CADD/CAP addendum.

The samples results from the piezometers were not useful because the samples contain remnant drilling fluid and are not representative of formation water. The sample collected from MV-3PZ was not analyzed because of the obvious presence of drilling fluid and the sample analyzed from MV-1PZ indicates the presence of significant amounts of bromide that was used as an additive in the drilling fluid to evaluate well development. Additional evaluation of the water chemistry data is needed to determine if the analytical results can be used to identify separate fault blocks at the site. The preliminary evaluation of ^{14}C age dates is inconclusive and a more detailed evaluation of the ^{14}C analysis and the water chemistry results will be included in an addendum to the CADD/CAP.

5.2 HC-4 Extended Purge with Sampling

The objective of the extended purge with additional sampling of well HC-4 was to obtain data that would help determine if increased well purging volumes would affect the tritium results. This activity required the well purging process to be continued after one well casing volume (approximately 700 gallons) had been purged and the initial sampling had been completed. The purging process continued to allow a total of 1,400 gallons of water to be removed from the well. Samples were collected after 1,050 gallons and 1,400 gallons of water had been removed. These samples were analyzed for tritium only.

Tritium concentrations versus gallons purged are presented as Figure 8. The 1997 tritium result obtained from the sample collected by Desert Research Institute is plotted with data obtained from 2007 through the present. Tritium results obtained prior to 2007 were not plotted because the well purge volumes were not available for the tritium results obtained from the EPA sampling events. Analytical results from samples collected in 2012 (Figure 8) after 700 gallons, 1,050 gallons, and 1,400 gallons of water had been purged from well HC-4 indicated tritium concentrations of 803 pCi/L, 723 pCi/L, and 918 pCi/L, respectively. These results correlate with the tritium result of 1,130 pCi/L obtained from the sample collected by Desert Research Institute in 1997. Tritium concentrations are lower in the samples collected before one well purge volume had been removed. This was also observed in 2012, when the sample collected after 400 gallons of water had been removed indicated a concentration of tritium of 343 pCi/L. A trend line plotted for these data indicate an increasing trend in the tritium concentrations that correspond to an increase in the well purge volumes for samples collected from well HC-4 (Figure 8).

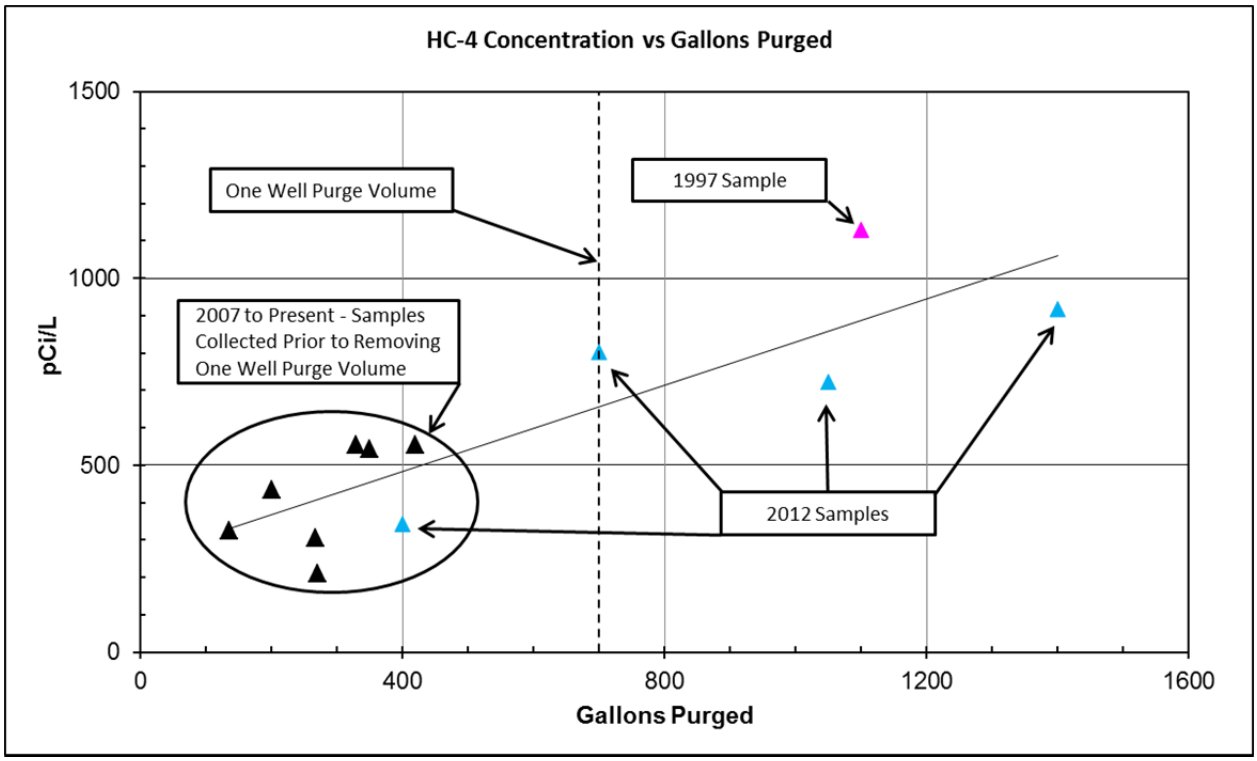


Figure 8. Well HC-4 Tritium Concentrations vs. Gallons Purged

5.3 HC-8 Infiltration Testing

The objective of the infiltration testing associated with well HC-8 was to determine if purged groundwater (4,000−5,000 gallons) generated from previous sampling events and discharged near well HC-8 has been infiltrating and causing the anomalous 1- to 2-ft over-recovery of water levels observed in this well 3−4 weeks after annual sampling events (Figure 6). The infiltration test included the use of a new discharge area for purged water generated from well HC-8 during the sampling event in May 2012. This test required running a hose to discharge purged water (approximately 2,800 gallons) from well HC-8 to the discharge area for well HC-5 (approximately 450 ft northwest of the HC-8 wellhead). Water level data obtained from

well HC-8 after the sampling event indicated that water levels over-recovered shortly after the sampling event as has been observed after previous sampling events when well HC-8 is purged and sampled (Figure 6). Based on this information, it can be concluded that the location of the discharge area for well HC-8 does not affect the over-recovery of water levels, but that the process of purging water from the well does affect the over-recovery of water levels in this well. This information in combination with the previous infiltration testing suggests that the over-recovery observed in well HC-8 shortly after the purging is not infiltration related and is likely caused by poroelastic effects near the well bore. The poroelastic effects in this well are likely influenced by the proximity of the well to the shear zone at the site.

5.4 Seismograph Station Monitoring Results

A temporary seismograph station was installed at the site on June 28, 2012. The seismograph station was installed as part of a feasibility test with the Nevada Seismological Laboratory, (a research division of the College of Science at the University of Nevada-Reno) to assess potential micro-earthquake activity and determine if additional monitoring for local event locations would be beneficial for the site. The laboratory is currently responsible for instrumental studies of earthquakes in the region. The laboratory operates a statewide network of seismograph stations and investigates the magnitude, frequency, and distribution of earthquakes in the region and other problems related to seismic risk in Nevada. The temporary seismograph station is telemetered, and the data are incorporated into the laboratory's existing monitoring network.

The temporary seismograph station identified 4 small earthquakes during the monitoring period that began on June 28, and extended through December 5, 2012. The earthquakes were estimated to be within 2 kilometers or 1.24 miles of the seismograph station. The small, local events were not detected by the regional network stations so the earthquake locations and depths cannot be determined, but the hypocentral distance was estimated from the single station. Refer to Appendix E for a summary of the data collected from the seismograph station at Shoal.

5.5 Rain Gage Monitoring Results

A rain gage was installed at the site on August 8, 2012. The rain gage was inspected, winterized, and downloaded on September 13, 2012. The data obtained for this monitoring period are presented as Figure 9. The total precipitation measured for this monitoring period was 3.81 millimeters or 0.15 inches. Precipitation data will be included in future annual monitoring reports.

6.0 Summary and Recommendations

Analytical results from the 2012 monitoring event are generally consistent with those of the previous year. The sample collected from well HC-4 was the only sample with tritium detected above the laboratory's MDC. The concentration of tritium was below the high of 1,130 pCi/L that was reported in 1998 (Pohll et al. 1998) and below the tritium EPA-established MCL of 20,000 pCi/L. Samples collected from wells HC-2, HC-4, and HC-7 had detectable gross alpha and uranium mass concentrations above the EPA-established MCLs of 15 pCi/L and 30 µg/L, respectively. Uranium was also detected above the EPA-established MCL in the sample collected from well HC-6. The gross alpha and uranium mass concentrations observed in

samples collected from wells HC-2 and HC-6 are consistent with historic trends. The gross alpha and uranium mass concentrations observed in samples collected from wells HC-4 and HC-7 increased from previous sampling events. These increases may be attributed to an increase in the pre-sampling purge volume during this sampling event than in previous years. If the gross alpha values observed in samples collected from wells HC-2, HC-4, and HC-7 are adjusted by subtracting activities of ^{234}U and ^{238}U, the values are less than zero, indicating that uranium accounts for all or nearly all gross alpha activity in these samples. Isotopic ratios of uranium obtained during this monitoring event continue to support the interpretation of a natural source of uranium in groundwater as opposed to a nuclear-test-related source. Water level trends obtained from the 2012 water level data are consistent with those of previous years.

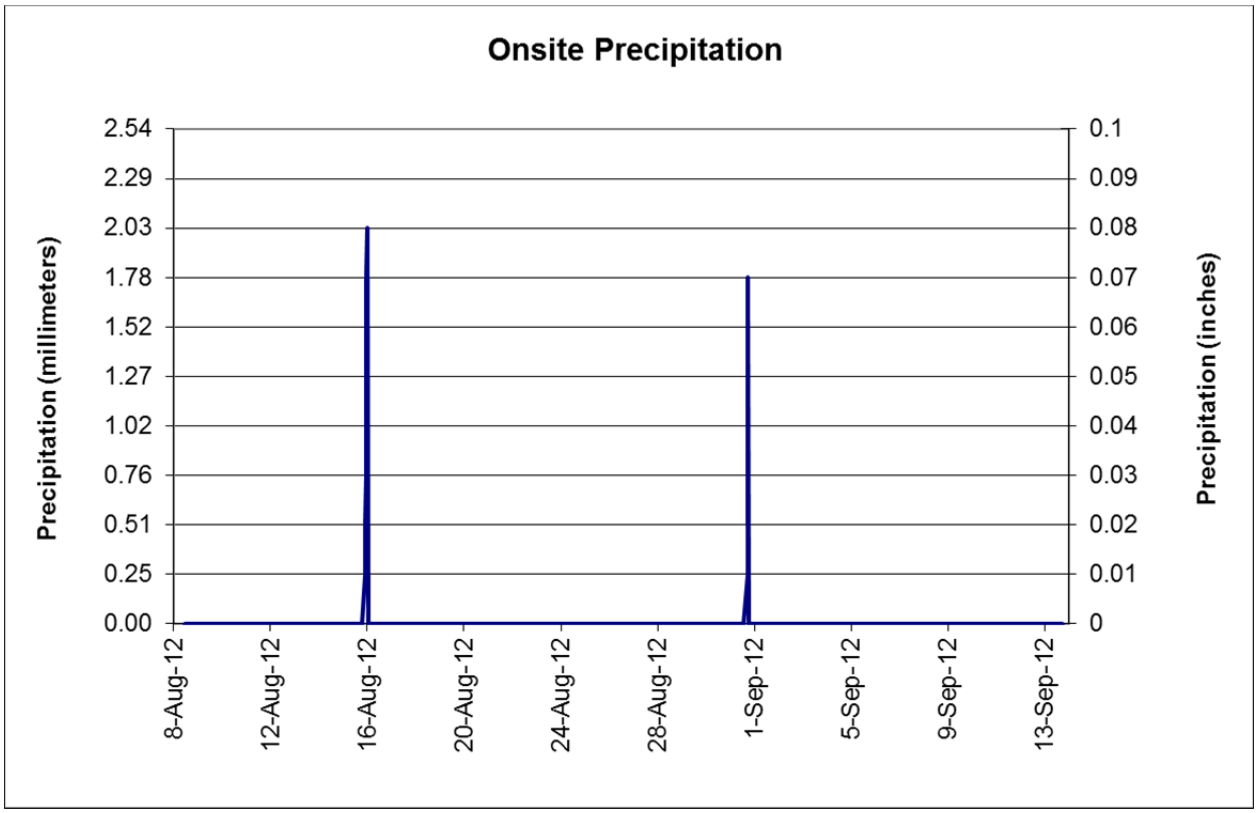


Figure 9. Precipitation Data, August 8 Through September 13, 2012

To advance the SCM during this next monitoring period, LM recommends the following:

- Continue collecting data from the temporary seismograph station at the site.
- Evaluate the geochemical, isotopic, and ^{14}C data collected during this monitoring period with historic data to identify variations in the groundwater as it relates to sample depth or location within certain fault blocks at the site. The purpose of this evaluation is to identify geologic structures that may be influencing groundwater flow, assess potential groundwater flow directions, and evaluating the monitoring well network. Interpretations obtained from this evaluation will be included with recommendations to enhance the monitoring well network in an addendum to the CADD/CAP for review and comment by NDEP.

- The Underground Test Area Project is working with laboratories to develop a procedure for the ^{14}C DOC method. It is recommended that any additional sampling for DOC be conducted after the procedure is developed.

7.0 References

AEC (U.S. Atomic Energy Commission/Nevada Operations Office), 1964. *Project Manager's Report, Project Shoal*, NVO-11, Las Vegas, Nevada, May.

AEC (U.S. Atomic Energy Commission/Nevada Operations Office), 1970. *Site Disposal Report Fallon Nuclear Test Site (Shoal) Churchill County, Nevada*, NVO-73, Las Vegas, Nevada.

Beal, L.H., S.E. Jerome, I. Lutsey, R.H. Olson, and J.H Schilling, 1964. "Geology of the Sand Springs Range," *Nevada Bureau of Mines and Geology, Final Report, Geological, Geophysical, Chemical and Hydrological Investigations of the Sand Springs Range, Fairview Valley, and Fourmile Flat, Churchill County, Nevada, for Shoal Event, Project Shade, Vela Uniform Program*, U.S. Atomic Energy Commission.

Bevans, H.E., M.S. Lico, and S.J. Lawrence, 1998. *Water Quality in the Las Vegas Valley Area and the Carson and Truckee River Basins, Nevada and California, 1992–96*, Circular 1170, U.S. Geological Survey, U.S. Department of the Interior, Carson City, Nevada.

Carroll, W.H. Rosemary; K. Pohlmann; G. Pohll; and T. Mihevc, 2001. *Investigation of Hydraulic Properties and Groundwater Levels Related to the Shear Zone at the Project Shoal Site*, Publication No. 45183, DOE/NV/13609-12, prepared by Desert Research Institute Division of Hydrologic Sciences for the U.S. Department of Energy National Nuclear Security Administration, Las Vegas, Nevada, September.

Cowart, J.B. and J.K. Osmond, 1977. "Uranium Isotopes in Groundwater: Their Use in Prospecting for Sandstone-type Uranium Deposits," *Journal of Geochemical Exploration*, 8: 365−379.

DOE (U.S. Department of Energy), 2009. *Final Path Forward: Short-Term Data Acquisition Plan for New Closure Strategy Subsurface Corrective Action Unit 447, Project Shoal Area, Nevada*, Office of Legacy Management, Grand Junction, Colorado, November.

DOE (U.S. Department of Energy), 2011a. *Path Forward: 2011 Short-Term Data Acquisition Plan, Project Shoal Area, Subsurface Corrective Action Unit 447, Nevada*, Office of Legacy Management, Grand Junction, Colorado, October.

DOE (U.S. Department of Energy), 2011b. *Surface Geophysics Survey Report Subsurface Corrective Action Unit 447, Project Shoal Area, Nevada*, Office of Legacy Management, Grand Junction, Colorado, April.

DOE/NNSA (U.S. Department of Energy, National Nuclear Security Administration), 2006. *Corrective Action Decision Document/Corrective Action Plan for Corrective Action Unit 447: Project Shoal Area, Subsurface*, *Nevada*, DOE/NV-1025, Rev. 3, Las Vegas, Nevada.

DOE/NV (U.S. Department of Energy/Nevada Operations Office), 1998. *Closure Report for Corrective Action Unit 416: Project Shoal Area*, DOE/NV-11718-179, Rev. 0, Las Vegas, Nevada, January.

Hazleton-Nuclear Science Corporation, 1965. *Vela Uniform Project Shoal Fallon, Nevada*, VUF-1014, Post-Shot Hydrologic Safety, October.

NDEP (Nevada Division of Environmental Protection), 1996. *Federal Facility Agreement and Consent Order (FFACO)* (as amended), Las Vegas, Nevada, May 10.

NDEP (Nevada Division of Environmental Protection), 1998. Letter of Acceptance of Closure Report for CAU 416, Project Shoal Area Surface, Las Vegas, Nevada, February.

NDEP (Nevada Division of Environmental Protection), 2005. Identification of the Contaminant Boundary for Corrective Action Unit (CAU) 447, Project Shoal Area (PSA)—Subsurface, *Federal Facility Agreement and Consent Order*, Letter dated January 19, 2005.

Pohll, G., J. Chapman, A. Hassan, C. Papelis, R. Andricevic, and C. Shirley, 1998. *Evaluation of Groundwater Flow and Transport at the Shoal Underground Nuclear Test: An Interim Report*, Publication No. 45162, DOE/NV/11508-35, UC-703, July.

Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites, LMS/PLN/S04351, continually updated, prepared by S.M. Stoller Corporation for the U.S. Department of Energy Office of Legacy Management, Grand Junction, Colorado.

Smith, D.K., 2001. *Unclassified Radiological Source Term for the Nevada Test Site Areas 19 and 20*, URCL-ID-141706, Lawrence Livermore National Laboratory, Livermore, California.

This page intentionally left blank

Appendix A

Well Purge Data, Carbon-14 Calculation Data, Water Chemistry and Stable Isotope Data, and Carbon-14 Age Data

This page intentionally left blank

Table A−1. Monitor Well Purge Data

Well	Date Sampled	Purged Volume (gallons)	Temperature (°C)	pH (s.u.)	Specific Conductance (µmhos/cm)
MV-1	5/25/2012	940	21.50	8.28	720
			22.02	8.26	714
			22.16	8.25	715
MV-1PZ	5/22/2012	1	20.4	8.85	680
MV-2	5/24/2012	1250	21.78	8.29	473
			21.68	8.39	478
			21.75	8.36	481
MV-3	5/25/2012	850	21.34	8.35	737
			21.53	8.37	739
			21.53	8.34	738
MV-3PZ	5/22/2012	1	18.5	10.75	1665
HC-1	5/23/2012	6	20.2	6.97	395
HC-2	5/22/2012	6	23.5	7.75	675
HC-3	5/23/2012	6	25.2	8.10	535
HC-4	5/24/2012	700	NA	NA	NA
			20.82	7.47	755
			21.65	7.53	750
HC-5	5/23/2012	2890	26.9	8.38	980
			26.9	8.40	980
			27.3	8.39	975
HC-6	5/23/2012	6	19.6	7.22	1095
HC-7	5/23/2012	2200	NA	NA	NA
			NA	NA	NA
			22.5	7.43	1320
HC-8	5/25/2012	2800	25.14	8.12	839
			26.99	8.24	836
			27.04	8.25	838

µmhos/cm = micromhos per centimeter
NA = not analyzed
s.u. = Standard Unit

Table A−2. Dissolved Inorganic Carbon-14 Radioisotope Calculation Data

Well ID	Sample Date	Mass Concentration Carbon (mg)	Fraction Modern Carbon	±1 s	pCi/L[a]
HC-1	5/23/2012	5.50	0.3631	0.0022	1.23E-02
HC-3	5/23/2012	9.30	0.2550	0.0018	1.45E-02
HC-4	5/24/2012	6.75	60.41	0.34	2.50
HC-5	5/23/2012	9.00	0.0671	0.0014	3.70E-03
HC-6	5/23/2012	11.65	0.1619	0.0018	1.16E-02
MV-3	5/25/2012	7.85	0.2201	0.0017	1.06E-02

[a] Modern ^{14}C standard at 1950 AD has activity of 13.6 dpm/gram C = 2.27×10^{-4} dps/mg C.
1 µCi = 3.7×10^{4} dps; therefore, modern C-14 standard at 1950 AD has activity of 6.135×10^{-9} µCi/mg.
pmc = percent modern carbon; mc = modern carbon; s = standard deviation

Example activity calculation (HC-1)

$$5.50\,\frac{mg\ C}{1\ L}\left(0.3631\,\frac{mg\ MC}{mg\ C}\right)\left(6.135*10^{-9}\,\frac{\mu Ci}{mg\ MC}\right)\left(1*10^{6}\,\frac{pCi}{\mu Ci}\right)=1.23*10^{-2}\ \frac{pCi}{L}$$

Table A−3. Water Chemistry and Stable Isotope Data from 2012 Sampling Event

Monitoring Location	Sample Date	Temperature* (°C)	pH* (s.u.)	Specific Conductance* (µmhos/cm)	Silica (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Chloride (mg/L)	Sulfate (mg/L)	Bicarbonate (mg/L)	Bromide (mg/L)	Stable Isotope Ratio		
														Hydrogen ($^0/_{00}$)	Oxygen ($^0/_{00}$)	Carbon-13 ($^0/_{00}$)
MV-1	5/25/2012	22.16	8.25	715	19	55	5.6	68	3.7	96	94	87	0.62	-115.17	-13.88	-10.4
MV-1PZ	5/22/2012	20.4	8.85	680	8.2	65	0.46	110	2.4	120	13	190	7	NA	NA	NA
MV-2	5/24/2012	21.75	8.36	481	19	38	4.4	44	2.3	52	41	100	0.22	-115.53	-14.06	-11.5
MV-3	5/25/2012	21.53	8.34	738	12	67	7.2	58	4.5	120	92	66	0.75	-115.69	-13.79	-10.1
HC-1	5/23/2012	20.2	6.97	395	6.1	33	3.9	34	2.5	50	17	100	0.38	-113.91	-14.18	-9.6
HC-2	5/22/2012	23.5	7.75	675	16	52	7.7	62	4.1	78	100	93	0.4	-115.70	-14.25	-11.4
HC-3	5/23/2012	25.2	8.1	535	1.1	13	3.9	71	6.7	120	2.7	55	2.4	-110.59	-13.35	6.4
HC-4	5/24/2012	21.65	7.53	750	20	66	9.7	61	3.6	86	56	170	0.64	-113.40	-13.78	-13.6
HC-5	5/23/2012	27.3	8.39	975	31	26	0.44	150	2.8	91	220	69	0.24	-121.90	-14.87	-8.6
HC-6	5/23/2012	19.6	7.22	1095	26	130	18	56	4.3	140	180	130	6.2	-105.90	-13.75	-5.9
HC-7	5/23/2012	22.5	7.43	1320	17	170	25	75	5.1	170	290	120	1.2	-115.00	-13.94	-8.8
HC-8	5/25/2012	27.04	8.25	838	27	35	0.36	110	3.3	110	120	74	0.36	-117.34	-14.51	-10.4

* = Indicates it is the last field measurement before the sample was collected.
NA = Not Analyzed
s.u. = Standard Unit
µmhos/cm = micromhos per centimeter
mg/L = milligrams per liter

This page intentionally left blank

Table A−4. Carbon-14 Radioisotope Age Data

Well ID	Sample Date	^{14}C Method	$\delta^{13}C$	Fraction Modern Carbon	Apparent Age (years)
MV-1	5/25/2012	DIC	–10.4	NA	12,242
		DOC	–31.7	0.6961	2,910
MV-2	5/24/2012	DIC	–11.5	NA	8,875
		DOC	–34.7	0.3766	7,844
MV-3	5/25/2012	DIC	–10.1	0.2201	12,159
		DOC	–29.1	0.4234	6,905
HC-1	5/23/2012	DIC	–9.6	0.3631	8,137
		DOC	–28.0	0.3894	7,576
HC-2	5/22/2012	DIC	–11.4	NA	11,571
		DOC	–27.1	0.4489	6,434
HC-3	5/23/2012	DIC	6.4	0.2550	10,977
		DOC	–26.4	0.3158	9,258
HC-4	5/24/2012	DIC	–13.6	60.41	Post-bomb
		DOC	NA	NA	Post-bomb
HC-5	5/23/2012	DIC	–8.6	0.0671	21,710
		DOC	–29.2	0.6540	3,411
HC-6	5/23/2012	DIC	–5.9	0.1619	14,627
		DOC	–35.7	0.1901	13,337
HC-7	5/23/2012	DIC	–8.8	NA	20,870
		DOC	–28.5	0.4152	7,061
HC-8	5/25/2012	DIC	–10.4	NA	18,860
		DOC	–31.9	0.4250	6,874

DIC = dissolved inorganic carbon
DOC = dissolved organic carbon
NA = not applicable (samples not analyzed or results not provided by the laboratory)
Note: Apparent age calculated from modern ^{14}C standard at 1950 AD

This page intentionally left blank

Appendix B

Analytical Data: 2007 through Present

This page intentionally left blank

Table B–1. Radioisotopic and Chemical Sampling Results

Monitoring Location	Date	Carbon-14[a] (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)	Uranium (µg/L)	Gross alpha (pCi/L)
MV-1	3/21/2007	<RDL (5.83E-03)[a]	<RDL (7.3E-11)	<359	42	25.6
	3/21/2007	NA	NA	NA	41[b]	21.5[b]
	3/11/2008	<RDL (2.49E-02)	<RDL (19.0E-11)	<180	21	14.0
	2/26/2009	<RDL (1.95E-02)	<RDL (10.5E-11)	<350	21	12.6
	3/11/2010	<RDL (1.93E-02)	<RDL (7.8E-11)	<300	21	11.3
	3/22/2011	NA	NA	<350	25	16.6
	3/22/2011[c]	NA	NA	<360	25	14.3
	5/25/2012		NA	<300	22	14.3
MV-2	3/21/2007	<RDL (1.77E-02)[a]	<RDL (8.3E-11)	<361	34	16.3
	3/21/2007	NA	NA	NA	34[b]	17.3[b]
	3/11/2008	<RDL (2.44E-02)	<RDL (29.5E-11)	<180	23	11.1
	2/26/2009	<RDL (2.13E-02)	NR	<360	24	12
	3/11/2010	<RDL (3.31E-02)	<RDL16.5 (E-11)	<300	21	13.8
	3/22/2011	NA	NA	<350	23	9.92
	5/24/2012		NA	<300	22	10.6
MV-3	3/21/2007	<RDL (5.90E-03)[a]	<RDL (13.5E-11)	<357	14	10.2
	3/21/2007	NA	NA	NA	14[b]	9.57[b]
	3/11/2008	<RDL (1.37E-02)	<RDL (18.0E-11)	<320	3.8	2.11
	2/26/2009	<RDL (8.37E-03)	<RDL (10.7E-11)	<360	3.8	<1.5
	3/12/2010	<RDL (1.29E-02)	<RDL (6.5E-11)	<300	4.2	2.63
	3/22/2011	NA	NA	<350	5.8	4.98
	5/25/2012		NA	<300	7	2.72
HC-1	3/21/2007	<RDL (1.52E-02)[a]	<RDL (9.6E-11)	<355	3.3	3.9
	3/21/2007	NA	NA	NA	3.4[b]	4.46[b]
	3/11/2008	<RDL (2.35E-02)	<RDL (4.9E-11)	<320	4.8	12.5
	2/26/2009	<RDL (2.01E-02)	NR	<360	1.4	<1.4
	3/24/2010	<RDL (3.18E-02)	<RDL (11.9E-11)	<310	3.3	4.93
	3/22/2011	NA	NA	<360	1.6	2.19
	5/23/2012		NA	<300	1.1	<0.75
HC-2	3/24/2010	<RDL(1.90E-02)	<RDL (2.5E-11)	<300	140	63.8
	3/22/2011	NA	NA	<360	120	197
	5/22/2012		NA	<300	110	64.5
HC-3	3/24/2010	<RDL (2.37E-02)	<RDL (541E-11)	<300	4.3	2.57
	3/22/2011	NA	NA	NA	NA	NA
	5/23/2012		NA	<300	2	0.283
HC-4	3/21/2007	<RDL (0.565)[a]	<RDL (32.4E-11)	<359	0.75	1.41
	3/21/2007	NA	NA	NA	0.85[b]	1.93[b]
	3/21/2007[c]	<RDL (0.436)[a]	<RDL (34.2E-11)	<359	0.69	1.75
	3/21/2007[c]	NA	NA	NA	0.81[b]	<0.876[b]
	3/11/2008	<RDL (2.06)	<RDL (21.5E-11)	555	4.5	2.88
	2/26/2009	<RDL (3.20)	<RDL (0.6E-11)	434	2.0	<1.4
	3/11/2010	<RDL (2.93)	<RDL (38.7E-11)	544	6.4	1.79[b]
	3/23/2011	NA	NA	554	8.9	3.82
	5/24/2012[c]	NA	NA	774	46	16.7
	5/24/2012	NA	NA	803	46	22.9

Table B–1 (continued). Radioisotopic and Chemical Sampling Results

Monitoring Location	Date	Carbon-14[a] (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)	Uranium (µg/L)	Gross alpha (pCi/L)
HC-5	3/11/2010	<RDL (5.11E-03)	<RDL (1.1E-11)	<300	0.48	<1.5
	3/23/2011	NA	NA	<360	0.45	<2.1
	5/23/2012		NA	<300	0.49	0.349
HC-6	3/24/2010	<RDL (1.14E-02)	<RDL (5.6E-11)	<300	35	25.7
	3/23/2011	NA	NA	<360	37	20.4
	5/23/2012		NA	<300	38	14.1
HC-7	3/11/2010	<RDL (5.31E-03)	<RDL (3.0E-11)	<300	7.4	5.77
	3/23/2011	NA	NA	<360	13	10.6
	5/23/2012		NA	<300	41	23.9
HC-8	3/10/2010	<RDL (9.63E-03)	<RDL (1.3E-11)	<300	0.25	<1.3
	3/23/2011	NA	NA	NA	NA	NA
	5/25/2012		NA	<300	0.2	0.454

[a] Estimated based on sample volume of 200 milliliters for 2007 samples.
[b] Indicates the sample was filtered.
[c] Indicates a duplicate sample.
NA = not applicable (samples not collected or samples not analyzed).
NR = not run, because sample bottle was broken during shipment to the laboratory.
<RDL = below required detection limit with laboratory result in parentheses; RDL is 5 pCi/L for ^{14}C, 0.1 pCi/L for ^{129}I, 300 pCi/L for tritium, 50 µg/L for uranium, and 4 pCi/L for gross alpha (DOE/NNSA 2006).

Table B–2. Uranium Isotopic Sampling Results

Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	U^{234}/U^{238}
MV-1	3/21/2007	16.8[a]	14.2[a]	1.18[a]
	3/21/2007	15.4	12.6	1.22
	3/11/2008	7.35	6.2	1.19
	2/26/2009	8.75	6.98	1.25
	3/11/2010	9.06	7.64	1.19
	3/22/2011	10.8	8.89	1.21
	3/22/2011[b]	10.4	8.77	1.19
	5/25/2012	8.14	6.81	1.20
MV-2	3/21/2007	13.6[a]	11.4[a]	1.19[a]
	3/21/2007	13.2	11.7	1.13
	3/11/2008	8.95	7.89	1.13
	2/26/2009	8.64	6.7	1.29
	3/11/2010	9.66	8.32	1.16
	3/22/2011	10.1	8.65	1.17
	5/24/2012	7.9	7.01	1.13
MV-3	3/21/2007	4.64[a]	4.37[a]	1.06[a]
	3/21/2007	5.47	4.68	1.17
	3/11/2008	1.47	1.17	1.25
	2/26/2009	1.33	0.998	1.33
	3/12/2010	1.7	1.42	1.20
	3/22/2011	2.55	2.2	1.16
	5/25/2012	2.49	2.3	1.08
HC-1	3/21/2007	1.28[a]	1.19[a]	1.08[a]
	3/21/2007	1.4	1.19	1.18
	3/11/2008	1.84	1.51	1.21
	2/26/2009	0.572	0.385	1.49
	3/24/2010	1.24	1.05	1.18
	3/22/2011	0.9	0.609	1.48
	5/23/2012	0.401	0.35	1.15
HC-2	3/24/2010	45.1	45.3	0.996
	3/22/2011	45.2	45.3	0.998
	5/22/2012	38.1	36.2	1.05
HC-3	3/24/2010	1.16	1.21	0.96
	3/22/2011	NA	NA	NA
	5/23/2012	0.678	0.668	1.01
HC-4	3/21/2007	0.349[a]	0.308[a]	1.12[a]
	3/21/2007[b]	0.313[a]	0.33[a]	0.95[a]
	3/21/2007	0.293	0.305	0.96
	3/21/2007[b]	0.31	0.336	0.92
	3/11/2008	1.53	1.63	0.94
	2/26/2009	0.654	0.722	0.91
	3/11/2010	2.27[a]	1.95[a]	1.16[a]
	3/23/2011	2.69	2.86	0.941
	5/24/2012[b]	14.4	15.1	0.95
	5/24/2012	14.2	14.8	0.96

Table B–2 (continued). Uranium Isotopic Sampling Results

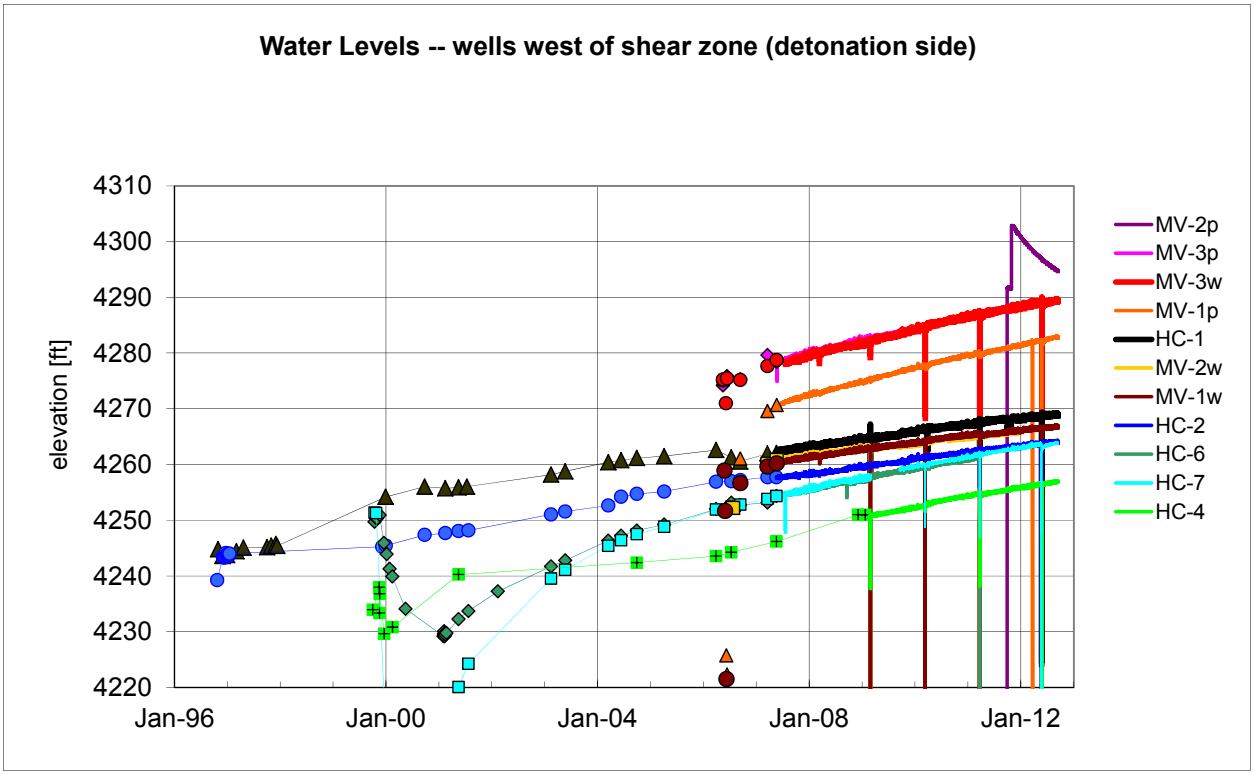
Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	U^{234}/U^{238}
HC-5	3/11/2010	0.295	0.173	1.71
	3/23/2011	0.264	0.117	2.26
	5/23/2012	0.227	0.126	1.80
HC-6	3/24/2010	14.4	12.2	1.18
	3/23/2011	15.4	13.5	1.14
	5/23/2012	14.4	12.2	1.18
HC-7	3/11/2010	3.43	3.08	1.11
	3/23/2011	5.9	4.78	1.23
	5/23/2012	16.1	13.9	1.16
HC-8	3/10/2010	0.187	0.101	1.85
	3/23/2011	NA	NA	NA
	5/25/2012	0.153	0.0553	2.77

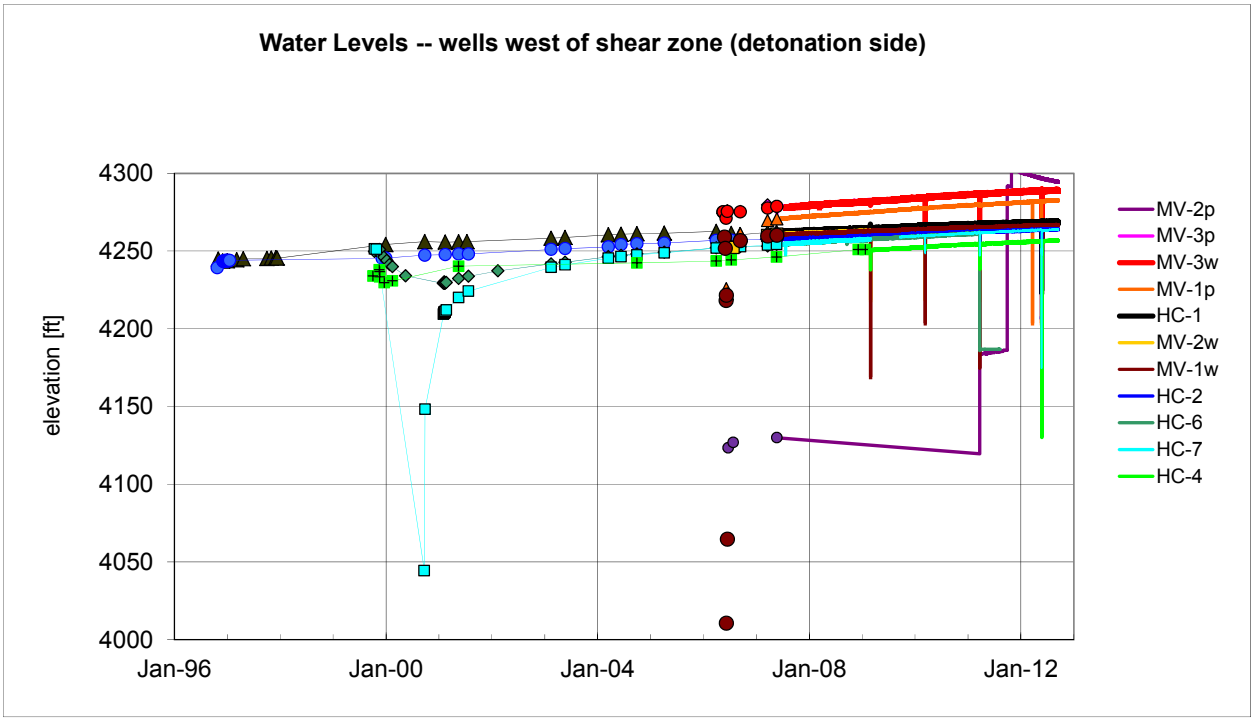
[a] Indicates the sample was filtered.
[b] Indicates a duplicate sample.
NA = not applicable (samples not collected or samples not analyzed)

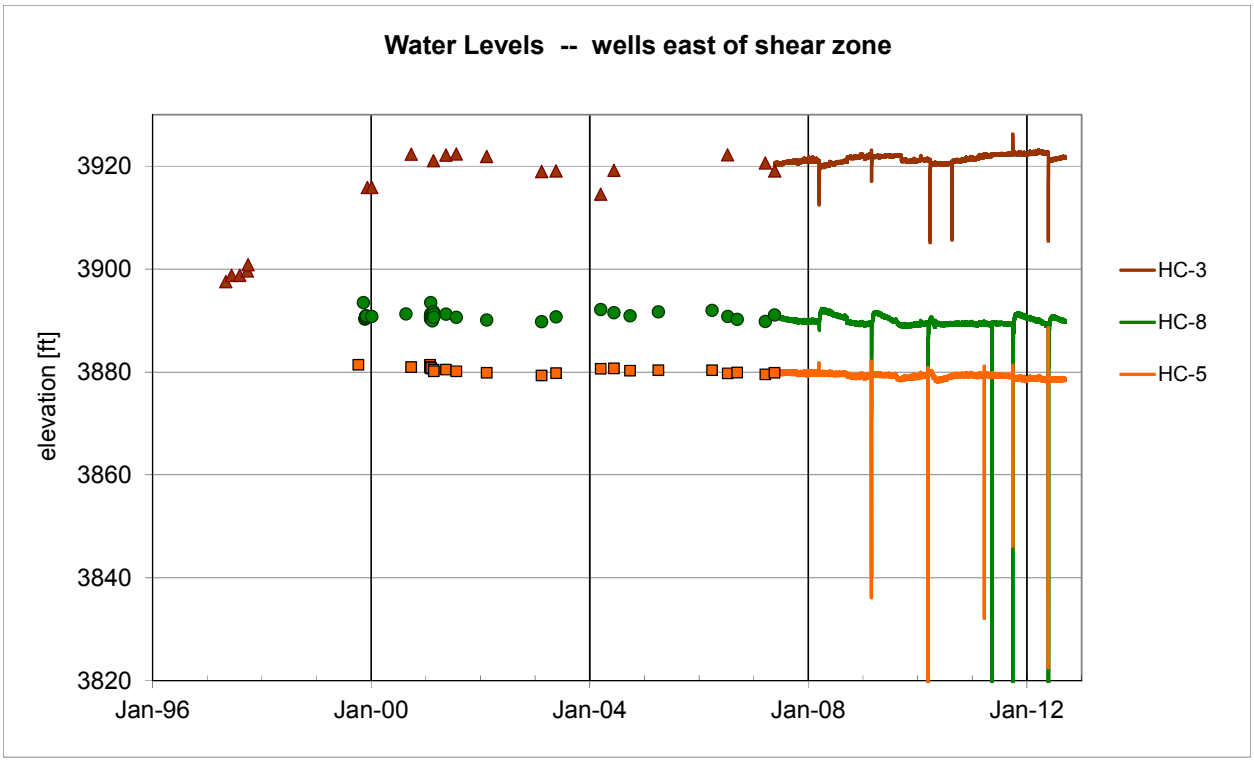
Appendix C

Hydraulic Head Data: 1996 through Present

This page intentionally left blank


Water Levels -- wells west of shear zone (detonation side)
elevation [ft]
4310
4300
4290
4280
4270
4260
4250
4240
4230
4220
Jan-96
Jan-00
Jan-04
Jan-08
Jan-12
MV-2p
MV-3p
MV-3w
MV-1p
HC-1
MV-2w
MV-1w
HC-2
HC-6
HC-7
HC-4


Water Levels -- wells west of shear zone (detonation side)
elevation [ft]
4300
4250
4200
4150
4100
4050
4000
Jan-96
Jan-00
Jan-04
Jan-08
Jan-12
MV-2p
MV-3p
MV-3w
MV-1p
HC-1
MV-2w
MV-1w
HC-2
HC-6
HC-7
HC-4


Water Levels -- wells east of shear zone
elevation [ft]
3920
3900
3880
3860
3840
3820
Jan-96
Jan-00
Jan-04
Jan-08
Jan-12
HC-3
HC-8
HC-5

Appendix D

Annual Water Level Changes in Wells West of Shear Zone: July 2007 through July 2012

This page intentionally left blank

Table D–1 Annual Water Level Changes in Wells West of the Shear Zone

Date Range	Wells/Piezometers West of Shear Zone (water level change in feet/year)										
	MV-1	**MV-1PZ**	**MV-2**	**MV-2PZ**	**MV-3**	**MV-3PZ**	**HC-1**	**HC-2**	**HC-4**	**HC-6**	**HC-7**
7/1/2007 – 7/1/2008	1.52	2.67	1.37	NM	2.71	2.57	1.40	1.09	NM	2.00	2.28
7/1/2008 – 7/1/2009	1.40	2.48	0.95	NM	2.16	2.20	1.32	1.40	NM	1.96	NM
7/1/2009 – 7/1/2010	1.38	2.48	1.36	NM	2.54	2.23	1.49	1.49	2.12	1.79	NM
7/1/2010 – 7/1/2011	0.79	1.80	0.76	NM	1.82	1.67	1.21	1.02	1.46	NM	1.64
7/1/2011 – 7/1/2012	1.23	2.10	0.94	NM	1.78	1.91	1.08	1.24	1.72	NM	NM

NM = Not Measured, because transducer data were not available.

This page intentionally left blank

Appendix E

Single-Seismograph-Station Earthquake Reconnaissance at the Shoal Site

This page intentionally left blank

Single-Seismograph-Station Earthquake Reconnaissance at the Shoal Site

Ken Smith

Nevada Seismological Laboratory MS/174
University of Nevada Reno
Reno, Nevada 89557

December 6, 2012

ken@seismo.unr.edu
http://www.seismo.unr.edu

Background:

A single telemetered seismograph station was installed near the 1963 12-kT Shoal underground nuclear test location to assess the local seismicity (Figure 1; provided by S.M. Stoller). With one station, earthquake locations and depths cannot be determined; however, hypocentral distances can be estimated from 'S-wave minus P-wave' arrival times. The purpose of the deployment is to identify local earthquake signals and identify any potential events that could be associated with geologic structures within and near the site area. There are very few seismograph stations operating in this region of Nevada; thereforem, there is generally 'poor' control on seismic activity near the Shoal site. Figure 2 shows the location of the station (SHL1) and the nearest permanent network station, KVN, 30 km to the SE. Also shown in Figure 2 are earthquakes located by the Nevada Seismological Laboratory since 2000, near the site area. Station SHL will provide a more complete accounting of the local seismicity than the regional network.

Instrumentation and Data:

A RefTek RT130 24-bit data-logger configured with 3-component GS-13 seismometers, and local power and radio system, was installed on June 28, 2012, at the Shoal site (Figures 1 and 2). The continuous 100 sps data is transmitted via a 900 MHz digital radio to NSL's Fairview Peak digital microwave communication site; the data is then transmitted to a communication relay on Virginia Peak, outside of Reno, and ultimately integrated in near real-time with NSL's regional network operation at the University of Nevada Reno (UNR). All real-time data from SHL1 is archived with regional network data at the NSL data center and accessible with event and waveform review software tools. To date, about 6 Gbytes of data has been collected at SHL1 (~36 Mbytes per day).

Data Review:

All continuous data (~160 days of time-series data, at the time of this report) has been visually reviewed for potential seismic signals. The site is near military flight paths out of the Fallon Naval Air Station and associated bombing ranges and there are numerous

blast records and sonic arrivals. In most cases discriminating between local earthquake activity and explosions, and other seismic noise sources, is straight forward, yet some signals, a small set, have been categorized as 'suspect' in order to account for any potential shallow seismic events. Clearly identified tectonic earthquake waveforms show characteristic P-wave and S-wave arrivals. In review of the continuous waveform data P-wave and S-wave arrivals from earthquakes with 'S minus P times' of <= 5.0 sec were 'flagged' in the arrival database table. A script was then developed to recognize all SHL1 noted events in the arrival database and subset associated 3-component event waveforms. Only events with S minus P times of <= 3.0 sec were selected from the reviewed waveform and database arrival entries and used in this report. Most of the events identified in this review were not located in routine regional network operations.

Analysis:

Four earthquakes with 'S minus P times'; of <= 0.5 seconds were identified in the data. Figures 3 and 4 show events on June 29 and July 9 with similar waveforms that are most likely from the same source area. Another pair of events that occurred on October 26 (within the same minute), appear to be from a different source area than those shown in Figures 3 and 4. These four events show clear earthquake signatures and have been the closest earthquakes station SHL1 since deployment (estimated magnitudes are M <= 0). As discussed above, with a single station, hypocentral distances can be estimated from 'S minus P times'; depths, locations, and source receiver azimuths cannot be determined. For shallow sources, distance estimates from 'S minus P times' is determined by the shallow seismic velocity structure. Figures 7 and 8 show estimates of hypocentral distances based on a range of Vp/Vs ratios (Vp = P-wave velocity; Vs = S-wave velocity). A Vp/Vs ratio of about 1.75 is expected in hard rock and stiff soils; weaker and unconsolidated soils will show higher Vp/Vs ratios. Based on the Liberty (2010) study on the Shoal site velocities, a Vp/Vs ratio of 1.75 would be an appropriate estimate. Also, the 2010 report estimates an average shallow velocity of about 4 km/sec on the western side of the study area. Therefore, distances to sources in Figure 3-4 are estimated to be <= ~ 2.0 km and events in Figures 5 and 6 are estimated to be <= ~3.0 km from the station. Figures 9-12 show examples of earthquakes near the site with 'S minus P times' of <= 2.0 seconds.

The source-receiver distance (D) for average Vp and Vs velocities can be estimated as:

$$D = (S \text{ minus } P) * (1 / (1/Vs - 1/Vp)).$$

The distance in km is about '8.0 x (S minus P time)' for typical tectonic earthquakes with primary travel paths within mid-crustal velocities. Assuming a seismogenic depth of ~15 km, typical of the western Basin and range, earthquakes with 'S minus P times' of ~2.0 sec could therefore locate directly under the site (i.e., within about 1 seismogenic depth). To establish locations and hypocentral depths for Shoal area events with 'S minus P times' of <= 2.0 sec would require additional seismograph stations.

Figure 14 shows the distribution of 'S minus P times' from reviewing the waveform data (this set includes all earthquake and suspect seismic events). Most events with 'S minus P times' of < 1.0 sec are 'suspect', but are included in the set of waveform images attachment to this report. An example of a suspect signal is shown in Figure 15; there are numerous examples of similar records. They are most likely related to an electronic issue or potential wind or sonic source. Additional seismic instrumentation would help resolve interpretations of the suspect events.

Summary:

To date, four confirmed earthquakes are estimated to be within 2 km of the seismograph station. Since we cannot confirm the event location these may or may not be occurring on faults or geologic structures within the Shoal site area. To constrain event depths and locations would require additional seismic stations; all distance estimates from the station in this reconnaissance study are approximate.

'S minus P times' of <= 0.5 seconds for local earthquakes are not unusual in Nevada and have been observed in the 1993 Rock Valley sequence on the Nevada Test Site (Smith et al., 2003; main shock Mw 3.8), the 2008 Mogul West Reno sequence (Smith et al., 2008; main shock Mw 5.0), and a 2011 sequence southwest of Hawthorne, Nevada (Smith et al., 2011; main shock Mw 4.7).

Liberty, L. (2010). Geophysical characterization at the project Shoal site, Project report to S.M. Stoller.

Smith, K.D., Johnson, C. Davies, J., Agbaje, T., Antonilevic, K., and Kent, G. (2011). The 2011 Hawthorne, Nevada Earthquake sequence, shallow normal faulting, Amer. Geophys. Union Fall Meeting 2011, abstract #S53B-2284.

Smith, K.D. von Seggern, D.H., DePolo, D., Anderson, J.G., Biasi, G.P., and Anooshehpoor, R. (2008). Seismicity of the 2008 Mogul-Somersett West Reno Nevada earthquake sequence, Amer. Geophys. Union Fall Meeting 2008, abstract #S53C-02.

Smith, K.D., Shields, G., and Brune J.N. (2000). A sequence of very shallow earthquakes in the Rock Valley fault zone, southern Nevada Test Site, USGS Professional Digital Data Series 058, Chapter L.

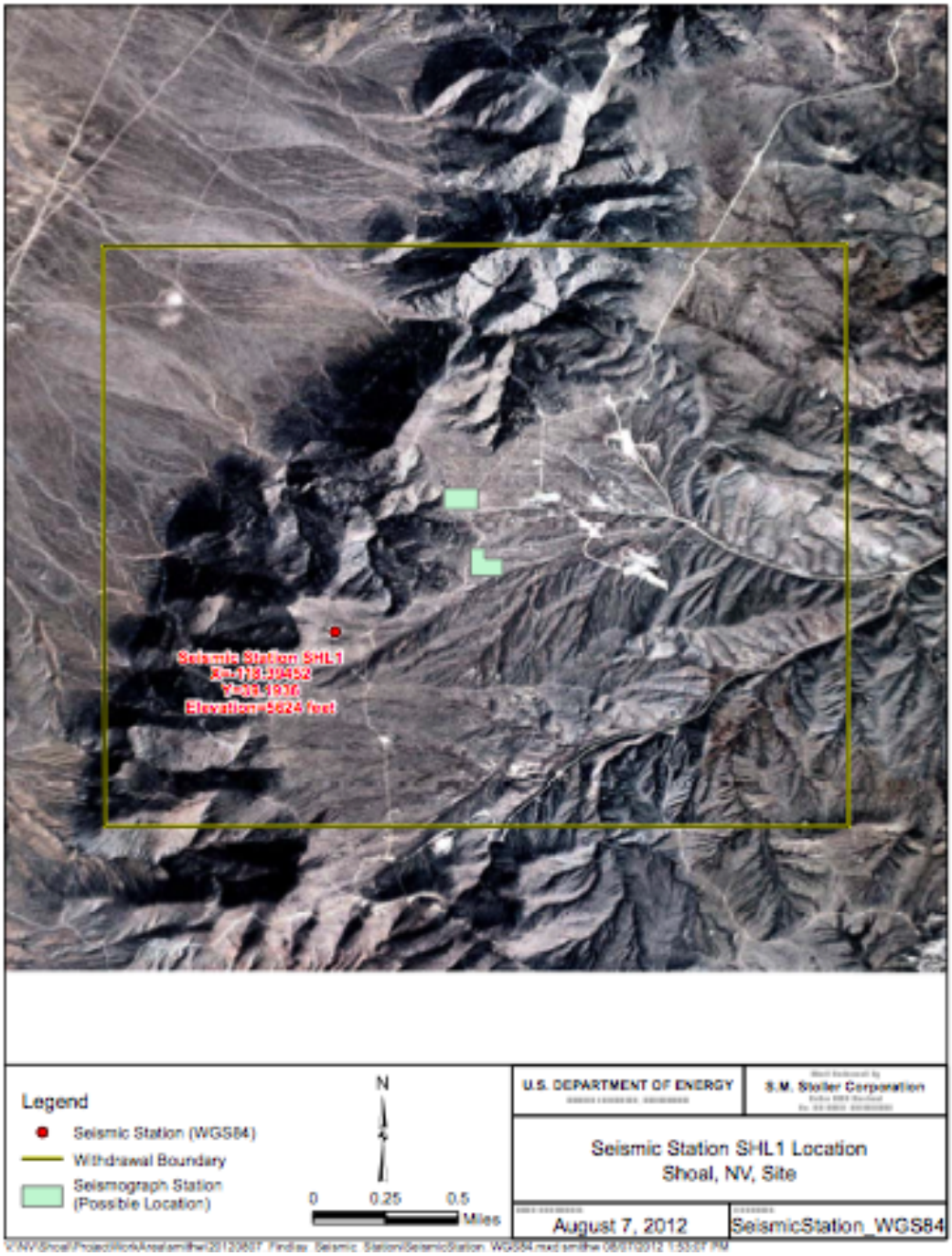


Figure 1. Location of temporary seismograph station (figure provided by S.M. Stoller).

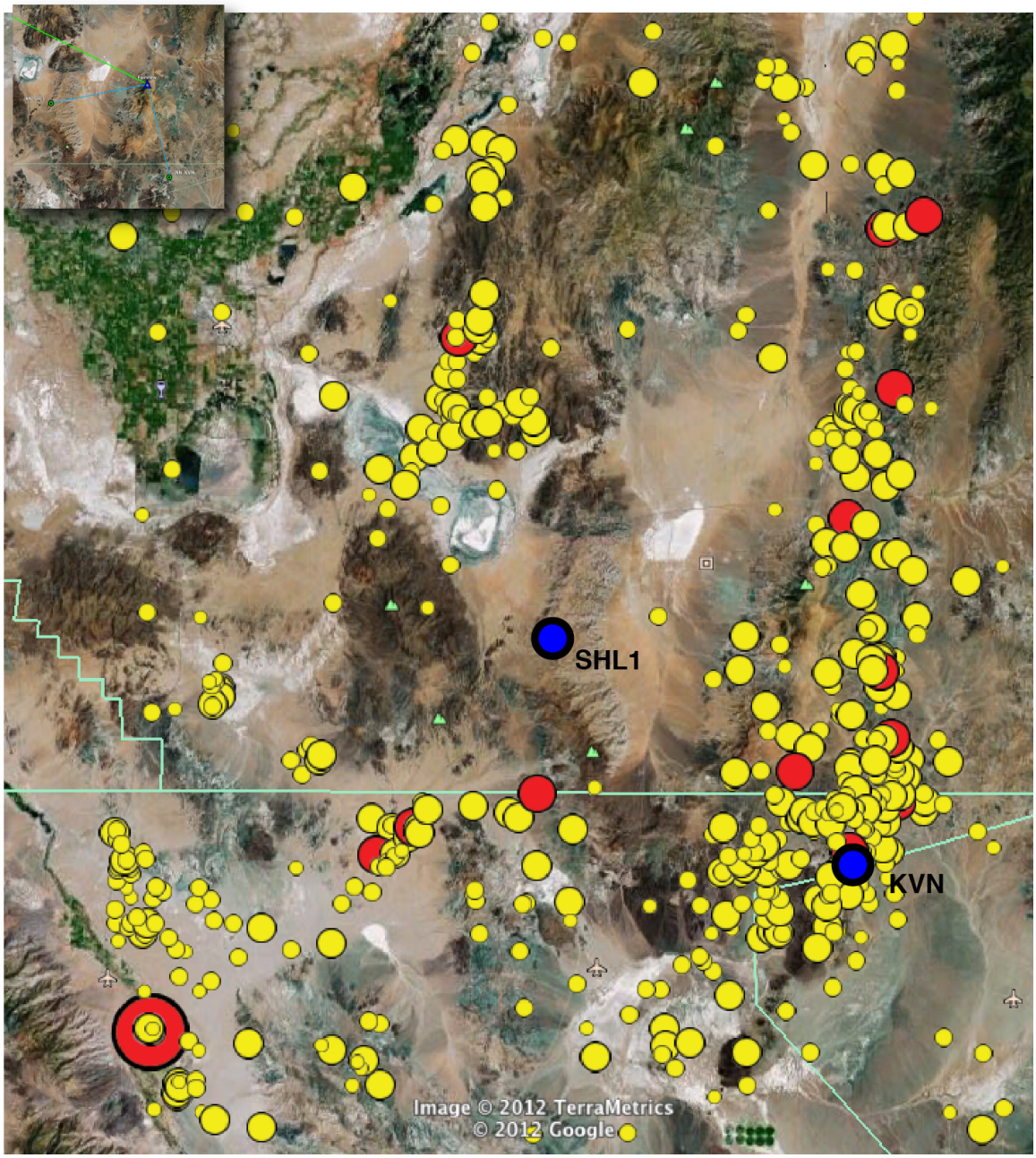


Figure 2. UNR catalog of earthquake locations from 2000-2012. Large 'red' symbols are Magnitdue 4-5, smaller 'red' symbols are Magniitude 3.0 – 3.9, and small yellow symbols are Magnitude < 3.

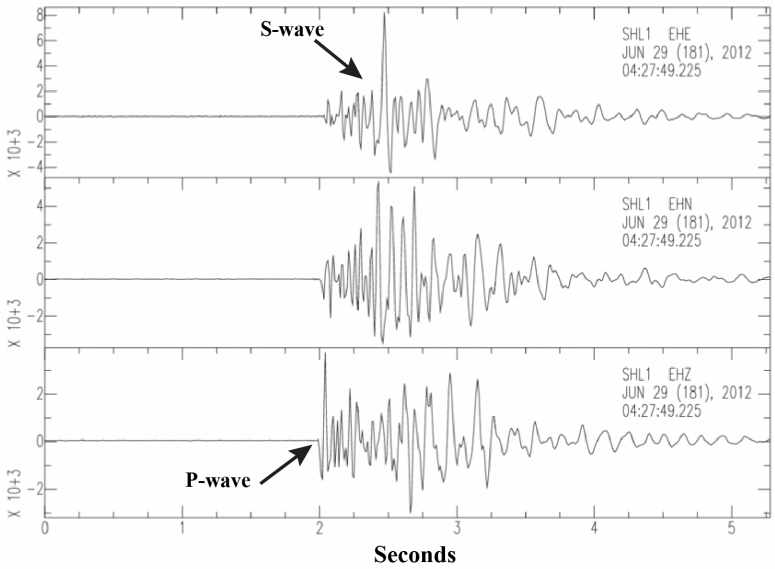


Figure 3. Close event with 'S minus P time' ~0.4 seconds; hypocentral distance from station estimated to be <= ~ 2.0 km. P and S arrivals labeled; amplitudes in all figures are in nm/sec.

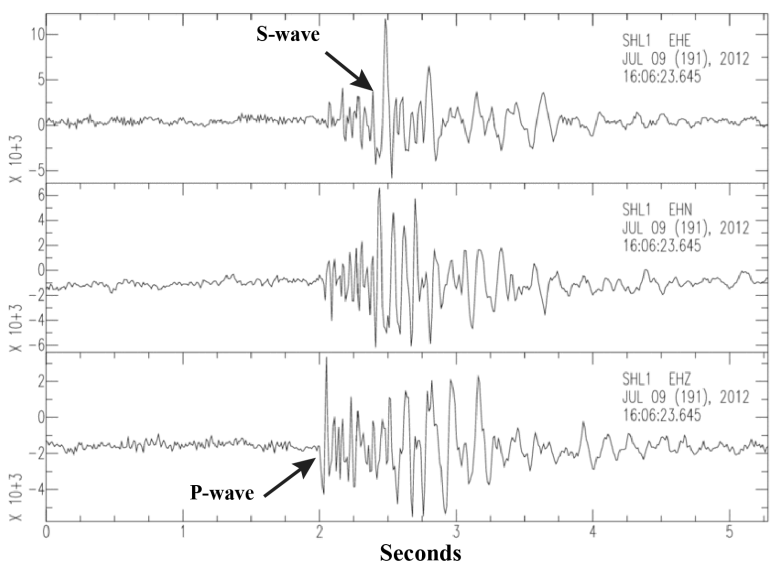


Figure 4. Close event with 'S minus P time' ~0.4 seconds; distance from station <= ~2.0 km. This event appears to be from the same source area as the event in Fig. 3.

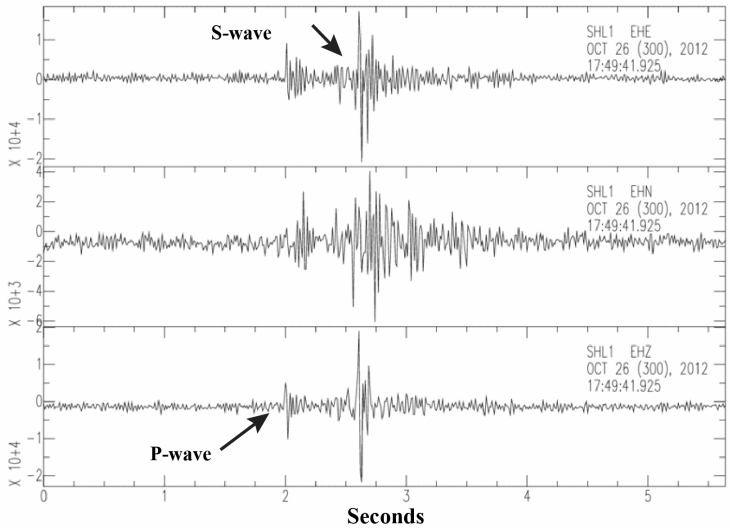


Figure 5. Close event with 'S minus P' time of approximately 0.5 seconds; hypocentral distance from station <= ~ 3.0 km.

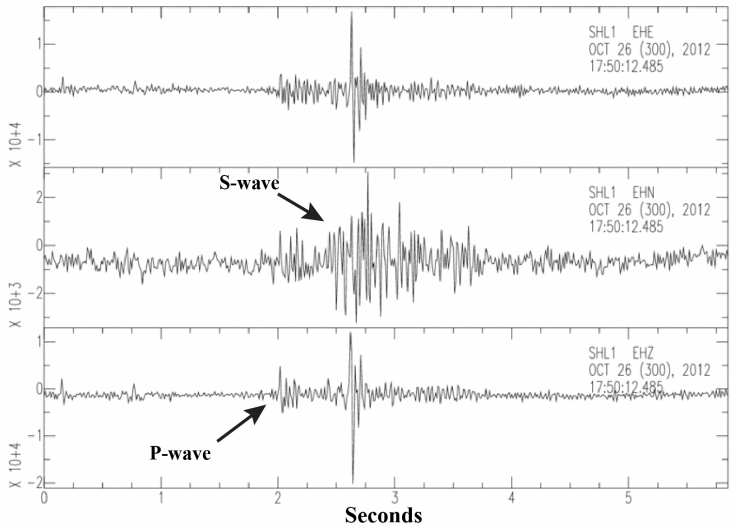


Figure 6. Close event with 'S minus P time' ~0.5 seconds; distance from station <= ~ 3.0 km. Appears to be from the same source area as event in Fig. 5.

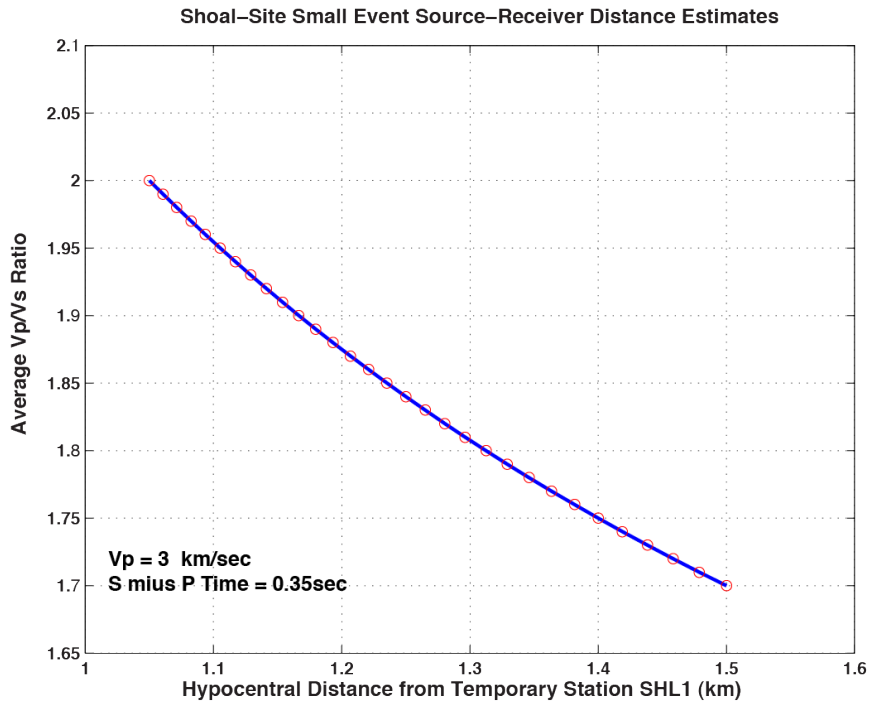


Figure 7. Estimated distance from the station based on a range of Vp/Vs ratios and an 'S minus P time' of 0.35 sec.

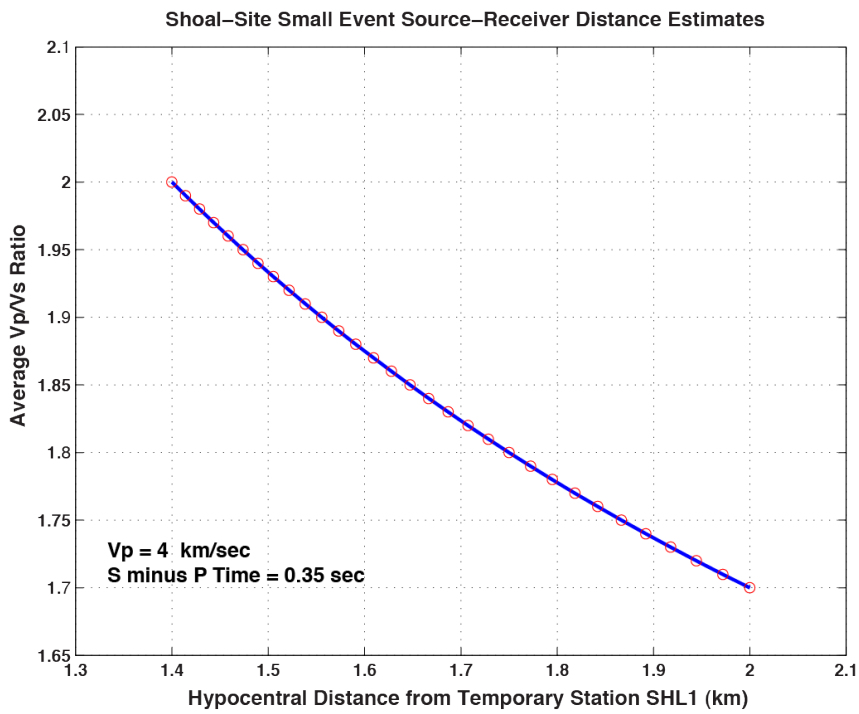


Figure 8. Estimated distance from the station based on a range of Vp/Vs ratios and an 'S minus P time' of 0.35 sec.

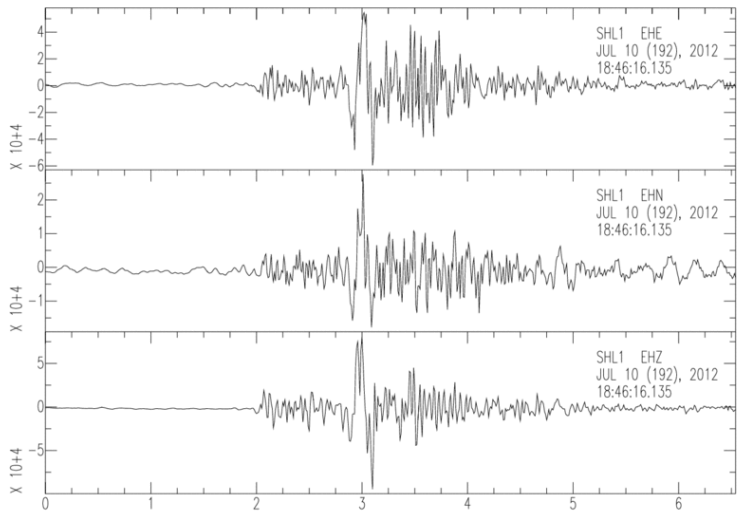


Figure 9. Example of an event with 'S minus P time' of ~ 1 sec.

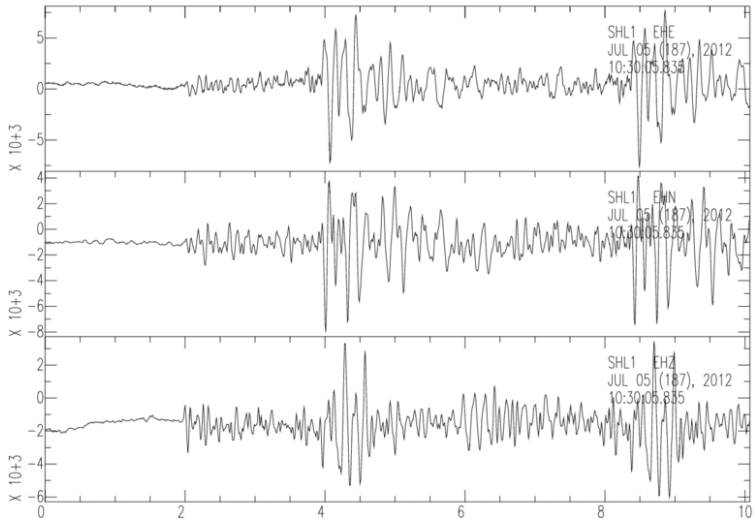


Figure 10. Example of an event with 'S minus P time' of ~ 2 sec (multiple event).

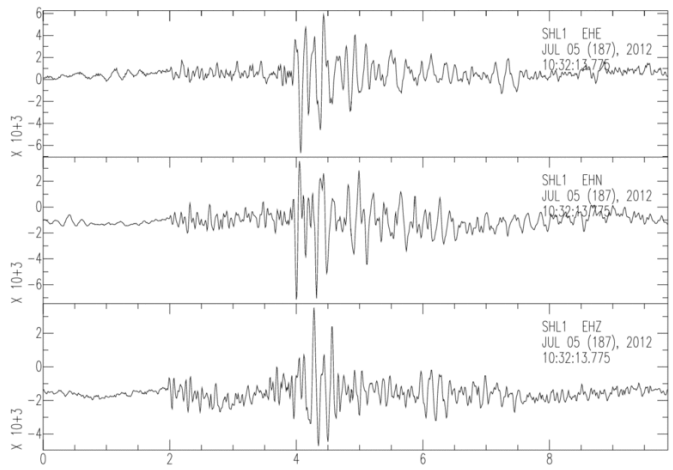


Figure 11. Example of an event with 'S minus P time' of ~ 2 sec.

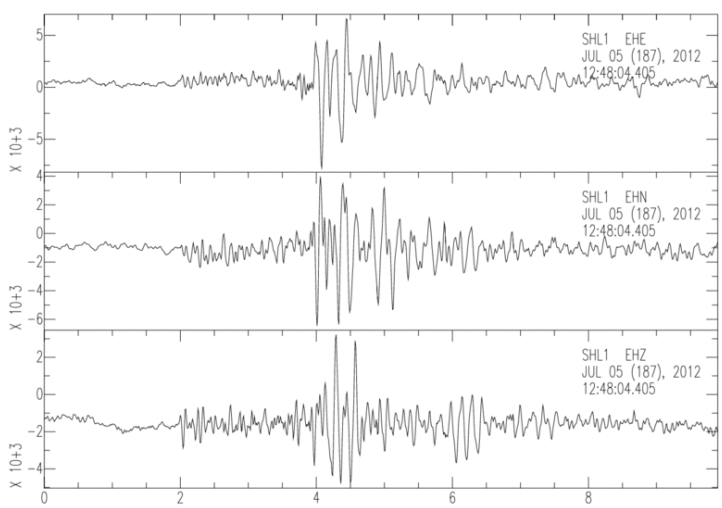


Figure 12. Example of an event with 'S minus P time' of ~ 2 sec.

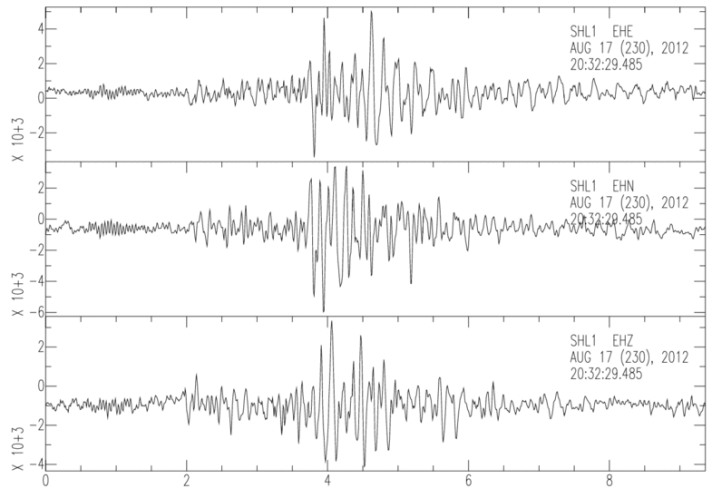


Figure 13. Example of an event with 'S minus P time' of ~ 2 sec.

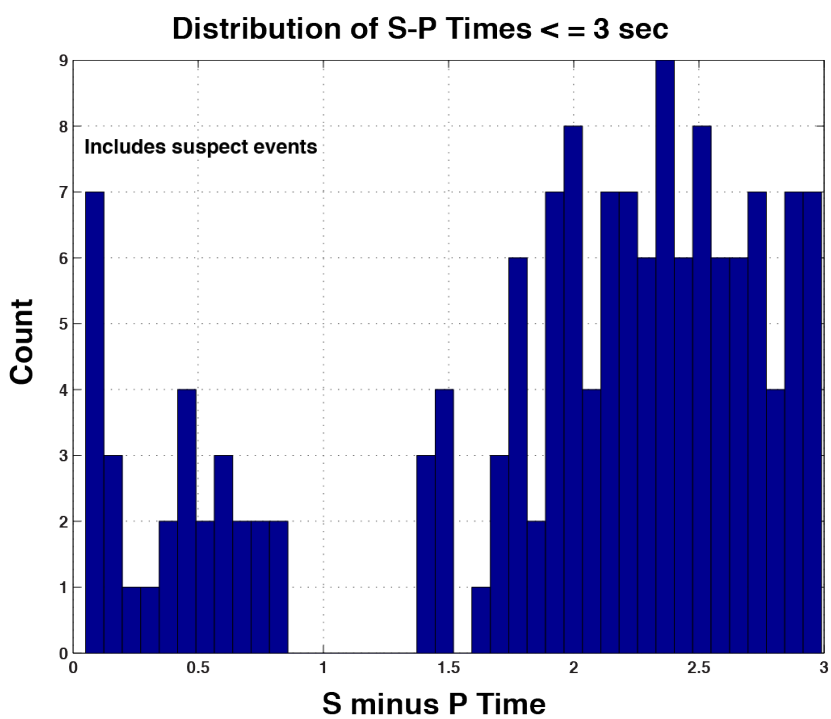


Figure 14. Distribution of 'S minus P times'; includes all suspect events and earthquake signals.

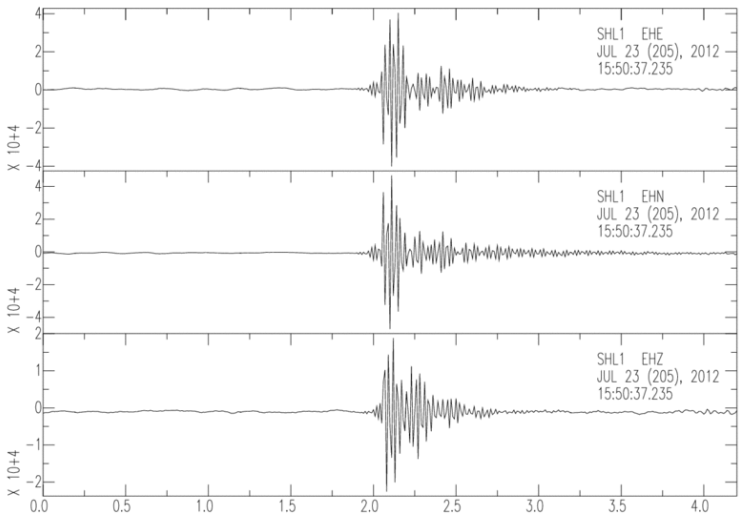


Figure 15. Suspect event; this is interpreted as a noise source, possibly a sonic, wind, or electronic noise. There are numerous examples of similar records.

Appendix F

NDEP Correspondence with Record of Review and Response to Comments

This page intentionally left blank

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

January 30, 2013

Mr. Mark Kautsky
Site Manager
U. S. Department of Energy
Office of Legacy Management
2597 Legacy Way
Grand Junction, CO 81503

RE: Draft 2012 Groundwater Monitoring Report, Subsurface Corrective Action Unit 447, Shoal, Nevada
January 2013
Federal Facility Agreement and Consent Order

Dear Mr. Kautsky:

The Nevada Division of Environmental Protection, Bureau of Federal Facilities (NDEP) has received and reviewed the U. S. Department of Energy, Office of Legacy Management's *Draft 2012 Groundwater Monitoring Report, Subsurface Correction Action Unit 447, Shoal, Nevada* (Report) received on January 14, 2013. The NDEP has the following comments or questions on the Report which should be addressed in the Final version of the Report:

1. Page v, Executive Summary, First Paragraph, Fifth Sentence and Page 18, Section 6.0, First Paragraph, Third through Fifth Sentences: It should be stated in these sentences if the MCL referred to is the U.S. Environmental Protection Agency (EPA)-established maximum contaminant level (MCL) as is done on Page 7, Section 4.1, Second Paragraph.

2. Page v, Executive Summary, Second Paragraph, Fourth Sentence and Page 7, Section 4.0, First Paragraph: It is stated in both these paragraphs that water levels at the site have been rising and the paragraph in the Executive Summary additionally states that water levels west of the shear zone have been rising. Because water levels east of the shear zone do not appear to be rising, are the "general" sentences in error or are they just implying wells west of the shear zone?

3. Page 10, Section 4.2, First Sentence under Figure 4: "Institute in 1997" is a duplication of words from the last sentence on Page 8 and should be removed.

4. Page 10, Section 4.2, First Full Paragraph on Page, Second Sentence: It is suggested that "with the exception of Gross Alpha concentrations in MV-1 in 2011" **or similar wording** be added to reflect the fact that the Gross Alpha concentration was 16.6 pCi/L in 2011, above the 15 pCi/l MCL.

5. Page 11, Section 4.2, First Full Paragraph on Page, Third Sentence: A Table and example calculation need to be added to this Report showing the actual results of doing the calculation(s) described in this sentence.

6. Page 16, Section 5.1, Paragraph on Top of Page, Fifth Sentence: There are no ^{14}C data presented in Table A-4. Either the narrative or the Table should be corrected.

7. Page 16, Section 5.1, Paragraph on Top of Page, Sixth Sentence: Why are "results generally consistent with conceptual models of the site with the exception of well HC-5"? Yes, there is a seven-fold difference in the results from HC-5 but five other wells have a two-, three- or six-fold difference between DIC and DOC values according to Table A-4. Reasons for why the said conclusions in this paragraph are drawn need to be explained.

8. Page 16, Section 5.1, First Full Paragraph on Page, Third Sentence: It should be stated, however briefly, why the preliminary evaluation of the water chemistry data "generally" supports the interpretation that there are separate fault blocks at the site.

9. Pages 16 and 17, Section 5.2, Second Paragraph, Second and Third Sentences on Page 16 and Figure 8 on Page 17: From this sentence, it is not clear what the solid black triangles on Figure 8 actually represent. It appears they represent the data from 2007 to the present, excluding the 2012 samples which are plotted in blue, but the black triangles need to be defined either in the narrative or on the Figure, or both.

10. Page 16, Section 5.2, Second Paragraph, Last Sentence on Page: The actual tritium value of the sample collected by DRI in 1997 should be added to this sentence.

11. Pages 18 and 19, Section 5.5 and Figure 9: The fourth sentence in Section 5.5 states the "total precipitation measured for this monitoring period was 3.81 millimeters or 0.15 inches." However, the totals on Figure 9 appear to be 0.50 millimeters or 0.02 inches. This discrepancy should either be corrected or explained.

12. Pages A-1 and A-3, Appendix A, Tables A-1 and A-3: In a comparison of these two Tables, it appears that **Temperature** and **pH** values listed in Table A-3 are the last values recorded after purging and right before sample collection. Whether or not this is a correct assumption, it should be stated in the narrative and/or on Table A-3 which **Temperature** and **pH** value is recorded.

13. Pages A-1 and A-3, Appendix A, Tables A-1 and A-3: the **Temperature** and **pH** values for HC-4 listed on Table A-3 are not found on Table A-1. This discrepancy should be corrected or explained.

14. Appendix E: The NDEP is aware that the report in this Appendix has been generated by another entity and therefore the OLM cannot change it but a question has arisen in regards to the first paragraph under **Analysis** and the three paragraphs on the last page of text in this Appendix. The first sentence under **Analysis** states "Four earthquakes with 'S minus P times' of <=0.5 seconds were identified in the data." which seems to correlate with the first sentence of the second paragraph on the last page stating, "To date, four confirmed earthquakes are estimated to be within 2 km of the seismograph station." However, The second sentence of the first paragraph on the last page states, "Most events with 'S minus P' times of < 1.0 sec are 'suspect'..." and the first sentence of the third paragraph states, "'S minus P times' of <= 0.5 seconds for local earthquakes are not unusual in Nevada..." Are not all these statements contradictory in some manner? If 'S minus P times' of <= 0.5 seconds for local earthquakes are not unusual in Nevada and events with 'S minus P' times of < 1.0 sec are 'suspect', then would not most Nevada events be suspect? Yet, four earthquakes have been confirmed and the assumption is made these are the four with 'S minus P times' of <=0.5 seconds.

The NDEP concurs with the Recommendations stated in Section 6.0 of the report. Please address any questions regarding this matter to Chris Andres at (702) 486-2850 ext. 232.

Sincerely,

T. H. Murphy
Chief
Bureau of Federal Facilities

CDA

cc: Jeffrey Fraher, DTRA/CXTS, Kirtland AFB, NM
J. B. Chapman, DRI, Las Vegas, NV
NSTec Technical Information Officer, Las Vegas, NV
R. F. Boehlecke, NNSA, Las Vegas, NV
FFACO Group, SNJV, Las Vegas, NV
D. Crawford, Stoller, Grand Junction, CO
R. Hutton, Stoller, Grand Junction, CO
R. Findlay, Stoller, Grand Junction, CO

This page intentionally left blank

Record of Review

Due Date	Review No.	Project	Type of Review
3/22/2013	1	Offsites Project - Shoal	Draft Report - Technical Review

Document Title and\or Number and Revision
2012 Draft Groundwater Monitoring Report Shoal, NV CAU 447 S09338

Author
Mark Kautsky

Author's Organization
Legacy Management

Author's Phone
(970) 248-6018

Reviewer
Chris D. Andres for T.H. Murphy

Reviewer's Organization
Nevada Division of Environmental Protection

Reviewer's Phone
(702) 486-2863

Reviewers' Recommendation

- ☐ Release Without Comment
- ☐ Consider Comments
- ☒ Resolve Comments and Reroute for Review

Refer to the NDEP letter dated January 30, 2013

Signature of Reviewer and Date

- ☒ Comments Have Been Addressed

Mark Kautsky 2013.03.18 12:41:55 -06'00'

Signature of Author and Date

- ☒ Comment Resolution Satisfactory
- ☐ Comment Resolution Unsatisfactory

Chris Andres 3/20/13

Signature of Reviewer and Date

Item No.	Reviewer's Comments and Recommendation	Reqd. (Y/N)	Item No.	Author's Response (if required)
1	Page v, Executive Summary, First Paragraph, Fifth Sentence and Page 18, Section 6.0, First Paragraph, Third through Fifth Sentences: It should be stated in these sentences if the MCL referred to is the U.S. Environmental Protection Agency (EPA)-established maximum contaminant level (MCL) as is done on Page 7, Section 4.1, Second Paragraph.			The change was made as requested and included changes throughout the document.
2	Page v, Executive Summary, Second Paragraph, Fourth Sentence and Page 7, Section 4.0, First Paragraph: It is stated in both these paragraphs that water levels at the site have been rising and the paragraph in the Executive Summary additionally states that water levels west of the shear zone have been rising. Because water levels east of the shear zone do not appear to be rising, are the "general" sentences in error or are they just implying wells west of the shear zone?			The requested sentences were revised to specify that water levels are rising in the site wells west of the shear zone.

Record of Review (continuation)

Review No.	Project Offsites Project - Shoal

Item No.	Reviewer's Comments and Recommendation	Reqd. (Y/N)	Item No.	Author's Response (if required)
3	Page 10, Section 4.2, First Sentence under Figure 4: "Institute in 1997" is a duplication of words from the last sentence on Page 8 and should be removed.			The change was made as requested.
4	Page 10, Section 4.2, First Full Paragraph on Page, Second Sentence: It is suggested that "with the exception of Gross Alpha concentrations in MV-1 in 2011" or similar wording be added to reflect the fact that the Gross Alpha concentration was 16.6 pCi/L in 2011, above the 15 pCi/1 MCL.			The sentence was revised as follows: "Concentrations in samples collected from these wells in 2008 declined below the EPA-established MCLs and have remained relatively constant since then with the exception of the sample collected from well MV-1 in 2011 that detected gross alpha (16.6 pCi/L) above the EPA-established MCL of 15 pCi/L."
5	Page 11, Section 4.2, First Full Paragraph on Page, Third Sentence: A Table and example calculation need to be added to this Report showing the actual results of doing the calculation(s) described in this sentence.			Example calculations have been provided for wells HC-2, HC-4, and HC-7 as requested.
6	Page 16, Section 5.1, Paragraph on Top of Page, Fifth Sentence: There are no 14C data presented in Table A-4. Either the narrative or the Table should be corrected.			Table A–4 in Appendix A provides a summary of 13C and 14C results from DOC and DIC with the apparent age dates obtained from the annual sampling event. The table title and header were changed and a footnote added to provide clarification.
7	Page 16, Section 5.1, Paragraph on Top of Page, Sixth Sentence: Why are "results generally consistent with conceptual models of the site with the exception of well HC-5"? Yes, there is a seven-fold difference in the results from HC-5 but five other wells have a two-, three- or six-fold difference between DIC and DOC values according to Table A-4. Reasons for why the said conclusions in this paragraph are drawn need to be explained.		Table 3 →	The paragraph was revised to create a new paragraph in this section to provide additional clarification on why the DOC result from well HC-5 was not consistent with the site conceptual model. The revised paragraph is provided below: "Current site conceptual models are based on the concept that older water is present at deeper depths and younger water is present at shallower depths in the saturated zone due to the contribution from more recent infiltration. The age date results are generally consistent with this conceptual model with the exception of the DOC age date from well HC-5. The DOC derived apparent age for water from HC-5 is one of the youngest (3,411 years) whereas the DIC derived age is the oldest (21,710 years). Well HC-5 is the deepest well at the site with an open interval over 1,000 ft deeper than the next deepest well and over 2,000 ft deeper than most site wells (**Error! Reference source not found.**). This geometry is consistent with the older DIC derived age date but not the DOC age date. The lighter oxygen and hydrogen isotopic results (Appendix A; Table A–3) from the HC-5 sample also indicate that the water is from precipitation during an older cooler climate. At this time it is uncertain why there is such variability between the two age dates, but discussions with personnel on the Underground Test

Record of Review (continuation)

Review No.	Project Offsites Project - Shoal

Item No.	Reviewer's Comments and Recommendation	Reqd. (Y/N)	Item No.	Author's Response (if required)
				Area Project indicate that this is not uncommon and that they are currently working with a laboratory to develop a procedure for the ^{14}C DOC method. A more thorough analysis of the major ion and stable isotope results will be included with CADD/CAP addendum".
8	Page 16, Section 5.1, First Full Paragraph on Page, Third Sentence: It should be stated, however briefly, why the preliminary evaluation of the water chemistry data "generally" supports the interpretation that there are separate fault blocks at the site.			Additional evaluation of the data is needed before a more complete interpretation can be provided. The sentence was revised as follows: "Additional evaluation of the water chemistry data is needed to determine if the analytical results can be used to identify separate fault blocks at the site."
9	Pages 16 and 17, Section 5.2, Second Paragraph, Second and Third Sentences on Page 16 and Figure 8 on Page 17: From this sentence, it is not clear what the solid black triangles on Figure 8 actually represent. It appears they represent the data from 2007 to the present, excluding the 2012 samples which are plotted in blue, but the black triangles need to be defined either in the narrative or on the Figure, or both.			Figure 8 was revised to more clearly indicate that the black triangles represent samples collected from 2007 to the present before one well purge volume had been removed. The following sentence was also added to the paragraph to highlight the result of the sample collected in 2012 before one well purge volume had been removed. "This was also observed in 2012, when the sample collected after 400 gallons of water had been removed indicated a concentration of tritium of 343 pCi/L."
10	Page 16, Section 5.2, Second Paragraph, Last Sentence on Page: The actual tritium value of the sample collected by DRI in 1997 should be added to this sentence.			The tritium result from the 1997 sample was added as requested. It was also added to Section 4.2.
11	Pages 18 and 19, Section 5.5 and Figure 9: The fourth sentence in Section 5.5 states the "total precipitation measured for this monitoring period was 3.81 millimeters or 0.15 inches." However, the totals on Figure 9 appear to be 0.50 millimeters or 0.02 inches. This discrepancy should either be corrected or explained.			Figure 9 was revised to be consitent with the text.
12	Pages A-1 and A-3, Appendix A, Tables A-1 and A-3: In a comparison of these two Tables, it appears that Temperature and pH values listed in Table A-3 are the last values recorded after purging and right before sample collection. Whether or not this is a correct assumption, it should be stated in the narrative and/or on Table A-3 which Temperature and pH value is recorded.			A footnote was added to Table A-3 and a statement was added to Section 5.1 indicating that the field parameters (pH, temperature, and specific conductance) in Table A-3 are the last set of measurements prior to collecting the sample.
13	Pages A-1 and A-3, Appendix A, Tables A-1 and A-3: the Temperature and pH values for HC-4 listed on Table A-3 are not found on Table A-1. This discrepancy should be corrected or explained.			The field parameters (pH, temperature, and specific conductance) for the sample from well HC-4 in Table A-3 were revised to reflect the last set of parameters before the sample

Record of Review (continuation)

Review No.	Project Offsites Project - Shoal

Item No.	Reviewer's Comments and Recommendation	Reqd. (Y/N)	Item No.	Author's Response (if required)
				was collected as provided in Table A-1.
14	Appendix E: The NDEP is aware that the report in this Appendix has been generated by another entity and therefore the OLM cannot change it but a question has arisen in regards to the first paragraph under Analysis and the three paragraphs on the last page of text in this Appendix. The first sentence under Analysis states "Four earthquakes with 'S minus P times' of <=0.5 seconds were identified in the data." which seems to correlate with the first sentence of the second paragraph on the last page stating, "To date, four confirmed earthquakes are estimated to be within 2 km of the seismograph station." However, The second sentence of the first paragraph on the last page states, "Most events with 'S minus P' times of< 1.0 sec are 'suspect'..." and the first sentence of the third paragraph states, "'S minus P times' of <= 0.5 seconds for local earthquakes are not unusual in Nevada..." Are not all these statements contradictory in some manner? If'S minus P times' of <= 0.5 seconds for local earthquakes are not unusual in Nevada and events with 'S minus P' times of < 1.0 sec are 'suspect', then would not most Nevada events be suspect? Yet, four earthquakes have been confirmed and the assumption is made these are the four with 'S minus P times' of <=0.5 seconds.			A single seismic recording station was placed at Shoal to determine the potential for low magnitude seismic activity at the site. There have been a number of recordings during this monitoring period that began June 28 and extended through December 5, 2012. Due to the limitation of a single station record, recorded events are designated as 'suspect' ('potential' subsurface seismic events). The majority of the 'suspect' signals are likely (interpreted as) surface noise sources, but there are many of them and to absolutely rule out they are not subsurface stress driven displacement events would require additional monitoring stations. Single station deployments are not typical and event identification is subjective. With four stations the locations of confirmed subsurface events could be established. The terminology 'S minus P' time is used for the suspect events since there are apparent dual phase arrival signals (see report). These phase arrivals could potentially be very shallow (within a few kilometers of the surface) shear dislocation events (earthquakes), surface noise sources that are generating both P- and S-wave arrivals, or potentially sonic sources. The high-frequency content of the apparent S-wave arrival for many of the suspect event signals is not consistent with surface waves and there are clearly two distinct arrivals in many cases. The use of the terminology 'S minus P time' is consistent for confirmed earthquakes, but should be considered an 'interpretation' for 'suspect' events that have 'apparent' S minus P times.

Library Distribution List

	Copies
U.S. Department of Energy National Nuclear Security Administration Nevada Site Office Technical Library P.O. Box 98518, M/S 505 Las Vegas, NV 89193-8518 702-295-3521	1 (Uncontrolled)
U.S. Department of Energy Office of Scientific and Technical Information P.O. Box 62 Oak Ridge, TN 37831-0062 865-576-8401	1 (Uncontrolled, electronic copy)
Southern Nevada Public Reading Facility c/o Nuclear Testing Archive P.O. Box 98521, M/S 400 Las Vegas, NV 89193-8521	2 (Uncontrolled, electronic copies)
Manager, Northern Nevada FFACO Public Reading Facility c/o Nevada State Library & Archives 100 N Stewart Street Carson City, NV 89701-4285 775-684-3313	1 (Uncontrolled, electronic copy)
Librarian Churchill County Library 553 South Main Fallon, NV 89406 775-423-7581	1 (Uncontrolled)

This page intentionally left blank