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2016 Groundwater Monitoring and Inspection Report Gnome-Coach, New Mexico, Site

January 2017

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Abbreviations

AEC	U.S. Atomic Energy Commission
bgs	below ground surface
BLM	U.S. Bureau of Land Management
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
ft	feet
GEMS	Geospatial Environmental Mapping System
LM	Office of Legacy Management
LTHMP	Long-Term Hydrologic Monitoring Program
LTS&MP	Long-Term Surveillance and Maintenance Plan
m/day	meters per day
OCD	New Mexico Oil Conservation Division
OSE	New Mexico Office of the State Engineer
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

Executive Summary

The Gnome-Coach, New Mexico, Site was the location of an underground nuclear test in 1961 and a groundwater tracer test in 1963. Residual contamination remaining in the subsurface from these events requires long-term oversight. The Long-Term Surveillance and Maintenance Plan for the site describes the U.S. Department of Energy Office of Legacy Management's (LM's) plan for monitoring groundwater (radiochemical sampling and hydraulic head measurements), inspecting the site, maintaining the site's institutional controls, evaluating and reporting data, and documenting the site's records and data management processes. Groundwater monitoring and site inspection activities are conducted annually. This report summarizes the results of these activities conducted during the October 2015 through September 2016 reporting period.

The site inspection and annual sampling were conducted on January 27, 2016. At the time of the site inspection, the signs installed near the emplacement shaft, near well USGS-1, and around the perimeter of the site were observed as being in good condition, as were the roads, wellheads, and Project Gnome monument. No new groundwater extraction wells or oil and gas wells were installed during this reporting period on the site or in the sections that surround the site. One new application was received by the New Mexico Oil Conservation Division to install a salt water disposal well approximately 0.8 miles northeast of the Project Gnome monument. The proposed well has a planned completion depth of 15,500 feet below ground surface, but as of November 2016 a drill date has not been established.

The annual sampling included the collection of samples from the wells completed in the Culebra Dolomite (wells USGS-1, USGS-4, and USGS-8) that monitor for radioisotopes used during the tracer test. No radiochemical sampling was done for the wells completed in the Salado Formation (wells DD-1 and LRL-7). Concentrations of tritium, strontium-90, and cesium-137 (which were among the radioisotopes used in the 1963 tracer tests) were detected in wells USGS-4 and USGS-8, and the levels were consistent with historical results. The tracer-test radioisotopes were not detected in the sample from well USGS-1, which is also consistent with historical results. Well USGS-1 has a submersible electric pump and is used to provide water for livestock belonging to area ranchers. Hydraulic head data continued to show that pumping in well USGS-1 produces a water level drawdown response in wells USGS-4 and USGS-8. Hydraulic head data from well LRL-7, which monitors the Coach drift, indicated that water levels have nearly recovered from the last radiochemical sampling of that well in January 2011. Manual water level measurements collected from the reentry well DD-1, which monitors the detonation cavity, confirmed that the transducer in this well failed in June 2011 and that water levels are rising at a rate of approximately 10 feet per year.

Data collected during this and previous monitoring events (including sample analysis and water-level measurements) are available on the Geospatial Environmental Mapping System (GEMS) website at http://gems.lm.doe.gov/#site=GNO. This report and other reports are available on the LM public website at http://www.lm.doe.gov/gnome/Sites.aspx, and copies of this report are sent to the individuals on the distribution list provided as Appendix C.

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1.0 Introduction

This report presents the groundwater monitoring and site inspection data collected by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) at the Gnome-Coach, New Mexico, Site (Figure 1). The site was the location of an underground nuclear test in 1961 and a radioisotopic groundwater tracer test in 1963, which resulted in residual radionuclide contamination in the groundwater and post-detonation features that require long-term oversight. Long-term responsibility for the site was transferred from the DOE National Nuclear Security Administration Nevada Site Office to LM on October 1, 2006. The Long-Term Surveillance and Maintenance Plan (LTS&MP) for the site describes LM's plan for monitoring groundwater (radioisotope concentrations and hydraulic head), inspecting the site and maintaining the institutional controls, evaluating and reporting data, and documenting the site's records and data management processes (DOE 2016b).

This report summarizes the results of the groundwater monitoring and site inspection activities conducted during the October 2015 through September 2016 reporting period. The purpose of these activities is to monitor the groundwater and ensure that the institutional controls are protective of the site and human health and the environment. This annual report and the LTS&MP are available on the LM public website at http://www.lm.doe.gov/gnome/Sites.aspx. Data collected during this and previous monitoring events (including sample analytical results and water-level data) are available on the Geospatial Environmental Mapping System (GEMS) website at http://gems.lm.doe.gov/#site=GNO.

2.0 Site Location and Background

The Gnome-Coach site is approximately 25 miles southeast of Carlsbad in Eddy County, New Mexico (Figure 1). The U.S. Atomic Energy Commission [(AEC) (a predecessor agency to DOE)] acquired the site through a land withdrawal from the U.S. Bureau of Land Management (BLM) in the early 1960s for underground nuclear testing through the Plowshare Program (AEC 1962). The Plowshare Program was a research and development initiative started in 1957 to determine the technical and economic feasibility for peaceful applications of nuclear energy. The withdrawal comprises two parcels of land of approximately 680 acres. The larger parcel (640 acres) is where the underground nuclear test and tracer test occurred and consists of Section 34 within Township 23 South, Range 30 East. The smaller parcel (40 acres) was used for observation during the underground test and is in Section 10, Township 23 South, Range 30 East. The focus of this report is the 640-acre parcel identified as the Gnome-Coach site, where the underground nuclear test and radioisotopic tracer test occurred (Figure 1).

The purpose of the underground nuclear test, identified as Project Gnome, was to study the possibility of converting the energy from nuclear detonations into electricity, investigate the production and retrieval of radioisotopes, measure neutron activation cross-sections of specific isotopes, collect data on the characteristics of nuclear explosions in salt formations, and collect data for use in future Plowshare projects (AEC 1962). Preparation for the test began in 1958 and involved multiple agencies. The U.S. Geological Survey (USGS) installed several wells and boreholes to assess the geologic and hydrologic conditions at the site (Section 2.1). The site was determined suitable for the experiment and a 10-foot-diameter vertical emplacement shaft was excavated to a depth of 1216 feet (ft) below ground surface (bgs) (Figure 2).

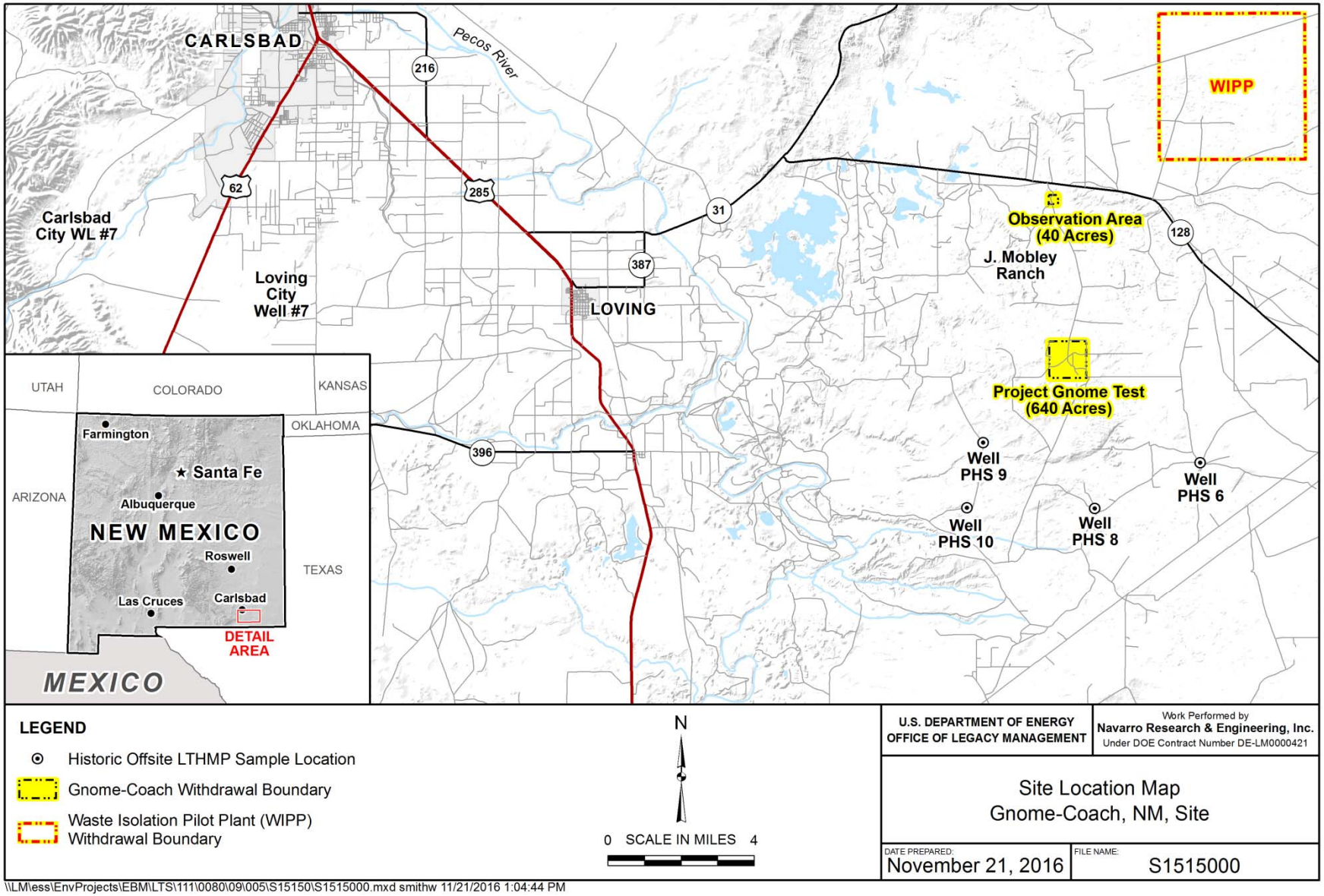

Figure 1. Location Map for the Gnome-Coach, New Mexico, Site

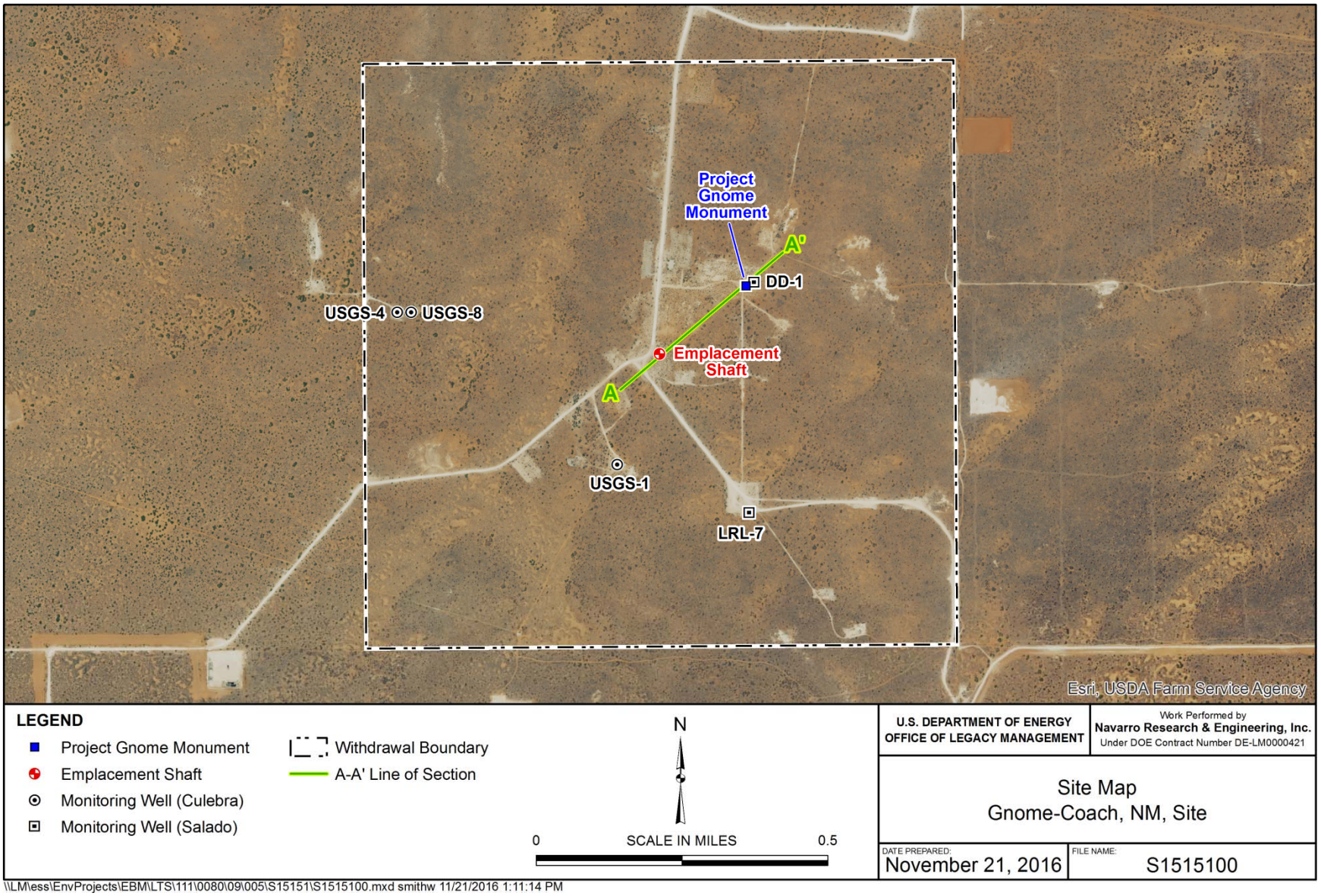

Figure 2. Site Map for the Gnome-Coach, New Mexico, Site

A horizontal drift (Gnome drift) was mined from the bottom of the shaft, extending 1116 ft to the northeast, ending in a hook shape that was completed in the Salado Formation. The hook shape was designed for placement of the nuclear device and was intended to be self-sealing following the detonation that occurred at a depth of 1184 ft bgs on December 10, 1961. The nuclear device had a reported yield of 3 kilotons. Immediately following the detonation, close-in stemming materials failed, and gases from the detonation cavity vented to the atmosphere through the Gnome drift and the emplacement shaft (AEC 1962). The cavity that resulted from the detonation has dimensions that are well documented because scientists entered the cavity 5 months after the test in May 1962 (Figure 3). Posttest drilling operations and preparations for another underground nuclear test, identified as Project Coach, began shortly after the Gnome test. The emplacement shaft was restored and deepened to a depth of 1284 ft bgs, and a second horizontal drift, which is called the Coach drift, was mined 1945 ft southeast from the shaft (AEC 1969). The Coach experiment was initially scheduled for 1963 but was canceled and no additional underground nuclear detonations occurred at the site. The site is still referred to as the Gnome-Coach site.

In 1963, the USGS conducted a groundwater tracer test between wells USGS-4 and USGS-8 using four dissolved radionuclides (tritium, iodine-131, strontium-90, and cesium-137) as tracers. Wells USGS-4 and USGS-8 are completed in the Culebra Dolomite and are approximately 3100 ft west of the Project Gnome monument, which is directly above the detonation cavity (Figure 2). The tracer test experiment was performed using USGS-4 as the extraction well and USGS-8 as the injection well. The extracted groundwater was mixed with the radioisotope tracer solution and injected into well USGS-8 at the same rate as the extraction to create a steady-state flow field between the wells. The Culebra Dolomite is a fractured carbonate aquifer that is approximately 500 ft bgs at the site and the most prolific aquifer near the site (Figure 3). The purpose of the tracer test was to estimate the dispersion coefficient and effective porosity of the Culebra for evaluating the potential movement of radionuclides (Beetem and Angelo 1964).

2.1 Geology and Hydrology

The Gnome-Coach site is in the northwestern part of the Delaware Basin, a deep, oval, sedimentary basin 75 miles wide and 135 miles long in southeastern New Mexico. The geology and hydrology of this basin are well studied because of oil and gas exploration, mining, and operation of the Waste Isolation Pilot Plant (WIPP) approximately 8.5 miles north-northeast of the site (measured from the approximate center of each withdrawal boundary). The basin lithology comprises crystalline sedimentary rocks overlain by evaporites that were deposited during the late Permian Period when a warm shallow sea was blocked from seawater circulation. As the seawater evaporated, the transition from a deep marine environment (limestone and dolomite) to a shallow marine and later dry environment (gypsum, halite, anhydrite, and potassium salts [potash]) resulted in several thousand feet of deposits accumulating on the basin floor (USGS 1962). The basin deposits and the lithostratigraphic units they compose are almost flat to gently dipping to the east and southeast in the vicinity of the Gnome site (USGS 1962).

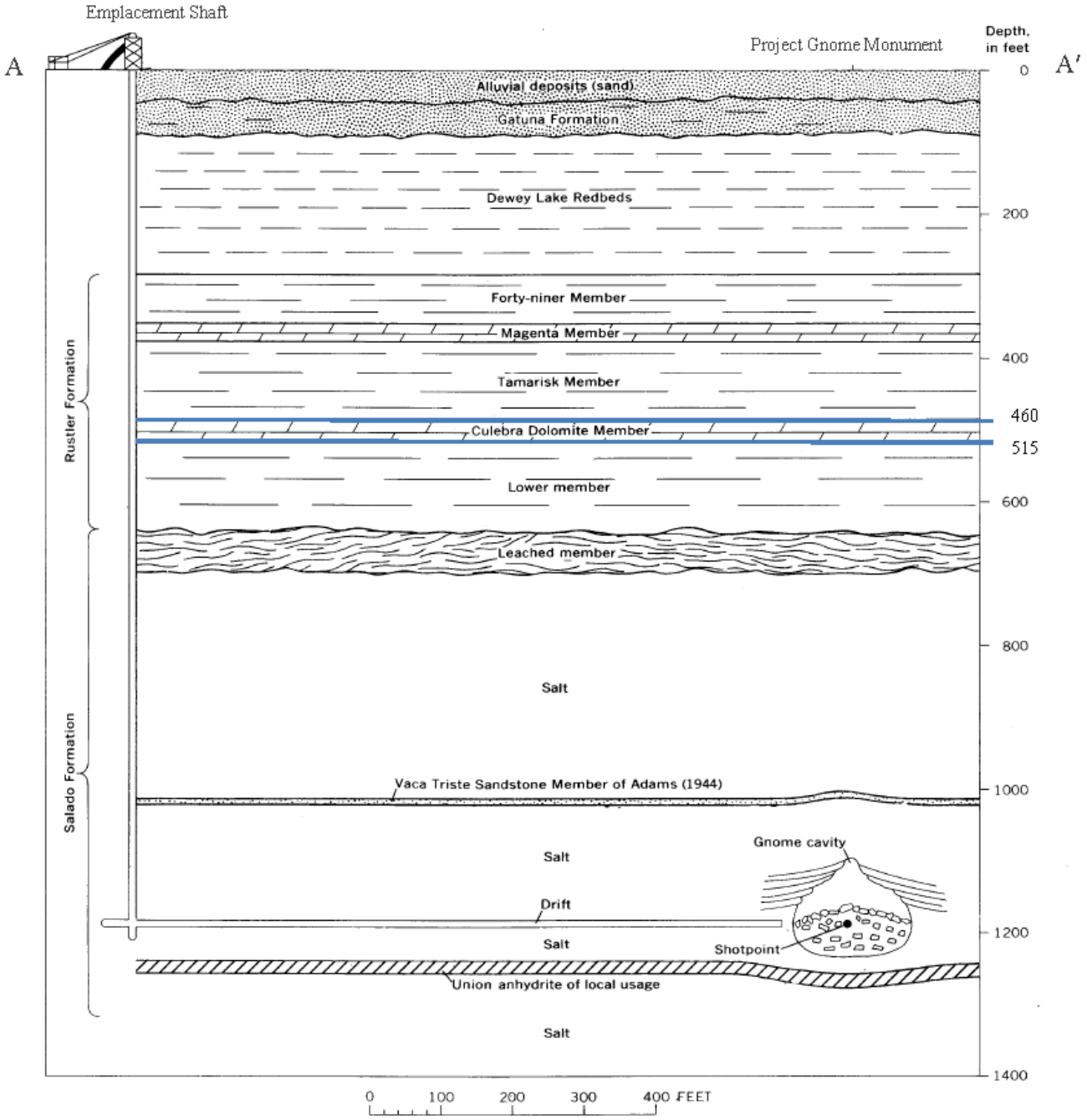

Figure 3. Stratigraphic Cross-Section at the Gnome-Coach, New Mexico, Site

The lithostratigraphic units beneath the Gnome site were defined during the pretest drilling and mining of the emplacement shaft. Figure 3 is a cross section that shows these units with the emplacement shaft, the Gnome drift, and the cavity that resulted from the nuclear detonation. The Salado Formation, in which the detonation took place, is an approximately 1500-ft-thick bed of halite with potassium minerals and minor amounts of sandstone, siltstone, shale, anhydrite, and gypsum that formed at the site during the Permian Period (USGS 1968). Overlying the Leached Member of the Salado Formation are five thinly bedded members of the Rustler Formation. In ascending order, these are the Lower Member (now referred to as the

Los Medanos Member), which primarily consists of clay and silt with some gypsum and anhydrite; the Culebra Dolomite Member; the Tamarisk Member, which consists of anhydrite and gypsum; the Magenta Member, which consists of silty dolomite; and the Forty-Niner Member, a mixture of gypsum and anhydrite (USGS 1968). The youngest Permian sequences in the site area are the thinly bedded siltstones of the Dewey Lake Redbeds Formation. Overlying the Dewey Lake Redbeds Formation are the Gatuna Formation, which was deposited after the Permian Period, and the alluvial sand deposits, which are Quaternary deposits (USGS 1968).

The Culebra Dolomite Member of the Rustler Formation is a widespread, laterally continuous, fractured carbonate aquifer in which the radioisotope groundwater tracer test took place. It is approximately 30 ft thick and is present at depths ranging from approximately 460 to 515 ft bgs at the site (Figure 3). The Culebra is the most prolific aquifer in the vicinity of the site; despite the poor water quality associated with high concentrations of dissolved solids (Mercer 1983), ranchers access it to provide water to their livestock throughout the area. Water level data collected from wells completed in the Culebra (Figure 2; USGS-1, USGS-4, and USGS-8) prior to and after the underground test indicate that the Culebra aquifer is confined (under artesian conditions) at the site. These data (historical and recent) also indicate that the aquifer is sensitive to pressure changes. Water level responses were seen in the observation wells (USGS-1 and USGS-4) immediately following the underground nuclear test (USGS 1962) and, more recently, wells USGS-4 and USGS-8 have responded to changes in the pumping of groundwater from well USGS-1 (DOE 2016a). Groundwater within the Culebra moves through fractures in the dolomite, which is fairly permeable at the site, with hydraulic conductivities measuring approximately 4 meters per day (m/day) (USGS 1971). The hydraulic conductivity generally decreases to the northeast near the WIPP facility, ranging from 0.27 to 2.7×10^{-3} m/day (DOE 2012b). It is reported that groundwater flow within the Culebra near the WIPP facility is generally to the south (DOE 2012a).

The Salado Formation, in which the nuclear detonation took place, is characterized as a regional aquiclude because of the hydraulic properties of the bedded halite within the formation (DOE 2012b). The plastic nature of salt under pressure of its own weight and that of overlying units results in movement over time that closes openings (fractures and void spaces) within the deposit, making any continuous movement of water through the formation highly unlikely. Permeability testing conducted in the Salado Formation near the WIPP facility measured hydraulic conductivities that were less than 6.5×10^{-9} m/day (DOE 2012b). The low permeability, low porosity, and plastic nature of salt are characteristics that supported the determination that the bedded halite of the Salado Formation is an optimal geologic material to host a nuclear waste repository (SNL 1997). These same characteristics also limit the transport potential of any residual contamination associated with the Gnome detonation cavity, and the assumption is that the detonation cavity and drifts will close over time. Fluids associated with the Salado Formation occur mainly as small fluid inclusions in the halite crystals and also occur between crystal boundaries (interstitial fluid) of the massive crystalline salt formation; fluids also occur in clay seams and anhydrite beds. Wastes were mixed with water and injected into the test cavity for disposal during surface cleanup activities (Section 2.2). Fluid levels in the detonation cavity are monitored by the reentry well DD-1 and in the Coach drift by well LRL-7, both of which are in the Salado Formation.

2.2 Summary of Reclamation and Remediation Activities

Cleanup of the surface and shallow subsurface contamination resulting from the underground nuclear testing, post-test drilling, and groundwater tracer test was conducted in 1968 and 1969. A second major cleanup was conducted from 1977 to 1979 (REECO 1981). During this phase of the cleanup, liquid waste was pumped into the cavity through existing vent holes; contaminated material was disposed of in the emplacement shaft and the Coach drift through existing drill holes; uncontaminated equipment was moved offsite; and drill holes were plugged except those retained for use as groundwater monitoring wells (AEC 1969). While conducting a survey and sampling event in 1994, the U.S. Environmental Protection Agency (EPA) identified radiological contamination on the surface and in the shallow subsurface. The DOE National Nuclear Security Administration Nevada Site Office conducted a corrective action investigation to assess the extent of contamination at the site. The field investigations were performed from February through June 2002 and in May 2003. Contamination identified during the field investigation was excavated and disposed of offsite. A post-remediation surface radiological survey identified areas having radiological concentrations above background, but none of the concentrations were above the action levels determined to be safe for the public. The Corrective Action Investigation Report (DOE/NNSA 2004) summarizes the results of the investigation. After discussions with the State of New Mexico, it was decided that the site would be administered under the Voluntary Remediation Program. DOE prepared a Completion Report in accordance with the Voluntary Remediation Program (DOE/NNSA 2005), and a Conditional Certificate of Completion documents that surface remediation activities have been completed in accordance with the Voluntary Remediation Program (NMED 2014).

Subsurface activities have consisted of annual sampling and monitoring of groundwater as part of the Long-Term Hydrologic Monitoring Program (LTHMP). EPA began the LTHMP in 1972 (EPA 1972) and conducted the sampling until 2008, when LM assumed responsibility for sampling. In 2009, LM evaluated the LTHMP to determine the effectiveness of the monitoring network and to determine future monitoring at the site. The evaluation considered potential transport pathways for contaminant migration from the detonation zone and tracer test area to surrounding receptors. Samples collected from these locations have generally been analyzed for gamma-emitting radionuclides (using high-resolution gamma spectrometry), strontium-90, and tritium (using conventional and electrolytic enrichment methods). Analytical results from more than 30 years of monitoring indicate that groundwater at sample locations outside the land-withdrawal boundary (Figure 1) were not impacted by nuclear-test-related contamination. For this reason, the monitoring was focused on the monitoring wells within the site boundary in 2010 (Figure 2). Table 1 provides the monitoring network wells with the unit monitored, purpose for monitoring, and frequency for monitoring (sampling and water levels).

Low-flow bladder pumps were installed in wells USGS-4, USGS-8, and LRL-7 in June 2008 to enhance monitoring at the site. The dedicated bladder pumps were installed to replace the previous sampling method that used a depth-specific bailer and to allow the collection of more representative samples using the low-flow sampling method. Pressure transducers were also installed in the onsite monitoring wells in 2008, 2009, and 2010 to monitor water level changes. Geophysical well logging was conducted in onsite wells USGS-1, USGS-4, and USGS-8 in April 2010. The well logging was conducted to obtain borehole deviation data from wells USGS-1 and USGS-4, natural gamma data from wells USGS-4 and USGS-8, and downhole video logs from wells USGS-4 and USGS-8. The borehole deviation data allow measured depths to be corrected to true vertical depths to support the calculation of hydraulic

head at site wells that deviate from vertical. The gamma ray logs provide geologic information that can be used to correlate with other wells in the area. The video log images suggest that the well casings are generally in good condition. The 2010 Groundwater Monitoring and Inspection Report (DOE 2011) summarizes the well-logging results.

Table 1. Gnome-Coach Site Monitoring Well Network

Well Identification	Purpose for Monitoring	Formation/Unit Monitored	Monitoring Frequency	
			Sampling	Water Levels
USGS-1[a]	Point of Access	Culebra Dolomite	Annual	Annual
USGS-4	Tracer Test			
USGS-8				
LRL-7	Coach Drift	Salado Formation	Periodic	
DD-1	Detonation Cavity			

Note:
[a] This well has been used since the early 1980s as a point of diversion to provide water for livestock belonging to area ranchers under the BLM water right C01901.

A seismic reflection survey was conducted at the site in early 2011. Seven seismic reflection profiles totaling approximately 13.9 miles were acquired to assist in the interpretation of subsurface conditions (geology and hydrogeology) at and near the site. The survey was designed to image the upper few thousand feet of the section, which includes the Culebra Dolomite (at a depth of about 475 ft bgs at wells USGS-4 and USGS-8) and the detonation (at a depth of 1184 ft bgs) within the Salado Formation. A check-shot survey was acquired in well USGS-4 to calibrate the seismic profiles to the subsurface lithology. Significant features identified that would influence groundwater flow were areas of collapse in the evaporites overlying the Salado Formation and possible faults that cross the site. The 2012 Groundwater Monitoring and Inspection Report (DOE 2013) summarizes the seismic survey results.

Well boxes were installed at USGS-4, USGS-8, LRL-7, and DD-1 in 2012 and 2013 to improve wellhead security at the site. This resulted in modifications to the USGS-4 and USGS-8 wellheads. The USGS-1 wellhead was also modified in 2013 to repair damage received from a water truck (DOE 2013). The wellhead modifications established new measuring points on the top of casing for measuring depth to groundwater in these wells. To account for these modifications, the monitoring wells were surveyed by a registered land surveyor in 2014 to provide northings and eastings with new top-of-casing elevations. The 2014 Groundwater Monitoring and Inspection Report (DOE 2015) summarizes the wellhead survey data.

Repairs were made to the DD-1 wellhead and a totalizing flow meter was installed at well USGS-1 in January 2015. Repairs to the reentry well DD-1 were necessary because of vandalism that occurred in July 2014 (DOE 2015). Well USGS-1 has a submersible electric pump, and a totalizing flow meter was installed to monitor total gallons removed from the well. Signs were also installed at the site in April 2015 to inform the public that ground-disturbing activities are not allowed at the site without permission from LM. These signs were installed near the emplacement shaft, near well USGS-1, and around the perimeter of the site. The signs fulfill a requirement of the Conditional Certificate of Completion that was issued by the New Mexico Environment Department. The 2015 Groundwater Monitoring and Inspection Report (DOE 2016a) summarizes these activities.

3.0 Groundwater Monitoring and Inspection Results

The LTS&MP provides guidance for groundwater monitoring and inspection activities at the site (DOE 2016b). These activities include working with the local agencies and frequent monitoring of public websites to maintain the institutional controls and ensure protectiveness of the site (Section 3.1). The field activities, which were conducted on January 27, 2016, included a site inspection (Section 3.1), downloading data from pressure transducers (Section 3.2), measuring depth-to-groundwater (Section 3.2), and collecting groundwater samples (Section 3.3). The data from the pressure transducers were downloaded again in early September 2016. The *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites* (LMS/PRO/S04351) provides the procedures used to guide the quality assurance / quality control of the annual sampling and monitoring program. These procedures incorporate standards and guidance from EPA, DOE, and American Society for Testing and Materials (ASTM) International. The Sampling and Analysis Plan can be accessed on the LM website at https://energy.gov/sites/prod/files/2015/02/f19/S04351_SAP.pdf. The site inspection and monitoring results are summarized in the following sections.

3.1 Site Inspection and Results

The Gnome-Coach site lands are under federal jurisdiction and administered by BLM. On October 26, 1961, the site was withdrawn from all forms of appropriation associated with mining laws and leasing through Public Land Order 2526 (Volume 26 *Federal Register* page 10279), which prohibits future oil and gas leasing or mineral claims at the site. LM monitors drilling activities near the site to ensure those activities do not impact the site. This includes inspecting the site for evidence of land use changes or significant land disturbances. It also includes evaluating the site roads and inspecting the monitoring network wellheads, the signs that inform the public that ground-disturbing activity is not allowed, the concrete cap that covers the emplacement shaft, and the Project Gnome monument for signs of damage, natural deterioration from weather, or vandalism.

The site inspection for this reporting period was conducted on January 27, 2016. At the time of the inspection, the signs installed near the emplacement shaft, near well USGS-1, and around the perimeter of the site were observed as being in good condition. The roads, the wellheads, and the Project Gnome monument were also observed as being in good condition. Appendix A provides photographs of the monument, reentry well DD-1, and concrete cap that covers the emplacement shaft.

Additional inspection activities and the results are provided below:

- The New Mexico Office of the State Engineer (OSE) website was accessed to determine if any new groundwater extraction wells had been permitted in the nine sections surrounding and including the site (Figure 4). No new groundwater extraction wells were permitted in referenced sections during this reporting period (OSE 2017).

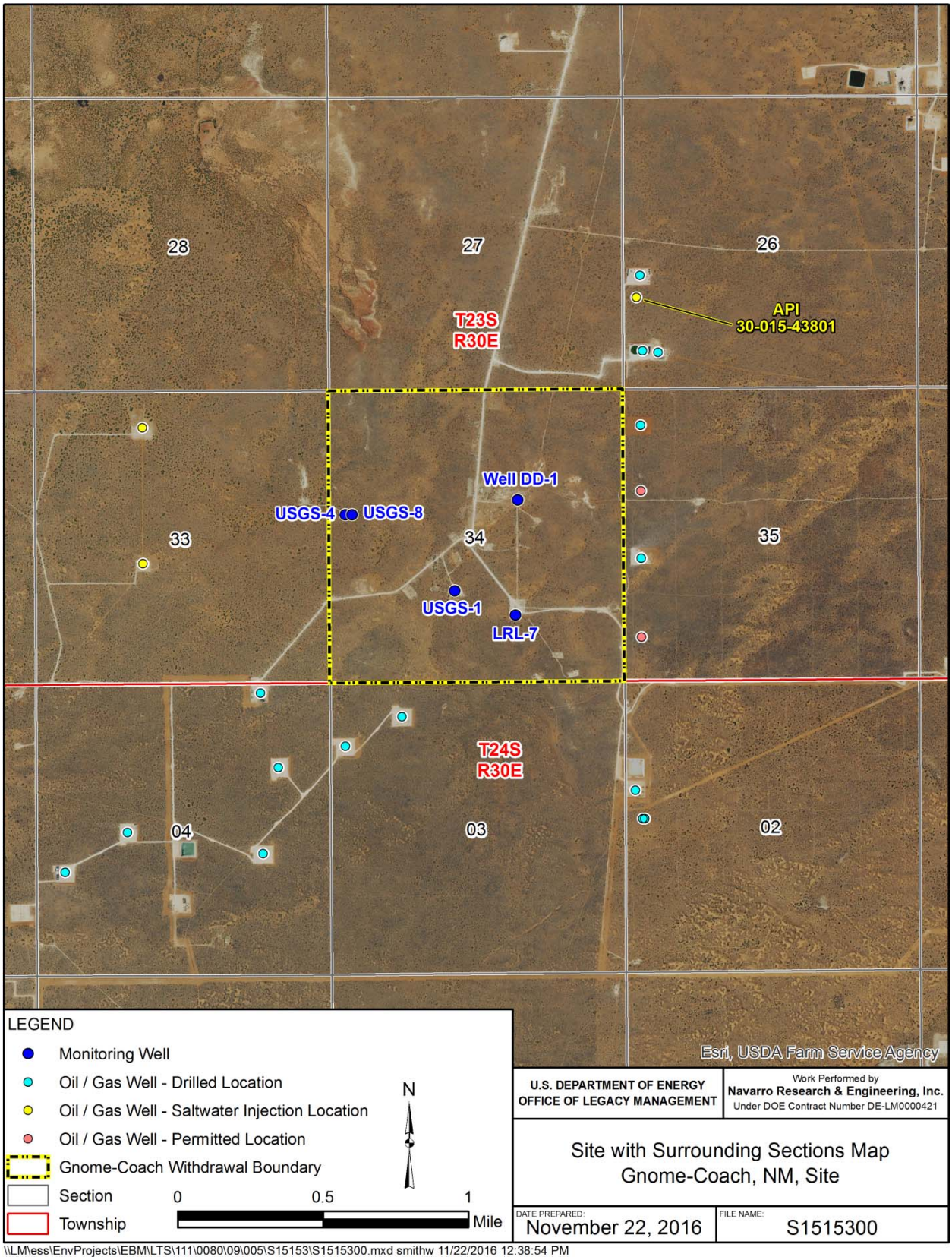

Figure 4. Sections Surrounding the Gnome-Coach, New Mexico, Site

- The New Mexico Oil Conservation Division (OCD) website was accessed to determine if any new oil and gas wells had been permitted in the nine sections surrounding and including the site. These wells generally target and produce oil and gas at depths ranging from 7600 to 10,500 ft bgs, which is much deeper than the depth of the underground nuclear test (1184 ft bgs). One new application was received by the Oil Conservation Division to drill a salt water disposal well in Section 26, 0.8 miles northeast of the Project Gnome monument (Figure 4). The well (API number 30-015-43801) has a planned completion depth of 15,500 ft bgs and was approved in September 2016. As of November 2016, a drill date was not available. No other applications were received during this reporting period (OCD 2017).
- The USGS Earthquake Hazards Program provides notifications of any seismic events near the site. No seismic events were reported during this reporting period.
- The LM public website was updated during this reporting period to include the updated Fact Sheet, the 2015 Groundwater Monitoring and Inspection Report (DOE 2016a), and the LTS&MP (DOE 2016b).

3.2 Hydraulic Head Monitoring and Results

The monitoring well network consists of three wells completed in the Culebra Dolomite (USGS-1, USGS-4, and USGS-8) and two wells completed in the Salado Formation (DD-1 and LRL-7). The monitoring of hydraulic head in these wells began in 2008, shortly after LM assumed responsibility for the site. This includes measuring water levels manually in all network wells during the site visits. Water levels in the Culebra wells are recorded more frequently using pressure transducers to detect short-term and long-term flow changes in the aquifer. Transducer data are no longer collected in the Salado wells due to the high salinity water that limits transducer life and the absence of short-term variations in the previous transducer data.

The transducer data were downloaded and the depth-to-groundwater was measured manually in the site wells on January 27, 2016. The transducer data were downloaded again on September 6, 2016 (with the exception of the transducer in well USGS-4, which failed because of a low battery). The manual water levels were used with the top-of-casing elevations to convert the transducer data to groundwater elevations. These data were corrected for the different specific gravity of water for each screened unit. The specific gravity of water from Culebra-screened wells is approximately 1.0035, and the specific gravity of water from Salado-screened wells is approximately 1.15. Table 2 presents the water level data and measured groundwater elevations obtained in January 2016, along with the top-of-casing elevations, the top and bottom screen-zone elevations, and the hydrostratigraphic unit monitored for the wells.

Hydrographs of hydraulic head data from when monitoring began in 2008 are shown in Figure 5 and Figure 6. The hydrographs are grouped according to each well's open interval and formation monitored. Head data obtained from manual water-level measurements are shown as individual datapoint symbols, and transducer data appear as lines. Borehole deviation data are available for wells USGS-1, USGS-4, and USGS-8 (Table 2), so hydraulic head data from these wells are corrected to true vertical depth. Borehole deviation data are currently not available for wells DD-1 and LRL-7, so groundwater elevations depicted in Figure 6 are approximate.

Table 2. Gnome-Coach Site Monitoring Well Network Water Levels

Well	Date	DTW (ft)[a]	TOC Elevation (ft amsl)	TSZ Elevation (ft amsl)	BSZ Elevation (ft amsl)	Formation/Unit Monitored	Groundwater Elevation (ft amsl)
USGS-1	1/27/2016	437.38[c]	3426.60	2907[b]	2875[b]	Culebra Dolomite	2989.31[b]
USGS-4	1/27/2016	428.95	3413.72	2940[b]	2907[b]	Culebra Dolomite	2989.67[b]
USGS-8	1/27/2016	421.70	3411.25	2947[b]	2915[b]	Culebra Dolomite	2989.55[b]
LRL-7	1/27/2016	461.63	3442.52	2653[d]	2127[d]	Salado Formation	2980.89[d]
DD-1	1/27/2016	977.42	3397.49[e]	2259[d]	NM	Salado Formation	2420.07[d]

Notes:
The TOC elevations are provided in U.S. State Plane, Zone New Mexico East, coordinate system, with vertical data based on the National Geodetic Vertical Datum of 1929 (NGVD 29) (DOE 2015).
[a] Depth to water has not been corrected for true vertical depth.
[b] Elevation has been corrected for true vertical depth. (At the water level depth, the deviation correction for USGS-1 is 0.09 ft; the deviation correction for USGS-4 is 4.90 ft; and no correction is required for USGS-8 because it did not deviate from vertical.)
[c] Well USGS-1 has a dedicated submersible pump that was not operating at the time of the water level measurement.
[d] Elevations for LRL-7 and DD-1 have not been corrected for true vertical depth because borehole deviation corrections are not available for these wells.
[e] TOC elevation is estimated because of repairs to the wellhead after the well was vandalized in 2014 (DOE 2016a).

Abbreviations:
amsl = above mean sea level
BSZ = bottom of screen zone, uncased/open interval, or perforated interval in feet above mean sea level
DTW = depth to water (all measurements obtained from north top-of-casing)
NM = not measured or unknown (the construction and open intervals of reentry well DD-1 are unknown)
TOC = top-of-casing elevation in feet above mean sea level (NGVD 29)
TSZ = top of screen zone, uncased/open interval, or perforated interval in feet above mean sea level

The hydrographs for wells USGS-1, USGS-4, and USGS-8 (completed in the Culebra Dolomite) are shown on Figure 5. BLM allows local ranchers to use well USGS-1 as a water supply well for livestock and the frequent water elevation changes are a response to the on-and-off pump cycles to fill a nearby water tank. This well has been used since the 1980s as a point of diversion under the BLM water right C01901. The hydraulic head data indicate that the frequency and rate of pumping increased in late November 2013. Prior to that time, water levels varied about 2 ft between pump cycles. Since then, water levels have varied about 5 ft between pump cycles (Figure 5). The average head is plotted for each month since the increased pumping began in November 2013. The increased magnitude of drawdown and the corresponding recovery of water levels during pump cycles are the result of a new dedicated pump installed in USGS-1 by the area ranchers and an increase in the frequency of pumping. A totalizing flow meter installed at well USGS-1 on April 21, 2015, indicates a total of 7.44 acre-feet of groundwater had been removed from the well through January 27, 2016. Figure 5 shows that water levels in wells USGS-4 and USGS-8 have also responded to the increased water removal from USGS-1. The hydraulic head in wells USGS-4 and USGS-8 has declined from an elevation of approximately 2993.5 ft in early 2013 to 2989.5 ft in August 2016. The decrease in water levels within the Culebra wells might also be the result of drilling and pumping from additional water supply wells outside the study area. The hydraulic head data from the Culebra wells continue to support a groundwater flow direction that is generally toward the south.

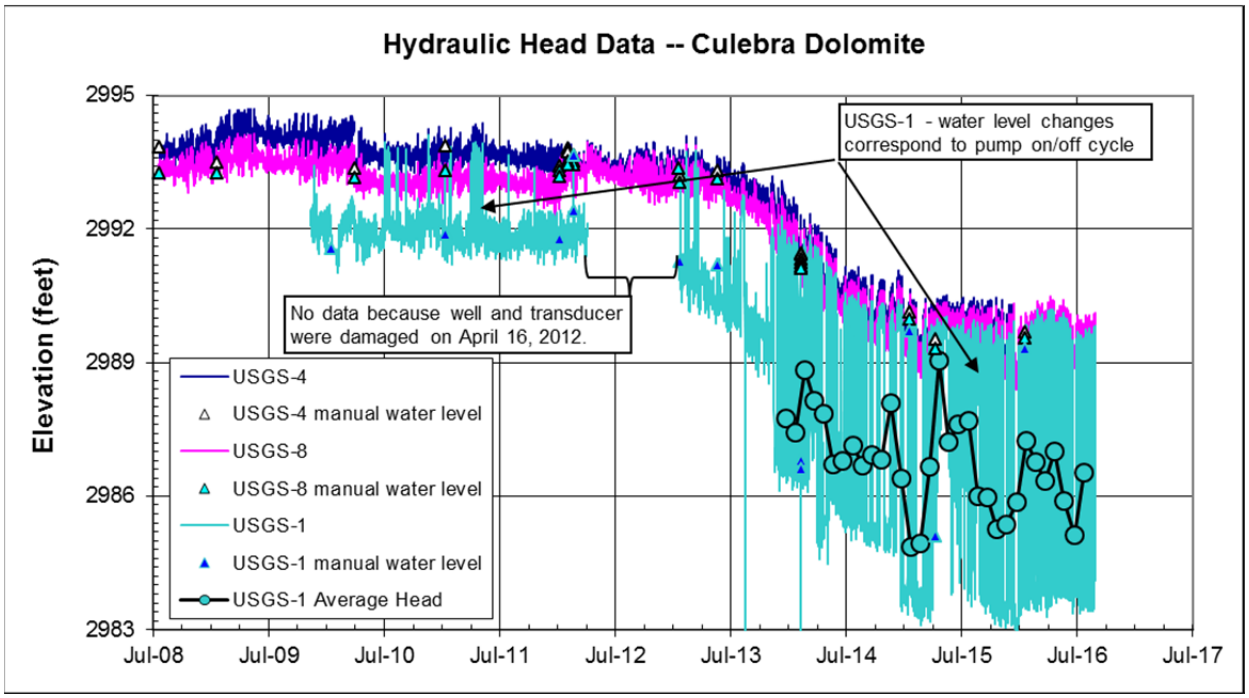

Figure 5. Hydrograph Showing Water Elevations in Wells USGS-1, USGS-4, and USGS-8

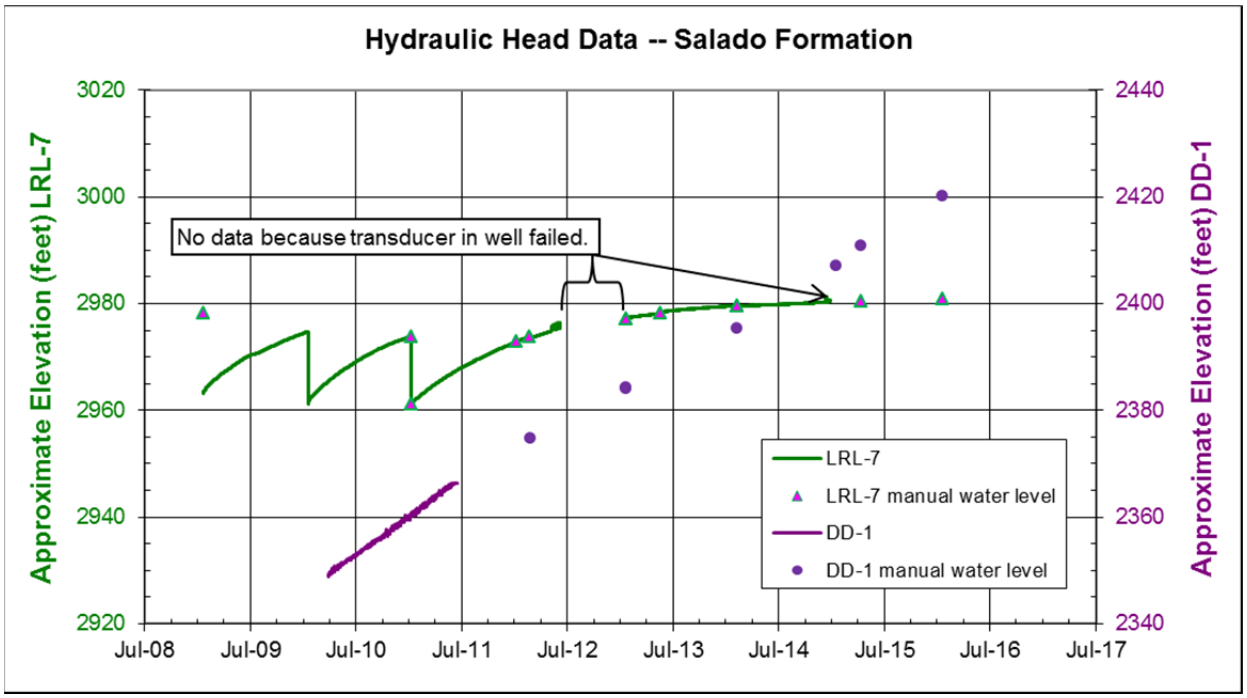

Figure 6. Hydrograph Showing Water Elevations in Reentry Wells DD-1 and LRL-7

Figure 6 shows the hydrographs for wells (DD-1 and LRL-7) completed in the Salado Formation. Water levels are monitored manually in well DD-1 and LRL-7, which are completed in the detonation cavity and the Coach drift, respectively. The transducer in LRL-7 failed in late 2014 and will not be replaced. The transducer data and subsequent manually measured water levels indicate that the rate of water level recovery since LRL-7 was last sampled in January 2011 continues to decrease and that water levels may be nearing static conditions. The transducer in reentry well DD-1 failed in June 2011 and was removed during the January 2015 sampling (DOE 2016). Manual water level measurements indicate that water levels are rising in this well at a rate of approximately 10 ft/year. Water levels in these wells might be influenced by remnant pressure effects associated with the detonation and disposal activities and might not be representative of the Salado Formation.

3.3 Groundwater Sampling and Results

The well network is designed to monitor the sources of radionuclide contamination (underground nuclear test and tracer test) and the point of access (well USGS-1). Sampling of these wells began in 1972, and LM assumed responsibility for the sampling in 2008. The monitoring wells completed in the Culebra Dolomite (USGS-1, USGS-4, and USGS-8) are sampled annually for the radioisotopes (tritium, cesium-137, and strontium-90) used during the tracer test in 1963. Wells completed in the Salado Formation (LRL-7 and DD-1) are sampled less frequently because of the low-permeability of the Salado Formation and limited potential for transport.

The monitoring wells USGS-1, USGS-4, and USGS-8 were sampled on January 27, 2016. Samples were not collected from wells DD-1 and LRL-7 during this monitoring event because the presence of radionuclides at these locations is well documented and have a limited potential for transport. Wells USGS-4 and USGS-8 were sampled using dedicated low-flow submersible bladder pumps. The tubing inlets of the bladder pumps are located in the screened or open interval to allow water to be collected directly from the adjacent geologic formation. The sample from well USGS-1 was collected as a grab sample using the dedicated pump that fills the nearby water tank. Samples were analyzed for gamma-emitting radionuclides (using high-resolution gamma spectrometry), strontium-90, and tritium (using conventional methods). An additional sample was collected from well USGS-1 for tritium analysis using the electrolytic enrichment method to obtain a lower laboratory method detection limit. The analytical results were validated in accordance with the "Standard Practice for Validation of Environmental Data" section in the *Environmental Procedures Catalog* (LMS/POL/S04325). Samples were analyzed using accepted procedures that were based on the specified methods. The laboratory radiochemical minimum detectable concentrations reported with these data are an estimate of the predicted detection capability of a given analytical procedure, not an absolute concentration that can or cannot be detected. A copy of the data validation package is available on the LM Website at http://www.lm.doe.gov/gnome/Sites.aspx.

Radiochemical analytical results obtained from the 2016 monitoring event were consistent with previous analytical results (Table 3). The radionuclide concentrations in wells USGS-4 and USGS-8 are the result of radionuclides injected during the tracer test in 1963. Concentrations are higher in well USGS-8 because it was used as the injection well for the tracer test; (well USGS-4 was used as the extraction well during the tracer test). Analytical results of the sample from well USGS-1 indicate no detection of radionuclides above the laboratory minimum detectable concentration (Table 3). Table 3 presents a summary of radiochemical analytical results from 2009 through 2016 for comparison.

Table 3. Radiochemical Analytical Results 2009 Through 2016

Sample Location	Collection Date	Tritium (pCi/L)	Tritium Enriched Method (pCi/L)	Cesium-137 (pCi/L)	Strontium-90 (pCi/L)	Formation/Unit Monitored
USGS-1	1/27/2009	<154	NA	<4.94	<1.8	Culebra Dolomite
	1/26/2010	<146	7.6	<2.1	<0.89	
	1/26/2010[a]	<146	<3.4	<1.4	<1.9	
	1/19/2011	<150	NA	<2.2	<3.6	
	1/19/2011[a]	<150	NA	<2.4	<1.1	
	1/18/2012	<240	<2.33	<5.69	<0.728	
	1/18/2012[a]	<243	NA	<6.82	<0.794	
	1/29/2013	<371	<2.18	<4.68	<0.909	
	1/29/2013[a]	<371	NA	<5.97	<0.716	
	2/19/2014	NA	<2.4	<5.68	<0.987	
	2/19/2014[a]	<298	NA	<4.81	<1.08	
	1/27/2015	NA	<2.24	<6.77	<0.722	
	1/27/2016	<364	<2.91	<6.08	<0.974	
USGS-4	1/27/2009	16,800	NA	<4.99	2980	Culebra Dolomite
	1/26/2010	13,200	NA	<1.4	2540	
	1/19/2011	11,300	NA	<2.4	2650	
	1/18/2012	9110	NA	<5.62	884	
	1/30/2013	10,200	NA	<5.33	987	
	2/19/2014	7680	NA	<5.85	1780	
	1/27/2015	6030	NA	<4.85	1740	
	1/27/2016	5240	NA	<6.03	1420	
USGS-8	1/27/2009	28,800	NA	163	3440	Culebra Dolomite
	1/27/2010	25,500	NA	181	3320	
	1/19/2011	21,200	NA	150	3650	
	1/18/2012	21,700	NA	154	1400	
	1/29/2013	20,900	NA	174	1580	
	2/19/2014	18,400	NA	176	1640	
	1/27/2015	17,400	NA	123	2650	
	1/27/2015[a]	16,400	NA	128	2480	
	1/27/2016	16,400	NA	142	2410	
	1/27/2016	16,100	NA	166	2270	
LRL-7	1/28/2009	4870	NA	139	<24	Salado Formation
	1/26/2010	4350	NA	129	<33	
	1/19/2011	3910	NA	134	<29	
	1/18/2012	NA	NA	NA	NA	
	1/30/2013	NA	NA	NA	NA	
	2/19/2014	NA	NA	NA	NA	

Note:
[a] Indicates a field duplicate sample.

Abbreviations:
NA = not analyzed
pCi/L = picocuries per liter

Charts 1 through 7 in Appendix B show temporal plots of radionuclide concentrations (1972 through 2016) in samples collected at wells LRL-7, USGS-4, and USGS-8. Well USGS-1 is not included because concentrations of tritium (using conventional methods), strontium-90, and cesium-137 have not been detected above the laboratory minimum detectable concentration in this well since monitoring began in 1972. Concentrations are plotted on a semi-logarithmic scale and all sample results, including non-detects, are plotted. Several results from sampling events before the late 1980s had no reported detection limit, as shown in the charts. For interpretation purposes, relatively high concentrations (i.e., concentrations significantly higher than detection limits associated with subsequent sampling) should be considered detections. The natural decay rates for tritium (12.3 years), strontium-90 (28.8 years), and cesium-137 (30.2 years) have been included on the charts when needed. The increases in tritium concentrations in samples collected from well LRL-7 (Chart 1) and cesium-137 concentrations in samples collected from wells USGS-8 and LRL-7 (Chart 4 and Chart 6) after the 2007 sampling event are attributed to changes in the sampling method. Prior to 2008, EPA collected samples using a depth-specific bailer, and starting in 2008 LM collected samples from dedicated bladder pumps using the low-flow sampling method. Tritium concentrations in samples collected from well USGS-4 (Chart 1) appear to be decreasing at a rate that is greater than the natural decay rate for tritium.

4.0 Summary and Conclusions

The site inspection and annual sampling were conducted on January 27, 2016. At the time of the site inspection, the signs installed near the emplacement shaft, near well USGS-1, and around the perimeter of the site were observed as being in good condition as were the roads, wellheads, and Project Gnome monument. No new groundwater extraction wells were permitted in the sections that surround and include the site during this reporting period. One new application was received by the Oil Conservation Division to drill a salt water disposal well in Section 26. The well (API number 30-015-43801) has a planned completion depth of 15,500 ft bgs and was approved in September 2016, but as of November 2016 a drill date has not been established. No additional applications were received during this reporting period.

The annual sampling included the collection of samples from the wells (USGS-1, USGS-4, and USGS-8) completed in the Culebra Dolomite to monitor radionuclide concentrations associated with the tracer test. No samples were collected from the wells (DD-1 and LRL-7) completed in Salado Formation during the 2016 monitoring period. Analytical results obtained from the recent sampling event indicate that concentrations of tritium, strontium-90, and cesium-137 detected in wells USGS-4 and USGS-8 were consistent with historical results. This includes no detections in the sample from well USGS-1, which has a submersible electric pump and is used to provide water for livestock belonging to area ranchers under BLM water right C01901. Hydraulic head data from this well indicate that the frequency and rate of pumping increased in late November 2013. This is evident by an increase of approximately 5 ft in the amount of drawdown and the recovery of water levels when the pump cycles on and off. The increased magnitude of drawdown and the corresponding recovery of water levels during pump cycles are the result of a new dedicated pump installed in USGS-1 by the area ranchers and an increase in the frequency of pumping. A totalizing flow meter installed at well USGS-1 on April 21, 2015, indicates a total of 7.44 acre-feet of groundwater had been removed from the well through January 27, 2016. The hydraulic head data continue to show that pumping in well USGS-1 produces a drawdown

response in wells USGS-4 and USGS-8, which also increased in late November 2013. The hydraulic head data from the Culebra wells continue to support a groundwater flow direction that is generally toward the south. Hydraulic head data from well LRL-7, which monitors the Coach drift, indicate that water levels have nearly recovered from the last radiochemical sampling event in January 2011. Manual water level measurements collected from the reentry well DD-1, which monitors the detonation cavity, confirmed that the transducer in this well failed in June 2011 and that water levels appear to be rising. Water levels in these wells might be influenced by remnant pressure effects associated with the detonation and disposal activities and might not be representative of the Salado Formation.

Data collected during this and previous monitoring events (including sample analytical and water-levels data) are available on the GEMS website at http://gems.lm.doe.gov/#site=GNO. This annual report and others are available on the LM public website at http://www.lm.doe.gov/gnome/Sites.aspx, and copies of this report are sent to the individuals on the distribution list provided as Appendix C.

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Appendix A

Photographic Documentation

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Photo showing the Gnome Monument and reentry well DD-1 that was repaired in January 2015.

Photo showing the concrete cap that covers the Gnome emplacement shaft.

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Appendix B

Well Concentration Plots

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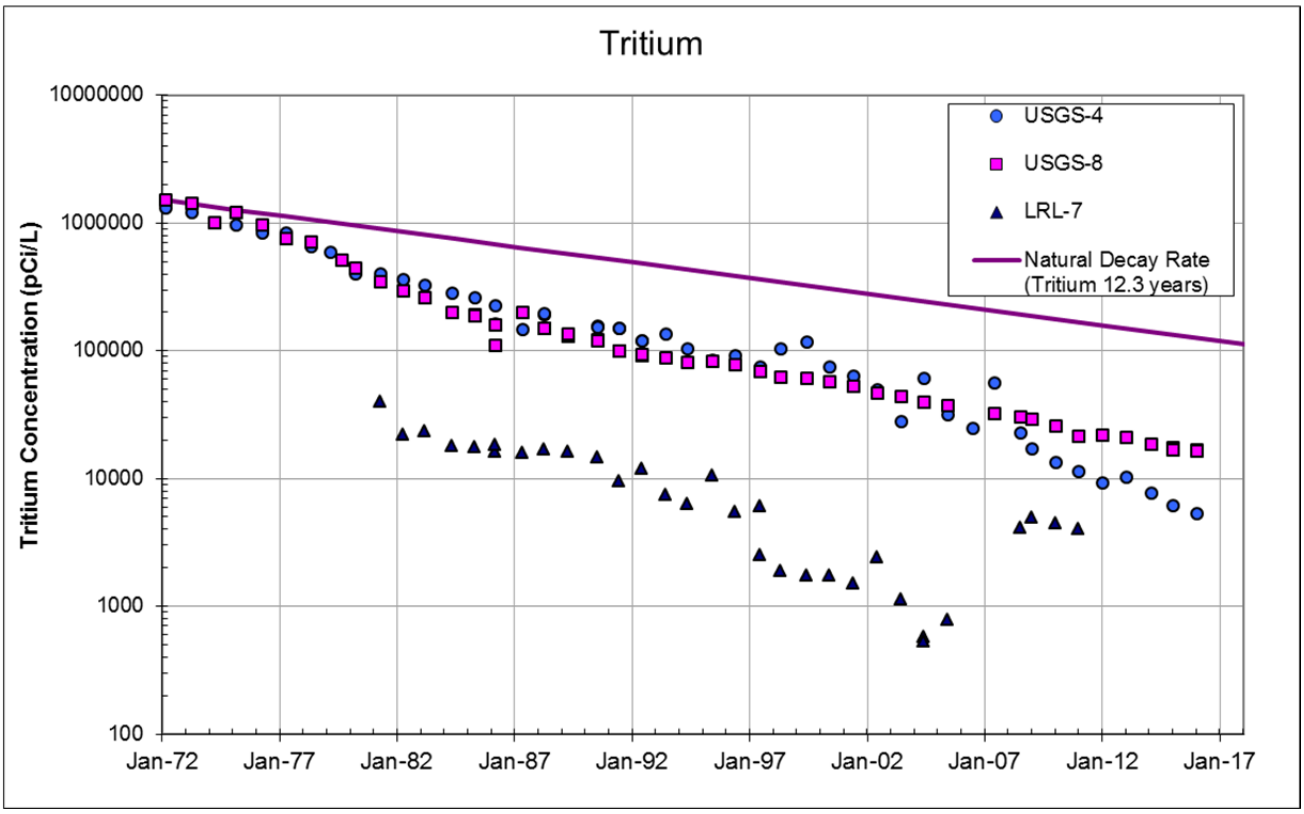

Chart 1. Tritium Concentrations at Wells USGS-4, USGS-8, and LRL-7

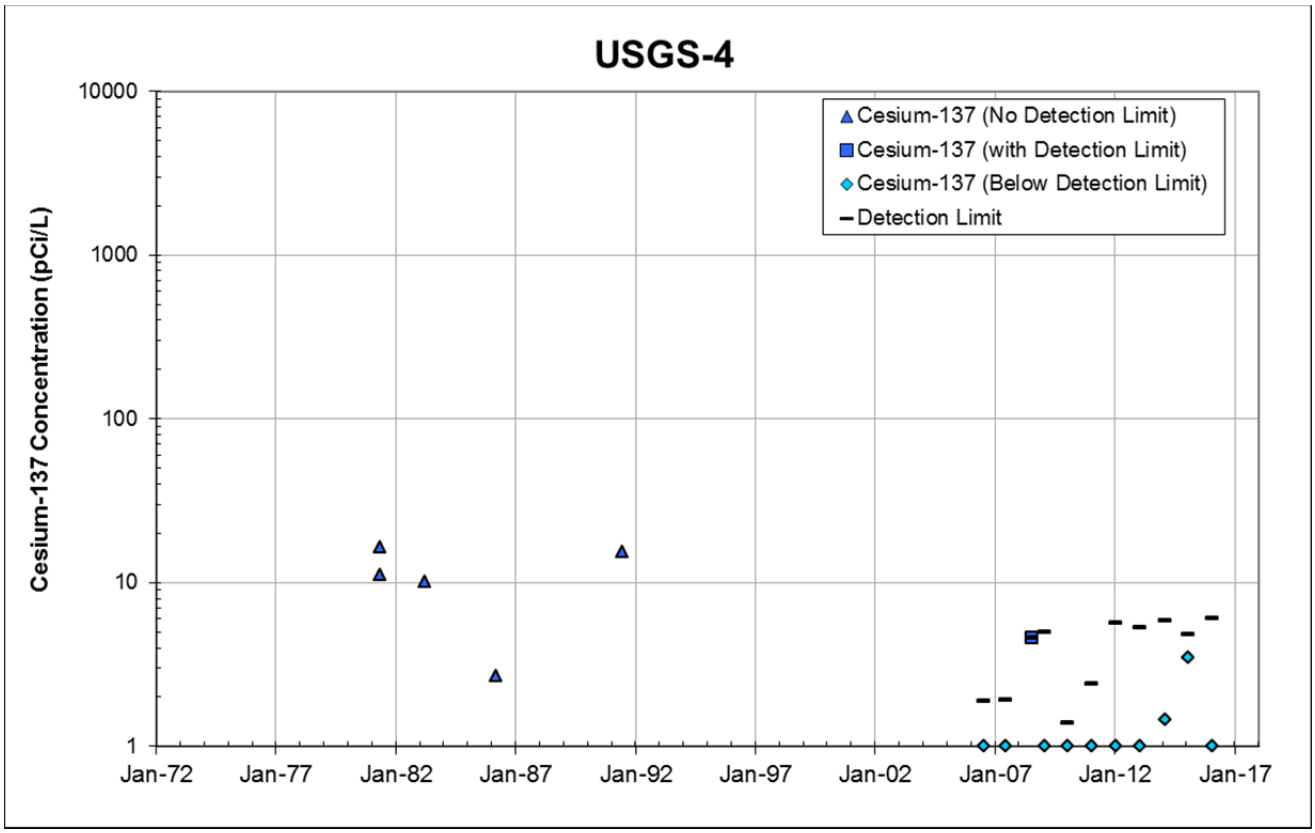

Chart 2. Cesium-137 Concentrations at Well USGS-4

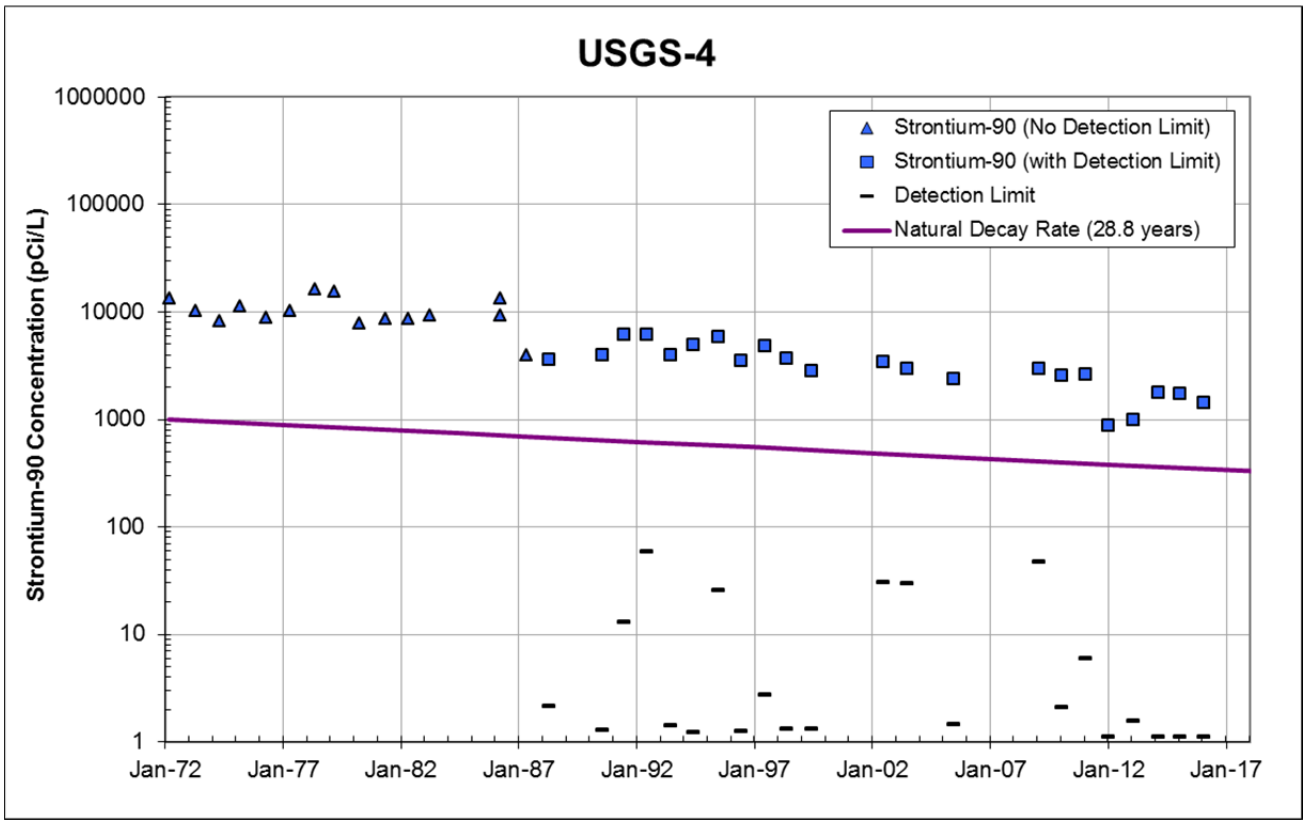

Chart 3. Strontium-90 Concentrations at Well USGS-4

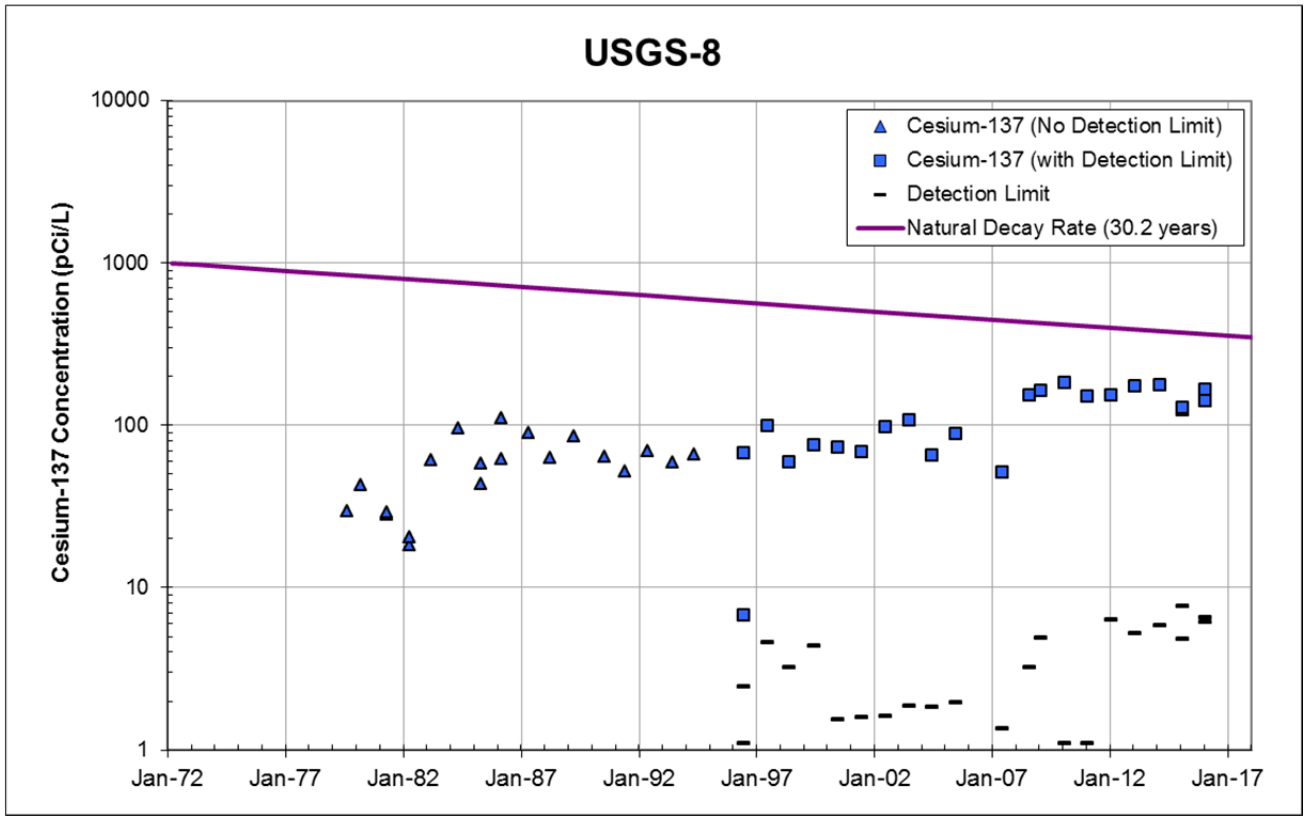

Chart 4. Cesium-137 Concentrations at Well USGS-8

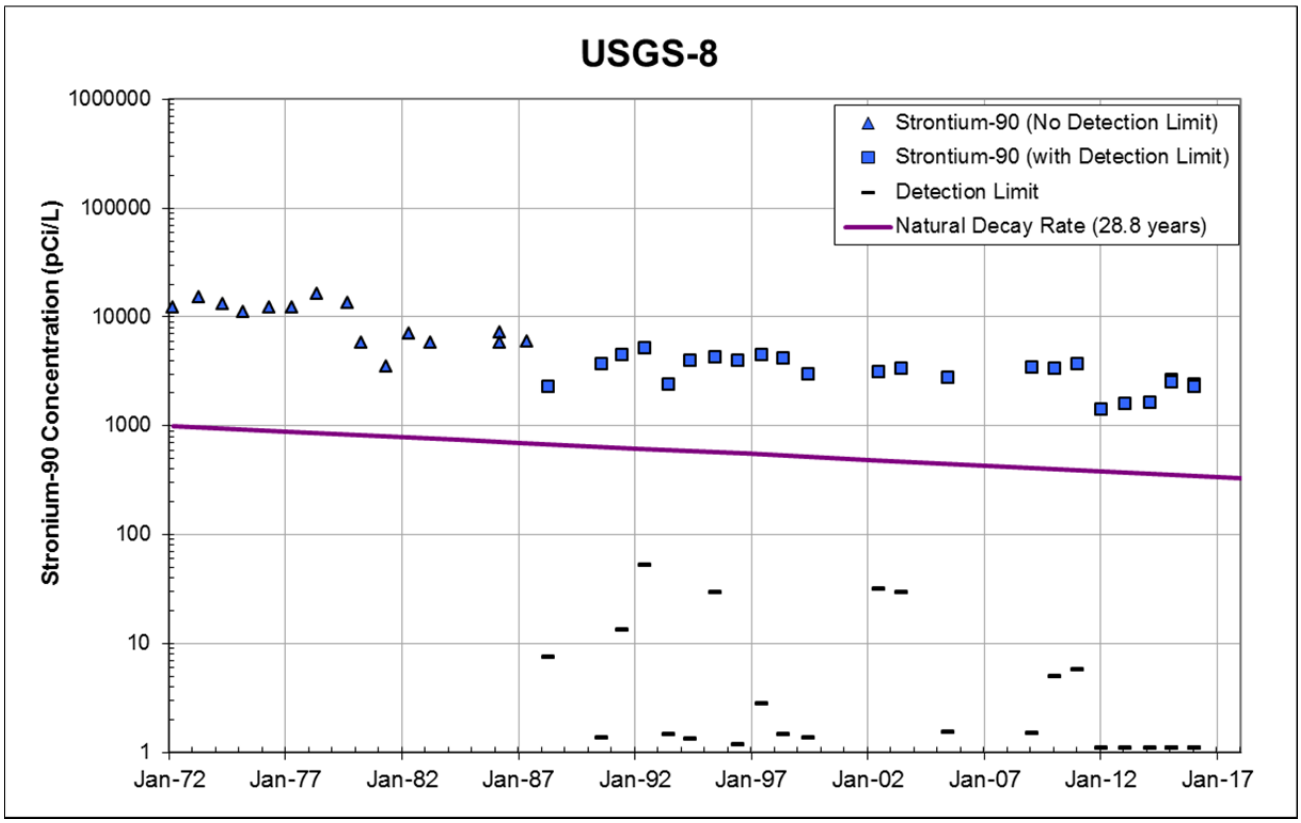

Chart 5. Strontium-90 Concentration at Well USGS-8

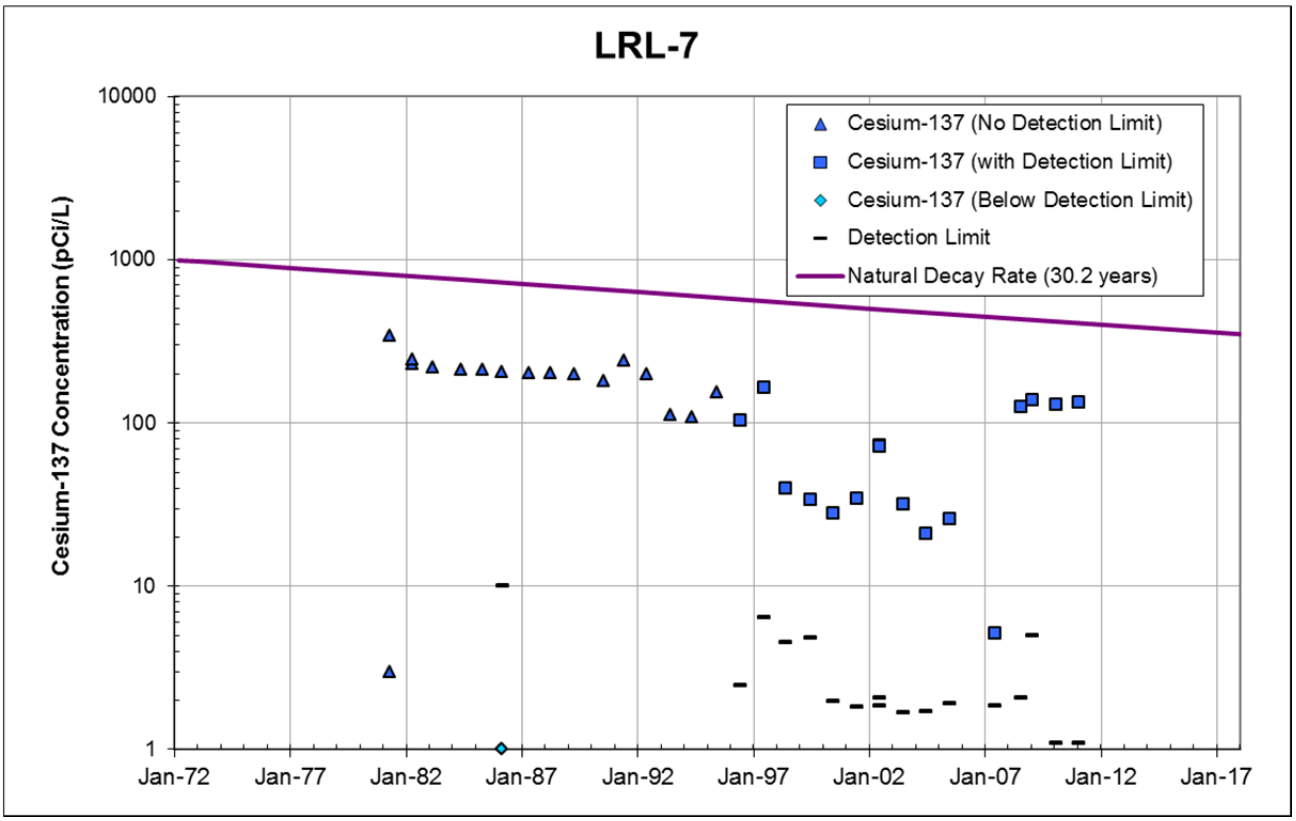

Chart 6. Cesium-137 Concentration at Well LRL-7

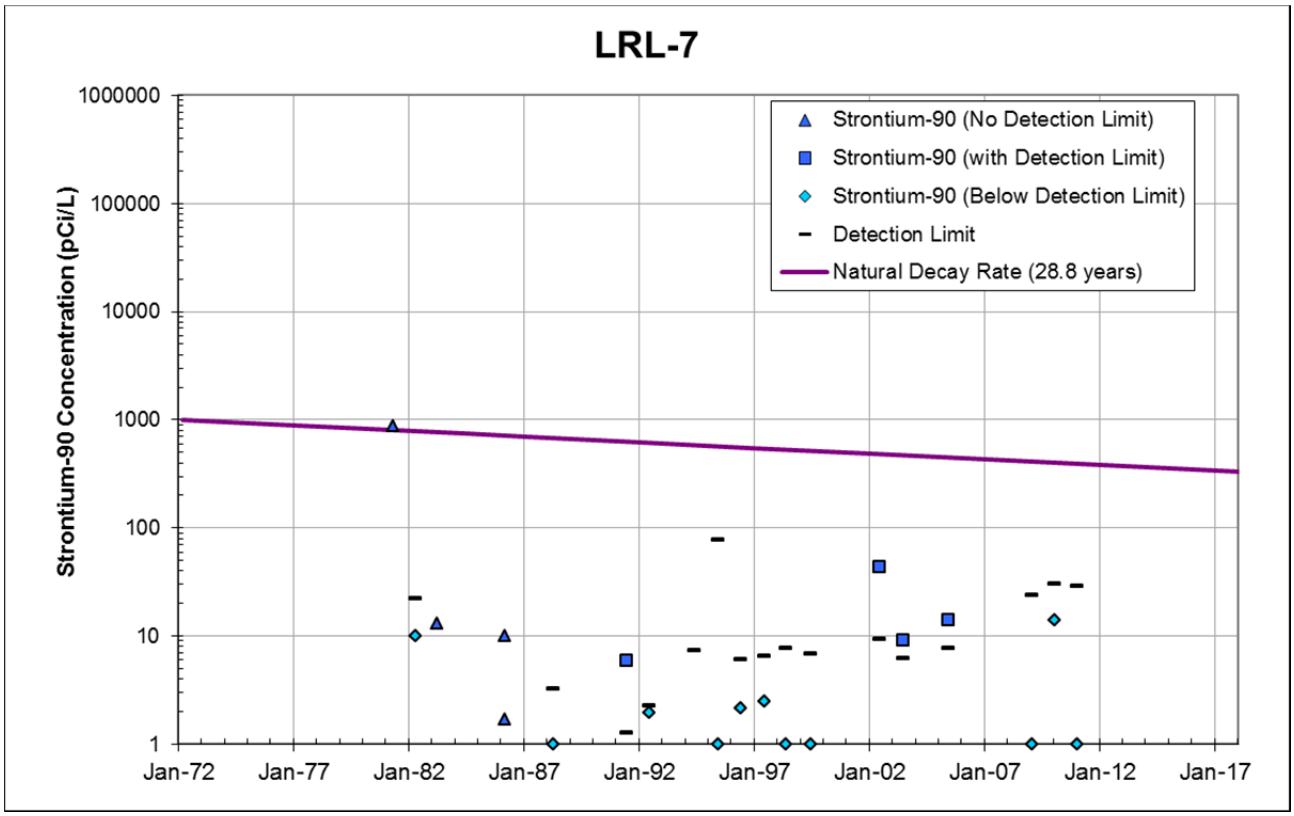

Chart 7. Strontium-90 Concentrations at Well LRL-7

Appendix C

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