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2009 Groundwater Monitoring Report Project Shoal Area, Corrective Action Unit 447

March 2010

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1.0 Introduction

This report presents the 2009 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 1996, as amended February 2008) entered into by DOE, the U.S. Department of Defense, and the State of Nevada. The corrective action strategy for the site includes monitoring in support of site closure. This report summarizes investigation activities associated with CAU 447 that were conducted at the PSA during fiscal year 2009.

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. 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) (Hazelton-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 levels for the area. The decontamination and restoration activities were minimal, because no large areas of 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 (ECH), and U.S. Bureau of Mines (USBM) 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. 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). The Nevada Division of Environmental Protection (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).

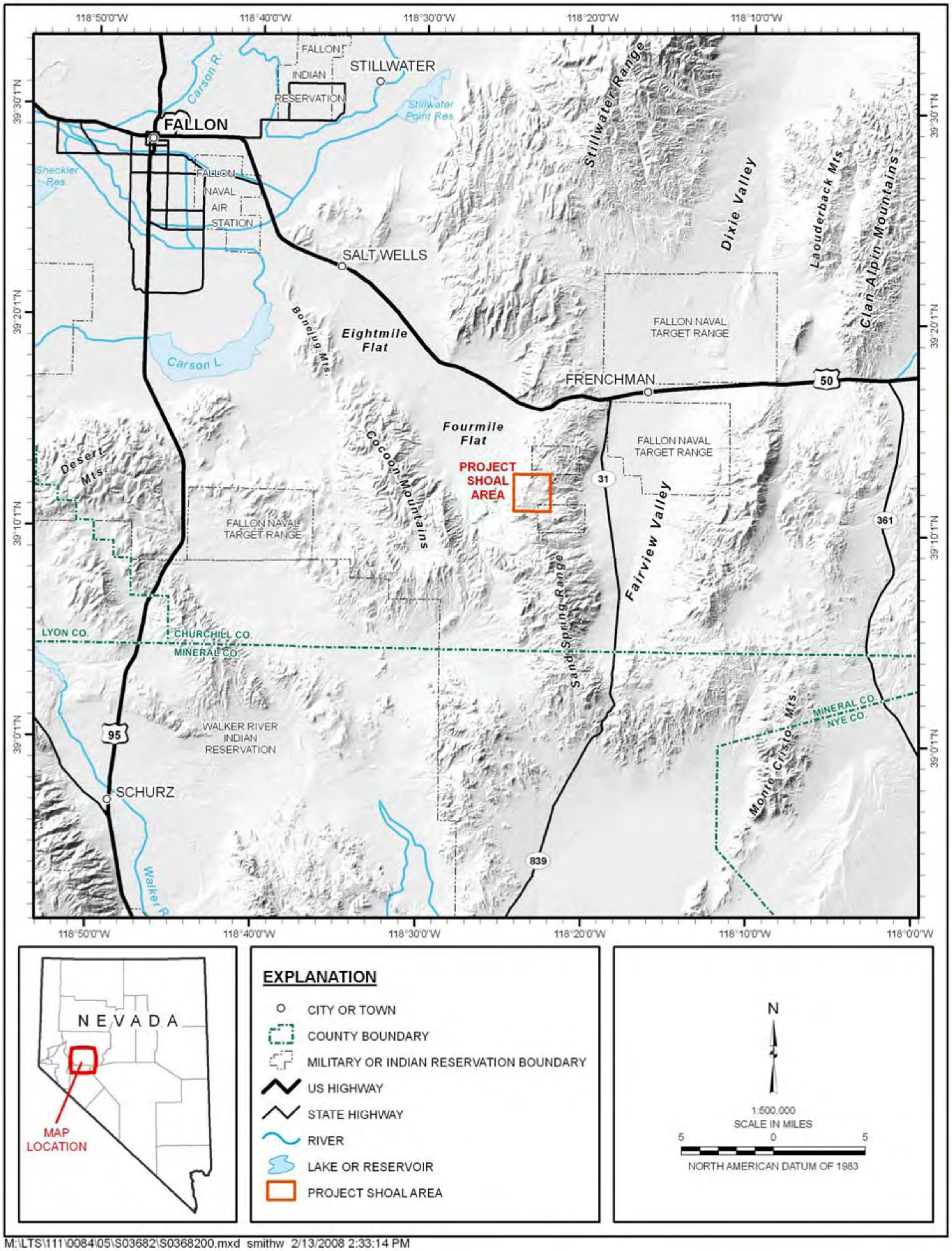

Figure 1. Location Map of the Project Shoal Area

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. A groundwater flow and transport model was developed by Desert Research Institute to assist in the evaluation of data and the selection of 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 groundwater outside the boundary has a 5% or less likelihood of exceeding the radiological standards of the Safe Drinking Water Act. The 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). The recommendation for the selected corrective action alternative was based largely on the results of the numerical model that was developed for the PSA.

Three wells (MV-1, MV-2, and MV-3) were installed in 2006 for the dual purpose of monitoring and evaluating the flow and transport model results. Based on the comparisons of monitoring data and modeling results, and pursuant to the FFACO process (FFACO 1996, as amended February 2008), LM is developing a new closure strategy for the PSA. In September 2009, DOE submitted a short-term data acquisition plan to NDEP detailing the proposed data collection and field investigation activities to support development of a new closure strategy. Proposed activities include (1) the use of geophysical methods to better define the water table and identify faults and fracture zones with the potential to affect groundwater flow and (2) an enhanced monitoring system for the collection of hydrologic and geochemical data. When the new closure strategy is developed it will be provided to NDEP in an addendum to the CADD/CAP for review and approval.

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 that strike northeast and northwest, joints that parallel the northwest-trending faults, and fracture cleavages that generally parallel the northeast-trending faults. These faults, joints, and fractures are distributed between two dominant structural trends that generally strike N 50^{o} W and N 30^{o} 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).

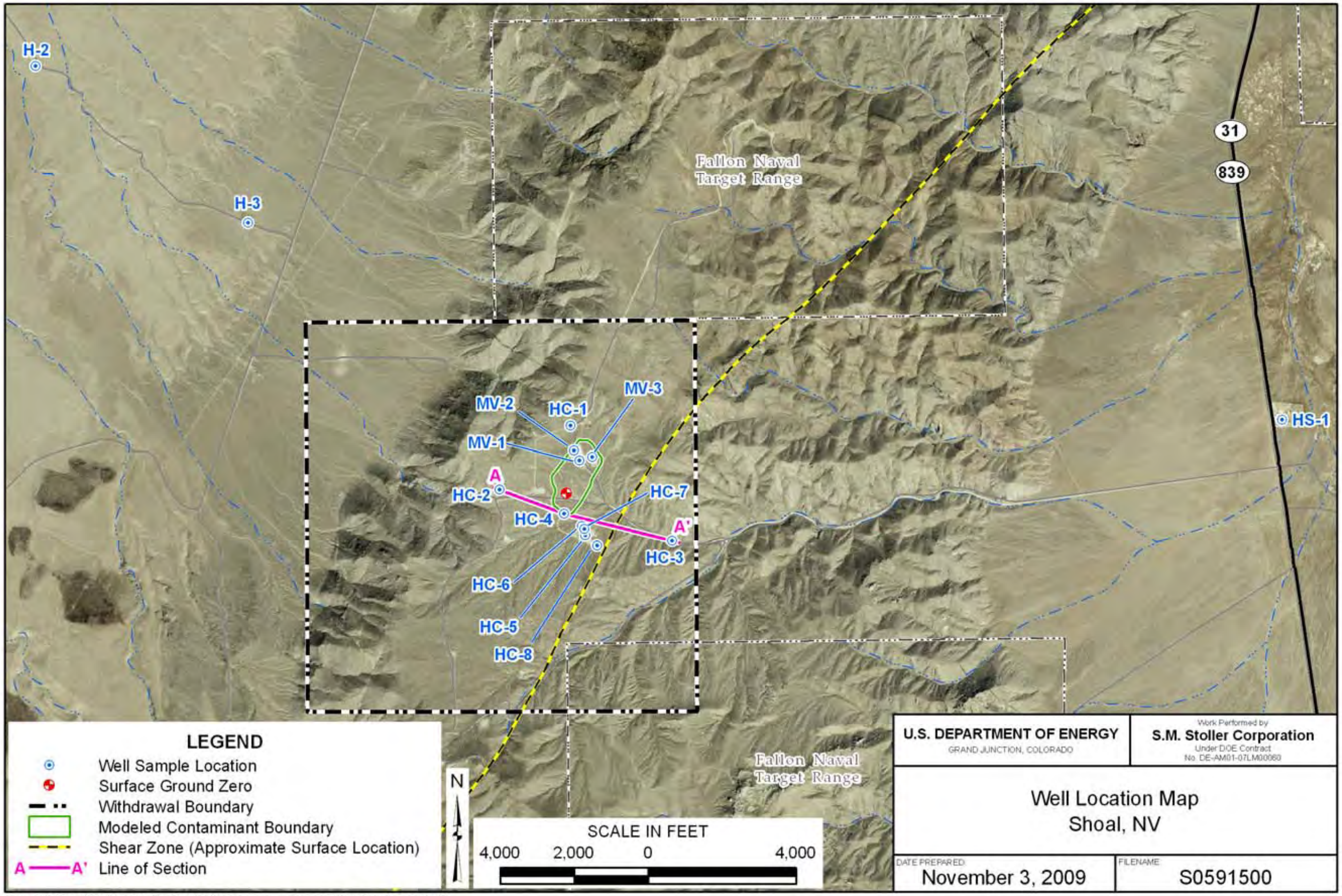

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Figure 2. Well Location Map Shoal, NV

The water table is present beneath the site at depths ranging from approximately 975 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 groundwater divide along the upland area of the range west of the site separates flow to the east and west. A shear zone, located about 1,500 ft east of the site (Figure 2 and Figure 3), is interpreted as a barrier to flow due to disparate head levels in wells separated by the shear zone. 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 monitoring network at the PSA consists of wells and piezometers in MV-1, MV-2, and MV-3, and the wells HC-1 and HC-4 (Figure 2). Monitoring at these locations includes the collection of hydraulic head data and groundwater samples for radioisotopic analyses as specified in the CADD/CAP (DOE/NNSA 2006). The general objectives of the monitoring 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 *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. Well construction information and hydraulic head data obtained in 2009 are presented in Table 1.

Table 1. Well Construction Details and 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	993.96	9/13/2009	4,263.57	3,684.81	3,531.00	153.81
MV-1 PZ	5,257.30	980.95	9/14/2009	4,276.35	3,919.80	3,859.80	60.00
MV-2	5,266.62	1,003.59	9/14/2009	4,263.03	3,446.75	3,275.98	170.77
MV-2 PZ[c]	5,266.51	NM	NM	NM	4,078.82	4,019.32	59.50
MV-3	5,261.50	978.01	9/14/2009	4,283.49	3,797.91	3,626.75	171.16
MV-3 PZ	5,261.17	977.51	9/14/2009	4,283.66	4,120.75	4,060.72	60.03
HC-1	5,309.21	1,064.99	9/14/2009	4,265.43	4,236.01	3,997.12	238.89
HC-2	5,347.12	1,087.71	2/26/2009	4,259.85	4,392.12	4,124.12	268.00
HC-3	5,081.52	1,179.34	9/14/2009	3,922.18	3,918.52	3,898.02	20.50
HC-4 [c]	5,260.90	1,012.91	9/14/2009	4,251.79	4,247.90	3,957.90	281.00
HC-5	5,247.37	1,368.85	9/14/2009	3,878.52	1,862.37	1,716.77	145.60
HC-6	5,228.68	970.72	9/14/2009	4,258.85	4,112.70	3,996.38	116.32
HC-7	5,229.72	971.93	2/25/2009	4,258.01	4,123.25	4,006.12	117.13
HC-8	5,259.91	1,371.69	9/14/2009	3,888.78	2,965.51	2,848.99	116.52

TOC = Top of casing (well/piezometer)
NM = Not measured
Elevation Water (TVD corrected), Water Depth (not TVD corrected)
TSZ, BSZ (top and bottom of open interval; screened, perforated, or open hole)
[a]Depth-to-water measurements not corrected for borehole deviation.
[b]Corrected for borehole deviation.
[c]Indicates that a transducer was not installed in the well/piezometer.

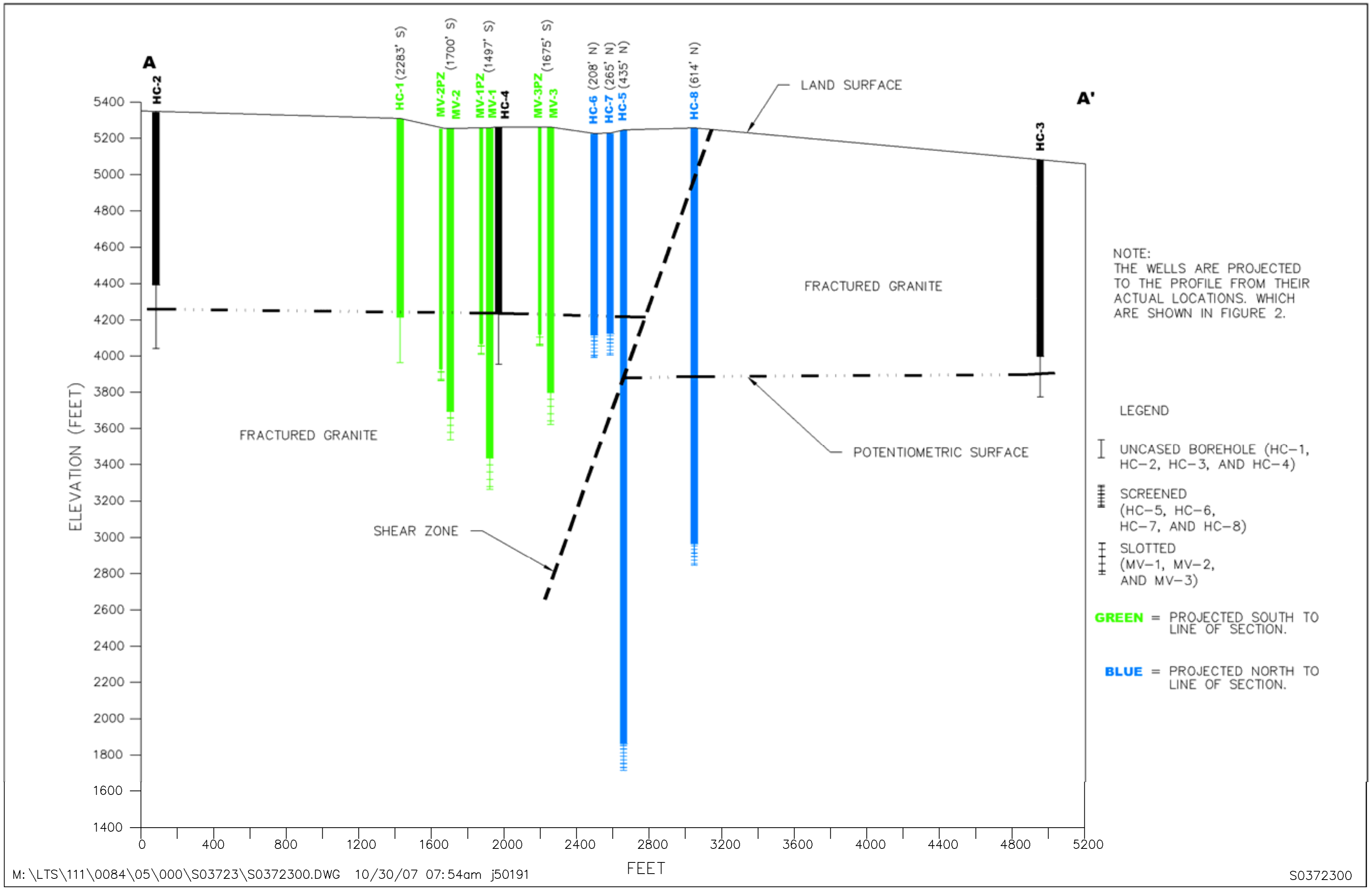


Figure 3. Cross Section A-A' Depicting Monitor Well and Shear Zone Location, Shoal, NV

4.1 Radioisotopic Monitoring

Groundwater samples were collected from wells MV-1, MV-2, MV-3, HC-1, and HC-4 for radioisotopic analyses on February 26, 2009. Monitoring wells MV-1, MV-2, MV-3, and HC-4 were purged prior to sampling using dedicated submersible pumps. At least one well volume was removed, and field parameters (temperature, pH, and specific conductance) were allowed to stabilize before samples were collected. Samples were collected from well HC-1 using a depth-specific bailer. The final set of field parameters and well purge volumes are presented in Appendix A.

Groundwater samples are analyzed for tritium, carbon-14 (C-14), iodine-129 (I-129), uranium isotopes, gross alpha, and mass concentrations of uranium as part of the annual monitoring at PSA and as specified in the CADD/CAP. 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 C-14 and I-129 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 MCL for gross alpha is exclusive of uranium and radon. Including uranium and uranium isotopic as part of the analytical suite provides data to demonstrate 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 (DOE/NNSA 2006) established regulatory levels for site groundwater of 20,000 pCi/L tritium, 2,000 pCi/L C-14, and 1 pCi/L I-129. These levels are not to be exceeded outside the compliance boundary, which is the modeled contaminant boundary (Figure 2). Modeling results indicate with a 95 percent certainty that groundwater will not pose a human health risk outside the contaminant/compliance boundary (Pohl and Pohlmann 2004). The MCLs for adjusted 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 (see further discussion in Section 5.1).

4.2 Hydraulic Head Monitoring

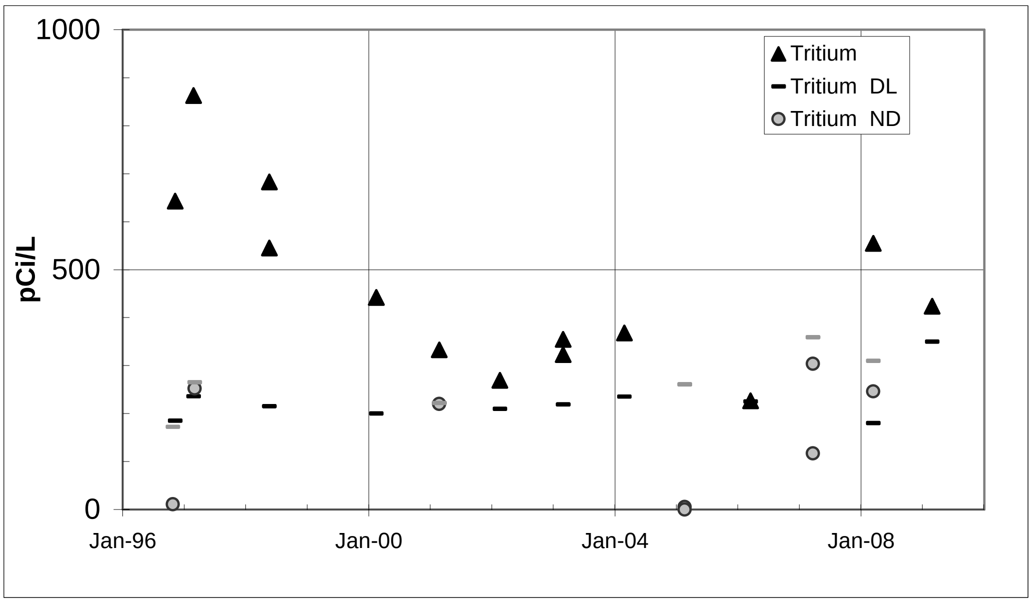
Monitoring of the groundwater flow system is performed by measuring hydraulic heads in the MV wells/piezometers and HC wells located on the site (Figure 2). Heads are measured every 3 hours by transducers installed in all on-site wells. The transducers are downloaded in the spring, as part of the annual sampling, and in the fall as part of a scheduled monitoring event and site inspection. Hydraulic heads could not be measured from the MV-2 piezometer because of remnant drilling fluid materials in the piezometer tubing. The drilling fluids prevent taking water level readings with a sounding tape or the installation of a transducer. It is unlikely that the MV-2 piezometer can be rehabilitated because the screened interval produces very little water, though an effort at redevelopment will be made in the spring of 2010.

5.0 Monitoring Results

Monitoring conducted at the PSA in 2009 consisted of annual sampling in February 2009 and downloading transducers in September 2009. As described in the CADD/CAP, the annual sampling and monitoring program requires the measurement of seven parameters—concentrations of tritium, C-14, I-129, uranium isotopes, and gross alpha; mass concentrations of uranium, and measurements of hydraulic head. Radioisotopic and concentration data are presented in Section 5.1, and head data are presented in Section 5.2.

5.1 Radioisotopic Results

Analytical results from the 2009 monitoring event indicate that all constituents in all wells are below established regulatory levels. Tritium was detected above the laboratory method detection limit in the sample collected from well HC-4. Tritium levels in well HC-4 were typically above detection limits from the mid-1990's until 2006, though some duplicate analyses were below detection limits. Tritium levels have been trending lower and were below the detection limit 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 detection for one sample and below detection for the other. Results shown in Figure 4 indicate that this is not an unusual occurrence for well HC-4. The presence of tritium in HC-4 is due to its close proximity to the nuclear detonation (nearest well to the detonation, Figure 2). This is supported by the elevated level of C-14 in HC-4 compared to levels in the other monitoring wells. The elevated concentration of C-14 in well HC-4 is likely the result of its migration in the gas phase near the water table, as part of the CO2 molecule, where it dissolved into groundwater in the upper saturated zone near the detonation. Estimated activities of C-14 and I-129 are comparable to previous sampling results and continue to provide a baseline for long-term monitoring. Samples collected from wells HC-1 and MV-2 could not be analyzed for I-129 because the sample bottles broke during shipment to the laboratory. Data used to calculate radioisotope activities for C-14 are provided in Appendix A.



DL =detection limit

ND = below detection limit

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

Table 2 presents a summary of analytical results for C-14, I-129, tritium, uranium, and gross alpha from the sampling event in February 2009 along with the results from 2007 and 2008 for comparison. Uranium (U) mass concentrations detected in samples collected from wells MV-1 and MV-2 exceeded the MCL of 30 µg/L in 2007 but declined below that level in 2008 and remained relatively constant in 2009. Unadjusted gross alpha activities shown in Table 2 are below the MCL of 15 pCi/L for the February 2009 sampling event; if these values are adjusted by subtracting activities of ^{234}U and ^{238}U shown in Table 3, values are even lower. The elevated concentrations of uranium observed in the past are believed to be naturally occurring. It has been demonstrated that ambient groundwater in the region surrounding the site is elevated in concentrations of gross alpha and uranium, among others (Bevans et al. 1998). Elevated uranium concentrations are attributed to leaching from granitic bedrock and associated sediments.

Table 2. 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, total unadjusted)
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
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
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
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
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

[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; RDL is 5 pCi/L for C-14, 0.1 pCi/L for I-129, 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 broke during shipment to the laboratory
NA = not applicable

Table 3. 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
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
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
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
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

[a]Indicates the sample was filtered.
[b]Indicates a duplicate sample.

Isotopic ratios of uranium further support a natural source of uranium in groundwater as opposed to 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 3 indicates that ratios observed in the PSA samples range from 0.91 to 1.49—consistent with a natural uranium source. In contrast, average estimates of radionuclides resulting from nuclear tests at the Nevada Test Site suggest a residual source term with a $^{234}U/^{238}U$ activity ratio of approximately 56.25 (Smith 2001).

5.2 Hydraulic Head Results

Hydrographs of hydraulic head data from site wells and piezometers are shown in Figure 5 and Figure 6. 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 transducer in well HC-7 was not functioning at the time of the September 2009 download and was replaced. The transducer in well HC-2 could not be retrieved during the September 2009 download. It is planned that a camera will be lowered into the well in mid November 2009 to assess the situation and to determine the best method of retrieval. The water level elevations for HC-4 (Figure 5) are now corrected for total vertical depth.

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 points 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). Head levels in wells west of the shear zone (detonation side) are generally 250 to 300 ft higher than those in wells east of the shear zone.

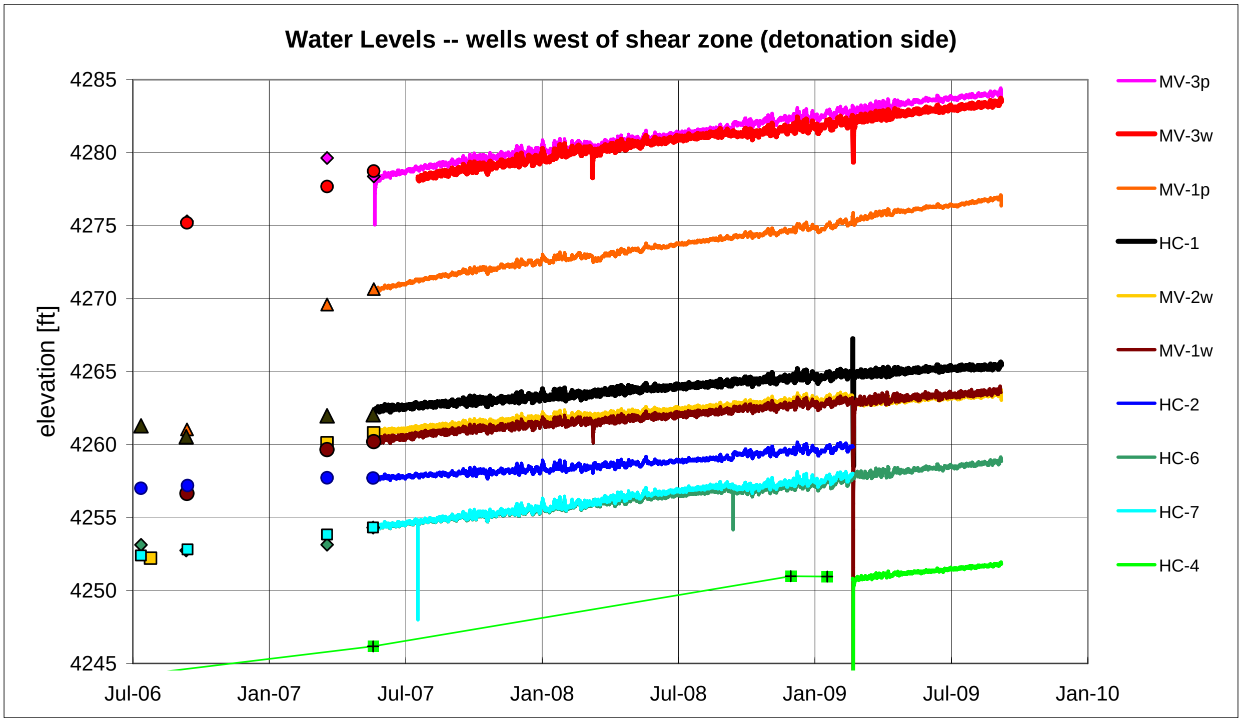


Figure 5. Hydrographs for Wells West of the Shear Zone

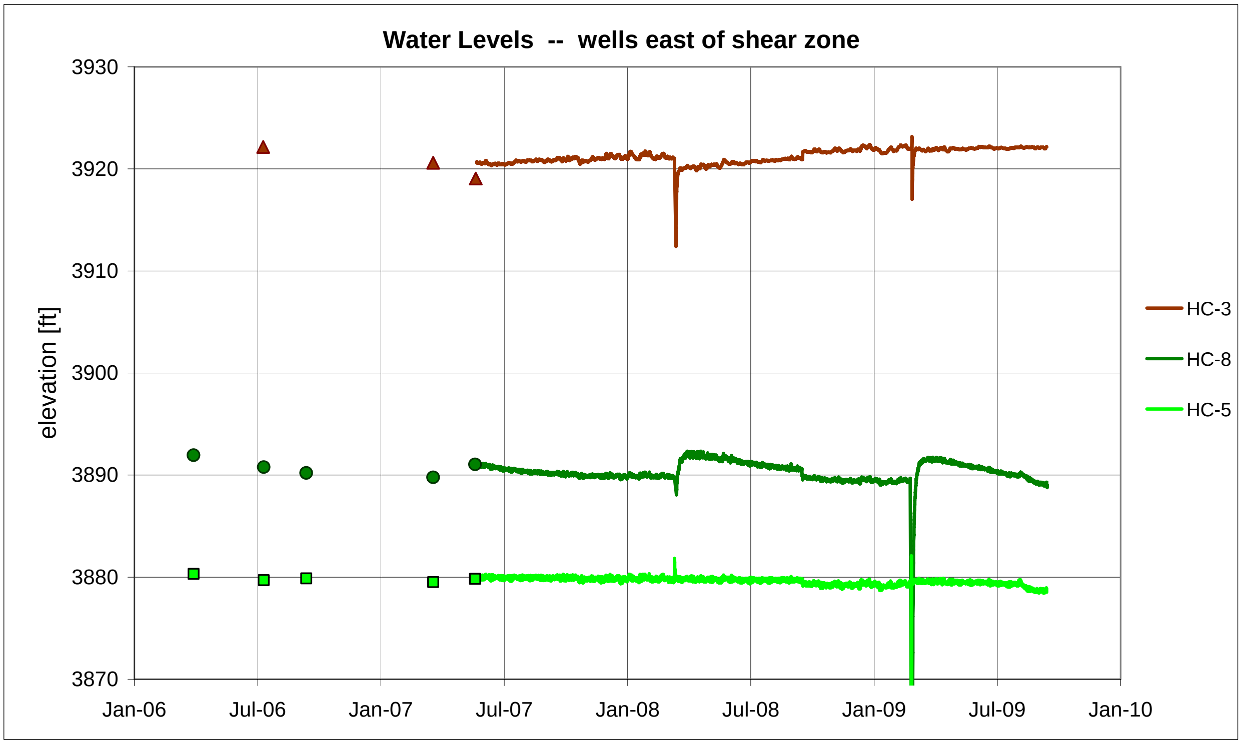


Figure 6. Hydrographs for Wells East of the Shear Zone

6.0 Summary

Monitoring results for 2009 indicate that concentrations of tritium, C-14, and I-129 in groundwater remain below established regulatory levels for all PSA monitoring wells. Analytical results from well HC-4 have a nuclear-test-related signature for C-14; however, concentrations are below the established regulatory level of 2,000 pCi/L. Tritium concentrations in this well have decreased significantly since a high of 1,130 pCi/L was reported in 1998 (Pohll et al. 1998) and remain well below the tritium MCL of 20,000 pCi/L. Uranium in all wells was below the MCL in 2009; elevated concentrations observed in the past are attributed to natural sources. An evaluation of the stability of the hydrologic system will be made after data have been collected over a longer period of time.

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Appendix A

Carbon-14 Calculation Data and Well Purge Data

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Table A−1. Monitor Well Purge Data

Well	Date Sampled	Purged Volume (gallons)	Temperature (°C)	pH (s.u.)	Specific Conductance (µmhos/cm)
MV-1	2/26/2009	770	21.8	7.85	735
			22.1	7.87	735
			22.2	8.02	735
MV-2	2/26/2009	1135	22.1	8.30	503
			22.6	8.20	495
			22.3	8.16	495
MV-3	2/26/2009	700	21.8	7.91	755
			22.2	8.03	750
			21.8	8.00	750
HC-1	2/26/2009	5	16.7	7.84	410
HC-4	2/26/2009	200	20.8	7.48	750
			21.0	7.52	750
			20.9	7.42	750

s.u. = Standard Unit
µmhos/cm = micromhos per centimeter

Table A−2. Carbon-14 Radioisotope Calculation Data

Well ID	Sample Date	Mass C[b] (mg)	δ ^{13}C (‰)	C-14 (pmc)	Fraction mc	±1 s	µCi/mg C[a]	pCi/L[b]
MV-1	2/26/2009	2.54	-M	25.00	0.2500	0.0020	1.68E-09	1.95-02
MV-2	2/26/2009	2.0	-11.9	34.79	0.3479	0.0024	2.11E-09	2.13E-02
MV-3	2/26/2009	1.18	-11.9	23.13	0.2313	0.0020	1.42E-09	8.37E-02
HC-1	2/26/2009	1.52	-10.2	43.08	0.4308	0.0028	2.66E-09	2.01E-02
HC-4	2/26/2009	4.9	-9.0	2126.10	21.2610	0.0980	1.30E-07	3.20E+00

[a]Modern C-14 standard at 1950 AD has activity of 13.6 dpm/gram C = 2.27 × $^{-4}$ 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.
[b]Assumes 200 mL sample used to obtain mass of carbon.
pmc = percent modern carbon; mc = modern carbon; s = standard deviation

Example activity calculation (MV-1)

$$2.54\,\frac{mg\ C}{0.2\ L}\left(0.2500\,\frac{mg\ MC}{mg\ C}\right)\left(6.135*10^{-9}\ \frac{\mu Ci}{mg\ MC}\right)\left(1*10^{6}\ \frac{pCi}{\mu Ci}\right)=1.95*10^{-2}\ \ \frac{pCi}{L}$$

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