LMS/RUL/S37449

2021 Long-Term Hydrologic Monitoring Program Report for the Rulison, Colorado, Site

April 2022

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Contents

Figures

Table

Abbreviations

CDPHE	Colorado Department of Public Health and Environment
CFR	*Code of Federal Regulations*
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
pCi/L	picocuries per liter
SAP	Sampling and Analysis Plan
SGZ	surface ground zero

1.0 Introduction

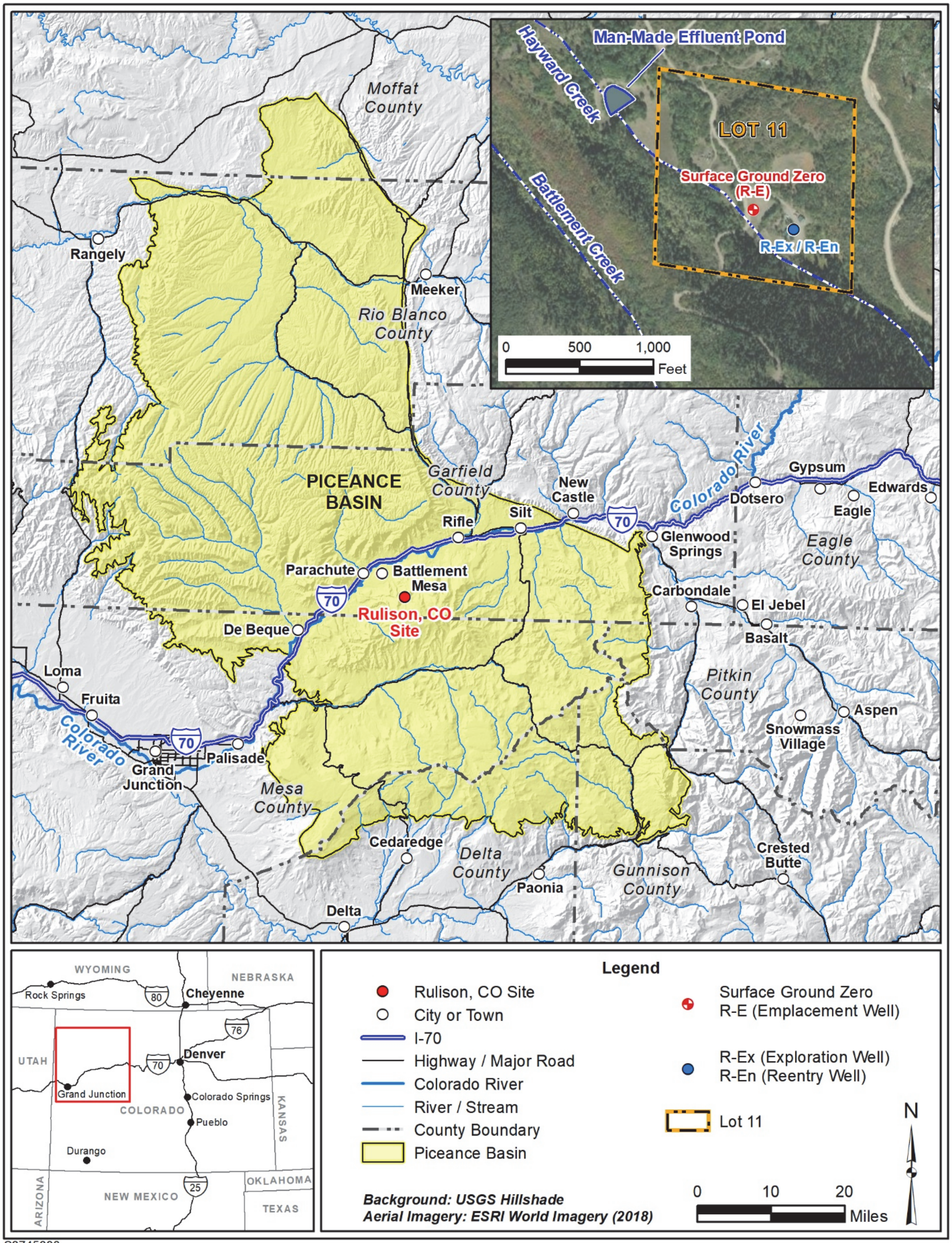
This report presents the monitoring data collected by the U.S. Department of Energy (DOE) Office of Legacy Management (LM) during the 2021 sampling event at the Rulison, Colorado, Site (Rulison site). The Rulison site was the location of an underground nuclear test in 1969. The test resulted in residual radionuclide contamination at the detonation depth of 8425 feet (ft). Monitoring at the site has included the collection of samples from shallow groundwater wells, surface water locations, and natural gas producing wells near the site to monitor for potential contamination that may be attributed to the nuclear test. This report summarizes the 2021 laboratory results of the samples collected from three shallow groundwater wells on and near the site. These results are compared with the historical results obtained since monitoring began in 1972. Laboratory results of samples collected from natural gas wells are summarized in a separate report. This annual report and the natural gas well monitoring reports are available on the LM public website at https://www.energy.gov/lm/rulison-colorado-site. Data collected during this and previous monitoring events are available on the Geospatial Environmental Mapping System (GEMS) website at https://gems.lm.doe.gov/#site=RUL.

2.0 Site Location and Background

The Rulison site (also called Lot 11) is in the Piceance Basin of western Colorado and is 40 miles northeast of Grand Junction, Colorado (Figure 1). The U.S. Atomic Energy Commission (a predecessor agency to DOE) conducted the underground nuclear test in partnership with the Austral Oil Company Inc. and the nuclear engineering firm CER Geonuclear Corporation (CER). The test was called Project Rulison, and it was designed to evaluate the use of a nuclear detonation to enhance natural gas production by fracturing low-permeability, gas-bearing sandstones of the Williams Fork Formation. This was the second natural gas stimulation experiment in the Plowshare Program, which was a program to develop peaceful uses for nuclear energy.

The underground nuclear test was conducted in the emplacement well (R-E) at a depth of 8425 ft on September 10, 1969 (DOE 2015). The location of the former emplacement well (R-E) now signifies surface ground zero (SGZ) at the site. The nuclear device that was detonated had a reported yield of 40 kilotons (DOE 2015) and produced extremely high temperatures that vaporized a volume of rock, creating a cavity surrounded by a fractured area extending outward from the detonation point (AEC 1973). Shortly after the detonation, the overlying fractured rock collapsed into the void space, creating a rubble-filled collapse chimney that extends above the detonation point. The former cavity, now the lower part of the collapse chimney, and the surrounding fractured rock are together referred to as the detonation zone. A reentry well (R-En) was drilled as a sidetrack hole off the exploration well (R-Ex) into the collapse chimney. Tests were conducted on the reentry well to evaluate the success of the detonation at improving gas production from the low-permeability sandstone reservoir (Reynolds 1972). Results of the gas well production testing are summarized in the *Modeling of Flow and Transport Induced by Gas Production Wells near the Project Rulison Site, Piceance Basin, Colorado* (DOE 2013).

Site decommissioning and cleanup activities were initiated in July 1972. These included collecting soil and vegetation samples to be analyzed for radiological contaminants, decontaminating equipment, and removing equipment and material not needed for future gas



Abbreviations: CO = Colorado, USGS = U.S. Geological Survey

Figure 1. Site Location Map, Rulison Site

production activities (AEC 1973). The "final" decommissioning and cleanup occurred in 1976 after the participating parties agreed future gas production would not occur at the site (ERDA 1977). Remaining equipment and material were removed; the mud pits adjacent to the R-Ex well (now referred to as R-En) were backfilled; tritium-contaminated soils were removed; and the radiological condition of the site was further characterized through extensive surficial soil sampling. At the request of the landowner, the effluent pond used to store drilling fluids during the installation of the R-E emplacement well was left in place. As part of this cleanup, the R-E and R-En wells were abandoned, and a deed restriction was established for the site (ERDA 1977). The deed restriction prohibits the penetration or withdrawal of any material below 6000 ft within the 40 acres of Lot 11 unless authorized by the U.S. government.

In 1994 and 1995, soil and sediment samples were collected from the former effluent pond and areas near the former R-E and R-En wells. Samples were analyzed for chemical and radiological contaminants to evaluate past cleanup operations (IT 1996). Corrective action consisted of draining the effluent pond and removing contaminated sediments that exceeded State of Colorado regulatory limits. Shallow groundwater monitoring wells were also installed near the effluent pond and monitored to verify that the remedial actions were complete. In 1998, DOE provided Colorado regulators with a Surface Closure Report and recommended closure of the site surface with no further action (DOE 1998). The Colorado Department of Public Health and Environment (CDPHE) reviewed the report, agreed with the recommendation, and approved the surface closure activities (CDPHE 1998). The shallow monitoring wells were abandoned in 1999.

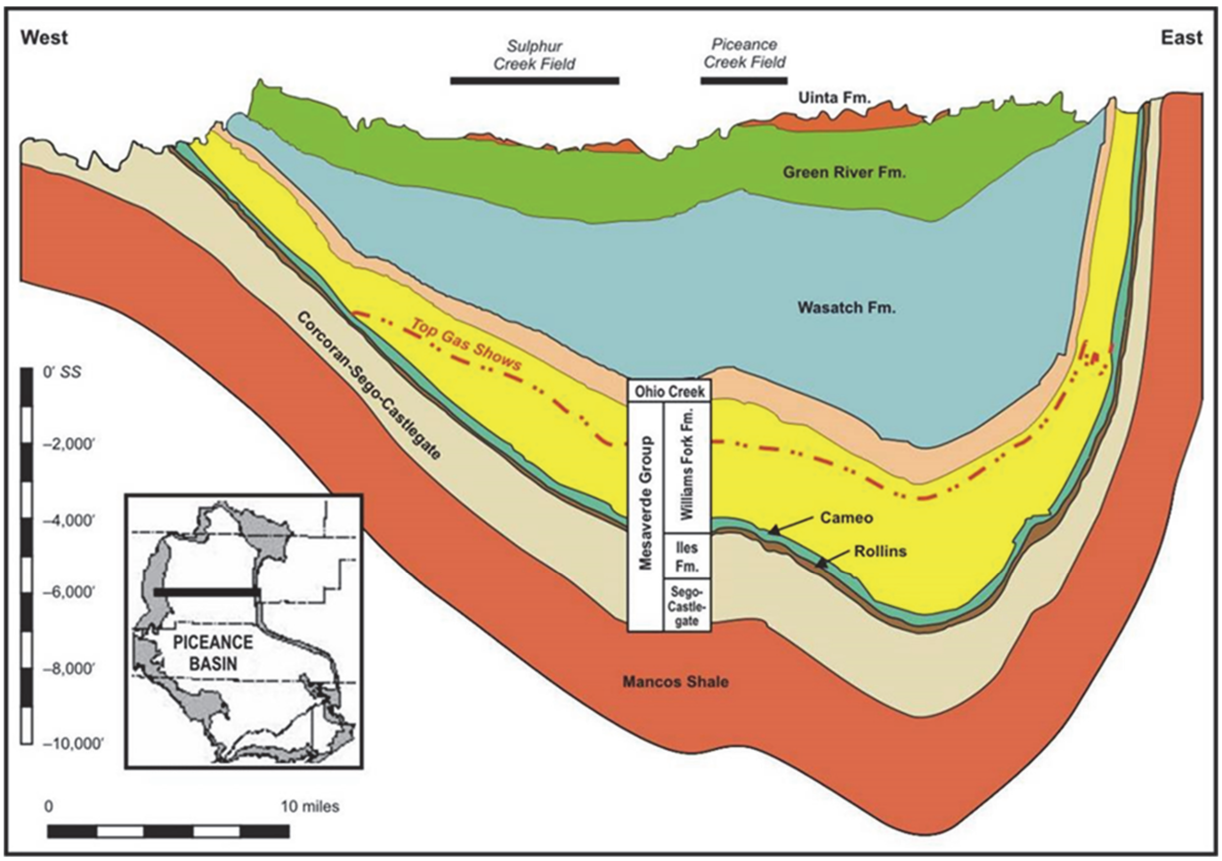
2.1 Source of Contamination

Surface and subsurface contamination resulted from the underground nuclear test at Rulison. The surface contamination was excavated and removed in 1996, and CDPHE approved closure of the surface with no further actions in 1998 (CDPHE 1998). Subsurface contamination remains in the detonation zone at a depth of 8425 ft near the R-E emplacement well, which includes the former cavity, collapse chimney, and fractured rock surrounding the former cavity. The detonation zone is contaminated by residual radioactive material, with the high-melting-point radionuclides trapped in the solidified melt rock (often referred to as melt glass due to its glassy texture) at the bottom of the former cavity. The radionuclides incorporated in the melt rock can only be released to groundwater very slowly through dissolution of the melt rock (e.g., as described by Tompson et al. [1999] and Pawloski et al. [2001]). Though dissolution of radionuclides from melt rock can represent a long-term source of subsurface contamination, dissolved-phase transport of radionuclides away from the detonation zone would be insignificant. Liquid movement in the formation is severely limited by its low permeability (only a few microdarcies), and the presence of gas in the pores makes the relative permeability of liquids even less. Due to these factors, radionuclides in the solidified melt rock are essentially immobile.

The primary contaminants of concern are expected to be those radionuclides that can exist in the gas phase because the gas phase is much more mobile than the liquid phase in the gas-producing reservoirs of the Williams Fork Formation. Of the radionuclides that can exist in the gas phase, tritium and krypton-85 are expected to constitute most of the radioactivity (Smith 1971). Samples collected during production testing in 1970 and 1971 indicated that most of the krypton-85 was removed and flared, but tritium remained as tritiated liquid water (DOE 2013). Since tritium is the most abundant radionuclide remaining in the detonation zone that can be present in the gas and aqueous phases, it is the radionuclide of concern at the Rulison site.

2.2 Geologic Setting

The Williams Fork Formation of the Mesaverde Group is the primary gas-producing zone within the Piceance Basin. The Piceance Basin is a northwest-southeast-oriented structure about 100 miles long and 40−50 miles wide (Figure 1). The bedding on the western flank of the basin dips gently to the east, and the bedding on the eastern flank of the basin dips steeply to the west, causing the basin to be asymmetrical and deepest along its eastern edge (Figure 2), where more than 20,000 ft of sedimentary rocks were deposited. The Williams Fork Formation is encountered between the depths of approximately 6500 and 9000 ft near the site and is overlain by the Ohio Creek Conglomerate and the Wasatch and Green River Formations. The Colorado River divides the Piceance Basin into northern and southern provinces. The southern province, which includes the Rulison site, is marked by two significant erosional remnants: Grand Mesa and Battlement Mesa. Figure 2 is a cross section of the Piceance Basin.



Abbreviation: Fm = Formation

Figure 2. Piceance Basin Cross Section (Modified from Yurewicz et al. [2003])

The Williams Fork Formation is composed of low-permeability, discontinuous, interbedded fluvio-deltaic sandstones and shales. These sandstones vary in clay content; the cleaner sandstones (less clay) in the lower two-thirds of the formation are the main targets for hydrofracturing and natural gas production. Sandstones in the upper one-third of the Williams Fork are not production targets because of their higher water content, which lowers the relative permeability of the gas phase and causes water production to be excessive compared to the amount of gas that can be produced. Despite improvements in hydrofracturing technology, formation properties greatly inhibit fluid migration beyond the extent of the hydrofractures. Wells near the Rulison site are being spaced relatively close (on 10-acre centers), about 400 ft north and south and about 1320 ft east and west of adjacent wells. The east-west trend of natural fractures in the Williams Fork causes the hydrofracturing and drainage patterns to be elongated in that direction (DOE 2013). A more detailed description of the hydrofracturing and drainage patterns at the Rulison site is provided in the *Modeling of Flow and Transport Induced by Gas Production Wells near the Project Rulison Site, Piceance Basin, Colorado* (DOE 2013).

2.2.1 Site Hydrology

There are three surface water features near Lot 11. They include Battlement Creek; a smaller, spring-fed tributary of Battlement Creek (locally known as Hayward Creek); and a man-made effluent pond (Figure 1). Battlement Creek is a perennial stream that flows near the southwest corner of the site and discharges into the Colorado River. The flow in Battlement Creek is regulated by Battlement Reservoir and is primarily fed by snow melt, shallow groundwater, and springs. The smaller, spring-fed tributary of Battlement Creek known as Hayward Creek flows across the site east of Battlement Creek. The man-made pond covers a surface area of approximately 1 acre and is approximately 1300 ft northwest of the R-E emplacement well, which is also referred to as SGZ. During the surface restoration, at the request of the landowner, DOE constructed the pond from the drilling effluent pond. Battlement Creek and its tributaries generally flow in a northwesterly direction toward the Colorado River (USGS 1969).

Groundwater is encountered in the surficial deposits (shallow alluvium <200 ft thick) near the site, with recharge from the infiltration of precipitation, primarily snowmelt. The wells used by local residents are completed in this shallow alluvial aquifer. The next potential groundwater source would be a few sandy zones in the lower part of the underlying Green River Formation (1700 ft thick) capable of yielding minor quantities of water. The Wasatch and Fort Union Formations and Ohio Creek Conglomerate extend from a depth of approximately 1700 to 6500 ft and are generally not a source of groundwater in the Rulison area. They effectively separate the overlying water-bearing aquifers from the gas-producing zones in the Mesaverde Group. The natural gas wells in the area also produce some liquids. The liquids (produced water and hydrocarbon condensate) are brought to the surface with the natural gas and mechanically separated at the wellhead. Produced water is a mixture of water vapor in the natural gas that condenses at the surface, formation water, and remnant water from hydrofracturing well development. The produced water is high in total dissolved solids and is not a usable water source.

2.3 Previous Monitoring Programs

Shallow groundwater and surface water surrounding the Rulison site has been monitored to ensure public safety under the Long-Term Hydrologic Monitoring Program (LTHMP) since

1972. The U.S. Environmental Protection Agency (EPA) performed the LTHMP sampling from the program's inception in 1972 through 2007. In 2008, LM assumed responsibility for the sampling and conducted a review of all previous LTHMP data to evaluate the effectiveness of the monitoring program. Laboratory results show that nuclear-test-related contamination has not impacted groundwater or surface water at the sampled locations. The evaluation considered the depth of the detonation and the potential transport pathways for contaminant migration from the detonation zone. It was concluded that the most likely contaminant transport pathway from the detonation zone to the surface would be through a gas production well drilled near enough to the site to allow hydrofractures from the well to interact with fractures from the nuclear detonation (DOE 2013). Based on these findings, a new monitoring program was implemented emphasizing the sampling of natural gas production wells near the site (DOE 2019). Although there are no reasonable pathways for detonation-related contaminants to impact the near-surface water, LM has continued sampling locations as described in the LTHMP reports.

3.0 Monitoring Program

The monitoring program for the Rulison site includes collecting samples from shallow groundwater wells, surface water locations, and natural gas producing wells near the site to monitor for potential contamination that might be attributed to the Rulison nuclear test. Information on the sampling of natural gas wells is provided in the *Rulison Monitoring Plan, Revision 1* (DOE 2019). Laboratory results from the sampling of natural gas wells are summarized in a separate report. A summary of 2021 groundwater sampling is provided with the laboratory results in the following sections.

3.1 Groundwater Monitoring

Samples were collected from three shallow groundwater wells on and near the site (DW-01, CER Test Well, and DW-02) during the 2021 monitoring event (Figure 3). These wells and other offsite wells and surface water locations have been sampled annually as part of the LTHMP since 1972. During this time, landowner names were used to identify some of the sample locations. This is not LM's practice, so the sample locations with landowner names where changed (e.g., Cary Weldon House is now DW-01) in the 2020 LTHMP (DOE 2021). This was not a change in the sample location, only a change to the sample identification. The LTHMP has historically included 13 locations that are a combination of shallow wells (<200 ft deep) and surface water locations. Four of the locations (three surface locations and one shallow well) are within the site boundary. The remaining nine locations (three surface locations and six shallow wells) are offsite, with these locations ranging from 2 to 6 miles from SGZ (Figure 3). Figure 3 shows the 13 LTHMP sample locations with the new sample identifiers and the shallow wells that were sampled during the 2021 monitoring event.

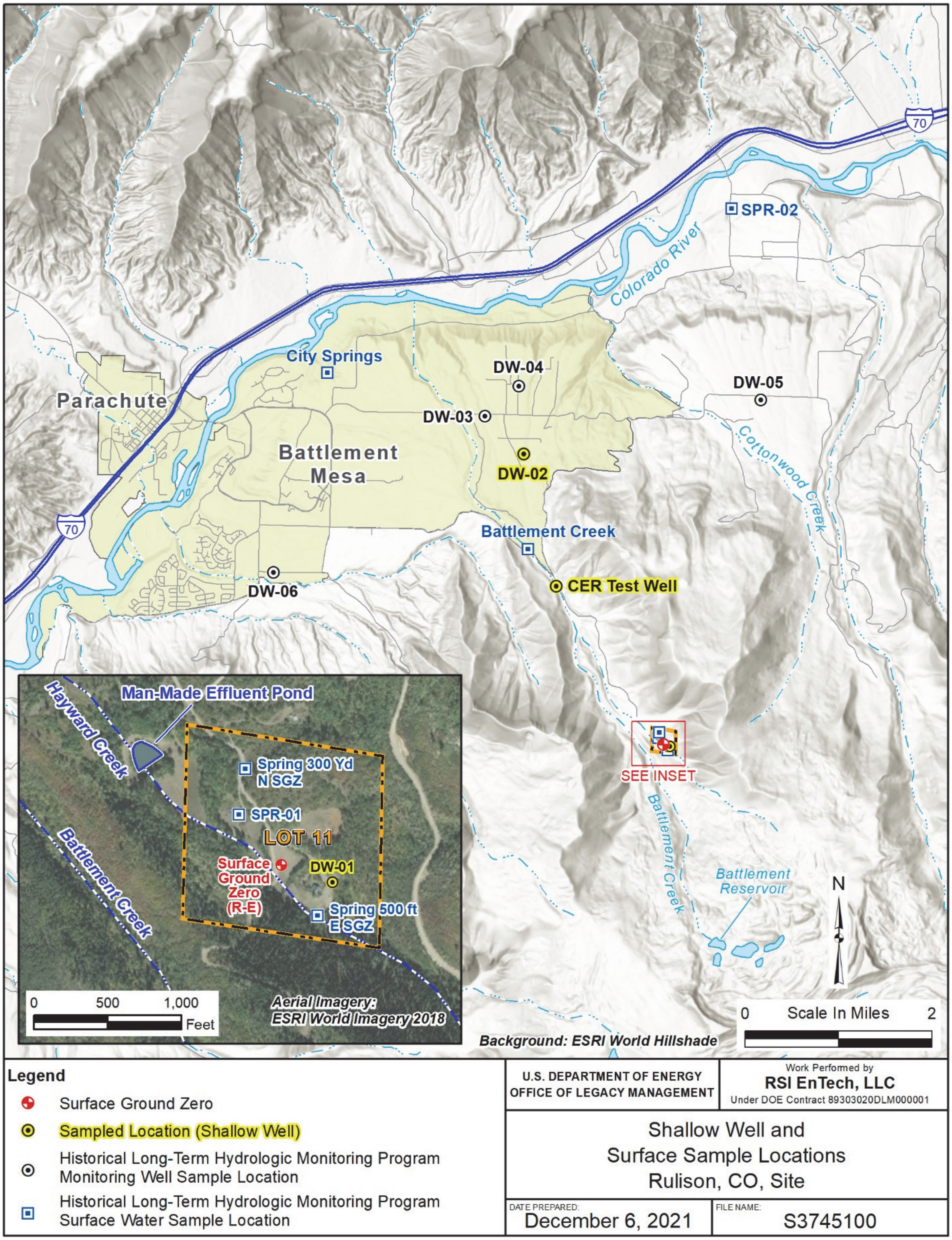


Figure 3. Shallow Groundwater and Surface Water Sample Location Map, Rulison Site

The LTHMP sampling was modified in 2020 following an evaluation of potential exposure pathways and an examination of historical site data (DOE 2020). The three shallow wells (DW-01, CER Test Well, and DW-02) were selected for sampling based on their proximity to the site. The samples are collected according to the *Sampling and Analysis Plan for U.S. Department of Energy Office of Legacy Management Sites* (LMS/PRO/S04351). That Sampling and Analysis Plan (SAP) provides the procedures used to guide the quality assurance and quality control of the annual sampling program. These procedures incorporate standards and guidance from EPA, DOE, and ASTM International. The SAP can be accessed at https://www.energy.gov/lm/articles/sampling-and-analysis-plan-us-department-energy-office-legacy-management-sites.

Samples were analyzed for tritium because it is the most mobile contaminant remaining in significant quantities in the detonation zone. All samples were analyzed for tritium using the conventional method, and one sample (DW-02) was analyzed using the electrolytic enrichment method, which allows the laboratory to provide a minimum detectable concentration that is approximately 2 orders of magnitude lower than the conventional method. The samples were submitted to ARS Aleut Analytical, LLC in Port Allen, Louisiana, which analyzed the samples using accepted procedures based on specified methods in accordance with the *Department of Defense (DoD) Department of Energy (DOE) Consolidated Quality Systems Manual (QSM) for Environmental Laboratories* (DOD and DOE 2019) to ensure data are of known, documented quality. The laboratory minimum detectable concentration reported with these data is an estimate of the predicted detection capability of a given analytical procedure, not an absolute concentration that can or cannot be detected. These laboratory analytical results were validated in accordance with Section 5.0, "Validation of Laboratory Data," of the *Environmental Data Validation Procedure* (LMS/PRO/S15870). A copy of the data validation memo is available upon request.

3.2 Groundwater Sample Results

The 2021 laboratory results continue to demonstrate that no detonation-related contaminants have impacted the sampled locations. Tritium was not detected above the laboratory minimum detectable concentration using the conventional laboratory method. One sample (DW-02) was analyzed using the enrichment method, and tritium was detected in this sample above the laboratory minimum detectable concentration (Table 1). The detection of tritium using this method is consistent with historical results and with the worldwide tritium distribution in precipitation that resulted from aboveground nuclear testing during the 1950s and early 1960s (IAEA 2022). Aboveground tests conducted by the United States and Soviet Union ended with the 1963 Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water. The tritium results obtained using the enrichment method are shown with the plot of tritium in precipitation (Figure 4 and Figure 5) at Ottawa, Canada (IAEA 2022), which is the longest record of tritium in precipitation in the northern hemisphere. The natural decay rate for tritium (half-life of 12.3 years) is also included in the figures for comparison. The similarity of the tritium levels obtained from the enrichment laboratory method to tritium levels in precipitation indicates that the wells and surface locations are supplied by recent infiltration of water from rain or snowmelt. These results are much lower than the EPA drinking water standard for tritium of 20,000 picocuries per liter (pCi/L) presented in Title 40 *Code of Federal Regulations* Section 141.16 (40 CFR 141.16). Table 1 provides the 2021 sample results.

Table 1. 2021 Sample Results, Rulison Site

Sample Location[a] (Shallow Wells)	Sample Location Type	Date Collected	Tritium by	
			Conventional Method (pCi/L)	Enrichment Method (pCi/L)
DW-01	Groundwater	5/25/2021	<282	Not analyzed
			<285[b]	Not analyzed
CER Test Well		5/25/2021	<283	Not analyzed
DW-02		5/25/2021	<286	18

Notes:
[a] Some sample location identifiers have changed, but the sample locations have not changed.
[b] This is a field duplicate sample.

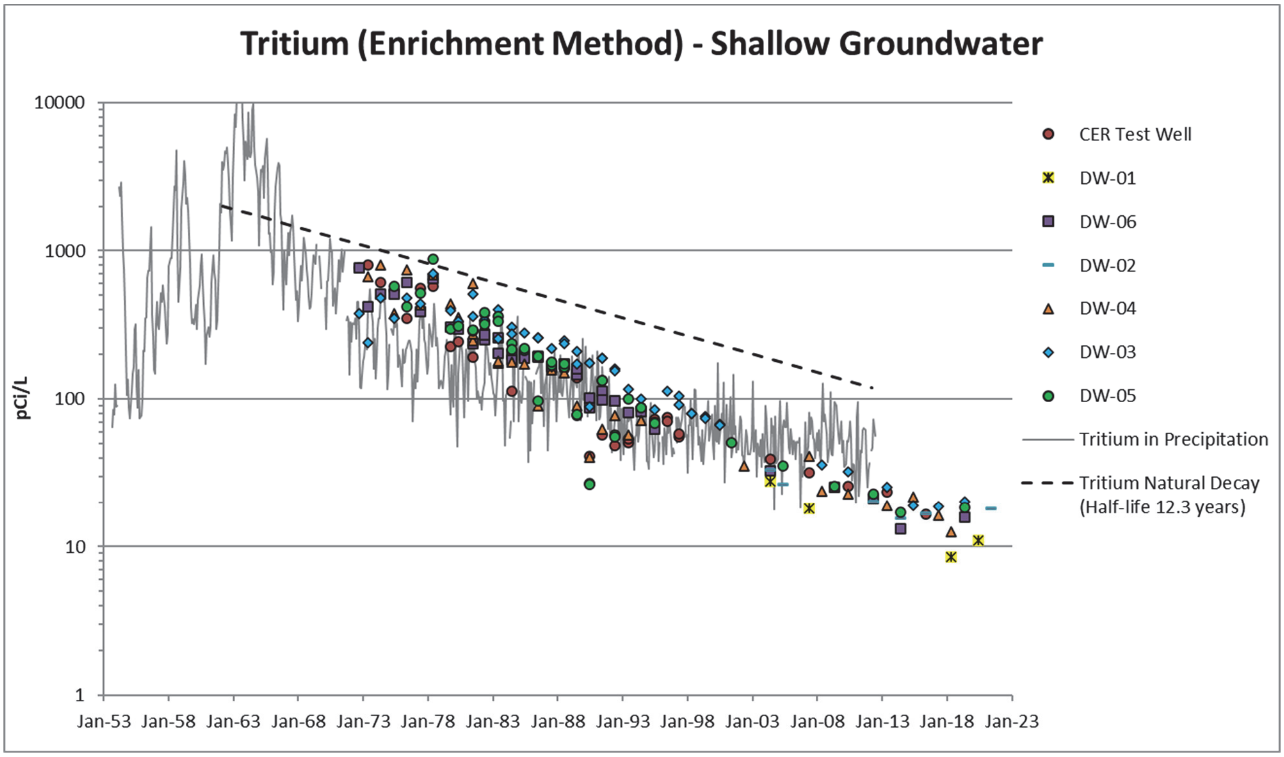


Figure 4. Comparison of Tritium in Shallow Wells near the Rulison Site with Tritium in Precipitation at Ottawa, Canada (Site with Longest Historical Tritium Record [IAEA 2022])

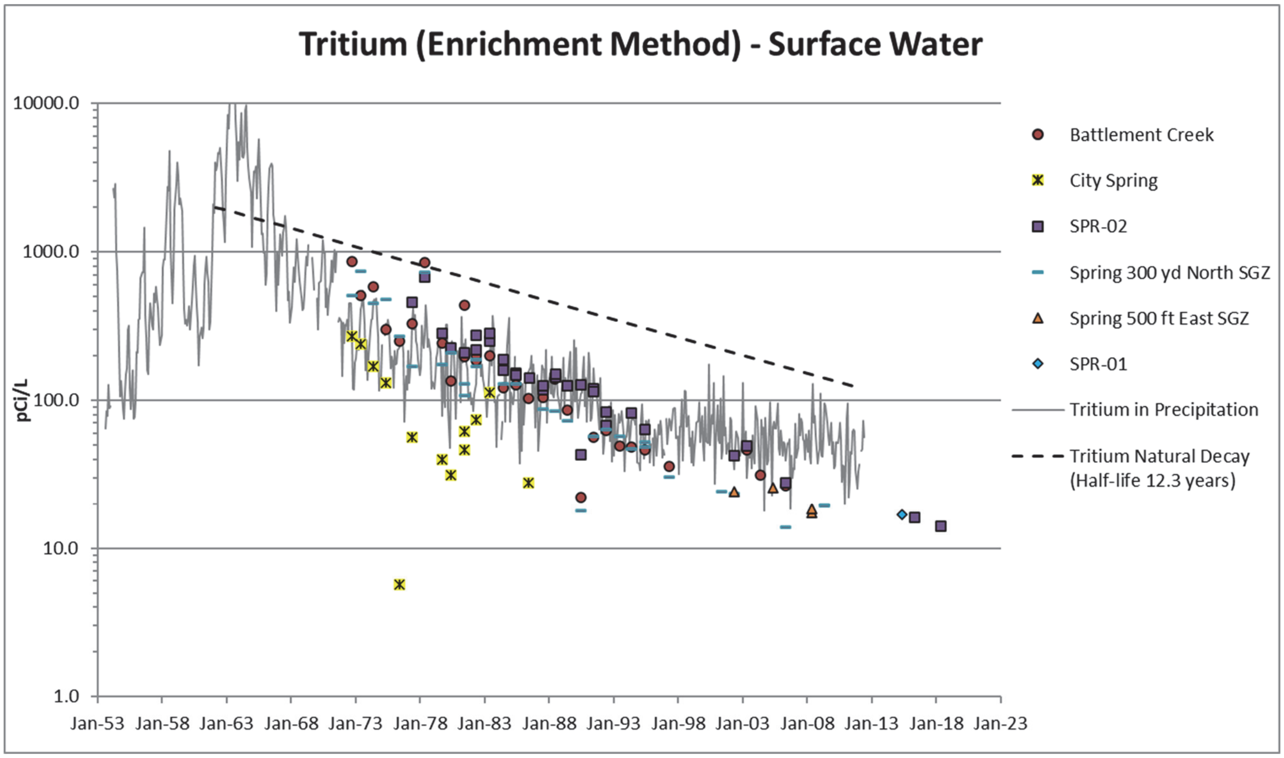


Figure 5. Comparison of Tritium in Surface Water near the Rulison Site with Tritium in Precipitation at Ottawa, Canada (Site with Longest Historical Tritium Record [IAEA 2022])

4.0 Conclusions

The laboratory results from the 2021 monitoring event indicate that no Rulison site detonation-related contaminants have impacted the sampled locations on and near the site. The detection of tritium at a concentration of 18 pCi/L in the sample collected from DW-02 is consistent with background tritium concentrations in precipitation that resulted from aboveground nuclear tests conducted at different global locations. Based on these results and past evaluations, the sampling planned for 2022 will continue focus on the onsite well (DW-01) and two offsite well locations (CER Test Well and DW-02). This report and previous reports are available on the LM public website at https://www.energy.gov/lm/rulison-colorado-site. Data collected during this and previous monitoring events are available on the GEMS website at https://gems.lm.doe.gov/#site=RUL.

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