LMS/GNO/46357

2023 Groundwater Monitoring and Inspection Report Gnome-Coach, New Mexico, Site

June 2024

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Abbreviations

BHL	bottom-hole location
BLM	U.S. Bureau of Land Management
COVID-19	coronavirus disease 2019
^{137}Cs	cesium-137
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
FR	*Federal Register*
ft	feet
IC	institutional control
LM	Office of Legacy Management
LMS	Legacy Management Support
LTHMP	Long-Term Hydrologic Monitoring Program
LTS&M Plan	Long-Term Surveillance and Maintenance Plan
m/d	meters per day
NMIMT	New Mexico Institute of Mining and Technology
pCi/L	picocuries per liter
SHL	surface-hole location
^{90}Sr	strontium-90
USGS	U.S. Geological Survey
WIPP	Waste Isolation Pilot Plant

Executive Summary

The Gnome-Coach, New Mexico, Site in southeastern New Mexico was the location of an underground nuclear test in 1961 and a groundwater tracer test in 1963 that resulted in residual radionuclide contamination at the site. The Long-Term Surveillance and Maintenance Plan for the site describes the U.S. Department of Energy Office of Legacy Management (LM) plan for monitoring groundwater (radiochemical sampling and water-level measurements), inspecting the site, maintaining site institutional controls, evaluating and reporting data, and documenting site records and data management processes. These activities are reported annually, and this report summarizes the results from the September 2022 to August 2023 reporting period; it includes the site inspection and annual sampling that were completed on February 7, 2023. At the time of the inspection, two signs were replaced and the remaining signs on the site and around the perimeter of the site were observed as being in good condition, as were the roads, wellheads, concrete cap that covers the emplacement shaft, and Project Gnome monument. A review of the public websites that monitor drilling activities indicated that no new wells (oil and gas wells, injection wells, or groundwater extraction wells) were drilled during this reporting period, but 36 applications to drill natural gas wells and 11 applications to drill oil wells were approved for the sections surrounding the site. A search of seismic events indicated that 29 events with a magnitude of 2.0 or greater occurred within 25 miles of the site during this reporting period.

Groundwater elevation data from the Culebra wells (USGS-1, USGS-4, and USGS-8) continue to support a regional groundwater flow direction that is generally toward the south but is influenced locally by the pumping in well USGS-1. This pumping produces an almost immediate water-level drawdown response in wells USGS-4 and USGS-8. Groundwater elevations in the Culebra wells, which had been decreasing overall since monitoring began in 2008, were stable in 2020 and 2021 and resumed decreasing in 2022. According to the 2023 data, groundwater elevation in the Culebra wells appears to have stabilized in 2023 with only a slight increase in elevation from 2022. The decrease in the overall groundwater elevation was likely due to an increase in oil and gas activity in 2022 after a slowdown during the previous 2 years that resulted from the coronavirus disease 2019 (also called COVID-19) pandemic. The oil and gas well industry uses groundwater from the Culebra Aquifer as part of the drilling and hydrologic fracturing process. Groundwater elevation data from well LRL-7, which monitors the Coach drift, indicate that water levels have recovered from the well's last sampling event in 2011. Water levels in reentry well DD-1, which monitors the detonation cavity, continued to rise at a rate of approximately 10 feet per year. Between the 2022 and 2023 sampling events, the water level rose 13.07 feet in DD-1. Water levels in LRL-7 and DD-1 might not be representative of the Salado Formation and are likely influenced by remnant pressure effects associated with the detonation, the plastic nature of the Salado Formation, and past disposal activities.

Samples were collected from wells USGS-1, USGS-4, and USGS-8 (completed in the Culebra Dolomite) on February 7, 2023, to monitor radionuclide concentrations associated with the tracer test. Laboratory radiochemical results were consistent with previous results. Samples were not collected from wells DD-1 and LRL-7 (completed in the Salado Formation), because these wells are not scheduled for annual sampling due to the limited potential for contaminant migration in the Salado Formation. Copies of this report are sent to the individuals on the distribution list provided as Appendix C, and the report is available on the LM public website at https://www.energy.gov/lm/gnome-coach-new-mexico-site.

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 radionuclide groundwater tracer test in 1963 that resulted in residual radionuclide contamination in the groundwater and postdetonation 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&M Plan) for the site describes LM's plan for monitoring groundwater, inspecting the site, maintaining institutional controls (ICs), evaluating and reporting data, and documenting the site's records and data management processes (DOE 2016b). Figure 1 shows the site location.

This report summarizes the results of the groundwater monitoring and site inspection activities conducted during the September 2022 to August 2023 reporting period. The purpose of these activities is to monitor the groundwater and ensure that the ICs are protective of the site and of human health and the environment. This report and the LTS&M Plan are available on the LM public website at https://www.energy.gov/lm/gnome-coach-new-mexico-site. Data collected during this and previous monitoring events (including laboratory results and water-level data) are available on the Geospatial Environmental Mapping System (GEMS) website at https://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, 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 totaling approximately 680 acres. The larger parcel (640 acres) is where the underground nuclear test and radionuclide tracer test occurred and is identified as the Gnome-Coach site in Section 34 within Township 23 South, Range 30 East. The smaller parcel (40 acres) was used for observation during the underground test and is identified as the observation area 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 (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 (ft)-diameter vertical emplacement shaft was excavated to a depth of 1216 ft (Figure 2). 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 on December 10, 1961. The nuclear device had a reported yield of 3 kilotons (DOE 2015b). 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 emplacement shaft was cleared, and a new drift was excavated after the detonation to inspect the effects of the detonation. The cavity that resulted from the detonation has well-documented dimensions confirmed by scientists who 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, and a second horizontal drift—the Coach drift—was mined 1945 ft southeast from the shaft (AEC 1969). The Coach experiment was initially scheduled for 1963 but it was canceled, and there were no additional underground nuclear detonations at the site. The site is still referred to as the Gnome-Coach site. Figure 2 is a map showing the site and site features (monitoring wells, emplacement shaft, and the Project Gnome monument). 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.

In 1963, USGS conducted a groundwater tracer test in the Culebra Dolomite, a fractured carbonate aquifer that is the most prolific aquifer near the site (Figure 3) and is at a depth of approximately 500 ft near the site. The tracer test was designed to estimate the dispersion coefficient and effective porosity of the Culebra Aquifer for evaluating the potential movement of radionuclides (Beetem and Angelo 1964). Wells USGS-4 and USGS-8 were used for the tracer test and are approximately 3100 ft west of the Project Gnome monument, which is directly above the detonation cavity and signifies surface ground zero (Figure 2). Water from the extraction well (USGS-4) was mixed with four dissolved radionuclides (tritium, iodine-131, strontium-90 [^{90}Sr], and cesium-137 [^{137}Cs]), and the solution was pumped into the injection well (USGS-8). The tracer test experiment was performed in two separate phases over 21 days in February and March 1963. Samples were collected at the extraction well (USGS-4) during the test to record the arrival and concentration of each tracer.

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 the presence 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 near the Gnome site (USGS 1962).

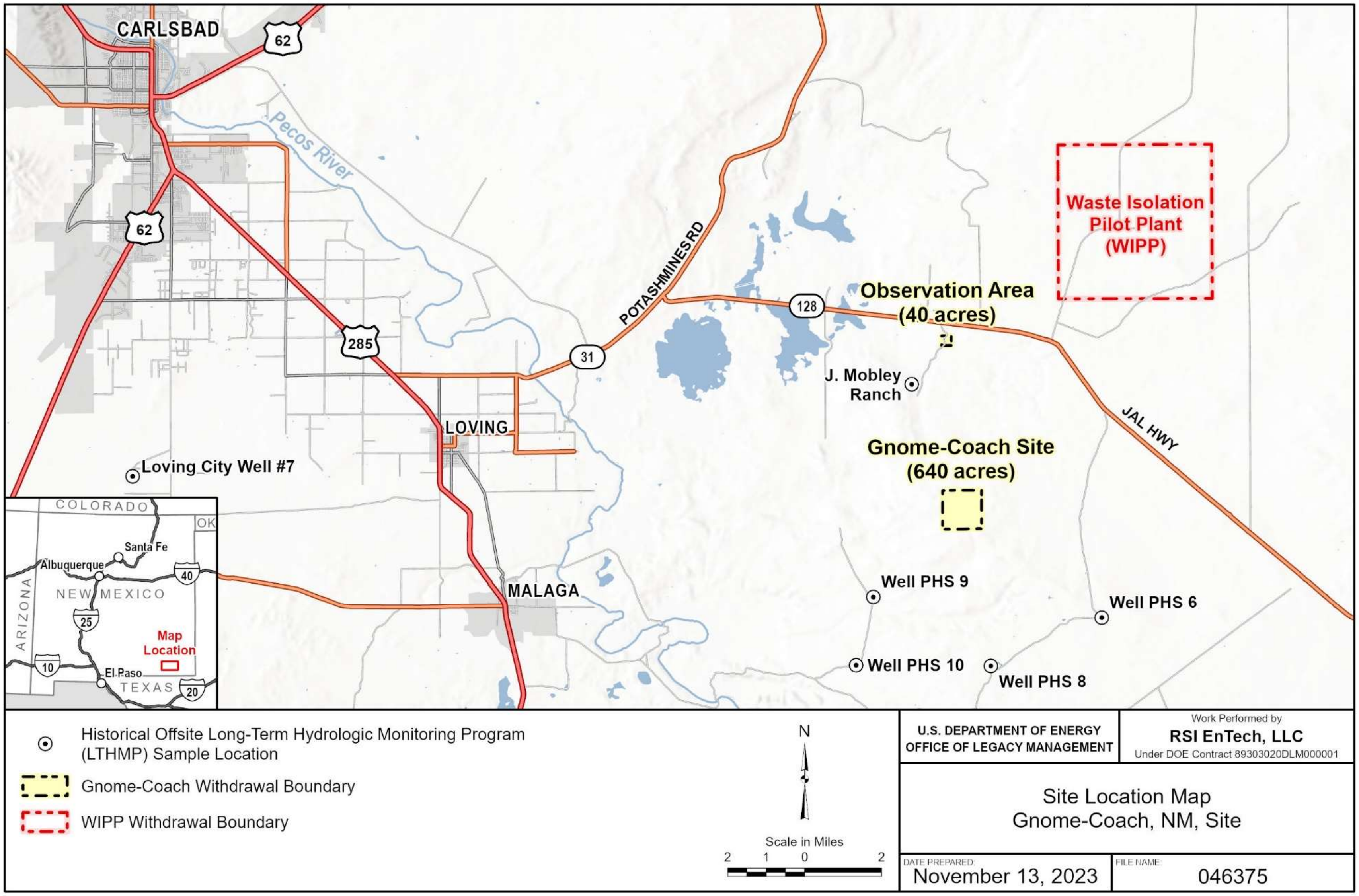

Figure 1. Location Map for the Gnome-Coach, New Mexico, Site

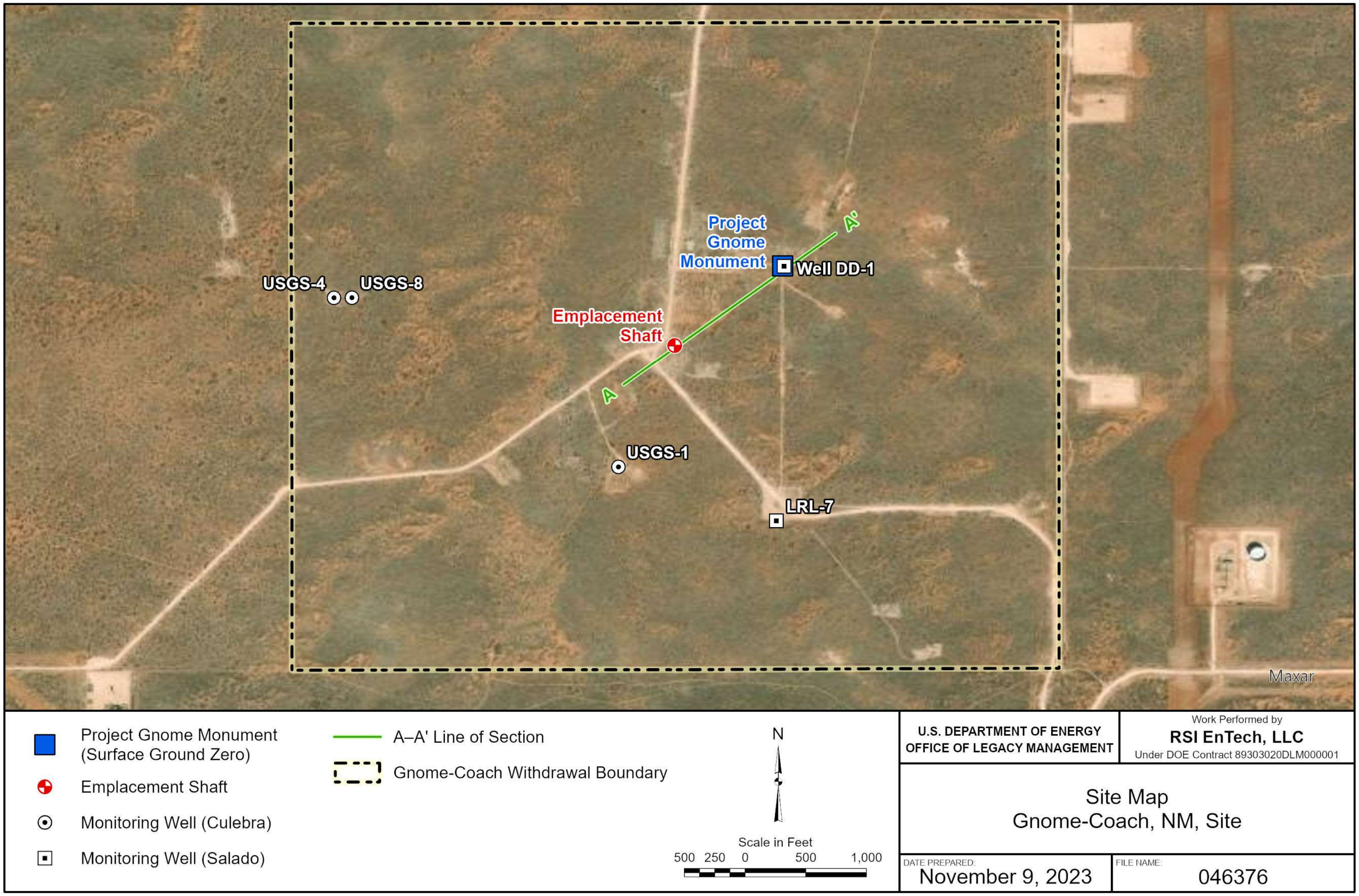

Figure 2. Site Map for the Gnome-Coach, New Mexico, Site

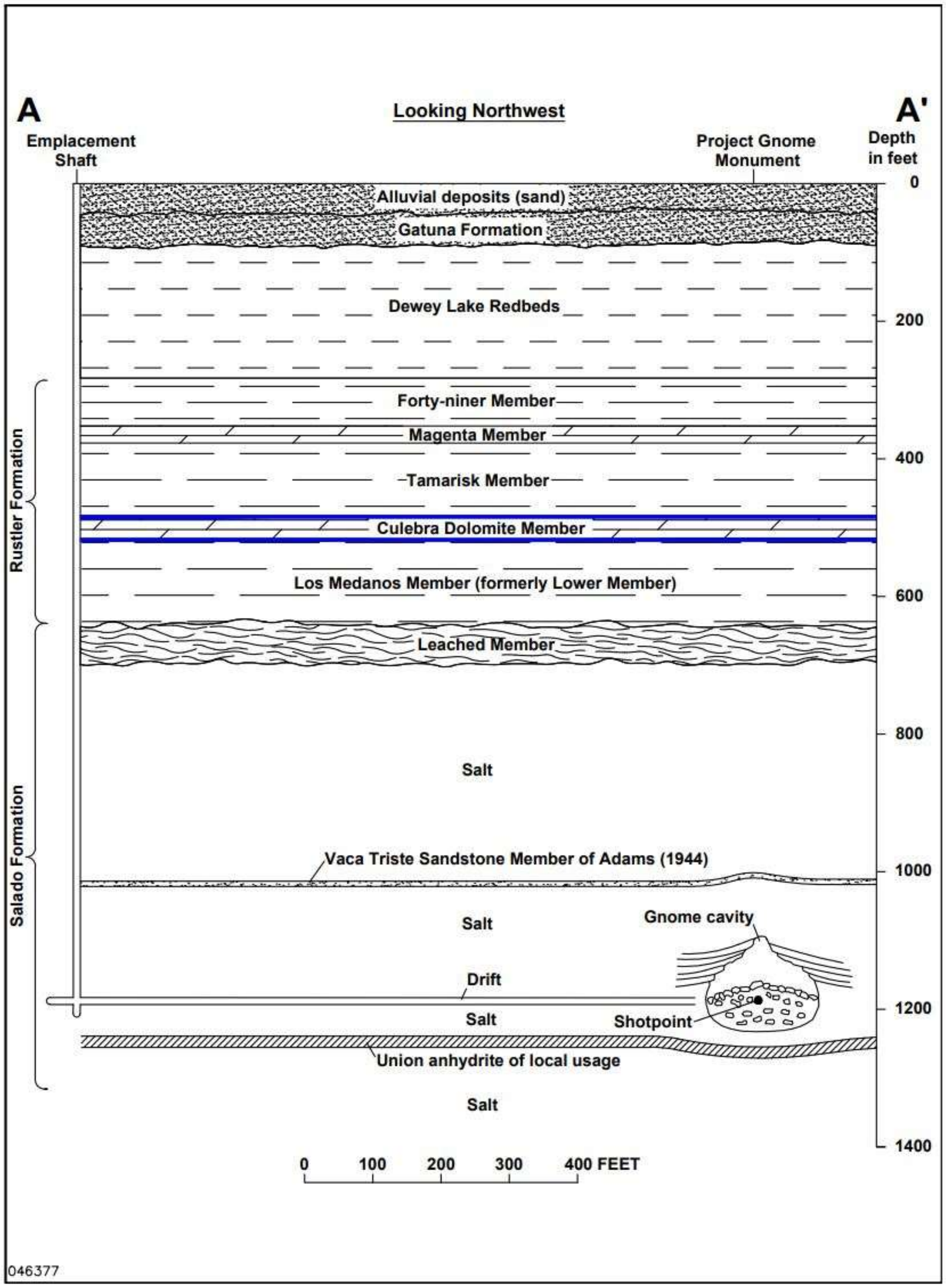

Figure 3. Stratigraphic Cross Section at the Gnome-Coach, New Mexico, Site

The lithostratigraphic units beneath the Gnome site were defined during the pretest drilling and mining of the emplacement shaft (Figure 3). 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 at the top of the Salado Formation are five thinly bedded members of the Rustler Formation (Figure 3). 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 radionuclide tracer test took place. It is approximately 30 ft thick and is present at depths ranging from approximately 460 to 515 ft at the site (Figure 3). The Culebra is the most prolific aquifer near 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 (USGS-1, USGS-4, and USGS-8) (Figure 2) before 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). More recently, wells USGS-4 and USGS-8 have responded to changes in the pumping of groundwater from well USGS-1 (DOE 2017). 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/d) (USGS 1971). The hydraulic conductivity decreases to the northeast near the WIPP facility, ranging from 0.27 m/d to 2.7×10^{-3} m/d (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/d (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. Fluids also occur between crystal boundaries (interstitial fluid) of the massive crystalline salt formation, there are fluids in clay seams and anhydrite beds. Wastes were mixed with water and injected through well DD-1 into the detonation 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 completed 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, posttest 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 boreholes; contaminated material was disposed of in the emplacement shaft and the Coach drift through existing drill holes; uncontaminated equipment was moved offsite; and boreholes were plugged except for 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 to June 2002 and in May 2003. Contamination identified during the field investigation was excavated and disposed of offsite. A postremediation 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 and 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 and NNSA 2005), and a Conditional Certificate of Completion which documents that surface remediation activities have been completed in accordance with the Voluntary Remediation Program (Schoeppner 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 assess the effectiveness of the monitoring network (Figure 1) 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), ^{90}Sr, 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) was not impacted by contamination related to nuclear tests. For this reason, starting in 2010, groundwater monitoring focused on monitoring wells within the site boundary (Figure 2). Table 1 lists the monitoring wells in the network, the purpose for monitoring, the unit monitored, and the frequency for monitoring (sampling and water levels).

Table 1. Gnome-Coach Site Monitoring Well Network

<table>
<tr><th rowspan="2">Well Identification</th><th rowspan="2">Purpose for Monitoring</th><th rowspan="2">Formation/ Unit Monitored</th><th colspan="2">Monitoring Frequency</th></tr>
<tr><th>Sampling</th><th>Water Level</th></tr>
<tr><td>USGS-1[a]</td><td>Point of access</td><td rowspan="3">Culebra Dolomite</td><td rowspan="3">Annual</td><td rowspan="5">Annual</td></tr>
<tr><td>USGS-4</td><td rowspan="2">Tracer test</td></tr>
<tr><td>USGS-8</td></tr>
<tr><td>LRL-7</td><td>Coach drift</td><td rowspan="2">Salado Formation</td><td rowspan="2">Periodic</td></tr>
<tr><td>DD-1</td><td>Detonation cavity</td></tr>
</table>

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.

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 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 radiation 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 groundwater elevations 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 were generally in good condition. The 2010 groundwater monitoring and inspection report (DOE 2011) summarizes the well-logging results.

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 at wells USGS-4 and USGS-8) and the detonation (at a depth of 1184 ft) 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 seismic survey results are summarized in the 2012 groundwater monitoring and inspection report (DOE 2013).

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 wellhead survey data are summarized in the 2014 groundwater monitoring and inspection report (DOE 2015a).

Repairs were made to the wellhead of reentry well DD-1, and a totalizing flow meter was installed at well USGS-1 in January 2015. Repairs to DD-1 were necessary because of vandalism in July 2014 (DOE 2016a). The flow meter was installed in the flow system of water-supply well USGS-1 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 (DOE 2016a). These signs were installed near the emplacement shaft, near well USGS-1, and around the site perimeter. The signs fulfill a requirement of the Conditional Certificate of Completion issued by the New Mexico Environment Department in 2014. LM’s plan for monitoring and inspecting the site and maintaining the site ICs is outlined in the LTS&M Plan for the site (DOE 2016b). The 2015 groundwater monitoring and inspection report documents repairs made to well DD-1 (DOE 2016a).

The totalizing flow meter installed at well USGS-1 was removed before the February 2022 sampling event by an unknown third party who installed a new flow meter at a new location at well USGS-1. The flow meters have been difficult to maintain because the relatively high salt content (total dissolved solids) causes buildup on flow meter parts over time. The new flow meter had extensive salt buildup and indicated that only 0.34 acre-feet of water had been removed from February 8 through October 6, 2022, which indicates that the flow meter was not functioning (DOE 2023). There are currently no plans to install or maintain a new flowmeter at well USGS-1.

3.0 Groundwater Monitoring and Inspection Results

Groundwater monitoring and inspections are conducted to look for changes at the site and obtain time-series data (radiochemical and water levels) to identify trends and maintain our understanding of the groundwater flow system as per the LTS&M Plan (DOE 2016b). These activities include working with local agencies and frequent monitoring of public websites to maintain ICs and ensure protectiveness of the site (Section 3.1). The field activities, which were conducted on February 7, 2023, included inspecting the site (Section 3.1), measuring depth-to-groundwater and downloading data from pressure transducers (Section 3.2), and collecting groundwater samples (Section 3.3). The *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites* (LMS/PRO/S04351) outlines 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 ASTM International. The site inspection and monitoring results are summarized in the following sections.

3.1 Site Inspection and Results

Gnome-Coach site lands are under federal jurisdiction and administered by BLM. The site was withdrawn on October 26, 1961, from all forms of appropriation associated with mining laws and leasing through Public Land Order 2526 (Volume 26 *Federal Register* page 10279 [26 FR 10279]), which prohibits future oil and gas leasing or mineral claims at the site. The ICs and associated restrictions are documented in the LTS&M Plan for the site (DOE 2016b). To maintain protectiveness of the site, the restrictions specific to ground-disturbing activities were provided to BLM (as shape files) for inclusion in BLM's database to increase the visibility of restrictions and prevent inadvertent intrusion. These restrictions allow BLM to make surface improvements with provisions for avoiding surface features (emplacement shaft, buried debris, salt muck, and monitoring wells) that remain at the site. LM monitors these surface features and drilling activities in the sections surrounding the site to ensure that those activities do not impact the site (Figure 4). LM duties include inspecting the site for evidence of land use changes or significant land disturbances. LM also evaluates site roads and inspects the well network; warning signs (that ground-disturbing activity is prohibited); the concrete cap that covers the emplacement shaft; and the monument for signs of damage, natural deterioration from weather, or vandalism. Figure 4 shows the site (Section 34) and surrounding sections that are monitored for drilling activity.

The site inspection for this reporting period was performed on February 7, 2023. At the time of the inspection, the site wells, roads, concrete cap, and monument at surface ground zero were in good condition, and no land use changes, or significant land disturbances were observed. All the signs onsite and around the site perimeter were observed as being in good condition. Appendix A provides photographs of some of the surface features at the site.

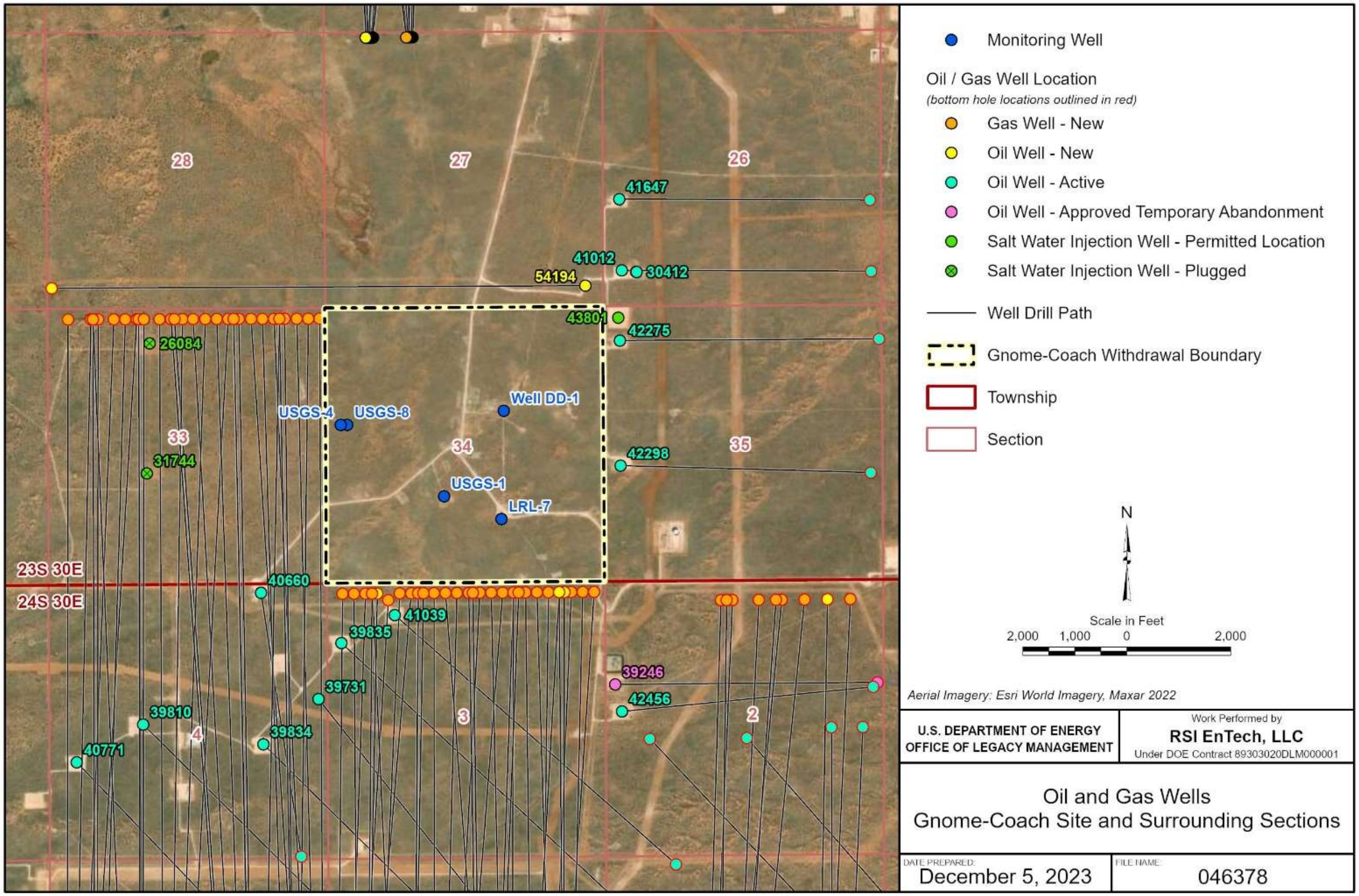

Figure 4. Sections Surrounding the Gnome-Coach, New Mexico, Site

On April 3, 2023, the Legacy Management Support (LMS) contractor was informed that the submersible electric pump in USGS-1 had been dropped in the well while the rancher that maintains the pump was conducting routine pump maintenance activities. The pump was attached to approximately 200 ft of discharge pipe when it was dropped in the well. LMS staff notified contractors with the Sandia National Laboratories, and they were able to remove the pressure transducer from well USGS-1 on April 4, 2023. On April 28, the LMS contractor was informed that the rancher had installed a new pump and discharge piping in well USGS-1; however, during the installation approximately 400 ft of 2-inch PVC water access pipe that was used to contain the pressure transducer had been dropped in the well. The rancher that maintains the pump is planning additional well maintenance activities to remove the PVC water access pipe, pump, and pump discharge pipe that remain in the well. Because there is no requirement to continuously monitor water levels in USGS-1, installation of a new water access pipe and reinstallation of the pressure transducer will not occur until the rancher is able to remove the pipe and pump from the well later in 2024.

Additional inspection activities and the results are as follows:

- The New Mexico Office of the State Engineer website was accessed to determine whether any new groundwater extraction wells had been permitted in the nine sections in and surrounding the site (Figure 4). There were no new groundwater extraction well permits in the referenced sections during this reporting period (OSE 2023).
- The New Mexico Oil Conservation Division website was accessed to determine whether any new oil and natural gas well applications had been permitted for wells having a planned surface or bottom-hole location (BHL) within the nine sections surrounding the site (Figure 4). Oil and gas wells in this area are initially drilled vertically until they near the target depth, where they build angle until the wellbore is horizontal. The wells are targeting the Brushy Canyon and Bone Spring Formation for oil and the Wolfcamp Formation for natural gas. Typically, the horizontal or lateral part of the well in the targeted formation is hydraulically fractured to increase formation permeability and stimulate production. The target depths range from 7600 to 10,500 ft for oil production and from 11,000 to 12,500 ft for natural gas production. The shallowest targeted interval is more than 6000 ft deeper than the depth of the nuclear test (1184 ft). The two locations in Section 35 (API numbers 30-015-43801 and 30-015-42299) that were issued permits during the 2016 reporting period (DOE 2017) have not been drilled and API 30-015-42299 was canceled during this reporting period. A well pad has been constructed for the injection well (API number 30-015-43801), which will be used to dispose of saltwater at a depth of 16,500 ft after it is installed (Figure 4). A total of 47 applications were permitted to drill natural gas (36) and oil (11) wells in the sections surrounding the site during this reporting period (OCD 2023). Of the 36 natural gas wells permitted, 31 have planned surface-hole locations (SHLs) within Sections 16 and 21 in Township 24 South, Range 30 East, which lie approximately 3 miles southwest of the site. The laterals of these wells will extend to planned BHLs within Section 33, Township 23 South, Range 30 East, west of the site. The remaining 6 natural gas wells have planned SHLs in Section 27, Township 23 South, Range 30 East, with laterals that will extend to BHLs in Section 15 approximately 3 miles north of the site. The 11 oil wells permitted during this reporting period have planned SHLs in Section 27 and laterals that will extend to planned BHLs in Section 15, with the exception of 1 well (API 30-015-54194) with a planned BHL in Section 28. All oil wells have SHLs approximately 1 mile north of the site excluding API 30-015-54194, which lies approximately 400 ft north of the Section 27 South baseline.

- The New Mexico Institute of Mining and Technology (NMIMT) website was accessed to obtain data on seismic events that occurred during this reporting period. In the past, these data were obtained from the USGS Earthquake Hazards Program, but NMIMT maintains a more detailed database for seismic events that occur in southeast New Mexico and west Texas, utilizing an array of nine seismic stations near the WIPP site. According to this database, 29 seismic events having a magnitude of 2.0 or greater were identified within 25 miles of the site during this reporting period (NMIMT 2023). The largest event was approximately 18 miles, south-southeast from the site and registered a 3.2 magnitude on January 15, 2023, with a second event occurring less than 0.5 miles from the previous event that registered a 3.13 magnitude on March 27, 2023. These seismic events were located within a 1.5-mile cluster of smaller events; 4 events registered between 2.5 and 3.0, with an additional 12 registering between a 2.0 and 2.5 magnitude (Figure 5). Seismic events having magnitudes between 3.0 and 3.9 may be felt at the surface, but do not result in any damage to surface structures (USGS 2021). All the remaining seismic events were below a 3.0 magnitude (NMIMT 2023). Seismic events having a magnitude between 2.0 and 2.9 are not felt at the surface (USGS 2021).
- The LM public website is undergoing an update and name change. Updates to include the 2023 groundwater monitoring and inspection report will be delayed until early 2024 (DOE 2022).

The LM public website is routinely updated to allow the public and stakeholders to access the most current site information. LM also monitors the above-mentioned public websites (water well drilling and extraction, oil and natural gas well drilling, saltwater or wastewater injection, and seismic activity) to assess any potential impacts these activities may have at the site. The hydraulic fracturing process used to stimulate oil and gas production uses millions of gallons of water for each well, much of which flows back during production as produced water. The produced water (a combination of fracturing water and formation water) is brine and is typically disposed of as saltwater or wastewater in injection wells. The two injection wells in Section 33 (API numbers 30-015-26084 and 30-015-31744) that were abandoned in February 2018 were used to dispose of saltwater and wastewater from 2001 through 2013. These wells injected wastewater at depths ranging from 8000 to 14,500 ft. It has been documented that injection wells caused earthquakes as great as magnitude 4.5 (damaging some surface structures) in Oklahoma before regulations were enacted to limit injection rates and pressures. In recent years, the number of seismic events in southeast New Mexico and west Texas has increased. This increase, which started in 2019, has been attributed to increased oil and gas drilling and disposal of wastewater through injection wells within the Delaware Basin (NMBGMR 2021). LM will continue to monitor these activities for any potential impacts to the site.

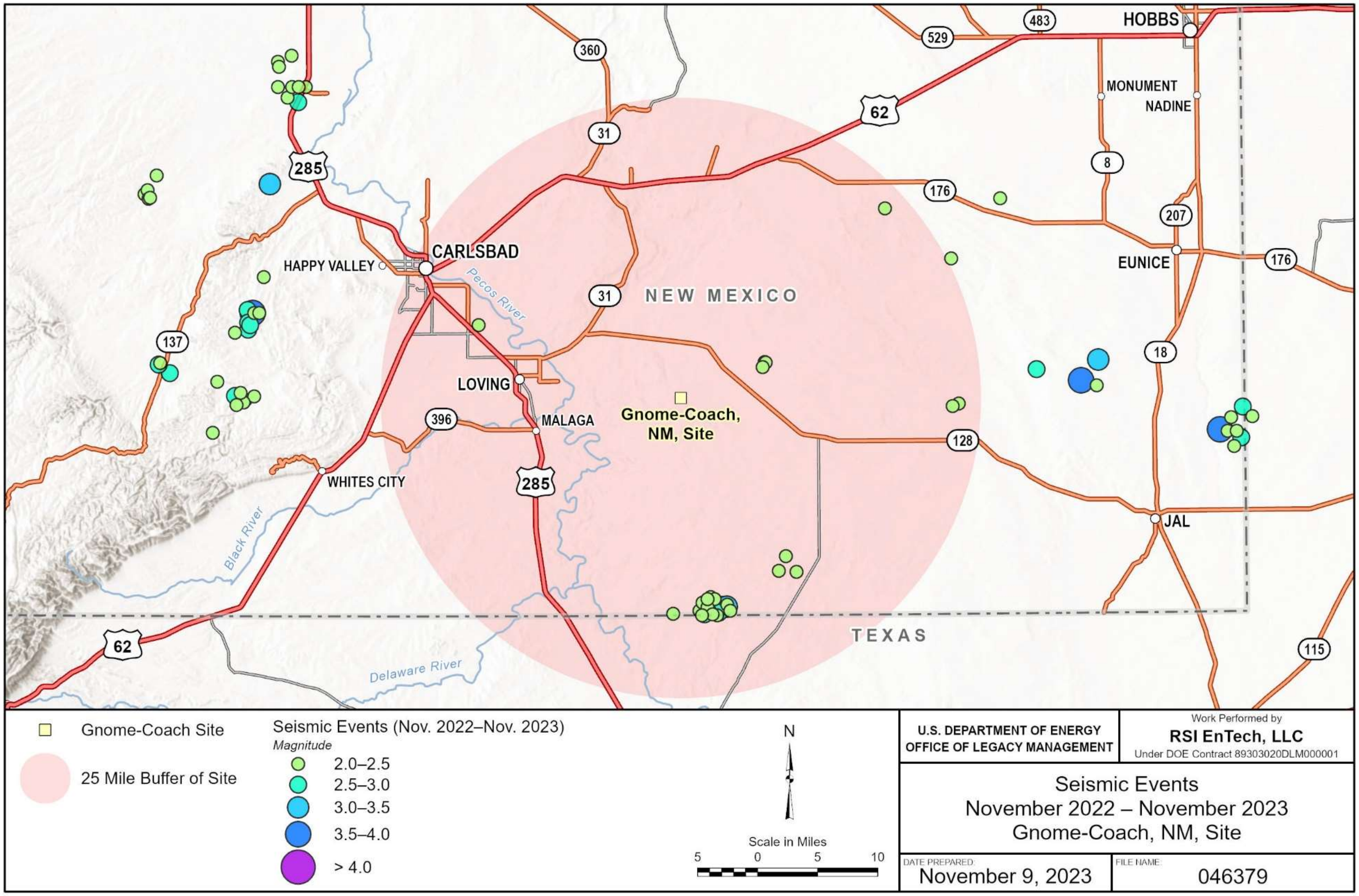

Figure 5. Seismic Activity Surrounding the Gnome-Coach, New Mexico, Site

3.2 Water-Level 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). LM began monitoring water levels in these wells in 2008, shortly after assuming responsibility for the site. This includes manually measuring the depth to water in all monitoring network wells using a water level indicator during site visits. Water levels in the Culebra wells are recorded more frequently using pressure transducers to evaluate short-term and long-term water level changes in the aquifer. Water levels in the Salado wells are no longer recorded using pressure transducers because high-salinity water limits transducer life and no short-term variations in water levels were observed by previous transducer data. Table 2 presents the depth-to-water data that were measured during the site inspection, along with the top-of-casing elevations, top and bottom screen-zone elevations, groundwater elevations, and the formation monitored for the wells. The top-of-casing elevations are documented in the U.S. State Plane, Zone New Mexico East coordinate system with the vertical data based on the North American Vertical Datum of 1988 and horizontal data based on the North American Datum of 1983. This coordinate system was implemented in the 2020 groundwater monitoring report (DOE 2021).

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	2/7/2023	440.47[b]	3428.72	2909[c]	2877[c]	Culebra Dolomite	2988.34[c]
USGS-4	2/7/2023	431.94	3415.84	2942[c]	2909[c]		2988.86[c]
USGS-8	2/7/2023	424.71	3413.37	2949[c]	2917[c]		2988.66[c]
LRL-7	2/7/2023	464.26	3444.64	2655[d]	2129[d]	Salado Formation	2980.38[d]
DD-1	2/7/2023	887.35	3399.53[e]	2261[d]	U/NM		2512.18[d]

Notes:
The TOC elevations are provided in U.S. State Plane, Zone New Mexico East coordinate system with vertical data based on NAVD 88 and horizontal data based on NAD 83 (DOE 2015a).
[a] Depth to water has not been corrected for true vertical depth.
[b] Well USGS-1 has a dedicated submersible pump that was not operating at the time of the water level measurement.
[c] Elevation has been corrected for true vertical depth. (At the current water-level depths, the deviation correction for USGS-1 is 0.09 ft; the deviation correction for USGS-4 is 4.96 ft; and no correction is required for USGS-8 because it did not deviate from vertical.)
[d] Elevations for LRL-7 and DD-1 have not been corrected for true vertical depth because borehole deviation data 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:
BSZ = bottom of screen zone, uncased, open, or perforated interval in ft amsl
DTW = depth to water (all measurements obtained from north top-of-casing)
ft amsl = feet above mean sea level
NAD 83 = North American Datum of 1983
NAVD 88 = North American Vertical Datum of 1988
TOC = top-of-casing elevation in ft amsl (NAVD 88)
TSZ = top of screen zone, uncased, open, or perforated interval in ft amsl
U/NM = unknown or not measured (the construction and open intervals of reentry well DD-1 are unknown)

The transducer data were downloaded from well USGS-1, and water levels were measured manually in the site wells on February 7, 2023. The transducers in wells USGS-4 and USGS-8 were replaced in February because of problems connecting to the transducers during the 2022 monitoring period (DOE 2023). The transducer data were downloaded again on October 19, 2023, but the transducer in well USGS-1 could not be downloaded because the transducer had been removed when the rancher replaced the pump in April 2023. The water access tube that contains the transducer was damaged during the pump replacement so the transducer could not be reinstalled in April 2023. The pump in well USGS-1 cycles on and off to provide water to the nearby water tank that supplies water to livestock. The volume of water in the tank is maintained by a float switch, which activates the pump in well USGS-1 to supply water to the tank at a rate of approximately 15 gallons per minute. When the pump cycles on, water levels in USGS-1 drop by approximately 5 ft. Manual water levels measured in February were used along with the top-of-casing elevations to convert the transducer data to groundwater elevations; these are presented as hydrographs to show data from the time monitoring began in 2008. The hydrographs are grouped according to each well's open interval and formation monitored (Figure 6 and Figure 9). Shorter time intervals of the Culebra well hydrographs are shown in Figure 7 and Figure 8 to highlight specific groundwater responses. Groundwater elevations from manual water-level measurements are shown as individual data point symbols, and transducer data appear as lines. These data were corrected for the 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. Borehole deviation data are available for wells USGS-1, USGS-4, and USGS-8, so groundwater elevation data from these wells include a correction for true vertical depth (Figure 6, Figure 7, and Figure 8). Borehole deviation data are not available for wells DD-1 and LRL-7, so groundwater elevations from these wells are approximate (Figure 9).

Groundwater elevation data were evaluated with the historical data to assess changes in the groundwater flow system. The hydrographs for wells USGS-1, USGS-4, and USGS-8 (completed in the Culebra Dolomite) are shown in Figure 6. Groundwater elevation data from the Culebra wells continue to support a regional groundwater flow direction that is generally toward the south but is locally influenced by pumping from well USGS-1. These data also continue to show that pumping from well USGS-1 produces an almost immediate water-level drawdown response in wells USGS-4 and USGS-8, which are about 2350 ft northwest of USGS-1 (Figure 8). Groundwater elevations have generally been decreasing in the Culebra wells since monitoring began in 2008 (Figure 6), except for the period from 2020 through 2021 when groundwater elevations were relatively stable. Groundwater elevations declined in 2022 with a slight increase in 2023. As the Culebra Dolomite member is a fractured, highly transmissive unit, a slight increase or decrease in groundwater elevation could be attributed to direct responses to demands on this water bearing zone. The initial decrease is likely the result of an increase in oil and gas activity in 2022 after a slowdown during the previous 2 years that resulted from the coronavirus disease 2019 (COVID-19) pandemic. Historical information on the total gallons removed from USGS-1 is limited by difficulties with maintaining the flow meter. Because historical data on the total gallons removed from well USGS-1 is limited, it is difficult to estimate the portion of the decreasing water levels in the Culebra that can be attributed to pumping from well USGS-1. Figure 7 is the hydrograph showing groundwater elevations for the Culebra wells during this reporting period.

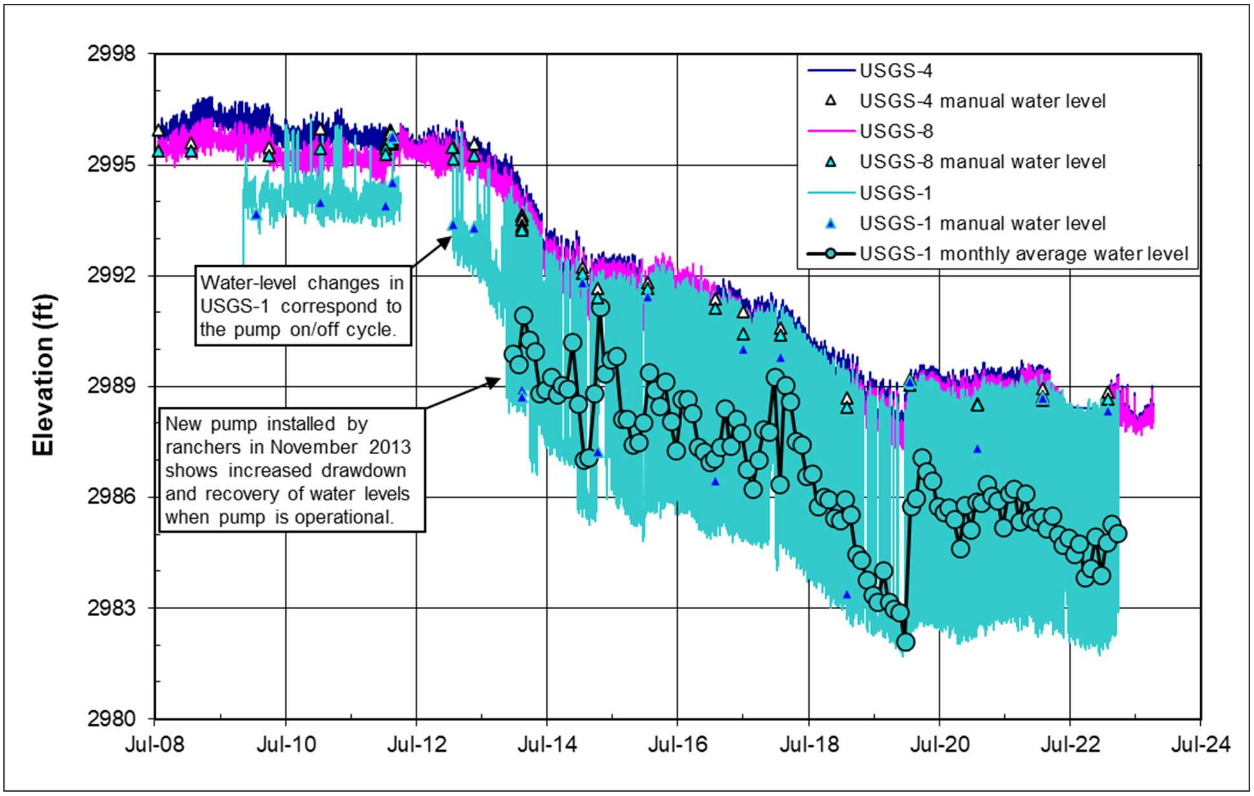

Figure 6. Groundwater Elevations in Culebra Wells, 2008 through 2023

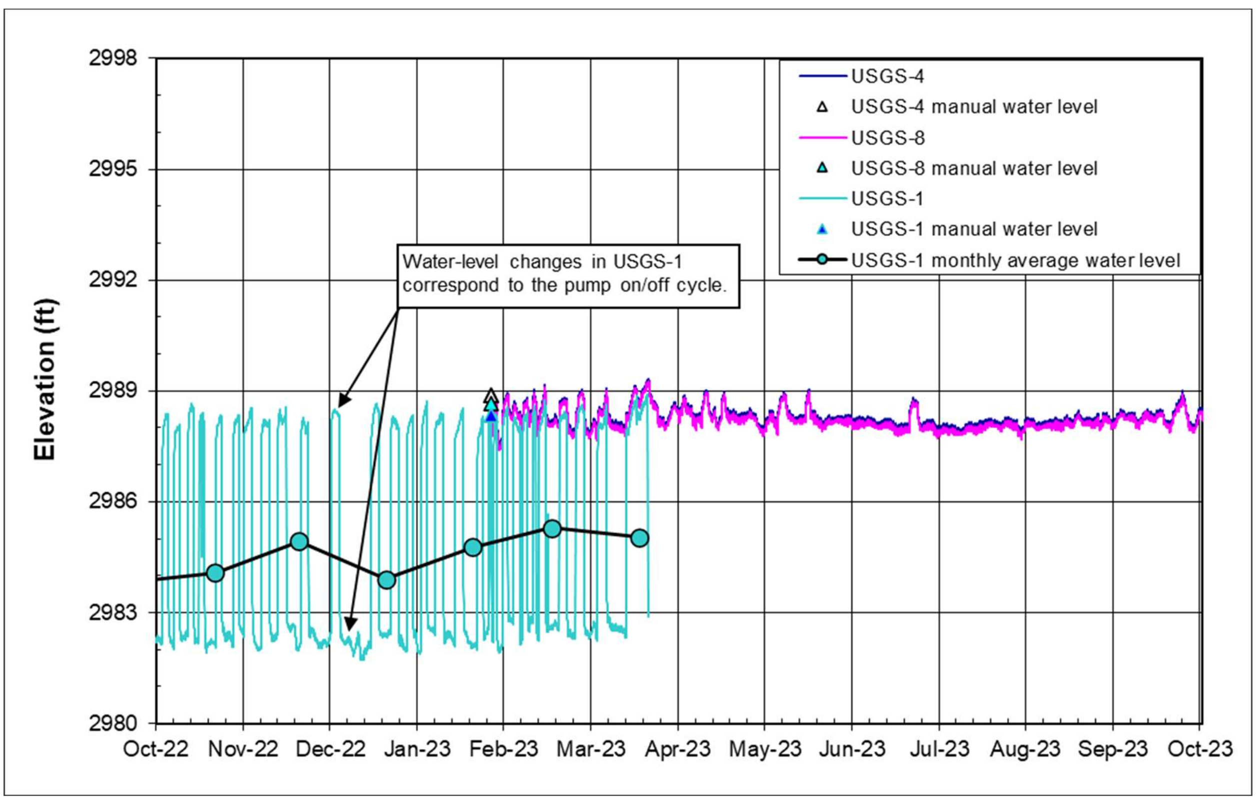

Figure 7. Groundwater Elevations in Culebra Wells, 2023 Reporting Period

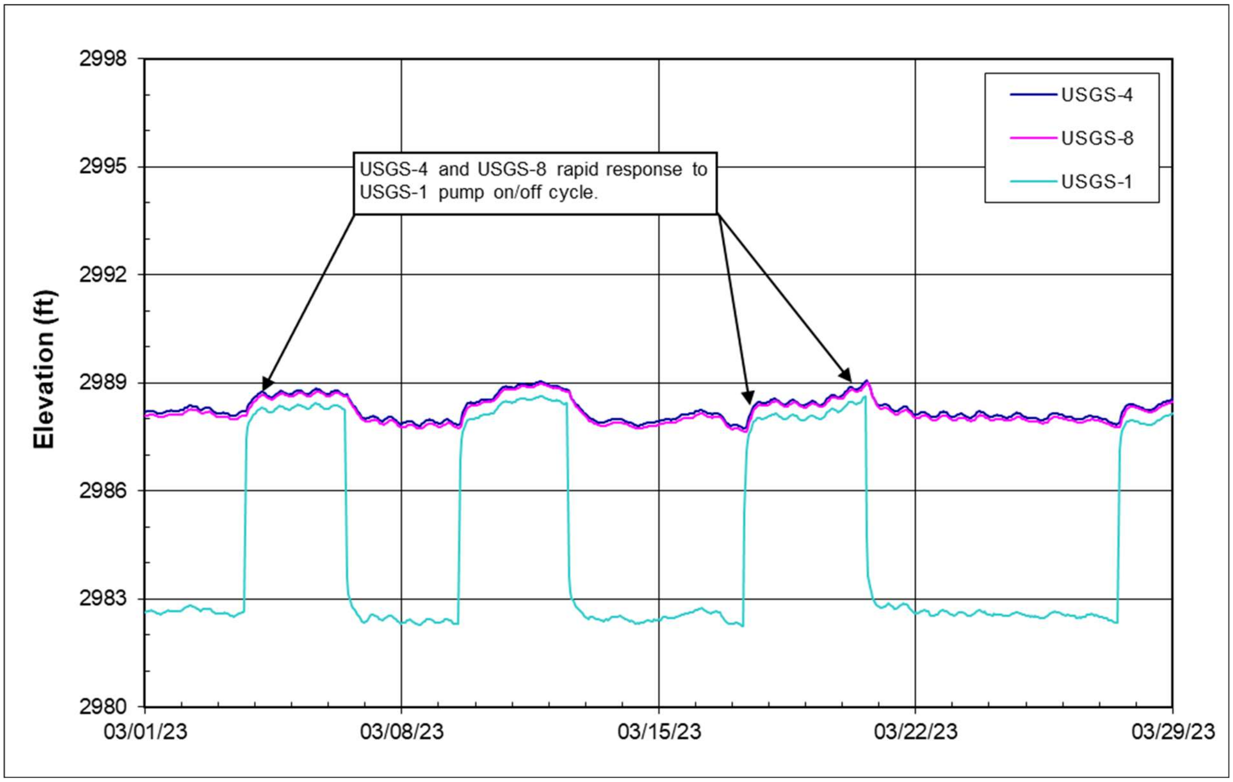

Figure 8. Groundwater Elevation Response in USGS-4 and USGS-8 to Pumping USGS-1, 2023 Reporting Period

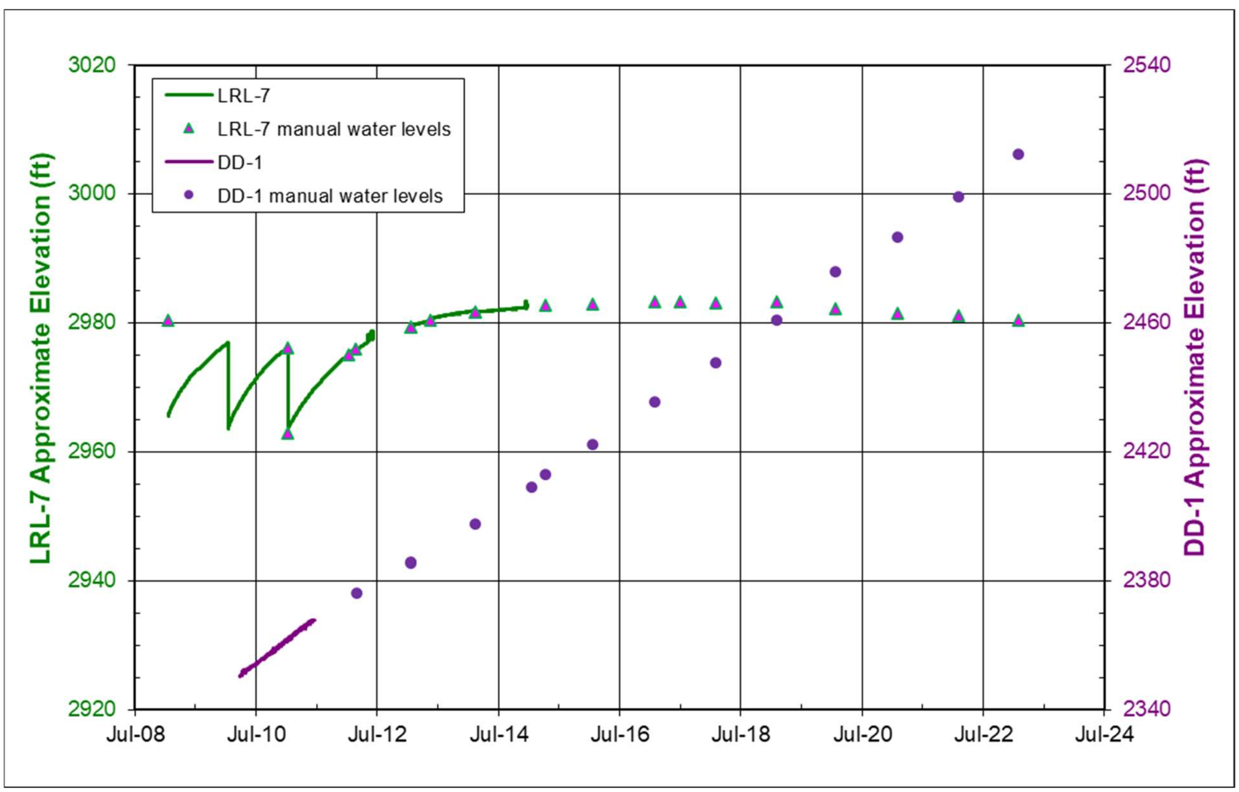

Figure 9. Groundwater Elevations in Reentry Well DD-1 and LRL-7, 2008 through 2023

Fluid levels in the detonation cavity are monitored by well DD-1 and in the Coach drift by well LRL-7; both wells are in the Salado Formation. The hydrograph for wells DD-1 and LRL-7 are shown in Figure 9. The water elevations in these wells are likely not indicative of the Salado Formation because of their connection to the large unnatural openings and their use for disposal of liquid waste during site cleanup activities in the late 1960s and 1970s. Water elevations in well LRL-7 (primary vertical axis) have stabilized and are no longer rising and have recovered from the last sampling event in January 2011. Water elevations in well DD-1 (secondary vertical axis) continue to rise at a rate of approximately 10 ft per year. Factors that influence water levels in wells LRL-7 and DD-1 include the slow refilling of the detonation cavity by the limited groundwater flow within the Salado, remnant pressure effects associated with the detonation, the plastic nature of the Salado Formation, and injections of liquefied waste material associated with past disposal activities. Water elevations from wells DD-1 and LRL-7 are approximate because borehole deviation data are not available for these wells (Figure 9).

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), and samples are collected to identify trends in the data. The monitoring of these wells was initiated in 1972. The monitoring wells completed in the Culebra Dolomite (USGS-1, USGS-4, and USGS-8) are sampled annually for the radionuclides of interest (tritium, ^{137}Cs, and ^{90}Sr) used during the tracer test in 1963. Iodine-131 was also used during the tracer test, but it is no longer present at the site because of its short half-life (8 days). 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.

Monitoring wells USGS-1, USGS-4, and USGS-8 were sampled on February 7, 2023. Wells DD-1 and LRL-7 were not planned for sampling during this monitoring event. The samples from well USGS-1 were collected as grab samples using the dedicated pump that fills the nearby water tank. The samples from USGS-4 and USGS-8 were sampled using dedicated high pressure bladder pumps. Samples were analyzed for gamma-emitting radionuclides (using high-resolution gamma spectrometry), ^{90}Sr, and tritium (using conventional methods). The laboratory analytical results were validated in accordance with the *Environmental Data Validation Procedure* (LMS/PRO/S15870). Samples were analyzed using accepted procedures based on 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 memo is available on request.

Laboratory radiochemical results from the February 2023 monitoring event continue to trend lower, consistent with previous results (Table 3). Sample results with a less-than symbol (<) indicate concentrations that are below the laboratory minimum detectable concentration. Laboratory results of samples from the February 7, 2023, sampling event, indicated that chemical recovery of ^{90}Sr exceeded the acceptance range for all samples. After calibration checks were performed by the laboratory on March 17, 2023, it was determined that the laboratory results for ^{90}Sr were biased high, so the results are qualified with a J flag, as estimated. Table 3 presents a summary of laboratory radiochemical results from 2015 to 2023 for comparison.

Table 3. Radiochemical Analytical Results 2015–2023

Sample Location	Collection Date	Tritium (pCi/L)	Tritium Enriched Method (pCi/L)	^{137}Cs (pCi/L)	^{90}Sr (pCi/L)	Formation/ Unit Monitored
USGS-1	1/27/2015	NA	<2.24	<6.77	<0.722	Culebra Dolomite
	1/27/2016	<364	<2.91	<6.08	<0.974	
	2/7/2017	<357	<3.1	<4.92	1.78[b] / <0.85	
	7/12/2017	<365	NA	NA	<0.69	
	2/6/2018	<344	<2.8	<2.67	<0.852	
	2/12/2019	<130	NA	<6.0	<0.57	
	1/28/2020	<110	NA	<4.1	<0.65	
	2/9/2021	<160	NA	<3.6	<0.50	
	2/9/2021[a]	<160	NA	<5.2	<0.50	
	2/9/2021	<160	NA	<3.6	<0.50	
	2/8/2022	<160	NA	<4.6	<0.68	
	2/7/2023	<443	NA	<2.6	1.35[c]	
USGS-4	1/27/2015	6030	NA	<4.85	1740	Culebra Dolomite
	1/27/2016	5240	NA	<6.03	1420	
	2/7/2017	4470	NA	<3.09	1050	
	2/6/2018	4102	NA	<2.55	1906	
	2/6/2018[a]	NA	NA	<2.77	1828	
	2/12/2019	4070	NA	<7.8	2260	
	1/28/2020	3700	NA	<6.2	2100	
	2/9/2021	2920	NA	<5.7	1910	
	2/8/2022	NS	NS	NS	NS	
	2/7/2023	3439	NA	<2.66	1240[c]	
USGS-8	1/27/2015	17,400	NA	123	2650	Culebra Dolomite
	1/27/2015[a]	16,400	NA	128	2480	
	1/27/2016	16,400	NA	142	2410	
	1/27/2016[a]	16,100	NA	166	2270	
	2/7/2017	11,300	NA	149	1640	
	2/7/2017[a]	11,600	NA	141	1670	
	2/12/2019	10,500	NA	142	3260	
	2/12/2019[a]	11,000	NA	127	3310	
	1/28/2020	10,600	NA	145	3280	
	1/28/2020[a]	10,000	NA	136	3250	
	2/9/2021	9120	NA	110	3010	
	2/8/2022	NS	NS	NS	NS	
	2/7/2023	7360	NA	96	2138[c]	
	2/7/2023[a]	7075	NA	117	2301[c]	

Notes:
[a] Indicates a field duplicate sample.
[b] Indicates the sample was reanalyzed because the result was suspected to be a laboratory error (DOE 2018).
[c] Indicates J flag, biased high, result estimated.

Abbreviations/Symbols:
NA = not analyzed — pCi/L = picocuries per liter
NS = not sampled — < = below the laboratory minimum detectable concentration

Figures B-1 through B-7 in Appendix B show temporal plots of radionuclide concentrations (1972–2023) in samples collected from wells LRL-7, USGS-4, and USGS-8 to support trend analysis. Sample results from well USGS-1 are not included because concentrations of tritium (using conventional methods), ^{90}Sr, and ^{137}Cs have not been detected above the laboratory minimum detectable concentration in this well since monitoring began in 1972. The detection of ^{90}Sr (1.78 picocuries per liter [pCi/L]) in the February 2017 and (1.35 pCi/L) February 2023 samples collected from USGS-1 are attributed to laboratory error (DOE 2018). Concentrations are plotted on a semilogarithmic scale, and all sample results are plotted, including results below the laboratory minimum detectable concentration. 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-year half-life), ^{90}Sr (28.8-year half-life), and ^{137}Cs (30.2-year half-life) have been included on the charts for reference. The increases in tritium concentrations in samples collected from well LRL-7 (Figure B-1) and ^{137}Cs concentrations in samples collected from wells USGS-8 and LRL-7 (Figure B-4 and Figure B-6) after the 2007 sampling event are attributed to changes in the sampling method. Before 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 (Figure B-1) continue to decrease 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 February 7, 2023. At the time of the inspection, the signs onsite and around the site perimeter were observed to be in good condition, as were the roads, wellheads, concrete cap, and Project Gnome monument. A review of the public websites that monitor drilling activity indicated that no new wells were drilled (oil wells, injection wells, or groundwater extraction wells). The New Mexico Oil Conservation Division approved 47 new applications to drill in surrounding sections of the site, no permits were received nor approved to drill onsite. A search of seismic events indicated that 29 events having a magnitude between 2.0 and 3. 2 occurred within 25 miles of the site. The frequency of these events has increased in southeast New Mexico and west Texas since 2019. This increase has been attributed to increased oil and gas drilling and disposal of wastewater through deep injection wells within the Delaware Basin.

The groundwater elevation data from the Culebra wells continue to support a regional groundwater flow direction that is generally toward the south but is influenced locally by the pumping in well USGS-1. This pumping continues to produce an almost immediate water-level drawdown response in wells USGS-4 and USGS-8. Groundwater elevations in the Culebra wells that had been decreasing overall since monitoring began in 2008, were stable in 2020 and 2021, resumed decreasing in 2022, and appear to have stabilized in 2023. The decrease in groundwater elevation was likely the result of an increase in oil and gas activity in 2022 after a slowdown during the previous 2 years that resulted from the COVID-19 pandemic. The oil and gas well industry uses groundwater from the Culebra as part of the drilling and hydrologic fracturing process. Groundwater elevation data from well LRL-7, which monitors the Coach drift, indicate that water levels have recovered and stabilized from the well's last sampling event in

January 2011. Water levels in reentry well DD-1, which monitors the detonation cavity, continued to rise at a rate of approximately 10 ft per year. Water levels in LRL-7 and DD-1 might not be representative of the Salado Formation and are likely influenced by remnant pressure effects associated with the detonation, the plastic nature of the Salado Formation, and past disposal activities.

Samples were collected from wells USGS-1, USGS-4, and USGS-8 on February 7, 2023. Wells DD-1 and LRL-7 (completed in the Salado Formation) were not planned for sampling during the 2023 reporting period. Laboratory results of the samples collected from wells USGS-1, USGS-4, and USGS-8 were consistent with previous results and continue to trend lower, except for the 90Sr detected in the sample collected from well USGS-1. It was determined during the laboratory post calibration check that the results for 90Sr are biased high, so they are J flagged as estimated. Copies of this report are sent to the individuals on the distribution list provided as Appendix C, and a copy is available on the LM public website at https://www.energy.gov/lm/gnome-coach-new-mexico-site.

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Appendix A

Photographic Documentation

Photograph A-1. Looking East at the Monument and Well DD-1 at the Gnome-Coach, New Mexico, Site

Photograph A-2. Looking East at the Concrete Cap That Covers the Project Gnome Emplacement Shaft and the Sign That Notifies the Public of No Excavating or Digging Without Permission

Photograph A-3. Looking East at the Concrete Cap That Covers the Project Gnome Emplacement Shaft

Photograph A-4. Looking East at Well USGS-1 and Water Storage Tank

Appendix B

Well Concentration Plots

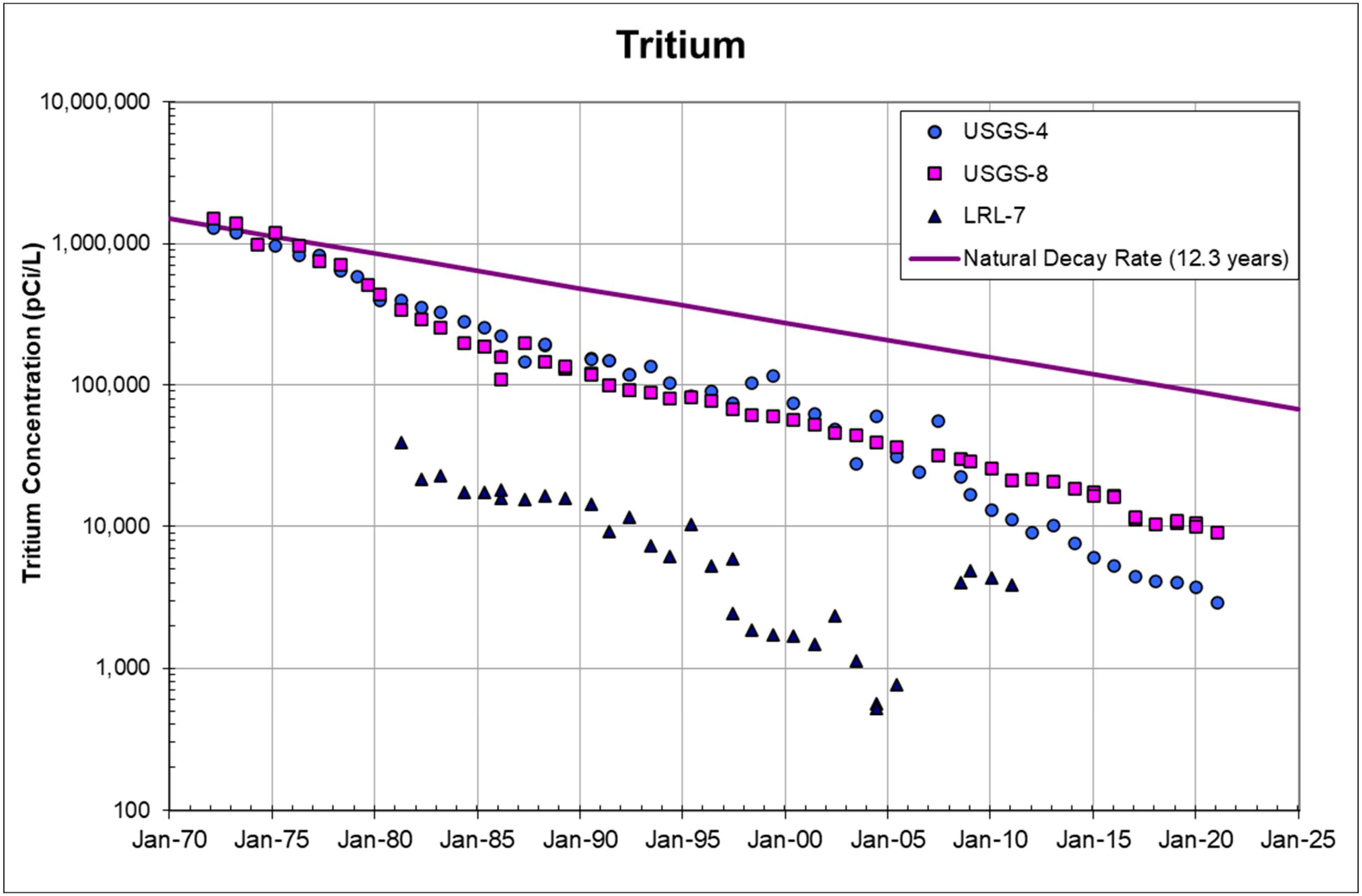

Figure B-1. Tritium Concentrations at Wells USGS-4, USGS-8, and LRL-7

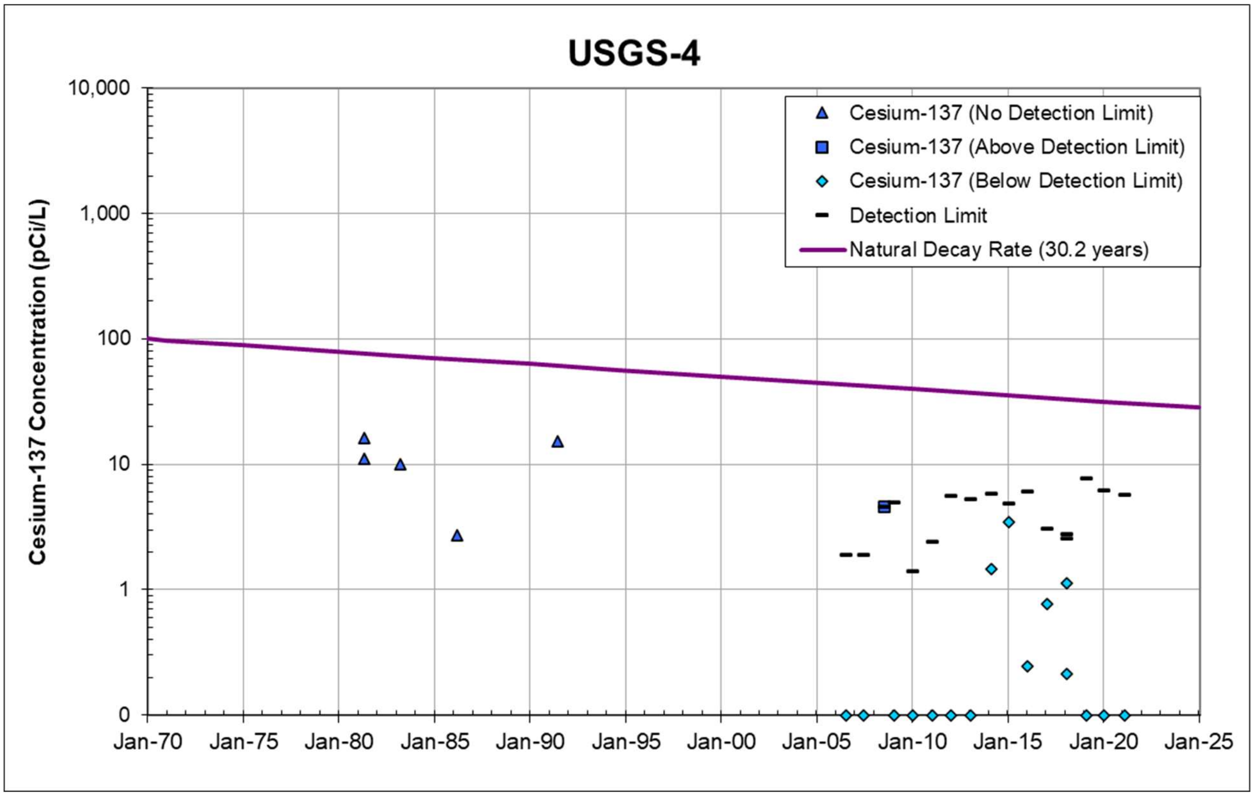

Figure B-2. Cesium-137 Concentrations at Well USGS-4

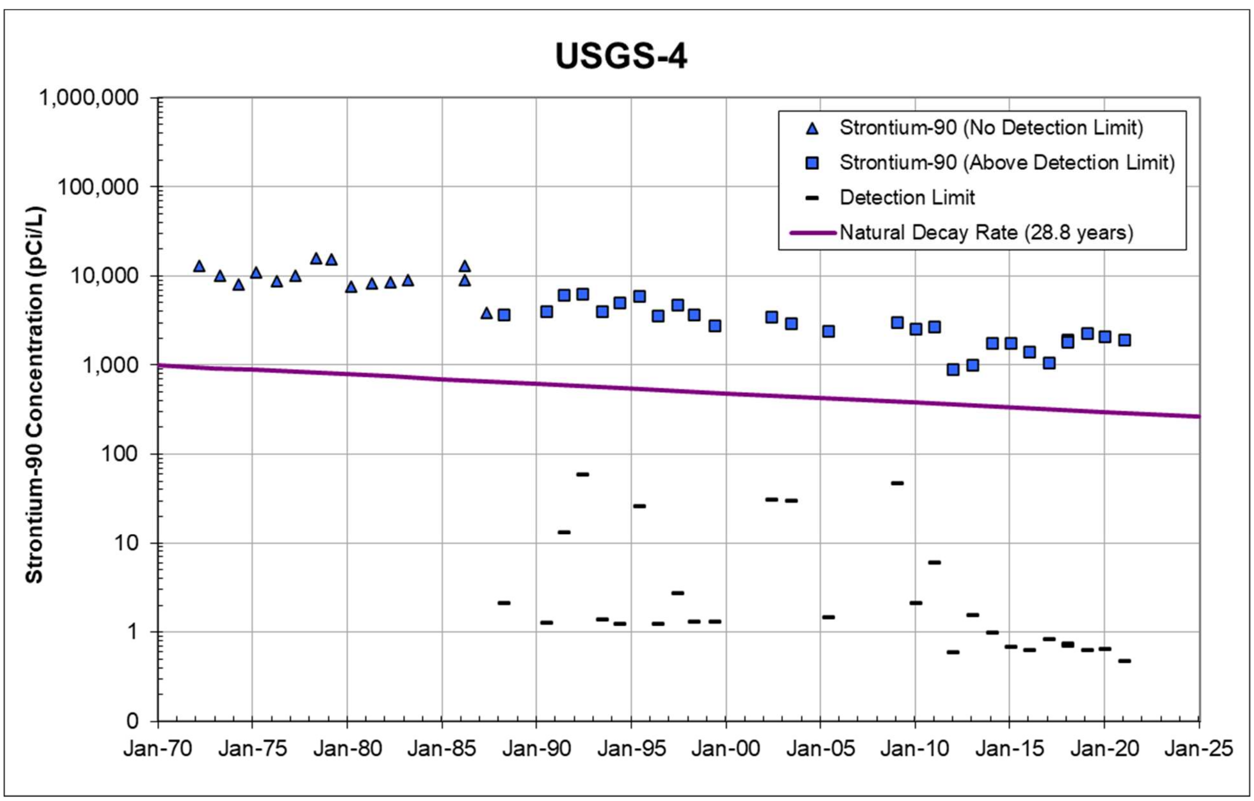

Figure B-3. Strontium-90 Concentrations at Well USGS-4

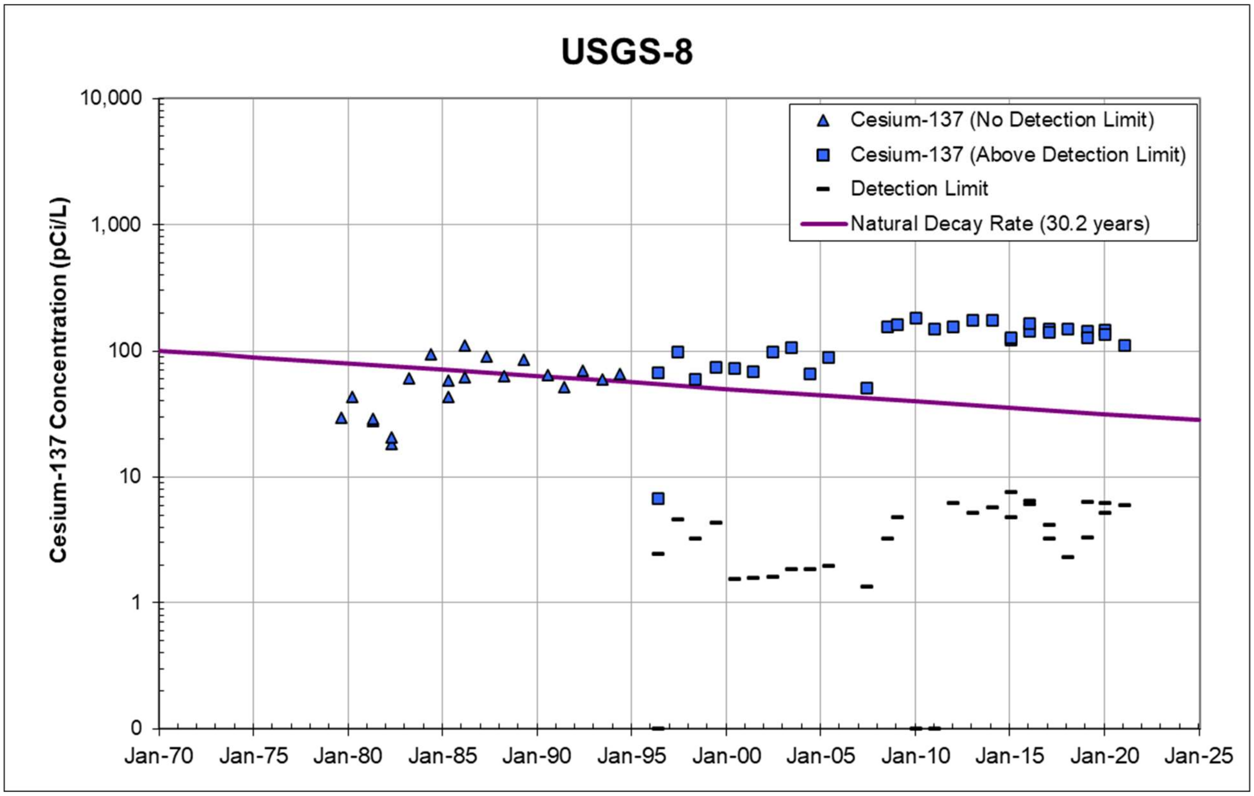

Figure B-4. Cesium-137 Concentrations at Well USGS-8

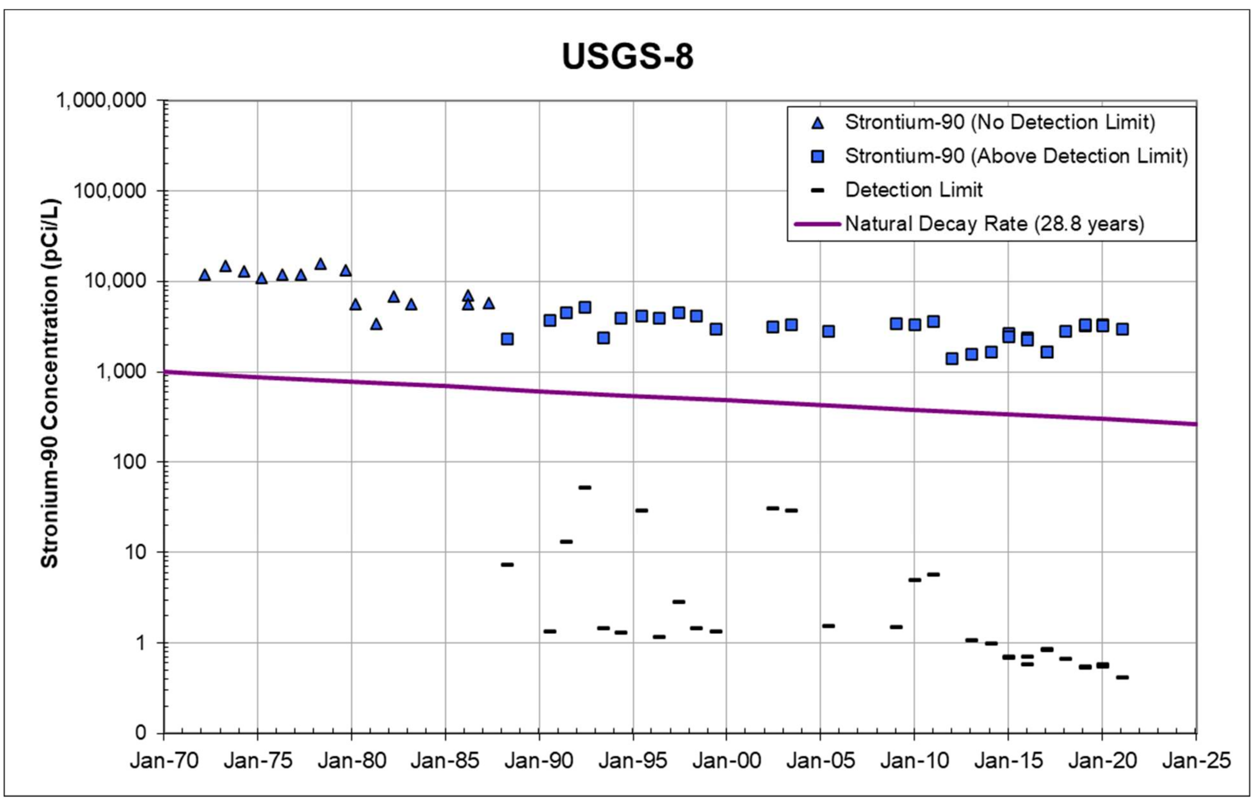

Figure B-5. Strontium-90 Concentrations at Well USGS-8

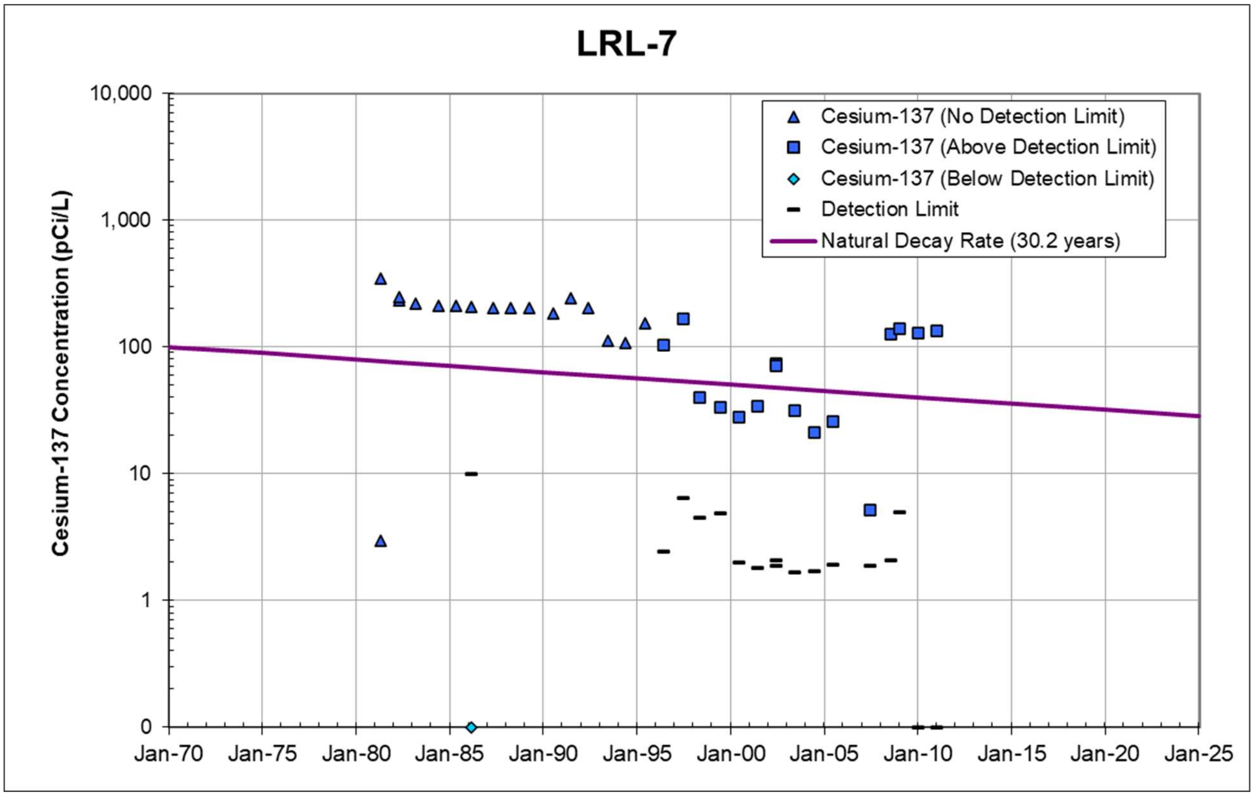

Figure B-6. Cesium-137 Concentrations at Well LRL-7

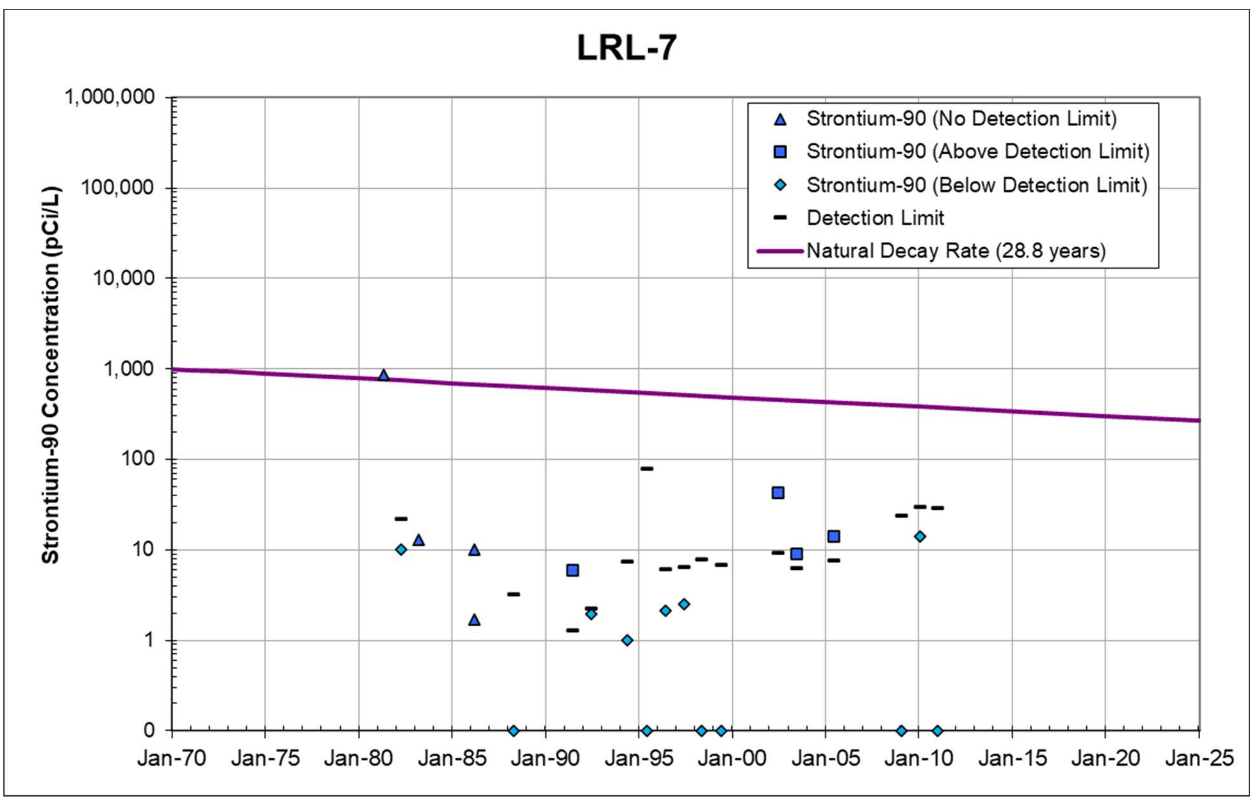

Figure B-7. Strontium-90 Concentrations at Well LRL-7

Appendix C

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