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2016 Groundwater Monitoring Report Project Shoal Area: Subsurface Corrective Action Unit 447

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U.S. DEPARTMENT OF ENERGY | Legacy Management

Contents

Figures

Tables

Appendixes

Abbreviations

AEC	U.S. Atomic Energy Commission
amsl	above mean sea level
^{14}C	carbon-14
CADD	Corrective Action Decision Document
CAP	Corrective Action Plan
CAU	Corrective Action Unit
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FFACO	Federal Facility Agreement and Consent Order
ft	feet
^{129}I	iodine-129
LM	Office of Legacy Management
MCL	maximum contaminant level
MDC	minimum detectable concentration
µg/L	micrograms per liter
mg/L	milligrams per liter
MV	monitoring/validation
NDEP	Nevada Division of Environmental Protection
pCi/L	picocuries per liter
RDL	required detection limit
SCM	site conceptual model
^{234}U	uranium-234
^{238}U	uranium-238

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Executive Summary

The Project Shoal Area in Nevada was the site of a 12-kiloton-yield underground nuclear test in 1963. It later came to be known as the “Shoal, Nevada, Site.” 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. The corrective action strategy is currently focused on revising the site conceptual model (SCM) and evaluating the adequacy of the 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. Although water levels in these wells continue to rise, the rate of increase is less than in previous years with the exception of last year, which had a reduced rate of water level increase that was attributed to impacts from the drilling program completed in late 2014. Revisions to the SCM and enhancements to the monitoring well network are to be provided to Nevada Division of Environmental Protection in a future addendum to the Corrective Action Decision Document/Corrective Action Plan (DOE 2011a).

Analytical results from the 2016 sampling event are consistent with those of previous years. Well HC-4 continues to be the only well with tritium concentrations above the laboratory’s minimum detectable concentration. The tritium concentration (725 picocuries per liter [pCi/L]) is consistent with past results and is below the U.S. Environmental Protection Agency’s (EPA’s) maximum contaminant level (MCL) of 20,000 pCi/L and below the well’s highest concentration of 1130 pCi/L reported in 1998. The carbon-14 (^{14}C) concentrations in this well have historically been below the required detection limit (RDL) of 5 pCi/L until the 2015 and 2016 sampling events, when the samples had concentrations of 14.6 pCi/L and 7.02 pCi/L, respectively. The presence of ^{14}C concentrations above the RDL is consistent with last year’s results, but is not consistent with the historic results. Sample results from well HC-4 show an increase in gross alpha and uranium mass concentrations above the MCLs beginning in 2012, with the highest concentration of uranium (120 micrograms per liter [µg/L]) detected during this sampling event. The increase continues and may be attributed to an increase in the volume of groundwater removed from the well during sampling. Samples from wells HC-6 and MV-4 also had gross alpha activity and uranium mass concentrations above the EPA MCLs, but those levels were consistent with past results. If the gross alpha values in samples collected from wells HC-4, HC-6, and MV-4 are adjusted by subtracting activities of uranium-234 and uranium-238, the values are less than zero, indicating that uranium accounts for all or nearly all gross alpha activity in these samples. Isotope ratios of uranium obtained during this monitoring event continue to support the interpretation of a natural source of uranium in the groundwater rather than a nuclear-test-related source.

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1.0 Introduction

This report presents the 2016 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. It later came to be known as the "Shoal, Nevada, Site." Responsibility for environmental site restoration of the PSA was transferred from the DOE, National Nuclear Security Administration, Nevada Field Office 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)* (as amended) (NDEP 1996) 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 results from the annual groundwater monitoring program conducted through August 2016.

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 U.S. Department of Defense and the U.S. Atomic Energy Commission (AEC) jointly conducted the Project Shoal underground nuclear test on October 26, 1963, as part of the Vela-Uniform program. The test consisted of detonating a 12-kiloton-yield nuclear device in granitic rock at a depth of approximately 1211 feet (ft) below ground surface (AEC 1964). A cavity created by the test collapsed shortly after the detonation and formed a rubble chimney (Hazleton-Nuclear Science Corporation 1965). The radius of the cavity was 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). The decontamination and restoration activities were minimal, because no large areas of surface radiological contamination were found during or following the test. During the cleanup effort, the emplacement shaft was covered with a concrete slab, and the particle motion boreholes, exploratory core holes, and U.S. Bureau of Mines boreholes on the site were plugged and abandoned. A radioactive materials survey conducted at the surface of the site in 1970 indicated that no radioactivity exceeded background for the area (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 remaining from the excavation of the emplacement shaft, and housekeeping areas that consisted of approximately 20 rusted and empty oil cans. Remediation of the surface of CAU 416 was completed in 1998 and is summarized in the *Closure Report for Corrective Action Unit 416, Project Shoal Area* (DOE/NV 1998) (referred to herein as the "Closure Report"). 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).

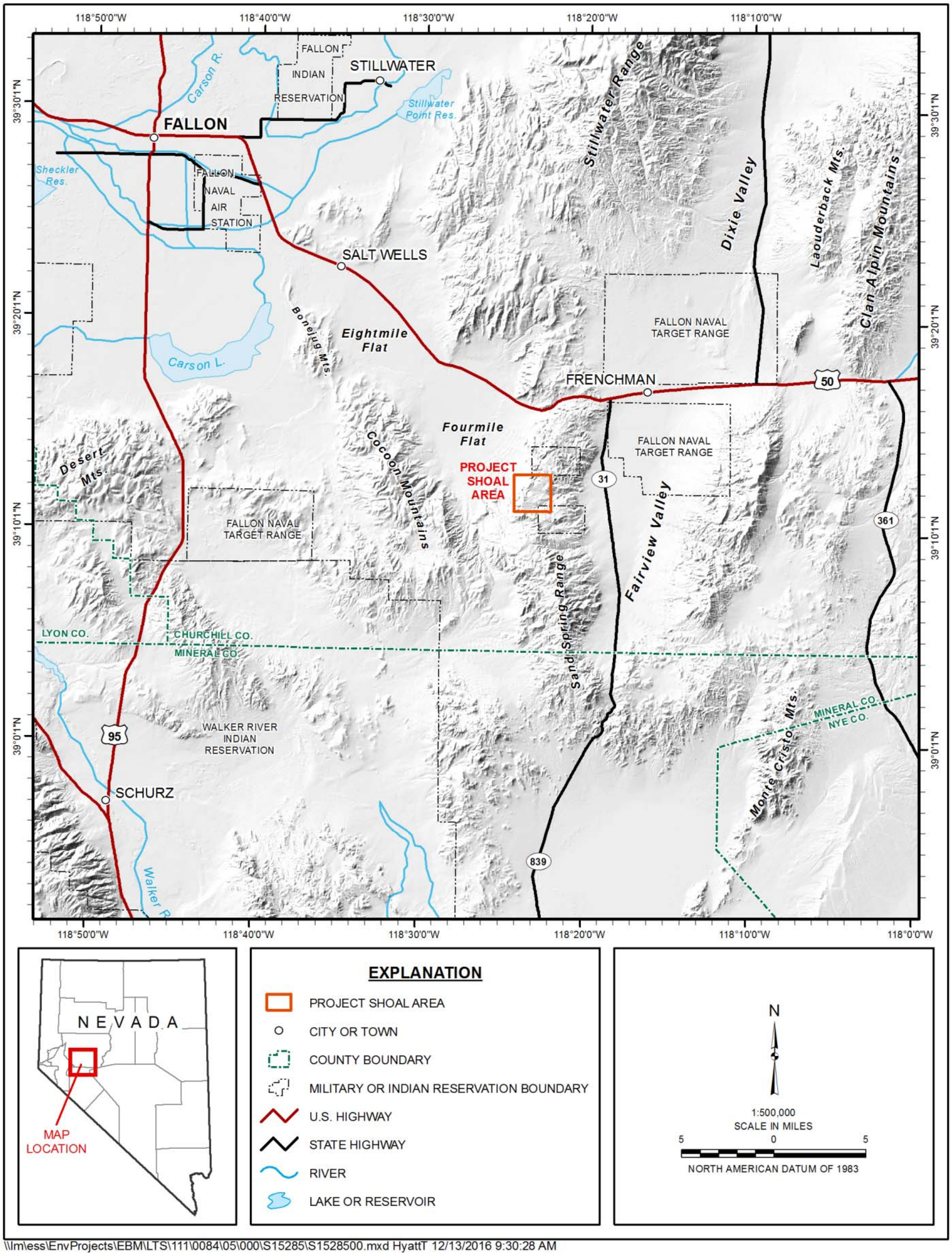

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Figure 1. Location of the Project Shoal Area

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 1000 years of radionuclide transport where test-related radionuclides in groundwater outside the boundary have a 5% 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 groundwater 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 1990s. Water levels were not monitored at the site (except in the adjacent valleys) before the HC wells and, later, the MV wells were installed. Pursuant to the FFACO (NDEP 1996), 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 (DOE 2009). The completed geophysical program included seismic and electromagnetic surveys. As part of the evaluation of data obtained from the surveys, there was a technical exchange meeting in March 2011 between the geophysicists who performed the surveys (Lee Liberty from Boise State University and Jim Hasbrouck from Hasbrouck Geophysics, Inc.), Desert Research Institute, and NDEP, to discuss the results and the potential SCMs. 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 the surface geophysics report provided the basis for developing the new data acquisition plan that was submitted to NDEP in October 2011 (DOE 2011a).

The 2011 data acquisition plan included further review of available reports and preparation of a detailed information resource tool that includes a summary of pertinent technical data. Analytical, hydrologic, and geologic data obtained from historical reports were reviewed and compared with more recent data; additional geophysical data was collected to help identify geologic structures that might influence groundwater flow at the site. These data were assembled for three-dimensional visualization. Revisions to the SCM and enhancements to the monitoring well network are to be provided to NDEP in a future addendum to the CADD/CAP (DOE 2011a).

The 2014 data acquisition plan included enhancements to the monitoring well network by installing two monitoring wells (MV-4 and MV-5) and deepening of the existing well HC-2, now identified as HC-2d (DOE 2014). Monitoring wells MV-4 and MV-5 were dually completed with a well and piezometer so that the vertical and horizontal gradients could be determined. The well casing in the existing well HC-2 was removed, and the borehole was deepened to allow the installation of the new well, HC-2d. The new wells and the deepened well were completed with dedicated electric submersible pumps to facilitate the collection of groundwater samples and to conduct aquifer tests. The new wells and existing wells/piezometers were surveyed to obtain new top-of-casing measuring point elevations after the drilling program. The top-of-casing elevations ranged from 2.89 to 3.04 ft lower than what was obtained from the 2006 well survey and included in the previous reports. The offsite wells H-2 and H-3 were not included in the 2006 survey, so previous reports used the ground surface elevations provided in the CADD/CAP. Results from the 2014 drilling program are provided in the well completion report (DOE 2015a). The well survey data are provided in the 2015 groundwater monitoring report (DOE 2015b).

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 6751 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 5250 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 are predominantly along 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 960 to 1100 ft below ground surface, 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 1500 ft east of surface ground zero (Figure 2 and Figure 3), is interpreted as a barrier to groundwater flow on the basis of 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.

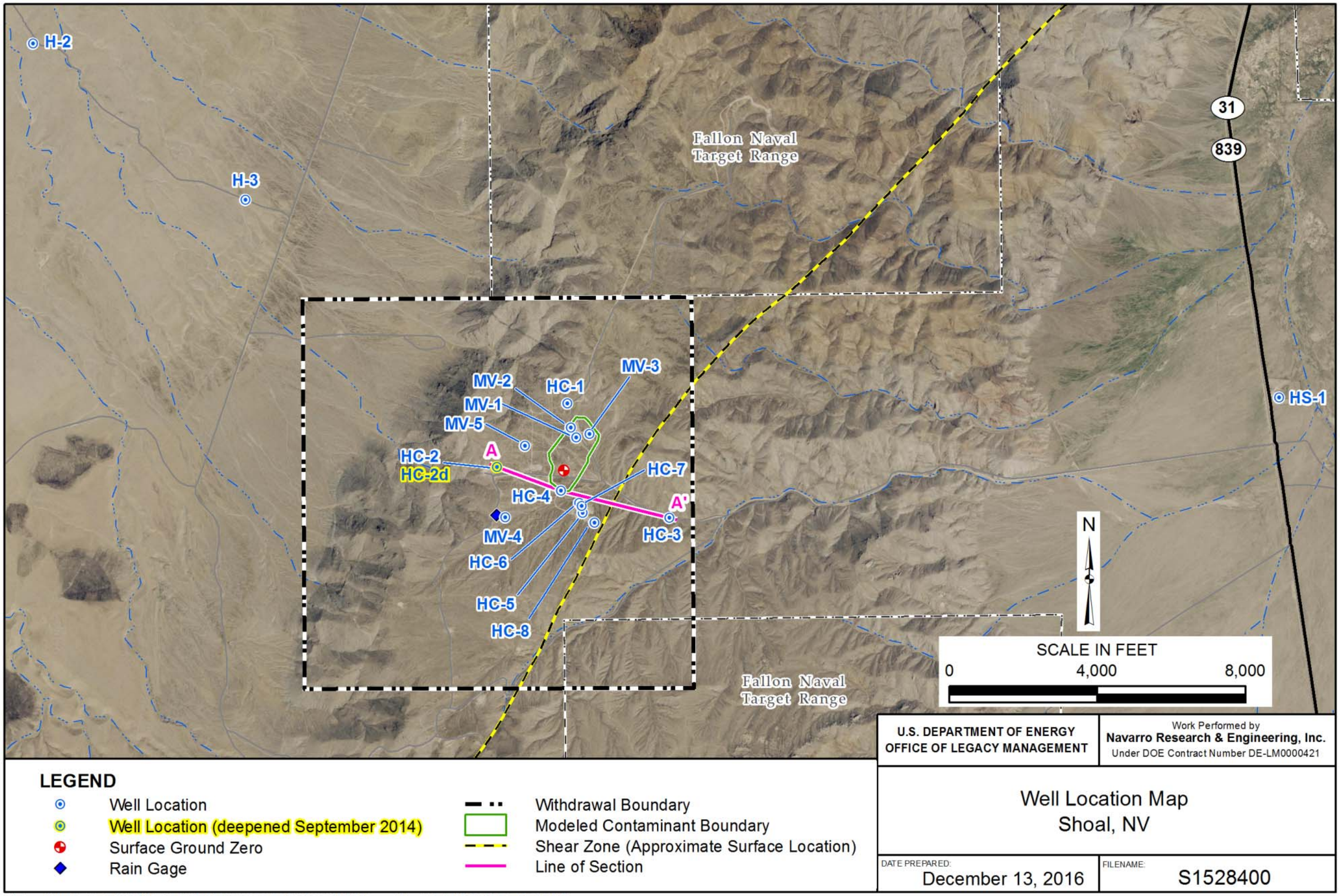

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Figure 2. Well Locations at the Shoal, Nevada, Site

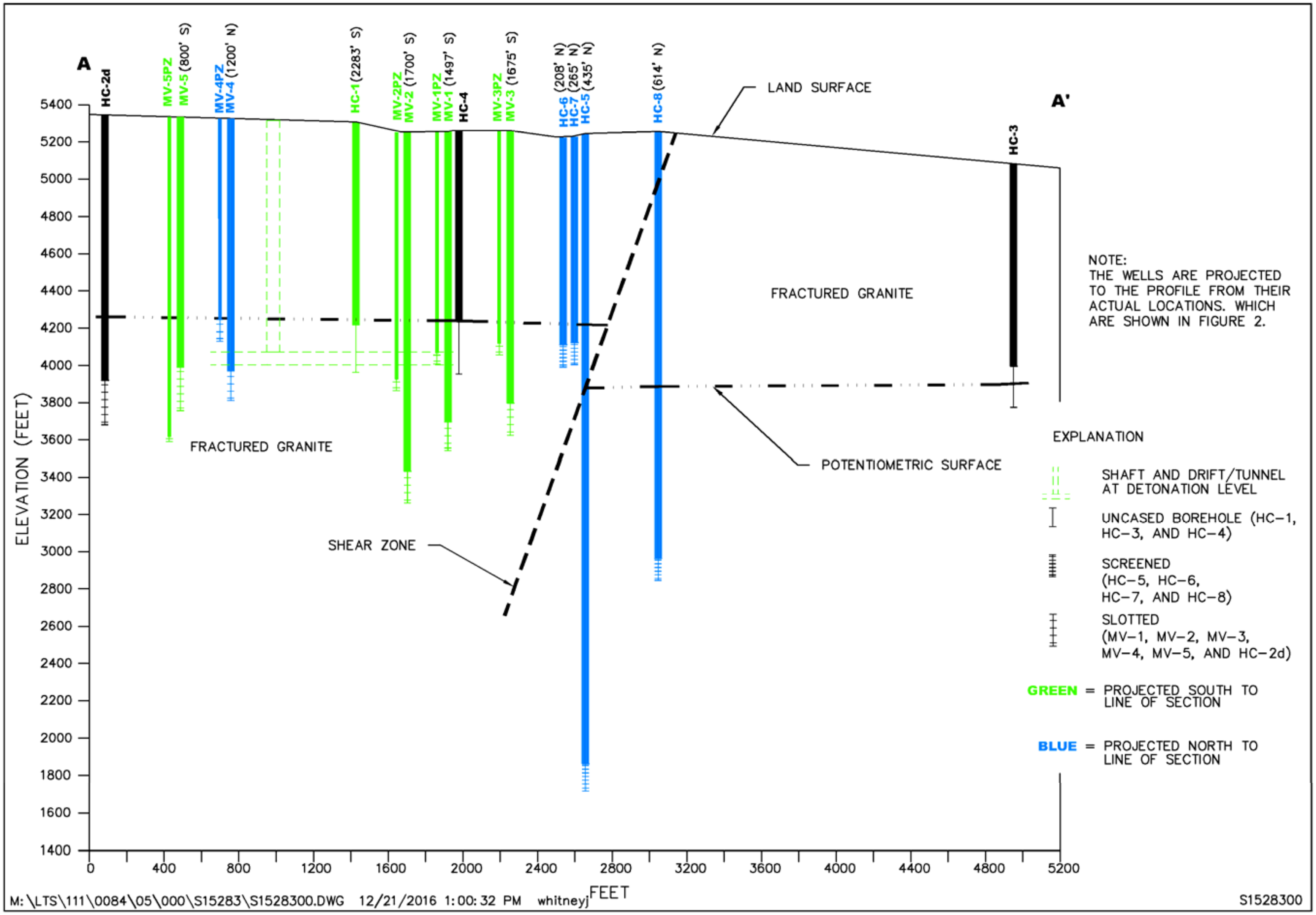

Figure 3. Cross Section A–A' Depicting Monitoring Well and Shear Zone Location, Shoal, Nevada, Site

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 completed in 2009, 2011, and 2014 to support the CADD/CAP and to provide interim guidance documents until an addendum to the CADD/CAP can be completed. The 2014 data acquisition plan included the installation of two new monitoring wells (MV-4 and MV-5) and the deepening of the existing well HC-2 now identified as HC-2d (DOE 2014). The *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites* (LMS/PRO/S04351) is used to guide the quality assurance/quality control of the annual sampling and monitoring program.

The corrective action strategy is focused on revising the SCM and evaluating the adequacy of the current monitoring well network. Two major points of concern in the SCM 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 (Figure 2). 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, which includes collecting samples for laboratory analysis, measuring depth to groundwater, downloading data from transducers in site monitoring wells, and downloading data from the rain gage that was installed in August 2012. The 2016 monitoring program was enhanced to include supplemental activities, which were the collection of an additional sample from well HC-4 for carbon-14 (^{14}C) analysis and the analysis of bromide at all sample locations. Plans for the 2016 monitoring program were specified in the 2016 sampling plan provided to NDEP (DOE 2016). Results from the monitoring program are provided below, and results from the supplemental activities are provided in Section 5.0.

4.1 Radioisotope Monitoring

Groundwater samples were collected from wells MV-1, MV-2, MV-3, MV-4, MV-5, HC-1, HC-2d, HC-3, HC-4, HC-5, HC-6, HC-7, and HC-8 during the May 2016 sampling event. Monitoring wells MV-1, MV-2, MV-3, MV-4, MV-5, HC-2d, 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 (Appendix A, Table A-1). Samples were collected from wells HC-1, 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 "Standard Practice for Validation of Environmental Data" section in the *Environmental Procedures Catalog* (LMS/POL/S04325). A copy of the Data Validation Package is available on the LM public website at http://www.lm.doe.gov/shoal/Sites.aspx. Table A-1 in Appendix A presents the final measurements of field parameters and well purge volumes.

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; DOE 2011a; DOE 2014), which enhanced the monitoring network defined in the CADD/CAP (DOE/NNSA 2006). An additional sample was collected from well HC-4 during this monitoring event to be analyzed for ^{14}C. The short-term data acquisition plan completed in 2009 (DOE 2009) reduced the frequency for analyzing samples for ^{14}C and iodine-129 (^{129}I) to every 5 years beginning after the 2010 sampling 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 relatively short half-life (12.3 years), ^{14}C and ^{129}I are also monitored to establish baseline conditions 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) maximum contaminant level (MCL) for gross alpha is exclusive of uranium and radon. Including uranium mass and uranium isotope 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 EPA MCLs for tritium, gross alpha, and uranium are 20,000 picocuries per liter (pCi/L), 15 pCi/L, and 30 micrograms per liter (µg/L), respectively.

The CADD/CAP established regulatory levels for site groundwater of 20,000 pCi/L tritium, 2000 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 CADD/CAP also established laboratory required detection limits (RDLs) to provide a minimum standard for the analytical laboratories to report the radiochemical results. The RDL originally established for tritium (300 pCi/L) was changed to 400 pCi/L to be consistent with the LM laboratory contract requirements. This change was documented in a record of technical change submitted to NDEP and approved in March 2012. The RDLs are higher than what the analytical laboratory provides as their minimum detectable concentrations (MDCs), and when applicable, the results are referenced to the laboratory MDCs. The exceptions are the results for ^{14}C and ^{129}I, which, because of the analytical method, do not report MDCs, and the analytical results are provided and compared to the RDLs established in the CADD/CAP. The RDLs are provided as footnotes to Table 1 and Table 2. The laboratory radiochemical MDCs reported with these data are a priori estimates of the detection capability of a given analytical procedure, not absolute concentrations that can or cannot be detected.

4.2 Radioisotope Results

Table 1 presents a summary of analytical results for ^{14}C, ^{129}I, tritium, uranium, and gross alpha from the samples collected in 2014 through 2016. Tables B-1 and B-2 in Appendix B present analytical results from when the CADD/CAP monitoring program began in 2007 through the present. A time-concentration plot for well HC-4 (Figure 4) presents tritium results from the CADD/CAP monitoring program and sampling events performed by EPA and Desert Research Institute before the CADD/CAP monitoring program began 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 B, Table B-1).

Table 1. Radioisotope and Chemical Sampling Results, 2014 Through 2016

Monitoring Location	Date	Carbon-14 (pCi/L)	Iodine-129 (pCi/L)	Tritium (pCi/L)	Uranium (µg/L)	Gross Alpha (pCi/L)
MV-1	5/27/2014	NA	NA	<320	21	10.7
	5/29/2015	<RDL (1.13 × 10^{-2})	<RDL (1.6 × 10^{-11})	<380	21	12.8
	5/24/2016	NA	NA	<364	20	11
MV-2	5/27/2014	NA	NA	<320	22	11.6
	5/27/2014[a]	NA	NA	<320	21	10.8
	5/29/2015	<RDL (1.77 × 10^{-2})	<RDL (1.6 × 10^{-11})	<380	22	15
	5/29/2015[a]	NA	NA	<370	23	14
	5/25/2016	NA	NA	<364	21	6.01
MV-3	5/27/2014	NA	NA	<320	8.3	4.98
	5/28/2015	<RDL (9.75 × 10^{-3})	<RDL (2.0 × 10^{-11})	<370	10	4.61
	5/25/2016	NA	NA	<363	11	4.33
MV-4	5/29/2015	<RDL (3.58 × 10^{-2})	<RDL (5.0 × 10^{-12})	<370	63	36.7
	5/25/2016	NA	NA	<368	41	22.3
MV-5	5/28/2015	<RDL (1.35 × 10^{-2})	<RDL (1.25 × 10^{-10})	<370	0.23	<1.4
	5/24/2016	NA	NA	<367	0.27	2.96
	5/24/2016[a]	NA	NA	<368	0.23	<1.2
HC-1	5/27/2014	NA	NA	<320	0.8	<1.2
	5/26/2015	<RDL (1.81 × 10^{-2})	<RDL (1.31 × 10^{-10})	<380	0.87	2.04
	5/24/2016	NA	NA	<365	0.6	1.22
HC-2	5/27/2014	NA	NA	<320	100	46.8
HC-2d	5/29/2015	<RDL (1.10 × 10^{-2})	<RDL (<1.4 × 10^{-11})	<380	3.2	8.54
	5/25/2016	NA	NA	<367	4.2	6.08
HC-3	5/28/2014	NA	NA	<320	0.32	<1.9
	5/26/2015	<RDL (6.24 × 10^{-3})	<RDL (<2.3 × 10^{-10})	<380	0.26	<1.2
	5/24/2016	NA	NA	<351	0.08	<0.98
HC-4	5/28/2014	NA	NA	700	62	27.8
	5/27/2015	14.6	<RDL (3.35 x 10^{-10})	731	110	60.6
	5/24/2016	7.02	NA	725	120	42.6
HC-5	5/28/2014	NA	NA	<320	0.33	<2.2
	5/28/2015	<RDL (2.52 × 10^{-3})	<RDL (3.2 x 10^{-11})	<380	0.53	<1.7
	5/25/2016	NA	NA	<368	0.45	<1.6
HC-6	5/27/2014	NA	NA	<320	39	16.9
	5/26/2015	<RDL (1.30 × 10^{-2})	<RDL (5.5 × 10^{-11})	<370	41	28.7
	5/24/2016	NA	NA	<364	41	19.7
HC-7	5/28/2014	NA	NA	<320	11	6.76
	5/27/2015	<RDL (6.20 × 10^{-3})	<RDL (<1.3 × 10^{-11})	<370	16	13.3
	5/26/2016	NA	NA	<364	18	6.94
HC-8	5/28/2014	NA	NA	<320	0.23	<1.9
	5/28/2015	<RDL (1.23 × 10^{-2})	<RDL (1.5 × 10^{-11})	<380	0.23	2.13
	5/26/2016	NA	NA	<353	0.14	<1.33

Notes:

[a] Indicates a duplicate sample.

<RDL = below required detection limit with laboratory result in parentheses; the RDLs are 5 pCi/L for ^{14}C, 0.1 pCi/L for ^{129}I, 400 pCi/L for tritium, 50 µg/L for uranium, and 4 pCi/L for gross alpha (DOE/NNSA 2006).

Abbreviations:

NA = not applicable (samples not collected or samples not analyzed).

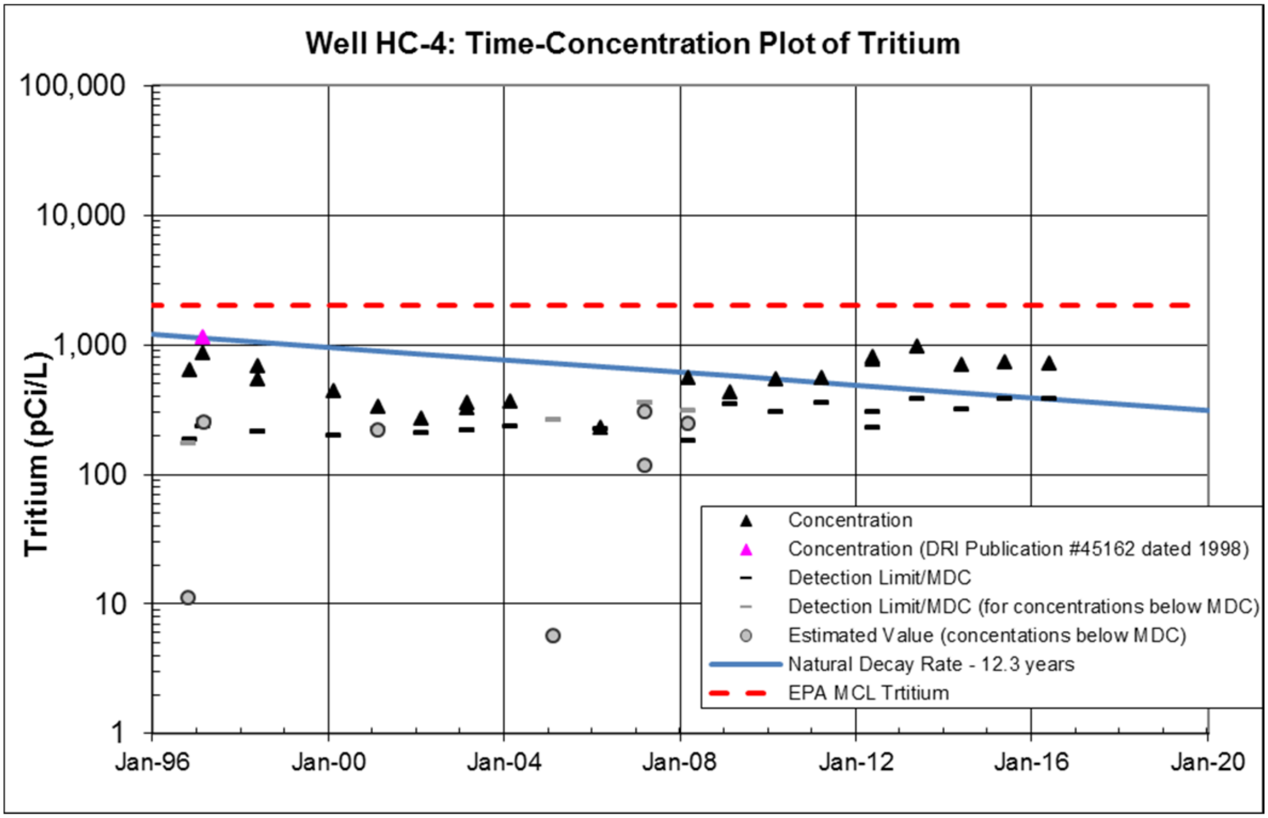

Figure 4. Time-Concentration Plot of Tritium at Well HC-4

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 carbon dioxide molecule, where it dissolved into groundwater in the upper saturated zone near the detonation. The concentrations of ^{14}C in well HC-4 have historically been below the RDL of 5 pCi/L (Table B-1 in Appendix B) until the 2015 and 2016 sampling events, when the samples had concentrations of 14.6 pCi/L and 7.02 pCi/L, respectively (Table 1). Well HC-4 was the only well sampled for ^{14}C during the 2016 monitoring event, to verify the 2015 result. Table B-3 in Appendix B provides the calculations with supporting laboratory data used to convert the ^{14}C data to a pCi/L concentration.

Tritium was detected in well HC-4 at a concentration of 725 pCi/L during the 2016 sampling event but was not detected in any of the remaining wells at the site (Table 1). 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 had 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 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 964 pCi/L in 2013. The variation in tritium concentrations is related to the different volumes of groundwater removed during the sampling events. The highest tritium concentration of 1130 pCi/L was from a sample collected in 1997 by Desert Research Institute after approximately 1100 gallons of groundwater were removed during an aquifer test. 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 (DOE 2013). The volume of groundwater removed from well HC-4 was increased after the 2011 sampling event to a minimum volume of 700 gallons (one well volume). The well purge volumes are not available for samples collected prior to 2007, with the exception of the sample collected by Desert Research Institute in 1997.

Analytical results from the 2016 sampling event (Table 1) indicate that samples from wells HC-4, HC-6, and MV-4 had gross alpha activity and uranium mass concentrations above the EPA MCLs of 15 pCi/L and 30 µg/L, respectively. Samples from wells HC-4 and HC-6 have historically had concentrations above the MCLs. The sample results from well HC-4 show an increase in gross alpha and uranium mass concentrations above the MCLs starting in 2012, with the highest concentration of uranium (120 µg/L) detected during this sampling event. The increase that started in 2012 may be attributed to an increase in the volume of groundwater removed from the well during sampling. Concentrations of gross alpha and uranium detected in well HC-6 are consistent with the past results. Well MV-4 was installed in late 2014 and samples collected in 2015 and 2016 had concentrations of gross alpha and uranium above the MCLs, but more data are needed to determine if this will be a continuing trend. Samples collected from wells MV-1, MV-2, and HC-7 during this monitoring event did not have concentrations of gross alpha or uranium above the MCLs, but have had concentrations above the MCLs in the past (Appendix B, Table B-1). Historically, samples from well HC-2 have had concentrations of gross alpha and uranium mass concentrations above the MCLs, but this well was deepened in 2014, and the new well HC-2d is completed across a deeper interval and sample results are below the respective MCLs. The remaining analytical results for gross alpha and uranium from the 2016 sampling event are below the MCLs and consistent with previous results.

Bevans et al. (1998) demonstrated that concentrations of uranium are elevated in ambient groundwater in the region surrounding the site. The elevated uranium concentrations are attributed to leaching from granitic bedrock and associated sediments. If the gross alpha values for samples from wells HC-4, HC-6, and MV-4 (Table 1) are adjusted by subtracting activities of uranium-234 (^{234}U) and uranium-238 (^{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 (see example calculation below for adjusted results). Isotope 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 in Appendix B provides the ^{234}U:^{238}U activity ratios since 2007, which range from 0.77 to 2.77—consistent with activity ratios that are in equilibrium and from 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 (pCi/L): Gross alpha – ^{234}U – ^{238}U = Adjusted result
HC-4 : 42.6 – 39.1 – 39.4 = −35.9
HC-6 : 19.7 – 16.3 – 13.7 = −10.3
MV-4: 22.3 – 14.7 – 13.6 = −6.0

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

Table 2. Uranium Isotope Sampling Results, 2014 Through 2016

Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	Uranium-234:Uranium-238
MV-1	5/27/2014	7.69	6.42	1.20
	5/29/2015	8.52	7.2	1.18
	5/24/2016	8.45	6.93	1.22
MV-2	5/27/2014	8.38	7.0	1.20
	5/27/2014[a]	8.15	7.16	1.14
	5/29/2015	8.37	7.15	1.17
	5/29/2015[a]	7.73	6.44	1.20
	5/25/2016	7.51	6.53	1.15
MV-3	5/27/2014	2.95	2.52	1.17
	5/28/2015	3.54	2.93	1.21
	5/25/2016	4.33	3.66	1.18
MV-4	5/29/2015	20.4	18.8	1.09
	5/25/2016	14.7	13.6	1.08
MV-5	5/28/2015	0.119	0.064	1.86
	5/24/2016	0.202	0.118	1.71
	5/24/2016[a]	0.092	0.119	0.77
HC-1	5/27/2014	0.373	0.25	1.49
	5/26/2015	0.353	0.264	1.34
	5/24/2016	0.301	0.261	1.15
HC-2	5/27/2014	33.4	32.5	1.03
HC-2d	5/29/2015	1.35	1.14	1.18
	5/25/2016	1.62	1.51	1.07
HC-3	5/28/2014	0.102	0.106	0.96
	5/26/2015	0.101	0.078	1.29
	5/24/2016	0.066	0.079	0.84
HC-4	5/28/2014	21.4	21.5	1.00
	5/27/2015	31.2	32.9	0.95
	5/24/2016	39.1	39.4	0.99
HC-5	5/28/2014	0.255	0.149	1.71
	5/28/2015	0.392	0.307	1.28
	5/25/2016	0.207	0.159	1.30
HC-6	5/27/2014	15.6	13.6	1.15
	5/26/2015	15.3	13	1.18
	5/24/2016	16.3	13.7	1.19
HC-7	5/28/2014	4.1	3.76	1.09
	5/27/2015	5.65	4.72	1.20
	5/26/2016	6.82	5.84	1.17
HC-8	5/28/2014	0.102	0.094	1.09
	5/28/2015	0.155	0.072	2.15
	5/26/2016	0.14	0.05	2.08

Notes:

[a] Indicates a duplicate sample.

The RDL for uranium isotopes is 0.1 pCi/L (DOE/NNSA 2006).

4.3 Hydraulic Head Monitoring

The groundwater flow system was monitored by measurements of hydraulic head in the onsite wells/piezometers and offsite wells (H-2 and H-3) (Figure 2). Piezometers are distinguished from the wells by the notation “PZ.” Heads were recorded every hour by transducers installed in the wells and piezometers. The monitoring location HC-7 is no longer monitored using a transducer because of its proximity to well HC-6 and similar hydraulic head. Wells H-2 and H-3 are also no longer monitored using transducers because water levels have been stable at these locations over the years (DOE 2015b). Water levels were measured manually in all wells/piezometers included in the monitoring network (Table 3), and the transducers were downloaded in May as part of the sampling and in August as part of the water level monitoring. The manual water levels were used with the top-of-casing elevations to convert the transducer data to groundwater elevations. Table 3 presents the well construction information, top-of-casing elevations, and manual water level measurements collected in 2016.

Table 3. Construction Details for Monitoring Wells and 2016 Water Level Measurements

Well/ Piezometer	TOC Elevation (ft amsl)[e]	Water Depth (ft)[a]	Date	Elevation Water (ft amsl)[b]	Elevation TSZ (ft amsl)	Elevation BSZ (ft amsl)	Screen Length (ft)
MV-1	5254.64	988.38	5/12/2016	4266.26	3680.24	3526.43	154
MV-1PZ	5254.38	968.14	5/12/2016	4286.24	3915.47	3855.47	60
MV-2	5263.72	997.78	5/11/2016	4265.94	3442.63	3271.86	171
MV-2PZ	5263.60	984.35[c]	5/25/2016	4279.25[c]	4074.80	4015.30	60
MV-3	5258.60	966.45	5/12/2016	4292.15	3793.61	3622.45	171
MV-3PZ	5258.24	965.97	5/12/2016	4292.27	4116.78	4056.75	60
MV-4	5370.78	1082.55	5/11/2016	4288.23	3969.08	3809.08	160
MV-4PZ	5370.41	1081.21	5/11/2016	4289.20	4249.08	4129.08	120
MV-5	5318.16	1051.31	5/11/2016	4266.85	3991.01	3751.01	240
MV-5PZ	5317.50	1050.44	5/11/2016	4267.06	3616.01	3586.01	30
HC-1	5306.32	1059.15	5/11/2016	4268.38	4210.44	3979.64	231
HC-2d	5343.93	1105.40	5/13/2016	4238.97	3925.15	3685.15	240
HC-3	5078.57	1180.08	5/12/2016	3918.49	3893.20	3872.70	21
HC-4	5257.88	1002.40	5/13/2016	4259.28	4242.63	3961.63	281
HC-5	5244.33	1369.52	5/13/2016	3874.81	1857.34	1711.74	146
HC-6	5225.73	960.54	5/13/2016	4266.08	4109.00	3992.68	116
HC-7	5226.74	960.60	5/13/2016	4266.36	4119.23	4002.10	117
HC-8	5256.89	1372.38	5/13/2016	3885.07	2960.85	2844.37	116
H-2	4018.22	110.06	5/14/2016	3908.16	3377.06	3237.06	340[d]
H-3	4233.95	325.57	5/14/2016	3908.38	3919.30	3762.30	157

Notes:

[a] Manual depth-to-water measurements are not corrected for borehole deviation.
[b] Elevation of water measurements are corrected for borehole deviation.
[c] Indicates the water level/groundwater elevation has not recovered from development with the addition of water.
[d] Indicates the well is screened across multiple intervals and the total effective screen length is provided.
[e] The TOC elevations obtained after the drilling program in 2014 are provided in U.S. State Plane, Zone Nevada West 2703 coordinate system, with vertical data based on the North American Vertical Datum 1929 (DOE 2015b).

Abbreviations:

BSZ = bottom of open interval; screened, perforated, or open hole.
TOC = top of casing (well/piezometer).
TSZ = top of open interval; screened, perforated, or open hole.

4.4 Hydraulic Head Results

Hydrographs of hydraulic head data from site wells/piezometers from when the CADD/CAP monitoring program was initiated in 2007 are shown in Figure 5, Figure 6, and Figure 7. Hydrographs of hydraulic head data obtained from when the first wells were installed at the site in 1996 to the present are shown in Figures C-1, C-2, and C-3 of Appendix C. 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 hour or two. The top-of-casing elevations (Table 3) were used to convert these data to groundwater elevations. The new top-of-casing elevations were projected back to early 2009, which resulted in a downward shift of approximately 3 ft in the groundwater elevations that are shown in the hydrographs provided as Figure 5 and Figure 6. 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 (detonation side) include the MV-1, MV-2, MV-3, MV-4, and MV-5 wells and piezometers and wells HC-1, HC-2d, HC-4, HC-6, and HC-7 (Figure 3). Water levels in all wells and piezometers west of the shear zone, except piezometer MV-2PZ and well HC-2d, continued to rise during the period from July 2015 through July 2016. The rate of increase, ranging from 0.75 ft in MV-2 to 2.20 ft in MV-3, was higher than last year (July 2014 through July 2015), which had a reduced rate of increase that was attributed to impacts from the drilling program completed in late 2014 (DOE 2016). The water level in piezometer MV-2PZ is continuing to decline slowly (Figure 5). This decline is attributed to water being added after a development event in 2012 to remove remnant drilling mud. The water level in piezometer MV-2PZ is not indicative of the static head level in the formation at its screened interval (DOE 2016). The rate of water level change was not assessed in well HC-2d because water levels in this well have been recovering from aquifer testing conducted in October 2015 and May 2016. Transducer data from MV-4PZ, HC-1, MV-5PZ, MV-5, MV-1, MV-2, and HC-2d are not available for the time period October 2015 through May 2016 because the hard drive in the field laptop computer used to download and store the data crashed during the May 2016 monitoring event and the data could not be recovered (Figure 5). Transducer data from the piezometer MV-1PZ are not available for the time period May through August 2016 because the battery in the transducer failed and the data could not be recovered. A new transducer was installed in this piezometer during the August monitoring event. Table D-1 in Appendix D shows the annual water level changes in wells west of the shear zone from July 2007 through July 2016.

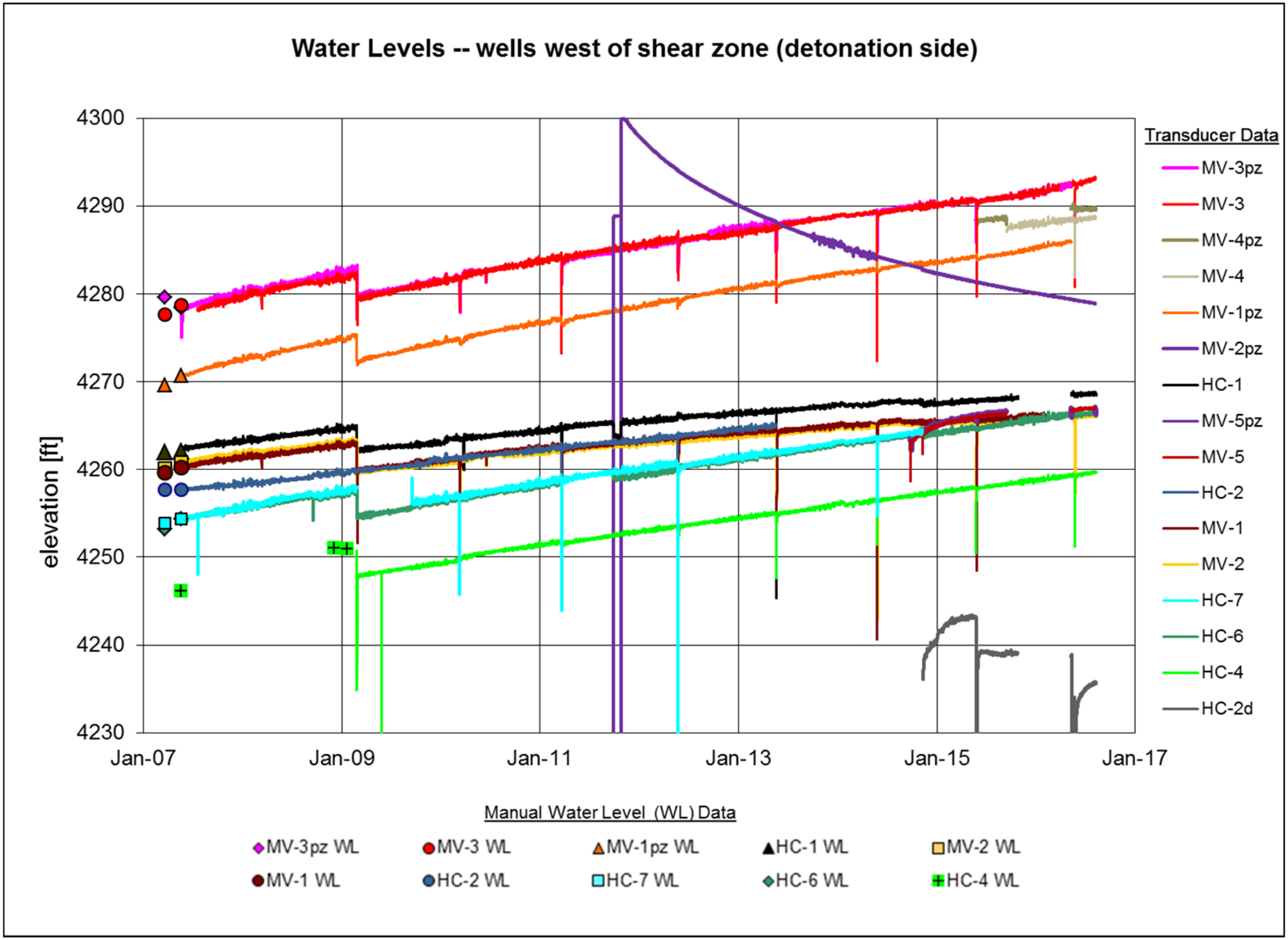

Figure 5. Hydrographs for Wells West of the Shear Zone

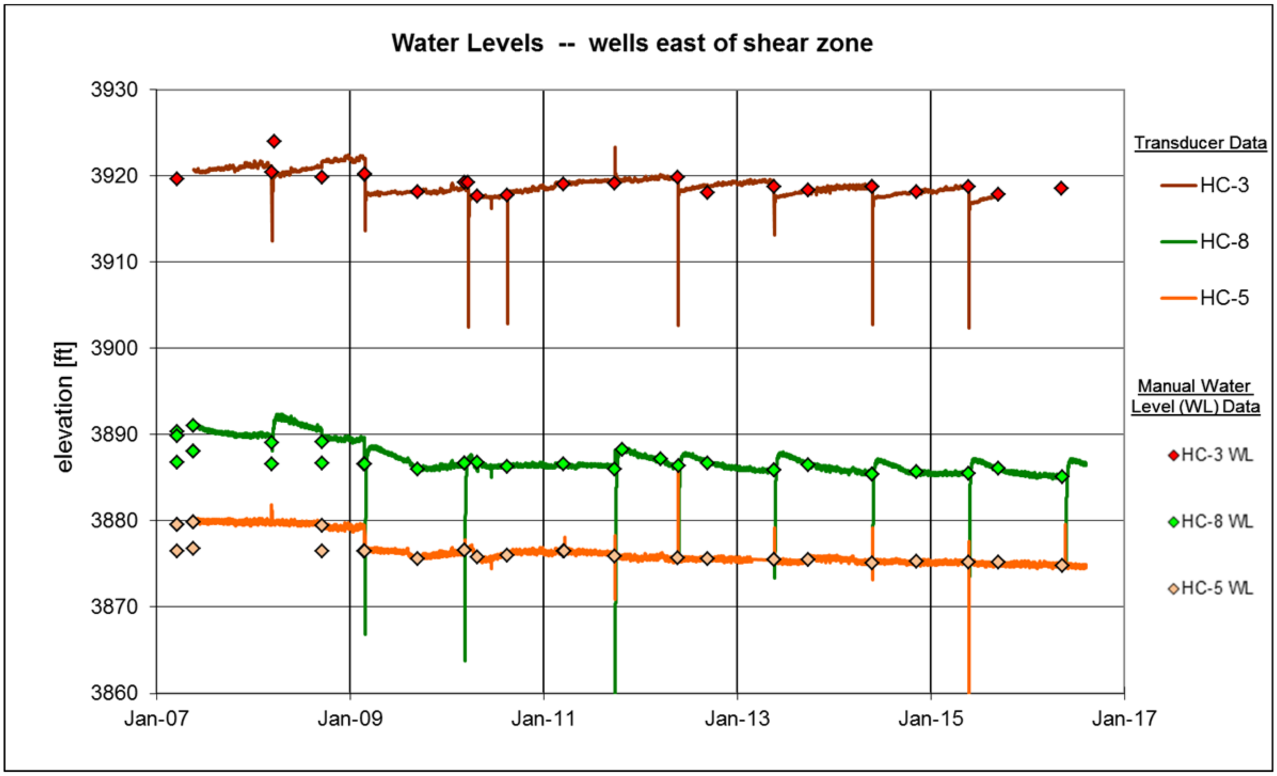

Figure 6. Hydrographs for Wells East of the Shear Zone

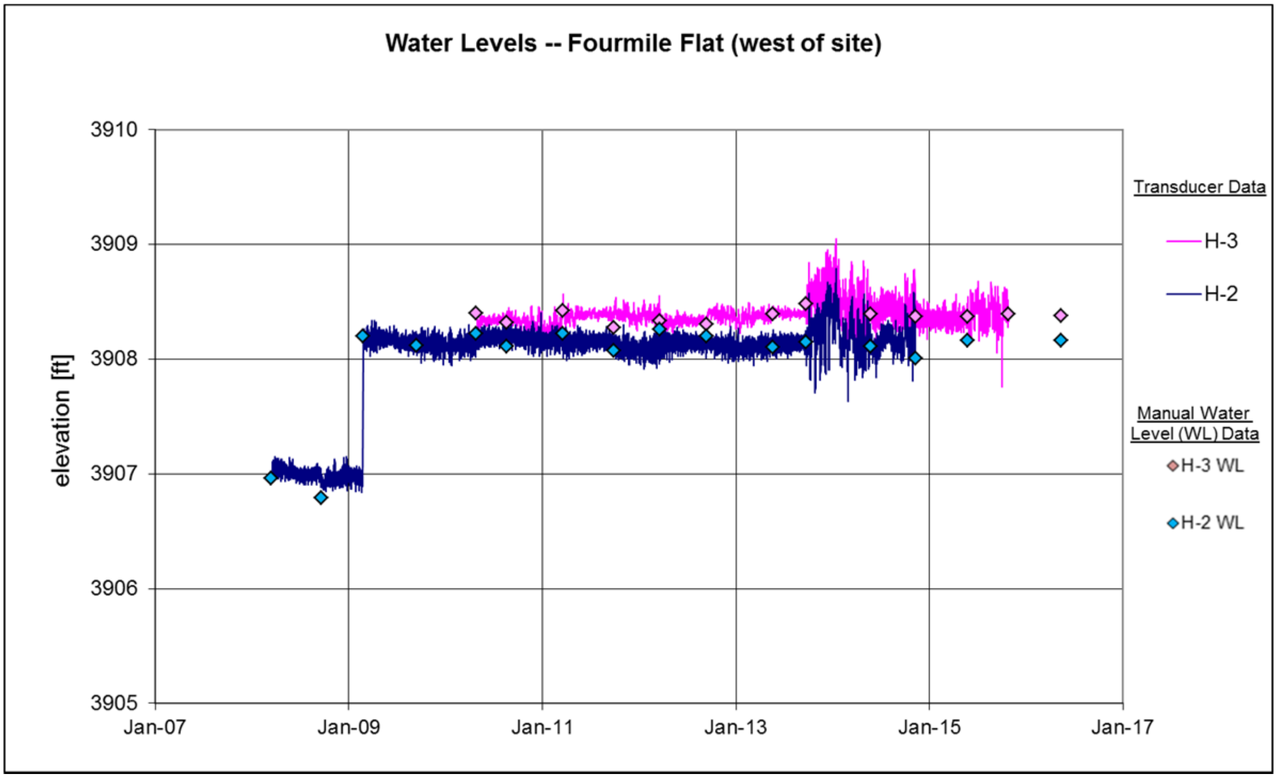

Figure 7. Hydrographs for Wells in Fourmile Flat

Monitoring locations east of the shear zone include wells HC-3, HC-5, and HC-8 (Figure 3). Water levels in these wells are 300 to 400 ft lower (Figure 6) than those in wells west of the shear zone (Figure 5). The water levels in wells HC-3, HC-5, and HC-8 have been interpreted as being stable, not increasing or decreasing, except for times when they are sampled. As more data have become available, it is apparent that the water levels in wells HC-5 and HC-8 are declining at the rate of approximately 1 to 2 ft every 10 years (Figure 6). This decline may be the cumulative result of purge water being removed during the sampling events. These wells (HC-5 and HC-8) have submersible electric pumps, and thousands of gallons are removed each sampling event (Table A-1, Appendix A). Well HC-3 is sampled with a bailer, and only a few gallons of water are removed during sampling. Transducer data from HC-3 are not available for the time period October 2015 through May 2016 because the hard drive in the field laptop computer used to download and store the data crashed during the May 2016 monitoring event and the data could not be recovered (Figure 6). The transducer was not reinstalled in well HC-3 during the May 2016 sampling event because of difficulties during the removal and installation. A new transducer was installed in this well during the August 2016 monitoring event. The downward shift in the groundwater elevations observed in 2009 is attributed to the new top-of-casing elevations obtained from the well survey completed after the drilling program in 2014 (DOE 2015b).

Monitoring locations offsite in Fourmile Flat include wells H-2 and H-3 (Figure 2). Water levels in these wells are 300 to 400 ft lower (Figure 7) than those in wells west of the shear zone at the site (Figure 5) and have been stable since they were installed in 1962. These wells are no longer monitored using transducers, but water levels continue to be measured manually as recommended in the 2014 groundwater monitoring report (DOE 2015b). The hydrograph showing head data from wells H-2 and H-3 was updated with the manual water level measurements (Figure 7). The upward shift in the groundwater elevations observed in 2009 is attributed to the new top of casing elevations obtained from the well survey completed after the drilling program in 2014 (DOE 2015b).

4.5 Rain Gage Monitoring Results

A Campbell Scientific tipping bucket rain gage with HOBO data logger was installed on August 8, 2012, to collect precipitation data at the site (Figure 2). The rain gage was inspected, winterized, and downloaded during the August monitoring event. The data obtained for this monitoring period (October 2015 through August 2016) are presented with the historical data as Figure 8. The total precipitation measured from October 28, 2015, through August 11, 2016, was 9.49 inches.

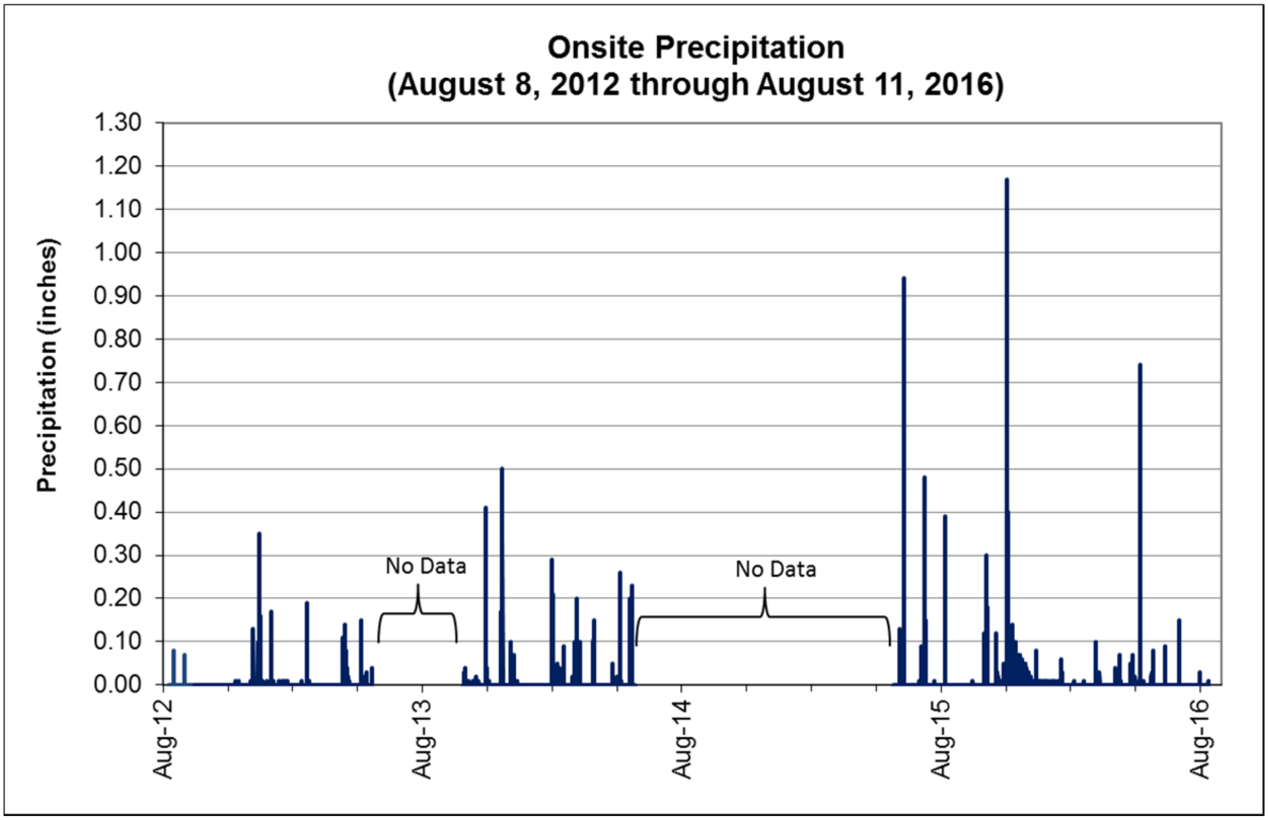

Figure 8. Precipitation Data, August 8, 2012, Through August 11, 2016

5.0 Site Inspection and Supplemental Site Activities

The site was inspected as part of the monitoring events in May and August 2016. This included inspecting the site roads, wellheads, rain gage, and monument at surface ground zero for signs of damage or vandalism. The site roads, wellheads, rain gage, and monument were all in good condition at the time of the inspections. Supplemental activities conducted during the annual sampling event in May included collecting samples from the onsite wells to be analyzed for bromide and collecting an additional sample from well HC-4 to be analyzed for ^{14}C. Results from the ^{14}C analysis are summarized in Section 4.2. Results from the bromide analysis are summarized in the following section.

5.1 Bromide Analysis

The May 2016 sampling event was enhanced by analyzing samples from the onsite wells for bromide. Bromide was an additive used during the drilling programs to evaluate well development. It was also used during a groundwater tracer test between wells HC-6 and HC-7 in 1999. The analytical results from this monitoring event indicate that the highest bromide concentration was 5.9 milligrams per liter (mg/L) in well HC-6. This well was used as the injection well during the tracer test in 1999 and has consistently had the highest bromide concentrations. Samples from the recently installed wells MV-4 and MV-5 had bromide concentrations that decreased from last year’s results of 3.1 mg/L and 4.3 mg/L, to 1.3 mg/L and 1.6 mg/L, respectively. These decreases are the result of additional developed and aquifer testing conducted in 2016. The sample from well HC-3 had a bromide concentration of 1.9 mg/L.

This well was constructed with a small-diameter casing (2.4-inch inside diameter) because of difficulties encountered during the installation in 1996 and 1997, which made development difficult. All remaining wells had concentrations that were 1.0 mg/L or below, which is consistent with the 2014 and 2015 results. Table E-1 in Appendix E presents a summary of the bromide results from the 2014 through 2016 sampling events.

6.0 Summary and Recommendations

Analytical results from the 2016 sampling event are consistent with those of previous years. Well HC-4 continues to be the only well with tritium concentrations above the laboratory's MDC. The tritium concentration (725 pCi/L) is consistent with past results and is below the EPA's MCL of 20,000 pCi/L and below the well's highest concentration of 1130 pCi/L reported in 1998 (Pohll et al. 1998). The ^{14}C concentrations in this well have historically been below the RDL of 5 pCi/L until the 2015 and 2016 sampling events, when the samples had concentrations of 14.6 pCi/L and 7.0 pCi/L, respectively. The presence of ^{14}C concentrations above the RDL is consistent with last year's results, but is not consistent with the historic results. Sample results from well HC-4 show an increase in gross alpha and uranium mass concentrations above the MCLs beginning in 2012, with the highest concentration of uranium (120 µg/L) detected during this sampling event. The increase that began in 2012 shows a trend that may be attributed to an increase in the volume of groundwater removed from the well during sampling. Samples from wells HC-6 and MV-4 also had gross alpha activity and uranium mass concentrations above the EPA MCLs, but those were consistent with past results. If the gross alpha values in samples collected from wells HC-4, HC-6, and MV-4 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. Isotope ratios of uranium obtained during this monitoring event continue to support the interpretation of a natural source of uranium in groundwater rather than a nuclear-test-related source.

Water level trends obtained from the 2016 water level data are consistent with those of previous years. Water levels in all wells/piezometers west of the shear zone (except for the locations described in Section 4.4) continued to rise during the period from July 2015 through July 2016. The rate of increase, ranging from 0.75 ft in MV-2 to 2.20 ft in MV-3, was higher than last year (July 2014 through July 2015), which reflected a lower rate of increase that was attributed to impacts from the drilling program completed in late 2014. Water levels in the onsite wells east of the shear zone continue to show that water levels in wells HC-5 and HC-8 are declining at a rate of approximately 1 to 2 ft every 10 years.

The site roads, wellheads, rain gage, and monument at surface ground zero were all in good condition during the site inspections. The total precipitation measured at the site from October 28, 2015, through August 11, 2016, was 9.49 inches. Supplemental activities included analyzing samples from the onsite wells for bromide. Well HC-6 continues to have the highest bromide concentration (5.9 mg/L), which is attributed to the tracer injected in this well during the tracer test in 1999. The recently installed wells MV-4 and MV-5 had bromide concentrations of 1.3 mg/L and 1.6 mg/L, respectively. These concentrations decreased from last year's results, which can be attributed to additional developed and aquifer testing that was conducted in 2016. The sample from well HC-3 had a bromide concentration of 1.9 mg/L, which can be attributed to the wells small-diameter casing (2.4-inch inside diameter) and difficulty in the development of the well following its installation in 1996 and 1997. All remaining wells had concentrations that were 1 mg/L or below, which is consistent with the 2014 and 2015 results.

LM recommends the following:

- Continue collecting samples from the site wells for bromide analysis to monitor bromide concentrations associated with the tracer test and past drilling programs.
- Conduct additional development and monitor bromide concentrations at well MV-4.
- Complete the aquifer test and monitor bromide concentrations at well MV-5.

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Appendix A

2016 Monitoring Well Purge Data

Table A-1. Monitoring Well Purge Data

Monitoring Location	Date Sampled	Purged Volume (gallons)	Temperature (^oC)	pH (s.u.)	Specific Conductance (µmhos/cm)	Turbidity (NTU)
MV-1	5/24/2016	930	22.07	8.27	743	1.83
			22.13	8.21	735	2.94
			22.04	8.16	735	9.97
MV-2	5/25/2016	1190	22.90	8.28	485	14.1
			22.83	8.21	485	1.58
			22.68	8.22	487	4.90
MV-3	5/25/2016	850	21.89	8.32	754	1.66
			22.04	8.27	767	1.51
			22.19	8.24	772	1.05
MV-4	5/25/2016	660	18.50	8.30	750	3.91
			19.10	8.23	786	9.21
			20.25	8.25	802	3.53
MV-5	5/24/2016	630	21.02	11.31	985	5.09
			20.99	11.29	967	4.57
			21.02	11.29	940	5.23
HC-1	5/24/2016	1.59	NA	7.85	415	55.4
HC-2d	5/25/2016	1000	20.94	8.12	670	17.7
			20.93	8.06	669	25.4
			20.94	8.08	672	25.1
HC-3	5/24/2016	1.59	NA	9.19	621	69.8
HC-4	5/24/2016	980	21.68	7.63	774	14.6
			21.48	7.65	782	11.4
			21.89	7.67	782	8.99
HC-5	5/25/2016	2540	26.28	8.45	1022	1.50
			26.39	8.48	1014	2.66
			26.43	8.46	1012	3.49
HC-6	5/24/2016	1.59	NA	8.08	1154	18.8
HC-7	5/26/2016	630	21.80	7.84	1439	1.72
			21.88	7.82	1436	2.21
			21.92	7.86	1458	1.25
HC-8	5/26/2016	3070	28.69	8.20	878	2.92
			28.75	8.23	873	2.40
			28.83	8.22	874	1.73

Abbreviations:
µmhos/cm = micromhos per centimeter
NA = not analyzed
NTU = Nephelometric Turbidity Units
s.u. = Standard Unit

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Appendix B

Analytical Data for 2007 Through 2016 and Calculations for Carbon-14

Table B-1. Radioisotope 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 (5.83 × 10^{-3})[a]	<RDL (7.3 × 10^{-11})	<359	42	25.6
	3/21/2007	NA	NA	NA	41[b]	21.5[b]
	3/11/2008	<RDL (2.49 × 10^{-2})	<RDL (1.90 × 10^{-10})	<180	21	14.0
	2/26/2009	<RDL (1.95 × 10^{-2})	<RDL (1.05 × 10^{-10})	<350	21	12.6
	3/11/2010	<RDL (1.93 × 10^{-2})	<RDL (7.8 × 10^{-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
	5/22/2013	NA	NA	<370	21	13.6
	5/27/2014	NA	NA	<320	21	10.7
	5/29/2015	<RDL (1.13 × 10^{-2})	<RDL (1.6 × 10^{-11})	<380	21	12.8
	5/24/2016	NA	NA	<364	20	11
MV-2	3/21/2007	<RDL (1.77 × 10^{-2})[a]	<RDL (8.3 × 10^{-11})	<361	34	16.3
	3/21/2007	NA	NA	NA	34[b]	17.3[b]
	3/11/2008	<RDL (2.44 × 10^{-2})	<RDL (2.95 × 10^{-10})	<180	23	11.1
	2/26/2009	<RDL (2.13 × 10^{-2})	NR	<360	24	12
	3/11/2010	<RDL (3.31 × 10^{-2})	<RDL (1.65 × 10^{-10})	<300	21	13.8
	3/22/2011	NA	NA	<350	23	9.92
	5/24/2012	NA	NA	<300	22	10.6
	5/22/2013	NA	NA	<320	22	9.79
	5/27/2014	NA	NA	<320	22	11.6
	5/27/2014[c]	NA	NA	<320	21	10.8
	5/29/2015	<RDL (1.77 × 10^{-2})	<RDL (1.6 × 10^{-11})	<380	22	15
	5/29/2015[c]	NA	NA	<370	23	14
	5/25/2016	NA	NA	<364	21	6.01
MV-3	3/21/2007	<RDL (5.90 × 10^{-3})[a]	<RDL (1.35 × 10^{-10})	<357	14	10.2
	3/21/2007	NA	NA	NA	14[b]	9.57[b]
	3/11/2008	<RDL (1.37 × 10^{-2})	<RDL (1.8 × 10^{-10})	<320	3.8	2.11
	2/26/2009	<RDL (8.37 × 10^{-3})	<RDL (1.07 × 10^{-10})	<360	3.8	<1.5
	3/12/2010	<RDL (1.29 × 10^{-2})	<RDL (6.5 × 10^{-11})	<300	4.2	2.63
	3/22/2011	NA	NA	<350	5.8	4.98
	5/25/2012	<RDL (1.06 × 10^{-2})	NA	<300	7	2.72
	5/21/2013	NA	NA	<340	8	5.08
	5/21/2013[c]	NA	NA	<380	8	5.84
	5/27/2014	NA	NA	<320	8.3	4.98
	5/28/2015	<RDL (9.75 × 10^{-3})	<RDL (2.0 × 10^{-11})	<370	10	4.61
	5/25/2016	NA	NA	<363	11	4.33
MV-4	5/29/2015	<RDL (3.58 × 10^{-2})	<RDL (5.0 × 10^{-12})	<370	63	36.7
	5/25/2016	NA	NA	<368	41	22.3
MV-5	5/28/2015	<RDL (1.35 × 10^{-2})	<RDL (1.25 × 10^{-10})	<370	0.23	<1.4
	5/24/2016	NA	NA	<367	0.27	2.96
	5/24/2016[c]	NA	NA	<368	0.23	<1.2

Table B-1 (continued). Radioisotope 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-1	3/21/2007	<RDL (1.52×10^{-2})[a]	<RDL (9.6×10^{-11})	<355	3.3	3.9
	3/21/2007	NA	NA	NA	3.4[b]	4.46[b]
	3/11/2008	<RDL (2.35×10^{-2})	<RDL (4.9×10^{-11})	<320	4.8	12.5
	2/26/2009	<RDL (2.01×10^{-2})	NR	<360	1.4	<1.4
	3/24/2010	<RDL (3.18×10^{-2})	<RDL (1.19×10^{-10})	<310	3.3	4.93
	3/22/2011	NA	NA	<360	1.6	2.19
	5/23/2012	<RDL (1.23×10^{-2})	NA	<300	1.1	<0.75
	5/22/2013	NA	NA	<340	0.9	3.19
	5/27/2014	NA	NA	<320	0.8	<1.2
	5/26/2015	<RDL (1.81×10^{-2})	<RDL (1.31×10^{-10})	<380	0.87	2.04
	5/24/2016	NA	NA	<365	0.6	1.22
HC-2	3/24/2010	<RDL(1.90×10^{-2})	<RDL (2.5×10^{-11})	<300	140	63.8
	3/22/2011	NA	NA	<360	120	197
	5/22/2012	NA	NA	<300	110	64.5
	5/22/2013	NA	NA	<330	100	61.1
	5/27/2014	NA	NA	<320	100	46.8
HC-2d	5/29/2015	<RDL (1.10×10^{-2})	<RDL (<1.4×10^{-11})	<380	3.2	8.54
	5/25/2016	NA	NA	<367	4.2	6.08
HC-3	3/24/2010	<RDL (2.37×10^{-2})	<RDL (5.41×10^{-9})	<300	4.3	2.57
	3/22/2011	NA	NA	NA	NA	NA
	5/23/2012	<RDL (1.45×10^{-2})	NA	<300	2	0.283
	5/22/2013	NA	NA	<350	2.7	0.724
	5/28/2014	NA	NA	<320	0.32	<1.9
	5/26/2015	<RDL (6.24×10^{-3})	<RDL (<2.3×10^{-10})	<380	0.26	<1.2
	5/24/2016	NA	NA	<351	0.08	<0.98
HC-4	3/21/2007	<RDL (0.565)[a]	<RDL (3.24×10^{-10})	<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 (3.42×10^{-10})	<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 (2.15×10^{-10})	555	4.5	2.88
	2/26/2009	<RDL (3.20)	<RDL (6.0×10^{-12})	434	2.0	<1.4
	3/11/2010	<RDL (2.93)	<RDL (3.87×10^{-10})	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
	5/21/2013	NA	NA	964	60	35.1
	5/28/2014	NA	NA	700	62	27.8
	5/27/2015	14.6	<RDL (3.35×10^{-10})	731	110	60.6
	5/24/2016	7.02	NA	725	120	42.6

Table B-1 (continued). Radioisotope 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 (5.11 × 10^{-3})	<RDL (1.1 × 10^{-11})	<300	0.48	<1.5
	3/23/2011	NA	NA	<360	0.45	<2.1
	5/23/2012	<RDL (3.70 × 10^{-3})	NA	<300	0.49	0.349
	5/22/2013	NA	NA	<340	0.40	0.957
	5/28/2014	NA	NA	<320	0.33	<2.2
	5/28/2015	<RDL (2.52 × 10^{-3})	<RDL (3.2 × 10^{-11})	<380	0.53	<1.7
	5/25/2016	NA	NA	<368	0.45	<1.6
HC-6	3/24/2010	<RDL (1.14 × 10^{-2})	<RDL (5.6 × 10^{-11})	<300	35	25.7
	3/23/2011	NA	NA	<360	37	20.4
	5/23/2012	<RDL (1.16 × 10^{-2})	NA	<300	38	14.1
	5/22/2013	NA	NA	<360	36	19.1
	5/27/2014	NA	NA	<320	39	16.9
	5/26/2015	<RDL (1.30 × 10^{-2})	<RDL (5.5 × 10^{-11})	<370	41	28.7
	5/24/2016	NA	NA	<364	41	19.7
HC-7	3/11/2010	<RDL (5.31 × 10^{-3})	<RDL (3.0 × 10^{-11})	<300	7.4	5.77
	3/23/2011	NA	NA	<360	13	10.6
	5/23/2012	NA	NA	<300	41	23.9
	5/21/2013	NA	NA	<370	15	13.8
	5/28/2014	NA	NA	<320	11	6.76
	5/27/2015	<RDL (6.20 × 10^{-3})	<RDL (<1.3 × 10^{-11})	<370	16	13.3
	5/26/2016	NA	NA	<364	18	6.94
HC-8	3/10/2010	<RDL (9.63 × 10^{-3})	<RDL (1.3 × 10^{-11})	<300	0.25	<1.3
	3/23/2011	NA	NA	NA	NA	NA
	5/25/2012	NA	NA	<300	0.2	0.454
	5/23/2013	NA	NA	<380	0.14	1.24
	5/28/2014	NA	NA	<320	0.23	<1.9
	5/28/2015	<RDL (1.23 × 10^{-2})	<RDL (1.5 × 10^{-11})	<380	0.23	2.13
	5/26/2016	NA	NA	<353	0.14	<1.33

Notes:

[a] Estimated based on sample volume of 200 milliliters for 2007 samples.

[b] Indicates the sample was filtered.

[c] Indicates a duplicate sample.

<RDL = below required detection limit with laboratory result in parentheses; the RDLs are 5 pCi/L for ^{14}C, 0.1 pCi/L for ^{129}I, 400 pCi/L for tritium, 50 µg/L for uranium, and 4 pCi/L for gross alpha (DOE/NNSA 2006).

Abbreviations:

NA = not applicable (samples not collected or samples not analyzed).
NR = not run (because sample bottle was broken during shipment to the laboratory).

Table B-2. Uranium Isotope Sampling Results

Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	Uranium-234:Uranium-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
	5/22/2013	8.72	7.35	1.19
	5/27/2014	7.69	6.42	1.20
	5/29/2015	8.52	7.2	1.18
	5/24/2016	8.45	6.93	1.22
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
	5/22/2013	8.83	7.85	1.12
	5/27/2014	8.38	7.0	1.20
	5/27/2014[b]	8.15	7.16	1.14
	5/29/2015	8.37	7.15	1.17
	5/29/2015[b]	7.73	6.44	1.20
	5/25/2016	7.51	6.53	1.15
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
	5/21/2013	3.6	2.73	1.32
	5/21/2013[b]	3.58	2.84	1.26
	5/27/2014	2.95	2.52	1.17
	5/28/2015	3.54	2.93	1.21
	5/25/2016	4.33	3.66	1.18
MV-4	5/29/2015	20.4	18.8	1.09
	5/25/2016	14.7	13.6	1.08
MV-5	5/28/2015	0.119	0.064	1.86
	5/24/2016	0.202	0.118	1.71
	5/24/2016[a]	0.092	0.119	0.77

Table B-2 (continued). Uranium Isotope Sampling Results

Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	Uranium-234:Uranium-238
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
	5/22/2013	0.425	0.291	1.46
	5/27/2014	0.373	0.25	1.49
	5/26/2015	0.353	0.264	1.34
	5/24/2016	0.301	0.261	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
	5/22/2013	37.2	37.2	1.00
	5/27/2014	33.4	32.5	1.03
HC-2d	5/29/2015	1.35	1.14	1.18
	5/25/2016	1.62	1.51	1.07
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
	5/22/2013	0.932	0.966	0.96
	5/28/2014	0.102	0.106	0.96
	5/26/2015	0.101	0.078	1.29
	5/24/2016	0.066	0.079	0.84
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
	5/21/2013	22	20.8	1.06
	5/28/2014	21.4	21.5	1.00
	5/27/2015	31.2	32.9	0.95
	5/24/2016	39.1	39.4	0.99

Table B-2 (continued). Uranium Isotope Sampling Results

Monitoring Location	Date	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	Uranium-234:Uranium-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
	5/22/2013	0.240	0.122	1.97
	5/28/2014	0.255	0.149	1.71
	5/28/2015	0.392	0.307	1.28
	5/25/2016	0.207	0.159	1.30
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
	5/22/2013	15.7	12.6	1.25
	5/27/2014	15.6	13.6	1.15
	5/26/2015	15.3	13	1.18
	5/24/2016	16.3	13.7	1.19
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
	5/21/2013	6.31	5.56	1.13
	5/28/2014	4.1	3.76	1.09
	5/27/2015	5.65	4.72	1.20
	5/26/2016	6.82	5.84	1.17
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
	5/23/2013	0.107	0.041	2.61
	5/28/2014	0.102	0.094	1.09
	5/28/2015	0.155	0.072	2.15
	5/26/2016	0.14	0.05	2.08

Notes:

[a] Indicates the sample was filtered.

[b] Indicates a duplicate sample.

Abbreviation:

NA = not applicable (samples not collected or samples not analyzed).

Table B−3. Carbon-14 Radioisotope Calculation Data

Well ID	Sample Date	Mass Concentration (mg/L)[b]	Fraction mc	±1 s	Carbon-14 (pMC)	Carbon-14 (pCi/L)[a]
HC-4	5/24/2016	16	71.50	1.10	7150	7.02

Notes:

[a] Modern ^{14}C standard at 1950 AD has a specific activity of 13.6 disintegrations per minute per gram (g).
C = 2.27 × 10^{-4} disintegrations per second (dps) per milligram (mg) C.
1 µCi = 3.7 × 10^{4} dps; therefore, modern ^{14}C standard at 1950 AD has a specific activity of 6.135 × 10^{-9} µCi/mg.

[b] The laboratory obtained a ^{14}C mass of 0.08 mg from an analyzed sample volume of 5 milliliters (mL). These data were used to calculate a mass concentration using the formula below.
C mass concentration = 0.08 mg / 0.005 L = 16 mg/L

The ^{14}C mass obtained from data provided by the laboratory was verified using a field measurement for total alkalinity ($CaCO_3$) of 134 mg/L, which was obtained during the sampling. The following formulas were used to determine the C fraction of total alkalinity and C mass concentration.
C fraction of total alkalinity = 12 g/mol (C) / 100 g/mol ($CaCO_3$) = 0.12
C mass concentration = 134 mg/L ($CaCO_3$) x 0.12 = 16.1 mg/L

Abbreviations:
mc = modern carbon
pMC = percent modern carbon
s = standard deviation

An example of calculation of activity (for well HC-4) is below.

$$16\,\frac{mg\ C}{1\,L}\left(71.5\,\frac{mg\ MC}{mg\ C}\right)\left(6.135\,x\,10^{-9}\ \frac{\mu Ci}{mg\ MC}\right)\left(1\,x\,10^{6}\ \frac{pCi}{\mu Ci}\right)=7.02\ \ \frac{pCi}{L}$$

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Appendix C

Hydraulic Head Data for 1996 Through 2016

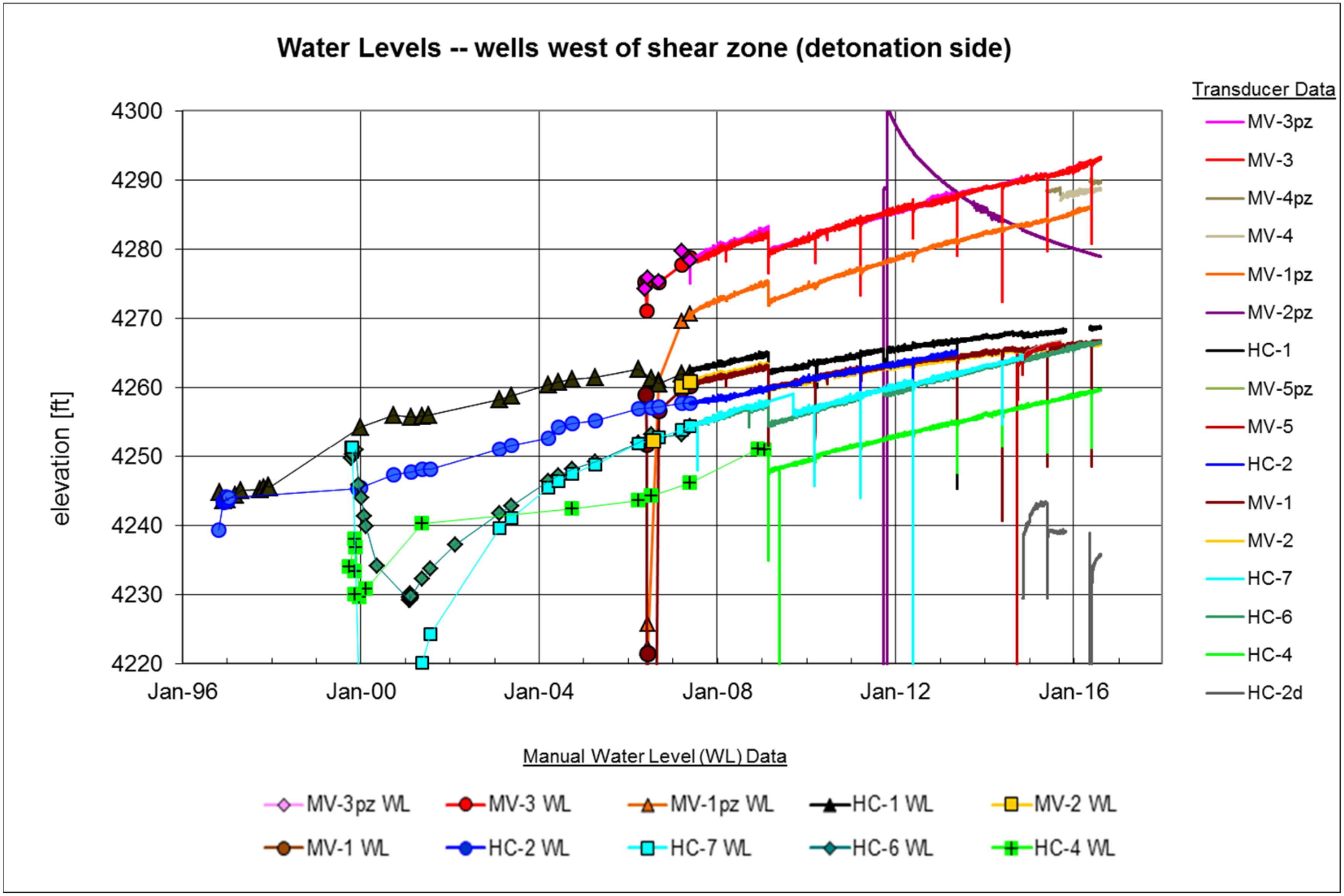

Figure C-1. Hydrographs for Wells West of the Shear Zone (expanded scale on Y axis)

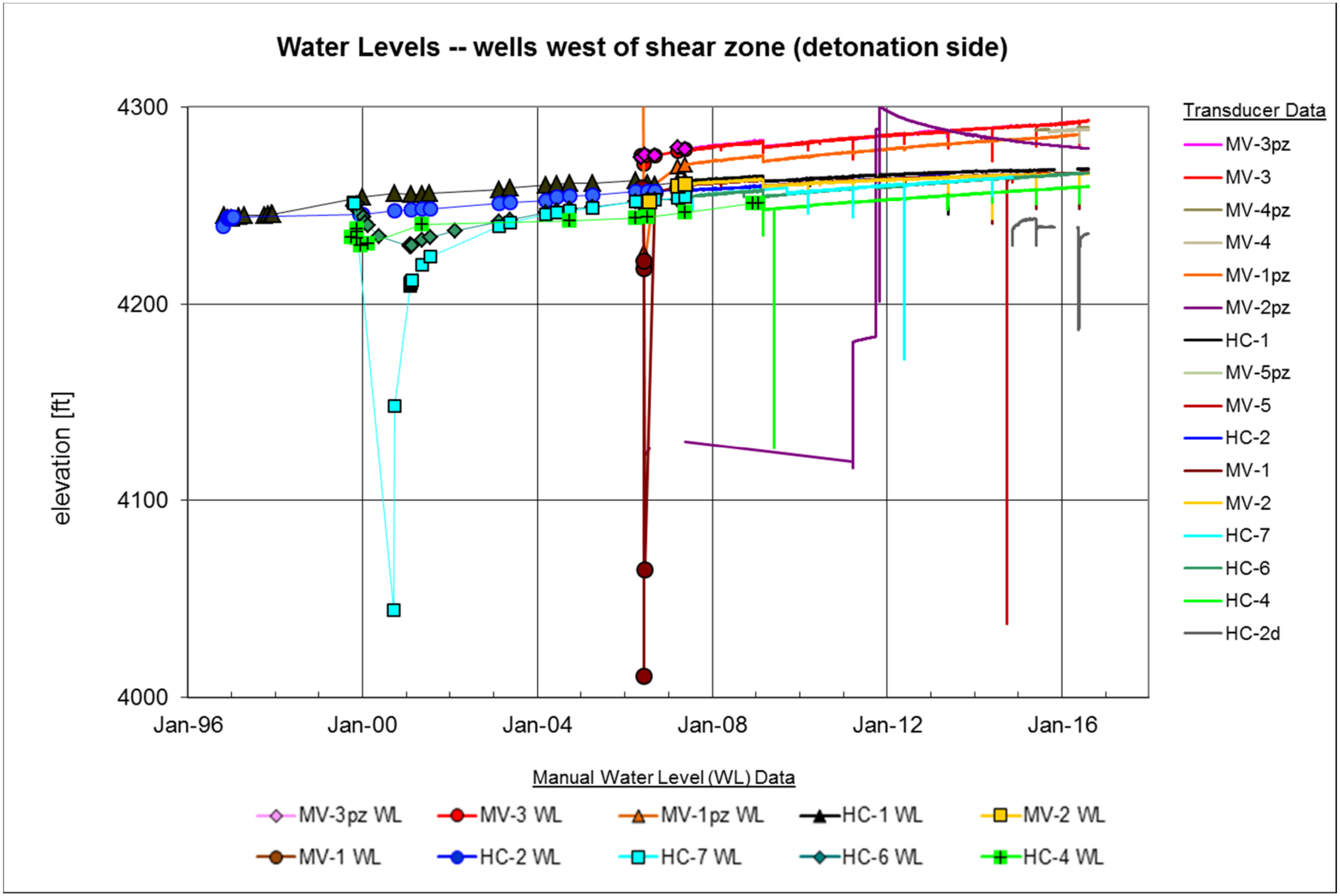

Figure C-2. Hydrographs for Wells West of the Shear Zone

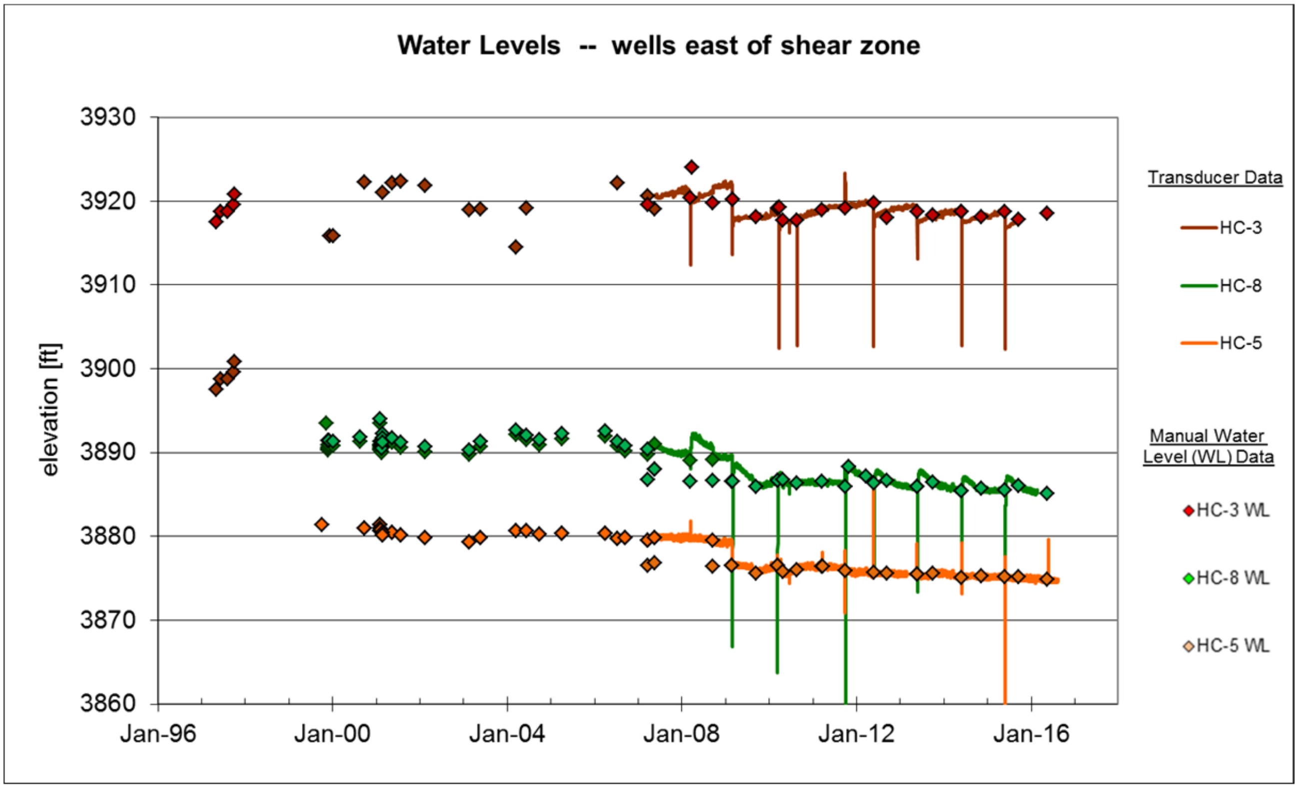

Figure C-3. Hydrographs for Wells East of the Shear Zone

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Appendix D

Annual Water Level Changes in Wells West of Shear Zone for July 2007 Through July 2016

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

Date Range (month/year)	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-2d**	**HC-4**	**HC-6**	**HC-7**
7/2007–7/2008	1.52	2.67	1.37	NM	2.71	2.57	1.40	1.09	NM	NM	2.00	2.28
7/2008–7/2009	1.40	2.48	0.95	NM	2.16	2.20	1.32	1.40	NM	NM	1.96	NM
7/2009–7/2010	1.38	2.48	1.36	NM	2.54	2.23	1.49	1.49	NM	2.12	1.79	NM
7/2010–7/2011	0.79	1.80	0.76	NM	1.82	1.67	1.21	1.02	NM	1.46	NM	1.64
7/2011–7/2012	1.23	2.10	0.94	NM	1.78	1.91	1.08	1.24	NM	1.72	NM	1.35
7/2012–7/2013	0.67	1.71	0.85	NM	1.65	1.84	0.72	1.34	NM	1.35	1.44	1.59
7/2013–7/2014	1.03	1.63	0.82	NM	1.43	1.41	0.94	NM	NM	1.52	1.64	1.57
7/2014–7/2015	0.16	1.21	0.26	NM	1.28	1.13	0.15	NM	NM	1.36	1.29	NM
7/2015–7/2016	1.00	NM	0.75	NM	2.20	NM	0.78	NM	NM	1.57	1.60	NM

Abbreviation:
NM = Not measured, because transducer data were not available.

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Appendix E

Bromide Results for 2014 Through 2016

Table E-1. Bromide Sample Results from 2014 Through 2016 Sampling Events

Monitoring Location	Sample Date	Bromide (mg/L)
MV-1	5/27/2014	0.60
	5/29/2015	0.55
	5/24/2016	1.00
MV-2	5/27/2014	0.25
	5/27/2014[a]	0.26
	5/29/2015	0.20
	5/29/2015[a]	0.20
	5/25/2016	0.20
MV-3	5/27/2014	0.89
	5/28/2015	0.87
	5/25/2016	1.00
MV-4	5/29/2015	3.10
	5/25/2016	1.30
MV-5	5/28/2015	4.30
	5/24/2016	1.60
	5/25/2016[a]	1.60
HC-1	5/27/2014	0.40
	5/26/2015	0.32
	5/24/2016	0.27
HC-2	5/27/2014	0.42
HC-2d	5/29/2015	0.29
	5/25/2016	0.20
HC-3	5/28/2014	2.50
	5/26/2015	2.30
	5/24/2016	1.90
HC-4	5/28/2014	0.67
	5/27/2015	0.54
	5/24/2016	0.44
HC-5	5/28/2014	0.27
	5/28/2015	0.26
	5/25/2016	1.00
HC-6	5/27/2014	7.00
	5/26/2015	6.90
	5/24/2016	5.90
HC-7	5/28/2014	0.96
	5/27/2015	0.81
	5/26/2016	0.80
HC-8	5/28/2014	0.43
	5/28/2015	0.35
	5/26/2016	0.80

Note:
[a] Indicates a duplicate sample

Abbreviation:
mg/L = milligrams per liter

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Appendix F

NDEP Correspondence with Record of Review and Response to Comments

NEVADA DIVISION OF
ENVIRONMENTAL PROTECTION

STATE OF NEVADA
Department of Conservation & Natural Resources
Brian Sandoval, Governor
Bradley Crowell, Director
David Emme, Administrator

RECEIVE DOE
JAN 3 1 2017
GRAND JUNCTION OFFICE

January 26, 2017

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

RE: Submittal of Draft 2016 Groundwater Monitoring Report Project Shoal Area: Subsurface Corrective Action Unit (CAU) 447
Federal Facility Agreement and Consent Order (FFACO)

Dear Mr. Kautsky:

The Nevada Division of Environmental Protection, Bureau of Federal Facilities (NDEP) has received and reviewed the above referenced report from the U. S. Department of Energy, Office of Legacy Management on January 11, 2017. While this letter serves as a Notice of Completion for the January 13, 2017 FFACO Milestone for the "Draft 2016 Groundwater Monitoring Report," the NDEP has the following comments on the Report which should be addressed in the Final version of the Report:

1) Executive Summary, First Paragraph, Last Sentence and Section 2.1, Summary of Corrective Action Activities, top of Page 4, Second Sentence: There is a discrepancy between the two sections' wording. Please make these two sections consistent.

2) Section 2.1, Page 3, Third Paragraph, Third Sentence: To preserve the chronology and historical knowledge from annual report to annual report, please insert "in March 2011" between "…technical exchange meeting" and "between the geophysicists…"

3) Section 4.3, Hydraulic Head Monitoring, Page 13, Table 3: Why does the "elevation water" for well MV-2PZ have a superscript "c" and the "water depth" not have a superscript?

4) Section 6.0, Summary and Recommendations, Page 19, Second Paragraph, Second Sentence: There are more wells/piezometers that were not measured than stated in the sentence. Why are they not listed?

5) Appendix B, Table B-1, Page B-1: Does footnote "a" apply to the **Carbon – 14** column and the MV-5 5/24/2016 sample?

6) Appendix E, Table E-1, Page E-1: Footnote "a" indicates duplicate sample. For well MV-2, is the sample date 5/29/2014a incorrect and actually 5/29/2015a?

If you would like to discuss these comments, please contact me at 702-486-2850, ext. 232, or Mark McLane at ext. 226.

Sincerely,

Chris Andres

Christine D. Andres
Chief
Bureau of Federal Facilities

CDA/MM

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U.S. Department of Energy Office of Legacy Management

Record of Review

Due Date 1/9/2017	**Review No.** 1	**Project** 1-104-1-04-621	**Type of Review** Draft Report Technical Review - NDEP

Document Title and\or Number and Revision
Draft 2016 Groundwater Monitoring Report, Project Shoal Area Subsurface, Corrective Action Unit 447

LMS/SHL/S15282

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Reviewers' Recommendation

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

Refer to NDEP letter dated January 26, 2017

Signature of Reviewer and Date

☒ Comments Have Been Addressed

Mark Kautsky
2017.02.16 16:09:10 -07'00'

Signature of Author and Date

☒ Comment Resolution Satisfactory
☐ Comment Resolution Unsatisfactory

Mark McLane 2/21/17

Signature of Reviewer and Date

Item No.	Reviewer's Comments and Recommendation	Reqd. (Y/N)	Item No.	Author's Response (if required)
1	Executive Summary, First Paragraph, Last Sentence and Section 2.1, Summary of Corrective Action Activities, top of Page 4, Second Sentence: There is a discrepancy between the two sections' wording. Please make these two sections consistent.	Y	1	The last sentence of the first paragraph in the Executive Summary was revised to match the last sentence of the first paragraph on Page 4, as requested.
2.	Section 2.1, Page 3, Third Paragraph, Third Sentence: To preserve the chronology and historical knowledge from annual report to annual report, please insert "in March 2011" between "…technical exchange meeting" and "between the geophysicists…"	Y	2	The third sentence in the third paragraph on page 3 was revised to include "in March 2011", as requested.
3	Section4.3, Hydraulic Head Monitoring, Page 13, Table 3: Why does the "elevation water" for well MV-2PZ have a superscript "c" and the "water depth" not have a superscript?	Y	3	The footnote "c" was added to the water depth for MV-2PZ in Table 3, as requested.
4	Section 6.0, Summary and Recommendations, Page 19, Second Paragraph, Second Sentence: There are more wells/piezometers that were not measured than stated in the sentence. Why are they not listed?	Y	4	The wells "not measured" were not listed because (1) they are discussed in detail in Section 4.4 and (2) that level of detail in the Summary and Recommendations Section was thought to be too extensive and repetitive. To be consistent, it's suggested that the wells with rising water levels be removed from the

Record of Review (continuation)

Review No.	Project

Item No.	Reviewer's Comments and Recommendation	Reqd. (Y/N)	Item No.	Author's Response (if required)
				sentence and that a reference to Section 4.4 be added to the sentence. The sentence was revised as follows: Water levels in all wells/piezometers west of the shear zone (except for the locations described in Section 4.4) continued to rise during the period from July 2015 through July 2016.
5	Appendix B, Table B-1, Page B-1: Does footnote "a" apply to the Carbon - 14 column and the MV-5 5/24/2016 sample?	Y	5	The footnote "a" was replaced with footnote "c" to indicate that the MV-5 sample collected on 5/24/2016 was a duplicate sample.
6	Appendix E, Table E-1, Page E-1: Footnote "a" indicates duplicate sample. For well MV-2, is the sample date 5/29/2014a incorrect and actually 5/29/2015a?	Y	6	The sample date for the duplicate sample for well MV-2 was incorrect and was changed from "5/29/2014a" to "5/29/2015a".

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