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2014 Well Completion Report for Corrective Action Unit 447 Project Shoal Area Churchill County, Nevada

November 2015

U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

AEC	U.S. Atomic Energy Commission
amsl	above mean sea level
API	American Petroleum Institute
AWG	American Wire Gauge
bgs	below ground surface
Boart	Boart Longyear Drilling Services
CADD	Corrective Action Decision Document
CAP	Corrective Action Plan
CAU	Corrective Action Unit
cfm	cubic feet per minute
DOE	U.S. Department of Energy
FMP	Fluid Management Plan
ft	feet
HC	hydrologic characterization
i.d.	inside diameter
JSA	Job Safety Analysis
LM	(DOE) Office of Legacy Management
MDC	minimum detectable concentration
mg/L	milligrams per liter
MV	monitor/validation
NAS	Naval Air Station
NDEP	Nevada Division of Environmental Protection
NTU	nephelometric turbidity unit
o.d.	outside diameter
pCi/L	picocuries per liter
PVC	polyvinyl chloride
SCM	site conceptual model
SGZ	surface ground zero
SHPO	State Historic Preservation Office
SP	spontaneous [electrical] potential

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Executive Summary

This report summarizes the drilling program conducted by the U.S. Department of Energy (DOE) Office of Legacy Management at the Project Shoal Area (Shoal) Subsurface Corrective Action Unit 447 in Churchill County, Nevada. Shoal was the location of an underground nuclear test conducted 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 (a predecessor to DOE). 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). The corrective action strategy for the site is focused on revising the site conceptual model and evaluating the adequacy of the monitoring well network at the site. Field activities associated with the project were conducted in accordance with the Federal Facility Agreement and Consent Order (FFACO 1996, as amended) and applicable Nevada Division of Environmental Protection (NDEP) policies and regulations.

The contractor was responsible for compliance with state and federal regulations during the drilling program. This included obtaining the necessary permits/waivers, providing a cultural resources inventory of potentially affected areas, completing the required National Environmental Policy Act documentation, and managing fluids and drill cuttings in accordance with the Fluid Management Plan and Well-Specific Fluid Management Strategy letter completed for the site and approved by NDEP.

The drilling program was designed to enhance the groundwater monitoring well network by establishing two new monitoring locations (MV-4 and MV-5) and improving an existing location by deepening well HC-2 (HC-2d). Groundwater at the site moves through fractures in the granite and was encountered during the drilling program at depths ranging from 1,050 to 1,100 ft bgs. The MV-5 borehole was completed with a piezometer, well, and stainless steel "bubbler tube." The piezometer was screened near the bottom of the borehole. The well was screened above the piezometer and across the deepest, most productive zone within the borehole based on geologic data collected during drilling and interpretations from the borehole geophysical logs to monitor groundwater below the depth of the detonation cavity. The stainless steel bubbler tube was installed just below the water table. The MV-4 borehole was completed with a well and piezometer. The well was screened across the deepest, most productive zone within the borehole based on geologic data collected during drilling and interpretations from the borehole geophysical logs to monitor groundwater at and below the depth of the emplacement drift/tunnel and detonation cavity. The piezometer was screened across the water table. The HC-2 well casing was removed, and the borehole was deepened to allow installation of a new well (HC-2d) that provides a monitoring location at and below the depth of the emplacement drift/tunnel and detonation cavity. Head data will be collected from the wells, piezometers, and bubbler tube to estimate hydraulic gradients at the installed locations. Electric submersible pumps were installed in MV-4, MV-5, and HC-2d to facilitate sample collection.

Samples of the drilling fluid and groundwater discharged during development were collected during the drilling program. The samples were screened in the field for tritium using a liquid scintillation counter. The samples were analyzed to ensure that fluid management controls were being implemented in accordance with the Fluid Management Plan and Well-Specific Fluid Management Strategy letter. The field screening detected no concentrations of tritium above the minimum detectable concentration, which ranged from 2,753 to 3,455 picocuries per liter. The

fluid management strategy was based on a far-field compliance strategy, which was verified through the field screening and onsite monitoring for tritium.

The drilling program (mobilizing; drilling, constructing, and developing wells; and installing pumps in the new wells) was completed in 57 days (August 11 through October 6, 2014). Operations were conducted 24 hours per day, 7 days per week for the duration of the project; for a few days during mobilization and demobilization of the project, work was only performed during daylight hours.

1.0 Introduction

This report summarizes field activities and data collected during the drilling program conducted by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) at the Project Shoal Area (Shoal) Subsurface Corrective Action Unit (CAU) 447 in Churchill County, Nevada. The drilling program was performed as part of the implementation of the 2014 Data Acquisition Plan (DOE 2014a). The 2014 Data Acquisition Plan is part of the corrective action strategy that is focused on revising the site conceptual model (SCM) and evaluating the adequacy of the monitoring well network. Field activities associated with the project were conducted in accordance with the Federal Facility Agreement and Consent Order (FFACO 1996, as amended) and applicable Nevada Division of Environmental Protection (NDEP) policies and regulations. The drilling program included drilling two monitoring/validation (MV) wells (MV-4 and MV-5) and deepening the existing hydrologic characterization (HC) well (HC-2) at the site.

1.1 Site Location and Background

The Shoal site is in west-central Nevada, south of U.S. Highway 50, and approximately 30 miles southeast of Fallon (Figure 1). The Project Shoal underground nuclear test was performed on October 26, 1963, as part of the Vela Uniform program sponsored jointly by the U.S. Department of Defense and the U.S. Atomic Energy Commission (AEC). In preparation for the test, an emplacement shaft was mined to a depth of approximately 1,315 feet (ft) below ground surface (bgs). A horizontal tunnel/drift was mined approximately 1,000 ft east from the shaft, ending in a hook shape where the nuclear device was emplaced in the granitic rock. The drift was also extended to the west from the shaft by approximately 300 ft. The test consisted of detonating a 12-kiloton nuclear device at a depth of approximately 1,211 ft 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 (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, 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).

1.1.1 Summary of Corrective Action Activities

Surface and subsurface contamination resulted from the underground nuclear test at the Shoal site. 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 muck pile of granite that remained from excavation of the emplacement shaft, and housekeeping areas that consisted of approximately 20 rusted and empty oil cans. Remediation of the surface of CAU 416 was completed in 1998 and is summarized in the *Closure Report for CAU No. 416, Project Shoal Area* (DOE/NV 1998).

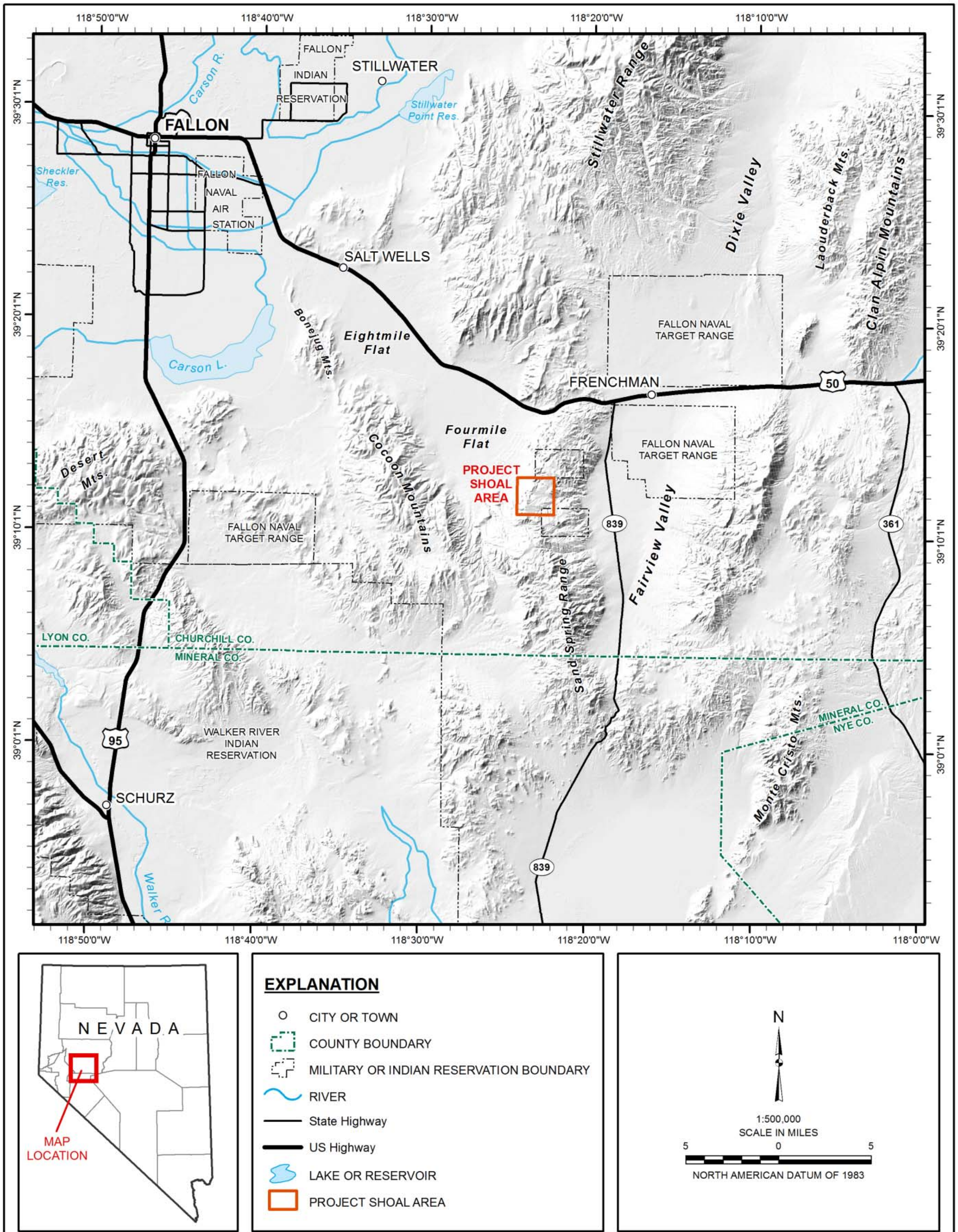

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Figure 1. Site Location

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).

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

As part of the original corrective action strategy, three MV wells (MV-1, MV-2, and MV-3) were installed in 2006 for the dual purpose of monitoring for contaminant migration and evaluating the flow and transport model results. The 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 for the adjacent valleys, prior to the installation of the HC wells and later MV wells. Pursuant to the FFACO (NDEP 1996, as amended), LM began implementing a new corrective action strategy for the site in 2009.

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

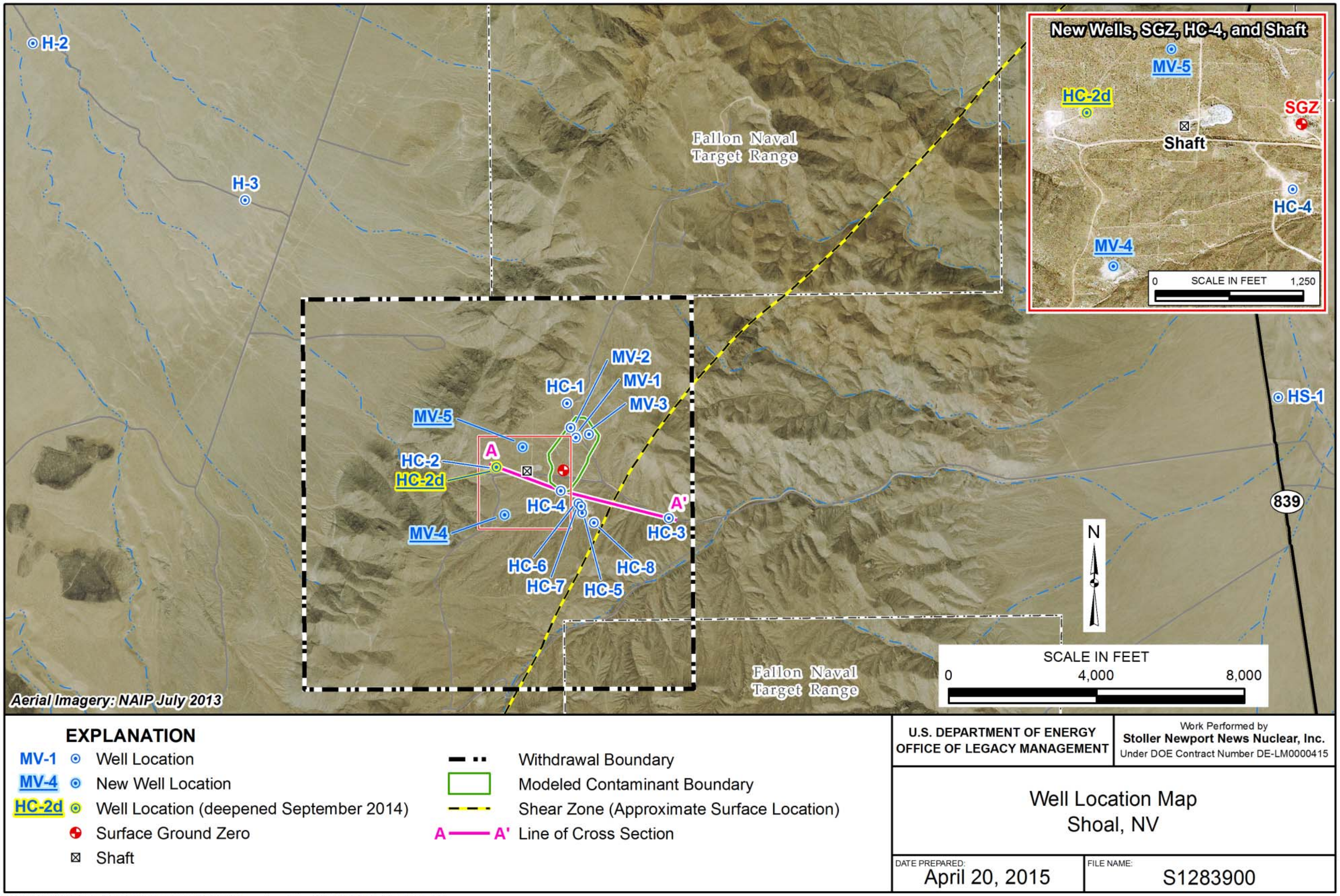

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Figure 2. Well Location Map

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 (DOE 2011b). Analytical, hydrologic, and geologic data obtained from the evaluation of historical reports have been reviewed with existing data and collected geophysical data to help identify geologic structures that might be influencing groundwater flow at the site. These data have been assembled for 3-dimensional visualization. Revisions to the SCM and enhancements to the monitoring well network will be provided to NDEP in an addendum to the CADD/CAP (DOE 2011b).

1.2 Scope of Work and Objective

The objective of the drilling program was to enhance the monitoring well network by establishing two new monitoring locations and improving an existing location by deepening well HC-2. To meet the objective, the drilling program scope of work included the following:

- Construction of drill pads with infiltration basins
- Drilling of two boreholes
- Geophysical well logging
- Construction of two monitoring wells with piezometers (MV-4 and MV-5)
- Deepen existing well HC-2 (renamed HC-2d)
- Construction of monitoring well HC-2d
- Development of monitoring wells and piezometers
- Installation of electric submersible pumps in wells MV-4, MV-5, and HC-2d

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2.0 Drilling Program Planning and Methods

Extensive planning was required to ensure compliance with state and federal regulations, establish a water source, and provide methods for drilling and sampling in advance of the drilling program. These activities were completed during the planning phase and required the following:

- Providing a cultural resources inventory of potentially affected areas as required by Section 106 of the National Historic Preservation Act.
- Evaluating potential impacts related to the drilling program and pad construction in compliance with the National Environmental Policy Act.
- Managing fluids and drill cuttings in accordance with the Fluid Management Plan (FMP) and site-specific fluid strategy letter.
- Obtaining permits and waivers required by the State of Nevada Division of Water Resources to install new monitoring wells and to use water from existing well HS-1.
- Establishing methods to complete the drilling program.

The following sections summarize the activities leading up to the drilling program as well as the methods used during the drilling program.

2.1 Cultural Resources and the National Environmental Policy Act

A Class III cultural resource inventory of 43.3 acres of potentially disturbed areas was conducted by Desert Research Institute for DOE in 2014. Field investigations identified three historic sites and eleven historic isolated objects and features, which were considered to be associated with the 1963 Project Shoal underground nuclear test. Although the sites were not individually considered eligible to the National Register of Historic Places, they were considered contributory elements to a possible Project Shoal historic district. To avoid potential impacts to one of the historic sites, DOE relocated an onsite office trailer and parking area. Desert Research Institute documented the results of their inventory in a report provided to DOE and to Fallon Naval Air Station (NAS), which manages the land surface (*Hydrologic Monitoring Wells in Gote Flat, Sand Springs Range, Churchill County, Nevada*, Fallon Naval Air Station Cultural Resources Technical Report #130; BLM Project # CCDO-CR-14-73).

In Nevada, the Nevada State Historic Preservation Office (SHPO) authorizes the Navy (through the NAS Fallon Programmatic Agreement with Nevada) to make determinations of effect on behalf of the SHPO, although the SHPO must still concur in the determination. The agreement also assumes that no historic properties will be affected. After DOE relocated the project components that would potentially impact one of the identified cultural sites, the NAS provided a determination of “no adverse effect” to the SHPO in a letter dated June 20, 2014, and received confirmation from the SHPO on July 23, 2014. The NAS also conducted tribal consultation with the Fallon Paiute-Shoshone Tribal Chairman Len George by letter and email notification. Tribal consultation was concluded July 9, 2014.

An Environmental Checklist was prepared to document the evaluation of potential impacts related to the DOE drilling program. The Checklist (LM# 6-14) was approved on July 2, 2014. As part of the environmental evaluation process, the U.S. Fish and Wildlife Service list of federally protected species for Churchill County was evaluated for the presence of potential species habitat or species presence.

2.2 Management of Drilling Fluids and Cuttings

An FMP and Well-Specific Fluid Management Strategy letter were prepared for the drilling program. The FMP guided the management of fluids and associated materials generated during the drilling program and provided the standards that governed their final disposition. Although NDEP is not a signatory to the FMP, it is involved in the negotiation of the content and approves the conditions described within the plan. The FMP was approved on September 22, 2011 (DOE 2011c). In accordance with the FMP, a Well-Specific Fluid Strategy letter was prepared to provide the rationale for selecting the far-field fluid management strategy and address specific details regarding the nature and configuration of the fluid containment to be used at the well site. The Well-Specific Fluid Management Strategy letter provided qualitative and quantitative data that supported the far-field strategy and established the use of an infiltration basin for managing fluids and materials generated during drilling and other well site activities (DOE 2014c). NDEP approved the Well-Specific Fluid Management Strategy on July 28, 2014.

The MV-4, MV-5, and HC-2d well pads were constructed with an infiltration basin to contain drilling fluids and cuttings generated during the drilling program. The well pads for MV-4 (former PM-1 well pad) and HC-2d only required modification of the existing well pad to allow the addition of an infiltration basin. The final well pad dimensions were approximately 200 ft by 165 ft. The infiltration basins were designed to contain approximately 5 times the estimated volume of material displaced from the borehole and included an overflow channel draining to a secondary natural infiltration area. Construction of the well pads began July 7 and was completed July 15, 2014.

2.3 Source Water for the Drilling Program

Well HS-1 in Fairview Valley approximately 4 miles east of surface ground zero (SGZ) (Figure 2) was used to provide water during the drilling program. This well was also used during the drilling programs completed in 1996, 2000, and 2006. The well is screened in the alluvial aquifer from 400 to 700 ft bgs and is equipped with a diesel-powered mechanical pump. The well is typically not sampled as part of the annual monitoring at the site but was sampled in May 2013 to establish background concentrations for selected radioisotopes. The samples were analyzed for water quality data and tritium, uranium isotopes, gross alpha, and mass concentration of uranium. A water sample was also collected from well HS-1 to establish background concentrations for tritium and bromide prior to the start of drilling on August 13, 2014. The analytical results from the 2013 sampling event are provided in Appendix A, Table A-1.

The State of Nevada's Department of Conservation and Natural Resources, Division of Water Resources, requires a waiver to use an existing well as a water source; the Division of Water Resources issued waiver WE-005 to DOE on July 2, 2014. The waiver for water use is temporary and limited to a 1-year use period. A separate waiver is required for installing monitoring wells; the identification number provided by the State Division of Water Resources stays with the well permanently. The waiver number MO-1933 was issued for the new wells on July 2, 2014. This waiver was modified to be MO-1933A on August 20, 2014, to accommodate a change in the proposed well designs.

A total of 368,900 gallons of water were withdrawn from well HS-1 during the drilling program. The water was used for soil compaction and dust control during the well pad construction and drilling make-up water during the drilling program. DOE reported the volume of water used in a letter to the State Division of Water Resources on January 5, 2015.

2.4 Drilling Method

Boart Longyear Drilling Services (Boart) was contracted to perform the drilling program at the site. Boart is a licensed drilling contractor (license number 0021976) with the State of Nevada. Boart completed the required notices of intent to drill (application numbers 71450, 71451, and 70673 for wells MV-4, MV-5, and HC-2d, respectively). The wells were drilled with an LM140 top head rotary drill rig using conventional rotary and dual-tube reverse circulation drilling methods. The initial 19-inch-diameter boreholes for wells MV-4 and MV-5 were drilled for the surface casing using conventional rotary, a tri-cone button bit, and bentonite-based drilling mud. The final boreholes for wells MV-4, MV-5, and HC-2d were completed using the dual-tube reverse circulation drilling method, a down-hole hammer button bit, and combination of air and water with Quik Foam and EZ Mud for drilling fluids. The drilling methods selected were based on expected drilling conditions and past drilling programs at the site. Borehole deviation surveys were performed approximately every 300 ft as the boreholes were advanced; a geolograph recorded drilling parameters and penetration rates. The daily drilling reports included penetration rates, the results of borehole deviation surveys, and other pertinent information.

The drilling program was completed in 57 days (August 11 through October 6, 2014). Operations were conducted 24 hours per day (during two 12-hour shifts) and 7 days per week for the duration of the project; for a few days during mobilization and demobilization of the project, work was only performed during daylight hours.

2.5 Sampling Methods

Geologic material, drilling fluid, and groundwater samples were collected during the advancement of the borehole and development of the monitoring wells and piezometers as part of the drilling program at the site. Samples included rock cuttings for lithologic description and drilling fluid and groundwater for radiological monitoring and water quality analysis. Samples were collected in accordance with the FMP (DOE 2011c) and Field Instructions (DOE 2014d). The following sections describe the sampling methods.

2.5.1 Geologic Material Sampling Methods

Samples of the drill cuttings were collected during the advancement of the borehole. These samples were collected from the drill rig shaker screen, washed, and composited for 10 ft intervals. A portion of the washed cuttings were placed in a chip tray for lithologic description. Samples of the cuttings were collected to determine the lithologic characteristics of the geologic units penetrated and to provide a detailed lithologic log as drilling progressed. The lithologic descriptions include grain size, mineralogy, alteration, color, fracturing, and other notable geologic characteristics. LM maintains a portion of the samples (in chip trays) collected during the drilling program in the Environmental Sciences Laboratory storage facility.

2.5.2 Radiological Sampling Methods

Samples of the drilling fluid, source water, and groundwater discharged during development were analyzed for tritium onsite. Samples of the drilling fluid were collected at approximately 30 ft intervals as the borehole was being advanced, or every hour from below the cyclone as fluid entered the mud tank. Samples obtained during the development were collected from the discharge line approximately every 2 hours. A Hidex (model Triathler) liquid scintillation counter was used to analyze the samples onsite. Sample count times were established to allow time to collect and analyze the samples every hour and to ensure that fluid management controls were being implemented in accordance with the FMP and site-specific fluid strategy letter. The minimum detectable concentrations (MDCs) obtained from the field analyses were based on the sample count times and ranged from 2,753 to 3,455 picocuries per liter (pCi/L). All samples were collected and analyzed—and the results of sample analyses were documented—in accordance with the *Radiological Control Manual* (LMS/POL/S04322).

Samples collected from well HS-1 were analyzed before each shift began (twice a day) to establish background concentrations for tritium. It was necessary to determine background levels of radiation in groundwater because many geologic strata contain naturally occurring radiation. The background concentrations were recorded and used for all counts during the respective shift. Background samples were collected, analyzed, and documented in accordance with the *Environmental Sciences Laboratory Procedures Manual* (LMS/PRO/S04343).

2.5.3 Bromide and Water Quality Sampling Methods

Samples of the drilling fluid, source water, and groundwater discharged during development were analyzed onsite for pH, temperature, specific conductance, and bromide. Samples of the groundwater discharged during development were also analyzed for turbidity. Concentrations of bromide were obtained from a sodium bromide tracer that was added to the makeup/source water used during the drilling and development operations. The sodium bromide tracer was added to each tanker truck of water obtained from the water supply well HS-1. Bromide concentrations in the makeup/source water were generally maintained between 20 and 40 milligrams per liter (mg/L). The purpose of the tracer was to assist in detecting perched water zones, assist in detecting the groundwater table, and provide a monitoring parameter to establish the effectiveness of well development. The water quality parameters pH, temperature, and specific conductance were analyzed using a HACH SensION MM150 water quality meter. Samples for turbidity were analyzed using a HACH 2100P turbidity meter. The samples for bromide were analyzed using a Dionex DX-120 Ion Chromatograph or Orion 9635BNWP ion-selective electrode.

2.6 Geophysical Well-Logging Methods

Boart contracted Pacific Surveys to perform geophysical well logging as part of the drilling program at the site. Pacific Surveys provided evidence of calibrations (pre-job/post-job) in accordance with American Petroleum Institute (API) guidance, manufacturer specifications, industry standards, and bench calibrations. The data obtained during the logging were set to a ground surface datum and not the drill rig floor. The wire-line logging truck was equipped with calibrated weight indicators and depth-control devices as required.

2.7 Well Development Methods

Development of the monitoring wells was conducted in two phases—an initial phase and a final phase. The initial development included swabbing, surging, and airlift pumping to remove sediment and drilling fluids and to restore the formation's natural hydraulic properties. The surging and airlift pumping were performed with the LM 140 drill rig using a 1,100 cubic feet per minute (cfm) air compressor (reduced to approximately 400 cfm) attached to a BQ (2.19-inch o.d.) airline inside an HQ (3.06-inch i.d.) eductor pipe. The dual pipe system was installed with the smaller diameter BQ airline inside the larger diameter HQ eductor pipe that brings the purge water to the surface. This allowed the eductor pipe to be set in or below the well screen interval because the air is contained in the eductor pipe and does not damage the formation's natural hydraulic properties. Airlift pumping was conducted to produce the maximum water discharge rate possible and required cycling of the air (on and off) to surge the well and allow time for water levels to recover between pumping cycles. A diverter was attached at the top of the well casing to contain and manage fluids produced during well development. Only water from well HS-1 was used with the sodium bromide tracer to flush and rinse the well. Airlift pumping continued until the discharge water was visually free of suspended sediment. Final development of wells was performed using the dedicated submersible electric pump. Samples were collected and analyzed in the field during the initial and final development phases to determine the effectiveness of the development.

Development of the piezometers was conducted using the airlift or bailing methods. The piezometers did not require the same level of development because they were designed for head measurements only and not as long-term sampling locations. The airlift method used the LM 140 drill rig with the 1,100 cfm air compressor attached to a 0.75-inch o.d. airline pipe. The smaller diameter piezometer (1.94-inch i.d.) did not allow for a dual pipe system, so the airline was maintained at a depth above the piezometer screen interval to prevent air from getting into the screened interval and damaging the formation's natural hydraulic properties. Airlift pumping was conducted to produce the maximum water discharge rate possible and required cycling of the air (on and off) to surge the piezometer and allow water levels to recover between pumping cycles. Water from well HS-1 was used with the sodium bromide tracer to flush and rinse the inside of the piezometers. Samples were collected during development and analyzed in the field to manage the fluids and determine the effectiveness and progress of the development. A bailer was used to develop the piezometer when the airlift method could not be used.

2.8 Wellhead Location Survey

Lumos and Associates, a Nevada-registered land surveyor, was contracted to survey new and existing well locations upon completion of the drilling program. The well locations were surveyed December 10 through 12, 2014. The survey provided northings and eastings with top-of-casing elevations for the existing and new wells, concrete pad, water-access-tube casing, and piezometer casings. All survey data were documented in the U.S. State Plane, Zone Nevada West 2703 coordinate system, with horizontal data based on the North American Datum 1983 and vertical data based on the North American Vertical Datum 1988. Figure 2 provides a map showing the well locations. The survey data are provided in Appendix A, Table A-2.

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3.0 The Project Shoal Area Geology

Information on the regional and local geologic setting for Shoal was obtained from various sources such as site inspections, borehole geophysical data, seismic data, U.S. Geological Survey literature, and previous investigation reports. The following sections summarize the regional and local geologic settings.

3.1 Regional Geologic Setting

The site is located in the southern portion of the Sand Springs Range in Churchill County. The Sand Springs Range is the southern extension of the north-northeast trending Stillwater Range, a fault block range that traverses Churchill County north to south. The Sand Springs and Stillwater Ranges are composed of late Mesozoic granitic plutons and stocks intruded into older Mesozoic sedimentary and volcanic rocks overlain locally by Tertiary volcanic rocks. These rocks record the late Mesozoic plutonism that followed the middle Mesozoic compressional tectonics associated with the Luning-Fencemaker thrust fault. Marine sediments deposited in an early Mesozoic back-arc basin during this orogenic event were folded, metamorphosed, thrust eastward, and then intruded (Stewart 1980; Satterfield and Oldow 1996). Tertiary volcanic rocks were deposited on the older Mesozoic rocks in a northeast-trending volcanic belt that cuts across the northern Sand Springs Range and the southern Stillwater Range (Willden and Speed 1974). The Sand Springs and Stillwater Ranges (Figure 1) form the eastern boundary of the Carson Sink.

The Shoal site is located in the Sand Springs pluton, a granitoid of Cretaceous age that comprises much of the southern part of the Sand Springs Range. The Sand Springs Range south of the site is composed of older Paleozoic- and Mesozoic-age sedimentary rocks that were recrystallized during Mesozoic regional metamorphism and intruded by small stocks of Triassic- and Jurassic-age granite porphyries and isolated cupolas of the Cretaceous Sand Springs granite pluton (Satterfield 2002; Greene et al. 1991). Younger Tertiary rhyolitic tuffs and andesitic lava flows overlie the granitic intrusions and metamorphic rocks in the very northern and southern parts of the range. Tertiary hydrothermal alteration and mineralization has localized gold- and silver-bearing quartz veins in shear zones and faults in the northern part of the Sand Springs Range that post-dates some of the Tertiary volcanic rocks (Beal et al. 1964).

3.2 Local Geologic Setting

The Sand Springs Range rises to an elevation of 7,467 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 located in Gote Flat at an elevation generally between 5,200 and 5,600 ft amsl and is surrounded by granite peaks, with the highest (6,342 ft amsl) being Aplite Ridge to the south. The Sand Springs granite underlies SGZ and is exposed at the surface throughout the Shoal area. The Sand Springs granite is composed of granite and granodiorite, with aplite and pegmatite dikes, quartz dikes, andesite dikes, rhyolite dikes, and rhyolitic intrusive breccia. A broad band of 1,500 to 3,000 ft long aplite, pegmatite, and quartz dikes exist northwest of SGZ, although few crop out near SGZ. This band of dikes extends for several miles to the north and south. Most of the dikes in the Shoal site area strike N 50° W to N 60° W and are vertical to very steeply dipping to the northeast or southwest (Beal et al. 1964). Additional larger andesite and rhyolite dikes exist to the north and east of SGZ.

Alteration and mineralization of the granitic rocks is widespread but not pervasive. Alteration is localized along faults, fractures, and partings, with unfaulted and unfractured granite exhibiting no alteration. The most common forms of alteration are hydrothermal bleaching, propylitic alteration, argillic alteration, iron-oxide staining, and disseminated pyrite. Propylitically altered rock typically contains calcite, dolomite, chlorite, epidote, and quartz. Argillic alteration is manifested as secondary clay minerals forming from the breakdown of feldspar minerals and as coatings on fracture surfaces. Clay gouge is also associated with structural lineations that exhibit small amounts of offset. Rhyolite and andesite dikes commonly exhibit propylitic alteration as well (Beal et. al. 1964).

Internal deformation of the Sand Springs granite is largely by high-angle normal faults that strike northeast and northwest, joints that parallel the northwest-striking faults, and a fracture cleavage that generally parallels the northeast-striking faults. These vertical to steeply dipping faults, joints, and fractures are distributed between two dominant structural trends that generally strike N 50^{o} W and N 30^{o} E. Several dikes of varying composition predominantly follow the same two structural trends and intrude along these zones of preexisting weakness. These orthogonal 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 the pluton (Beal et. al. 1964). There is no fracture cleavage associated with Tertiary-age faulting. Cross-cutting relations indicate that the northeast-striking faults formed during the same time interval as the northwest-striking faults and likely resulted from the same stress regime. Fracture cleavage data suggest that most of the offset on the northeast-striking faults occurred early, after emplacement of the granitic pluton and the aplite and pegmatite dikes, with only modest amounts of offset occurring at a later time (Beal et al. 1964).

3.3 Local Hydrogeologic Setting

Groundwater is present beneath the site (near SGZ and west of the shear zone) at depths ranging from approximately 965 to 1,090 ft bgs, and groundwater moves primarily through fractures in the granite. Recharge occurs by infiltration of precipitation on the mountain range, and regional discharge occurs in the adjacent valleys. A shear zone, located approximately 1,500 ft east of SGZ (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). Water levels have been monitored at the site since the first HC wells were installed in 1996. Water levels from the wells west of the shear zone have been rising approximately 1 to 2 ft per year during the time they have been monitored (DOE 2014b).

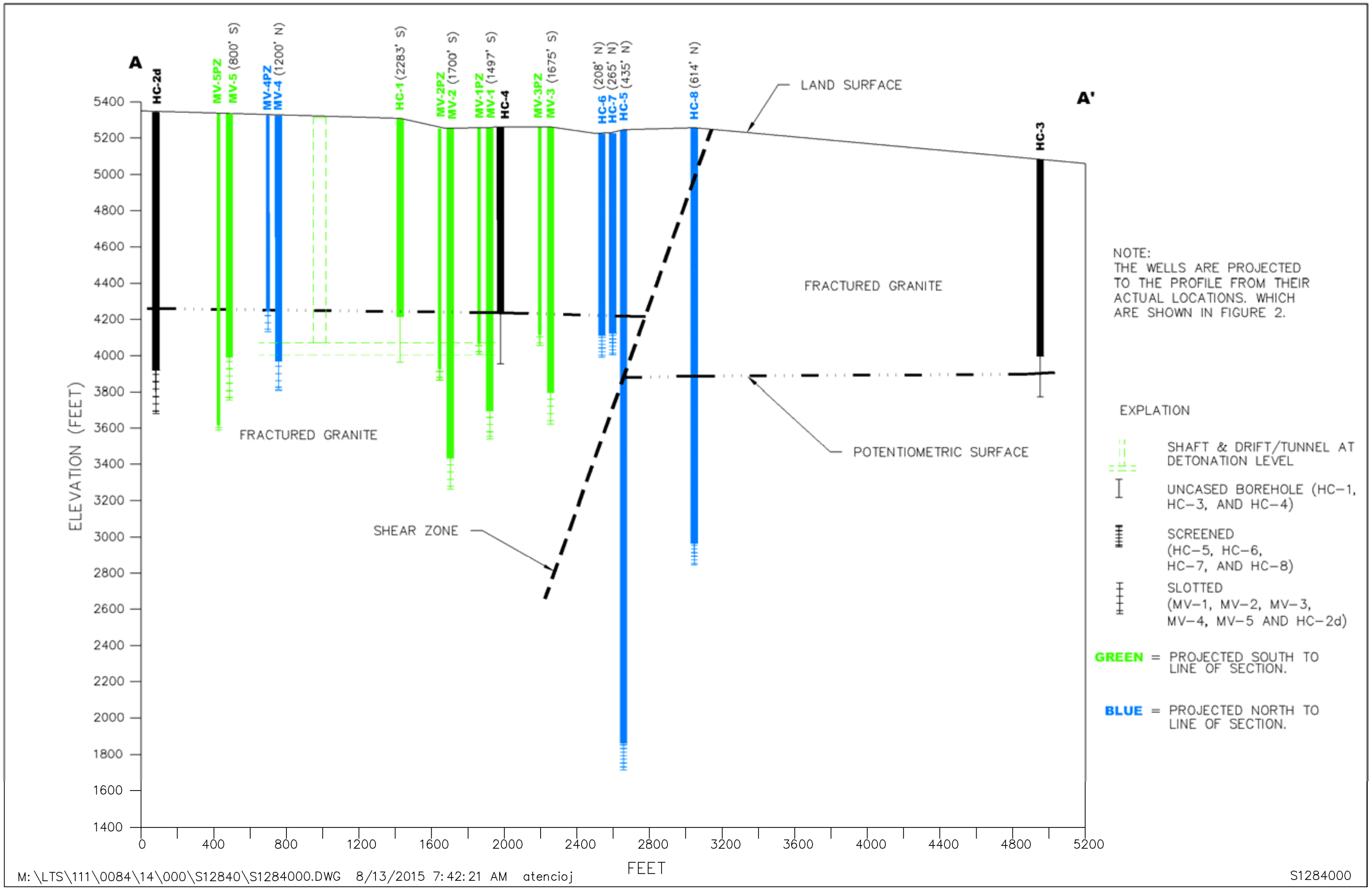

Figure 3. Cross Section A-A'

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4.0 Summary of MV-5 Activities

Groundwater monitoring well MV-5 was installed approximately 1,200 ft west-northwest of SGZ (Figure 2). The well was installed in an area where dikes are visible at the surface, and electrical resistivity data from the 2010 electromagnetic survey are similar to resistivities observed near the drift/tunnel and detonation zone (DOE 2014a). The well was dually completed with a piezometer and well to obtain head levels and vertical hydraulic gradients at the location. The piezometer was screened near the bottom of the borehole. The well was screened across the deepest, most productive zone within the borehole based on geologic data collected during drilling and interpretations from the borehole geophysical logs (Section 4.2) to monitor groundwater at and below the depth of the detonation cavity. A 0.25-inch stainless steel “bubbler tube” was installed near the water table to measure head levels and vertical hydraulic gradients and to correlate water level data with shallow wells/piezometers at the site.

Drilling operations began on August 16, 2014, and the borehole was completed to a total depth of 1,751 ft bgs on August 21, 2014. Geophysical logging of the borehole was completed on August 22, 2014. The well casing was received on August 26, 2014, after the delivery was delayed from the supplier. Construction of the well and piezometer began after the well casing arrived and was completed on August 30, 2014. A total of approximately 73,000 gallons of water were withdrawn from the water supply well HS-1 and used during the drilling and well installation. Initial airlift development of the well and piezometer was completed on September 2, 2014. The dedicated submersible electric pump was installed on September 27, 2014, and final well development using the submersible pump took place intermittently during the drilling program from September 27 through October 6, 2014. A final pump development event was conducted on November 10, 2014. The following sections summarize the well construction, geophysical well logging, sampling, well development, and pump installation activities. Table B-1 in Appendix B provides a chronology of the drilling operations at MV-5.

4.1 Drilling and Construction

Installation of MV-5 included drilling an initial 19-inch-diameter borehole to a depth of 60 ft bgs to allow a 14-inch-diameter carbon-steel casing with fully welded joints to be installed as a surface seal and wellhead control apparatus. This casing was set to a depth of 60 ft bgs and cemented in place using Portland Type II cement. The final borehole was drilled from 60 ft to the completion depth of 1,751 ft bgs using dual-tube reverse circulation and a 12.25-inch down-hole hammer bit. Slough filled the bottom of the borehole from the total depth to 1,730 ft bgs following the geophysical well logging and prior to well construction. The selection of well and piezometer screen intervals was based on geologic data collected while drilling (cuttings, drill rates) and interpretations from the borehole geophysical logs.

The MV-5 borehole was completed with a well, piezometer, and stainless steel bubbler tube in the 12.25-inch borehole. The well was constructed with 5.5-inch-o.d. internally epoxy-coated carbon-steel casing. The well was screened from 1,325 to 1,565 ft bgs with manufactured 3-by-0.078-inch slotted openings on 6-inch centers staggered at 10 degrees with 18 slots per row. The well was completed to a total depth of 1,565 ft bgs. Centralizers were placed around the well and screen at approximately 80 ft intervals to ensure that the well was centered in the borehole. The piezometer was constructed with 2.375-inch-o.d. carbon-steel casing with 30 ft of slotted (0.078-inch) screen installed from 1,700 to 1,730 ft bgs. The piezometer was completed to a total depth of 1,730 ft bgs. A 0.25-inch stainless steel bubbler tube was strapped alongside the 5.5-inch well and is open to the borehole at a depth of 1,100 ft bgs. The bubbler tube was installed to allow head measurements to be acquired in the shallow part of the saturated zone.

A filter pack was installed around the slotted interval of the well and piezometer. Filter pack material for the MV-5 well was graded to include ⅛- to ¼-inch clean gravel and No. 6 clean silica sand. The filter pack for the piezometer included ⅛- to ¼-inch clean gravel only. The silica sand was placed above the gravel as transition sand for the well, but sand was not installed around the piezometer because during installation the gravel extended above the planned set depth. Gravel and sand filter pack materials were pumped through a tremie pipe using a sand pump. A seal composed of ⅜-inch bentonite chips was used on top of the sand filter pack for the well and on top of the gravel filter pack for the piezometer. Portland Type II cement was placed on top of the bentonite chips to seal the formation. A 3 ft thick bentonite seal, a 75 ft thick cement seal, and 9 ft thick bentonite seal was placed between the piezometer filter pack and the well filter pack to ensure separation of water-producing zones. A 5 ft thick bentonite seal, and a 158 ft thick cement seal was placed on top of the well filter pack to isolate the monitoring well screen from the stainless steel bubbler tube. The remaining borehole is open from 1,157 ft bgs to the surface. Cement was pumped down the tremie, followed by a clean-water rinse. The tremie was raised in stages during the placement of the stemming materials to help ensure proper placement without plugging or bridging. However, in the process of placing the cement seal above the piezometer filter pack, a portion of the cement infiltrated the well screen, plugging the screen at a depth of 1,507 ft bgs. Table B-2 in Appendix B lists the well construction materials and volumes used to complete MV-5. Figure 4 provides a diagram showing the details of the MV-5 well construction.

4.2 Geophysical Logging

Pacific Surveys acquired borehole geophysical logs from the MV-5 borehole. The geophysical logging was performed in the 12.25-inch-diameter borehole from below the surface casing (60 ft) to the borehole completion depth or top of fill material. The logging suite included caliper, borehole deviation, natural gamma ray, spontaneous potential (SP), temperature and differential temperature, resistivity (dual laterolog/induction logs), and optical televiewer logs. The natural gamma ray, SP, temperature and differential temperature, and resistivity (dual laterolog/induction logs) logs were run from the borehole fluid level (approximately 1,056 ft) to the borehole completion depth. The logging was completed on August 22, 2014. Figure 5 provides a condensed version of the geophysical logs obtained from well MV-5. The zones of higher caliper readings (primarily 1,400 ft and below) indicate fractured zones, as do high SP and low resistivity readings. Temperature increases with depth in response to the geothermal gradient. Extrapolating the relatively constant temperature increase from 1,100 to 1,400 ft to the depth of the borehole gives an approximation of the geothermal gradient. Zones where the temperature increase slows (drops below the geothermal gradient line) are interpreted as fractured zones where formation water flows into the borehole (below 1,400 ft), cooling the deeper hotter water. Zones where the temperature returns to the geothermal gradient are interpreted as fractured zones where water flows from the borehole into the formation (below 1,700 ft).

The borehole deviation log provided the extent the borehole deviated from vertical. The bottom of the MV-5 borehole deviated less than 1 degree from true vertical, placing the bottom of the borehole approximately 6 ft southeast from the surface collar. Figure 6 provides a deviation plot of the MV-5 borehole.

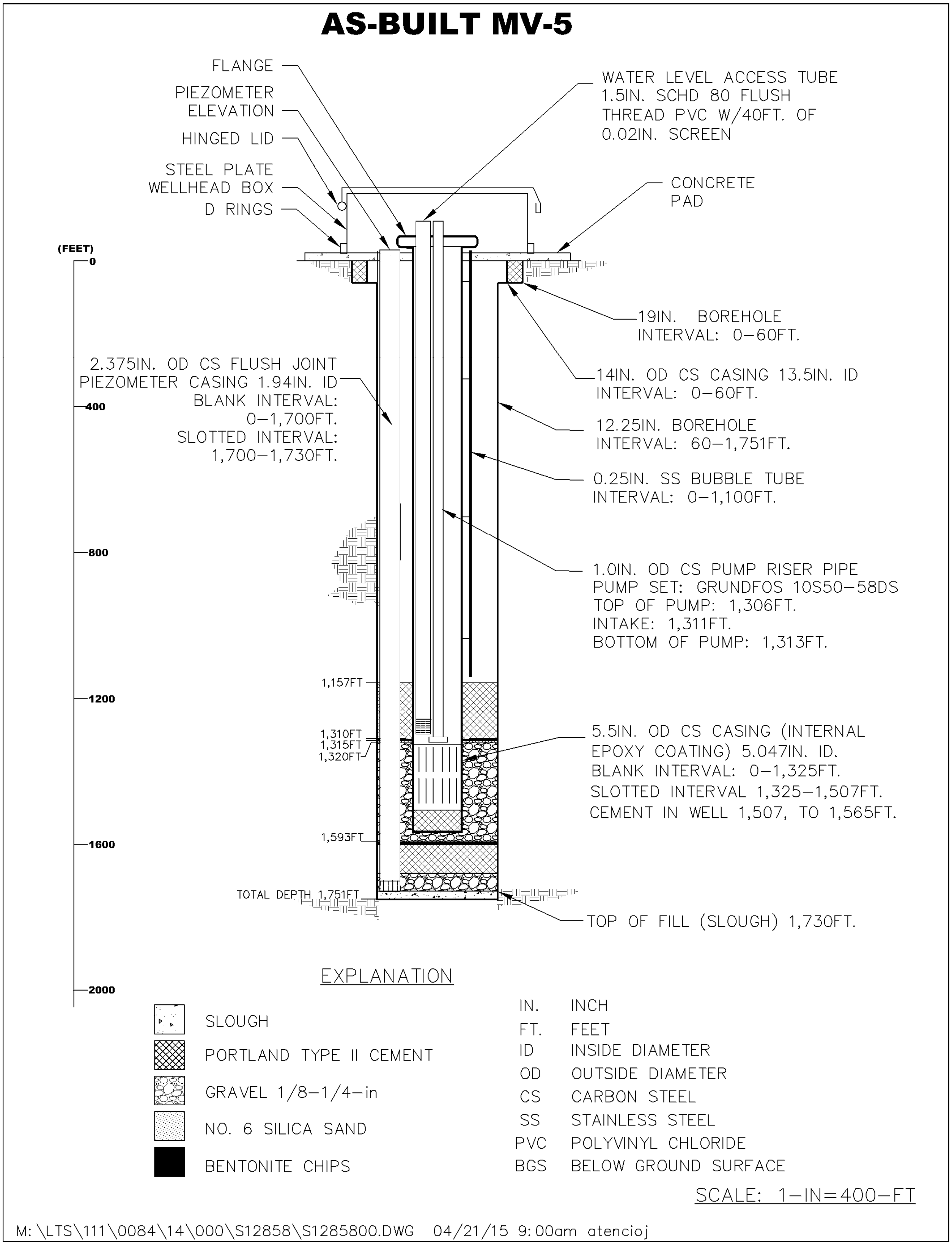

Figure 4. As-Built Completion Diagram of MV-5

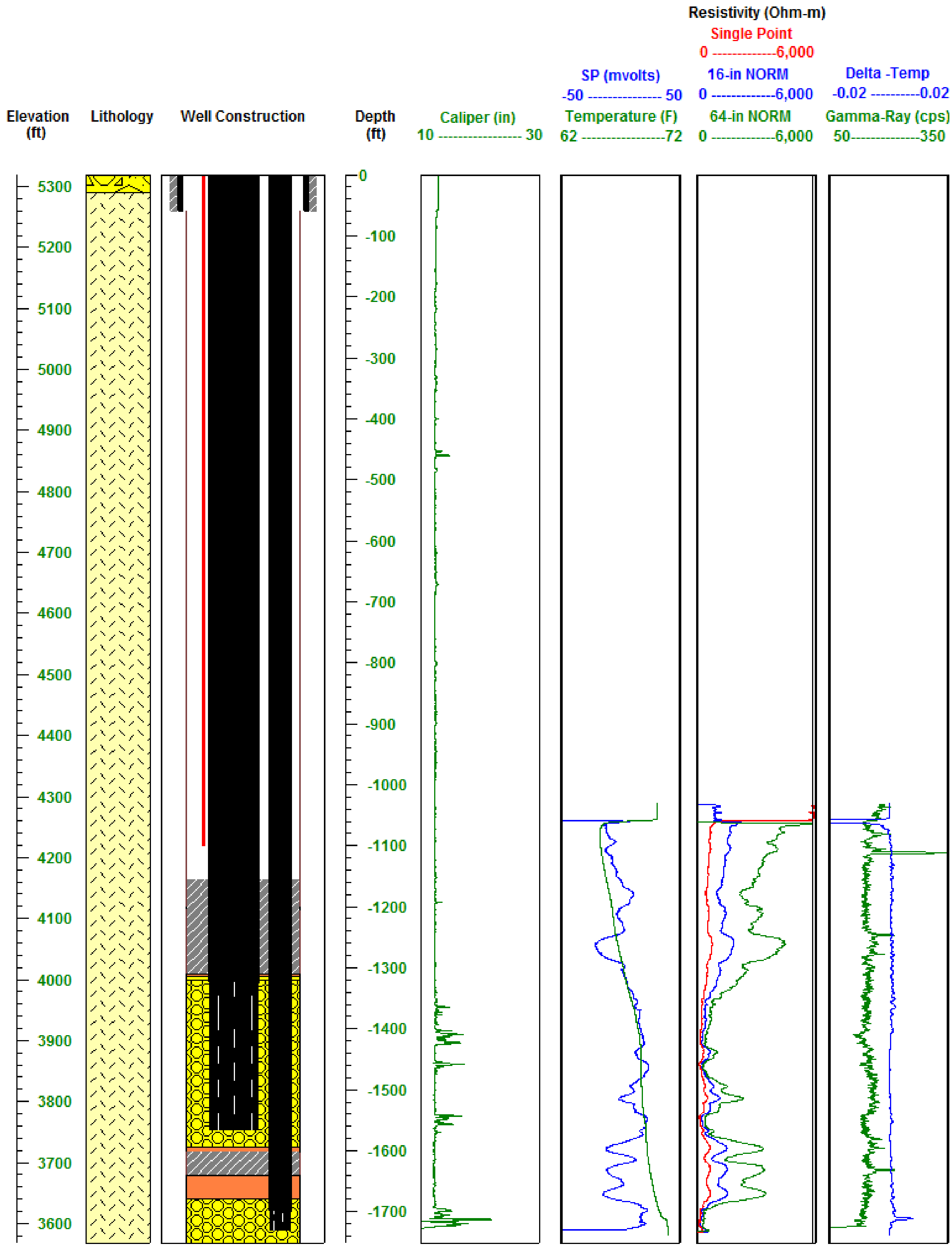

Figure 5. MV-5 Geophysical Logs

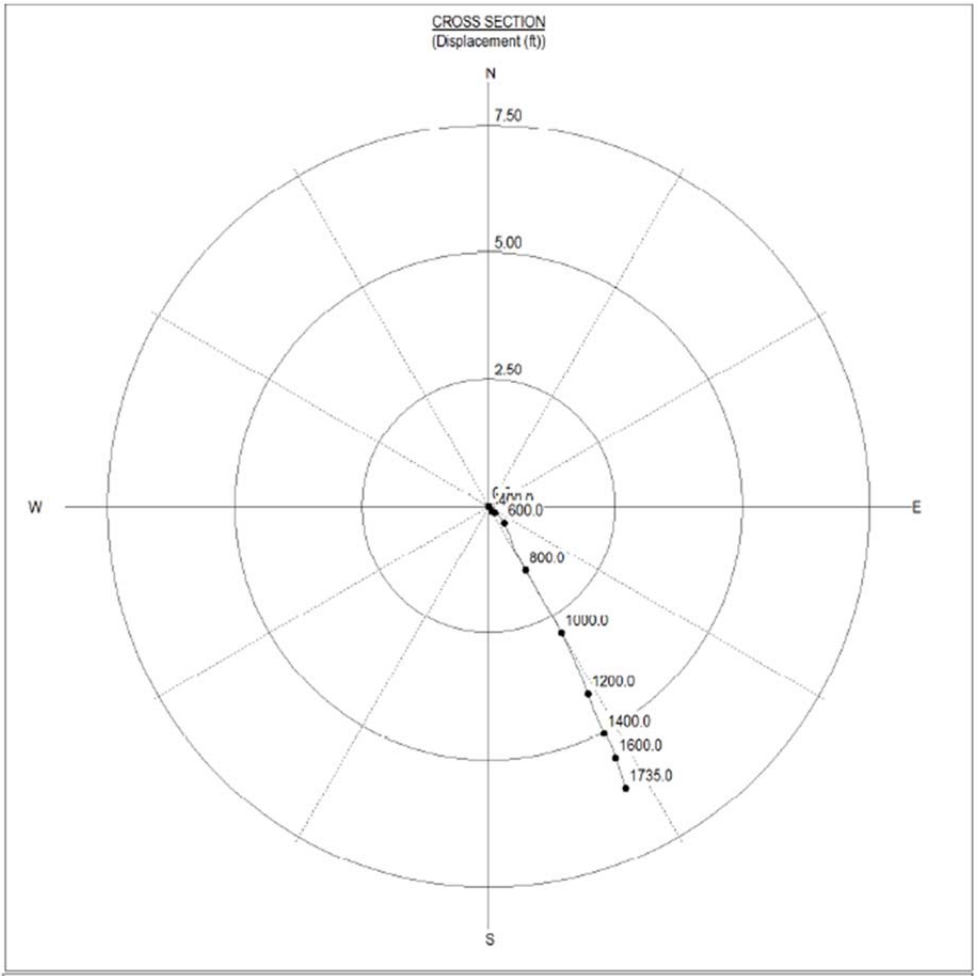

Figure 6. Borehole Deviation Plot of MV-5

4.3 Sampling

Geologic material and water quality samples were collected during the advancement of the borehole and development of the well and piezometer. Samples included rock cuttings for lithologic description and drilling fluid and groundwater for water quality analysis. A total of approximately 73,000 gallons of water were withdrawn from the water supply well HS-1 and used during the drilling and well installation. Samples were collected according to the FMP (DOE 2011c) and Field Instructions (DOE 2014d). Sections 4.3.1–4.3.3 summarize the sampling activities.

4.3.1 Geologic Material Sampling

Samples of the drill cuttings were collected during advancement of the borehole. The rock cuttings were collected from the drill rig shaker screen, washed, and composited for 10 ft intervals. The lithologic units encountered during the drilling are summarized below. Appendix B provides a detailed lithologic description of the MV-5 well cuttings.

0–450 ft	Granite, moderately crystalline, very light grey, with white to very light grey potassium feldspar, very light grey sodic plagioclase, quartz, biotite, hornblende, and sphene in the upper few hundred feet, which transitions into a similar granite at depth that contains very light pinkish-grey potassium feldspar instead. Because of the small size of the drill cuttings, it is not known whether this is an equicrystalline granite or a porphyritic granite at depth (both types appear in surface bedrock exposures).
450–460 ft	Granitic dike, light yellowish-grey, moderately crystalline, with potassium feldspar, sodic plagioclase, quartz, biotite, hornblende, pyrite, magnetite, traces of epidote, and some secondary euhedral, void-filling, quartz crystals partially in fracture apertures.
460–750 ft	Granite, light grey to light greenish-grey, moderately crystalline, major mineral composition is the same, with some biotite altering to chlorite and some feldspar altering to clay, plus minor secondary dolomite and epidote. Within this depth interval the granite varies from very light grey granite with no alteration to light greenish-grey granite with mild propylitic alteration.

4.3.2 Radiological Sampling and Monitoring

Tritium was not detected above the MDC in samples collected and analyzed during the drilling and development of well MV-5. A few sample analyses initially indicated detectable concentrations of tritium, but when the samples were reanalyzed with close adherence to the procedure of limiting their exposure to light prior to analysis, the results were below the MDC. Table B-3 in Appendix B provides the tritium results obtained during the drilling and development of well MV-5.

4.3.3 Bromide and Water Quality Parameter Sampling

Samples of the drilling fluid and groundwater discharged during development were collected and analyzed to monitor bromide, pH, temperature, specific conductance, and turbidity. Concentrations of bromide in the drilling fluid ranged from 43 to 0.5 mg/L during drilling operations, from 62 to 16 mg/L during development using the airlifting method, and from 7.5 to 3.8 mg/L during the final development using the submersible electric pump. For reference, bromide concentrations were maintained at 20 to 40 mg/L in the water used during drilling. Section 4.4 summarizes the well development activities. Figure 7 provides a chart of the bromide results obtained during the drilling and well development. Table B-4 in Appendix B provides the groundwater quality parameters and bromide results obtained during drilling and development of well MV-5.

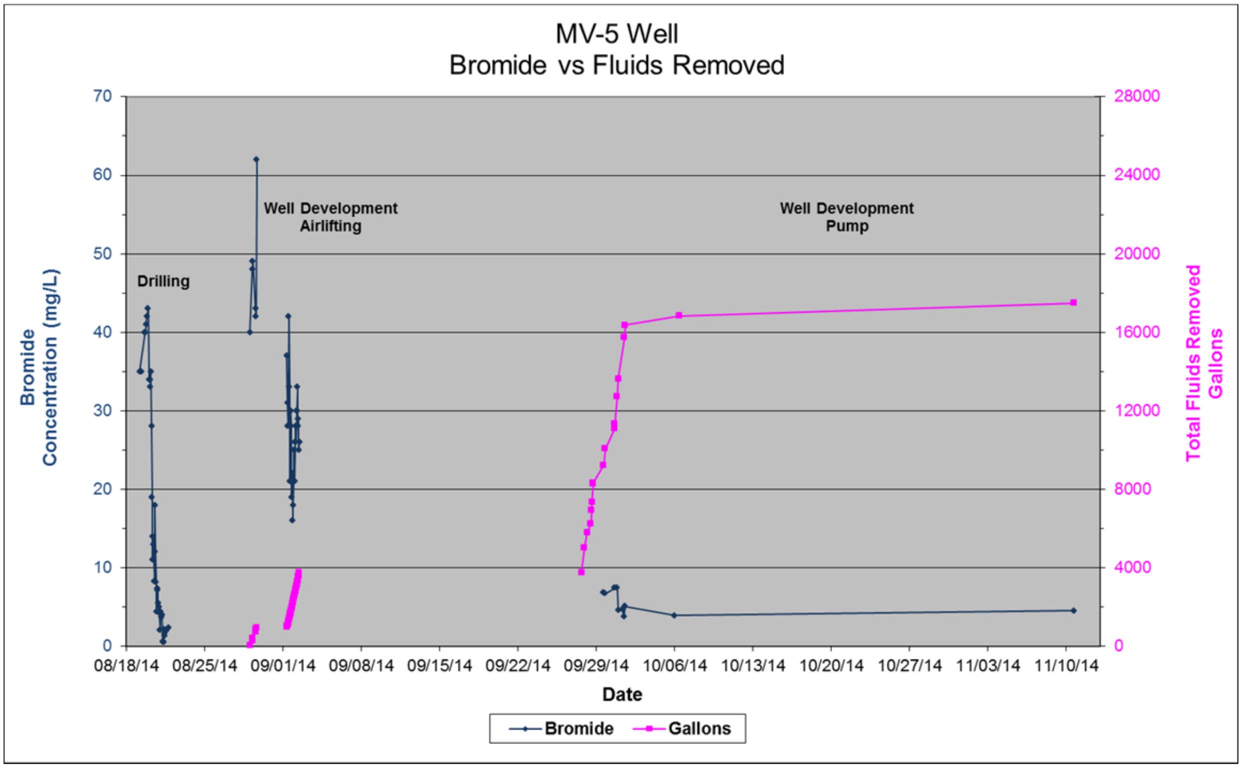

Figure 7. Bromide Concentration Versus Gallons Removed from Well MV-5

4.4 Initial Development

Initial development of well MV-5 began on August 29, 2014. The development included approximately 40 hours of swabbing, airlifting, and surging of the monitoring well. Fluid discharge rates were very low throughout the development and could not be sustained because of slow recharge from the formation. Airlifting was conducted by cycling the air (on and off) to surge the well and allow time for water levels in the well to recover. Airlift pumping continued until the discharge water was visually free of suspended sediment. The last sample collected and analyzed during the initial development had a bromide concentration of 26 mg/L. The initial development was completed on September 2, 2014, after a total of 3,770 gallons of fluid were removed from the MV-5 well.

Development of the MV-5 piezometer began on August 30, 2014. This development included approximately 32 hours of air lifting and surging the piezometer. Fluid discharge rates were very low throughout the development and could not be sustained because of slow recharge from the formation. Airlifting was conducted by cycling the air (on and off) to surge the piezometer and allow time for water levels in the piezometer to recover. Piezometer development was completed on August 31, 2014. The bromide concentration at the end of development was 0.9 mg/L. A total of 585 gallons of fluid were removed from the piezometer during development. Table B-4 in Appendix B provides the groundwater quality parameters and bromide results obtained during the drilling and development of MV-5.

4.5 Pump Installation and Final Development

A 4-inch stainless-steel submersible electric Grundfos pump, model 10S50-58DS, was installed in well MV-5. The pump is powered by an MS4000, 5-horsepower, 480-volt, three-phase Franklin Electric motor, model 2343278602. Installation of the pump began on September 26, 2014, using Boart's truck-mounted crane. The pump is set on 1-inch-o.d. carbon-steel API pipe with external upset ends, and the intake for the pump is set at approximately 1,311 ft bgs. Power is supplied to the pump using Kalas 8 AWG #10 600-volt, four-wire, flat submersible cable that is banded and clamped to the pump riser pipe. A 1.5-inch-o.d. schedule-80 PVC pipe with flush joints is also banded and clamped to the pump riser pipe to allow access for water level measurements. The water level access tube is completed with 40 ft of 0.02-inch screen that is set just above the top of the pump. Installation of the pump was completed on September 27, 2014. Table B-5 in Appendix B provides the pump and tubing specifications used to complete MV-5.

Final development of the MV-5 well was performed using the dedicated submersible electric pump and began on September 27, 2014. The pump was run intermittently for approximately 41 hours from September 27 through October 6, 2014. The last sample collected during the well development had a bromide concentration of 3.9 mg/L and a turbidity of 1.35 nephelometric turbidity units (NTU). All samples collected and analyzed for tritium during the development were below the MDC. MV-5 well development during the drilling program ended on October 6, 2014. Additional development was conducted on November 10, 2014, during a site visit to download transducer data and measure depth to groundwater. Approximately 17,000 gallons of fluid were removed during the development of the MV-5 well. Figure 7 provides a graph comparing bromide concentrations to gallons removed during well development.

5.0 Summary of MV-4 Activities

Groundwater monitoring well MV-4 was installed approximately 1,950 ft southwest of SGZ (Figure 2). The MV-4 well was installed on the pad where the former PM-1 borehole was drilled prior to the underground test in 1963 and abandoned shortly after the test. The MV-4 borehole was dually completed with a well and piezometer to collect water level data and determine vertical hydraulic gradients at the location. The piezometer was screened near the water table to correlate with other piezometers and shallow wells at the site. The well was screened across the deepest, most productive zone within the borehole based on geologic data collected during drilling and interpretations from the borehole geophysical logs (Section 5.2) to monitor groundwater at and below the depth of the drift/tunnel and detonation cavity.

Drilling operations began on September 3, 2014, and the borehole was completed to a total depth of 1,570 ft bgs on September 15, 2014. Geophysical logging of the borehole was completed on September 15, 2014. Construction of the well and piezometer began after logging operations and was completed on September 18, 2014. The cement surface seal could not be completed from 892 ft bgs to the surface on September 18 because of problems with the pump in the water supply well HS-1. A total of approximately 173,000 gallons of water were withdrawn from the water supply well HS-1 and used during the drilling and well installation. Initial airlift development of the well and piezometer was completed on September 22, 2014. Cementing of the borehole from 892 ft bgs to surface was completed on September 23, 2014. The dedicated submersible electric pump was installed on September 30, 2014, and final well development using the submersible pump took place intermittently during the drilling program from September 30 through October 6, 2014. A final pump development event was conducted on November 12, 2014. Sections 5.1 through 5.5 summarize the well construction, geophysical well logging, sampling, well development, and pump installation activities. Table C-1 in Appendix C provides a chronology of the drilling operations at well MV-4.

5.1 Drilling and Construction

Installation of MV-4 included drilling an initial 19-inch-diameter borehole to a depth of 60 ft bgs to allow a 14-inch-diameter carbon-steel casing with fully welded joints to be installed as a surface seal and wellhead control apparatus. This casing was set to a depth of 60 ft bgs and cemented in place with Portland Type II cement. The final borehole was drilled from 60 ft to the completion depth of 1,570 ft bgs using a 12.25-inch down-hole hammer bit. Difficulties with the stability of the borehole resulted in 8 days (September 7–15, 2014) being spent trying to get the drill string unstuck from the borehole and then deepen the borehole. Repairs to the drill rig were also required during this time. To complete the borehole to the drilled depth of 1,570 ft bgs, it was necessary to change the drilling method to flooded reverse circulation using a tricone bit, and bentonite-based drilling mud to remove bridges and stabilize the borehole. The change in drilling method resulted in an increase in water use from the water supply well HS-1 (approximately 173,000 gallons) to complete drilling and well installation. Borehole stability problems prevented the borehole from being drilled to the planned depth (1,800 ft) and resulted in the borehole being completed at 1,570 ft bgs. The selection of well and piezometer screen intervals was based on geologic data collected while drilling (cuttings, drill rates) and the geophysical logs.

Well MV-4 was completed with a well and piezometer in the 12.25-inch-diameter borehole. The well consisted of a 5.5-inch-o.d. internally epoxy-coated carbon-steel casing. The well was screened from 1,400 to 1,560 ft bgs with manufactured 3-by-0.078-inch slotted openings on 6-inch centers staggered at 10 degrees with 18 slots per row. The well was completed to a total depth of 1,560 ft bgs. Centralizers were placed around the well screen at approximately 80 ft intervals to ensure that the well was centered in the borehole. The piezometer was constructed with 2.375-inch-o.d. carbon-steel casing with 120 ft of slotted (0.078-inch) screen installed from 1,120 to 1,240 ft bgs. The piezometer was completed to a total depth of 1,240 ft bgs.

A graded filter pack was installed around the slotted intervals of the well and piezometer. Filter pack materials for MV-4 included ⅛- to ¼-inch clean gravel and No. 6 clean silica sand for the well and piezometer. The silica sand was placed above the gravel as transition sand. Gravel and sand filter pack materials were pumped through a tremie pipe using a sand pump. A seal composed of ⅜-inch bentonite chips was used on top of the sand filter pack for the well and piezometer filter packs. Portland Type II cement was placed on top of the bentonite chips to seal the formation. A 6 ft thick bentonite seal, a 45 ft thick cement seal, and another 54 ft thick bentonite seal was placed between the well filter pack and the piezometer filter pack to ensure the separation of water-producing zones. A 5 ft thick bentonite seal and a 1,090 ft thick cement seal was placed from the top of the well filter pack to isolate the monitoring well screen. Cement was pumped down the tremie pipe, followed by a clean-water rinse. The final cement seal above the piezometer screen was installed in two phases from 1,090 to 892 ft bgs and from 892 ft bgs to surface because of problems with the pump and getting water from the water supply well HS-1. The tremie was raised in stages during the placement of the stemming materials to help ensure proper placement without plugging or bridging. Table C-2 in Appendix C lists the well construction materials and volumes used to complete MV-4 (Figure 8).

5.2 Geophysical Logging

Pacific Surveys acquired borehole geophysical logs from the MV-4 borehole. The geophysical logging was performed in the 12.25-inch-diameter borehole from below the surface casing (60 ft) to the completion depth of approximately 1,570 ft bgs. The logging suite included caliper, borehole deviation, natural gamma ray, SP, temperature and differential temperature, and resistivity (dual laterolog/induction logs) logs. The optical or acoustic televiewer logs could not be acquired because the bentonite-based drilling mud used to maintain the borehole stability resulted in reduced visibility and acoustic responses in the borehole. The natural gamma ray, SP, temperature and differential temperature, and resistivity (dual laterolog/induction logs) logs were run from the borehole fluid level (approximately 350 ft) to the borehole completion depth. The logging was completed on September 15, 2014. Figure 9 provides a condensed version of the geophysical logs obtained from well MV-4. The zones of higher caliper readings (primarily 1,120 ft to 1,440 ft bgs) indicate fractured zones and provide an indication of the borehole stability problems and decision to switch to a bentonite-based drilling mud to stabilize the borehole. The bentonite-based drilling mud resulted in a higher fluid level in the borehole (groundwater was encountered in the borehole at approximately 1,080 ft bgs), reduced the response in the resistivity log, and increased the response in the gamma-ray log.

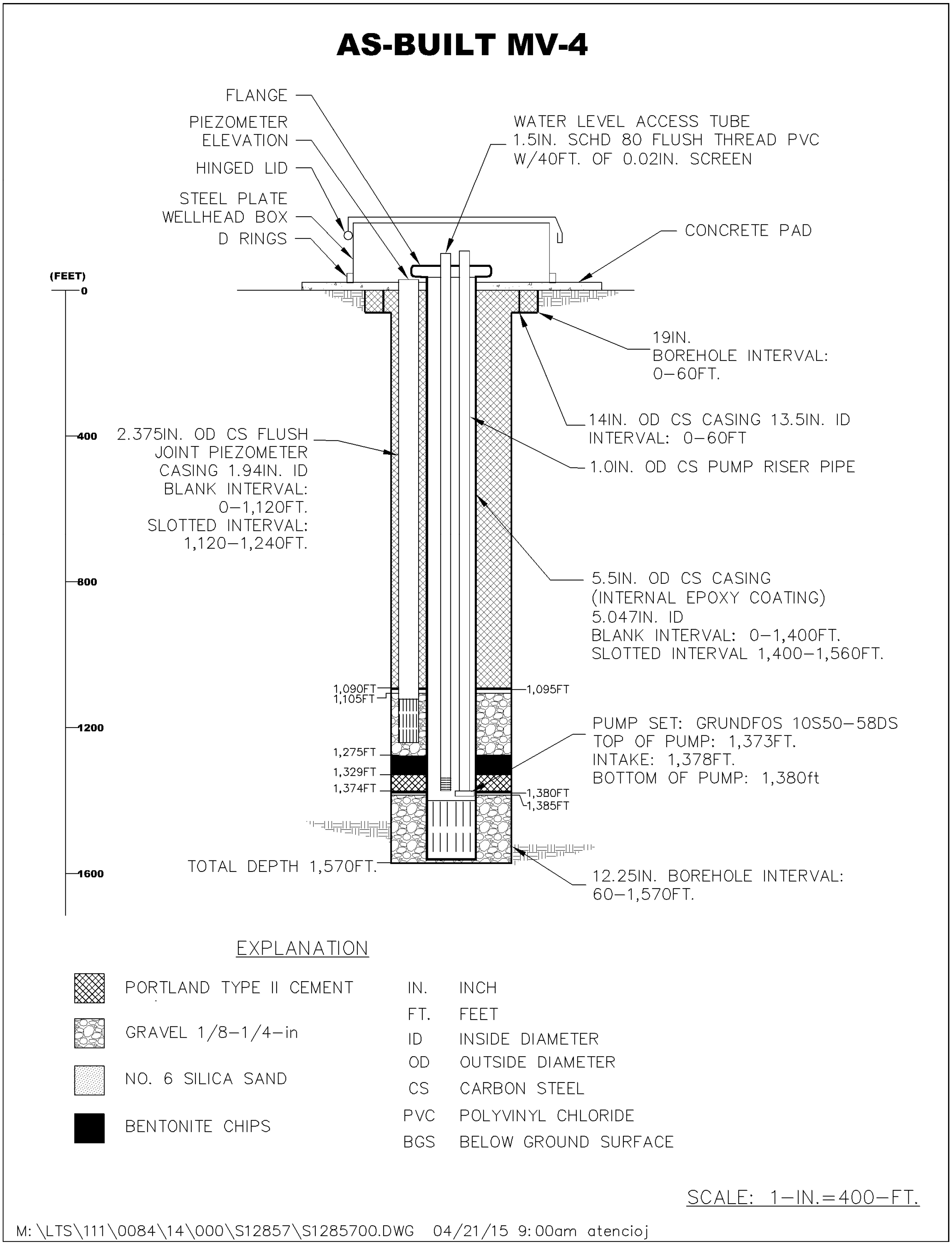

Figure 8. As-Built Completion Diagram of MV-4

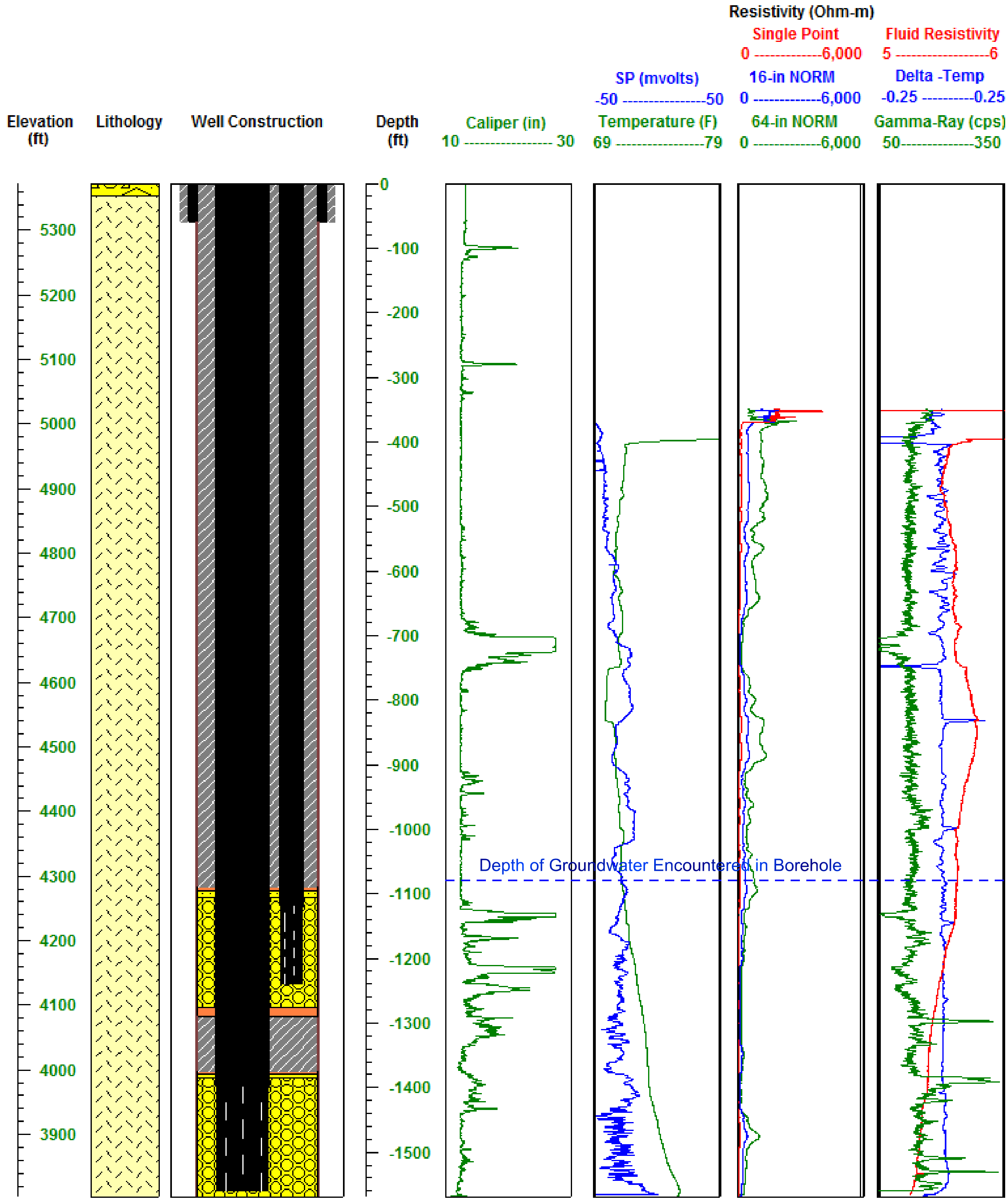

Figure 9. MV-4 Geophysical Logs

The borehole deviation log provided the extent the borehole deviated from vertical. The bottom of the MV-4 borehole deviated less than 1 degree from true vertical, with the bottom of the borehole completed approximately 1.6 ft southeast of the surface collar. Figure 10 provides a deviation plot of the MV-4 borehole.

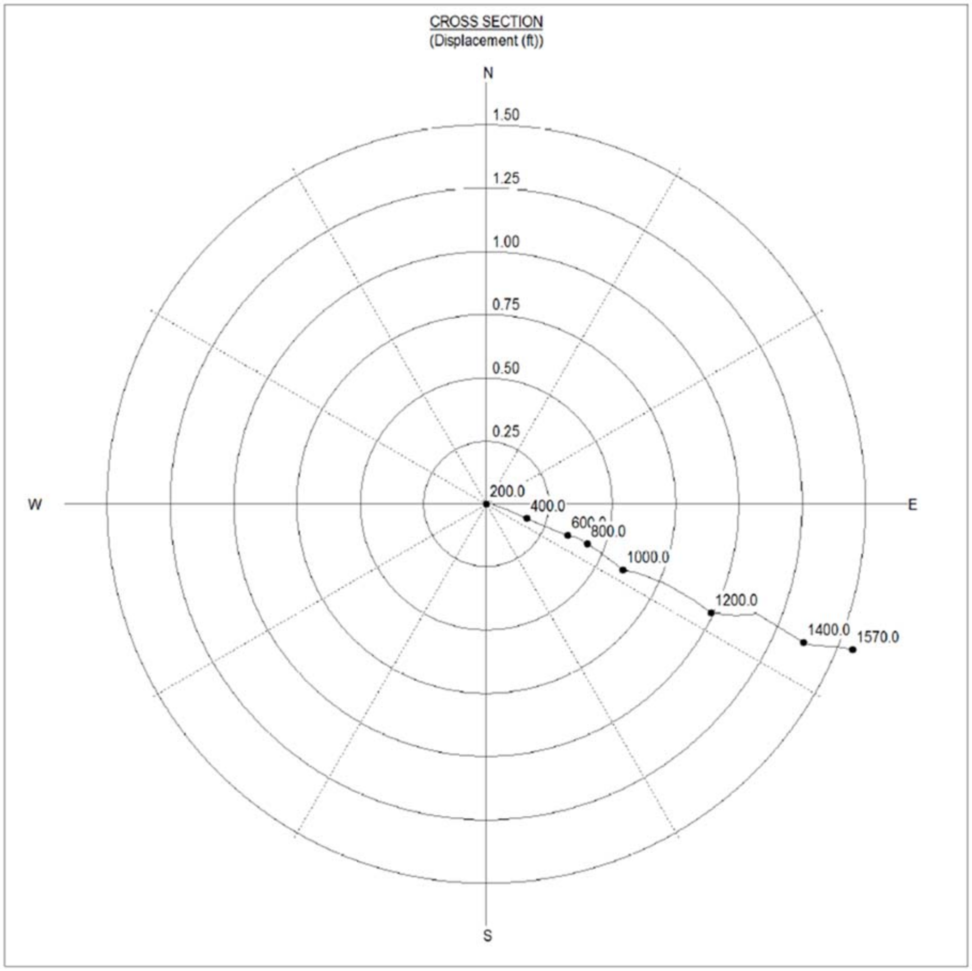

Figure 10. Borehole Deviation Plot of MV-4

5.3 Sampling

Geologic material and water quality samples were collected during the advancement of the borehole, construction of the well and piezometer, and development of the well and piezometer. Samples included rock cuttings for lithologic description and drilling fluid and groundwater for water quality analysis. A total of approximately 173,000 gallons of water were withdrawn from the water supply well HS-1 and used during the drilling and well installation. Samples were collected according to the FMP (DOE 2011c) and Field Instructions (DOE 2014d). Sections 5.3.1–5.3.3 summarize the sampling activities.

5.3.1 Geologic Material Sampling

Samples of the drill cuttings were collected during the advancement of the borehole. The rock cuttings were collected from the drill rig shaker screen, washed, and composited for 10 ft intervals. The lithologic units encountered during the drilling are summarized below. Appendix C provides a detailed lithologic description of the cuttings obtained from the MV-4 borehole.

0–20 ft	Pegmatite dike, very light greenish-grey and very light pinkish-grey, coarsely crystalline—possibly porphyritic, with large crystals of potassium feldspar in a groundmass of intergrown laths of sodic plagioclase and intercrystalline quartz, with very small quantities of biotite, magnetite, and pyrolusite dendrites on fracture surfaces.
20–100 ft	Granite, light grey, moderately crystalline, composed of white sodic plagioclase, light pinkish-grey potassium feldspar, quartz, biotite, and hornblende, with traces of magnetite, sphene, and epidote.
100–110 ft	Pegmatite dike, light pinkish-grey, very coarsely crystalline, composed of light pinkish-grey potassium feldspar, white sodic plagioclase, and quartz.
110–230 ft	Granite, light grey, moderately crystalline, alternating with light greenish-grey, moderately crystalline granite, both composed of white sodic plagioclase, light pinkish-grey potassium feldspar, quartz, biotite, and hornblende, with traces of magnetite, sphene, and epidote. The greenish-grey granite manifests modest propylitic alteration with additional chlorite, dolomite, and pyrite.
230–345 ft	Pegmatite, light pinkish-grey, very coarsely crystalline, composed primarily of light pink potassium feldspar and white sodic plagioclase, with some quartz, including some void-filling secondary euhedral quartz crystal overgrowths.
345–1,570 ft	Granite, light grey, moderately crystalline, alternating with light greenish-grey, moderately crystalline granite, both composed of white sodic plagioclase, light pinkish-grey potassium feldspar, quartz, biotite, and hornblende, with traces of magnetite, sphene, and epidote. The greenish-grey granite manifests modest propylitic alteration with additional chlorite, dolomite, and pyrite. Fracture surfaces within this interval typically have secondary mineral coatings of clay, chlorite, chlorite and dolomite, or calcite.

5.3.2 Radiological Sampling and Monitoring

Tritium was not detected above the MDC in samples collected and analyzed during the drilling and development of well MV-4. A few sample analyses initially indicated detectable concentrations of tritium, but when the samples were reanalyzed with close adherence to the procedure of limiting their exposure to light prior to analysis; the results were below the MDC. Table C-3 in Appendix C provides the tritium results obtained during the drilling and development of well MV-4.

5.3.3 Bromide and Water Quality Sampling

Samples of the drilling fluid and groundwater discharged during development were collected and analyzed to monitor bromide, pH, temperature, specific conductance, and turbidity. Bromide concentrations ranged from 33 to 3.5 mg/L during the drilling operations, from 44 to 4.2 mg/L during development using the airlifting method, and from 6.1 to 2.6 mg/L during development using an electric submersible pump. Section 4.4 summarizes the well development activities. Figure 11 provides a chart of the bromide results obtained during the drilling and well development. Table C-4 in Appendix C provides the groundwater quality parameter and bromide results obtained during the drilling and development of well MV-4.

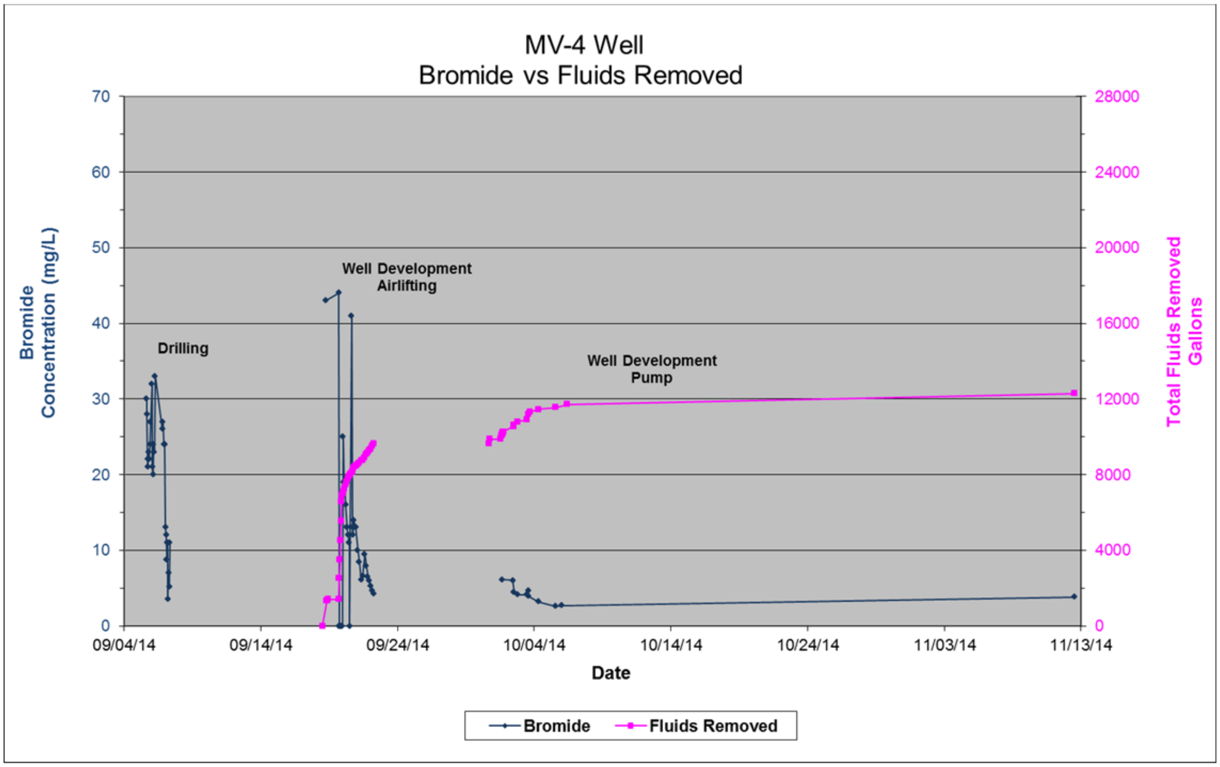

Figure 11. Bromide Concentration Versus Gallons Removed from Well MV-4

5.4 Initial Development

The initial development of well MV-4 began on September 18, 2014. The development included approximately 91 hours of airlifting and swabbing of the monitoring well. Fluid discharge rates during the initial development were very low and could not be sustained because of slow recharge from the formation. The mud dispersant Tackle was mixed with water and added to the well to break down the bentonite-based drilling mud in an attempt to restore the formation's natural hydraulic conductivity. Water was also added to the well on September 19, 2014, at a rate of 2 to 3 gallons per minute to maintain a constant purge rate and wash down the inside of the well. The remaining airlift development was conducted by cycling the air purging (on and off) with 20-minute lifts followed by 10 to 20 minutes of shut-in to allow water levels in the well to recover. The last sample collected and analyzed during the initial development indicated a bromide concentration of 4.2 mg/L. The initial development was completed on September 22, 2014, after a total of 9,628 gallons of fluid were removed from the MV-4 well.

The development of the MV-4 piezometer was conducted with a bailer and began on September 29, 2014. A total of 31 hours over a period of 2 days were spent bailing the MV-4 piezometer. The development of the piezometer was completed on October 2, 2014. A total of approximately 100 gallons of fluid (4.2 casing volumes) were removed from the piezometer during the initial development of MV-4.

5.5 Pump Installation and Final Development

A 4-inch stainless-steel submersible electric Grundfos pump, model 10S50-58DS, was installed in well MV-4. The pump is powered by an MS4000, 5-horsepower, 480-volt, three-phase Franklin Electric motor, model 2343278602. Installation of the pump began on September 28, 2014, using Boart's truck-mounted crane. The pump is set on 1-inch-o.d. carbon-steel API pipe with external upset ends, and the intake for the pump is set at approximately 1,378 ft bgs. Power is supplied to the pump using Kalas 8 AWG #10, 600-volt, four-wire, flat submersible cable that is banded and clamped to the pump riser pipe. A 1.5-inch-o.d. schedule-80 PVC pipe with flush joints is also banded and clamped to the pump riser pipe to allow access for water level measurements. The water level access tube is completed with 40 ft of 0.02-inch screen that is set just above the top of the pump. Installation of the pump was completed on September 30, 2014. Table C-5 in Appendix C provides the pump and tubing specifications used to complete well MV-4.

The final development of well MV-4 was performed using the dedicated submersible electric pump and began on September 30, 2014. The pump was run intermittingly for approximately 23 hours from September 30 through October 6, 2014. The last sample collected during the well development had a bromide concentration of 2.7 mg/L and a turbidity of 28.3 NTU. All samples collected and analyzed for tritium during the development were below the MDC. Well development was completed during the drilling program on October 6, 2014. Additional development was conducted on November 12, 2014, during a site visit to download transducer data and measure depth to groundwater. Approximately 12,300 gallons of fluid were removed during the development of well MV-4. Figure 11 is a graph comparing bromide concentrations to gallons removed during well development.

6.0 Summary of HC-2d Activities

The existing well HC-2 was deepened and recompleted as a groundwater monitoring well during the drilling program. This well was installed in 1996 and is approximately 1,800 ft west of SGZ (Figure 2). The well was deepened because the original completion depth was above the level of the drift/tunnel and detonation cavity. The well (HC-2d) was deepened to better monitor groundwater at and below the depth of the drift/tunnel and detonation zone.

The original well casing was pulled from the HC-2 borehole on August 14 and 15, 2014. The borehole remained open but secured at the surface until September 23, 2014, when drilling operations to deepen the borehole began. The drill bit was tripped into the borehole's original completed depth of 1,303 ft bgs on September 25, 2014, and the borehole was deepened to the total depth of 1,836 ft bgs on September 26, 2014. Geophysical logging of the borehole could not be completed because of borehole stability problems. The new well casing was installed to a depth of 1,657 ft bgs on September 29, 2014. A total of approximately 45,000 gallons of water were withdrawn from the water supply well HS-1 and used during the drilling and well installation. Initial airlift development of the well was completed on October 3, 2014. The dedicated submersible electric pump was installed on October 3, 2014, and final development using the submersible pump took place intermittently from October 4 through October 6, 2014. A final pump development event was conducted on November 11, 2014. Upon recompletion of well HC-2, the location identification was changed to HC-2d. Sections 6.1 through 6.4 summarize the drilling, well construction, pump installation, and development activities. Table D-1 in Appendix D provides a chronology of the recompletion activities at well HC-2d.

6.1 Drilling and Construction

The HC-2 well casing was removed from the 8-inch-diameter borehole on August 15, 2014. The original 8.625-inch-o.d. surface casing, installed to a depth of approximately 100 ft bgs, was used as a surface seal and wellhead control apparatus during the drilling, which began on September 23, 2014. The borehole was deepened from the original completion depth of 1,303 ft to a final completion depth of 1,836 ft bgs using an 8-inch down-hole hammer bit. Attempts to complete the borehole geophysical logging were unsuccessful because of bridges in the borehole and borehole stability problems. The borehole was reentered and cleaned out to a depth of 1,700 ft bgs. Selection of the well screen interval was based on the borehole completion depth and subsurface elevation of the test cavity below SGZ.

The HC-2d borehole was completed with 5.5-inch-o.d. internally epoxy-coated carbon-steel well casing. The well was completed with two screened intervals from 1,417 to 1,517 ft bgs and from 1,557 to 1,657 ft bgs using manufactured 3-by-0.078-inch slotted openings on 6-inch centers staggered at 10 degrees with 18 slots per row. The two screened intervals were separated by 40 ft of blank casing to allow the submersible electric pump to be installed in the blank section between the screens to allow flow across the pump motor to prevent overheating when pumping. The well was completed to a total depth of 1,657 ft bgs. No filter pack was installed around the well screen, and no annular seal was installed around the casing. The well casing was hung and suspended within the borehole from the surface plate. Table D-2 in Appendix D lists the well construction materials used to complete HC-2d. Figure 12 provides a diagram of the HC-2d well construction details.

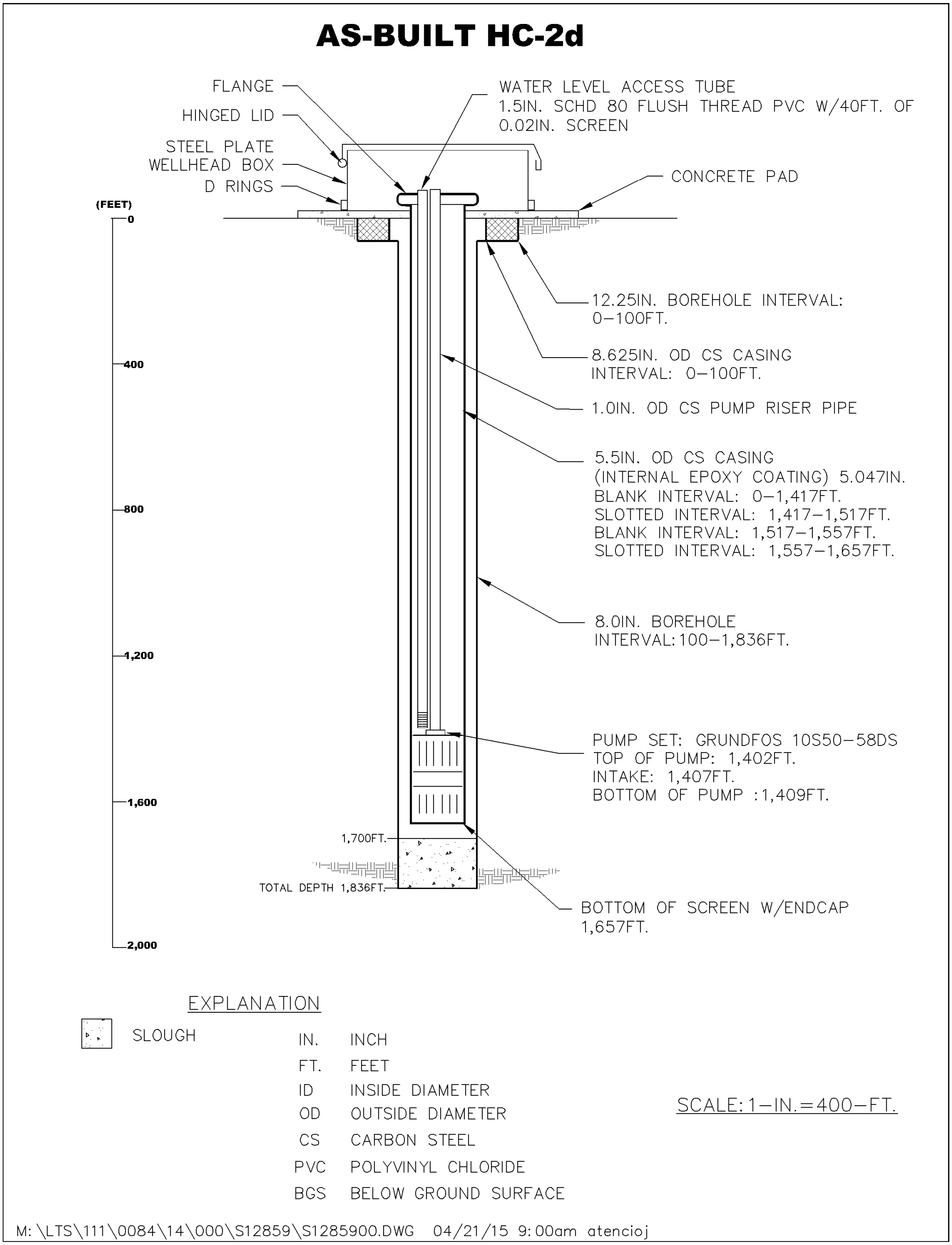

Figure 12. As-Built Completion Diagram of HC-2d

6.2 Sampling

Geologic material and water quality samples were collected during the advancement of the borehole, construction of the well, and development of the well. Samples included rock cuttings for lithologic description and drilling fluid and groundwater for water quality analysis. A total of approximately 45,000 gallons of water were withdrawn from the water supply well HS-1 and used for the drilling and well installation. Samples were collected according to the FMP (DOE 2011c) and Field Instructions (DOE 2014d). Sections 6.2.1–6.2.3 summarize the sampling activities.

6.2.1 Geologic Material Sampling

Samples of the drill cuttings were collected during the advancement of the borehole. The rock cuttings were collected from the drill rig shaker screen, washed, and composited for 10 ft intervals. Lithologic units encountered during the drilling are summarized below. Appendix D provides a detailed lithologic description of the cuttings from the HC-2d borehole.

1303–1836 ft Granite, very light grey to light greenish-grey, medium crystallinity, composed of light greenish-grey plagioclase, light grey potassium feldspar, quartz, biotite, actinolitic hornblende, sphene, magnetite, and traces of pyrite and chlorite. Xenoliths of chloritized amphibolites are locally present. The light-greenish-grey granite manifests modest propylitic alteration with additional chlorite, dolomite, and pyrite. Fracture surfaces within this interval typically have secondary mineral coatings of clay or chlorite, or both.

6.2.2 Radiological Sampling and Monitoring

Tritium was not detected above the MDC in samples collected and analyzed during drilling and development of well HC-2d. Table D-3 in Appendix D provides the tritium results obtained during drilling and development.

6.2.3 Bromide and Water Quality Sampling

Samples of the drilling fluid and groundwater discharged during development were collected and analyzed to monitor bromide, pH, temperature, specific conductance, and turbidity. Bromide concentrations ranged from 46 to 24 mg/L during the drilling operations, from 10 to 2.6 mg/L during development using the airlifting method, and from 3.9 to 0.53 mg/L during development using the electric submersible pump. Section 4.4 summarizes the well development activities. Figure 13 provides a chart of the results obtained during the drilling and well development. Table D-4 in Appendix D provides the groundwater quality parameter and bromide results obtained during the drilling and development of well HC-2d.

6.3 Initial Development

The initial development of well HC-2d began on September 29, 2014. The development included approximately 65 hours of airlifting and swabbing of the monitoring well. Fluid discharge rates were very low during development and could not be sustained because of the slow recharge from the formation. The airlift development was conducted by cycling the air (on and off) to surge the well and allow time for water levels in the well to recover. The last sample collected and analyzed during the initial development had a bromide concentration of 3.0 mg/L. The initial development was completed on October 2, 2014, after a total of 2,878 gallons of fluid had been removed from the well.

6.4 Pump Installation and Final Development

A 4-inch stainless-steel submersible electric Grundfos pump, model 10S50-58DS, was installed in well HC-2d. The pump is powered by an MS4000, 5-horsepower, 480-volt, three-phase Franklin Electric motor, model 2343278602. Installation of the pump began on October 3, 2014, using Boart's truck-mounted crane. The pump is set on 1-inch o.d. carbon-steel API pipe with external upset ends, and the intake for the pump is set at approximately 1,407 ft bgs. Power is supplied to the pump using Kalas 8 AWG #10 600-volt, four-wire, flat submersible cable that is banded and clamped to the pump riser pipe. A 1.5-inch-o.d. schedule-80 PVC pipe with flush joints is also banded and clamped to the pump riser pipe to allow access for water level measurements. The water level access tube is completed with 40 ft of 0.02-inch screen set just above the top of the pump. Installation of the pump was completed on October 4, 2014. Table D-5 in Appendix D provides the pump and tubing specifications used to complete well HC-2d.

The final development of well HC-2d was performed using the dedicated submersible electric pump and began on October 4, 2014. The pump was run intermittingly for approximately 16 hours from October 4 through October 6, 2014. Results obtained from the last sample collected during the well development indicated concentrations of bromide at 0.71 mg/L and turbidity of 17.5 NTU. All samples collected and analyzed for tritium during the development were below the MDC. Well development was completed during the drilling program on October 6, 2014. Additional development was conducted on November 11, 2014, during a site visit to download transducer data and measure depth to groundwater. A total of approximately 6,300 gallons of fluid were removed during the development of well HC-2d. Figure 13 provides a graph comparing bromide concentrations to gallons removed during the development of well HC-2d.

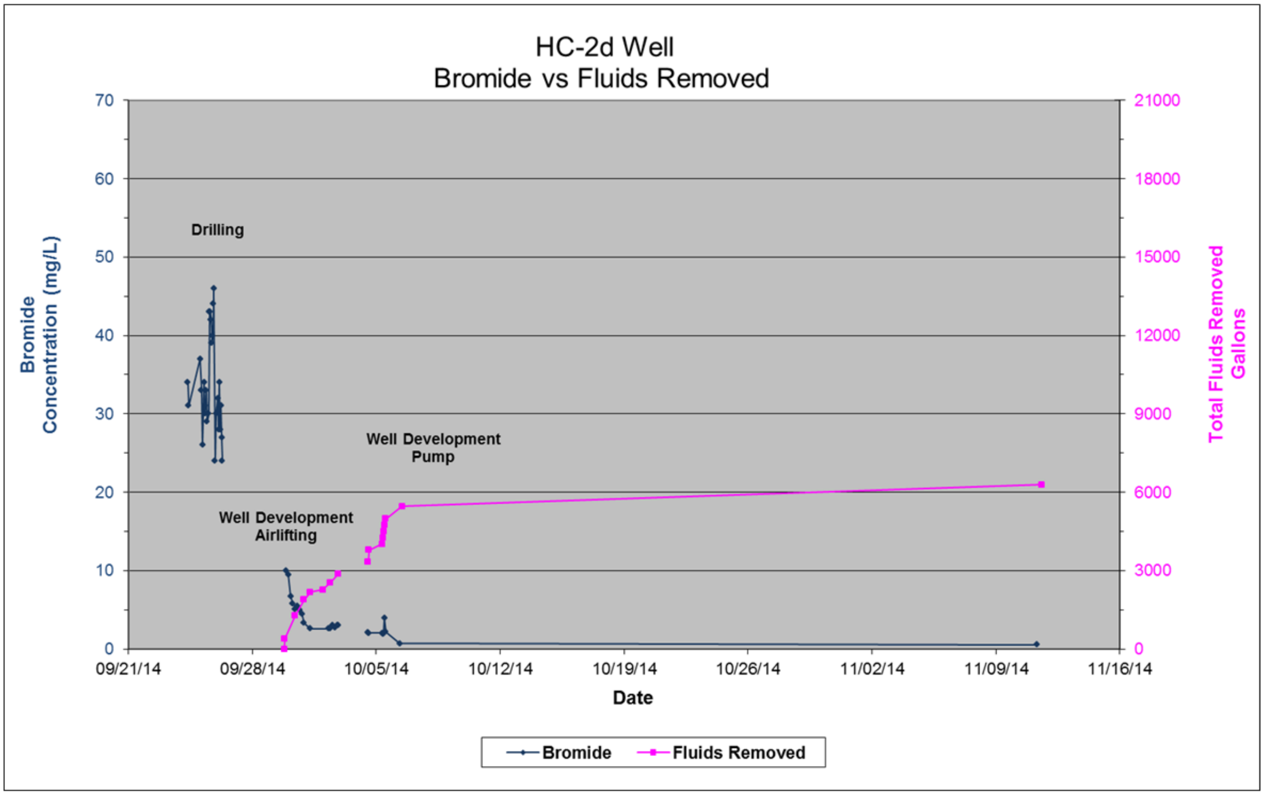

Figure 13. Bromide Concentration Versus Gallons Removed from Well HC-2d

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7.0 Environmental Compliance and Waste Management

The contractor was responsible for environmental compliance during the drilling program at Shoal. The environmental compliance elements of the drilling program included managing waste, tracking water use from well HS-1, and managing fluids in accordance with the FMP. Copies of Material Safety Data Sheets/Safety Data Sheets for chemicals used during the drilling program were maintained onsite. Spill response equipment was also maintained onsite, and emergency contact information was made available to all employees at the site. Sections 7.1−7.3 summarize the environmental compliance and waste management activities.

7.1 Waste Management

Construction debris and nonhazardous waste were generated during the drilling program at Shoal. Construction debris and nonhazardous waste were contained in roll-off bins onsite and disposed of by Boart. Incidental spills occurred during the drilling operations; however, no reportable spills (greater than 25 gallons) occurred. Secondary containment (e.g., plastic sheeting) was used under equipment to contain minor leaks that occur during operation. Fuel was stored in approved containers with appropriate labeling and secondary containment systems. Boart managed and disposed of hydrocarbon liquids and solids. No hazardous or radioactive waste was generated during the drilling program.

7.2 Source Water Management

The use of water from well HS-1 was monitored during the well pad construction and drilling program. A total of 77,700 gallons were used during the well pad construction, and 291,200 gallons were used during the drilling program. The water removed from well HS-1 during the drilling program was transported using a water truck and temporarily stored in a storage tank at each of the well pads. Water used for each well was estimated from water hauling records. It was determined that approximately 73,000 gallons of water were used during the drilling, construction, and development of well MV-5, approximately 173,000 gallons of water were used for MV-4, and approximately 45,000 gallons of water were used for HC-2d. Water was not used for dust suppression during the drilling program.

7.3 Fluid Management

Fluids generated during drilling and well development were managed in accordance with the FMP (DOE 2011c) and Well-Specific Fluid Management Strategy (DOE 2014c). The fluid management strategy was based on a far-field compliance strategy, which was verified through field screening and onsite monitoring for tritium. Tritium levels of discharged fluids remained within the background range during the drilling program. An infiltration basin was constructed near each well in accordance with the FMP (DOE 2011c). The infiltration basin contained fluids and cuttings from the respective wells. The secondary infiltration area was used during the drilling and development of wells MV-5 and MV-4 in accordance with the Well-Specific Fluid Management Strategy (DOE 2014c).

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8.0 Site Safety and Health

All work at the Shoal site was conducted in accordance with Title 10 *Code of Federal Regulations* Parts 835 and 851 (10 CFR 835 and 851), the contractor's Integrated Safety Management System, and the Field Instructions (DOE 2014d). Additionally, all activities were conducted in compliance with DOE orders and Occupational Safety and Health Administration regulations. The safety and health training requirements, project information, site and material characteristics, hazard analysis, site controls, site operations, and emergency procedures were given to the subcontractor before the drilling project started and were outlined in Section 01020 (Construction Health and Safety) of the Project Shoal drilling statement of work. Personnel who supported the drilling project had appropriate and current safety and health training as specified in Section 01020 and the Job Safety Analysis (JSA). Training documentation was maintained onsite during the project.

The JSA developed for the project addressed the Integrated Safety Management System core functions—defining the scope of work and specific activities, analyzing the hazards associated with the activities, and developing and implementing the controls and protective equipment to mitigate those hazards. The JSA and any additional supporting documents were included as part of the required reading for the project. Contractor personnel conducted tailgate safety briefings and plan-of-the-day discussions at the beginning of each work shift through the duration of the project. All personnel who attended the briefings and discussions signed the necessary attendance sheets. Visitors and delivery personnel were given a tailgate safety briefing and were informed of the general hazards associated with the planned activities.

The drilling program was completed safely with only one minor incident that occurred on September 18, 2014. The incident involved a Boart worker who was struck in the mouth with a cable. The worker sustained a minor injury to his upper lip that did not require a trip to the hospital. No lost time recordable incidents occurred during the drilling program.

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Appendix A

Analytical Data for Well HS-1 and Wellhead Survey Data

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Table A-1. Well HS-1 Radioisotope Data from 2013 Sampling Event

GROUNDWATER QUALITY DATA BY LOCATION (USEE100) FOR SITE SHL01, Shoal Site
LOCATION: HS-1 <well>
REPORT DATE: 4/12/2015 10:31 am

PARAMETER	UNITS	SAMPLE: DATE	SAMPLE: ID	DEPTH. RANGE	RESULT	QUALIFIERS: LAB	QUALIFIERS: DATA	QUALIFIERS: QA	DETECTION LIMIT	UN-CERTAINTY
Alkalinity, Total (As CaCO3)	mg/L	05/22/2013	N001	14241.78 - 14241.78	145			#	-	-
Bicarbonate	mg/L	05/22/2013	N001	14241.78 - 14241.78	120			#	20	-
Calcium	mg/L	05/22/2013	N001	14241.78 - 14241.78	35.000			#	0.012	-
Carbon-14, Dissolved Inorganic (pCi/L)	pCi/L	05/22/2013	0002	14241.78 - 14241.78	0.00207			#	-	-
Carbon-14, Dissolved Inorganic (pMC)	pMC	05/22/2013	0002	14241.78 - 14241.78	8.23			#	-	-
Carbon-14, Dissolved Inorganic (YBP)	years	05/22/2013	0002	14241.78 - 14241.78	20060			#	-	± 170.
Chloride	mg/L	05/22/2013	N001	14241.78 - 14241.78	33			#	1	-
Dissolved Oxygen	mg/L	05/22/2013	N001	14241.78 - 14241.78	2.05			#	-	-
Gross Alpha	pCi/L	05/22/2013	N001	14241.78 - 14241.78	4.22			#	1.3	± 1.20
Gross Beta	pCi/L	05/22/2013	N001	14241.78 - 14241.78	7.89			#	2.5	± 2.04
Magnesium	mg/L	05/22/2013	N001	14241.78 - 14241.78	5.500			#	0.013	-
Nitrate + Nitrite as Nitrogen	mg/L	05/22/2013	N001	14241.78 - 14241.78	0.85			#	0.01	-
Oxidation Reduction Potential	mV	05/22/2013	N001	14241.78 - 14241.78	48.7			#	-	-
pH	s.u.	05/22/2013	N001	14241.78 - 14241.78	7.98			#	-	-
Potassium	mg/L	05/22/2013	N001	14241.78 - 14241.78	7.000	E	J	#	0.11	-
Silica	mg/L	05/22/2013	N001	14241.78 - 14241.78	67.000			#	0.0095	-
Silicon	mg/L	05/22/2013	N001	14241.78 - 14241.78	31.000			#	0.0044	-
Sodium	mg/L	05/22/2013	N001	14241.78 - 14241.78	42.000	E	J	#	0.0066	-
Specific Conductance	umhos/c	05/22/2013	N001	14241.78 - 14241.78	421			#	-	-
Stable isotope ratio H2/H1 in Water	parts per t	05/22/2013	0001	14241.78 - 14241.78	-124.65			#	-	-

Table A-1 (continued). Well HS-1 Radioisotope Data from 2013 Sampling Event

GROUNDWATER QUALITY DATA BY LOCATION (USEE100) FOR SITE SHL01, Shoal Site
LOCATION: HS-1 <well>
REPORT DATE: 4/12/2015 10:31 am

PARAMETER	UNITS	SAMPLE: DATE	ID	DEPTH. RANGE	RESULT	QUALIFIERS: LAB	DATA	QA	DETECTION LIMIT	UN-CERTAINTY
Stable isotope ratio O18/O16 in Water	parts per t	05/22/2013	0001	14241.78 - 14241.78	-15.78			#	-	-
Sulfate	mg/L	05/22/2013	N001	14241.78 - 14241.78	55			#	2.5	-
Temperature	C	05/22/2013	N001	14241.78 - 14241.78	19.05			#	-	-
Tritium	pCi/L	05/22/2013	N001	14241.78 - 14241.78	89.6	U		#	380	± 231.
Turbidity	NTU	05/22/2013	N001	14241.78 - 14241.78	8.65			#	-	-
Uranium	mg/L	05/22/2013	N001	14241.78 - 14241.78	0.0057			#	2.9E-05	-
Uranium-234	pCi/L	05/22/2013	N001	14241.78 - 14241.78	2.99			#	0.056	± 0.50
Uranium-235	pCi/L	05/22/2013	N001	14241.78 - 14241.78	0.0963		U	#	0.045	± 0.05
Uranium-238	pCi/L	05/22/2013	N001	14241.78 - 14241.78	1.77			#	0.038	± 0.32

Table A-1 (continued). Well HS-1 Radioisotope Data from 2013 Sampling Event

GROUNDWATER QUALITY DATA BY LOCATION (USEE100) FOR SITE SHL01, Shoal Site
LOCATION: HS-1 <well>
REPORT DATE: 4/12/2015 10:31 am

		SAMPLE:		DEPTH.		QUALIFIERS:			DETECTION	UN-
PARAMETER	UNITS	DATE	ID	RANGE	RESULT	LAB	DATA	QA	LIMIT	CERTAINTY

RECORDS: SELECTED FROM USEE100 WHERE site_code='SHL01' AND location_code in('HS-1') AND quality_assurance = TRUE AND (data_validation_qualifiers IS NULL OR data_validation_qualifiers NOT LIKE '%R%' AND data_validation_qualifiers NOT LIKE '%X%') AND DATE_SAMPLED between #1/1/2013# and #12/31/2013#

SAMPLE ID CODES: 000X = Filtered sample. N00X = Unfiltered sample. X = replicate number.

LAB QUALIFIERS:

- * Replicate analysis not within control limits.
- + Correlation coefficient for MSA < 0.995.
- > Result above upper detection limit.
- A TIC is a suspected aldol-condensation product.
- B Inorganic: Result is between the IDL and CRDL. Organic & Radiochemistry: Analyte also found in method blank.
- C Pesticide result confirmed by GC-MS.
- D Analyte determined in diluted sample.
- E Inorganic: Estimate value because of interference, see case narrative. Organic: Analyte exceeded calibration range of the GC-MS.
- H Holding time expired, value suspect.
- I Increased detection limit due to required dilution.
- J Estimated
- M GFAA duplicate injection precision not met.
- N Inorganic or radiochemical: Spike sample recovery not within control limits. Organic: Tentatively identified compund (TIC).
- P > 25% difference in detected pesticide or Aroclor concentrations between 2 columns.
- S Result determined by method of standard addition (MSA).
- U Analytical result below detection limit.
- W Post-digestion spike outside control limits while sample absorbance < 50% of analytical spike absorbance.
- X Laboratory defined (USEPA CLP organic) qualifier, see case narrative.
- Y Laboratory defined (USEPA CLP organic) qualifier, see case narrative.
- Z Laboratory defined (USEPA CLP organic) qualifier, see case narrative.

DATA QUALIFIERS:

- F Low flow sampling method used.
- G Possible grout contamination, pH > 9.
- J Estimated value.
- L Less than 3 bore volumes purged prior to sampling.
- N Presumptive evidence that analyte is present. The analyte is "tentatively identified".
- Q Qualitative result due to sampling technique
- R Unusable result.
- U Parameter analyzed for but was not detected.
- X Location is undefined.

QA QUALIFIER: # = validated according to Quality Assurance guidelines.

Table A-2. 2014 Wellhead Survey Data

Location Identification	Northing (ft)	Easting (ft)	Top of Casing Elevation (ft)
HC-1	14745325	2682030	5309.69
HC-2d	14743606	2680117	5347.32
HC-3	14742221	2684784	5081.96
HC-4	14742959	2681857	5261.27
HC-5	14742365	2682433	5247.73
HC-6	14742621	2682341	5229.12
HC-7	14742546	2682410	5230.13
HC-8	14742098	2682761	5260.29
MV-1	14744399	2682269	5258.01
MV-1PZ	14744400	2682270	5257.75
MV-2	14744670	2682123	5267.09
MV-2PZ	14744671	2682122	5266.97
MV-3	14744493	2682624	5261.97
MV-3PZ	14744492	2682623	5261.61
MV-4	14742311	2680342	5374.18
MV-4PZ	14742310	2680342	5373.81
MV-5	14744144	2680832	5321.54
MV-5PZ	14744144	2680832	5320.88
H-3	14750815	2673322	4237.25
H-2	14755054	2667581	4021.47

PZ = piezometer
d = indicates the well was deepened from the originally completed depth
Top of casing elevations represent the measuring point location for determining depth to groundwater and are provided in feet above mean sea level.

Coordinate System: U.S. State Plane, Zone Nevada West 2703
Horizontal Datum: North American Datum 1983
Vertical Datum: North American Vertical Datum 1988

Appendix B

MV-5 Data

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Table B-1. MV-5 Chronology

Date	Time	Depth (ft bgs)	Activity
08/11/2014–08/13/2014	NA	NA	Mobilize supporting infrastructure (lab and office trailers, dumpsters, generators, light plants, toilets, etc.) to Shoal site, inspect drill pads, organize lay-down yard, pipe, and equipment storage.
08/13/2014	08:15	NA	Started mobilization of drilling and support equipment to the MV-5 pad.
08/15/2014	11:15	NA	Started moving drill rig from HC-2 pad to the MV-5 pad.
08/16/2014	16:45	NA	Drill rig set up on MV-5 and started drilling the 19-inch-diameter borehole for the surface casing.
08/17/2014	13:15	60	Competed drilling the surface casing borehole to 60 feet.
08/17/2014	20:30	60	Installed 14-inch-diameter surface casing to 60 feet bgs and cemented in place.
08/18/2014	03:00	60	Completed setup and bottom hole assembly for drilling air-foam with a 12.25-inch downhole hammer bit.
08/18/2014	19:45	271	Advanced the 12.25-inch borehole to 271 feet bgs. Identified a leaking hydraulic hose on the drive head and prepared to make the repair.
08/18/2014	23:45	271	Completed repairs to the rig drive head.
08/19/2014	23:45	1,011	Advanced the borehole to 1,011 feet bgs.
08/20/2014	23:45	1,551	Advanced the borehole to 1,551 feet bgs.
08/21/2014	19:00	1,751	Advanced the borehole to the total depth of 1,751 feet bgs.
08/22/2014	02:30	1,751	Tripped out of the borehole and rigged up to run the borehole geophysical logs.
08/22/2014	02:30	1,751	Pacific Surveys started geophysical logging of the MV-5 borehole.
08/22/2014	15:00	1,751	Completed the borehole geophysical logging. Reviewed geophysical logs for well construction. Informed that the 5.5-inch well casing will not be onsite for a few days because of delays with Boart's well casing supplier.
08/22/2014	20:00	1,751	Modified well completion design so the piezometer would be completed below the well screen and a 0.25-inch bubbler tube would be installed above the well screen at approximately 1,100 feet bgs.
08/23/2014	20:00	1,751	While waiting on well casing to arrive, water from primary infiltration basin was siphoned to secondary infiltration basin in preparation of well development.
08/24/2014	23:45	1,751	Well casing delivery is scheduled for 08/26/2014. Boart on standby, but completes extensive rig maintenance. Water level tagged at 1,056 feet bgs.
08/25/2009	23:45	1,751	Boart on standby, but performs general maintenance and housekeeping. MV-5 well design is finalized.
08/26/2014	11:45	1,751	5.5-inch well casing arrived onsite.
08/26/2014	19:30	1,751	Bottom tagged at 1,730 feet bgs. Piezometer tubing is run in, with the piezometer screen placed at 1,700 to 1,730 feet bgs.
08/27/2014	11:45	1,751	Completed running in well casing and bubbler tube. Well screen placed at 1,325 to 1,565 feet bgs and bubbler tube placed at 1,100 feet bgs.
08/27/2014	22:30	1,751	Piezometer gravel pack installed to 1,680 feet bgs, bentonite hole plug installed to 1,677 feet bgs, and cement and bentonite seal installed to 1,602 feet bgs.
08/28/2014	10:10	1,751	Completed installation of bentonite seal from 1,602 to 1,593 and monitoring well gravel pack from 1,593 to 1,320 feet bgs. Set up to surge and swab well.
08/28/2014	17:00	1,751	Completed swabbing of the well screened interval and settling the gravel pack, but discovered cement blocking the bottom portion of the well screen beginning at 1,507 feet bgs. Set up to airlift the well.
08/29/2014	16:15	1,751	Completed airlift operations to clean out monitoring well screen.
08/30/2014	09:00	1,751	Raise gravel pack to 1,320 feet, sand pack from 1,320 to 1,315 feet bgs, and bentonite hole plug installed to 1,310 feet bgs. Installed cement seal to 1,157 feet bgs. Cementing operations completed at this depth to allow access for the bubbler tube set at 1,100 feet bgs.
08/30/2014	13:20	NA	Rig up to airlift/develop piezometer, started development.
08/31/2014	22:05	NA	Completed airlift development of piezometer, a total of 585 gallons removed.

Table B-1. (continued). MV-5 Chronology

Date	Time	Depth (ft bgs)	Activity
09/01/2014	11:45	NA	Rig up to develop monitoring well, completed swabbing the well.
09/01/2014	23:45	NA	Continued airlift development of well.
09/02/2014	11:35	NA	Completed airlift development of MV-5 well, a total of 3,770 gallons removed.
09/02/2014	19:20	NA	Tripped out and secured the MV-5 wellhead.
09/02/2014	23:45	NA	Demobilized the drill rig from the MV-5 pad.
09/26/2014	06:20	NA	Boart pump personnel set up to install submersible electrical pump.
09/27/2014	17:00	NA	Completed installation of submersible electric pump, started development of monitoring well using the submersible electric pump.
09/27/2014	23:00	NA	Stopped pump development at MV-5 well, a total of 1,260 gallons removed for the day.
09/28/2014	17:15	NA	Pumping with submersible electrical pump in MV-5 well stopped for the day, a total of 3,311 gallons removed for the day.
09/29/2014	19:00	NA	Pumping with submersible electrical pump in MV-5 well stopped for the day, a total of 1,729 gallons removed for the day.
09/30/2014	23:00	NA	Pumping with submersible electrical pump in MV-5 well stopped for the day, a total of 3,560 gallons removed for the day.
10/01/2014	14:10	NA	Pumping with submersible electrical pump in MV-5 well stopped for the day, a total of 2,727 gallons removed for the day.
10/03/2014	14:00	NA	Well box installed on MV-5.
10/06/2014	10:00	NA	Pumping with submersible electric pump in MV-5 well produced 480 gallons of water.
11/10/2014	15:40	NA	Pumping with submersible electrical pump in MV-5 well produced 655 gallons of water, for 16,958 cumulative gallons purged during the initial airlift and final pump development.

Table B-2. MV-5 Construction Details

Construction	Material	Description	Depth Interval (ft)	Stemming Material	Volume (ft^3)	Interval (ft)
Surface casing	14 inch o.d. CS casing	Blank	0–60	Cement seal	167.4	0 - 60
Bubbler tube	0.25 inch stainless steel tubing strapped to outside of CS casing	Blank	0–1,100	⅛–¼ inch gravel pack	20	1,010–1,130 (Open with filter cap at 1,100 ft)
Monitoring well casing	5.5 inch o.d. CS flush-joint casing	Blank	0–1,325	Cement seal	137	1,152–1,310
				⅜ inch bentonite chips	3.3	1,310–1,315
				No. 6 sand pack	5.3	1,315–1,320
		Screen w/ bullnose	1,325–1,565	⅛–¼ inch gravel pack	137	1,324–1,593
Intermediate seal	NA	Below bullnose	1,565–1,677	⅜ inch Bentonite chips	5	1,593–1,602
			1,640–1,602	Cement seal	38	1,640–1,602
			1,675–1,640	⅜ inch Bentonite chips	7.0	1,675–1,640
			1,675–1,677	Cement seal	34.7	1,675–1,677
Piezometer casing	2.375 inch o.d. CS flush-joint casing	Blank	0–1,700	⅜ inch Bentonite chips	4.7	1,677–1,680
		Screen w/ bullnose	1,700–1,730	⅛–¼ inch Gravel pack	63	1,680–1,730
Bottom seal	Fall back material	Below piezometer	1,730–1,751	Nothing added to fall back material	~103	1,730–1,751

CS = carbon steel
ft^3 = cubic feet

Volumes for stemming material are calculated from the recorded quantities of materials used, not from the calculated size of the annulus (the well bore contains numerous out-of-gage intervals that make such calculations very inaccurate).

Table B-3. MV-5 Drilling and Development Tritium Analyses

Sample ID	Date	Time	Sample Depth (ft)	Tritium (pCi/L)	MDC (pCi/L)	±2 sigma (%)	Notes
Well Drilling							
MV-5 1050 ft	8/20/14	02:30	1,050	−1982	3157	61	<MDC
MV-5 1090 ft	8/20/14	03:30	1,090	−2793	2988	71	<MDC
MV-5 1110 ft	8/20/14	04:30	1,110	−3784	3076	42	<MDC
MV-5 1130 ft	8/20/14	05:30	1,130	−1622	3131	76	<MDC
MV-5 1160 ft	8/20/14	06:30	1,160	−2162	2979	100	<MDC
MV-5 1190 ft	8/20/14	07:30	1,190	−270	3243	100	<MDC
MV-5 1230 ft	8/20/14	08:30	1,230	−2613	3091	58	<MDC
MV-5 1250 ft	8/20/14	09:30	1,250	−631	3168	111	<MDC
MV-5 1290 ft	8/20/14	10:30	1,290	−90	3350	76	<MDC
MV-5 1330 ft	8/20/14	13:00	1,330	−721*	2869	484	<MDC
MV-5 1360 ft	8/20/14	14:15	1,360	1622*	2928	120	<MDC
MV-5 1380 ft	8/20/14	15:15	1,380	991*	3030	942	<MDC
MV-5 1410 ft	8/20/14	16:30	1,410	2162*	2963	120	<MDC
MV-5 1440 ft	8/20/14	17:30	1,440	1622*	3065	946	<MDC
MV-5 1460 ft	8/20/14	19:00	1,460	631*	3152	480	<MDC
MV-5 1480 ft	8/20/14	20:00	1,480	−1171*	2978	190	<MDC
MV-5 1500 ft	8/20/14	21:00	1,500	180*	3038	NA	<MDC
MV-5 1520 ft	8/20/14	22:00	1,520	−721*	3150	105	<MDC
MV-5 1550 ft	8/21/14	00:30	1,550	1532	3002	317	<MDC
MV-5 1570 ft	8/21/14	01:30	1,570	2613	3096	191	<MDC
MV-5 1585 ft	8/21/14	02:30	1,585	2432	3022	137	<MDC
MV-5 1590 ft	8/21/14	03:30	1,590	2523*	3120	191	<MDC
MV-5 1610 ft	8/21/14	04:30	1,610	2432*	2961	88	<MDC
MV-5 1620 ft	8/21/14	05:30	1,620	2432	2974	107	<MDC
MV-5 1630 ft	8/21/14	06:30	1,630	1982	2782	65	<MDC
MV-5 1635 ft	8/21/1	07:30	1,635	1532*	2940	137	<MDC
MV-5 1650 ft	8/21/14	08:30	1,650	1441*	2904	120	<MDC
MV-5 1660 ft	8/21/14	09:30	1,660	1982	2939	120	<MDC
MV-5 1670 ft	8/21/14	10:30	1,670	1982	2987	159	<MDC
MV-5 1685 ft	8/21/14	11:30	1,685	2793	3173	317	<MDC
MV-5 1700 ft	8/21/14	14:00	1,700	360*	2964	192	<MDC
MV-5 1730 ft	8/21/14	16:15	1,730	811*	3024	243	<MDC
MV-5 1750 ft	8/21/14	18:30	1,750	1171*	3227	480	<MDC
Well Development—Air							
MV-5 devel.	8/29/14	01:50	WD	1802	3242	202	<MDC
MV-5 devel.	8/29/14	06:35	WD	3243	3290	251	<MDC
MV-5 devel.	8/29/14	07:55	WD	901	3182	247	<MDC
MV-5 devel.	8/29/14	13:25	WD	1532	3232	252	<MDC
MV-5 devel.	8/29/14	14:25	WD	2523	3261	127	<MDC
MV-5 devel.	8/29/14	15:50	WD	1532	3306	1001	<MDC
MV-5 devel.	9/1/14	10:00	WD	2972	3065	96	<MDC
MV-5 devel.	9/1/14	15:00	WD	2793	3100	83	<MDC

Table B-3 (continued). MV-5 Drilling and Development Tritium Analyses

Sample ID	Date	Time	Sample Depth (ft)	Tritium (pCi/L)	MDC (pCi/L)	±2 sigma (%)	Notes
MV-5 devel.	9/1/14	21:00	WD	811	3110	974	<MDC
MV-5 devel.	9/2/14	03:25	WD	−450	3342	81	<MDC
MV-5 devel.	9/2/14	09:27	WD	1441	3258	1005	<MDC
Piezometer Development—Air							
MV-5pz devel	8/30/14**	NA	WD	NA	NA	NA	NA
MV-5pz devel.	8/31/14	00:15	WD	180	3221	191	<MDC
MV-5pz devel.	8/31/14	01:30	WD	541	3111	966	<MDC
MV-5pz devel.	8/31/14	02:45	WD	1261	3034	123	<MDC
MV-5pz devel.	8/31/14	03:45	WD	631	3073	323	<MDC
MV-5pz devel.	8/31/14	05:05	WD	541	3012	195	<MDC
MV-5pz devel.	8/31/14	06:15	WD	1171	3094	195	<MDC
MV-5pz devel.	8/31/14	07:30	WD	360	3086	966	<MDC
MV-5pz devel.	8/31/14	08:45	WD	180	3013	323	<MDC
MV-5pz devel.	8/31/14	10:10	WD	2432	3233	163	<MDC
MV-5pz devel.	8/31/14	11:20	WD	2252	3214	327	<MDC
MV-5pz devel.	8/31/14	12:45	WD	3063	3294	246	<MDC
MV-5pz devel.	8/31/14	13:55	WD	1982	3129	197	<MDC
MV-5pz devel.	8/31/14	15:05	WD	2613	3235	246	<MDC
MV-5pz devel.	8/31/14	16:15	WD	901	3240	193	<MDC
MV-5pz devel.	8/31/14	17:25	WD	3153	3206	124	<MDC
MV-5pz devel.	8/31/14	18:35	WD	1712	3245	974	<MDC
MV-5pz devel.	8/31/14	19:45	WD	90	2907	246	<MDC
MV-5pz devel.	8/31/14	20:55	WD	1261	3133	978	<MDC
MV-5pz devel.	8/31/14	22:00	WD	−450	3077	161	<MDC
Well Development—Pump							
MV-5 devel.	9/29/14	16:00	WD	2703	3001	165	<MDC
MV-5 devel.	9/29/14	19:00	WD	2703	3024	197	<MDC
MV-5 devel.	9/30/14	16:00	WD	1351	3036	498	<MDC
MV-5 devel.	9/30/14	21:00	WD	1892	3060	250	<MDC
MV-5 devel.	9/30/14	23:00	WD	1892	3083	332	<MDC
MV-5 devel.	10/1/14	08:15	WD	541	2952	986	<MDC
MV-5 devel.	10/1/14	11:15	WD	1081	2954	496	<MDC
MV-5 devel.	10/1/14	14:05	WD	1622	2951	92	<MDC

* = Sample recounted due to light contamination
** = Samples not analyzed on 8/30/14 because instrument needed to be recalibrated
MDC = minimum detectable concentration
WD = well development

Table B-4. MV-5 Drilling and Development Water Quality and Bromide Analyses

Sample ID	Date	Time	Sample Depth (ft)	pH (s.u.)	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Br^- (mg/L)
Well Drilling								
MV-5 1050 ft	8/20/14	02:30	1,050	8.07	21.1	661	NA	34
MV-5 1090 ft	8/20/14	03:30	1,090	8.41	20	484	NA	34
MV-5 1110 ft	8/20/14	04:30	1,110	8.26	20.4	740	NA	33
MV-5 1130 ft	8/20/14	05:30	1,130	8.13	20.9	726	NA	35
MV-5 1160 ft	8/20/14	06:30	1,160	8.16	20.4	651	NA	28
MV-5 1190 ft	8/20/14	07:30	1,190	8.07	22.7	686	NA	19
MV-5 1250 ft	8/20/14	09:30	1,250	8.05	22.7	653	NA	14
MV-5 1290 ft	8/20/14	10:30	1,290	8.06	21.7	593	NA	13
MV-5 1330 ft	8/20/14	13:00	1,330	7.69	22.2	748	NA	8.3
MV-5 1360 ft	8/20/14	14:00	1,360	7.92	21.4	704	NA	18
MV-5 1380 ft	8/20/14	15:00	1,380	7.82	22.1	636	NA	12
MV-5 1410 ft	8/20/14	16:15	1,410	7.92	22.4	565	NA	8.2
MV-5 1440 ft	8/20/14	17:30	1,440	7.94	19.5	547	NA	4.4
MV-5 1460 ft	8/20/14	19:00	1,460	7.89	20.2	571	NA	7.1
MV-5 1480 ft	8/20/14	20:00	1,480	7.9	20.2	573	NA	7.3
MV-5 1500 ft	8/20/14	21:00	1,500	7.87	19.8	556	NA	5.5
MV-5 1520 ft	8/20/14	22:00	1,520	7.72	20	488	NA	5.0
MV-5 1550 ft	8/21/14	00:30	1,550	7.77	20.5	575	NA	2.0
MV-5 1570 ft	8/21/14	01:30	1,570	7.84	20	580	NA	4.4
MV-5 1585 ft	8/21/14	02:30	1,585	7.93	19.7	570	NA	4.1
MV-5 1590 ft	8/21/14	03:30	1,590	7.73	19.6	534	NA	3.7
MV-5 1610 ft	8/21/14	04:30	1,610	7.65	20	542	NA	4.0
MV-5 1620 ft	8/21/14	05:30	1,620	7.69	20.4	510	NA	4.0
MV-5 1630 ft	8/21/14	06:30	1,630	7.82	19.6	550	NA	0.67
MV-5 1635 ft	8/21/14	07:30	1,635	7.82	19	539	NA	0.54
MV-5 1650 ft	8/21/14	08:30	1,650	7.78	20	553	NA	0.47
MV-5 1660 ft	8/21/14	09:30	1,660	7.75	20	546	NA	2.1
MV-5 1670 ft	8/21/14	10:30	1,670	7.73	20	561	NA	1.3
MV-5 1685 ft	8/21/14	11:30	1,685	7.81	20.4	567	NA	1.6
MV-5 1700 ft	8/21/14	14:00	1,700	7.89	21.7	539	NA	1.9
MV-5 1730 ft	8/21/14	14:00	1,730	7.77	21.2	565	NA	2.2
MV-5 1750 ft	8/21/14	18:30	1,750	7.83	20.3	566	NA	2.4
Well Development—Air								
MV-5 devel.	8/29/14	01:50	WD	12.11	24.2	988	>1000	40
MV-5 devel.	8/29/14	06:35	WD	11.37	21.8	1,245	>1000	48
MV-5 devel.	8/29/14	07:55	WD	12.15	24.9	641	>1000	49
MV-5 devel.	8/29/14	13:25	WD	11.37	13.7	2,990	78.9	43
MV-5 devel.	8/29/14	14:25	WD	12.02	11.3	4,940	96.6	42
MV-5 devel.	8/29/14	15:50	WD	10.68	24.7	1,576	>1000	62

Table B-4 (continued). MV-5 Drilling and Development Water Quality and Bromide Analyses

Sample ID	Date	Time	Sample Depth (ft)	pH (s.u.)	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Br^- (mg/L)
MV-5 devel	9/1/14	08:49	WD	10.18	22.2	1000	>1000	37
MV-5 devel	9/1/14	10:02	WD	11.50	20.9	1445	984	31
MV-5 devel	9/1/14	11:05	WD	11.88	25.6	711	>1000	28
MV-5 devel	9/1/14	13:00	WD	12.03	21.2	7310	340	42
MV-5 devel	9/1/14	14:00	WD	11.99	21.8	7300	802	33
MV-5 devel	9/1/14	15:00	WD	11.77	21.9	3200	>1000	21
MV-5 devel	9/1/14	16:00	WD	11.94	21.7	5670	710	21
MV-5 devel	9/1/14	17:00	WD	8.97	23.2	921	423	30
MV-5 devel	9/1/14	18:00	WD	12.02	21.4	6180	147	28
MV-5 devel	9/1/14	19:00	WD	12.16	21.0	6560	156	19
MV-5 devel	9/1/14	20:00	WD	12.01	20.7	5320	156	22
MV-5 devel	9/1/14	21:00	WD	12.06	20.3	6310	60.9	16
MV-5 devel	9/1/14	22:00	WD	11.74	20.5	2970	61.7	18
MV-5 devel	9/1/14	23:00	WD	11.96	20.6	5050	33.5	21
MV-5 devel	9/1/14	23:45	WD	12.0	20.7	5410	22.9	25
MV-5 devel	9/2/14	00:45	WD	12.0	21.7	6390	29.2	25
MV-5 devel	9/2/14	01:25	WD	11.06	20.0	1187	98.9	21
MV-5 devel	9/2/14	02:25	WD	11.20	19.8	1268	605	26
MV-5 devel	9/2/14	03:25	WD	12.04	20.2	5970	652	28
MV-5 devel	9/2/14	04:25	WD	12.01	20.6	6170	168	26
MV-5 devel	9/2/14	05:25	WD	11.96	20.2	4820	185	30
MV-5 devel	9/2/14	06:30	WD	11.52	20.4	1832	>1000	30
MV-5 devel	9/2/14	07:30	WD	11.96	20.5	5290	465	33
MV-5 devel	9/2/14	08:30	WD	11.29	20.6	1487	773	28
MV-5 devel	9/2/14	09:25	WD	11.96	20.2	5900	305	29
MV-5 devel	9/2/14	10:25	WD	12.08	20.5	5370	209	25
MV-5 devel	9/2/14	11:30	WD	11.06	20.6	1261	202	26
Piezometer Development—Air								
MV-5PZ devel.	8/30/14	14:10	WD	8.29	23.4	631	193	3.6
MV-5PZ devel.	8/30/14	15:50	WD	8.79	21.6	618	721	9.5
MV-5PZ devel.	8/30/14	16:45	WD	9.16	20.9	570	>1000	10
MV-5PZ devel.	8/30/14	17:45	WD	8.58	20.4	549	>1000	6.2
MV-5PZ devel.	8/30/14	18:45	WD	7.92	20.2	559	>1000	7.2
MV-5PZ devel.	8/30/14	19:45	WD	7.93	19.2	523	>1000	6.5
MV-5PZ devel.	8/30/14	20:45	WD	8.07	19.3	530	>1000	4.2
MV-5PZ devel.	8/30/14	21:45	WD	7.90	18.7	518	>1000	6.8
MV-5PZ devel.	8/30/14	22:45	WD	7.95	18.8	517	>1000	2.9
MV-5PZ devel.	8/31/14	00:15	WD	7.79	18.0	527	>1000	6.6
MV-5PZ devel.	8/31/14	01:30	WD	7.88	18.6	516	>1000	9.2

Table B-4 (continued). MV-5 Drilling and Development Water Quality and Bromide Analyses

Sample ID	Date	Time	Sample Depth (ft)	pH (s.u.)	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Br^- (mg/L)
MV-5PZ devel.	8/31/14	02:45	WD	7.89	18.8	511	>1000	4.7
MV-5PZ devel.	8/31/14	03:45	WD	7.89	19.2	511	>1000	3.8
MV-5PZ devel.	8/31/14	05:05	WD	7.87	17.8	510	>1000	3.5
MV-5PZ devel.	8/31/14	06:15	WD	7.85	17.8	510	>1000	5.3
MV-5PZ devel.	8/31/14	07:30	WD	7.74	20.0	509	>1000	4.8
MV-5PZ devel.	8/31/14	08:45	WD	7.75	19.2	506	>1000	5.0
MV-5PZ devel.	8/31/14	10:10	WD	7.87	19.4	511	>1000	4.4
MV-5PZ devel.	8/31/14	11:20	WD	7.84	20.9	508	>1000	4.0
MV-5PZ devel.	8/31/14	12:45	WD	7.71	20.8	514	>1000	5.5
MV-5PZ devel.	8/31/14	13:55	WD	7.77	21.0	509	>1000	2.6
MV-5PZ devel.	8/31/14	15:05	WD	7.82	21.0	510	>1000	2.1
MV-5PZ devel.	8/31/14	16:15	WD	7.68	19.7	509	>1000	1.7
MV-5PZ devel.	8/31/14	17:25	WD	7.8	19.8	509	>1000	1.3
MV-5PZ devel.	8/31/14	18:35	WD	7.79	19.8	507	>1000	1.0
MV-5PZ devel.	8/31/14	19:45	WD	7.78	18.8	505	>1000	0.89
MV-5PZ devel.	8/31/14	20:55	WD	7.77	18.5	507	>1000	0.83
MV-5PZ devel.	8/31/14	22:00	WD	7.64	19.1	497	>1000	0.85
Well Development—Pump								
MV-5 devel	9/29/14	16:00	WD	11.63	21.5	2800	3.23	6.8
MV-5 devel	9/29/14	19:00	WD	11.66	21.5	2650	2.21	6.7
MV-5 devel	9/30/14	16:00	WD	11.74	23.7	2660	2.66	7.4
MV-5 devel	9/30/14	21:00	WD	11.75	21.6	2560	2.58	7.5
MV-5 devel	9/30/14	23:00	WD	11.73	20.8	2470	3.07	4.6
MV-5 devel	10/1/14	08:15	WD	11.78	19.5	2580	1.50	4.7
MV-5 devel	10/1/14	11:15	WD	11.71	21.3	2370	1.55	3.8
MV-5 devel	10/1/14	14:05	WD	11.62	22.6	2250	1.35	5.1
MV-5 devel	10/6/14	08:00	WD	NA	NA	NA	NA	3.9
MV-5 devel	**11/10/14**	**15:40**	**WD**	**NA**	**NA**	**NA**	**NA**	**4.5**

Notes: The high pH and specific conductance measurements collected during the development of the well are attributed to cement in the well screen. NA = not analyzed

Table B-5. MV-5 Pump and Tubing Details

Well ID	Pump Riser Material	Diameter	Estimated Depths	Material Description
MV-5	Carbon Steel Riser Pipe	1 inch	0–1,305 ft bgs	Approximate 32 ft lengths of API J-55 riser pipe with external upset ends.
	PVC Water Access Tubing	1.5 inches	0–1,305 ft bgs	Flush joint schedule 80 PVC with 40 ft of 0.02-inch screen.
	Electric Supply Cable	Flat	0–1,305 ft bgs	Kalas 8 AWG #10, 600-volt, 4-wire submersible pump cable.
	Electric Pump	<5 inches	1,305 ft bgs (top) 1,310 ft bgs(intake) 1,312 ft bgs (bottom)	Grundfos pump, model 10S50-58DS, with MS4000 5-horsepower, 480-volt, three-phase motor.

MV-5 Lithologic Descriptions

(well cuttings described dry and in natural light)

The lithologic descriptions provided here are from the surface down to the total drilled depth of 1,751 ft bgs. The lithology in MV-5 is a moderately crystalline, very light grey granite with white to very light grey potassium feldspar in the upper few hundred feet, which transitions into a similar granite at depth that contains very light pinkish-grey potassium feldspar instead. Because of the small size of the drill cuttings, it is not known whether this is an equicrystalline granite or a porphyritic granite at depth (both types appear in surface bedrock exposures). The various borehole geophysical logs for MV-5 are compared to the lithologic descriptions here, with potentially significant geophysical anomalies described in italics at the appropriate depths following the lithologic description for that depth interval.

0–30 ft	Granite, light grey to light yellowish-grey, moderately crystalline, approximately 35 percent very light grey subhedral sodic plagioclase, 35 percent white subhedral potassium feldspar, 20 percent anhedral quartz, 7 percent euhedral biotite, 2 percent euhedral to subhedral hornblende, 1 percent euhedral sphene, <1 percent euhedral magnetite. This depth interval shows the effects of surface and near surface chemical/physical weathering on the granite, with iron oxide stains surrounding magnetite and biotite crystals, and partly to pervasively oxidized biotite to a bronze-colored oxy-biotite.
30–60 ft	Granite, very light grey, moderately crystalline, major mineral composition as above, with only minor iron oxide staining and some oxy-biotite. *Note:* Minor amounts of iron oxide staining in this granite typically manifests itself as hematite halos around magnetite crystals (and pyrite crystals when pyrite is present) and as hematite/limonite stains on both small and large fracture surfaces. When only a trace of iron oxide staining is present, it typically forms only local fracture coatings over very small areas.
60–90 ft	Granite, very light grey, major mineral composition as above, with only a trace of iron oxide staining and a trace of oxy-biotite.
90–120 ft	Granite, very light grey, major mineral composition as above, with fresh, unaltered biotite, only a trace of iron oxide staining, and a trace of unaltered, euhedral to subhedral green epidote.
120–130 ft	Granite, very light grey, major mineral composition as above, but with only a trace of iron oxide staining and no visible epidote.
130–140 ft	Granite, very light grey, major mineral composition as above, but with minor iron oxide staining, a trace of chloritization of biotite, and no visible epidote. *Note:* The presence of oxy-biotite and minor chloritization of biotite represents geochemically antithetical mineral responses to alteration and indicate two distinct episodes of biotite alteration. Chloritization of biotite occurs in a geochemically reduced environment and at elevated temperatures, similar to the temperatures of low grade metamorphism. In contrast, oxidation of biotite occurs in an oxidizing environment and typically at low temperature, which is why oxy-biotite is so common in surface and near-surface environments. Hence, the chloritization of the biotite in the Sand Springs granite likely occurred early in the history of this batholith, whereas the oxidation of the biotite occurred much later and likely represents the passage of oxidizing meteoric water or groundwater through this fractured granite.
140–170 ft	Granite, very light grey, major mineral composition as above, but with only a trace of iron oxide staining, a trace of chloritization of biotite, and a trace of epidote.
170–180 ft	Granite, very light grey, major mineral composition as above, but with a trace of chloritization of biotite and a trace of oxy-biotite, a trace of epidote, and no iron oxide staining.

180–300 ft	Granite, very light grey, major mineral composition as above, but with only a trace of chloritization of biotite, and a trace of epidote, and iron oxide staining varying between a trace and not present.
300–330 ft	Granite, very light grey, major mineral composition as above but with a change in color to light pinkish-grey to white of the potassium feldspar, minor epidote, a trace of chloritization of biotite, and iron oxide staining varying between a trace and not present. *Note:* Although the surface exposures of the Sand Springs granite in the area of the Shoal site typically show white to very light grey potassium feldspar, the waste rock piles from the test shaft and tunnel show both a porphyritic granite and an equicrystalline granite with phenocrysts/crystals of light pinkish-grey potassium feldspar. It is assumed here that the feldspar color change at this depth represents the penetration of one of these two granites at this depth, although these cuttings are too small to determine whether the MV-5 drill hole has encountered the porphyritic granite or the equicrystalline granite.
330–350 ft	Granite, very light grey, major mineral composition as above, but with minor iron oxide staining, only a trace of epidote, and a trace of chloritization of biotite.
350–360 ft	Granite, very light grey to light greenish grey, moderately crystalline, major mineral composition as above but with additional zones of alteration where the granite has been partially to pervasively altered to a mineral assemblage of chlorite and dolomite; this sample interval also contains minor iron oxide staining, a trace of oxy-biotite, a trace of chloritization of biotite, and a trace of epidote.
360–370 ft	Granite, very light grey, major mineral composition as above in unaltered granite, with minor iron oxide staining, a trace of chloritization of biotite, and a trace of epidote.
370–380 ft	Granite, very light grey, major mineral composition as in unaltered granite, with a trace of iron oxide staining, a trace of chloritization of biotite, and a trace of epidote.
380–400 ft	Granite, very light grey, major mineral composition as in unaltered granite, with a trace of chloritization of biotite, a trace of epidote, and no iron oxide staining.
400–410 ft	Granite, very light grey and minor light greenish-grey, moderately crystalline, major mineral composition the same, with common iron oxide staining, minor chlorite and dolomite alteration, trace of pyrite, trace of chloritization of biotite, trace of argillic alteration. *Note:* This localized interval with some argillic and propylitic alteration, plus enhanced oxidation of iron minerals is interpreted as being a fracture zone that has permitted infiltration of the granite by several generations of fluids (both warm and potentially cool).
410–430 ft	Granite, very light grey, major mineral composition as in unaltered granite, with a trace of chloritization of biotite, a trace of epidote, a trace of pyrite, and a trace of iron oxide staining.
430–450 ft	As above, but with no pyrite.
450–460 ft	Granitic dike, light yellowish-grey, moderately crystalline, 40 percent potassium feldspar, 35 percent sodic plagioclase, 17 percent quartz, 4 percent biotite, 2 percent hornblende, 1 percent pyrite, 1 percent magnetite, trace epidote, trace sphene, some secondary euhedral, void-filling, quartz crystals partially in-filling fracture apertures, significant iron oxide staining (hematite and limonite) with halos around oxidized magnetite and pyrite crystals. *Note:* Surface exposures of dikes have shown them to invariably contain more fractures than the typical granite that comprises the country rock in Gote Flat. Thus, I interpret this potential higher fracture density to have assisted the fluid infiltration that caused much of the iron oxidation.
460–490 ft	Granitic dike as above, but with minor chlorite and dolomite alteration.
490–520 ft	Granite, very light grey, moderately crystalline, approximately 35 percent very light grey subhedral sodic plagioclase, 35 percent white subhedral potassium feldspar, 20 percent anhedral quartz, 7 percent euhedral biotite, 2 percent euhedral to subhedral hornblende,

	1 percent euhedral sphene, <1 percent euhedral magnetite, trace of epidote, trace of iron oxide staining, trace of chloritization of biotite, no visible pyrite.
520–540 ft	Granite, very light grey, moderately crystalline, major mineral composition as above for granite, but with a minor increase in chloritization of biotite, minor dolomite and epidote in the groundmass, and minor chlorite and dolomite infilling fracture apertures and coating fracture surfaces.
540–550 ft	Granite, very light grey, moderately crystalline, major mineral composition as above but with diminished dolomite and epidote in the groundmass, a trace of iron oxide staining, and no fractures or secondary fracture minerals.
550–590 ft	Granite, very light grey to light greenish-grey, moderately crystalline, major mineral composition as above but with some chlorite and dolomite alteration, some chloritization of biotite, trace of hornblende alteration to epidote, trace of disseminated epidote, trace of iron oxide staining, but no visible pyrite.
590–620 ft	Granite, very light grey to light greenish-grey as above, but with less chlorite and dolomite alteration, less alteration of hornblende to epidote.
620–670 ft	Granite, very light grey to light greenish-grey as above, but with more chlorite and dolomite alteration, more chloritization of biotite, but no alteration of hornblende. Chlorite and dolomite on fracture surfaces at 640 ft.
670–690 ft	Granite, very light grey and some light greenish-grey, moderately crystalline, major mineral composition as above, but with significant chloritization of biotite and hornblende, very minor dolomite, trace of epidote, and trace of iron oxide staining.
690–700 ft	Granite, very light grey, moderately crystalline, major mineral composition as above but with no chlorite and dolomite alteration, only minor chloritization of biotite, no alteration of hornblende, minor iron oxide staining, and a trace of epidote.
700–790 ft	Granite, very light grey as above, but with no iron oxide staining and only a trace of chloritization of biotite.
790–802 ft	Granite, light greenish-grey, moderately crystalline, with some chlorite and dolomite alteration, some chloritization of biotite, some iron oxide staining, trace of epidote, chlorite coating fracture surfaces, clay coating fracture surfaces, and pyrolusite dendrites coating fracture surfaces.
802–820 ft	Granite, light grey, moderately crystalline, same major mineral composition but with only minor dolomite, some chloritization of biotite, minor iron oxide staining, trace epidote, but with no fracture coatings.
820–830 ft	Granite, light greenish-grey, moderately crystalline, same major mineral composition but with some chlorite and dolomite alteration, significant chloritization of biotite, and some chlorite on fracture surfaces.
830–860 ft	Granite, very light grey, moderately crystalline, major mineral composition as above but with no chlorite and dolomite alteration, only minor chloritization of biotite, a trace of iron oxide staining and a trace of epidote.
860–900 ft	Granite, light grey and light greenish-grey, moderately crystalline, same major mineral composition but with some chlorite and dolomite alteration, significant chloritization of biotite, some chlorite on fracture surfaces, trace pyrolusite dendrites on fracture surfaces.
900–920 ft	Granite, very light grey, moderately crystalline, major mineral composition as above but with no chlorite and dolomite alteration, some chloritization of biotite, trace of dolomite, a trace of epidote, and a trace iron oxide staining and pyrolusite on fracture surfaces.
920–940 ft	Granite, light grey and light greenish-grey, moderately crystalline, same major mineral composition but with some local zones of chlorite and dolomite alteration near fracture surfaces, chlorite coating fracture surfaces, increased chloritization of biotite, and trace of epidote.

940–990 ft	Granite, light grey and light greenish-grey, moderately crystalline, same major mineral composition but with increased chlorite and dolomite alteration, chlorite and dolomite coating fracture surfaces and filling fracture apertures, increased chloritization of biotite, trace of iron oxide staining and trace of epidote.
990–1040 ft	Granite, light grey and minor light greenish-grey, moderately crystalline, same major mineral composition but with only minor chlorite and dolomite alteration, some chloritization of biotite, and trace of epidote, trace of iron oxide staining, trace of pyrite, some fracture surfaces coated with clay and/or chlorite.
1040–1050 ft	As above, but with a modest increase in chlorite and dolomite alteration, increased chlorite on fracture surfaces.
1050–1100 ft	Granite, light grey and light greenish-grey, moderately crystalline, same major mineral composition but with only minor chloritization of biotite, minor dolomite, trace of epidote, trace of iron oxide staining. *Note:* No sample from 1070 to 1080. *Geophysical Note: There is a positive gamma ray anomaly (about 2× background) from 1079 ft to 1082 ft bgs.*
1100–1120 ft	Granite, very light grey, moderately crystalline, major mineral composition as above, with minor chloritization of biotite, no dolomite, minor iron oxide staining, and trace of epidote. *Geophysical Note: There is a significant positive gamma ray anomaly (about 3× background) from 1110 ft to 1114 ft bgs.*
1120–1160 ft	Granite, very light grey, with minor light greenish-grey, moderately crystalline, minor chlorite and dolomite, slight increase in chloritization of biotite, trace iron oxide staining, some chlorite on fracture surfaces.
1160–1190 ft	Granite, very light grey, moderately crystalline, major mineral composition same, no chlorite and only a trace of dolomite, trace of chloritization of biotite, trace of epidote, minor to trace of iron oxide staining, with this staining diminishing downward.
1190–1220 ft	Granite, very light grey, moderately crystalline, same major mineral composition, with unaltered groundmass and only a trace of chloritization of biotite, trace of epidote.
1220–1250 ft	Granite, very light grey, moderately crystalline, same major mineral composition, with a trace of dolomite, some chlorite coating fracture surfaces and minor chlorite and dolomite alteration adjacent to these fractures. *Geophysical Note: There is a positive gamma ray anomaly (about 2× background) from 1246 ft to 1248 ft bgs.*
1250–1280 ft	Granite, very light grey, moderately crystalline, same major mineral composition, with no alteration, no dolomite, and only a trace of chloritization of biotite, trace of epidote. *Geophysical Note: There is a smaller positive gamma ray anomaly (about 1.7× background) from 1276 ft to 1280 ft bgs. From 1250 ft down to 1292 ft bgs both the laterolog and the electric log show higher resistivity, and the SP curve shows a lower voltage.*
1280–1300 ft	Granite, very light grey, moderately crystalline, same major mineral composition, but with a trace of dolomite, trace of epidote.
1300–1330 ft	Granite, very light grey, moderately crystalline, same major mineral composition, with no dolomite, trace of epidote, trace of iron oxide staining.
1330–1360 ft	Granite, very light grey, moderately crystalline, same major mineral composition, with a trace of dolomite, trace of iron oxide staining, trace of clay on fracture surfaces.
1360–1377 ft	Granite, very light grey, moderately crystalline, same major mineral composition, with minor chlorite and dolomite alteration, minor iron oxide staining, minor chloritization of biotite, chlorite on fracture surfaces, trace of pyrolusite dendrites on fracture surfaces.
1377–1393 ft	Granite, light greenish-grey, moderately crystalline, same major mineral composition but with chlorite and dolomite alteration, significant chloritization of biotite, chlorite on fracture surfaces, trace of epidote, trace of iron oxide staining.

1393–1400 ft Granite, very light grey, moderately crystalline, major mineral composition same, with minor dolomite, minor chloritization of biotite, trace of iron oxide staining, trace of pyrolusite and hematite dendrites on fracture surfaces.

1400–1430 ft Granite, light grey to light greenish-grey, moderately crystalline, major mineral composition same, with some chloritization of biotite, some argillic alteration of feldspar, minor dolomite, trace epidote, some clay on fracture surfaces. *Note:* Most of these cutting clasts are unusually coarse–gravel-sized. In fact, there are no “fines” in the samples from 1410 to 1430. Unusually coarse drilling cuttings is often a sign of a fault zone or intense fracture zone, the large clast size resulting from the drill bit going through the damage zone of a fault. Thus, I interpret this zone as being a fault zone with potential to produce water from this fracture-dominated crystalline-rock aquifer. *Geophysical Note: The caliper log shows the interval from 1400 ft to 1425 ft bgs as being slightly out-of-gage by up to 4 inches in an otherwise completely in-gage, gun barrel-smooth borehole. The temperature log shows the water temperature as no longer warming along a geothermal warming gradient, and manifesting a fairly homogenous temperature from 1420 ft down to about 1520 ft bgs. This suggests that water is entering the borehole from the formation. The laterolog and electric logs show low resistivity between 1400 ft and 1428 ft bgs, and the SP curve shows higher voltage.*

1430–1450 ft Granite, very light grey, moderately crystalline, major mineral composition same, with no argillic alteration of feldspar, only minor chloritization of biotite, minor dolomite filling fracture apertures, trace dolomite in the groundmass, trace epidote, and trace of iron oxide staining. *Geophysical Note: From 1430 ft to 1452 ft bgs the laterolog and the electric log show a higher-than-normal resistivity, and the SP curve shows lower-than-average voltage.*

1450–1460 ft Granite, light greenish-grey, moderately crystalline, major mineral composition same but with significant chlorite and dolomite alteration, pervasive chloritization of biotite, trace iron oxide staining, chlorite and clay coating fracture surfaces, and no visible epidote. *Geophysical Note: The caliper log shows the interval from 1455 ft to 1460 ft bgs as being slightly out-of-gage by up to 4 inches in a normally smooth borehole. From 1452 ft to 1475 ft bgs both the laterolog and the electrical log shows a zone of low resistivity and a zone of higher SP voltage.*

1460–1500 ft Granite, very light grey, moderately crystalline, major mineral composition same, with minor chloritization of biotite, minor dolomite, very minor argillic alteration of feldspar, minor iron oxide staining, and trace epidote. Chloritization of biotite and dolomite in groundmass decrease downward in this interval.

1500–1520 ft Granite, very light grey, moderately crystalline, major mineral composition same, with only a trace of chloritization of biotite, trace of iron oxide staining, trace of pyrite, and no dolomite. *Geophysical Note: From 1510 ft to 1520 ft bgs the laterolog and the electrical log display a positive resistivity anomaly and a lower SP anomaly.*

1520–1530 ft As above but with minor chloritization of biotite and increased iron oxide staining.

1530–1560 ft Granite, very light grey, moderately crystalline, major mineral composition same, with some chlorite and dolomite alteration, increased chloritization of biotite, minor iron oxide staining, trace of epidote, trace pyrite, trace pyrolusite dendrites. *Geophysical Note: The caliper log shows the interval between 1540 ft and 1555 ft bgs as being slightly out-of-gage by up to 4 inches in a normally smooth borehole. The temperature log shows the borehole fluid temperature as beginning to increase in temperature again around 1530 ft bgs, although the rate of warming with depth is not as great as that shown by the geothermal gradient between 1080 ft and 1410 ft bgs. From 1540 ft to 1570 ft bgs there is an interval with low resistivity on the laterolog and electrical log and a higher voltage on the SP curve.*

1560–1590 ft Granite, very light grey, moderately crystalline, major mineral composition same, with very minor chloritization of biotite, trace dolomite, trace epidote, some dolomite filling fracture apertures.

1690–1600 ft Granite, very light grey, as above, but with increased iron oxide staining.

1600–1630 ft Granite, very light grey, as above, but with only very minor iron oxide staining. *Note:* Dolomite fills fracture apertures at 1610 ft. Very coarse cuttings clasts from 1620 ft to 1630 ft bgs potentially means the presence of a fracture zone or fault. *Geophysical Note: From 1610 ft to 1620 ft bgs both the laterolog and the electrical log shows a zone of low resistivity and a zone of higher SP voltage.*

1630–1640 ft Granite, very light grey, moderately crystalline, major mineral composition same for unaltered granite, with no dolomite, only very minor chloritization of biotite, no iron oxide staining, and a trace of epidote. *Geophysical Note: There is a positive gamma ray anomaly (about 2× background) from 1630 ft to 1634 ft bgs. The temperature log shows an inflection point at 1640 where the rate of warming increases to a rate that approximates the same geothermal gradient as that observed between 1080 and 1410 ft bgs.*

1640–1690 ft Granite, very light grey, moderately crystalline, major mineral composition same as above but with very minor dolomite, very minor iron oxide staining, clay coating fracture surfaces, trace of epidote.

1690–1700 ft Granite, very light grey, moderately crystalline, major mineral composition same as above, but with only a trace of iron oxide staining, trace of epidote. *Geophysical Note: The caliper log shows the interval between 1695 ft and 1726 ft bgs as being the most out-of-gage (up to 10 inches) portion of this normally smooth borehole. From 1684 ft to 1730 ft bgs the laterolog and electrical logs show unusually low resistivity and the SP curve shows unusually high voltage.*

1700–1750 ft Granite, light grey, moderately crystalline, major mineral composition same as above, with very minor chlorite and dolomite alteration, minor chloritization of biotite, trace of iron oxide staining, trace of epidote, some dolomite-filled fracture apertures, some clay coating fracture surfaces, and minor chlorite coating fracture surfaces. *Geophysical Note: The temperature log shows a sudden, 0.5 °F temperature increase over a 2 ft interval at 1710 ft bgs. This is interpreted as the borehole losing water above this point to the formation. The fractured zone from 1400 to 1430 (borehole gaining water) would have a higher hydraulic head than the fractured zone from 1684 to 1730 (borehole losing water).The temperature log is indicative of the water temperature in the borehole, not the formation. Prior to well completion, the borehole acts as a conduit that allows water to flow from zones of high to low hydraulic head.*

Appendix C

MV-4 Data

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Table C-1. MV-4 Chronology

Date	Time	Depth (ft bgs)	Activity
09/02/2014 −09/03/2014	N/A	NA	Moved rig and equipment from MV-5 pad to MV-4 pad in preparation for drilling.
09/03/2014	10:00	0	Started drilling 19-inch-diameter borehole for the surface casing.
09/03/2014	20:30	60	Drilled to 60 feet and tripped out bottom-hole assembly.
09/03/2014	21:30	60	Started installing the 14-inch diameter surface casing to 60 feet bgs.
09/04/2014	04:00	60	Surface casing installed to 60 feet bgs and cemented in place.
09/04/2014	13:00	60	Completed setup and started drilling with 12.25-inch downhole hammer bit.
09/04/2014	23:40	270	Advanced 12.25-inch borehole to 270 feet.
09/05/2014	23:40	1,010	Advanced 12.25-inch borehole to 1,010 feet.
09/06/2014	07:00	1,200	Advanced 12.25-inch borehole to 1,200 feet.
09/06/2014	21:15	1,200	Tripped out bottom-hole assembly, replaced the bit, and resumed drilling.
09/06/2014	23:40	1,370	Advanced 12.25-inch borehole to 1,370 feet.
09/07/2014	11:40	1,570	Advanced 12.25-inch borehole to 1,570 feet when cross-over sub plugged off and bottom-hole assembly became stuck in the borehole.
09/08/2014	11:40	1,570	Boart continues to work the stuck drill string, using EZ-Mud polymer to help stabilize borehole.
09/08/2014	15:30	1,570	Mechanic inspected the drill rig engine and determined two cylinders needed repair and that the engine was not at full capacity. Drill rig operation is limited to rotating drill rods for 15 minutes every hour until engine repairs are made.
09/09/2014	21:00	1,570	Mechanic repaired the drill rig engine and drilling operations resume trying to remove the stuck drill rods and bottom-hole assembly.
09/09/2014	23:40	1,570	Boart works the stuck pipe, returning rotation to the stuck drill string.
09/10/2014	21:50	1,570	Boart continues to work the stuck drill string using EZ-Mud and air. The bottom-hole assembly is at a depth of 1,490 feet when the top head king swivel fails and drilling operations are stopped for repairs.
09/11/2014	14:00	1,570	Boart replaces top head king swivel on the drill rig and drilling operations resume trying to remove the stuck drill rods and bottom-hole assembly.
09/11/2009	23:40	1,570	Boart works the stuck drill string, and is able to pull back to 1,350 feet.
09/12/2014	18:00	1,570	Boart works the drill string free and trips out of the borehole.
09/13/2014	03:00	1,570	Boart trips back into the borehole with reconfigured the bottom-hole assembly, but hits a bridge at 1,300 feet and clogs the cross-over.
09/13/2014	05:20	1,570	Boart trips out to un-clog the cross-over.
09/13/2014	11:40	1,570	Boart trips back into the borehole to 1,250 feet. Clean, well-sorted sand flowing into the borehole through fractures. Air used during the drilling is observed escaping from fractures at the surface near the drilling rig and in the mud pit.
09/14/2014	16:00	1,570	The decision was made to switch the drilling method to mud rotary and tri-cone bit to stabilize the borehole to 1,570 feet bgs.
09/14/2014	07:00	1,570	Tripped in to 1,100 feet and started drilling flooded reverse-circulation with bentonite based drilling mud and tri-cone bit to remove bridges and stabilize borehole.
09/14/2014	23:40	1,570	Drilling and circulating down to 1,482 feet.
09/15/2014	11:40	1,570	Drilled and circulate down to 1,570 feet, circulate to lighten mud weight, and then trip out of the hole in preparation for geophysical logging.
09/15/2014	12:30	NA	Pacific Surveys onsite to conduct the geophysical logging.
09/15/2014	18:40	NA	Completed the borehole geophysical logging. Reviewed geophysical logs for well construction.
09/16/2014	14:00	NA	Installed piezometer with screen from 1,120 to 1,240 feet bgs, and installed well with screen from 1,400 to 1,560 feet bgs.

Table C-1 (continued). MV-4 Chronology

Date	Time	Depth (ft bgs)	Activity
09/17/2014	08:30	NA	Installed well gravel pack to 1,385 feet, sand pack to 1,380 feet, bentonite hole plug to 1,374 feet, cement to 1,329 feet bgs, and a final bentonite seal to 1,275 feet bgs.
09/17/2014	20:10	NA	Installed piezometer gravel pack to 1,105 feet, sand pack to 1,095 feet, and bentonite hole plug to 1,090 feet bgs.
09/18/2014	04:40	NA	Installed cement grout to 892 feet bgs then stopped to conserve water because pump in the water supply well is not operational.
09/18/2014	11:40	NA	Trip out tremie pipe and rig up to airlift for well development.
09/18/2014	12:15	NA	Started airlift development of the well.
09/18/2014	22:00	NA	Airlifted 1,395 gallons of water from MV-4 well. During operations to remove the cyclone from the mud tanks and place it on the ground, Boart worker was struck in the mouth with a cable, sustaining minor injury to his upper lip. An Incident Report was completed for the minor injury.
09/19/2014	11:40	NA	Trip in surge block and swab the well.
09/19/2014	16:45	NA	Trip in HQ and BQ rods and rig up to airlift on well.
09/19/2014	23:15	NA	Airlifted 20 gallons per minute (gpm) while adding 2–3 gpm to stabilized flow for 5 hours; airlift without adding water for 45 minutes. A total of 5,515 gallons of water was purged for the day.
09/20/2014	23:00	NA	Airlifted with 10 minutes of flow followed with 10 minutes of shut-in. A total of 1,548 gallons of water purged for the day.
09/21/2014	23:40	NA	Airlift with 10 minutes of flow followed with 20 minutes of shut-in. A total of 823 gallons of water purged for the day.
09/22/2014	07:15	NA	Completed initial airlift development. Removed 347 gallons for the day and a total of 9,628 cumulative gallons for the initial airlift development. Set up to finish cementing of the borehole to the surface.
09/23/2014	00:30	NA	Completed cementing of the borehole to surface.
09/29/2014	18:00	NA	Bail piezometer on MV-4, producing 37.5 gallons of water.
09/30/2014	06:30	NA	Boart begins installation of the submersible electric pump in MV-4 well.
09/30/2014	16:47	NA	Completed installation of the submersible electric pump and started purging well as part of the final development. The pump was turned off at 17:35 because the water level dropped to near the depth of the pump. A total of 236 gallons of water was purged before the pump was stopped.
10/01/2014	18:00	NA	Bailed piezometer on MV-4, producing 37.5 gallons of water.
10/01/2014	18:20	NA	Pumping with submersible electrical pump in MV-4 monitoring well, A total of 404 gallons of water purged for the day.
10/02/2014	14:30	NA	Bailed piezometer on MV-4, producing 25 gallons of water.
10/02/2014	18:30	NA	Pumping with submersible electrical pump in MV-4 monitoring well. A total of 519 gallons of water purged for the day.
10/03/2014	16:08	NA	Pumping with submersible electrical pump in MV-4 monitoring well. A total of 509 gallons of water purged for the day.
10/03/2014	19:00	NA	Well box installed on MV-4.
10/04/2014	10:00	NA	Pumping with submersible electrical pump in MV-4 monitoring well. A total of 150 gallons of water purged for the day.
10/05/2014	10:00	NA	Pumping with submersible electrical pump in MV-4 monitoring well. A total of 100 gallons of water purged for the day.
10/06/2014	10:00	NA	Pumping with submersible electrical pump in MV-4 monitoring well. A total of 160 gallons of water purged for the day.
11/12/2014	12:30	NA	Pumping with submersible electrical pump in MV-4 monitoring well. A total of 590 gallons of water purged for the day.

Table C-2. MV-4 Construction Details

Construction	Material	Type	Depth Interval (ft)	Stemming Material	Volume (ft^3)	Interval (ft)
Surface casing	14-inch o.d. CS casing	Blank	0–60	Cement seal	167.4	0–60
Piezometer casing	2.375-inch o.d. CS flush-joint casing	Blank	0–1,120	Cement seal	1,280	0–1,090
				⅜-inch bentonite chips	3.3	1,090–1,095
				No. 6 sand pack	6.7	1,095–1,105
		Screen w/bullnose	1,120–1,240	⅛–¼-inch gravel pack	216	1,105–1,275
Intermediate seal	NA	Below piezometer bullnose		⅜-inch bentonite chips	6.7	1,275–1,329
				Cement seal	62.8	1,329–1,374
Monitoring well casing	5.5-inch o.d. CS flush-joint casing	Blank	0–1,400	⅜-inch bentonite chips	3.3	1,374–1,380
				No. 6 sand pack	3.3	1,380–1,385
		Screen w/bullnose	1,400–1,560	⅛–¼-inch gravel pack	128.2	1,385–1,560
Bottom seal	NA	Below bullnose	1,560–1,570	⅛–¼-inch gravel pack		1,560–1,570

Volumes for stemming material are calculated from the recorded quantities of materials used, not from the calculated size of the annulus (the well bore contains numerous out-of-gage intervals that make such calculations misleading).
CS = carbon steel
ft^3 = cubic feet

Table C-3. MV-4 Drilling and Development Tritium Analyses

Sample ID	Date	Time	Sample Depth (ft)	Tritium (pCi/L)	MDC (pCi/L)	±2 sigma (%)	Notes
Well Drilling							
MV-4 1030 ft	9/6/14	01:00	1,030	2432	3033	90	<MDC
MV-4 1050 ft	9/6/14	02:10	1,050	1622	3071	196	<MDC
MV-4 1080 ft	9/6/14	03:00	1,080	180	2861	163	<MDC
MV-4 1120 ft	9/6/14	04:10	1,120	2342	3022	90	<MDC
MV-4 1150 ft	9/6/14	05:20	1,150	180	2977	970	<MDC
MV-4 1200 ft	9/6/14	06:30	1,200	2523	2955	67	<MDC
MV-4 1250 ft	9/6/14	19:30	1,250	2883	3192	102	<MDC
MV-4 1290 ft	9/6/14	20:30	1,290	901	3130	502	<MDC
MV-4 1330 ft	9/6/14	22:30	1,330	1802	3271	1001	<MDC
MV-4 1370 ft	9/6/14	23:30	1,370	180	3156	331	<MDC
MV-4 1390 ft	9/7/14	01:00	1,390	450	3060	90	<MDC
MV-4 1420 ft	9/7/14	02:15	1,420	−721	2977	196	<MDC
MV-4 1430 ft	9/7/14	03:15	1,430	−1261	2905	163	<MDC
MV-4 1450 ft	9/7/14	04:15	1,450	901	3002	90	<MDC
MV-4 1480 ft	9/7/14	05:15	1,480	−2883	2897	970	<MDC
MV-4 1510 ft	9/7/14	06:10	1,510	−631	2942	67	<MDC
MV-4 1540 ft	9/7/14	07:30	1,540	2883	3455	90	<MDC
MV-4 1560 ft	9/7/14	08:30	1,560	1892	3246	196	<MDC
Well Development—Air							
MV-4 devel.	9/18/14	18:05	WD	180	2743	950	<MDC
MV-4 devel.	9/19/14	16:50	WD	1081	2951	121	<MDC
MV-4 devel.	9/19/14	19:10	WD	2072	2961	75	<MDC
MV-4 devel.	9/19/14	20:00	WD	−811	2796	239	<MDC
MV-4 devel.	9/19/14	21:00	WD	811	2916	121	<MDC
MV-4 devel.	9/19/14	22:00	WD	−991	2818	476	<MDC
MV-4 devel.	9/19/14	23:00	WD	−1712	2791	946	<MDC
MV-4 devel.	9/20/14	00:30	WD	−1982	2952	322	<MDC
MV-4 devel.	9/20/14	01:35	WD	−541	3001	326	<MDC
MV-4 devel.	9/20/14	03:35	WD	−1622	3105	137	<MDC
MV-4 devel.	9/20/14	05:30	WD	−360	3098	999	<MDC
MV-4 devel.	9/20/14	07:35	WD	360	3047	164	<MDC
MV-4 devel.	9/20/14	09:30	WD	2793	3259	99	<MDC
MV-4 devel.	9/20/14	11:30	WD	991	3177	245	<MDC
MV-4 devel.	9/20/14	13:30	WD	2162	3046	139	<MDC
MV-4 devel.	9/20/14	15:30	WD	2613	3104	139	<MDC
MV-4 devel.	9/20/14	17:30	WD	2613	3009	89	<MDC
MV-4 devel.	9/20/14	19:30	WD	811	2989	480	<MDC
MV-4 devel.	9/20/14	21:30	WD	1171	2941	161	<MDC
MV-4 devel.	9/20/14	23:00	WD	1892	2987	122	<MDC
MV-4 devel.	9/21/14	02:15	WD	1712	3259	160	<MDC

Table C-3 (continued). MV-4 Drilling and Development Tritium Analyses

Sample ID	Date	Time	Sample Depth (ft)	Tritium (pCi/L)	MDC (pCi/L)	±2 sigma (%)	Notes
MV-4 devel.	9/21/14	05:15	WD	−721	2804	158	<MDC
MV-4 devel.	9/21/14	08:15	WD	2523	3094	160	<MDC
MV-4 devel.	9/21/14	11:15	WD	−1532	2763	314	<MDC
MV-4 devel.	9/21/14	14:25	WD	2973	3079	99	<MDC
MV-4 devel.	9/21/14	17:00	WD	631	3090	321	<MDC
MV-4 devel.	9/21/14	19:45	WD	270	2989	196	<MDC
MV-4 devel.	9/21/14	22:25	WD	1261	3074	970	<MDC
MV-4 devel.	9/22/14	01:05	WD	1171	2965	196	<MDC
MV-4 devel.	9/22/14	04:05	WD	−180	3081	136	<MDC
MV-4 devel.	9/22/14	07:05	WD	541	2861	163	<MDC
Well Development—Pump							
MV-4 devel.	10/1/14	16:15	WD	2883	3292	334	<MDC
MV-4 devel.	10/2/14	10:40	WD	1892	3047	197	<MDC
MV-4 devel.	10/2/14	12:40	WD	541	3025	1001	<MDC
MV-4 devel.	10/2/14	18:30	WD	1892	2932	79	<MDC
MV-4 devel.	10/3/14	11:05	WD	2793	2877	90	<MDC
MV-4 devel.	10/3/14	13:30	WD	1982	3007	68	<MDC
MV-4 devel.	10/3/14	14:15	WD	2252	3060	73	<MDC
MV-4 devel	10/4/14	07:40	WD	901	2807	84	<MDC
MV-4 devel	10/5/14	13:55	WD	2342	NR	NR	<MDC

NR = The values for the MDC and ±2 sigma were not recorded but were documented as being below MDC
MDC = minimum detectable concentration
WD = well development

Table C-4. MV-4 Drilling and Development Water Quality and Bromide Analyses

Sample ID	Date	Time	Sample Depth (ft)	pH (s.u.)	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Br^- (mg/L)
Well Drilling								
MV-4 1030 ft	9/06/14	01:00	1,030	7.85	19.8	504	NA	32
MV-4 1050 ft	9/06/14	02:10	1,050	8.03	20.0	669	NA	21
MV-4 1080 ft	9/06/14	03:00	1,080	8.32	19.1	519	NA	20
MV-4 1120 ft	9/06/14	04:10	1,120	7.89	19.6	529	NA	24
MV-4 1150 ft	9/06/14	05:20	1,150	7.95	19.1	644	NA	23
MV-4 1200 ft	9/06/14	06:30	1,200	8.09	19.4	673	NA	33
MV-4 1250 ft	9/06/14	19:30	1,250	7.72	24.0	140	NA	26
MV-4 1290 ft	9/06/14	20:30	1,290	7.92	26.9	601	NA	27
MV-4 1330 ft	9/06/14	22:30	1,330	7.91	23.5	150	NA	24
MV-4 1370 ft	9/06/14	23:30	1,370	7.73	20.4	610	NA	24
MV-4 1390 ft	9/07/14	01:00	1,390	7.62	20.8	219	NA	13
MV-4 1420 ft	9/07/14	02:15	1,420	8.03	20.9	690	NA	12
MV-4 1430 ft	9/07/14	03:15	1,430	7.92	19.6	703	NA	8.7
MV-4 1450 ft	9/07/14	04:15	1,450	7.94	20.1	563	NA	11
MV-4 1480 ft	9/07/14	05:15	1,480	8.01	19.2	701	NA	3.5
MV-4 1510 ft	9/07/14	06:10	1,510	7.91	19.5	500	NA	7.0
MV-4 1540 ft	9/07/14	07:30	1,540	7.87	20.8	732	NA	5.2
MV-4 1560 ft	9/07/14	08:30	1,560	7.83	20.2	289	NA	11
Well Development—Air								
MV-4 devel.	9/18/14	22:00	WD	7.75	20.6	566	747	44
MV-4 devel.	9/19/14	23:00	WD	7.77	23.3	513	95.1	16
MV-4 devel.	9/20/14	00:30	WD	7.67	20.4	580	481	25
MV-4 devel.	9/20/14	01:35	WD	7.81	20.3	609	700	19
MV-4 devel.	9/20/14	03:35	WD	7.81	20.5	641	887	18
MV-4 devel.	9/20/14	05:30	WD	7.07	21.0	962	698	16
MV-4 devel.	9/20/14	07:35	WD	7.01	21.8	1060	735	13
MV-4 devel.	9/20/14	09:25	WD	8.06	22.2	1016	819	12
MV-4 devel.	9/20/14	11:30	WD	8.20	25.5	1047	705	11
MV-4 devel.	9/20/14	12:05	WD	8.24	26.1	1369	819	NA
MV-4 devel.	9/20/14	13:58	WD	8.38	25.1	1019	736	13
MV-4 devel.	9/20/14	15:58	WD	8.10	25.2	1053	736	41
MV-4 devel.	9/20/14	17:47	WD	8.37	26.2	1002	>1000	12
MV-4 devel.	9/20/14	19:47	WD	8.40	24.5	1012	>1000	14
MV-4 devel.	9/20/14	21:55	WD	8.24	22.9	1079	>1000	13
MV-4 devel.	9/20/14	23:00	WD	8.24	22.0	1106	>1000	13
MV-4 devel.	9/21/14	02:10	WD	8.08	20.1	1088	>1000	10
MV-4 devel.	9/21/14	05:10	WD	8.08	20.8	1044	>1000	8.4
MV-4 devel.	9/21/14	08:10	WD	8.02	21.8	1008	>1000	6.1
MV-4 devel.	9/21/14	11:10	WD	8.08	23.3	1012	945	6.6

Table C-4 (continued). MV-4 Drilling and Development Water Quality and Bromide Analyses

Sample ID	Date	Time	Sample Depth (ft)	pH (s.u.)	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Br^- (mg/L)
MV-4 devel.	9/21/14	14:25	WD	8.12	26.7	1077	>1000	9.5
MV-4 devel.	9/21/14	17:00	WD	8.17	26.4	1030	>1000	7.9
MV-4 devel.	9/21/14	19:45	WD	8.01	22.3	1027	>1000	6.5
MV-4 devel.	9/21/14	22:25	WD	8.16	21.8	990	>1000	6.0
MV-4 devel.	9/22/14	01:05	WD	7.91	19.7	1040	>1000	5.3
MV-4 devel.	9/22/14	04:05	WD	8.00	22.2	1026	>1000	4.7
MV-4 devel.	9/22/14	07:05	WD	7.93	20.0	941	>1000	4.2
Well Development - Pump								
MV-4 devel.	10/1/14	16:15	WD	7.34	21.0	924	219	6.1
MV-4 devel.	10/2/14	10:40	WD	7.44	18.6	921	156	6.0
MV-4 devel.	10/2/14	12:40	WD	7.62	26.1	887	71.8	4.5
MV-4 devel.	10/2/14	18:30	WD	7.35	20.6	882	22.3	4.1
MV-4 devel.	10/3/14	11:05	WD	7.28	20.3	869	7.93	4.1
MV-4 devel.	10/3/14	13:30	WD	7.20	21.2	864	20.8	4.7
MV-4 devel.	10/3/14	14:15	WD	7.37	23.3	861	21.8	3.9
MV-4 devel.	10/6/14	10:00	WD	NA	NA	NA	NA	2.7
MV-4 devel.	11/12/14	12:30	WD	NA	NA	NA	NA	3.8

WD = well development
NA = not analyzed

Table C-5. MV-4 Pump and Tubing Details

Well ID	Pump Riser Material	Diameter	Estimated Depths	Material Description
MV-4	Carbon Steel Riser Pipe	1-inch	0–1,100 ft bgs	Approximate 32 ft lengths of API J-55 riser pipe with external upset ends.
	PVC Water Access Tubing	1.5-inch	0–1,100 ft bgs	Flush joint schedule 80 PVC with 40 ft of 0.02-inch screen.
	Electric Supply Cable	Flat	0–1,100 ft bgs	Kalas 8 AWG #10, 600-volt flat, 4 wire submersible pump cable.
	Electric Pump	<5-inch	1,100 ft bgs (top) 1,105 ft bgs(intake) 1,107 ft bgs(bottom)	Grundfos pump, model 10S50-58DS, with MS4000 5-horsepower, 480-volt, three-phase motor.

MV-4 Lithologic Descriptions

(well cuttings described dry and in natural light)

The lithologic descriptions provided here are from the surface down to the 1,570 ft bgs total depth. The dominant granitic lithology at depth in MV-4 is a moderately crystalline, very light grey granite very similar to the dominant granite encountered at depth in MV-5; the top 120 feet of MV-4 shows much more lithologic variability. For example, there are two dikes, one a coarsely crystalline, porphyritic, granitic dike, another one a pegmatite dike. Enveloping these two dikes is distinct granite with very few mafic minerals consisting of unusually small crystals of biotite, hornblende, and magnetite, with a conspicuous absence of sphene. Below these granitic lithologies lie the more familiar, moderately crystalline granite observed in MV-5. Because of the small size of the drill cuttings, it is not known whether this moderately crystalline granite is equicrystalline or porphyritic. Both equicrystalline and porphyritic granite appear in surface bedrock exposures at the Shoal site. The various borehole geophysical logs for MV-4 are compared to the lithologic descriptions here, with potentially significant geophysical anomalies described in italics at the appropriate depths following the lithologic description for that depth interval.

0–20 ft — Granitic dike, very light greenish-grey and very light pinkish-grey, coarsely crystalline—possibly porphyritic, with euhedral to subhedral phenocrysts of potassium feldspar in a groundmass of intergrown laths of sodic plagioclase and intercrystalline quartz. This yields a groundmass “cuneiform” texture similar to that of graphic granite. Major mineral composition is approximately 40 percent white to greenish-white subhedral plagioclase, 40 percent euhedral to subhedral, light pink to very light green potassium feldspar as phenocrysts and in the groundmass, 15 percent subhedral quartz in the groundmass, 5 percent black minerals (mostly biotite, some magnetite, minor pyrolusite dendrites on fracture surfaces) minor iron oxide (hematite) halos around magnetite crystals.

20–70 ft — Granite, light grey, moderately crystalline, major mineral composition approximately 35 percent white sodic plagioclase, 35 percent light pinkish-grey potassium feldspar, 23 percent quartz, 5 percent biotite (small euhedral crystals <2 mm), 1 percent very small hornblende crystals, <1 percent magnetite, trace sphene, trace epidote, trace iron oxide staining. *Note:* The cuttings from this interval are much smaller than those of the top 20 feet.

70–90 ft — Granite, light grey as above, but with slight increase in iron oxide staining.

90–100 ft — Granite, light grey as above, but with considerable clay in the sample, possibly associated with a fracture zone. *Note:* Drilling at deeper depths with higher air pressure resulted in dozens of places on the surface where air bubbled out the wet surface around the drilling rig, indicating that the rock in this borehole was quite fractured, with fractures that projected to the surface from various depths in the borehole.

100–110 ft — Pegmatite dike, light pinkish-grey, very coarsely crystalline, composed of 45 percent light pinkish-grey, euhedral to subhedral potassium feldspar, 34 percent white sodic plagioclase, 20 percent subhedral quartz in the groundmass, about 1 percent hornblende, and minor pyrolusite dendrites on fracture surfaces. *Geophysical Note: The caliper log shows a “washout” in the borehole where the diameter of the borehole increases, by approximately 11 inches from 96 ft down to 102 ft bgs.*

110–120 ft — Granite, light grey, moderately crystalline, major mineral composition approximately 35 percent white sodic plagioclase, 35 percent light pinkish-grey potassium feldspar, 23 percent quartz, 5 percent biotite (small euhedral crystals <2 mm), 1 percent very small hornblende crystals, <1 percent magnetite, trace sphene, trace epidote, and iron oxide staining. *Note: This sample also contained a significant amount of clay, which possibly indicates the presence of a fracture zone*.

120–140 ft Granite, light grey as above, with minor oxybiotite and clasts that look like discrete zones of medium brownish-green, pervasive chlorite and dolomite alteration that has completely replaced the protolith granite.

140–180 ft Granite, light greenish-grey, moderately crystalline, major mineral composition is approximately 35 percent potassium feldspar, 35 percent sodic plagioclase, 20 percent quartz, 7 percent euhedral to subhedral biotite (biotite crystals typically >3 mm) with some oxy-biotite and some chloritized biotite, 2 percent hornblende, <1 percent sphene, trace of epidote, trace of euhedral pyrite (crystals are partly to significantly oxidized to hematite, but the pyritohedron crystal forms are well preserved), trace of pyrolusite dendrites, some iron oxide staining, and some localized zones of chlorite plus dolomite alteration.

180–200 ft Granite, very light grey, moderately crystalline, major mineral composition as above, but with no chlorite and dolomite alteration, and only a trace amount of chloritization of biotite, trace of epidote, trace of iron oxide stain, and no pyrolusite.

200–210 ft Granite, very light grey to light greenish-grey, moderately crystalline, mineral composite same, but with minor chlorite and dolomite alteration, minor chloritization of biotite, minor iron oxide staining, trace of epidote.

210–220 ft Granite as above, but with less chlorite and dolomite alteration, less iron oxide staining.

220–233 ft Granite, very light grey, moderately crystalline, mineral composite same, but with only a trace of chlorite and dolomite alteration, trace chloritization of biotite, trace of epidote.

233–250 ft Granite, light greenish-grey, moderately crystalline, mineral composite same, but with discrete zones of medium brownish-green, pervasive chlorite and dolomite alteration and chlorite and calcite alteration that has completely replaced the protolith granite. Calcite coats some fracture surfaces. Trace of epidote in unaltered granite, minor iron oxide staining, and minor pyrolusite dendrites on fracture surfaces.

250–270 ft Granite, very light grey, moderately crystalline, major mineral composition as above for unaltered granite but with minor chloritization of biotite, minor iron oxide staining, minor pyrolusite dendrites, trace of epidote.

270–290 ft Granite, very light grey, moderately crystalline, major mineral composition as above for unaltered granite but with some discrete zones with pervasive chlorite and dolomite alteration, minor chloritization of biotite, some iron oxide staining, minor pyrolusite dendrites, trace of epidote. *Note: These samples also contained a considerable amount of clay, potentially signifying the presence of a fracture zone*.

290–310 ft Granite, very light grey, moderately crystalline, major mineral composition as above for unaltered granite but with some discrete zones with pervasive chlorite and dolomite alteration, minor chloritization of biotite, some iron oxide staining, minor pyrolusite dendrites, minor clay coatings on fracture surfaces, trace of epidote. Unlike in the above interval (270–290 ft), clay was not part of these samples.

310–320 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with minor chloritization of biotite, trace of epidote, trace of dolomite, trace of iron oxide staining.

320–345 ft Pegmatite, light pinkish-grey, very coarsely crystalline, composed of approximately 50 percent light pink potassium feldspar, 35 percent white sodic plagioclase, 15 percent quartz, with no mafic minerals, no alteration, but with some void-filling secondary euhedral quartz crystal overgrowths.

345–380 ft Granite, very light grey, moderately crystalline, major mineral composition is approximately 35 percent potassium feldspar, 35 percent sodic plagioclase, 20 percent quartz, 7 percent biotite, 2 percent hornblende, <1 percent sphene, trace of epidote, trace of dolomite, trace of iron oxide stain, minor clay coating fracture surfaces. *Geophysical Note: The caliper log shows a "washout" in the borehole where the diameter of the borehole increases, by approximately 11 inches from 376 ft down to 382 ft bgs. There is no gamma ray data recorded for this interval.*

380–410 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with increased chloritization of biotite, chlorite filling fracture apertures, and some chlorite and dolomite alteration adjacent to chloritized fractures.

410–530 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with no chlorite alteration of the groundmass, minor chloritization of biotite, minor iron oxide staining, trace of dolomite, trace of epidote. *Geophysical Note: The fluid in the borehole at these depths is remnant drilling fluid that have not been displaced or drained from the borehole. Depth to groundwater in the formation is approximately 1,080 ft bgs at this location.*

530–550 ft Granite, very light grey to light greenish-grey; the very light grey granite is as above, but the light greenish-grey granite contains zones of pervasive chlorite and dolomite alteration, minor to pervasive chloritization of the biotite, minor iron oxide staining, and dendrites of pyrolusite and hematite on fracture surfaces.

550–570 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with minor chloritization of biotite, minor iron oxide staining, trace of epidote.

570–600 ft Granite, very light grey and light greenish-grey, moderately crystalline, major mineral composition as above, with some zones of minor to pervasive chlorite and dolomite alteration, some chloritization of the biotite, minor iron oxide staining, and dendrites of pyrolusite and hematite on fracture surfaces.

600–620 ft Granite, light greenish-grey, moderately crystalline, major mineral composition as above, significant pervasive chlorite and dolomite alteration, with secondary calcite commonly associated with fractures, minor to common chloritization of biotite, trace of iron oxide staining, trace of epidote.

620–660 ft Granite, light greenish-grey, moderately crystalline, major mineral composition as above but with less pervasive alteration and more scattered chlorite and dolomite within the groundmass, pyrolusite and iron oxide mineral dendrites on fracture surfaces, minor secondary clay coatings on fracture surfaces, fracture surfaces with slickensides, trace of epidote.

660–680 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with minor dolomite, minor iron oxide staining, pyrolusite and iron oxide dendrites on fractures, and with only minor local zones with more pervasive chlorite and dolomite alteration.

680–700 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with minor dolomite, minor iron oxide staining, pyrolusite and iron oxide dendrites on fractures, but with increased chlorite and dolomite alteration, and increased pyrolusite and iron oxide mineral dendrites on fracture surfaces.

700–750 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with only minor zones characterized by chlorite and dolomite alteration, minor iron oxide staining. This sample contained increased amount of clay in the cuttings—argillic alteration of fracture zone? *Geophysical Note: The caliper log shows a "washout" in the borehole where the diameter of the borehole sharply increases beyond the maximum extent of the caliper tool from 700 ft to 726 ft bgs. There is a pair of negative gamma ray spikes (−0.8x background) from 702 ft to 727 ft bgs, which is essentially coincident with the washout and is an artifact of the increased borehole diameter associated with the washout.*

750–780 ft Granite, very light grey, moderately crystalline, major mineral composition as above, minor chloritization of biotite, minor dolomite, minor iron oxide staining, very small and localized zones with chlorite and dolomite alteration.

780–820 ft Granite, very light grey, moderately crystalline, major mineral composition as above, no zones of chlorite and dolomite alteration, but minor chloritization of biotite, minor dolomite, minor iron oxide staining, trace of epidote.

820–840 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with a slight increase in the chloritization of biotite, slight increase in iron oxide staining, pyrolusite and iron oxide mineral dendrites on fracture surfaces, trace of dolomite.

840–860 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with a slight increase in iron oxide staining, minor local zones of chlorite and dolomite alteration.

860–870 ft Granite, very light grey, moderately crystalline, major mineral composition as above but with no zones containing chlorite and dolomite alteration, minor iron oxide staining.

870–880 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with minor zones containing chlorite and dolomite alteration, minor iron oxide stains and halos around magnetite crystals.

880–930 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with no zones of chlorite and dolomite alteration, minor chloritization of biotite, minor iron oxide staining.

930–940 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with no zones of chlorite and dolomite alteration, trace chloritization of biotite, minor iron oxide staining, minor clay on fracture surfaces, minor dolomite filling the apertures of smaller fractures.

940–960 ft Granite, very light grey, moderately crystalline, major mineral composition as above, no chlorite and dolomite alteration, trace chloritization of biotite, slight increase in iron oxide staining.

960–990 ft Granite, very light grey, moderately crystalline, major mineral composition as above, no chlorite and dolomite alteration, trace chloritization of biotite, minor iron oxide staining.

990–1000 ft Granite, very light grey, moderately crystalline, major mineral composition as above, no chlorite and dolomite alteration, trace chloritization of biotite, minor iron oxide staining. This sample contained a significant amount of clay in the cuttings.

1000–1010 ft Granite, very light grey, moderately crystalline, major mineral composition as above, minor local zones of chlorite and dolomite alteration, minor chloritization of biotite, minor iron oxide staining. No clay in the cuttings from this interval.

1010–1020 ft Granite, very light grey, moderately crystalline, major mineral composition as above, no chlorite and dolomite alteration but minor dolomite in the groundmass, trace chloritization of biotite, minor iron oxide staining.

1020–1060 ft Granite, very light grey, moderately crystalline, major mineral composition as above, trace chloritization of biotite, with minor increase in iron oxide staining.

1060–1080 ft Granite, very light grey, moderately crystalline, major mineral composition as above, trace chloritization of biotite, with decrease in iron oxide mineral staining but with pyrolusite dendrites on fracture surfaces.

1080–1110 ft Granite, very light grey, moderately crystalline, major mineral composition as above, trace chloritization of biotite, very minor iron oxide staining, very few dendrites. *Geophysical Note: From 1085 ft to 1105 ft bgs there is a region of anomalously high resistivity in the electric log and the laterolog and, unusually, a slight increase in the SP voltage as well that correlates with the depth of groundwater in the formation at approximately 1080 ft bgs at this location.*

1110–1130 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with dolomite in groundmass, a few localized zones of chlorite and dolomite alteration, increased chloritization of biotite. *Geophysical Note: From 1120 ft to 1125 ft bgs there is a region of anomalously high resistivity in the electric log and the laterolog.*

1130–1140 ft Granite, very light grey, moderately crystalline, major mineral composition as above, minor chloritization of biotite, trace iron oxide staining, trace of pyrite, chlorite in fractures, and increased clay in the sample cuttings (potential fracture zone?). *Note: Starting at 1140 ft, non-granitic sand in sample cuttings–probably from the adjacent abandoned borehole on the MV-4 drill pad*. Transport of the sand from the adjacent borehole into the cuttings from MV-4 likely occurred through a robust network of open fractures within the granite at depth at MV-4. *Geophysical Note: The caliper log shows a "washout" in the borehole where the diameter of the borehole sharply increases beyond the maximum extent of the caliper tool* *from 1130 ft to 1136 ft bgs. A negative gamma ray signal (−0.5x background) is directly coincident with the washout on the caliper log and is an artifact of the increased borehole diameter associated with the washout.*

1140–1150 ft Granite, very light grey, moderately crystalline, major mineral composition as above, minor chloritization of biotite, minor dolomite, slight increase in iron oxide staining and halos around magnetite. No clay in the cuttings of this sample interval.

1150–1180 ft Granite, very light grey, moderately crystalline, major mineral composition as above, minor chloritization of biotite, minor dolomite, chlorite on fracture surfaces, trace pyrite.

1180–1200 ft Granite, very light grey, moderately crystalline, major mineral composition as above, no chlorite and dolomite alteration, minor chloritization of biotite, trace iron oxide staining.

1200–1210 ft Granite, very light grey and light greenish-grey, with some zones of pervasive chlorite and dolomite alteration, increased chloritization of biotite, some chlorite filling fracture apertures, trace of pyrolusite and iron oxide mineral dendrites, trace of iron oxide staining.

1210–1220 ft No sample. *Geophysical Note: The caliper log shows a "washout" in the borehole where the diameter of the borehole sharply increases beyond the maximum extent of the caliper tool from 1210 ft to 1223 ft bgs. A small negative gamma ray signal (−0.4x background) is directly coincident with this washout on the caliper log, and is an artifact of the increased borehole diameter associated with the washout. Both the laterolog and electrical log record a long interval from 1212 ft to 1434 ft bgs of unusually low and noise-free resistivity, whereas the SP voltage curve for this same interval is much noisier than anything recorded at shallower depths, and manifests numerous subtle decreases and increases in voltage.*

1220–1240 ft Granite, very light grey and light greenish-grey, with increased zones of pervasive chlorite and dolomite alteration, chloritization of biotite, increased of iron oxide staining.

1240–1250 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with only very minor chlorite and dolomite alteration, minor chloritization of biotite, trace dolomite, minor iron oxide staining. *Geophysical Note: The caliper log shows a "washout" in the borehole where the diameter of the borehole increases by approximately 4.5 to 11 inches from 1240 ft to 1254 ft bgs. A small negative gamma ray signal (−0.3x background) is directly coincident with this washout on the caliper log and is an artifact of the increased borehole diameter associated with the washout.*

1250–1260 ft Granite, very light grey and some light greenish-grey, with minor zones of chlorite and dolomite alteration, minor chloritization of biotite, minor iron oxide staining, and much clay in the sample cuttings.

1260–1270 ft Granite, light greenish-grey, some very light grey, with increased zones of pervasive chlorite and dolomite alteration, minor dolomite, some chloritization of biotite.

1270–1320 ft Granite, light greenish-grey, some very light grey, increased zones of pervasive chlorite and dolomite alteration, minor dolomite, some chloritization of biotite, trace of pyrite, and much clay in the sample cuttings. *Geophysical Note: The caliper log shows a "washout" in the borehole where the diameter of the borehole increases, by approximately 2.5 to 8 inches from 1290 ft to 1320 ft bgs. There is also a very prominent positive gamma ray spike (2.6x background) from 1292 ft to 1301 ft bgs.*

1320–1330 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with only minor chlorite and dolomite alteration, some clay on fracture surfaces, minor iron oxide staining and halos around magnetite, minor dendrites of pyrolusite and iron oxide minerals, minor calcite filling fracture apertures.

1330–1340 ft Granite, very light grey and light greenish-grey, with some zones of chlorite alteration (with and without calcite), minor chloritization of biotite, trace of dolomite (not necessarily associated with the chlorite), minor iron oxide staining.

1340–1350 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with a trace of chlorite alteration, trace of dolomite, minor chloritization of biotite, trace of iron oxide staining.

1350–1360 ft Granite, very light grey and light greenish-grey, with minor zones of chlorite and dolomite alteration, minor dolomite, significant chloritization of biotite, trace epidote, no iron oxide staining.

1360–1370 ft Granite, light greenish-grey and very light grey, with some chlorite and dolomite alteration, significant chloritization of biotite, some clay on fracture surfaces, trace iron oxide staining, trace epidote.

1370–1380 ft Granite, light greenish-grey and very light grey, with some chlorite and dolomite alteration, significant chloritization of biotite, some dolomite filling fractures, some iron oxide staining, trace epidote.

1380–1420 ft Granite, very light grey and minor light greenish-grey, with minor chlorite and dolomite alteration, some chloritization of biotite, minor iron oxide staining, trace epidote. *Geophysical Note: There is a major positive gamma ray spike (2.6x background) from 1384 ft to 1395 ft bgs.*

1420–1430 ft Granite, very light grey and minor light greenish-grey, with minor chlorite and dolomite alteration, some chloritization of biotite, minor iron oxide staining, trace epidote, and with significant clay in the sample cuttings. *Geophysical Note: There is a small positive gamma ray spike (1.5x background) from 1418 ft to 1424 ft bgs.*

1430–1450 ft Granite, light greenish-grey and very light grey, with some chlorite and dolomite alteration, some chloritization of biotite, some calcite filling fractures, minor iron oxide staining, trace epidote.

1450–1460 ft Granite, light greenish-grey and very light grey, with minor zones of pervasive chlorite and dolomite alteration, minor chloritization of biotite, some clay on fracture surfaces, chlorite and calcite on fracture surfaces, minor iron oxide staining, trace epidote. *Geophysical Note: The electric log and lateral log indicate a high resistivity anomaly from 1465 ft to 1485 ft bgs; this same interval shows a very noisy SP curve that, nonetheless, does show a very subtle decrease in voltage (the amplitude of the voltage signal decrease is much smaller than the amplitude of the peaks and troughs in the background noise, however).*

1460–1480 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with minor chlorite and dolomite alteration, minor dolomite in groundmass without chlorite, minor chloritization of biotite, trace epidote.

1480–1490 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with a trace of chlorite alteration, trace chloritization of biotite, trace of epidote.

1490–1500 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with a trace of chlorite alteration, minor chloritization of biotite, minor iron oxide staining, trace of epidote, chlorite and dolomite on fracture surfaces.

1500–1510 ft Granite, very light grey to light greenish-grey, moderately crystalline, major mineral composition as above, with minor chlorite and dolomite alteration, minor chloritization of biotite, trace of calcite, trace of iron oxide staining. *Geophysical Note: There is a positive gamma ray spike (1.8x background) from 1507 ft to 1512 ft bgs).*

1510–1530 ft Granite, very light grey, moderately crystalline, major mineral composition as above, with trace chlorite and dolomite alteration, trace dolomite, trace of iron oxide staining, trace of calcite on fracture surfaces, trace epidote. *Geophysical Note: There is a large positive gamma ray spike (2.15x background) from 1528 ft to 1532 ft bgs.*

1530–1540 ft Granite, very light grey and light greenish-grey, moderately crystalline, major mineral composition as above, with minor of chlorite and dolomite alteration, minor dolomite, trace of iron oxide staining, minor of calcite on fracture surfaces, trace epidote. *Geophysical Note: There is an anomalous reading in the resistivity curve that manifests as a positive spike at 1535 ft bgs; this corresponds to the inflection point where the rate of temperature* *increase becomes greater than that shown for the local geothermal gradient in the previous 400 ft.*

1540–1550 ft Granite, very light grey, moderately crystalline, major mineral composition as above, minor chlorite alteration, minor chloritization of biotite, minor iron oxide staining, trace dolomite, minor calcite on fracture surfaces.

1550–1560 ft Granite, very light grey, moderately crystalline, major mineral composition as above, minor chlorite alteration, minor chloritization of biotite, trace dolomite, trace iron oxide staining, trace pyrite, with unusual amounts of clay in the sample cuttings.

1560–1570 ft Granite, very light grey to light greenish-grey, moderately crystalline, major mineral composition as above, increased chlorite alteration, minor chloritization of biotite, trace dolomite, minor iron oxide staining, trace pyrite, clay on fracture surfaces, minor argillic alteration, with unusual amounts of clay in the sample cuttings.

Appendix D

HC-2d Data

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Table D-1. HC-2d Chronology

Date	Time	Depth (ft bgs)	Activity
08/13/2014	14:20	NA	Commence mobilization and set-up of drilling rig on HC-2 to pull casing from old HC-2 well.
08/14/2014	11:23	NA	Rig set up on HC-2 complete; commence pulling out old well casing from HC-2 well.
08/15/2014	11:15	NA	Complete pulling old casing from HC-2, weld protective cap on open HC-2 wellhead, and mobilize drill rig off the HC-2 drill pad.
09/23/2014	00:30	NA	Started moving drill rig and equipment to the HC-2 well pad.
09/23/2014	20:00	NA	Started tripping into HC-2 borehole with 8-inch-diameter down-hole hammer bit.
09/24/2014	11:40	1,140	Tripped in to 1,140 feet when the drill bit plugged off.
09/24/2014	16:00	1,140	Tripped out of the borehole and removed sand/material that plugged cross-over and bottom-hole assembly.
09/24/2014	23:40	1,140	Tripped back in to 920 feet, where another bridge was encountered. Bit was washed down to 1,140 feet bgs.
09/25/2014	05:30	1,303	Started drilling new borehole HC-2d at 1,303 feet bgs.
09/25/2014	11:40	1,420	Borehole advanced to 1,420 feet bgs.
09/25/2014	23:40	1,700	Borehole advanced to 1,700 feet bgs.
09/26/2014	08:00	1,836	Borehole advanced to 1,836 feet bgs.
09/26/2014	14:00	1,836	Tripped drill string out of the borehole and rigged up for geophysical logging.
09/26/2014	14:00	1,836	Pacific Survey started logging but logging tool stopped at 840 feet bgs. A video log was run and a bridge in the borehole was identified at 840 feet bgs.
09/26/2014	17:30	1,836	Pacific Survey departed the site for Fallon and Boart set up to reenter the borehole and remove the bridge.
09/27/2014	06:00	1,836	Cleared borehole to the original drilled depth of 1,836 feet bgs and started tripping out in preparation for geophysical logging.
09/27/2014	12:15	1,836	Pacific Survey onsite and started logging, but encountered another bridge at 877 feet bgs. It was decided that the borehole would not be logged and that Boart would reenter and clear the borehole in preparation for well installation.
09/27/2014	23:40	1,836	Tripped in the drill string to 1,620 feet bgs removing bridges and clearing the borehole. At 1,620 feet bgs the cross-over became plugged.
09/28/2014	03:00	1,836	Tripped back out of the borehole to clear drill bit and cross-over blockage.
09/28/2014	18:30	1,836	Trip in and wash down to 1,700 feet bgs, cleaning hole and regaining circulation, with cuttings to surface.
09/28/2014	22:15	1,836	Trip out to prepare for well construction.
09/29/2014	13:00	1,836	Well casing installed, well landed at 1,657 feet bgs, with screened interval from 1,417 to 1,517 feet bgs.
09/29/2014	19:15	NA	Trip in and rig up for airlifting/well development on the HC-2d monitoring well.
09/29/2014	23:40	NA	Airlifted with 10 minutes of flow followed with 10 minutes of shut-in. A total of 399 gallons removed for the day.
09/30/2009	23:40	NA	Continued airlifting with 10 minutes of flow followed by 10 minutes of shut-in and some periods of continuous flow. A total of 1,489 gallons removed for the day.
10/01/2014	09:30	NA	Airlifted with 10 minutes of flow followed with 10 minutes of shut-in.
10/01/2014	19:30	NA	Trip out HQ rod from airlifting, trip in and swab the HC-2d monitoring well.
10/01/2014	23:45	NA	Airlifted with 10 minutes of flow followed with 10 minutes of shut-in. A total of 370 gallons removed for the day.
10/02/2014	21:00	NA	Airlifting was completed with a total of 620 gallons removed for the day and a cumulative 2,878 gallons removed during the initial development.
10/03/2014	19:00	NA	Drill rig demobilized off well pad. Submersible electric pump installed in HC-2d monitoring well.

Table D-1 (continued). HC-2d Chronology

Date	Time	Depth (ft bgs)	Activity
10/04/2014	11:25	NA	Submersible pump installation completed and started final development with the submersible electric pump.
10/04/2014	14:05	NA	Pumping with submersible electric pump in HC-2d well removed 900 gallons for the day.
10/05/2014	18:40	NA	Purged 1,200 gallons using the submersible electric pump.
10/06/2014	18:30	NA	Purged 480 gallons using the submersible electric pump. Well box installed on HC-2d.
11/11/2014	14:35	NA	Pumping with the submersible electric pump in HC-2d removed 830 gallons of water, with 6,288 cumulative gallons purged during the development.

Table D-2. HC-2d Construction Details

Construction	Material	Type	Depth Interval (ft)	Stemming Material	Volume (ft^3)	Interval (ft)
Monitoring well casing	5.5-inch o.d. CS flush-joint casing	Blank	0–1,417	NA	NA	NA
				NA	NA	NA
		Screen	1,417–1,517	NA	NA	NA
		Blank	1,517–1,557	NA	NA	NA
		Screen/end cap	1,557–1,657	NA	NA	NA

Notes: No stemming materials were used in the construction of HC-2d. Well was constructed and suspended by welded flanges on the surface casing and sealed at the surface.
CS = carbon steel
ft^3 = cubic feet
NA = not applicable

Table D-3. HC-2d Drilling and Development Tritium Analyses

Sample ID	Date	Time	Sample Depth (ft)	Tritium (pCi/L)	MDC (pCi/L)	±2 sigma (%)	Notes
Well Drilling							
HC-2d 1060 ft	9/24/14	09:55	1,060	−90.09	3024	NR	<MDC
HC-2d 1170 ft	9/25/14	01:40	1,170	1892	3070	145	<MDC
HC-2d 1230 ft	9/25/14	03:05	1,230	−1622	2947	165	<MDC
HC-2d 1270 ft	9/25/14	04:40	1,270	−1622	2971	141	<MDC
HC-2d 1310 ft	9/25/14	06:50	1,310	−1892	2798	1001	<MDC
HC-2d 1325 ft	9/25/14	07:45	1,325	−811	2896	1005	<MDC
HC-2d 1350 ft	9/25/14	08:35	1,350	−270	2944	504	<MDC
HC-2d 1370 ft	9/25/14	09:30	1,370	0	3048	1001	<MDC
HC-2d 1400 ft	9/25/14	10:45	1,400	−721	2999	332	<MDC
HC-2d 1440 ft	9/25/14	13:00	1,440	1441	2881	101	<MDC
HC-2d 1450 ft	9/25/14	14:00	1,450	2432	3025	112	<MDC
HC-2d 1480 ft	9/25/14	15:00	1,480	2432	3025	112	<MDC
HC-2d 1510 ft	9/25/14	16:00	1,510	2252	2917	78	<MDC
HC-2d 1550 ft	9/25/14	17:00	1,550	811	2824	112	<MDC
HC-2d 1570 ft	9/25/14	18:15	1,570	901	2944	249	<MDC
HC-2d 1590 ft	9/25/14	19:10	1,590	2883	3036	92	<MDC
HC-2d 1610 ft	9/25/14	20:05	1,610	2072	2875	72	<MDC
HC-2d 1650 ft	9/25/14	21:20	1,650	1712	2832	73	<MDC
HC-2d 1660 ft	9/25/14	23:15	1,660	811	2866	143	<MDC
HC-2d 1690 ft	9/26/14	01:15	1,690	1261	3083	496	<MDC
HC-2d 1720 ft	9/26/14	02:10	1,720	90	2908	331	<MDC
HC-2d 1740 ft	9/26/14	03:15	1,740	−1171	2766	496	<MDC
HC-2d 1760 ft	9/26/14	04:45	1,760	−360	3012	245	<MDC
HC-2d 1790 ft	9/26/14	05:40	1,790	−1261	2775	990	<MDC
HC-2d 1810 ft	9/26/14	06:35	1,810	−900	2868	986	<MDC
HC-2d 1830 ft	9/26/14	07:15	1,830	991	2934	143	<MDC
Well Development—Air							
HC-2d devel.	9/29/14	22:00	WD	2703	2934	111	<MDC
HC-2d devel.	9/30/14	01:00	WD	901	2927	322	<MDC
HC-2d devel.	9/30/14	04:00	WD	541	2762	488	<MDC
HC-2d devel.	9/30/14	06:50	WD	1171	2868	974	<MDC
HC-2d devel.	9/30/14	10:20	WD	901	2879	970	<MDC
HC-2d devel.	9/30/14	13:20	WD	1171	3036	994	<MDC
HC-2d devel.	9/30/14	16:30	WD	811	2966	498	<MDC
HC-2d devel.	9/30/14	19:20	WD	1622	3095	994	<MDC
HC-2d devel.	9/30/14	22:20	WD	541	2887	250	<MDC
HC-2d devel.	10/1/14	07:00	WD	1441	2978	331	<MDC
HC-2d devel.	10/2/14	07:00	WD	1261	3013	327	<MDC
HC-2d devel.	10/2/14	10:00	WD	1802	3036	197	<MDC
HC-2d devel.	10/2/14	13:00	WD	2703	3093	102	<MDC
HC-2d devel.	10/2/14	16:00	WD	360	3096	331	<MDC
HC-2d devel.	10/2/14	19:00	WD	−180	2931	1001	<MDC
HC-2d devel.	10/2/14	21:00	WD	2703	3050	85	<MDC

Table D-3 (continued). HC-2d Drilling and Development Tritium Analyses

Sample ID	Date	Time	Sample Depth (ft)	Tritium (pCi/L)	MDC (pCi/L)	±2 sigma (%)	Notes
Well Development—Pump							
HC-2d devel.	10/4/14	12:45	WD	991	2983	170	<MDC
HC-2d devel.	10/4/14	14:05	WD	2703	3219	203	<MDC
HC-2d devel.	10/5/14	08:00	WD	2162	NR	NR	<MDC
HC-2d devel.	10/5/14	09:00	WD	270	NR	NR	<MDC
HC-2d devel.	10/5/14	10:00	WD	−270	NR	NR	<MDC
HC-2d devel.	10/5/14	11:30	WD	991	NR	NR	<MDC
HC-2d devel.	10/5/14	13:00	WD	360	NR	NR	<MDC

NR = The values for the MDC and ±2 sigma were not recorded but were documented as being below MDC
MDC = minimum detectable concentration

Table D-4. HC-2d Drilling and Development Water Quality and Bromide Analyses

Sample ID	Date	Time	Sample Depth (ft)	pH (s.u.)	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Br^- (mg/L)
Well Drilling								
HC-2d 1060 ft	9/24/14	09:55	1,060	7.55	20.4	596	NM	31
HC-2d 1170 ft	9/25/14	01:40	1,170	7.94	19.2	659	NM	37
HC-2d 1230 ft	9/25/14	03:05	1,230	7.79	19.9	691	NM	33
HC-2d 1270 ft	9/25/14	04:40	1,270	7.85	19.8	663	NM	26
HC-2d 1310 ft	9/25/14	06:50	1,310	7.96	17.3	699	NM	34
HC-2d 1325 ft	9/25/14	07:45	1,325	7.85	18.4	657	NM	30
HC-2d 1350 ft	9/25/14	08:35	1,350	8.16	19.3	667	NM	31
HC-2d 1370 ft	9/25/14	09:30	1,370	8.17	18.9	640	NM	33
HC-2d 1400 ft	9/25/14	10:45	1,400	7.74	21.6	623	NM	25
HC-2d 1440 ft	9/25/14	13:00	1,440	7.95	21.3	601	NM	30
HC-2d 1450 ft	9/25/14	14:00	1,450	8.07	21.9	649	NM	43
HC-2d 1480 ft	9/25/14	15:00	1,480	8.00	21.8	662	NM	43
HC-2d 1510 ft	9/25/14	16:00	1,510	8.05	21.0	718	NM	42
HC-2d 1550 ft	9/25/14	17:00	1,550	8.11	19.5	622	NM	39
HC-2d 1570 ft	9/25/14	18:15	1,570	7,70	19.4	565	NM	40
HC-2d 1590 ft	9/25/14	19:10	1,590	8.11	18.6	694	NM	44
HC-2d 1610 ft	9/25/14	20:05	1,610	8.00	19.1	607	NM	46
HC-2d 1650 ft	9/25/14	21:20	1,650	7.92	19.1	521	NM	24
HC-2d 1660 ft	9/25/14	23:15	1,660	8.09	17.1	521	NM	30
HC-2d 1690 ft	9/26/14	01:15	1,690	8.09	16.4	702	NM	32
HC-2d 1720 ft	9/26/14	02:10	1,720	8.24	16.8	680	NM	28
HC-2d 1740 ft	9/26/14	03:15	1,740	8.23	16.5	697	NM	34
HC-2d 1760 ft	9/26/14	04:45	1,760	7.83	16.1	577	NM	28
HC-2d 1790 ft	9/26/14	05:40	1,790	8.06	14.8	722	NM	31
HC-2d 1810 ft	9/26/14	06:35	1,810	8.01	14.5	722	NM	27

Table D-4 (continued). HC-2d Drilling and Development Water Quality and Bromide Analyses

Sample ID	Date	Time	Sample Depth (ft)	pH (s.u.)	Temperature (°C)	Specific Conductance (µS/cm)	Turbidity (NTU)	Br^- (mg/L)
HC-2d 1830 ft	9/26/14	07:15	1,830	7.90	14.1	685	NM	24
Well Development—Air								
HC-2d devel.	9/29/14	22:00	WD	7.81	19.4	628	>1000	10
HC-2d devel.	9/30/14	01:00	WD	7.95	21.5	749	>1000	9.5
HC-2d devel.	9/30/14	04:00	WD	7.91	21.6	689	692	6.7
HC-2d devel.	9/30/14	06:50	WD	7.94	21.9	677	872	5.8
HC-2d devel.	9/30/14	10:20	WD	8.00	20.4	667	484	5.1
HC-2d devel.	9/30/14	13:20	WD	8.06	22.1	696	291	5.5
HC-2d devel.	9/30/14	16:30	WD	8.10	21.3	686	124	5.0
HC-2d devel.	9/30/14	19:20	WD	8.01	18.1	691	214	4.5
HC-2d devel.	9/30/14	22:20	WD	8.01	19.3	709	94.1	3.3
HC-2d devel.	10/1/14	07:00	WD	8.10	17.9	690	112	2.6
HC-2d devel.	10/2/14	07:00	WD	7.90	16.2	701	52.2	2.6
HC-2d devel.	10/2/14	10:00	WD	8.01	19.1	704	62.5	2.6
HC-2d devel.	10/2/14	13:00	WD	8.02	20.7	704	33.9	3.0
HC-2d devel.	10/2/14	16:00	WD	8.05	20.6	706	18.9	2.7
HC-2d devel.	10/2/14	19:00	WD	8.03	18.8	699	14.7	3.0
HC-2d devel.	10/2/14	21:00	WD	8.02	19.1	703	17.2	3.0
Well Development—Pump								
HC-2d devel.	10/4/14	12:45	WD	7.36	21.1	690	20.7	2.1
HC-2d devel.	10/4/14	14:05	WD	7.41	22.2	693	49.3	2.0
HC-2d devel.	10/5/14	08:00	WD	7.48	18.9	678	24.6	2.0
HC-2d devel.	10/5/14	09:00	WD	7.5	20	699	22.6	1.9
HC-2d devel.	10/5/14	10:00	WD	7.48	20.7	697	41.8	2.0
HC-2d devel.	10/5/14	11:30	WD	7.56	21.4	705	86	3.9
HC-2d devel.	10/5/14	13:00	WD	7.58	22.4	695	17.5	2.2
HC-2d devel.	10/6/14	08:00	WD	NM	NM	NM	NM	0.71
HC-2d devel.	10/6/14	08:00	WD	NM	NM	NM	NM	0.53

NM = not measured
WD = well development
s.u. = standard units

Table D-5. HC-2d Pump and Tubing Details

Well ID	Pump Riser Material	Diameter	Estimated Depths	Material Description
HC-2d	Carbon steel riser pipe	1 inch	0–1,397 ft bgs	Approximate 32 ft lengths of API J-55 riser pipe with external upset ends.
	Electric supply cable	NA	0-1,402 ft bgs	Kalas 8 AWG #10, 600-volt flat, 4 wire submersible pump cable.
	Electric pump	<5 inches	1,397 ft bgs (top) 1,402 ft bgs (intake) 1,404 ft bgs (bottom)	Grundfos pump, model 10S50-58DS, with MS4000 5-horsepower, 480-volt, three-phase motor.

HC-2d Lithologic Descriptions

(well cuttings described dry and in natural light)

Well HC-2d is the monitoring well installed at the HC-2 well site after this well had its original well casing pulled out of the ground and the original well bore was deepened. The lithologic descriptions provided here are only for the section from 1,303 ft bgs (the depth of the original well) down to 1,836 ft bgs, total depth for the deepened well. The lithology in the deepened portion of HC-2d is largely the same medium crystallinity very light grey to light greenish-grey granite. The basic mineral composition of the granite does not appreciably change. The primary lithologic differences within the granite are the degree to which it has been chloritized, and whether sulfide minerals are visible or not. Typically, sulfide minerals are found in the more chloritically altered portions of the granite in HC-2d, whereas the unaltered portions of it are largely (but not always) barren of sulfide minerals. While pyrite is by far the dominant sulfide mineral, chalcopyrite has also been observed in these cuttings. Fracture coatings are primarily chlorite and clay, occasionally calcite.

1303–1350 ft	Granite, medium crystallinity, very light grey to light greenish-grey, 20% quartz, 34% light greenish-grey plagioclase, 34% potassium feldspar, 7% biotite, 2–3% actinolitic hornblende, 1% sphene, 1% magnetite, trace of pyrite. Biotite is partially altered to chlorite (chloritized) and, locally, hornblende exhibits incipient chloritization, and some secondary chlorite occurs within the groundmass. Trace of iron oxide staining. Locally, these cuttings contain xenoliths of chloritized amphibolites.
1350–1370 ft	Granite, medium crystallinity, light greenish-grey, mineral composition same as above, with only minor chloritization of biotite (none of hornblende), some oxidation of magnetite, no pyrite.
1370–1380 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above but with minor chloritization of the groundmass, chloritized biotite, and chlorite coating fracture surfaces, trace of pyrite. *Note: The cuttings for this sample were unusually coarse, which has been associated with fault zones or fracture zones in other drill holes at the Shoal site. Therefore, I interpret a fracture zone at this interval.*
1380–1390 ft	Granite, medium crystallinity, very light grey, mineral composition as above, but with no chlorite in the groundmass and only incipient chloritization of the biotite.
1390–1400 ft	Granite, medium crystallinity, light greenish-grey, mineral composition as above but with minor chlorite in the groundmass, and minor chloritization of the biotite, some oxidation of magnetite and iron oxide staining, and a minor increase in sulfide minerals (pyrite and chalcopyrite). The cuttings for this sample were unusually coarse.
1400–1415 ft	Granite, medium crystallinity, very light grey, mineral composition as above but no chlorite in the groundmass and only incipient chloritization of the biotite.
1415–1450 ft	Granite, medium crystallinity, light greenish-grey, mineral composition as above, but with some chlorite in the groundmass, and some chloritization of the biotite; clay and chlorite mineral coatings on fracture surfaces. From 1430 to 1450 ft bgs the cuttings for these samples were unusually coarse.
1450–1460 ft	Granite, medium crystallinity, light greenish-grey, mineral composition as above but with some chlorite in the groundmass and some chloritization of the biotite, increase in pyrite; clay and chlorite mineral coatings on fracture surfaces.
1460–1480 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above, but with no chloritization of the groundmass, some chloritized biotite; chlorite coating some fracture surfaces and calcite coating other fracture surfaces.

1480–1500 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above but with minor chloritization of the groundmass and chloritized biotite, trace of pyrite, and trace of iron oxide mineral staining.
1500–1510 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above, minor chloritization of the groundmass and chloritized biotite as above, but with metamorphic xenoliths. Sample contains extensive clay coatings on fracture surfaces.
1510–1530 ft	Granite, medium crystallinity, light greenish-grey, mineral composition as above, with some chlorite and dolomite in the groundmass, some chloritization of the biotite, trace of pyrite, minor iron oxide staining.
1530–1590 ft	Granite, medium crystallinity, very light grey, mineral composition as above but with no chlorite in the groundmass, and only minor chloritization of the biotite, no other alteration, no visible sulfides.
1590–1600 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above, with minor chlorite in the groundmass, some chloritization of the biotite, and minor iron oxide staining.
1600–1630 ft	Granite, medium crystallinity, very light grey, mineral composition as above, with no chlorite or other alteration of the groundmass, but incipient to pervasive chloritization of the biotite.
1630–1660 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above, with some chlorite in the groundmass, and some chloritization of the biotite, minor pyrite, trace of iron oxide staining, clay coatings on fracture surfaces.
1660–1670 ft	Same as above, but with significant pinkish clay in the sample, indicating argillically altered fractures.
1670–1700 ft	Granite, medium crystallinity, very light grey, mineral composition as above, no chlorite in the groundmass, minor to trace of chloritization of the biotite (biotite alteration decreases downward through this interval), minor iron oxide staining, no sulfides (pyrite).
1700–1720 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above, no alteration of the groundmass but some chloritization of the biotite, trace of pyrite, trace of iron oxide staining.
1720–1750 ft	Granite, medium crystallinity, very light grey, mineral composition as above, no alteration of the groundmass but some chloritization of the biotite, trace of pyrite, trace of iron oxide staining.
1750–1800 ft	Granite, medium crystallinity, very light grey, mineral composition as above, no alteration of the groundmass, chloritization of the biotite decreases downward, no visible pyrite, trace of iron oxide staining.
1800–1830 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above, with some chlorite in the groundmass, and increasing chloritization of the biotite, trace pyrite, trace of iron oxide staining, local chlorite coatings on fracture surfaces.
1830–1836 ft	Granite, medium crystallinity, very light grey to light greenish-grey, mineral composition as above, with some chlorite in the groundmass, and some chloritization of the biotite, minor pyrite, trace of iron oxide staining, clay coatings on fracture surfaces.

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