LMS/RBL/42095

2022 Long-Term Hydrologic Monitoring Program Report for the Rio Blanco, Colorado, Site

January 2023

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U.S. DEPARTMENT OF ENERGY | Legacy Management

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Abbreviations

bgs	below ground surface
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

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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 2022 sampling event at the Rio Blanco, Colorado, Site, where an underground nuclear test was conducted in 1973. The test resulted in residual radionuclide contamination at the detonation depth. The 2022 sampling event included the collection of samples from onsite groundwater wells to monitor for any potential contamination that might be attributed to the Rio Blanco nuclear tests. This report summarizes the laboratory results obtained from the sampling along with the historical results since monitoring began in the 1970s. This annual report and previous reports are available on the LM public website at https://www.energy.gov/lm/rio-blanco-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=RBL.

2.0 Site Location and Background

The Rio Blanco site is in the Piceance Basin of western Colorado and lies 50 miles north 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 nuclear engineering firm CER Geonuclear Corporation and Continental Oil Company (Conoco). The test was called Project Rio Blanco and was designed to evaluate the use of nuclear detonation to enhance natural gas production in low-permeability, gas-bearing sandstones of the Williams Fork and Fort Union Formations. Project Rio Blanco was the third and final natural gas reservoir stimulation test in the Plowshare Program, which aimed to develop peaceful uses for nuclear energy.

On May 17, 1963, three nuclear devices were detonated nearly simultaneously at the Rio Blanco site in the RB-E-01 emplacement hole at depths of 5840, 6230, and 6690 feet (ft) below ground surface (bgs). Each device had a reported yield of 33 kilotons (DOE 2015), which produced extremely high temperatures that vaporized a volume of rock, temporarily creating a cavity at each depth (Toman 1975). The fractured rock above each cavity collapsed shortly after the detonation, filling each cavity with rubble and forming a collapse chimney that extended above each detonation point. Each former cavity and surrounding fractured rock, as well as the collapse chimney are collectively referred to as the detonation zone. It was expected that the three collapse chimneys created by the detonations would connect, allowing improved gas production within the detonation zone (Toman 1975). Reentry wells were drilled into two of the collapse chimneys and tested to determine the success of the nuclear test at improving natural gas production. The first reentry well (RB-AR-1) was a sidetrack hole off the RB-E-01 emplacement hole that was drilled into the upper chimney. The second reentry well (RB-AR-2) was drilled into the lower chimney and tested to determine the success of the detonations at creating a continuous chimney and improving gas productivity. It was determined that the simultaneous detonations failed to create a single elongated interconnected chimney based on tracers included with each device. Additionally, production testing on the reentry wells did not indicate significant increases in productivity from the formation. Results of the testing are summarized in the *Modeling of Flow and Transport Induced by Gas Production Wells near the Project Rio Blanco Site, Piceance Basin, Colorado* (DOE 2013).

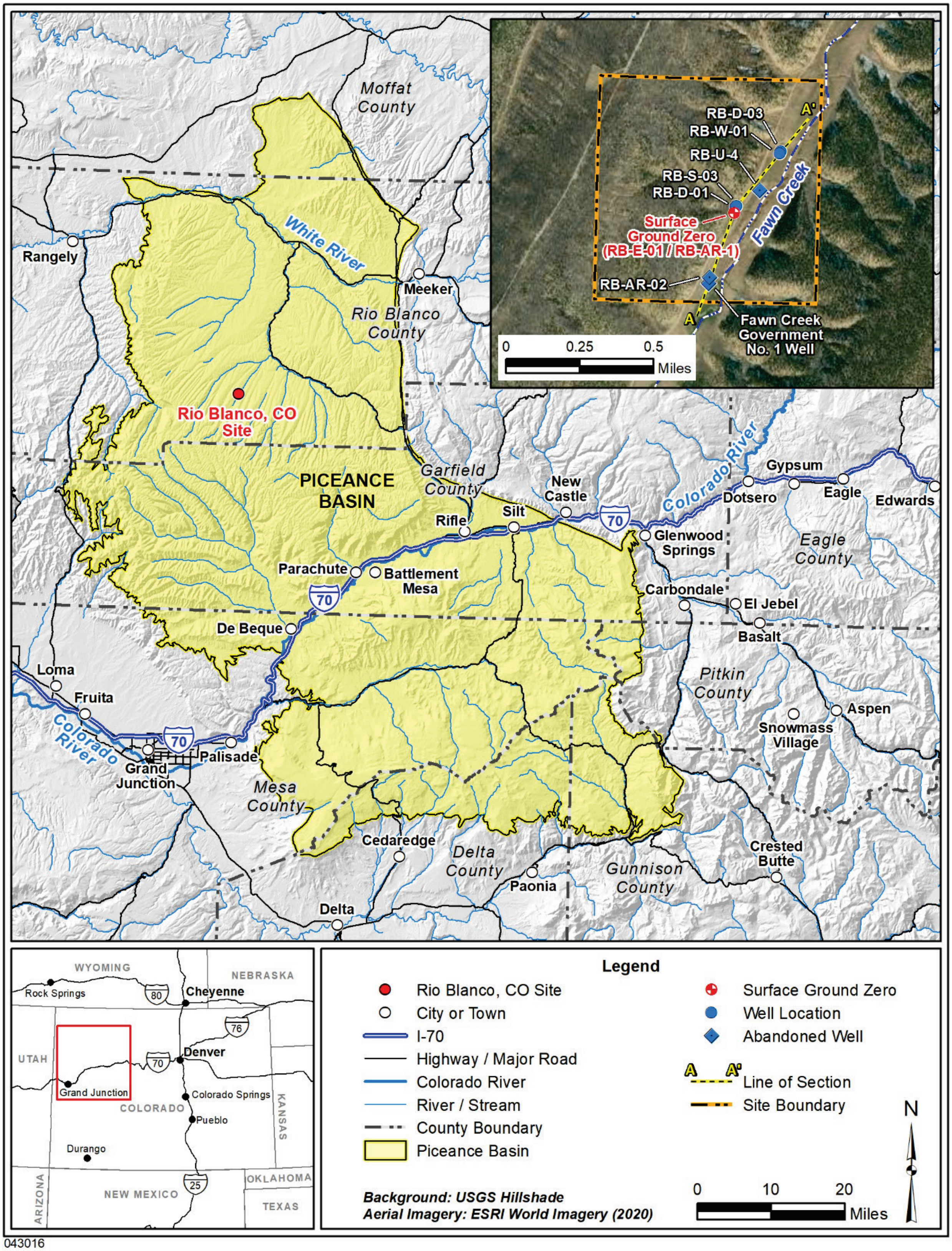

Figure 1. Site Location Map, Rio Blanco, Colorado, Site

Site decommissioning and cleanup activities were initiated in May 1976, which included the removal of facility structures and surface liquid waste generated during the test, disposal of liquid waste into the Fawn Creek Government No. 1 well, and restoration of the site surface. Liquid waste injected into the Fawn Creek Government No. 1 well was pumped through perforations in the well between depths of 5600 to 6100 ft bgs. After liquid waste was removed from the surface and pumped into the Fawn Creek Government No. 1 well, it was recompleted as a gas production well with perforated depths at a shallower interval from 5084 to 5126 ft (ERDA 1978). The RB-E-01 emplacement well, reentry wells RB-AR-1 and RB-AR-2, and wells not planned for long-term monitoring were plugged and abandoned, and the cleanup was completed in November 1976 (ERDA 1978). The Fawn Creek Government No. 1 well was plugged and abandoned in 1986. Figure 2 depicts a cross section of the Piceance Basin and Rio Blanco site that shows the former gas production wells that were plugged and abandoned, the groundwater wells that were maintained for long-term monitoring, and a schematic of the detonation zone that is not to scale.

A corrective action investigation and risk assessment were completed for the site surface in 2002 (NNSA 2002). The investigation determined that no gamma-emitting radionuclides above background levels were present in the site soil or groundwater. Lead and total petroleum hydrocarbons were found in some of the soil samples collected below a depth of 12 ft; however, the risk assessment concluded that they were not present in sufficient quantities to pose a risk to human health. Groundwater samples collected in 2002 showed no contaminants of concern above the screening levels. The subsequent report recommended that no corrective actions be required, and no surface use restrictions be placed on the site (NNSA 2002). The Colorado Department of Public Health and Environment (CDPHE) reviewed and approved the report in 2003 (Stoner 2003).

2.1 Source of Contamination

Surface and subsurface contamination resulted from the underground Rio Blanco nuclear test. The surface cleanup was approved with No Further Action by CDPHE in 2003. Subsurface contamination remains in the detonation zone near the RB-E-01 emplacement hole; this zone includes the former cavities and surrounding fractured rock along with the collapse chimneys (Figure 2). The detonation zone is contaminated by residual radioactive isotopes, and the high-melting-point radionuclides are trapped in the solidified melt rock (often referred to as melt glass due to its glassy texture) at the bottom of the former cavities. The radionuclides incorporated in the melt rock can only be released to groundwater very slowly through dissolution of the melt rock (e.g., Tompson et al. 1999; 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 is considered insignificant, because the rock surrounding the former cavities and collapse chimneys is unsaturated with respect to groundwater. The presence of gas in the surrounding formations also severely limits liquid movement, making any solidified radionuclides that may have dissolved in the former cavities essentially immobile.

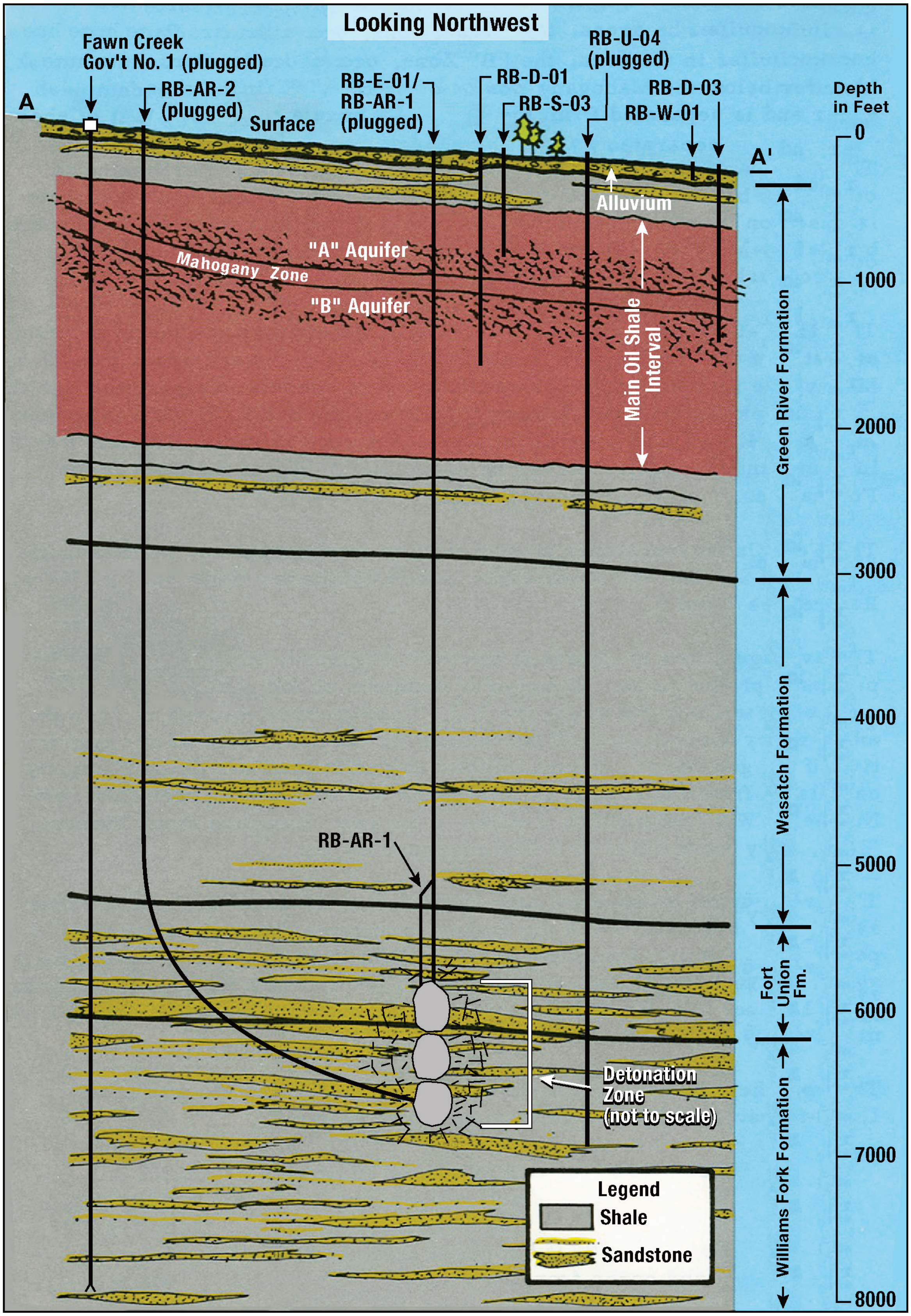

Figure 2. Cross Section of the Piceance Basin and Rio Blanco, Colorado, Site

The primary contaminants of concern are expected to be radionuclides that can exist in the gas phase because gas is much more mobile than liquids in the gas-producing reservoirs of the Fort Union and Williams Fork Formations. Of the radionuclides that can exist in the gas phase, tritium and krypton-85 are expected to constitute most of the gaseous radioactivity (Toman 1974). An evaluation of the data obtained from the production testing in 1973 and 1974 indicates that significant quantities of tritium and krypton-85 remain in the detonation zone (DOE 2013). Tritium is the most abundant and considered the greater risk due to its ability to be incorporated into human tissue, whereas krypton-85 is a noble gas and is not as easily retained in the body (ANL 2007). Because tritium presents the greatest health risk and is the most abundant radionuclide in the detonation zone that can be present in both gas and aqueous phases, it is the primary radionuclide of concern at the Rio Blanco site.

2.2 Geologic Setting

The detonations took place in the Fort Union Formation and upper part of the Williams Fork Formation (Figure 2). The Williams Fork Formation is the primary gas-producing zone in the Piceance Basin, a northwest-southeast-oriented structure about 100 miles long and 40−50 miles wide. More than 20,000 ft of sedimentary rocks were deposited in this basin. The Colorado River divides the Piceance Basin into northern and southern provinces (Figure 1). The Rio Blanco site is in the northern province; this portion of the Piceance Basin between the Colorado and White Rivers retains basinlike features, with rocks dipping inward from the margins toward the deepest part of the basin at the northern end (MacLachlan 1987).

The Fort Union and Williams Fork Formations are encountered at depths of 5330 and 6160 ft bgs, respectively, at the site (ERDA 1975). 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 (containing less clay) in the lower two-thirds of the formation have recently been the main targets for hydraulic fracturing and natural gas production. Sandstones in the upper third of the Williams Fork are not production targets due to 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. This increased water content was seen in the gas well production testing data obtained at the Rio Blanco site (DOE 2013) and is also supported by the limited number of natural gas wells in production at the detonation depths near the Rio Blanco site. A more detailed description of natural gas production near the Rio Blanco site is provided in *Modeling of Flow and Transport Induced by Gas Production Wells near the Project Rio Blanco Site, Piceance Basin, Colorado* (DOE 2013).

2.2.1 Site Hydrology

Fawn Creek is the dominant surface water feature on the site (Figure 1). It is a spring-fed perennial stream that receives much of its water from snowmelt and precipitation (USGS 1972). Fawn Creek flows across the site from south to northeast and is approximately 300 ft from the RB-E-01 emplacement well (also referred to as surface ground zero or SGZ), which was later recompleted as the RB-AR-1 reentry well before it was plugged and abandoned in 1976. Fawn Creek discharges into Black Sulphur Creek and then Piceance Creek before it reaches the White River.

Groundwater is encountered at the site in the surficial deposits (shallow alluvium <150 ft thick) and the underlying Green River Formation (approximately 2800 ft thick). The alluvial aquifer is present in the stream valleys and generally consists of sand, gravel, and clay eroded from the Uinta siltstone. The alluvial aquifer is reported as having the highest transmissivity of all rocks in the basin and yields as much as 1500 gallons per minute (USGS 1972). The Green River Formation has two water-bearing zones, an upper aquifer (Zone A or Aquifer A) and a lower zone (Zone B or Aquifer B). These aquifers are separated by the Mahogany Zone (Figure 2), which acts as an aquitard, separating the upper zone from the lower aquifer zone (USGS 1972). Groundwater flow in the shallow alluvium and the dual A/B aquifer system of the Green River Formation is generally to the east-northeast, which is consistent with the topography in the area. Groundwater in the deeper formations (Wasatch and Fort Union) is too brackish to be considered a usable water source.

The natural gas wells near the site produce some liquids along with natural gas. These liquids consist of produced water and hydrocarbon condensate, which 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 Program

Groundwater and surface water surrounding the site has been monitored since 1973. This sampling was included in the Long-Term Hydrologic Monitoring Program (LTHMP) in 1976 to assure the public that no radiological contamination associated with the Rio Blanco underground nuclear test has impacted the sample locations near the site. The U.S. Environmental Protection Agency (EPA) performed the LTHMP sampling from the program's inception 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 Rio Blanco site contamination related to the Project Rio Blanco nuclear test has not impacted groundwater or surface water at any of 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 from this evaluation and numerical modeling studies 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 hydraulically-induced fractures from the well to interact with nuclear-induced fractures of the detonation (DOE 2013). Based on these findings, a new monitoring program was implemented to emphasize the sampling of natural gas production wells near the site. This sampling program was later refined to the producing natural gas wells within 1 mile of the site. Although gas production wells are the most likely transport path for detonation-related contaminants, LM has continued the sampling of select locations that have been part of the LTHMP.

3.0 Monitoring Program

The monitoring program for the Rio Blanco site includes the collection of samples from groundwater wells and surface water locations on and near the site and from producing natural gas wells within 1 mile of the site to assess for any potential impacts that may be attributed to the underground nuclear test. Natural gas wells, surface water locations, and offsite wells were not sampled during this monitoring period. Natural gas wells were not sampled because there are no producing natural gas wells currently within 1 mile of the site. The surface water locations and offsite wells were not sampled because there are no reasonable pathways for detonation-related contaminants to impact these locations and historical sample results support the determination that these locations have not been impacted by the Rio Blanco detonation (DOE 2020). A summary of the 2022 groundwater sampling is provided with laboratory results in the following sections.

3.1 Groundwater Sampling

Samples were collected from the four groundwater wells onsite (RB-D-01, RB-D-03, RB-S-03, and RB-W-01) during the annual monitoring event that was completed on May 18, 2022. Since 1976, these wells and other offsite wells and surface water locations have been sampled annually as part of the LTHMP (Figure 3). The LTHMP has historically included 15 locations that are a combination of groundwater wells and surface water locations. Six of these locations (four wells and two surface locations) are on the Rio Blanco site. The remaining nine locations (two wells and seven surface locations) are located offsite and range from 1 to 7 miles from the former RB-E-01 emplacement well and SGZ (Figure 3). 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), also called the Sampling and Analysis Plan (SAP). The SAP provides the procedures used to guide the quality assurance and quality control of the annual sampling and monitoring 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; one sample (well RB-W-01) 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 that of the conventional method. The samples were submitted to ARS Aleut Analytical in Port Allen, Louisiana, which analyzed the samples using accepted procedures based on the 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 that data are of known, documented quality. The laboratory radiochemical 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. The laboratory analytical results were validated in accordance with the *Environmental Data Validation Procedure* (LMS/PRO/S15870). A copy of the data validation memo is available upon request.

3.2 Groundwater Sampling Results

The 2022 laboratory results continue to demonstrate that no detonation-related contaminants have impacted the sampled locations (Table 1). Tritium was not detected above the laboratory minimum detectable concentration using the conventional or enrichment analytical methods. Table 1 shows the 2022 laboratory results.

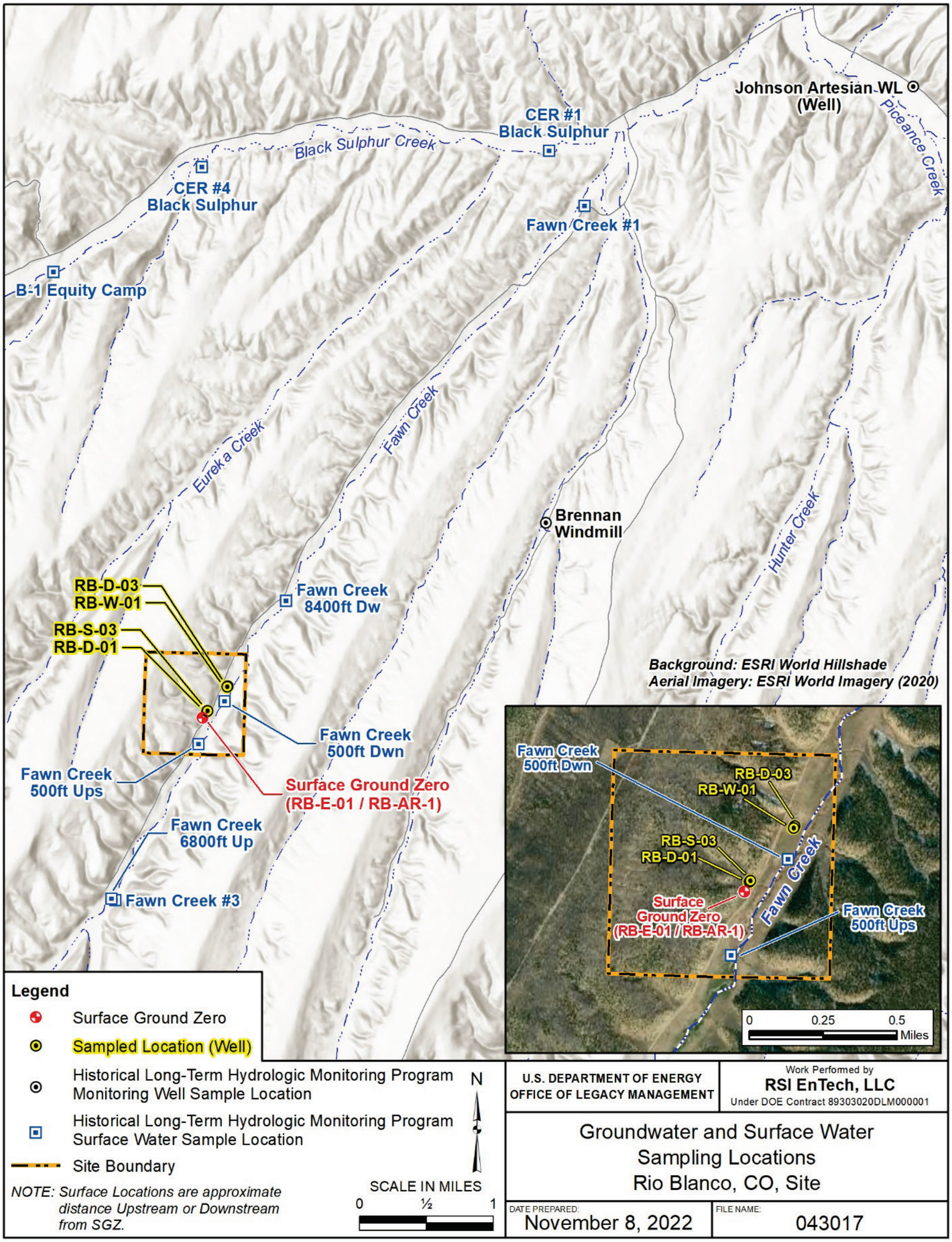

Figure 3. Groundwater and Surface Water Sample Locations, Rio Blanco, Colorado, Site

Table 1. 2022 Sample Results, Rio Blanco, Colorado, Site

<table>
<tr><th>Sample Location</th><th>Sample Type</th><th>Sample Date</th><th>Tritium by Conventional Method (pCi/L)</th><th>Tritium by Enrichment Method (pCi/L)</th></tr>
<tr><td>RB-D-01 (well)</td><td rowspan="5">Groundwater</td><td>5/18/2022</td><td><357</td><td>Not analyzed</td></tr>
<tr><td>RB-D-03 (private well)</td><td>5/18/2022</td><td><356</td><td><2.85</td></tr>
<tr><td>RB-S-03 (well)</td><td>5/18/2022</td><td><357</td><td>Not analyzed</td></tr>
<tr><td rowspan="2">RB-W-01 (well)</td><td rowspan="2">5/18/2022</td><td><354</td><td>Not analyzed</td></tr>
<tr><td><355[a]</td><td>Not analyzed</td></tr>
</table>

Note:
[a] Field duplicate sample.

Abbreviation:
pCi/L = picocuries per liter

Historical LTHMP sample results have detected tritium using the enriched method at levels consistent with tritium concentrations in precipitation. The elevated tritium levels in the atmosphere resulted from aboveground nuclear tests conducted by the United States and Soviet Union during the 1950s and early 1960s (IAEA 2021). The aboveground testing ended in 1963 with the test ban treaty, and tritium levels in the atmosphere (and precipitation) have been decreasing since then. The tritium results obtained using the enrichment method are plotted with tritium in precipitation (Figure 4 and Figure 5) at Ottawa, Canada, which was collected through 2012 and has the longest record of tritium in precipitation in the Northern Hemisphere (IAEA 2021). The natural decay rate for tritium (12.3 years) is also included as the dotted line in the figures for comparison. The tritium levels in well samples are noticeably lower than those in precipitation (Figure 4), indicating a significant contribution from groundwater that has not been exposed to the atmosphere. The similarity of tritium levels in surface water samples to tritium levels in precipitation (Figure 5) indicates that the tritium in surface water locations is primarily supplied by recent precipitation. These results are much lower than the EPA drinking water standard for tritium of 20,000 picocuries per liter (pCi/L) in accordance with Title 40 *Code of Federal Regulations* Section 141.16 (40 CFR 141.16).

4.0 Conclusions

The laboratory results obtained from the 2022 monitoring event indicate that no Rio Blanco site detonation-related radionuclides have impacted the wells onsite. This is consistent with historical monitoring results from LTHMP sampling events dating back to 1976. Tritium has only been detected at levels at or below tritium concentrations in precipitation at the time the samples were taken. Annual sampling will continue at the site in 2023 and will be focused on the onsite wells (RB-D-01, RB-D-03, RB-S-03, and RB-W-01) because the historical results do not support the sampling of the offsite locations or onsite surface water locations. This report is available on the LM website at https://www.energy.gov/lm/rio-blanco-colorado-site (DOE 2022). Data collected during this and previous monitoring events are available on the GEMS website at https://gems.lm.doe.gov/#site=RBL.

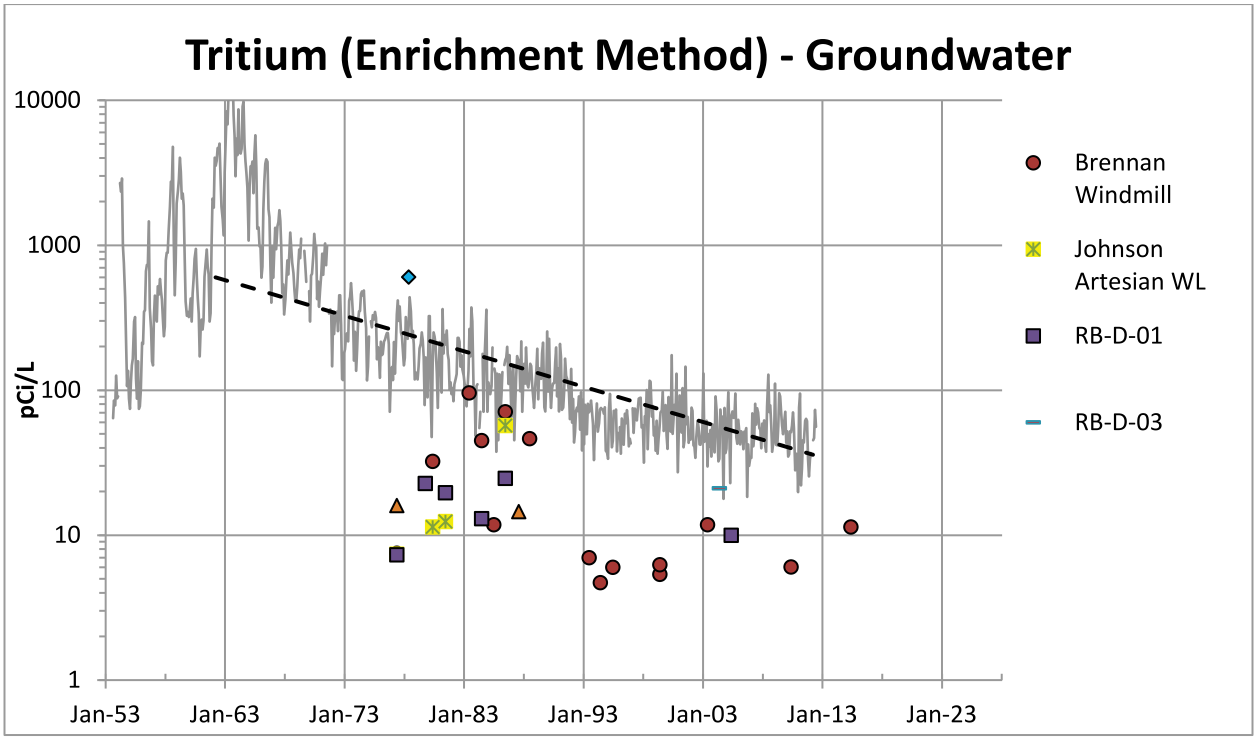

Figure 4. Comparison of Tritium in Wells near the Rio Blanco Site with Tritium in Precipitation at Ottawa, Canada (Site with Longest Historical Tritium Record [IAEA 2022])

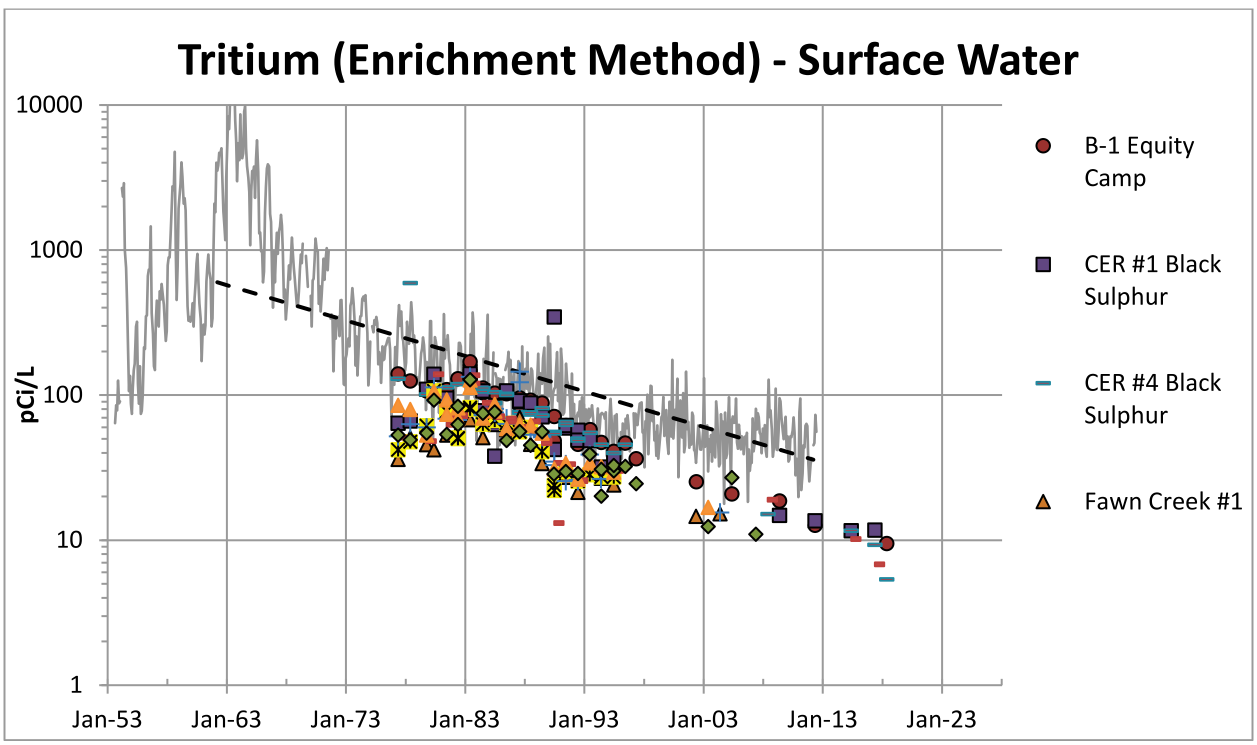

Figure 5. Comparison of Tritium in Surface Water near the Rio Blanco Site with Tritium in Precipitation at Ottawa, Canada (Site with Longest Historical Tritium Record [IAEA 2022])

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