MISSION SUPPORT AND TEST SERVICES LLC

DOE/NV/03624--0870

NEVADA NATIONAL SECURITY SITE 2019 WASTE MANAGEMENT MONITORING REPORT AREA 3 AND AREA 5 RADIOACTIVE WASTE MANAGEMENT SITES

September 2020

Prepared for:

U.S. Department of Energy

National Nuclear Security Administration

Nevada Field Office

Prepared by:

Mission Support and Test Services, LLC

Las Vegas, Nevada

DISCLAIMER

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LIST OF ACRONYMS AND ABBREVIATIONS

ac	acre(s)
AGL	above ground level
Am	americium
AMSL	above mean sea level
ARL/SORD	Air Resources Laboratory, Special Operations and Research Division
BJY	Buster-Jangle Y
BN	Bechtel Nevada
°C	degree(s) Celsius
CAU	Corrective Action Unit
CFR	Code of Federal Regulations
cm	centimeter(s)
DCS	Derived Concentration Standard
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
E	evaporation
ET	evapotranspiration
ET_{ref}	reference evapotranspiration
°F	degree(s) Fahrenheit
ft	foot (feet)
ft^3	cubic foot (feet)
GCD	greater confinement disposal
g/m^3	gram(s) per cubic meter
ha	hectare(s)
HDPE	high-density polyethylene
IL	investigation level
in.	inch(es)
km	kilometer(s)
kPa	kilopascal(s)
LLW	low-level waste
m	meter(s)
m^3	cubic meter(s)
m/s	meter(s) per second
MEDA	Meteorological Data Acquisition
mg/L	milligram(s) per liter
mi	mile(s)
MLLW	mixed low-level waste
mmho/cm	millimho(s) per centimeter

mph	mile(s) per hour
mR	milliroentgen(s)
mrem	millirem(s)
mrem/yr	millirem(s) per year
mR/yr	milliroentgen(s) per year
MSTS	Mission Support and Test Services, LLC
NNSS	Nevada National Security Site
NSTec	National Security Technologies, LLC
PA	performance assessment
PCB	polychlorinated biphenyl
pCi/L	picocurie(s) per liter
$pCi/m^2/s$	picocurie(s) per square meter per second
pCi/m^3	picocurie(s) per cubic meter
PSI	pound(s) per square inch
PST	Pacific Standard Time
Pu	plutonium
RCRA	*Resource Conservation and Recovery Act*
RREMP	Routine Radiological Environmental Monitoring Plan
RTD	resistance temperature detector
RTG	radioisotope thermoelectric generator
RWMS	Radioactive Waste Management Site
SC	specific conductance
TDR	time-domain reflectometry
TLD	thermoluminescent dosimeter
TOC	total organic carbon
TOX	total organic halides
TTR	Tonopah Test Range
VWC	volumetric water content

EXECUTIVE SUMMARY

Environmental monitoring data are collected at and around the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs) within the Nevada National Security Site (NNSS). This report summarizes the 2019 environmental data to provide an overall evaluation of RWMS performance and to support environmental compliance and performance assessment (PA) activities. Some of these data (e.g., radiation exposure, air, and groundwater) are presented in other reports (Mission Support and Test Services, LLC 2019, 2020a, 2020b).

Direct radiation monitoring data indicate exposure levels at the Area 3 and Area 5 RWMSs are within the range of background levels measured at the NNSS. Slightly elevated exposure levels outside the Area 3 RWMS are attributed to nearby historical aboveground nuclear weapons tests. Air monitoring data at the Area 3 and Area 5 RWMSs show that tritium concentrations in water vapor and americium and plutonium concentrations in air particles are below Derived Concentration Standards for these radionuclides. Groundwater monitoring data indicate the groundwater in the uppermost aquifer beneath the Area 5 RWMS is not impacted by RWMS operations. Results of groundwater analysis from wells around the Area 5 RWMS are below established investigation levels. Leachate samples collected from the leachate collection systems at the Area 5 mixed low-level waste disposal unit are below established contaminant regulatory limits. During 2019, precipitation at the Area 3 RWMS was 77 percent above average, and precipitation at the Area 5 RWMS was 69 percent above average. Water balance measurements indicate that evapotranspiration from the vegetated weighing lysimeter at the Area 5 RWMS dries the soil and prevents downward percolation of precipitation more effectively than evaporation as measured from the bare-soil weighing lysimeter. Vadose zone monitoring in the Area 3 and Area 5 RWMS soil covers shows no evidence of precipitation percolating through the covers to the waste. Moisture from precipitation did not percolate below 120 centimeters (3.9 feet [ft]) in the vegetated final cover on the U-3ax/bl disposal unit at the Area 3 RWMS during 2019. There was no drainage through 2.4 meters (8 ft) of soil as indicated from the Area 3 drainage lysimeters that received only natural precipitation. At the Area 3 RWMS, which received three times the natural precipitation, 57 percent of the applied precipitation and irrigation drained from the bare-soil drainage lysimeter.

All 2019 monitoring data indicate that the Area 3 and Area 5 RWMSs are performing within expectations of the model and parameter assumptions for the facilities' PAs.

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1.0 INTRODUCTION

This document summarizes calendar year 2019 waste management environmental monitoring data for the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs). Characterization reports for the Area 3 RWMS (National Security Technologies, LLC [NSTec] 2007a) and the Area 5 RWMS (Bechtel Nevada [BN] 2006) provide descriptions of each RWMS, including locations, settings, waste disposal operations, and monitoring programs. These reports also provide brief summaries of characterization and monitoring data. The *Closure Plan for the Area 3 Radioactive Waste Management Site at the Nevada Test Site* (NSTec 2007b) and the *Closure Plan for the Area 5 Radioactive Waste Management Site at the Nevada Test Site* (NSTec 2008) identify the regulatory requirements and describe the intended approach for closing and monitoring the RWMSs after waste disposal is finished.

This report summarizes environmental data, as briefly described below:

- Direct radiation monitoring to confirm that RWMS activities do not result in significant exposure above background levels
- Air monitoring to confirm that RWMS activities do not result in significant radionuclide concentrations above background levels and to confirm compliance with National Emission Standards for Hazardous Air Pollutants
- Groundwater monitoring, as required by U.S. Environmental Protection Agency regulations and U.S. Department of Energy (DOE) orders, to assess the water quality of the aquifer beneath the Area 5 RWMS and to confirm that Area 5 RWMS activities are not affecting the aquifer
- Vadose zone monitoring to assess the water balance at the RWMSs, confirm the assumptions made in performance assessments (PAs) (including no downward pathway), and evaluate the performance of waste covers
- Subsidence monitoring to assess waste cover stability
- Biota monitoring to assess vegetated covers on closed waste cells and to evaluate the upward biological pathway for radionuclides

These data are collected by Mission Support and Test Services, LLC (MSTS), as required by various DOE orders and requirements from the Code of Federal Regulations (CFR). For a detailed description of these regulatory drivers, refer to the closure plans for the Area 3 RWMS and the Area 5 RWMS (NSTec 2007b, 2008). The following regulatory drivers exist to mitigate risk to the public and the environment:

- DOE O 435.1, "Radioactive Waste Management"
- DOE O 436.1, "Departmental Sustainability"
- DOE O 458.1, "Radiation Protection of the Public and the Environment"
- 40 CFR 61, "National Emission Standards for Hazardous Air Pollutants"
- 40 CFR 264, "Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities"
- 40 CFR 265, "Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities"

Environmental monitoring data are collected and analyzed as described in Quality Assurance, Analysis, and Sampling Plans, which can be found in the *Nevada Test Site Routine Radiological Environmental Monitoring Plan* (RREMP) (BN 2003). The RREMP was written with a Data Quality Objectives-driven process to identify the types and methods for collection of technically defensible environmental monitoring data.

2.0 SITE DESCRIPTIONS

2.1 AREA 3 RWMS

The Area 3 RWMS is located on Yucca Flat within the Nevada National Security Site (NNSS). Yucca Flat is an elongated, sediment-filled basin that trends roughly north-south. The north-south long axis extends approximately 27 kilometers (km) (17 miles [mi]), and the west-east short axis extends approximately 16 km (9.9 mi). Yucca Flat is bounded by Quartzite Ridge and Rainier Mesa on the north, the Halfpint Range on the east, Massachusetts Mountain and CP Hills on the south, and Mine Mountain and the Eleana Range on the west (Figure 2-1). The Yucca Flat basin slopes from the north at an elevation of approximately 1,402 meters (m) (4,600 feet [ft]) above mean sea level (AMSL) to the south toward Yucca Playa, with the lowest part of the basin at an elevation of approximately 1,189 m (3,901 ft) AMSL. The Area 3 RWMS elevation is 1,223 m (4,012 ft). Yucca Flat was one of several primary underground nuclear test areas, and much of the length of the valley is marked with subsidence craters (NSTec 2007a).

The unsaturated zone at the Area 3 RWMS is estimated to be approximately 488 m (1,600 ft) thick (BN 1998), and the water table is assumed to occur in Tertiary tuff. The alluvium thickness is estimated to be between 370 and 460 m (1,214 and 1,509 ft) (BN 2005a).

Based on a 21-year record from 1981 to 2001 at location Buster-Jangle Y (BJY) (4.5 km [2.8 mi] northwest of the Area 3 RWMS), typical daily air temperatures vary from -3 degrees Celsius (°C) (26 degrees Fahrenheit [°F]) to 12°C (54°F) during the winter months of December, January, and February and from 14°C (57°F) to 34°C (94°F) during the summer months of June, July, and August. The average winter temperature during this 21-year period was 4°C (40°F), and the average summer temperature was 24°C (75°F). During this 21-year period, the maximum observed temperature was 43.3°C (110°F), and the minimum observed temperature was -20°C (-4°F). Average relative humidity during this 21-year period was 53% at 4:00 Pacific Standard Time (PST), 28% at 10:00 PST, 26% at 16:00 PST, and 45% at 22:00 PST. January had the highest relative humidity of 67% at 4:00 PST, 42% at 10:00 PST, 43% at 16:00 PST, and 62% at 22:00 PST. July had the lowest relative humidity of 40% at 4:00 PST, 19% at 10:00 PST, 17% at 16:00 PST, and 30% at 22:00 PST. The maximum wind gust observed at BJY during this 21-year period was 29.3 meters per second (m/s) (65.6 miles per hour [mph]) in 1987 (Soule 2006).

The average annual precipitation at BJY during the 59-year period from 1961 through 2019 is 16.1 centimeters (cm) (6.34 inches [in.]). Typically, low-intensity, longer duration storms occur during the winter, and thunderstorms occur during the late summer. February has the most precipitation, and June has the least precipitation (Soule 2006). Annual reference evapotranspiration (ET_{ref}) at the Area 3 RWMS, calculated using local meteorology data, is approximately 10 times the annual average precipitation (Desotell et al. 2007).

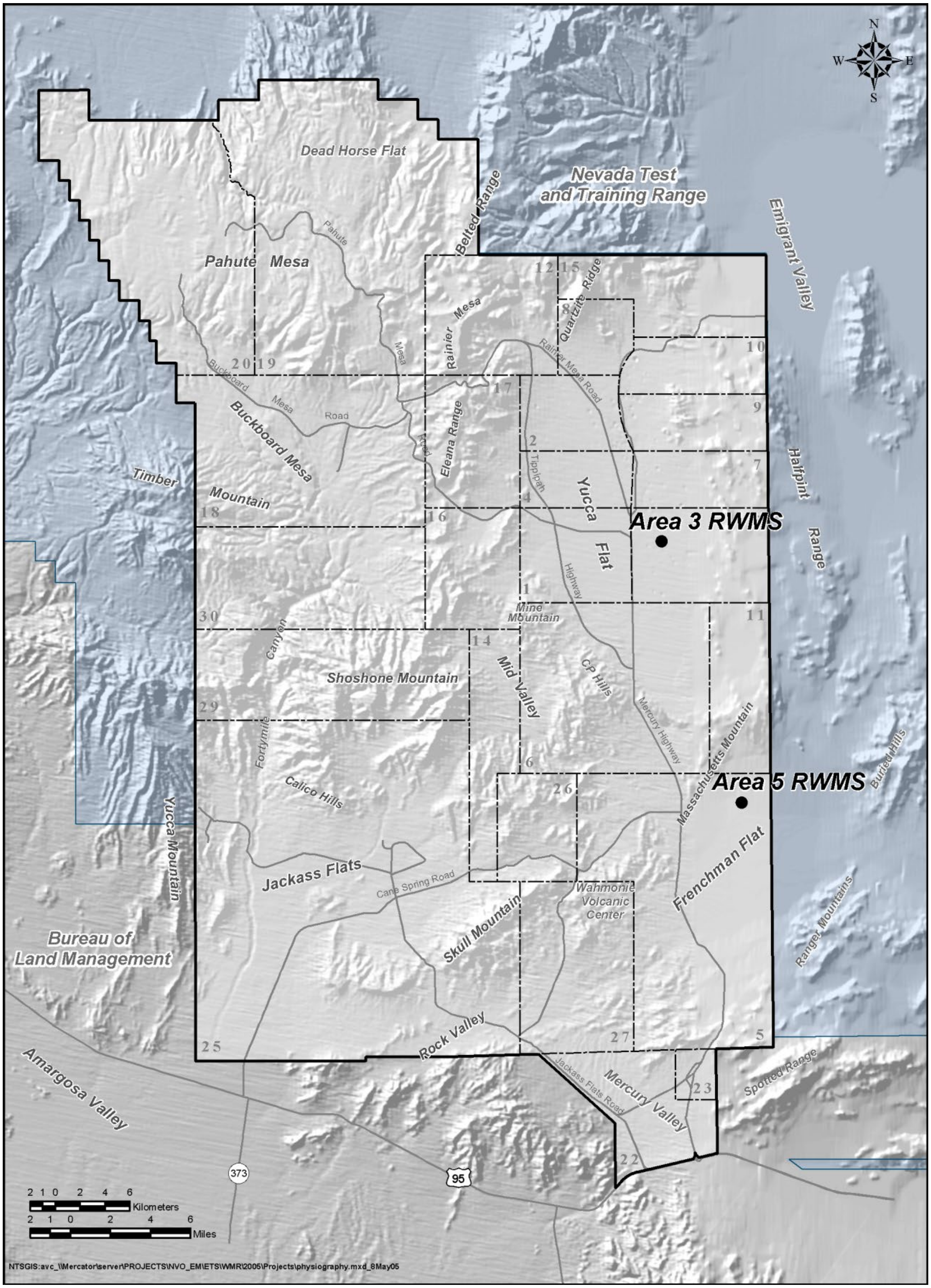

Figure 2-1. Locations of the Area 3 and Area 5 RWMSs

2.2 AREA 5 RWMS

The Area 5 RWMS is located on northern Frenchman Flat at the juncture of three coalescing alluvial fan piedmonts (Snyder et al. 1995). Frenchman Flat is a closed intermontane basin located in the southeastern portion of the NNSS. Frenchman Flat is bounded by Massachusetts Mountain and the Halfpint Range on the north, the Buried Hills on the east, the Spotted Range on the south, and the Wahmonie Volcanic Center on the west (Figure 2-1). The valley floor slopes gently toward a central playa (BN 2006). Ground surface elevations range from 938.8 m (3,080 ft) AMSL at the playa to over 1,220 m (4,003 ft) AMSL in the nearby surrounding mountains. The Area 5 RWMS elevation is 961.9 m (3,156 ft).

The thickness of the unsaturated zone at the Area 5 RWMS is 235.9 m (773.9 ft) at the southeast corner of the RWMS (Well UE5PW-1), 256.5 m (841.5 ft) at the northeast corner (Well UE5PW-2), and 271.6 m (891.1 ft) to the northwest of the RWMS (Well UE5PW-3). Wells UE5PW-1 and UE5PW-2 penetrate only alluvium, while Well UE5PW-3 encounters tertiary tuff at a depth of approximately 189 m (620 ft) (BN 2005b). The water table beneath the Area 5 RWMS is extremely flat with flow velocities of less than 0.10 m per year (0.33 ft per year). The average groundwater elevation measured at these wells in 2019 was 733.7 m (2,407 ft) AMSL.

Based on a 21-year record from 1981 to 2001 at location Well 5B (6.4 km [4.0 mi] south of the Area 5 RWMS), typical daily air temperatures vary from -4°C (25°F) to 14°C (57°F) during the winter months of December, January, and February and from 15°C (59°F) to 37°C (99°F) during the summer months of June, July, and August. The average winter temperature during this 21-year period was 5°C (41°F), and the average summer temperature was 26°C (79°F). During this 21-year period, the maximum observed temperature was 46°C (115°F) and the minimum observed temperature was -21°C (-6°F). Average relative humidity during this 21-year period was 46% at 4:00 PST, 25% at 10:00 PST, 20% at 16:00 PST, and 37% at 22:00 PST. January had the highest relative humidity of 65% at 4:00 PST, 46% at 10:00 PST, 34% at 16:00 PST, and 58% at 22:00 PST. June had the lowest relative humidity of 32% at 4:00 PST, 14% at 10:00 PST, 12% at 16:00 PST, and 21% at 22:00 PST. The maximum wind gust observed at Well 5B during this 21-year period was 29.8 m/s (66.7 mph) in 1988 (Soule 2006).

The average annual precipitation at Well 5B during the 56-year period from 1964 through 2019 is 12.4 cm (4.88 in.). Typically, low-intensity, longer duration storms occur during the winter, and thunderstorms occur during the late summer. February has the most precipitation, and June has the least precipitation (Soule 2006). Annual ET_{ref} at the Area 5 RWMS, calculated using local meteorology data, is approximately 12 times the annual average precipitation (Desotell et al. 2006).

Areas 3 and 5 are similar, with only slight differences in air temperature, precipitation, and soil texture. Area 3 receives approximately 30 percent more rainfall than Area 5, and the annual average temperature at Area 3 is about 2°C (4°F) cooler than at Area 5.

2.3 HYDROLOGIC CONCEPTUAL MODELS OF THE AREA 3 RWMS AND AREA 5 RWMS

Climate and vegetation strongly control the water movement in the upper few meters of alluvium at both RWMSs. The magnitude and direction of both liquid and vapor fluxes vary seasonally and often daily. Except for periods following precipitation events, water content values in the near-surface are quite low. Below the dynamic near-surface is a region where relatively steady upward water movement is occurring. In this region of slow upward flow, stable isotope compositions of soil water confirm that evaporation (E) is the dominant process (Tyler et al. 1996). The upward flow region is located at depths from approximately 3 to 49 m (10 to 160 ft) in Area 3, and from approximately 3 to 40 m (10 to 130 ft) in Area 5. Below the upward flow region, water potential measurements indicate the existence of a static region. The hydraulic gradient in the static region is zero. The static region is located between approximately 49 and 119 m (160 to 390 ft) deep in Area 3, and between approximately 40 and 90 m (130 to 300 ft) deep in Area 5 (Shott et al. 1997, 1998). In the static region, essentially no vertical liquid flow is currently occurring. Below the static region, flow is steady and downward due to gravity (Figure 2-2). Lysimeter water balance measurements show the arid climate and native vegetation at the NNSS provide a natural sustainable system to prevent transport of contaminants from the RWMSs through the vadose zone to groundwater. Transport by infiltration and percolation of present-day precipitation at the RWMSs is prevented. The native desert vegetation is adapted to extract moisture from very dry soils and maintains negative matric potentials at the base of the root zone, effectively buffering the deep vadose zone from episodic precipitation events at the surface. The very negative matric potential at the base of the root zone intercepts almost all infiltration from precipitation and draws moisture upward from the vadose zone below the root zone. This system is sustainable because it does not rely on engineered features and mimics the stable landscapes and the lack of groundwater recharge with the current conditions surrounding the RWMSs. The system depends on establishing native vegetation in the covers above the waste cells and a stable climate (Hudson et al. 2015). Stable isotope compositions of soil water from these depths indicate that infiltration into this zone occurred under cooler past climatic conditions (Tyler et al. 1996). If water were to migrate below the current static zones, movement to the groundwater would be extremely slow due to the low water content of the alluvium. Estimates of travel time to the groundwater (assuming zero upward flux), based on hydraulic characteristics of the alluvium, and assuming that current conditions would still apply, are in excess of 500,000 years in Area 3 (Levitt and Yucel 2002) and 50,000 years in Area 5 (Shott et al. 1998).

Based on the results of extensive research, field studies, modeling efforts, and monitoring data, which are summarized in the Area 3 and Area 5 PAs (Shott et al. 1997, 1998; Levitt et al. 1999; Levitt and Yucel 2002; Desotell et al. 2006; Hudson et al. 2015), groundwater recharge is not occurring under current climatic conditions at the RWMSs. Studies indicate that under bare-soil conditions, such as those found at the operational waste cell covers, some drainage may eventually occur through the waste covers into the waste zone. This drainage is estimated to be about 8 percent of the annual rainfall at Area 5, based on one-dimensional modeling results (Desotell et al. 2006).

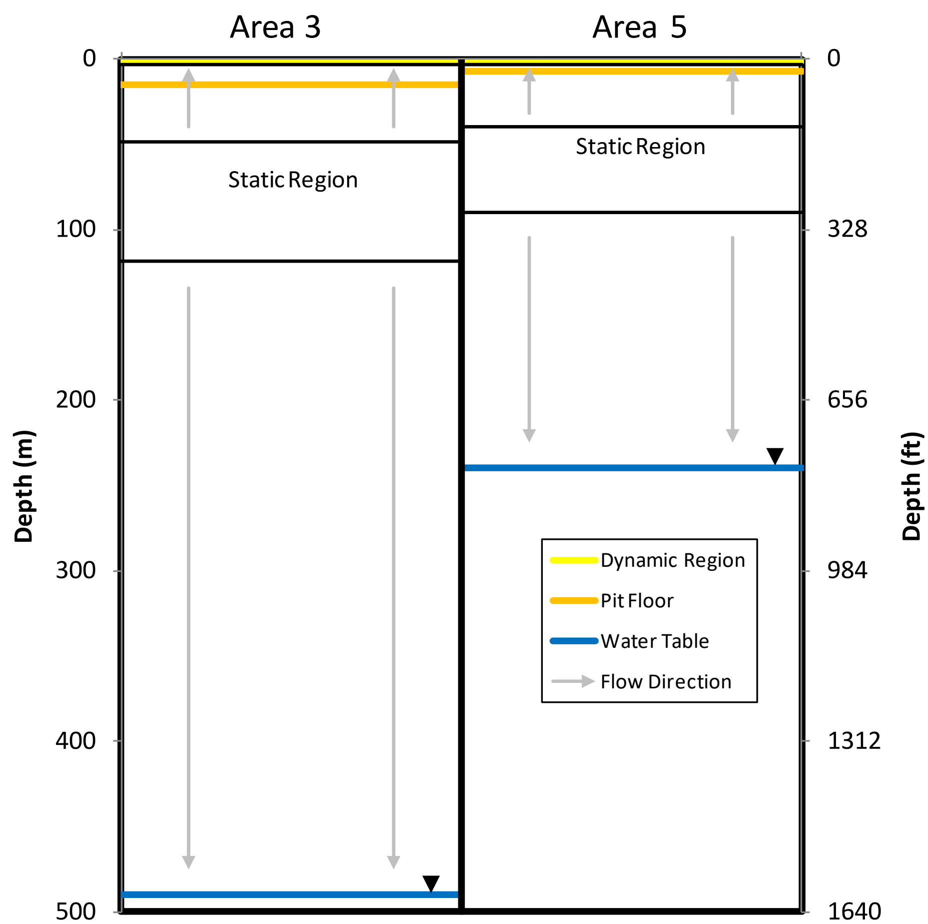

Figure 2-2. Vadose Zone Conceptual Models of the Area 3 and Area 5 RWMSs

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3.0 PROJECT DESCRIPTION

The Area 3 and Area 5 RWMSs are designed and operated for the disposal of radioactive low-level waste (LLW) and mixed low-level waste (MLLW) that is generated at the NNSS, from DOE offsite locations, and from other approved offsite generators.

3.1 AREA 3 RWMS

The Area 3 RWMS covers approximately 51 hectares (ha) (126 acres [ac]). The area enclosed by a fence is used for waste disposal operations and covers approximately 49 ha (121 ac). The Area 3 RWMS includes seven subsidence craters from underground nuclear testing: U-3ax, U-3bl, U-3ah, U-3at, U-3bh, U-3az, and U-3bg. At the time of formation, these seven craters ranged from 122 to 177 m (400 to 581 ft) in diameter and from 14 to 32 m (46 to 110 ft) in depth (Plannerer 1996). Five of these subsidence craters were developed into three waste disposal units. Alluvium between craters U-3ax and U-3bl and between craters U-3ah and U-3at was excavated to form two large disposal units (U-3ax/bl and U-3ah/at). Crater U-3bh is also used for waste disposal. Craters U-3az and U-3bg are not used for waste disposal (Figure 3-1).

U-3bh and U-3ah/at can accept unclassified LLW. U-3bh was originally used for disposal of contaminated soil from the Tonopah Test Range (TTR) in 1997 and was later used for disposal of waste from other approved generators. Disposal in U-3ah/at began in 1988 and has been used for disposal of bulk LLW from the NNSS and approved offsite generators. U-3bh and U-3ah/at were covered with operational covers and placed in standby mode in 2006. In October 2018, waste disposal resumed at U-3ah/at with disposal of contaminated soil and debris from TTR. The final waste package from TTR was received in August 2019, concluding an 11-month shipping campaign of over 450 shipments totaling 225,000 cubic feet (ft^3) of LLW.

U-3ax/bl received unclassified LLW and potential MLLW from 1968 to 1987. Disposal in the U-3ax crater began in the late 1960s, and disposal in U-3bl began in 1984. Waste forms consisted primarily of contaminated soil and scrap metal, with some construction debris, equipment, and containerized waste. U-3ax/bl was closed in 2000 by constructing an engineered, monolayer, vegetated, evapotranspiration (ET) cover under the *Federal Facility Agreement and Consent Order*, a legally binding agreement between the State of Nevada, DOE Environmental Management, the U.S. Department of Defense (DoD), and DOE Legacy Management. U-3ax/bl is identified as Corrective Action Unit (CAU) 110 and is permanently closed under the *Resource Conservation and Recovery Act* (RCRA) as a hazardous waste landfill. The RCRA-equivalent cover is constructed of native alluvium at least 2.4 m (8 ft) thick planted with native plants (U.S. Department of Energy, Nevada Operations Office 2000, 2001).

For a detailed description of the facilities at the Area 3 RWMS, refer to Shott et al. (1997) and NSTec (2007a).

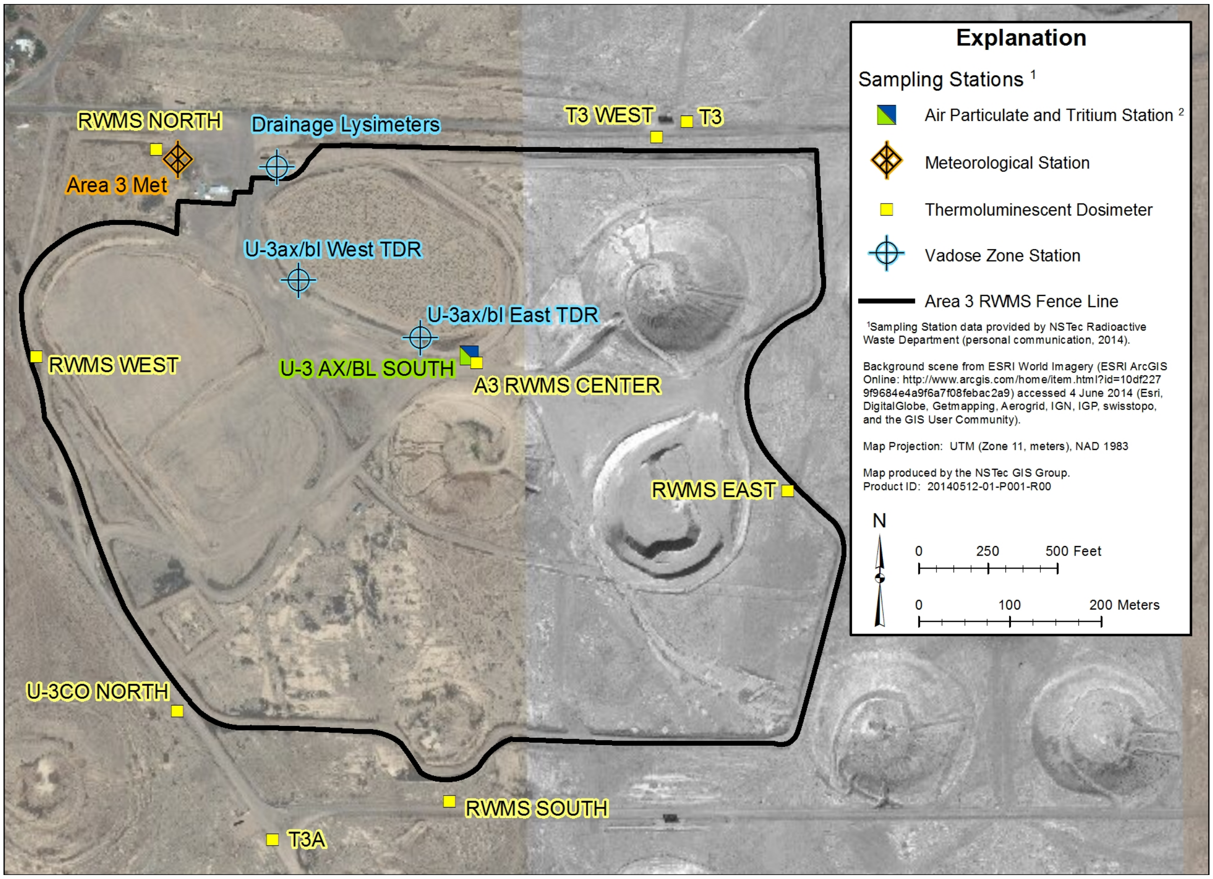

Figure 3-1. Monitoring Locations at the Area 3 RWMS

3.2 AREA 5 RWMS

The Area 5 RWMS (NNSS Area 5A) covers approximately 300 ha (741 ac) with approximately 100 ha (247 ac) enclosed by a fence and used for waste disposal operations. This area consists of 40 disposal cells (pits and trenches) and 13 greater confinement disposal (GCD) boreholes (Figure 3-2). The excavated disposal cells range in depth from 4.6 to 15 m (15 to 49 ft). Cell 18 (P18) and Cell 25 (P25) were built with RCRA-compliant double liners and leachate collection systems over geosynthetic clay liners. All other cells are unlined. GCD boreholes are uncased, 36.0 m (118 ft) deep, and 3.0 to 3.7 m (10 to 12 ft) in diameter.

Waste disposal has occurred at the Area 5 RWMS since the early 1960s. Initially, LLW and MLLW from the demolition of nuclear test sites and facilities at the NNSS were buried at the Area 5 RWMS. In 1978, DOE formally established the Area 5 RWMS, and it became a disposal site for other DOE facilities. During the 1980s, the GCD boreholes were constructed and received high-specific-activity LLW and transuranic waste.

Currently, the disposal units receive sealed waste containers. Containers are stacked to approximately 1.2 m (4.0 ft) below original grade, and soil backfill is pushed over the containers in a single layer to a thickness of approximately 2.4 m (8.0 ft) thick. For a detailed description of the facilities at the Area 5 RWMS, refer to Shott et al. (1998). For further descriptions of pits, trenches, and GCD boreholes, refer to BN (2005b, 2006) and Cochran et al. (2001). During 2019, waste was disposed in ten cells at the Area 5 RWMS: P18, P19, P20, P21, P22, P23, P25, P27, P28, and T13. All active cells contain LLW, and P18 and P25 also contain MLLW.

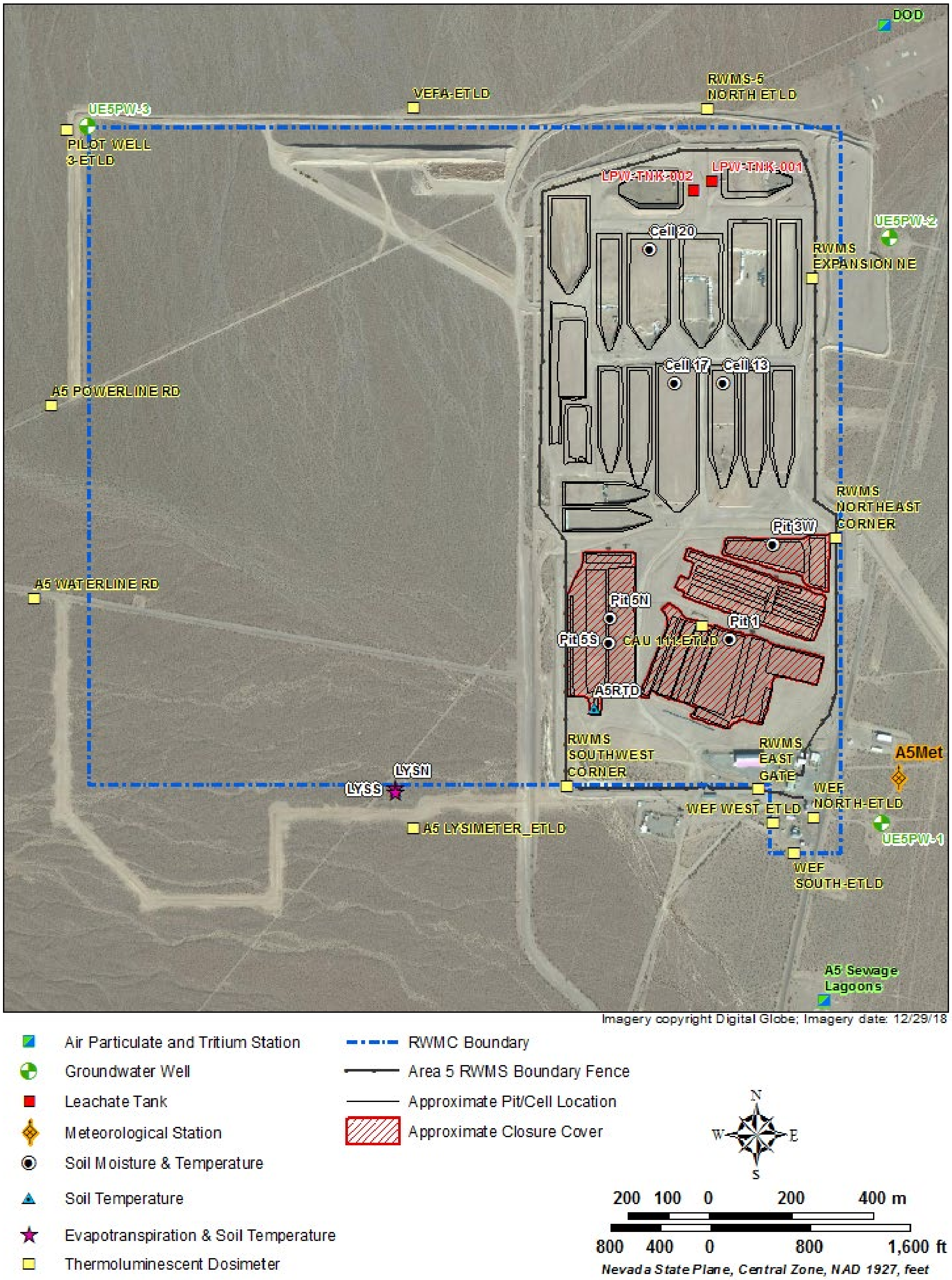

Figure 3-2. Monitoring Locations at the Area 5 RWMS

The 92-Acre Area in the southern portion of the Area 5 RWMS was permanently closed by constructing three engineered, monolayer, vegetated ET covers with a minimum thickness of 2.5 m (8.2 ft) over the waste cells. The three covers are separated by drainage channels and access roads and are designated as the North Cover, the South Cover, and the West Cover. The 92-Acre Area ET covers closed 25 cells (P01, P02, P03, P04, P05, P06, P07, P09, P11,T01B, T02B, T03B, T04B, T06B, T07B, T01A, T02A, T03A, T04A, T04A-1, T05, T06A, T07A, T08, and T09);12 GCD boreholes (GCD-01, GCD-02, GCD-03, GCD-04, GCD-05, GCD-06, GCD-07, GCD-08, GCD-09, GCD-10, GCD-11, and GCD-12); and the CH2M Hill Washington Group International Idaho trenches. P26 was also closed by the ET cover, but it is completely within P03. Eight cells outside the 92-Acre Area (P08, P10, P12, P13, P14, P15, P16, and P17) are operationally inactive.

After grading and soil preparation was completed at the 92-Acre Area, the covers were seeded with a mixture of native species during October through December 2011. Construction was completed in January 2012. A solid set irrigation system was installed on the covers, and irrigation was applied during seed germination in the spring and fall of 2012 (Goodrich 2010; U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office 2010, 2012; The Delphi Group and J. A. Cesare and Associates 2012).

On May 7, 2013, an initial vegetation survey was completed on the 92-Acre Area covers by sampling forty 100-m (328-ft) transects. Successful establishment of the seeded species was low, and there were high concentrations of invasive weeds (primarily *Halogeton glomeratus* [halogeton] and *Salsola iberica* [Russian thistle]). Based on the interpretation of this survey, remedial revegetation was required to establish a viable plant community on the covers.

The first remedial trial was done on the northern section of the North Cover with planting in October 2013. Results indicated that broadcast seeding was the preferred method of seeding and that the benefit of mulching was questionable. It was also noted that the impact of rabbits grazing on the new seedlings was a key factor.

The second remedial trial was done on the southern portion of the North Cover. The soil was tested and harrowed, and the seeds were tested for viability and washed before planting on October 29, 2014. Supplemental irrigation was applied from December to February and then again in May to facilitate germination. A total of 107 mm (4.21 in.) of irrigation was provided to augment 37 mm (1.5 in.) of natural precipitation for a total of 144 mm (5.67 in.), just less than the 174 mm (6.85 in.) typically needed to be considered a good growing season.

On March 11, 2015, it was determined that germination occurred on both the mulched and non-mulched treatments that were irrigated, but that no germination occurred on the non-irrigated treatments. Rabbit-proof fencing was installed around the southern portion of the North Cover, but unfortunately it was not completed until late spring 2015 after germination had occurred. On June 4, 2015, a quantitative survey was performed, and there were only a few *Atriplex canescens* (four-wing saltbush) plants from the previous seeding trial. No newly seeded species were present during the sampling along several 100-m (328-ft) transects. It was presumed the young seedlings seen in March were eaten by rabbits that were observed inside the fence and that were also evidenced by the number of rabbit pellets documented in the March inspection. The only species observed during the June survey were Russian thistle and halogeton. These two weed species covered 34 percent of the irrigated sites and 2 percent of the non-irrigated sites. In August 2015, the entire southern portion of the North Cover was sprayed with the herbicide glyphosate.

In 2016 there were no attempts to establish vegetation on the covers or any test treatments made. On June 29, 2016, a qualitative survey was performed. It was noted that no new four-wing saltbush plants were growing, but the ones seen from the previous survey were still present and continuing to grow. On September 4, 2019, another qualitative survey was performed, and it was noted that the same four-wing saltbush were growing and that had the area been protected from rabbits as advised, the whole area would have similar sized plants growing.

In August 2017, the Tribal Revegetation Committee, Portland State University, and the Desert Research Institute convened to spiritually interact with the land and initiate a revegetation study on the southern portion of the North Cover. They conducted inventories of nearby plant communities and finalized a field observation form. NSTec (the Management and Operating Contractor at the time) collected and set aside topsoil from a comparable ecological setting on the NNSS and also purchased seeds and transplants.

The southern portion of the North Cover area was divided into 138 10 m by 10 m square study areas and eight 10 m by 100 m rectangular study areas. In December 2017, a subcontractor ripped the surface of the study areas and spread the collected topsoil on selected study areas. The rectangular plots on the western side of the cover were used for transplants, and the square plots on the east side were used for seeds and transplants. Each square plot was fitted with eight sprinklers, and the rectangular rows were fitted with drip irrigation. The entire area around the rectangular rows was fenced. The seeds and transplants were watered with 1 cm of water twice per week for the first 5 months. After 5 months, irrigation was reduced to once per week. The transplants with drip irrigation were watered with two gallons twice per week for the first 5 months and two gallons once per week after that. Three species were transplanted: *Sphaeralcea ambigua, Larrea tridentata, and Atriplex canescens*. The transplants in the square plots were fitted with cage fences.

Fifteen of the 138 square plots were randomly chosen, and nine species were included in a seed mix and dispersed in the 10 m x 10 m plots. The species included *Sphaeralcea ambigua, Lycium andersonii, Larrea tridentata, Ephedra nevadensis, Elymus elymoides, Baileya multiradiata, Atriplex confertifolia, Atriplex canescens,* and *Achnatherum hymenoides.* Five treatments were used on the square plots: soil amendment/mulch, straw, transplant/soil amendment/straw, transplant/mulch, and a control. The transplants in the rows had four treatments: watered with soil amendment, watered, soil amendment with no water, and control.

In the spring of 2018, fifteen more square plots were randomly chosen and were seeded and transplants were planted. Four more rows of transplants were also planted in the fenced-off rectangular area. The same treatments and watering regime used in the fall were followed for the spring plantings.

Preliminary results generated at the end of 2019 show that transplants planted in the spring fared better than those planted in the fall for all treatments. It was noted that there was a portion of the cover where few native and non-native invasive species fared well. The four-wing saltbush did nearly the same in all treatments, so additional water and soil amendments provided little difference. Only Desert marigold (*Baileya multiradiata*) and Indian ricegrass (*Achnatherum hymenoides)* survived in the seeded areas, while the invasive species thrived (Tribal Revegetation Project 2020).

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4.0 ENVIRONMENTAL MONITORING DATA

4.1 TYPES OF ENVIRONMENTAL MONITORING DATA

Area 3 RWMS monitoring locations are shown in Figure 3-1, and Area 5 RWMS monitoring locations are shown in Figure 3-2. A summary of the types of environmental monitoring data at the Area 3 RWMS is provided in Table 4-1, and a summary of the types of environmental monitoring at the Area 5 RWMS is provided in Table 4-2. This report provides a general description and graphical representations of some of these data.

Table 4-1. Environmental Monitoring at the Area 3 RWMS

Monitoring	Description
Radiation Exposure	• 3-month measurement interval at 9 locations • Thermoluminescent dosimeter (TLD) measurements of total radiation exposure
Air	• 2-week sample interval at 3 locations • Tritium concentration in atmospheric moisture • Gross alpha and beta concentration of particulates • Air particulate analysis on quarterly composites for concentrations of gamma-emitting radionuclides, americium (Am), and plutonium (Pu)
Radon Flux	• Periodic radon flux measurements • Various locations on waste covers
Meteorology	• Daily and hourly measurements at 1 location • Air temperature at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Relative humidity at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Vapor pressure at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Wind speed and direction at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Barometric pressure • Hourly, daily, and 5-minute precipitation rate • Solar radiation • Energy balance for ET calculation (net solar radiation, soil heat flux, soil temperature, and soil water content)

Vadose Zone	• Drainage lysimeters
	  o 8 lysimeters at 1 location
	  o 3 vegetation treatments (bare-soil, invader species, and native species) with 2 irrigation treatments (precipitation and 3-times precipitation)
	  o Daily and hourly measurements at each lysimeter (drainage, water content, water potential, and temperature)
	• Daily water content profiles in final U-3ax/bl cover at 4 locations

Biota	• Periodic sampling of vegetation, small mammals, and animal burrow spoils analyzed for tritium, gamma-emitting radionuclides by gamma spectroscopy, and ^{238}Pu, $^{239+240}$Pu, and ^{241}Am by alpha spectroscopy • Annual plant density and plant cover measurements for drainage lysimeters • Plant density and plant cover measurements on the U-3ax/bl cover every 5 years
Subsidence	• 8 surveyed subsidence monuments on the U-3ax/bl cover at 2-year measurement interval • Bi-annual visual inspections of U-3ax/bl cover for subsidence • Monthly visual inspections of operational covers for subsidence

Table 4-2. Environmental Monitoring at the Area 5 RWMS

Monitoring	Description
Radiation Exposure	• 3-month measurement interval at 14 locations • TLD measurements of total radiation exposure
Air	• 2-week sample interval at 2 locations • Tritium concentration in atmospheric moisture • Gross alpha and beta concentration of particulates • Air particulate analysis on quarterly composites for concentrations of gamma-emitting radionuclides, Am, and Pu
Radon Flux	• Periodic radon flux measurements • Various locations on waste covers
Groundwater	• 3 wells surrounding Area 5 RWMS • Water level measurements at 3-month interval • Groundwater samples at 6-month interval • Analysis of indicators of contamination (Field measurements of pH and specific conductance [SC] and laboratory analysis of total organic carbon [TOC], total organic halides [TOX], and tritium) • Analysis of water chemistry (calcium, magnesium, potassium, sodium, iron, manganese, sulfate, chloride, fluoride, silicate, and alkalinity) • Sampling and chemical analysis when P18 leachate collection tank is full
Meteorology	• Daily and hourly measurements at 1 location • Air temperature at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Relative humidity at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Vapor pressure at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Wind speed and direction at 3.0 m (9.8 ft) and 9.5 m (31 ft) • Barometric pressure • Hourly, daily, and 5-minute precipitation rate • Solar radiation • Energy balance measurements for ET calculation (net solar radiation, soil heat flux, soil temperature, and soil water content)

Vadose Zone	• Weighing lysimeters
	  o Two lysimeters (one simulating a bare-soil treatment and the other simulating a native species treatment)
	  o Direct measurements of ET
	  o Daily water content, water potential, and temperature profiles at each lysimeter
	• Daily water content, water potential, and temperature profiles in the covers at 7 locations
	• Daily water content below closed disposal cells at 4 locations
	• Soil temperature around radioisotope thermoelectric generators (RTGs)

Biota	• Periodic sampling of vegetation, small mammals, and animal burrow spoils analyzed for tritium, gamma-emitting radionuclides by gamma spectroscopy, and ^{238}Pu, $^{239+240}$Pu, and ^{241}Am by alpha spectroscopy • Annual plant density and plant cover measurements on each weighing lysimeter and the 92-Acre Area covers
Subsidence	• Annual survey of 52 subsidence monuments on the 92-Acre Area covers • Quarterly visual inspections of 92-Acre Area covers for subsidence • Weekly visual inspections of operational covers for subsidence

4.2 RADIATION EXPOSURE DATA

Direct radiation monitoring assesses and detects changes in the external radiation environment and measures gamma radiation levels near potential exposure sites. Performance objectives in DOE Manual DOE M 435.1-1, "Radioactive Waste Management Manual," (DOE 2001a) require that LLW disposal facilities be sited, designed, operated, maintained, and closed so a reasonable, expected, total effective dose equivalent from the facility to a representative member of the public is less than 25 millirems per year (mrem/yr). The effective dose equivalent is from all exposure pathways associated with the facility but does not include the dose from radon or background radiation. The RWMSs are located well within the NNSS boundaries, so the public does not have access to these areas for significant periods of time. However, exposure rates measured by TLDs located at the RWMSs show the potential dose to a hypothetical person residing continuously at the RWMSs.

TLDs (Panasonic UD 814AS) are used to measure ionizing radiation exposure from all sources, including natural and man-made radioactivity. These TLDs have three calcium-sulfate elements housed in an air-tight, water-tight, ultraviolet-light-protected case. The elements measure the total exposure rate from penetrating gamma radiation including background radiation. The penetrating gamma radiation makes up the deep dose, which is compared to the 25-mrem/yr limit when background exposure is subtracted.

Figure 3-1 and Figure 3-2 show TLD monitoring locations near the Area 3 and Area 5 RWMSs, respectively. The boundary of the Area 5 RWMS was recently expanded to the west. Five new TLD locations were established around the new boundary during 2019 (A5 Lysimeter-ETLD, A5 Powerline Rd, A5 Waterline Rd, Pilot Well 3-ETLD, and Vefa-ETLD). In addition, one new TLD location was established inside the RWMS boundary on the 92-Acre Area South Cover (CAU 111-ETLD). Four TLDs were removed from the Area 5 RWMS (Bldg 5-31, RWMS Expansion NW, RWMS South Gate, and WEF East) because of the change in boundary or to reduce density in the highly monitored southeast corner (Figure 3-2). A pair of TLDs is placed 1 ± 0.3 m (39 ± 12 in.) above ground level (AGL) at each location and exchanged for analysis on a quarterly basis. TLDs are analyzed using automated TLD readers that are calibrated and maintained by the MSTS Radiological Control Department. Reference TLDs exposed to 100 milliroentgen (mR) from a cesium-137 radiation source under controlled conditions are used to scale the response of the measured TLDs. Direct radiation exposure is usually reported in mR, which is a measure of exposure in terms of numbers of ionizations in air. Generally, the dose in human tissue resulting from an exposure from the most common external radionuclides can be approximated by equating a 1-mR exposure with a 1-millirem (mrem) dose.

Between 1952 and 1972, 60 nuclear weapons tests were conducted within 400 m (1,312 ft) of the Area 3 RWMS. Fourteen of these were atmospheric tests that caused radionuclide-contaminated surface soil with elevated radiation exposures across the area. Five of the seven subsidence craters within the Area 3 RWMS were converted into three disposal units. During disposal operations, the waste is covered with clean soil, resulting in lower exposures inside the Area 3 RWMS when compared with the average exposures at the Area 3 RWMS fence line or in Area 3 outside the fence line.

Annual radiation exposures measured in milliroentgens per year (mR/yr) during 2019 at nine locations inside and near the Area 3 RWMS ranged from 118 to 277 mR/yr (Figure 4-1). The Area 3 monitoring locations are inside the Area 3 RWMS (RWMS Center), on the RWMS boundary (RWMS North, RWMS East, RWMS South, and RWMS West), and outside the RWMS boundary (T3, T3 West, T3A, and U3CO North) (Figure 3-1). The exposures measured inside the Area 3 RWMS and three of four measurements at the boundary were within the range of background exposures (Figure 4-1).

The four TLD locations outside the Area 3 RWMS boundary and one TLD on the boundary (RWMS South) have higher exposures due to nearby historical aboveground nuclear weapons tests. This distribution of exposures indicates radionuclides in the Area 3 RWMS have a negligible contribution to total exposure for a hypothetical person residing at the Area 3 RWMS when compared with exposures resulting from historical aboveground nuclear weapons tests. Estimated daily exposure rates in mR per day from the quarterly exposure rate data at the Area 3 RWMS were within the range of exposure rates at NNSS background locations (Figure 4-2).

Between 1951 and 1971, 25 nuclear weapons tests were conducted within 6.3 km (3.9 mi) of the Area 5 RWMS. Fifteen of these were atmospheric tests, and nine of the remaining ten tests released radioactivity to the surface. There were no nuclear weapons tests within the boundaries of the Area 5 RWMS. Over the past 10 years, all exposure rate measurements at the Area 5 RWMS were within the range of background levels measured on the NNSS.

Comparisons of 2006 to 2019 direct radiation exposure data using TLDs from the two RWMSs with direct radiation data from NNSS background locations indicate that direct radiation exposure at the Area 3 and Area 5 RWMSs is generally low or declining (Figure 4-2 and Figure 4-3).

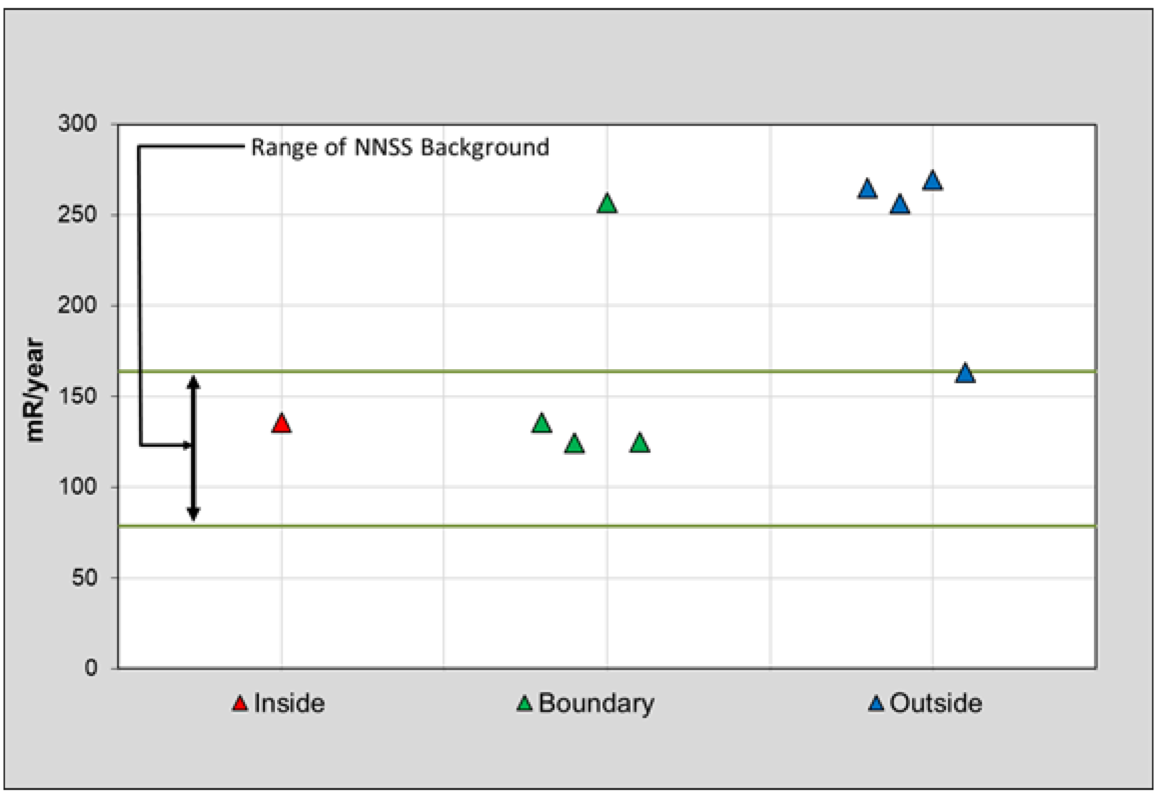

Figure 4-1. Annual Radiation Exposure Rates at the Area 3 RWMS

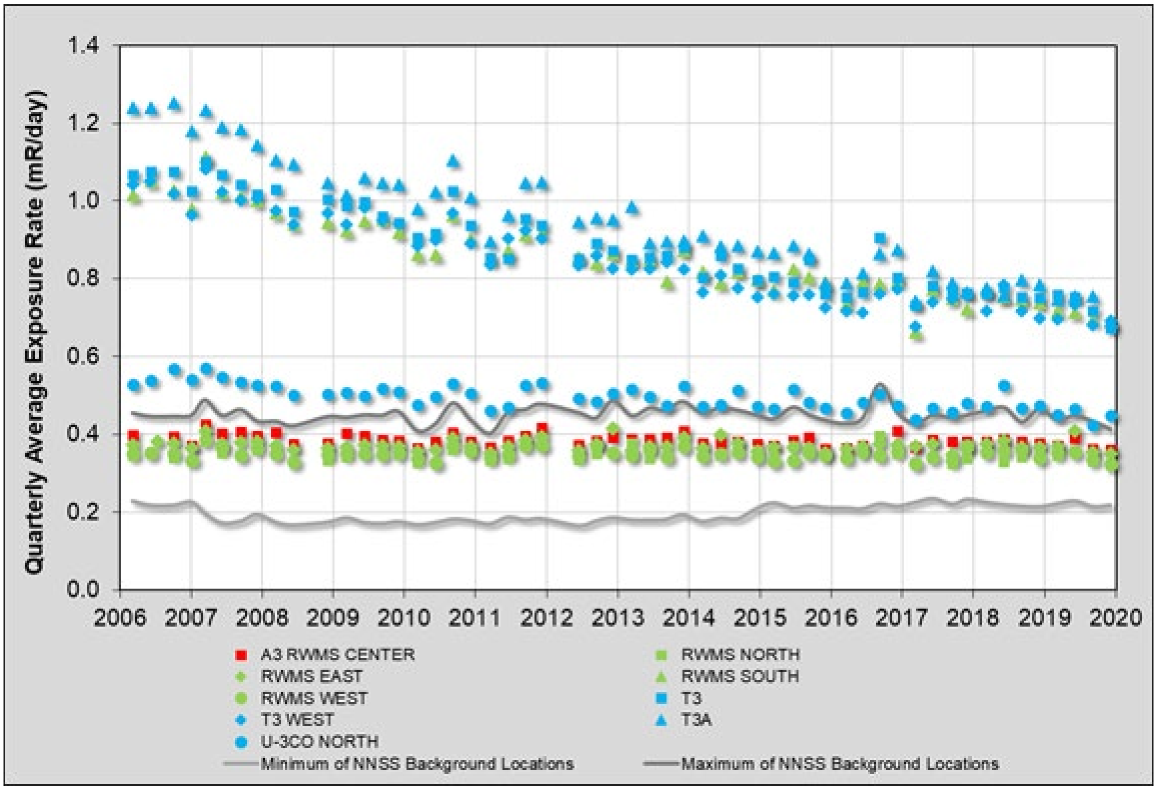

Figure 4-2. Quarterly Average Daily Exposure Rates at the Area 3 RWMS

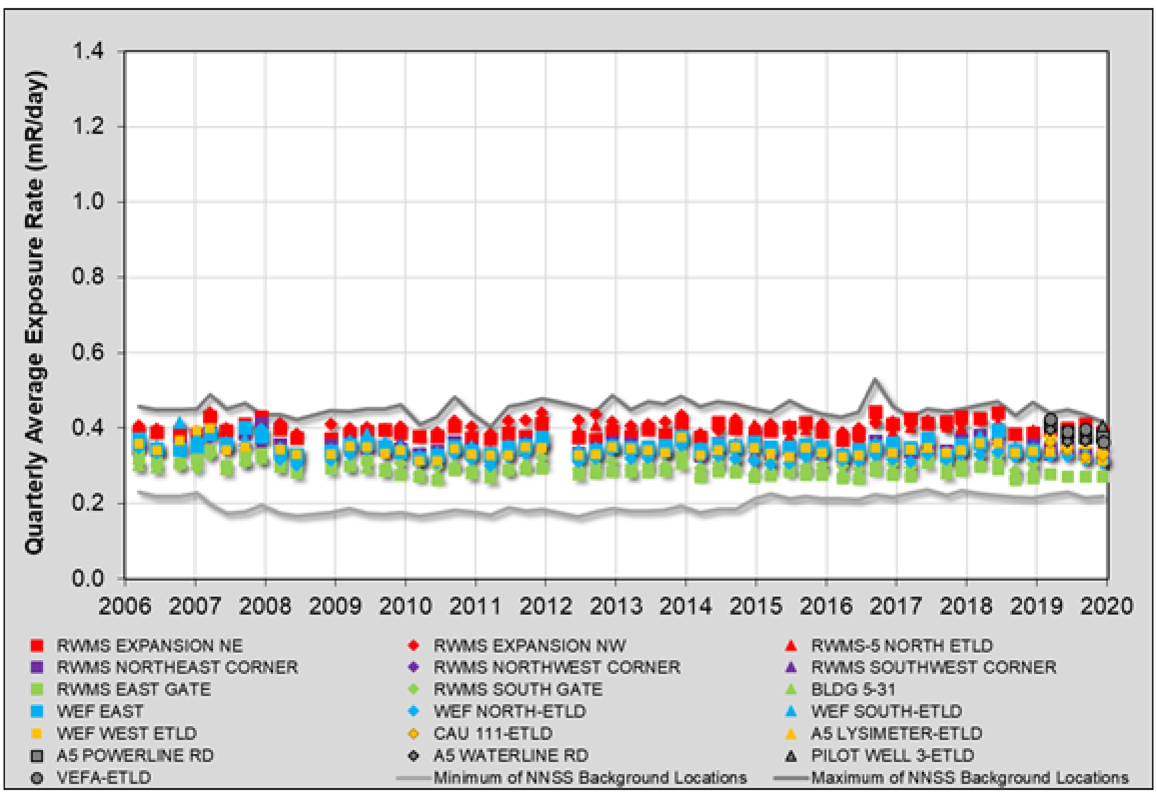

Figure 4-3. Quarterly Average Daily Exposure Rates at the Area 5 RWMS

4.3 AIR MONITORING DATA

4.3.1 Tritium

Tritium is a highly mobile isotope of hydrogen that acts as a conservative tracer. It is an excellent performance indicator of volatile radionuclide migration from waste cells. Atmospheric moisture is continuously collected at the Area 3 and Area 5 RWMSs and analyzed for tritium. Approximately 11 cubic meters (m^3) (388 ft^3) of air are drawn across a desiccant during each 2-week sample period to collect atmospheric moisture. Moisture is distilled from the desiccant, and tritium activity is measured by liquid scintillation.

Tritium was sampled at one air monitoring location inside the Area 3 RWMS and two nearby locations during 2019 (Figure 3-1). These locations were U-3ax/bl South, Bilby Crater, and Kestrel Crater N. The U-3ax/bl South station measures radionuclide concentrations near the center of the Area 3 RWMS, while the Bilby Crater and Kestrel Crater N stations measure radionuclide concentrations in the prevailing wind directions at the Area 3 RWMS. The Bilby Crater station is approximately 1.2 km (0.75 mi) north of the Area 3 RWMS, and the Kestrel Crater N station is approximately 1.5 km (0.93 mi) south of the Area 3 RWMS. Consistently higher radionuclide concentrations at U-3ax/bl South compared to Bilby Crater and Kestrel Crater N might indicate the Area 3 RWMS is the source of the elevated radionuclide concentrations, while similar radionuclide concentrations would indicate the Area 3 RWMS is not a strong source of radionuclides.

Tritium was sampled at two air monitoring locations near the Area 5 RWMS during 2019 (Figure 3-2). These locations were DoD and RWMS 5 Lagoons. The DoD station is approximately 1.0 km (0.62 mi) north-northeast of the center of the Area 5 RWMS, and the RWMS 5 Lagoons station is approximately 1.5 km (0.93 mi) south-southeast of the center of the Area 5 RWMS (Figure 3-2). These monitoring locations are generally in the prevailing wind.

During 2019, tritium concentrations at the Area 3 and Area 5 RWMSs ranged from -0.41 to 6.62 picocuries per cubic meter (pCi/m^3). Concentrations at all the Area 5 RWMS locations were higher from August through November and were similar to other locations throughout the rest of the year (Figure 4-4). Other than the August through November concentrations, the majority of the tritium results from both the Area 3 and 5 RWMSs were below the minimum detectable concentration. All 2019 results were well below the DOE Derived Concentration Standard (DCS) (DOE 2011) for tritium adjusted to the 10-mrem/yr dose limit specified in DOE M 435.1 for the air pathway. This scaled DCS is the tritium concentration in air that results in a 10-mrem annual effective dose to a person breathing it for the entire year.

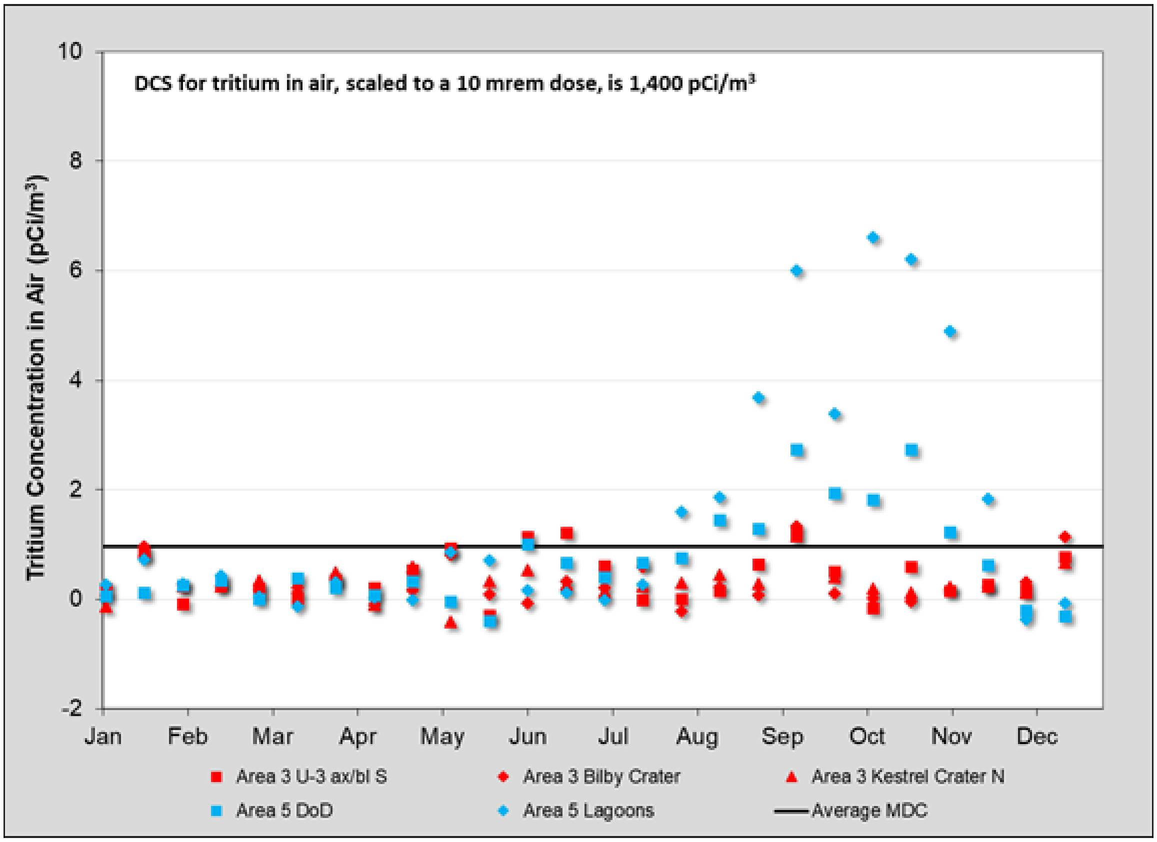

Figure 4-4. Tritium Concentration in Air at the Area 3 and Area 5 RWMSs

4.3.2 Particulates

Air particulate samples were collected every 2 weeks during 2019 at the same locations described above for tritium monitoring (Figure 3-1 and Figure 3-2). Each sample was collected using a vacuum pump to draw approximately 1,700 m^3 (60,000 ft^3) of air through a glass-fiber filter with a collection efficiency of 99.99 percent. Air particulates were collected on the filter. Each filter was screened for gross alpha and gross beta radioactivity to provide early detection of any change in environmental concentrations of airborne radioactivity. Quarterly composites of the filters from each sampling location were analyzed by gamma spectroscopy for gamma-emitting radionuclides and by alpha spectroscopy for Am and Pu.

The results for ^{241}Am, ^{238}Pu, and $^{239+240}$Pu in air are provided in Figure 4-5, Figure 4-6, and Figure 4-7, respectively. ^{241}Am and $^{239+240}$Pu concentrations tend to be slightly higher at the Area 3 RWMS compared with those at the Area 5 RWMS, and concentrations are generally higher during the second or third quarter. This is likely a result of dry soil conditions and relatively high, unstable winds that generally occur during that time. All 2019 results were well below the 10-mrem/yr adjusted DCS for each radionuclide.

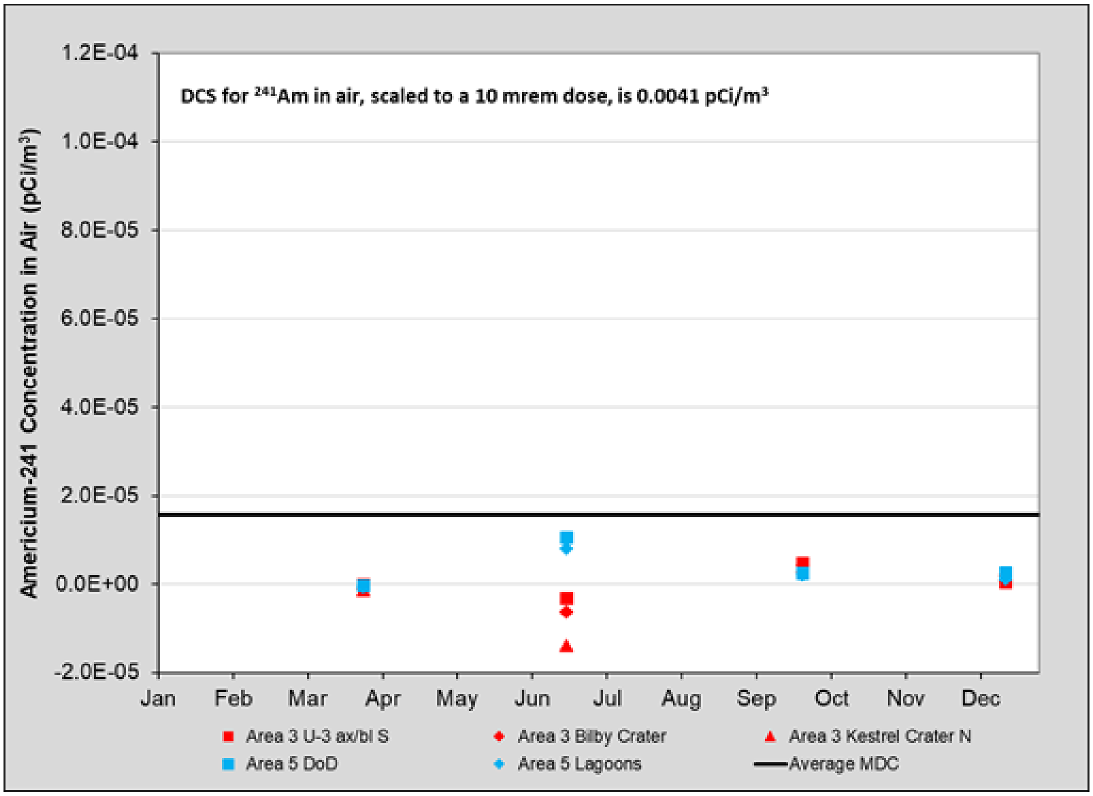

Figure 4-5. Concentration of ^{241}Am in Air at the Area 3 and Area 5 RWMSs

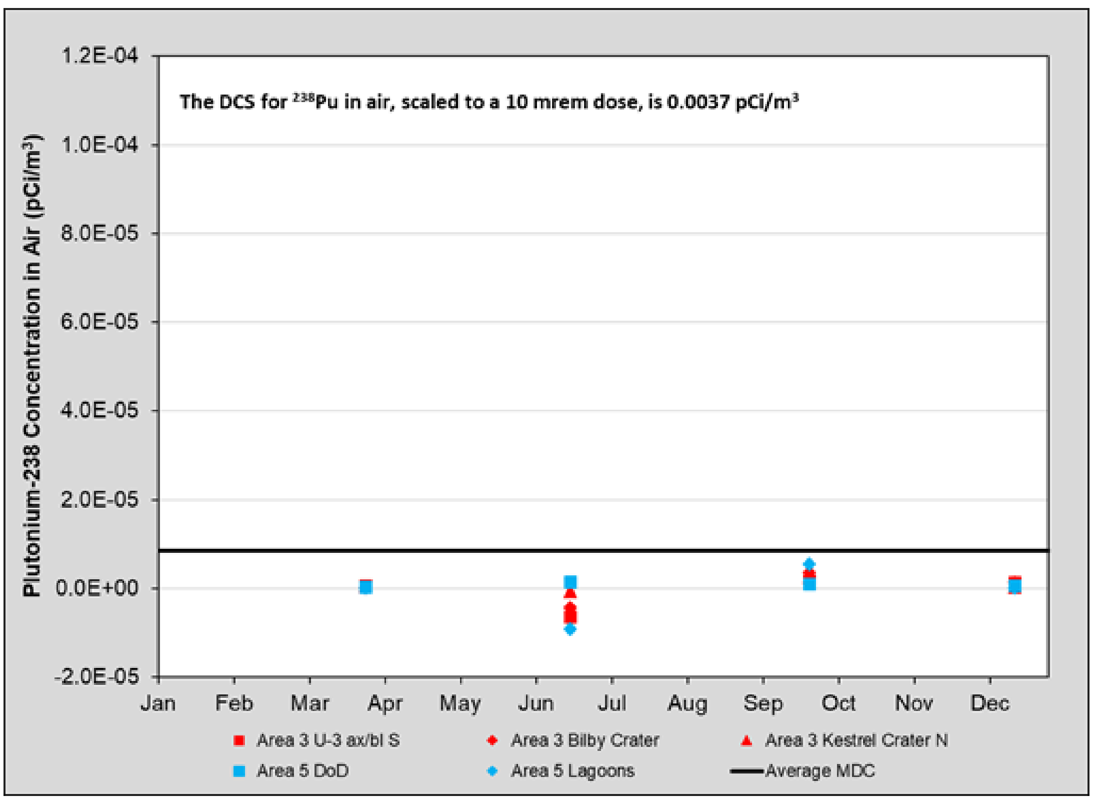

Figure 4-6. Concentration of ^{238}Pu in Air at the Area 3 and Area 5 RWMSs

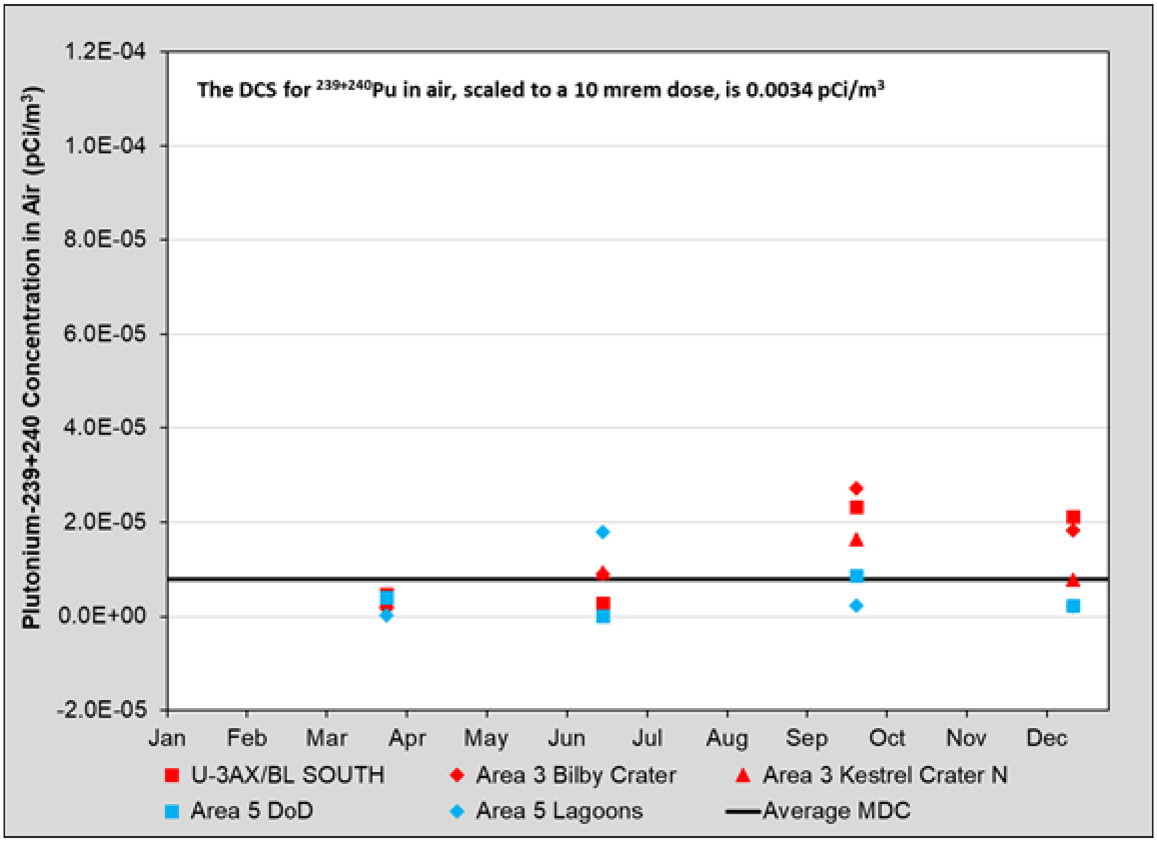

Figure 4-7. Concentration of $^{239+240}Pu$ in Air at the Area 3 and Area 5 RWMSs

4.3.3 Radon

The performance objective from DOE M 435.1-1, "Radioactive Waste Management Manual," for radon emissions from DOE radioactive waste facilities is 20 picocuries per square meter per second (pCi/m^2/s). Radon flux was measured during 2019 on final covers in the Area 3 and Area 5 RWMSs and at an undisturbed, control site outside of each RWMS. Measurements were collected December 23–30, 2019, using radon flux domes (Rad Elec, Inc.) placed on the ground surface. Electrets inserted in the domes are electrically discharged by ionization of air from radon. The amount of discharge is correlated with radon flux from the ground. Results show radon flux was well below the 20-pCi/m^2/s limit (Figure 4-8).

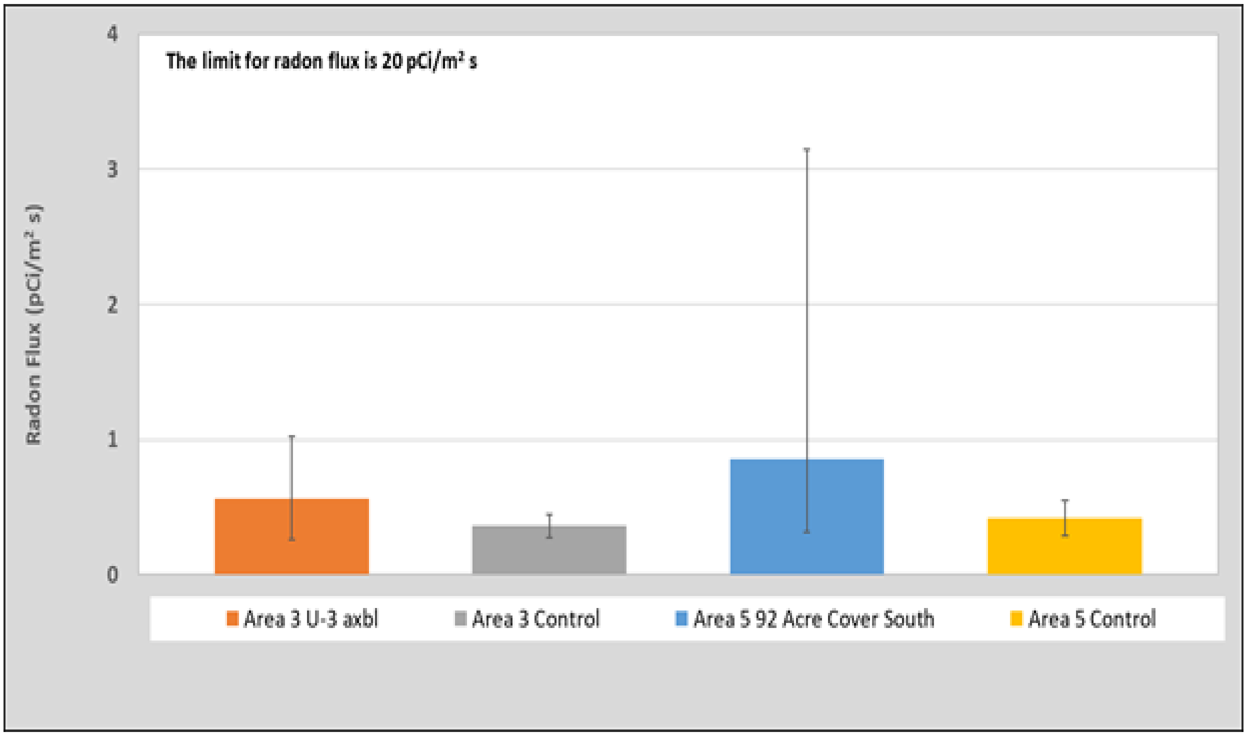

Figure 4-8. Radon Flux Results at the Area 3 and Area 5 RWMSs

4.4 GROUNDWATER MONITORING DATA

4.4.1 Groundwater Monitoring at the Area 5 RWMS Pilot Wells

Three wells (UE5PW-1, UE5PW-2, and UE5PW-3) were drilled around the perimeter of the Area 5 RWMS in 1993 (Figure 3-2). These wells are sampled twice a year to monitor the groundwater below the Area 5 RWMS. Groundwater samples were collected on March 5 and 12 and August 6, 2019. Investigation levels (ILs) have been established for five indicators of contamination migration. The measured indicators are SC, pH, TOC, TOX, and tritium. Further groundwater analyses are required if any analyte exceeds its IL. Results from 2019 are summarized in Table 4-3. General water chemistry parameters are also measured. Negative tritium results indicate the measured activity is less than the measured laboratory background activity.

To date, all analytical data from groundwater sampling events from the wells indicate that the groundwater in the uppermost aquifer is unaffected by activities at the Area 5 RWMS. Detailed information and data on the groundwater monitoring program at the Area 5 RWMS are presented in the *Nevada National Security Site 2019 Data Report: Groundwater Monitoring Program, Area 5 Radioactive Waste Management Site* (MSTS 2020a).

Table 4-3. Investigation Levels and Results from 2019 Groundwater Monitoring

Indicator Parameter	Investigation Level	Results
pH	< 7.6 or > 9.2	8.08 to 8.47
SC	0.440 mmho/cm	0.357 to 0.383 mmho/cm
TOC	2.0 mg/L	All < 1 mg/L
TOX	0.1 mg/L	All < 0.01 mg/L
Tritium	2000 pCi/L	All < 300 pCi/L

mmho/cm: millimho(s) per centimeter
mg/L: milligram(s) per liter
pCi/L: picocurie(s) per liter

Groundwater elevations at the pilot wells are measured quarterly using an electronic tape. Elevations were measured on March 4 and 6, June 10, August 5, and October 14, 2019. Groundwater elevation data since 2015 are shown in Figure 4-9. The 2019 average groundwater elevations were 733.41 m (2,406.2 ft) AMSL at UE5PW-1, 733.54 m (2,406.6 ft) AMSL at UE5PW-2, and 733.66 m (2,407.0 ft) AMSL at UE5PW-3. These data indicate that the water table beneath the Area 5 RWMS is flat, with little or no groundwater flow. Estimated groundwater flow velocity is 10.4 cm per year (4.10 in. per year) to the south-southeast.

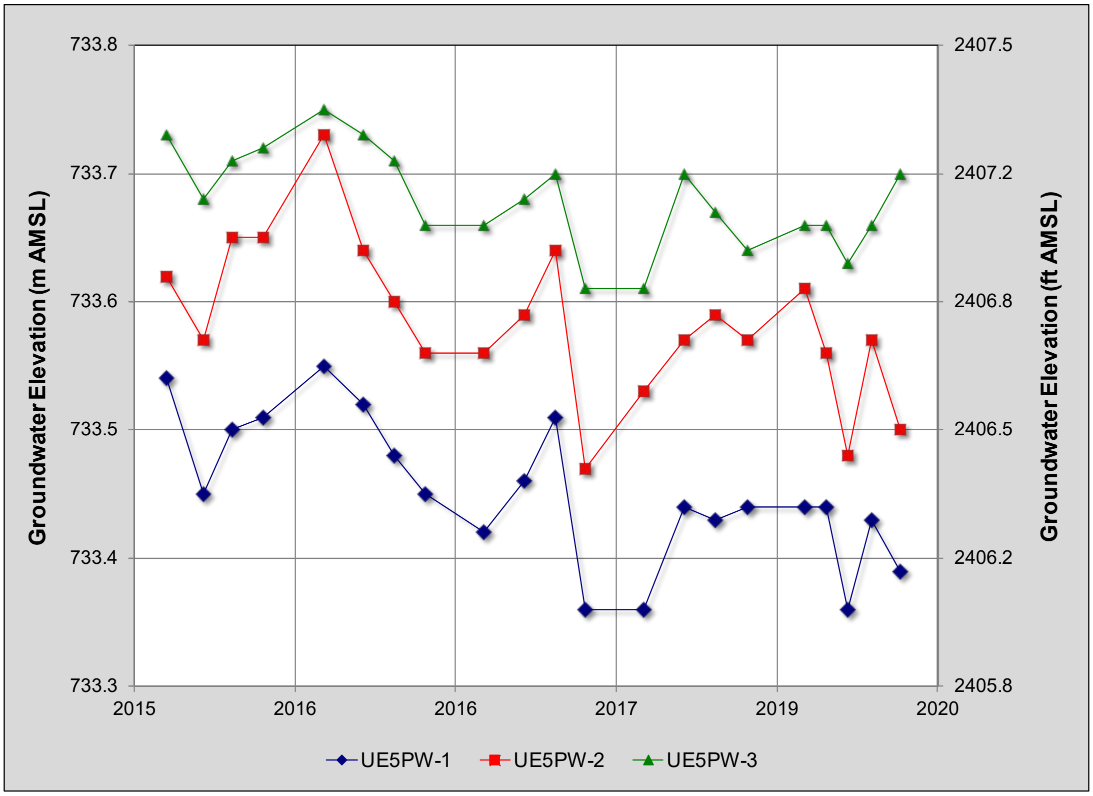

Figure 4-9. Groundwater Elevations at the Area 5 Pilot Wells

4.4.2 Leachate Monitoring at P18 and P25

Cell 18 (P18) is a lined, MLLW disposal cell located in the northeastern corner of the Area 5 RWMS. It was constructed in 2010 and began receiving waste in January 2011. The last waste package was received in 2019. The Cell 18 liner is a RCRA-compliant double liner with a leachate collection and leak detection system placed over a geosynthetic clay liner. In 2018, construction finished on a second MLLW disposal cell, Cell 25 (P25). It is due west of Cell 18, and the first waste was received in August 2018. Cell 25 has a 10,000-gallon leachate collection tank, and Cell 18 has a 3,000-gallon leachate collection tank. Cell 25 and has an area, including the sloped sides, of 1.42 ha (3.50 ac), and Cell 18 has an area of 1.35 ha (3.33 ac).

Cell 18 and Cell 25 have double liners covered by approximately 61 cm (24 in.) of compacted soil on the cell side slopes and approximately 76 cm (30 in.) of compacted soil on the cell floor. Each primary liner is 80-mil textured high-density polyethylene (HDPE), and each secondary liner is 60-mil textured HDPE. Each primary liner is directly below a 160-mil double-sided geocomposite drainage layer, and a second 160-mil double-sided geocomposite drainage layer separates the primary liner from the underlying secondary liner.

Any precipitation or other water applied to the area covered by the liner that is not removed by ET eventually infiltrates into the soil above the liner, percolates through the soil to the primary liner, and eventually drains into the primary sump in the floor of the cells. Any water leaking through the primary liner would percolate to the secondary liner and eventually drain into the secondary sump in the floor of the cells. Water collected in the primary sump is pumped from the sump to the leachate tanks on the surface above the cells.

The total volume pumped from the primary sump at Cell 18 into the leachate collection tank from January 2011 through December 2019 was 388,243 liters (102,563 gallons) (Figure 4-10). From January 2011 through December 2019, 108.45 cm (42.697 in.) of precipitation were received at the Area 5 RWMS. The equivalent depth of the collected leachate distributed over the 1.35 ha (3.33 ac) covered by the Cell 18 liner was 2.91 cm (1.14 in.). Neglecting additional water applied to Cell 18 for dust control, leachate was approximately 2.7 percent of precipitation. The total volume pumped from the primary sump into the leachate collection tank in 2019 was 28,030 liters (7,404 gallons). In 2019, 20.42 cm (8.03 in.) of precipitation were received at the Area 5 RWMS. The equivalent depth of the yearly collected leachate distributed over the 1.35 ha (3.33 ac) covered by the Cell 18 liner was 0.21 cm (0.083 in.). Neglecting additional water applied to Cell 18 for dust control, leachate was approximately 1.0 percent of the 2019 precipitation.

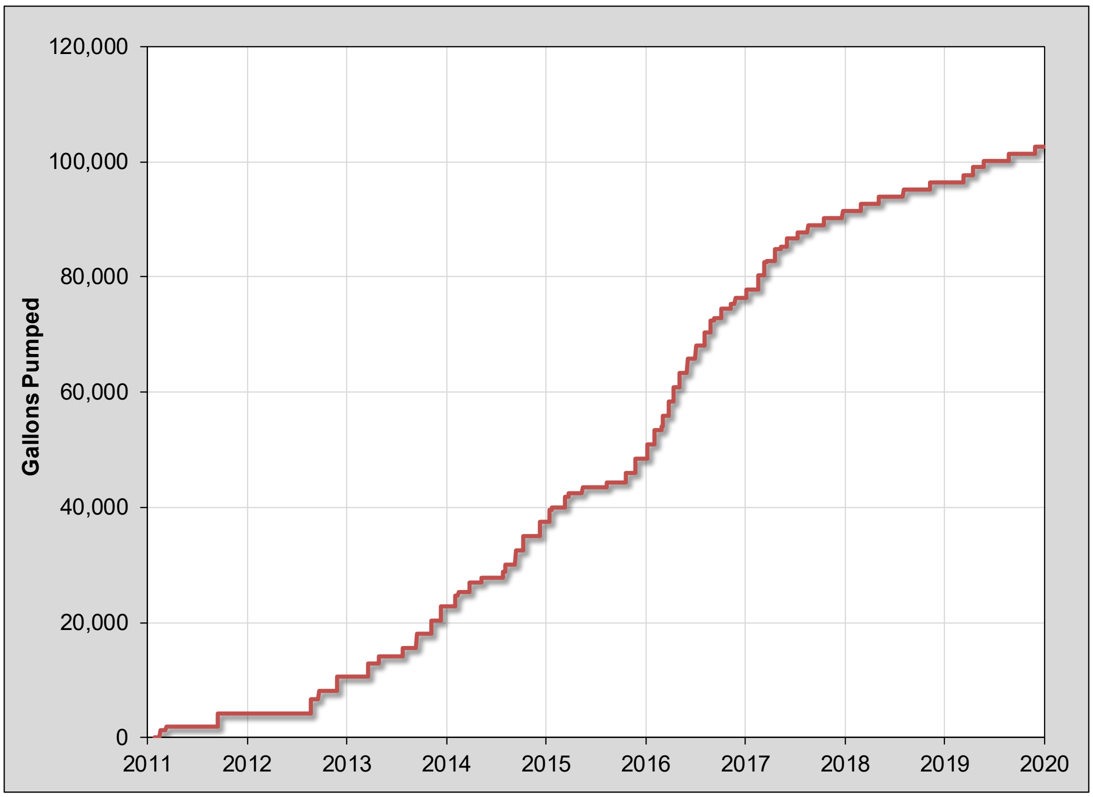

Figure 4-10. Leachate Volume Pumped from the Cell 18 Primary Sump

Although the Cell 25 leachate tank was not full, it was sampled on August 1, 2019, and then emptied for the first time on August 15, 2019, to meet the regulatory requirement for annual sampling of leachate tanks. The total volume of leachate in the Cell 25 leachate tank was 22,660 liters (5,986 gallons). The equivalent depth of the leachate distributed over the 1.41 ha (3.48 ac) covered by the Cell 25 liner was 0.16 cm (0.063 in.). The Cell 25 leachate amount was 0.8 percent of the 2019 precipitation at the Area 5 RWMS.

When the tanks approach capacity, or at least annually if the tanks are not full, leachate samples are collected and analyzed for the toxicity characteristic contaminants listed in Table 1 of 40 CFR 261.24 (2003) (polychlorinated biphenyls [PCBs], pH, and SC). Leachate samples from the Cell 18 leachate tank were collected on March 14, May 29, and December 11, 2019, and leachate samples were collected from the Cell 25 leachate tank on August 1, 2019. Indicators of contamination monitored in leachate include the following:

- Toxicity characteristic contaminants
  - Metals (arsenic, barium, cadmium, chromium, lead, selenium, and silver)
  - Mercury
  - Semi-volatiles (o-cresol, m-cresol, p-cresol, 1,4-dichlorobenzene, 2,4-dinitrotoluene, hexachlorobenzene, hexachlorobutadiene, hexachloroethane, nitrobenzene, pentrachlorophenol, pyridine, 2,4,5-trichlorophenol, and 2,4,6-trichlorophenol)
  - Volatiles (benzene, carbon tetrachloride, chlorobenzene, chloroform, 1,2-dichloroethane, 1,1-dichloroethylene, methyl ethyl ketone, tetrachloroethylene, trichloroethylene, and vinyl chloride)
  - Organochlorine pesticides (chlordane, endrin, heptachlor [and its epoxide], lindane, methoxychlor, and toxaphene)
  - Chlorinated herbicides (2,4-D and 2,4,5-TP [Silvex])
- PCBs
- pH
- SC

Through 2019, no regulatory limits for toxicity characteristic contaminants were exceeded, and no PCBs exceeded the analysis method quantification limit. After sample results were evaluated, the leachate tanks were emptied and the leachate used for dust control on the cell where the leachate was collected. Detailed results for the leachate are presented in the *Nevada National Security Site 2019 Data Report: Groundwater Monitoring Program, Area 5 Radioactive Waste Management Site* (MSTS 2020a).

4.5 METEOROLOGY MONITORING DATA

Meteorology monitoring data collected in 2019 included precipitation, air temperature, humidity, wind speed and direction, barometric pressure, and incoming solar radiation. Net solar radiation, soil heat flux, soil temperature, and soil water content were also measured for energy balance-based calculations of ET. These are basic meteorological parameters required to quantify the exchange of water and heat between the soil and the atmosphere. These data were collected from two meteorology stations, one located approximately 30 m (100 ft) northwest of the Area 3 RWMS, and one near the Area 5 RWMS about 100 m (328 ft) north of Well UE5PW-1 (Figure 3-1 and Figure 3-2).

4.5.1 Air Temperature

Air temperatures at the Area 3 RWMS are slightly cooler than air temperatures at the Area 5 RWMS. The 2019 average recorded temperatures at 9.5 m (31 ft) AGL were 14.0°C (57.2°F) at the Area 3 RWMS and 16.1°C (61.0°F) at the Area 5 RWMS. The 2019 maximum and minimum temperatures at 9.5 m (31 ft) AGL at the Area 3 RWMS were 38.7°C (101.7°F) on August 27, 2019, and -13.2°C (8.24°F) on November 30, 2019. The 2019 maximum and minimum temperatures at 9.5 m (31 ft) AGL at the Area 5 RWMS were 40.5°C (105°F) on July 28, 2019, and -9.1°C (16°F) on November 30, 2019 (Figure 4-11).

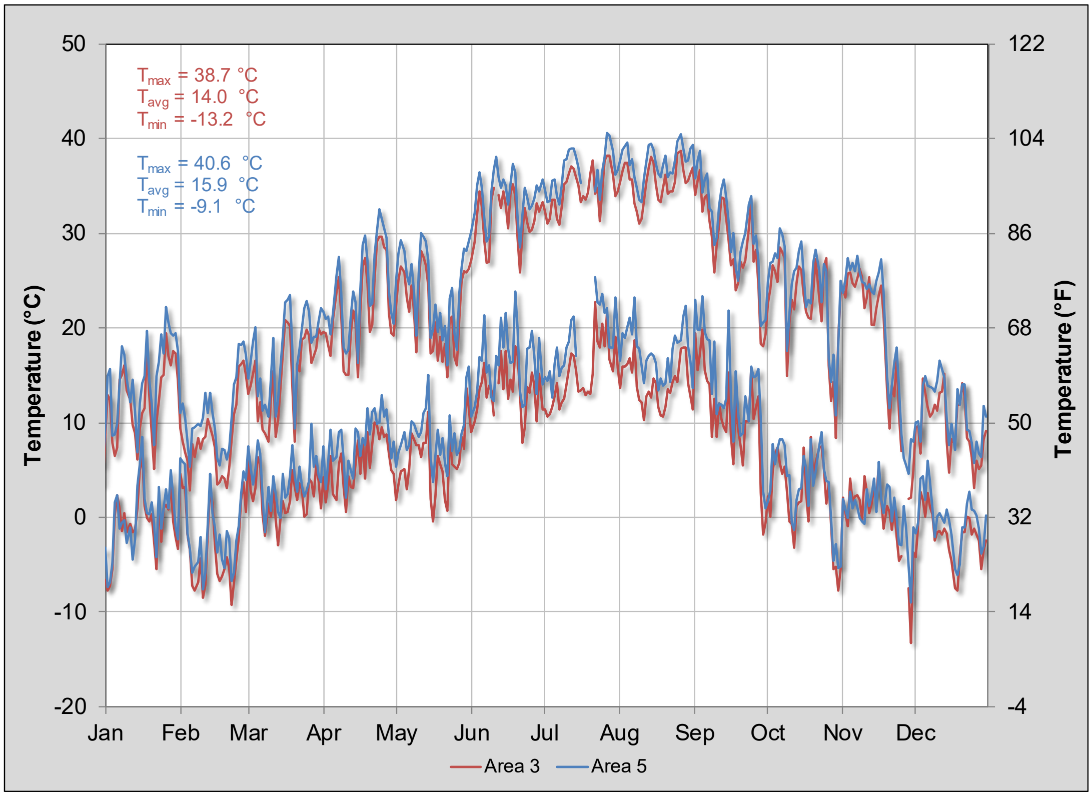

Figure 4-11. Daily Maximum and Minimum Air Temperature at the Area 3 and Area 5 RWMSs

4.5.2 Relative Humidity

Measured relative humidity at the Area 3 RWMS and the Area 5 RWMS is similar. The daily average relative humidity during 2019 at 9.5 m (31 ft) AGL was 33.4% for Area 3 and 35.0% for Area 5 (Figure 4-12). Measured daily average relative humidity ranged from 7.05% to 93.5%.

Water density, or absolute humidity, measures the amount of water vapor in air as grams per cubic meter (g/m^3) and can be calculated from relative humidity and air temperature. It is directly related to the air vapor pressure and measures the absolute amount of water in the air. Unlike relative humidity, vapor density is not temperature dependent. The daily average water density during 2019 was 3.8 g/m^3 at the Area 3 RWMS and 4.0 g/m^3 at the Area 5 RWMS (Figure 4-13). The measured daily average water density ranged from 0.5 g/m^3 to 10.2 g/m^3.

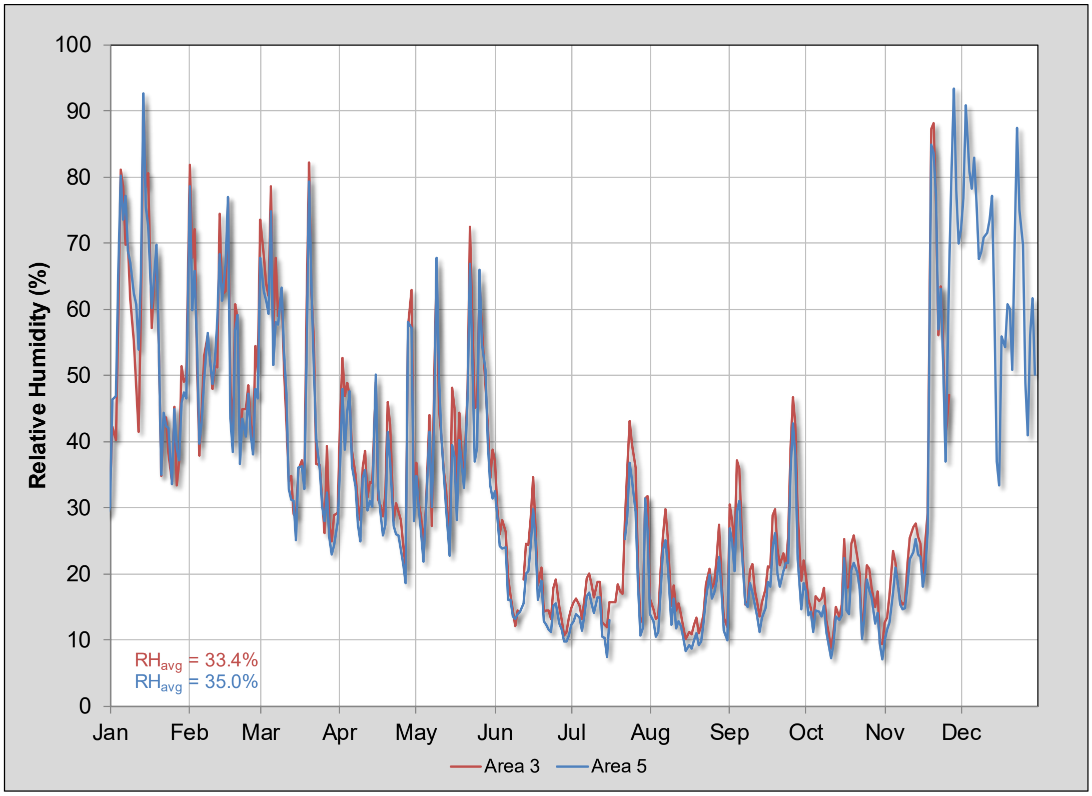

Figure 4-12. Daily Average Relative Humidity at the Area 3 and Area 5 RWMSs

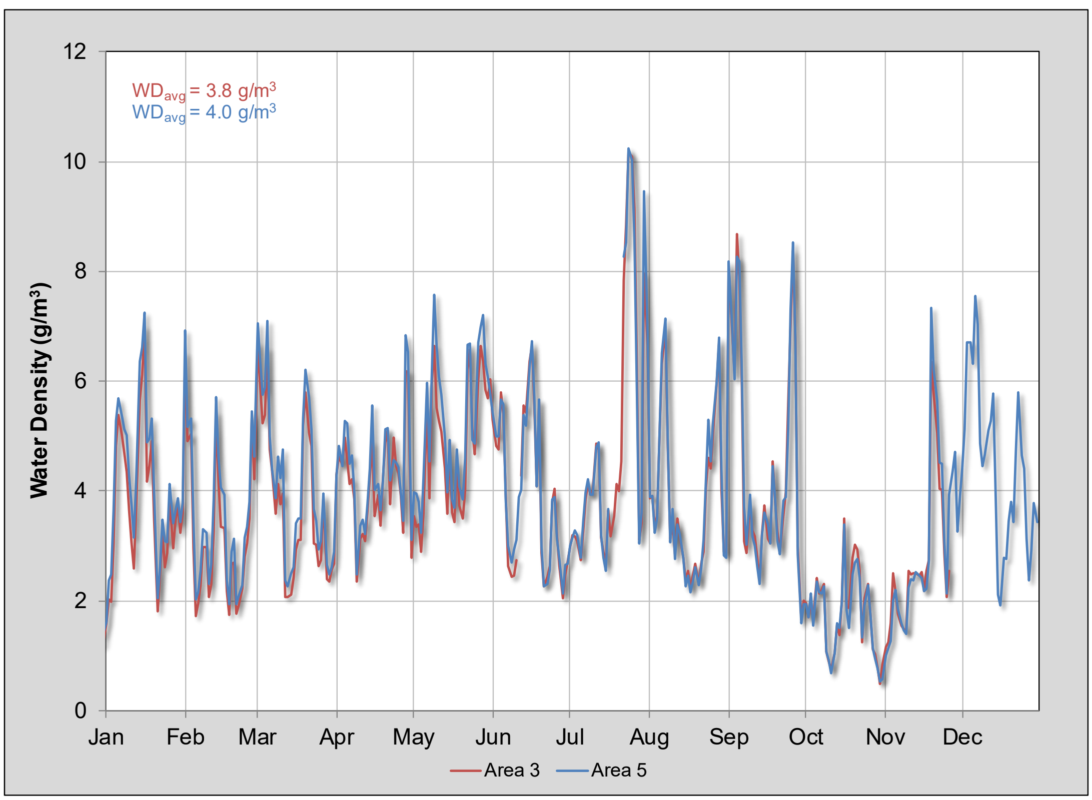

Figure 4-13. Daily Average Atmospheric Water Density at the Area 3 and Area 5 RWMSs

4.5.3 Barometric Pressure

Average daily barometric pressure measured at the Area 3 RWMS and the Area 5 RWMS typically shows very similar patterns (Figure 4-14). The average barometric pressure at the Area 3 RWMS in 2019 was 87.8 kilopascals (kPa) (12.7 pounds per square inch [PSI]). The average barometric pressure at the Area 5 RWMS in 2019 was 90.5 kPa (13.1 PSI). The difference in barometric pressure readings between the two locations reflects the 261 m (856 ft) difference in elevation.

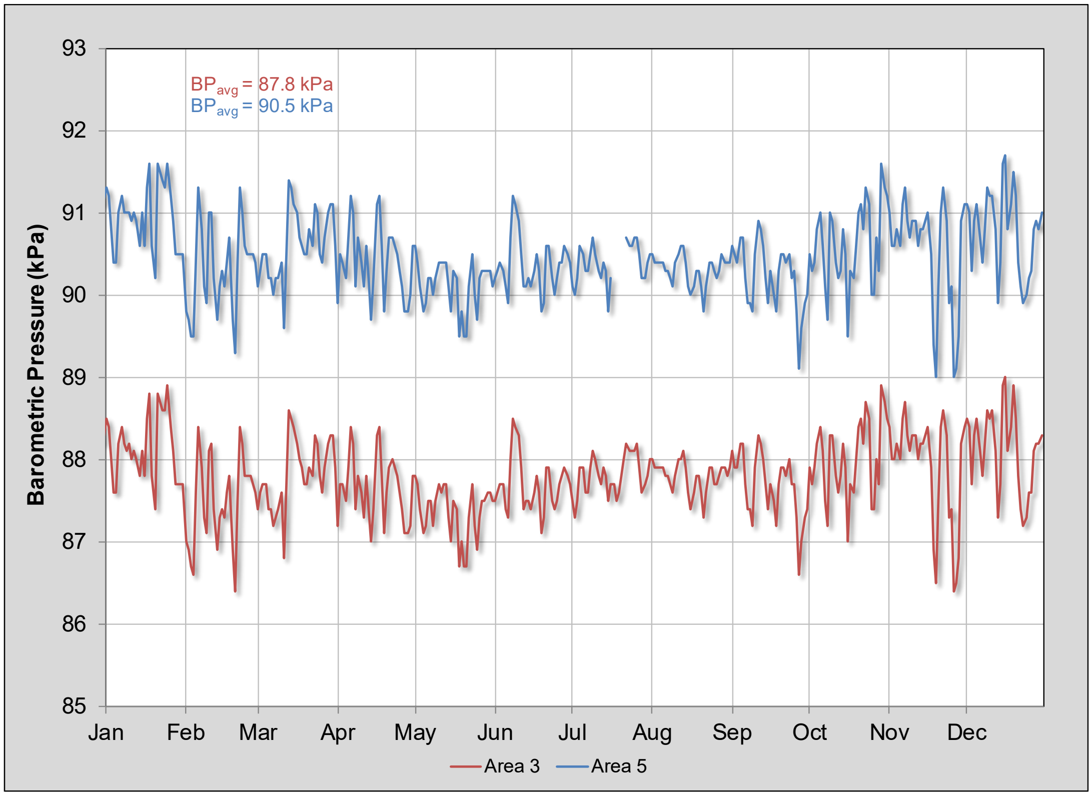

Figure 4-14. Daily Average Barometric Pressure at the Area 3 and Area 5 RWMSs

4.5.4 Wind Speed and Wind Direction

The average wind speed is slightly higher at the Area 3 RWMS than at the Area 5 RWMS. During 2019, the average daily wind speed at the Area 3 RWMS at 9.5 m (31 ft) AGL was 3.7 m/s (8.3 mph), and the maximum gust was 22.7 m/s (50.8 mph) on March 12. During 2019, the average daily wind speed at the Area 5 RWMS at 9.5 m (31 ft) AGL was 3.1 m/s (6.9 mph), and the maximum gust was 23.7 m/s (53.0 mph) on April 2. Daily maximum and average wind speeds at the Area 3 and Area 5 RWMSs are shown in Figure 4-15 and Figure 4-16, respectively.

Wind rose diagrams illustrate wind direction and wind speed distribution in each direction using hourly wind data measured at a height of 9.5 m (31 ft) AGL. Generally, the wind comes from the south/southwest during the day, and shifts to the north at night. Wind roses from the Area 3 and Area 5 RWMSs are presented in Figure 4-17 and Figure 4-18, respectively. The 1-year wind roses presented here are very similar to the multiple-year wind roses.

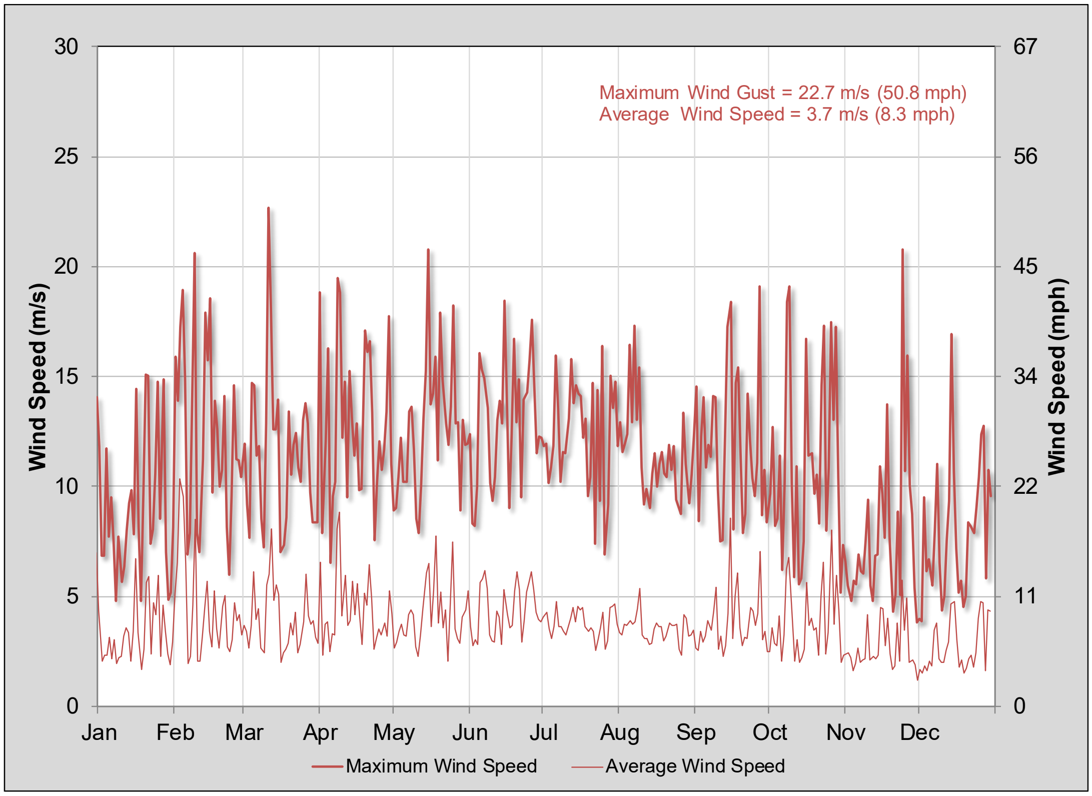

Figure 4-15. Daily Wind Speed at the Area 3 RWMS

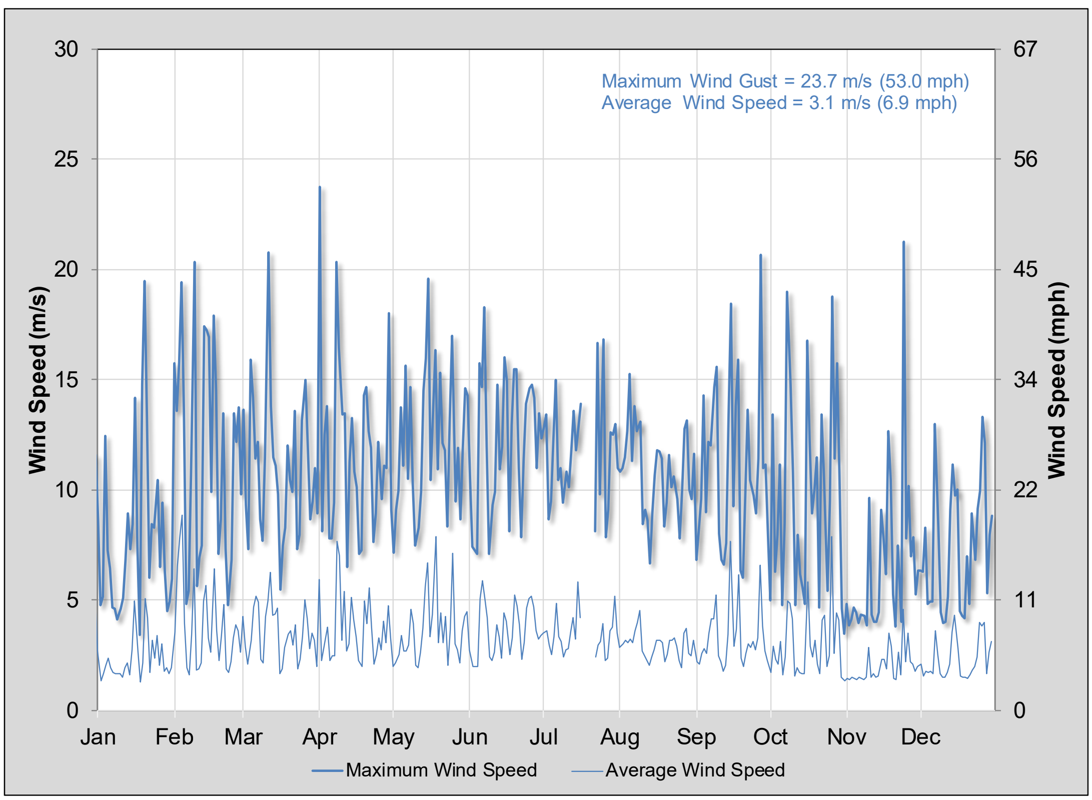

Figure 4-16. Daily Wind Speed at the Area 5 RWMS

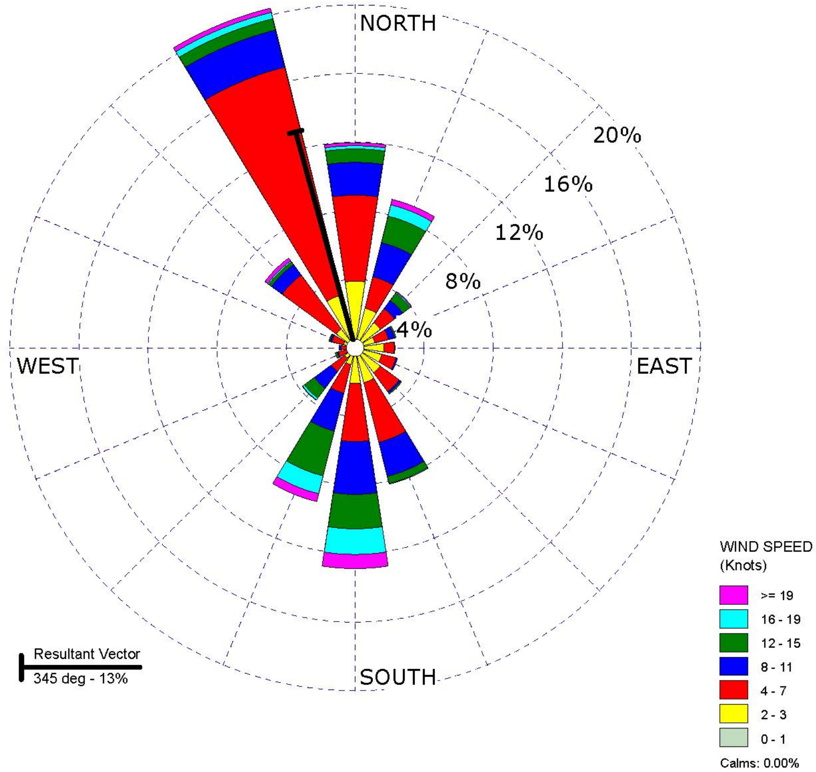

Figure 4-17. Wind Rose Diagram for the Area 3 RWMS

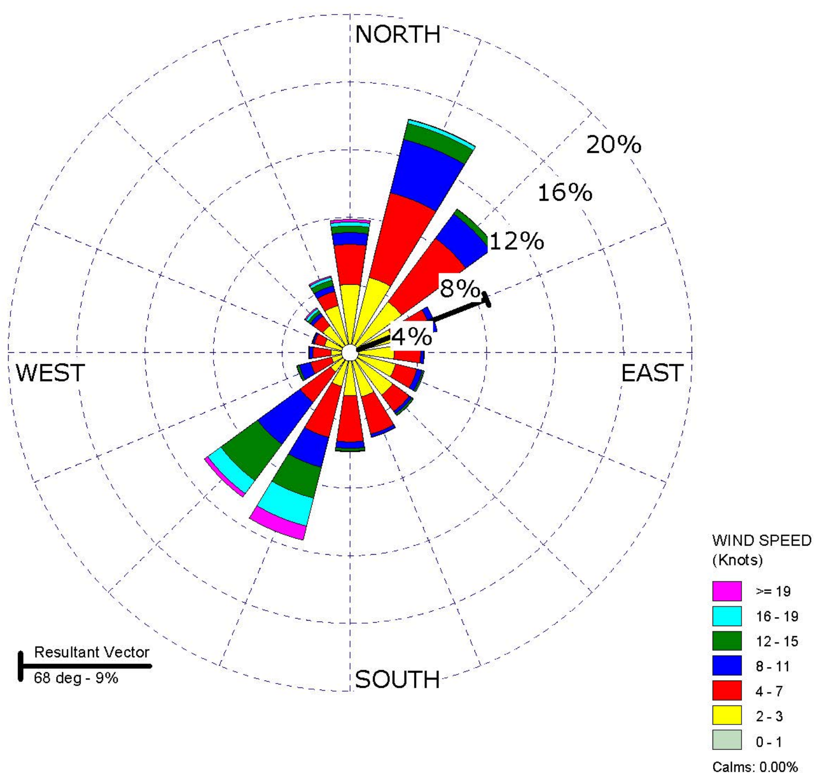

Figure 4-18. Wind Rose Diagram for the Area 5 RWMS

4.5.5 Precipitation

Rainfall at the Area 3 RWMS in 2019 was 86 percent above the 19-year average, totaling 261.2 mm (10.28 in.). The average annual precipitation measured at the Area 3 RWMS from 2001 through 2019 was 147 mm (5.79 in.). The maximum daily rainfall at the Area 3 RWMS during 2019 was 29.8 mm (1.17 in.) on November 20. Figure 4-19 compares the highest, lowest, average, and 2019 precipitation amounts for the last 19 years in Area 3. Rainfall in the first four months was considerably above average, the summer was dry, and the end of the year was wetter than normal. Precipitation was measured on 60 days during 2019 at the Area 3 RWMS.

Rainfall at the Area 5 RWMS in 2019 was 69 percent above the 24-year average, totaling 204.2 mm (8.039 in.). The average annual precipitation measured at the Area 5 RWMS from 1996 through 2019 was 124 mm (4.88 in.). The maximum daily rainfall at the Area 5 RWMS during 2019 was 31 mm (1.2 in.) on March 6. Figure 4-20 compares the highest, lowest, average, and 2019 precipitation amounts for the last 24 years in Area 5. Rainfall in the first four months was considerably above average, the summer was dry, and the end of the year was wetter than normal. Precipitation was measured on 31 days during 2019 at the Area 5 RWMS. April and May 2019 were particularly wet and cool, which is atypical of this area, so growing conditions were extended for more than a month longer than normal.

Historical precipitation data recorded at BJY (located about 3 km [2 mi] northwest of the Area 3 RWMS) and at the Area 3 RWMS are shown in Figure 4-21. The BJY station is a Meteorological Data Acquisition (MEDA) station operated by the Air Resources Laboratory, Special Operations and Research Division (ARL/SORD). The 59-year average annual precipitation at BJY from 1961 to 2019 was 161 mm (6.34 in.) (ARL/SORD 2020). Historical precipitation data recorded at the Well 5B station (located about 5.5 km [3.4 mi] south of the Area 5 RWMS) and at the Area 5 RWMS are provided in Figure 4-22. The Well 5B station is also an ARL/SORD MEDA station. The 56-year average annual precipitation at Well 5B from 1964 to 2019 was 124 mm (4.88 in.) (ARL/SORD 2020).

4.5.6 Reference Evapotranspiration

The calculated 2019 ET_{ref} at the Area 3 RWMS was 1,370 mm (53.9 in.) and at the Area 5 RWMS was 1,450 mm (57.1 in.). ET_{ref} is the rate at which readily available soil water is removed from a uniform surface of dense, actively growing vegetation. Crop coefficients are used to convert ET_{ref} to potential ET rates (Allen et al. 2005). ET_{ref} is calculated using a modified version of the radiation-based equation of Doorenbos and Pruitt (1977). The equation calculates ET_{ref} from hourly measurements of solar radiation, air temperature, relative humidity, wind speed, and barometric pressure. This method provides results similar to the Penman Equation that was previously used for the data reports through 2001 (Campbell 1977). The Doorenbos and Pruitt equation reduces data input requirements because no net radiation data are used. The ratio of ET_{ref} to precipitation in 2019 at the Area 3 RWMS was 5.2, and the ratio of ET_{ref} to precipitation in 2019 at the Area 5 RWMS was 7.1.

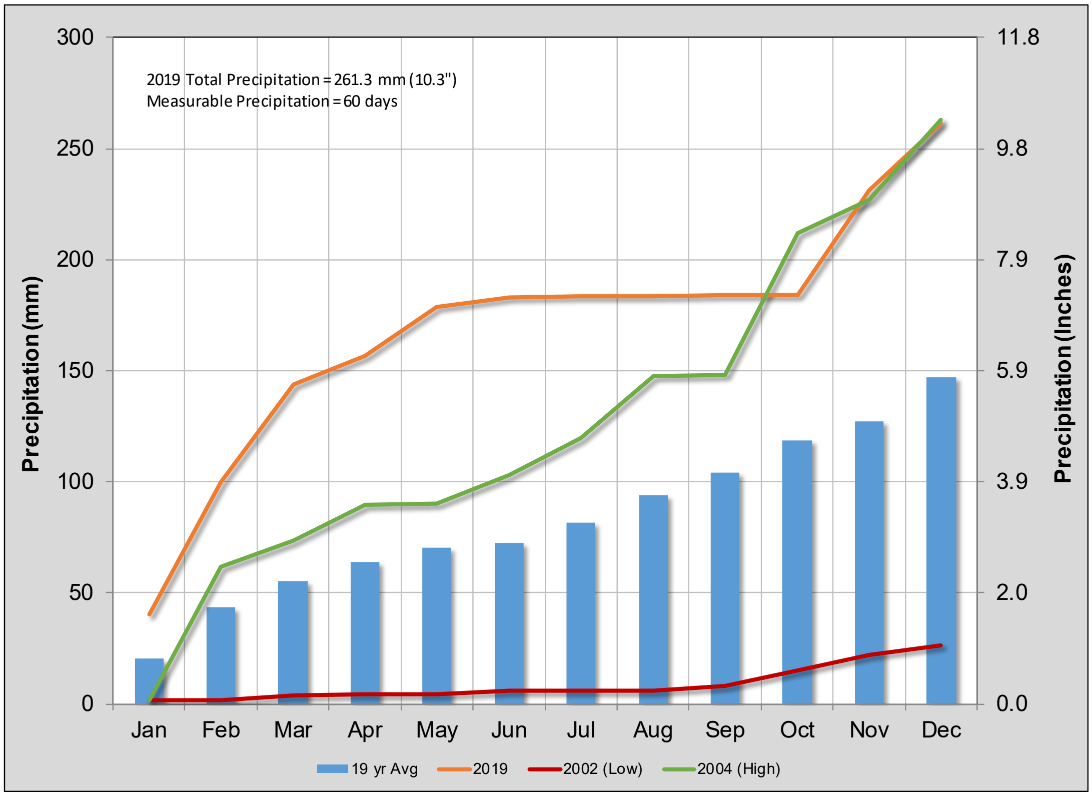

Figure 4-19. Precipitation at the Area 3 RWMS

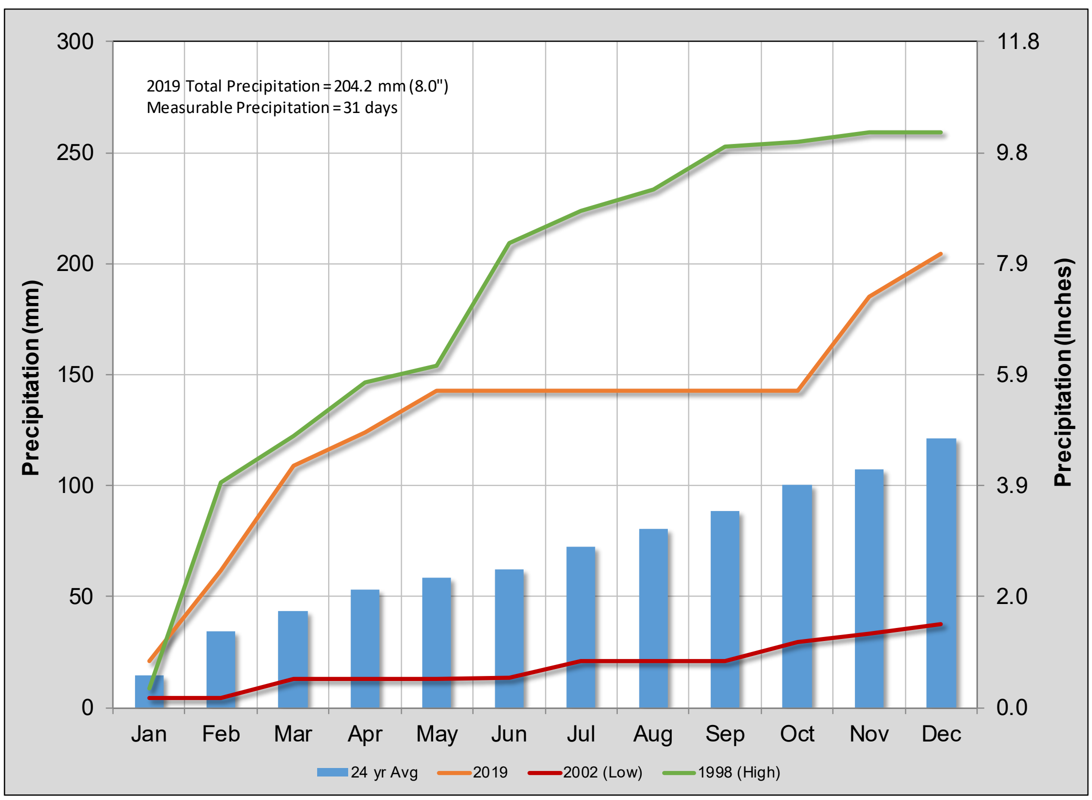

Figure 4-20. Precipitation at the Area 5 RWMS

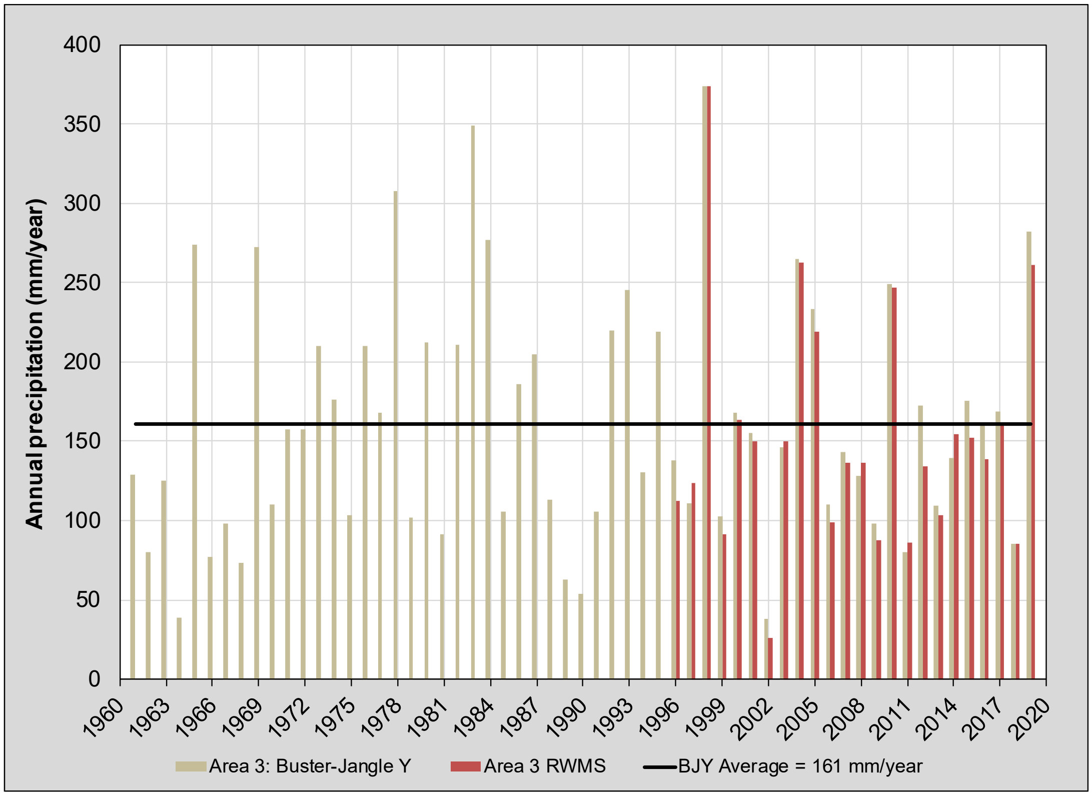

Figure 4-21. Historical Precipitation Record for Buster-Jangle Y and the Area 3 RWMS

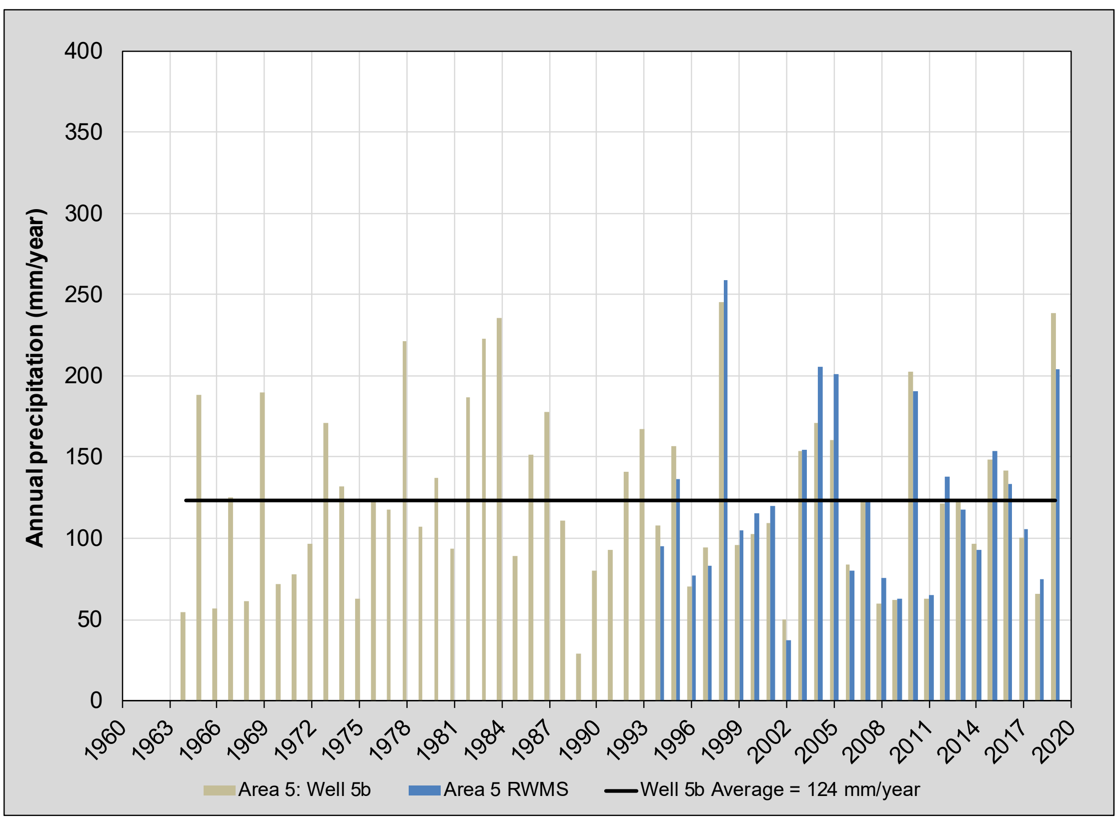

Figure 4-22. Historical Precipitation Record for Well 5B and the Area 5 RWMS

4.6 VADOSE ZONE MONITORING DATA

4.6.1 Monitoring Strategy

Vadose zone monitoring is conducted at the Area 3 and Area 5 RWMSs to demonstrate compliance with DOE O 435.1 (DOE 2001b) and confirm the assumptions in the PA for each RWMS (e.g., hydrologic conceptual models, including soil water contents, flux rates and directions, and volatile radionuclide releases). Vadose zone monitoring is also performed to detect changing trends in performance, provide added assurance to PA conclusions regarding facility performance, evaluate the performance of operational waste covers, and confirm the PA performance objective of protecting groundwater resources.

The design of the current vadose zone monitoring program at the RWMSs is based on an understanding of the vadose zone system acquired through extensive characterization studies (BN 1998, 2005a, 2005b; Blout et al. 1995; Reynolds Electrical & Engineering Co., Inc., 1993a, 1993b; Shott et al. 1997, 1998; Tyler et al. 1996) and modeling studies (Levitt et al. 1999; Desotell et al. 2006, 2007). The objectives of the vadose zone monitoring program are accomplished, in part, by measuring water balances at each RWMS. Water balance studies involve using meteorology data to calculate ET_{ref} values (the driving force of upward flow), directly measuring ET and bare-soil E at the RWMS lysimeter facilities, and measuring soil water content and soil water potential in waste cell covers and floors using automated waste cover monitoring systems.

4.6.2 Area 5 Weighing Lysimeter Facility

The Area 5 Weighing Lysimeter Facility consists of two precision weighing lysimeters located just below the southern boundary of the Area 5 RWMS (Figure 3-2). Each lysimeter is an open-top steel box, measuring 2.0 m wide by 4.0 m long by 2.0 m deep (6.6 ft wide by 13 ft long by 6.6 ft deep), filled with soil, and mounted on a sensitive scale. Weight changes of each lysimeter are continuously monitored using an electronic load cell. Each load cell can measure approximately 0.1 mm (0.004 in.) of precipitation or ET. One lysimeter is vegetated with the native plant species *Larrea tridentata* (creosote bush), *Lycium pallidum* (pale desert thorn), and *Schismus arabicus* (Arabian schismus) at the approximate density of the surrounding desert. The other lysimeter is kept bare to simulate the bare operational waste covers at the Area 5 RWMS. The lysimeters have provided surface water balance data at the Area 5 RWMS since March 1994.

The weighing lysimeter data represent a simplified water balance. The change in soil water storage is equal to precipitation minus E (on bare lysimeters) or ET (on vegetated lysimeters). The water balance is simplified because no drainage can occur through the solid bottoms of the lysimeters and because a 2.5 cm (0.98 in.) lip around the edge of the lysimeters prevents run-on and runoff. Total soil water storage for the period of January 1, 1995, through December 31, 2019, is provided in Figure 4-23.

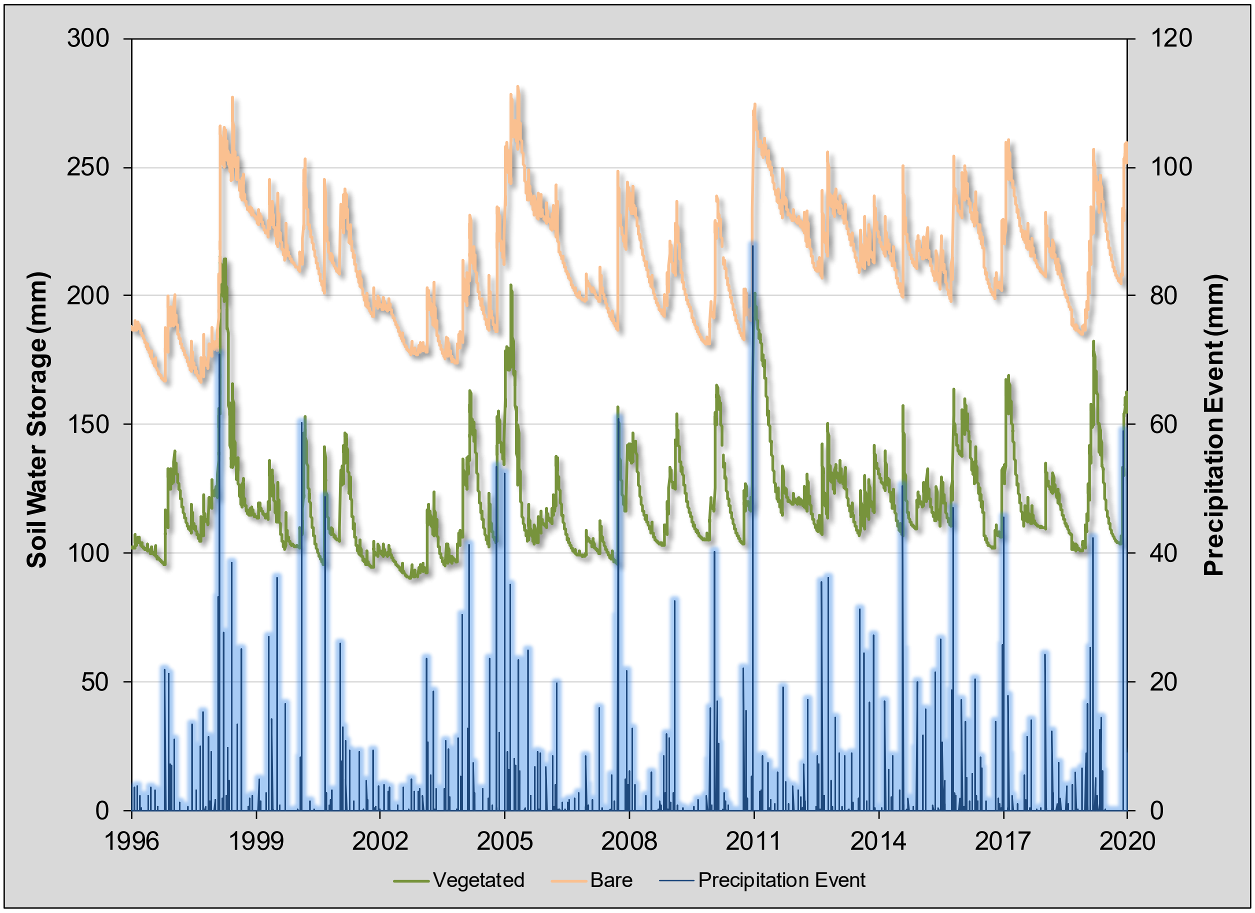

Figure 4-23. Weighing Lysimeter Data from January 1995 through December 2019 at the Area 5 Weighing Lysimeter Facility

The vegetated lysimeter is considerably drier than the bare-soil lysimeter despite the small number of plants on the vegetated lysimeter. Typically, the vegetated lysimeter has 10 to 15 percent plant cover. Cover was measured for both the vegetated and bare-soil weighing lysimeters on May 20, 2019, using an ocular projection device. Plant cover on the vegetated lysimeter consisted of four shrubs (two *Larrea tridentate* [creosote bush] and two *Lycium pallidum* [pale desert thorn]) and roughly 225 small annual grasses (*Schismus arabicus* [Arabian schismus]) and nine *Lupinus flavoculatus* [yellow-eyed lupine]. The results are summarized in Table 4-4.

Table 4-4. Area 5 Weighing Lysimeters Percent Cover

Lysimeter	Plant Cover (percent)	Bare (percent)	Gravel (percent)	Litter (percent)
Vegetated	35	15	50	0
Bare-Soil	0	10	80	10

The average soil water storage depth in the vegetated lysimeter from January 1, 1996, through December 31, 2019, was 119 mm (4.69 in.). This is equivalent to an average volumetric water content (VWC) of 6.0 percent. For the same period, the average soil water storage depth in the bare lysimeter was 212 mm (8.35 in.), which is equivalent to an average VWC of 10.6 percent. During 2019, the average soil water storage depth in the vegetated lysimeter was 129 mm (5.08 in.), and the average water storage depth in the bare lysimeter was 225 mm (8.86 in.). Rains in late winter and early spring promote plant growth, which removes water by ET. In summer, the vegetated lysimeter dries out and plant growth and ET both slow. Eventually, E from the bare lysimeter exceeds ET from the vegetated lysimeter in the summer due to the higher water content in the bare lysimeter.

No water has ever accumulated at the bottom of the vegetated lysimeter. Heavy precipitation during late fall and winter combined with low E rates and higher initial water contents may result in water accumulation at the bottom of the bare lysimeter. Suction of -8.0 kPa (-1.2 PSI) was applied to the porous suction candles on the bottom of the bare lysimeter on May 5–June 19, 2008; March 2–May 12, 2009; and February 3–April 27, 2010. No water effluent was collected from the suction candles during these periods. Long-term numerical simulations (30 years) using a unit gradient bottom boundary estimate the amount of drainage that would have occurred if water could drain from the lysimeters. These simulations indicate an average of 1 cm (0.4 in.) per year of water reaches the bottom of the bare lysimeter, and essentially no water reaches the bottom of the vegetated lysimeter (Desotell et al. 2006).

During 2019, E from the bare lysimeter was 163 mm (6.42 in.) and ET from the vegetated lysimeter was 175 mm (6.89 in.). Water content in the vegetated lysimeter increased during 2019 because annual ET from the vegetated lysimeter was less than the 223 mm (8.76 in.) of precipitation. Water content in the bare lysimeter increased during 2019 because the annual E from the bare lysimeter was less than the precipitation.

Figure 4-24 shows the cumulative precipitation (blue line) and the calculated cumulative ET (green line) and E (orange line) for the lysimeters during 2019. It also plots the storage in the vegetated lysimeter (purple line) and the storage in the bare lysimeter (red line). It shows that at the end of the year the ET and E was less than the precipitation and thus both lysimeters gained water in storage.

The first three months were wet, and starting in March and continuing through June, ET was high and exceeded E as plants grew. In July through the end of the year it was dry, and E was greater than ET as most available water was removed by ET earlier in the vegetated lysimeter. November was wet, but the plants were not able to remove the water through ET (Figure 4-25).

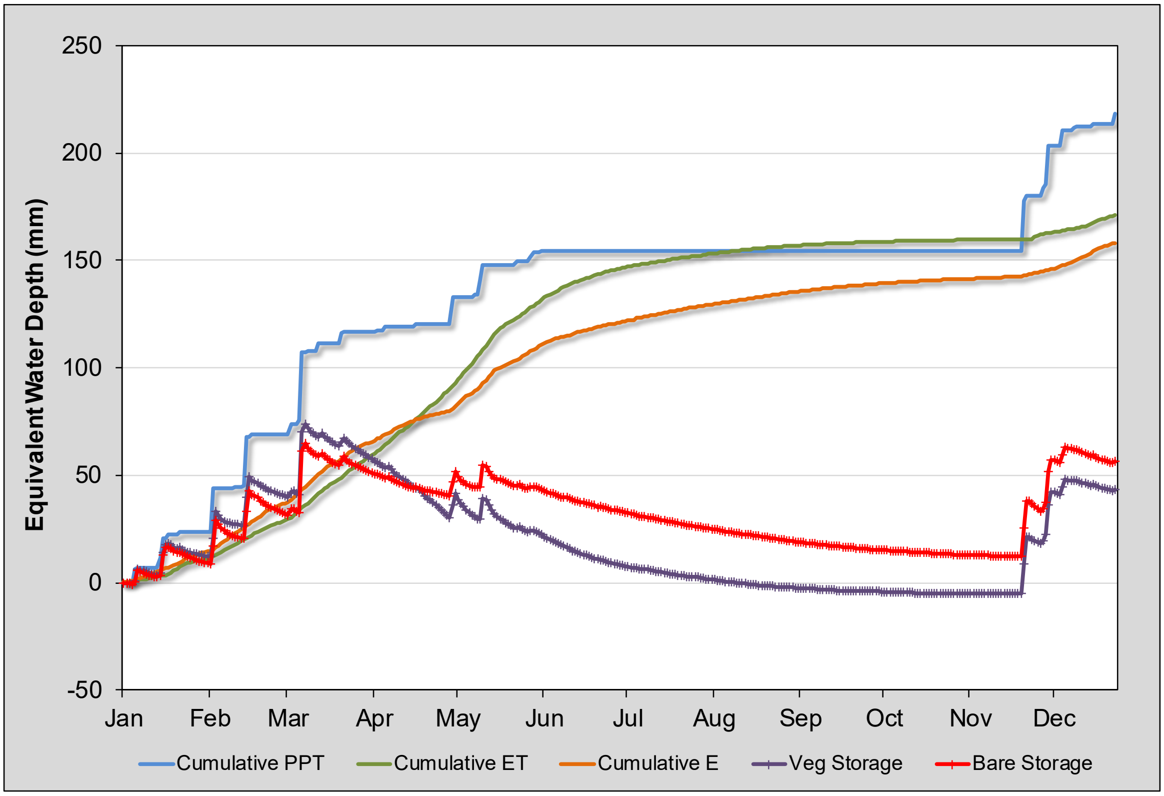

Figure 4-24. Precipitation, ET, E, and Storage for the Area 5 Weighing Lysimeters

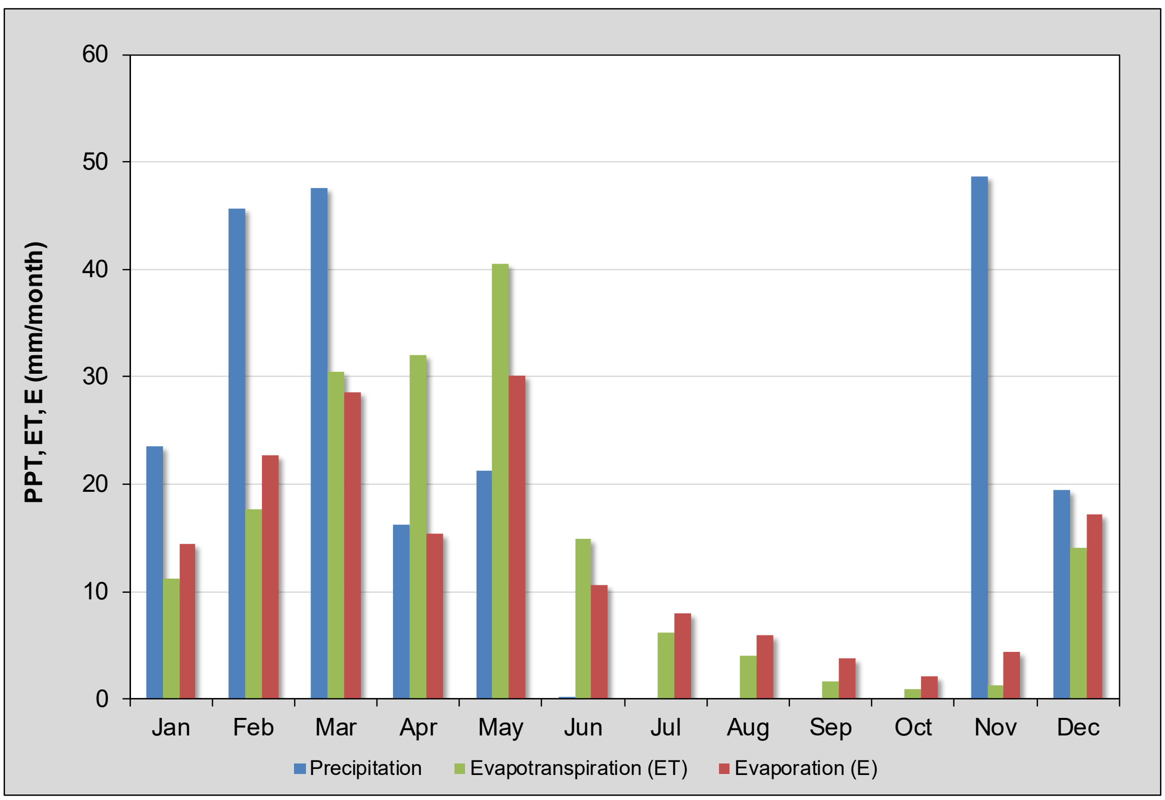

Figure 4-25. Monthly Precipitation, E, and ET at the Area 5 Weighing Lysimeters

4.6.3 Automated Waste Cover Monitoring System

In 1998, time-domain reflectometry (TDR) probes were buried 1.2 m (4.0 ft) beneath the floor of open Cell 5 at the Area 5 RWMS. The four probes are adjacent to the Cell 5N and Cell 5S monitoring locations. At each monitoring location, one probe is buried near the centerline and one probe is buried near the eastern edge (Figure 3-2). Approximately 4.4 m (14 ft) of waste and approximately 2.4 m (7.9 ft) of cover were placed above these probes during disposal. The depth of these probes is now approximately 7.9 m (26 ft).

Measured VWC in the floor of Cell 5 has remained constant at approximately 10 percent since measurements began in early 1999 (Figure 4-26). The near constant measured water content indicates that no moisture has percolated to 1.2 m (3.9 ft) below the waste. Data are missing in 2011 due to the construction of the final cover. Cell 5 also has a nest of probes in the cover above the waste in two locations. The original probes in the temporary cover above the waste were abandoned and left in place, and new probes were installed on the final cover in December 2011.

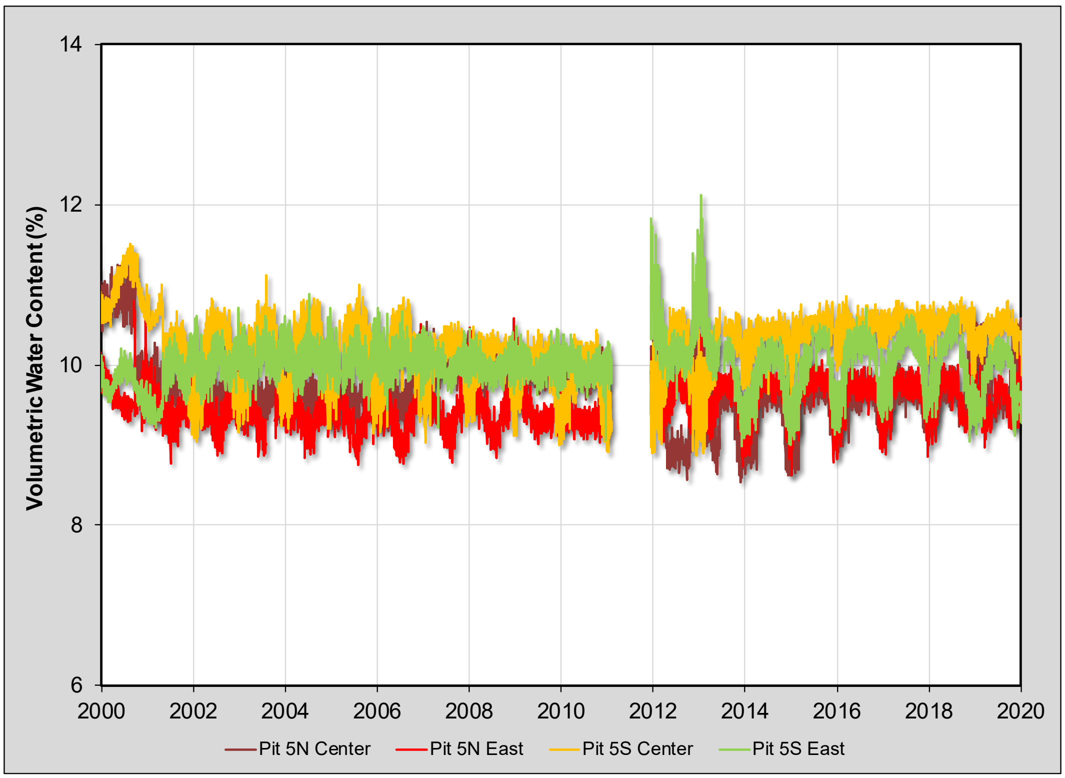

Figure 4-26. Soil Water Content in the Cell 5 Floor at the Area 5 RWMS

TDR probes were installed in the final covers of the 92-Acre Area after cover construction was completed. Moisture monitoring began at Cell 1, Cell 3W, Cell 5N, and Cell 5S by December 2011. Eight vertically arranged TDR probes were installed at each of four locations at depths ranging from 15 to 180 cm (5.9 to 71 in.). The measured VWC profiles are similar at the four locations. Measured VWC values for Cell 5N are shown in Figure 4-27. From January 2012 to June 2012, 97 mm (3.8 in.) of water was applied to help establish vegetation, and the VWC approached 10 percent. Once irrigation stopped, the VWC below 45 cm (18 in.) decreased and settled around 7 percent until late 2015. In 2015, precipitation events in July wetted the soil to 45 cm (18 in.) and in September, 46 mm (1.8 in.) of precipitation wetted the soil to 180 cm (71 in.), as shown by the slightly rising purple line.

The first 6 months of 2019 produced 143 mm (5.6 in.) of precipitation which is above normal and the furthest the water reached was 120 cm (47 in.) at Cell 5S. Cells 1, 3W, and 5N all had less infiltration. In November and December of 2019 there was 68 mm (2.6 in.) of total precipitation and the Cell 5N cover showed wetting only down to 45 cm (18 in.)

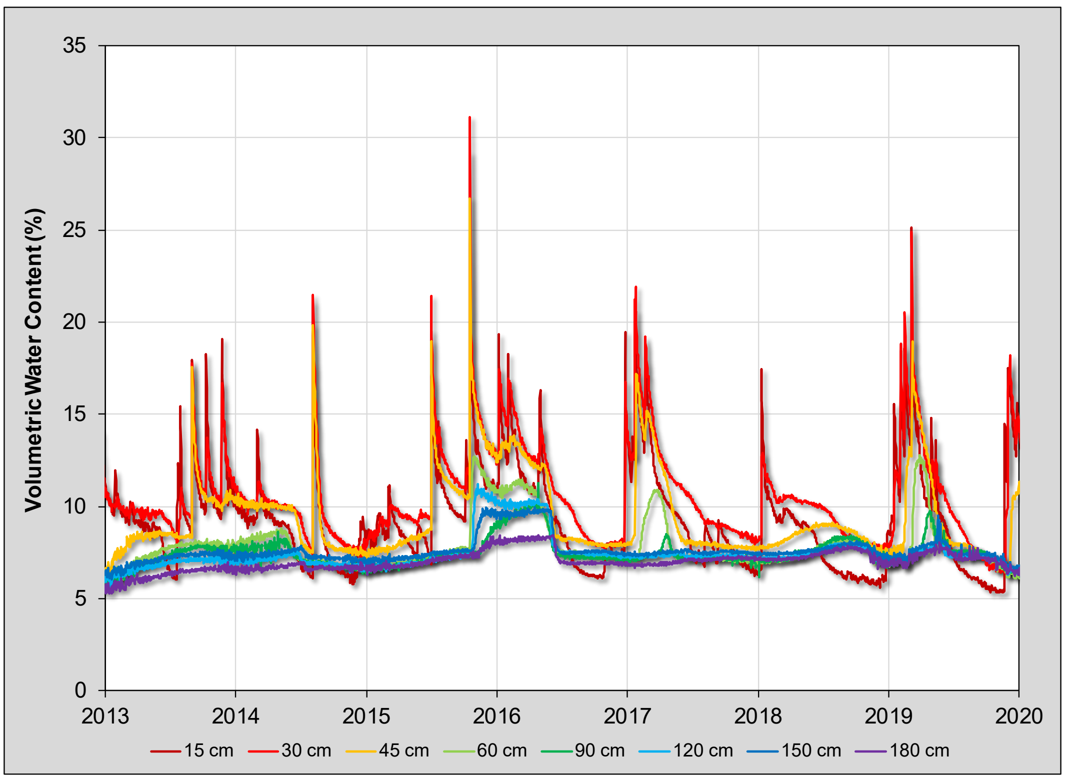

Figure 4-27. Soil Water Content in the 92-Acre Area Cover at Cell 5N at the Area 5 RWMS

In March 2018, three new vadose moisture monitoring stations were constructed on Cells 13, 17, and 20. The stations have three sensors, two TDR probes, and one heat dissipation probe buried at eight locations from 15 cm (5.9 in.) to 180 cm (71 in.), the same as the other existing stations. All three stations were collecting data by June 1, 2018. The final cover for these cells has not been installed as of the end of 2019. TDR probes in these three cells show water in the wet spring may have infiltrated to 120 cm (47 in.) on all three cell covers.

Four strontium-90 RTGs were disposed in Cell 5 on September 27, 2007. The power output of all four RTGs combined is approximately 450 watts. Area 5 RWMS disposal requirements are that RTG surface temperatures remain below 300°C (572°F), soil temperatures within 2.0 m (6.6 ft) of the surface remain less than 100°C (212°F), and temperatures in LLW adjacent to the RTGs stay below 38°C (100°F). Platinum resistance temperature detectors (RTDs) were installed to measure vertical and horizontal temperature profiles around each RTG. RTDs in the vertical profile were placed directly over the RTG up to 400 cm (13 ft) above the RTG. The top of the RTG is approximately 550 cm (18 ft) below the soil surface. RTDs in the horizontal profile were placed to the side of the same RTG up to 400 cm (13 ft) away from it. The RTDs in the horizontal profile are approximately 550 cm (18 ft) deep. Figure 4-28 provides the measurements from the vertical temperature profile above the RTG. Locations are given as the distance above the RTG followed by the depth from the soil surface in parentheses. Since about 2012, temperatures at the top of the RTD and approximately 550 cm (18 ft) below the ground surface have a seasonal fluctuation but stay below 110°C (230°F). Temperature measurements 270 cm (8.9 ft) above the RTG and approximately 280 cm (9.2 ft) below the ground surface are not affected by the heat flux from the RTGs.

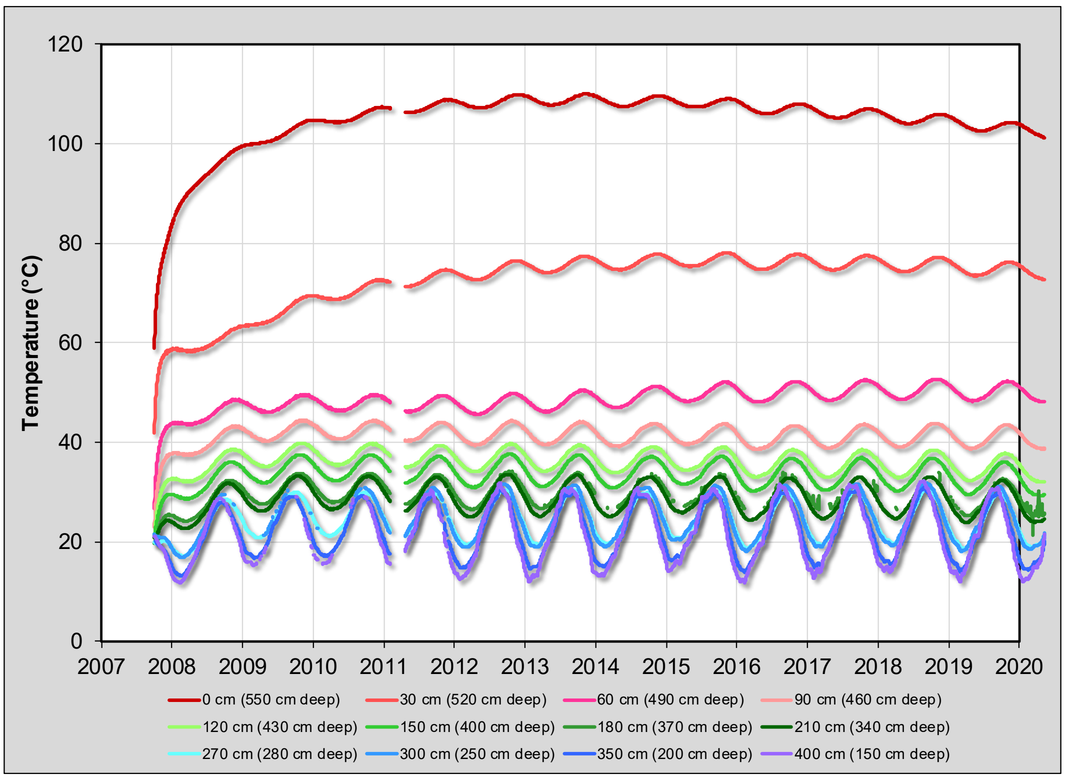

Figure 4-28. Temperatures above an RTG in Cell 5 at the Area 5 RWMS

In December 2000, TDR probes were installed during construction of the final vegetated cover of the U-3ax/bl waste disposal unit at the Area 3 RWMS (Figure 3-1). Eight vertically arranged TDR probes were installed at four locations at depths ranging from 30 to 240 cm (1.0 to 7.9 ft). Measured soil water content values for one location (West Nest B) in the U-3ax/bl waste cover are shown in Figure 4-29. From 2001 to 2010, the TDR data indicate that the soil water content in the cover generally decreased over time as the vegetation on the cover grew. A series of precipitation events in early 2010 caused wetting to 90 cm (3 ft), and another event in late 2010 caused wetting down to 120 cm (3.9 ft). Precipitation in late 2015 and into 2016 caused wetting down to 150 cm (4.9 ft), as shown by the green line in Figure 4-30 reaching 15 percent VWC. 2019 was a wet year, and wetting may have reached down to 120 cm (3.9 ft). The annual variation is most likely a temperature effect.

Vegetation is critical to the effectiveness of the U-3ax/bl cover. In the native environment, about 12 percent of the surface area is covered by plant material. Obtaining 12 percent vegetative cover on the soil caps is dependent upon the seed germination success and seedling survival of native plants seeded or transplanted onto the cover. The dominant perennial plant on the U-3ax/bl cover is *Atriplex confertifolia* (shadscale saltbush), which accounted for 12.2 percent of the vegetation cover in 2014.

A qualitative assessment of the vegetation on CAU 110, U3-ax/bl closure cover was made on September 4, 2019. The vegetative cover appears to be stable and in very good condition. The plants on the cap showed good growth in 2019 with many producing seed because of the increase in precipitation. Some dead shadscale saltbush plants were observed, but this is to be expected as the plant community matures and due to the drought a few years ago. No perennial plant seedlings were observed, which might be an issue. The annual forb component of the plant community was surprisingly low this year considering the above-normal precipitation. The area surrounding the cover, which was not seeded, continues to be covered with noxious weeds, primarily *Halogeton glomeratus* (saltlover), which highlights the importance of seeding to establish a perennial plant community.

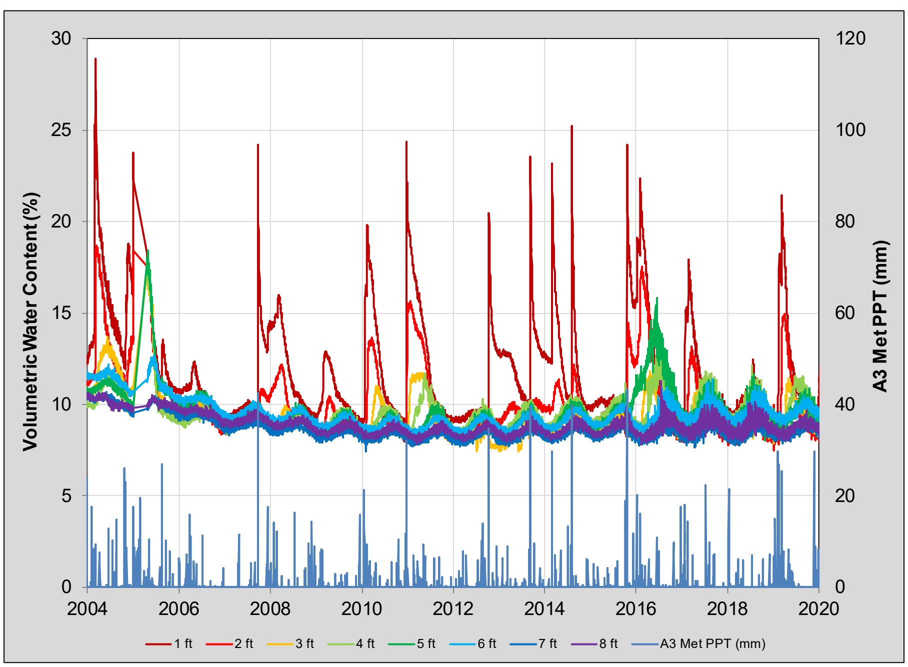

Figure 4-29. Soil Volumetric Water Content in the U-3 ax/bl Cover at the Area 3 RWMS

4.6.4 Area 3 Drainage Lysimeter Facility

The Area 3 Drainage Lysimeter Facility is immediately northwest of the U-3ax/bl waste disposal unit at the Area 3 RWMS (Figure 3-1). This facility is designed to collect saturated gravity drainage from eight lysimeters measuring 3.1 m (10 ft) in diameter by 2.4 m (7.9 ft) deep. The lysimeters are filled with native soil packed to mimic the U-3ax/bl soil cover. Each lysimeter has eight TDR probes to measure moisture content depth profiles, paired with eight heat dissipation probes to measure soil water potential depth profiles. The probes are installed at 7.0 cm (0.23 ft), 15 cm (0.50 ft), 30 cm (1 ft), 60 cm (2 ft), 90 cm (3 ft), 120 cm (4.0 ft), 180 cm (6.0 ft), and 240 cm (8.0 ft) deep. Measured water content values at the bottom of the lysimeters and drainage from the lysimeters provide an indirect measure of potential drainage from the U-3ax/bl soil cover. The lysimeter facility was constructed to provide data needed to reduce uncertainty in the expected performance of monolayer ET closure cover under various surface vegetation treatments and increased rainfall.

There are three surface vegetation treatments subject to two climate treatments on the lysimeters. The three surface vegetation treatments are bare-soil, invader species (primarily *Bromus tectorum* [cheatgrass], *Halogeton glomeratus* [halogeton], and *Eriogonium deflexum* [flatcrown buckwheat]), and native species (primarily *Krascheninnikovia lanata* [winterfat], *Ephedra nevadensis* [Nevada jointfir], and *Elymus elymoides* [squirreltail grass]). The climate treatments are natural precipitation and three times natural precipitation. The three times natural precipitation lysimeters receive natural precipitation and are irrigated with an amount equal to two times natural precipitation.

The 2019 lysimeter treatments, precipitation, irrigation, and drainage are summarized in Table 4-5. The eight lysimeters are identified as Lysimeter A through Lysimeter H. Lysimeter A is bare-soil with natural precipitation; Lysimeter B is bare-soil with three times natural precipitation; Lysimeter C is invader species with natural precipitation; Lysimeter D is invader species with three times natural precipitation; Lysimeters E and G are native species with natural precipitation; and Lysimeters F and H are native species with three times natural precipitation.

The 2019 precipitation at the drainage lysimeters was 244 mm (9.61 in.). The 2019 irrigation applied to Lysimeters B, D, F, and H was 433 mm (17.0 in.). The actual applied irrigation in 2019 was 56 mm (2.2 in.) short of the three times natural precipitation goal. The actual rate was 2.8 times natural precipitation. There were 2,820 liters (745 gallons) of drainage from Lysimeter B during 2019. The equivalent depth of this drainage is 386 mm (15.2 in.). Drainage from Lysimeter B started on February 7, 2019, and continued through December 31, 2019. The 2019 Lysimeter B drainage was 57 percent of total 2019 precipitation and applied irrigation.

There were 103 liters (27.2 gallons) of drainage from Lysimeter D during 2019. The equivalent depth of this drainage is 14 mm (0.55 in.). Drainage from Lysimeter D started on March 16, 2019, and continued through April 28, 2019. The 2019 Lysimeter B drainage was 2 percent of total 2019 precipitation and applied irrigation.

There was no drainage from any other lysimeter during 2019. Drainage has only occurred from the irrigated lysimeters. Total cumulative drainage from the beginning of the measurements for each irrigated lysimeter is 247 cm (97.2 in.) from Lysimeter B, 18.8 cm (7.41 in.) from Lysimeter D, 28.4 cm (11.2 in.) from Lysimeter F, and 11 cm (4.3 in.) from Lysimeter H (Figure 4-30).

Plant cover was measured for each of the eight drainage lysimeters on May 20, 2019. The results are summarized in Table 4-6. On April 26, 2018, six *Atriplex canescens* (four-wing saltbush) were purchased from the Nevada Division of Forestry. Three were planted on Lysimeter E, two were planted on Lysimeter F, and one was planted on Lysimeter H. All six transplants survived and were growing when this report was completed.

Table 4-5. Area 3 Drainage Lysimeter Treatments in 2019

Lysimeter	Climate	Surface Vegetation	Precipitation and Irrigation (mm [in.])	Drainage (mm [in.])	Drainage (%)
A	Natural precipitation	Bare-soil	244 (9.61)	0 (0)	0
B	Three times natural precipitation	Bare-soil	678 (26.7)	386 (15.2)	13
C	Natural precipitation	Invader species	244 (9.61)	0 (0)	0
D	Three times natural precipitation	Invader species	678 (26.7)	14 (0.55)	2
E	Natural precipitation	Native species	244 (9.61)	0 (0)	0
F	Three times natural precipitation	Native species	678 (26.7)	0 (0)	0
G	Natural precipitation	Native species	244 (9.61)	0 (0)	0
H	Three times natural precipitation	Native species	678 (26.7)	0 (0)	0

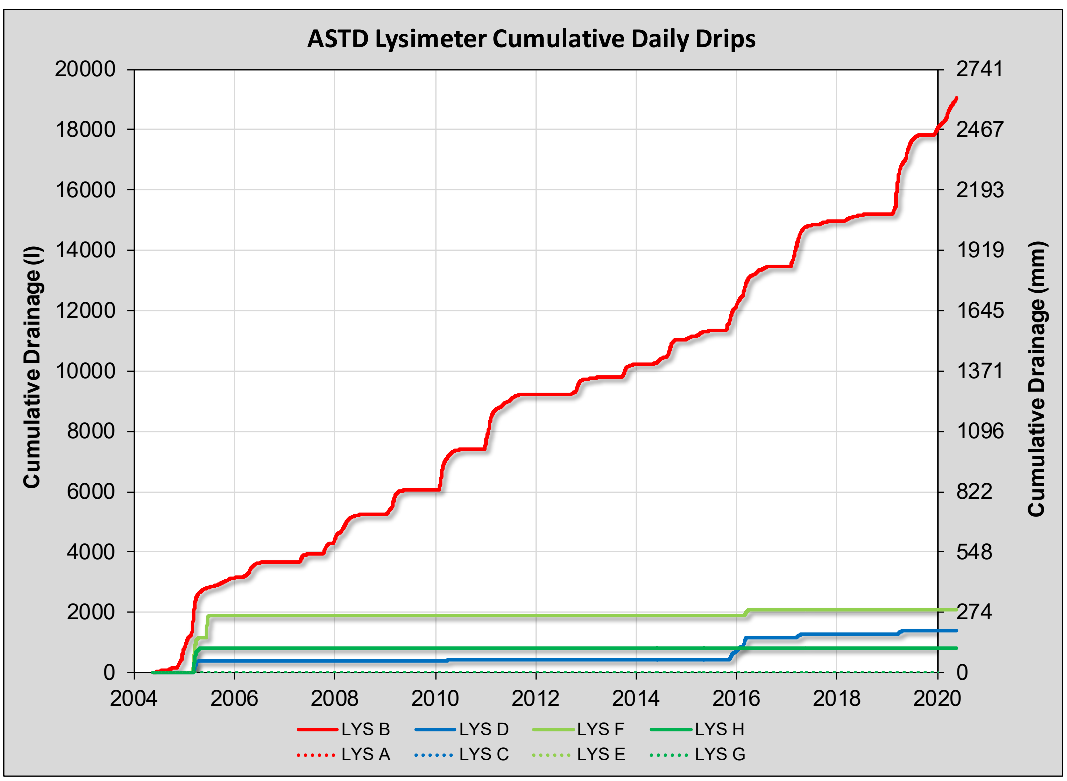

Figure 4-30. Cumulative Drainage from the Area 3 Drainage Lysimeters

Table 4-6. Area 3 Drainage Lysimeter Percent Cover in 2019

Lysimeter	Plant Cover (percent)	Bare (percent)	Gravel (percent)	Litter (percent)
A	2.5	40.0	52.5	5.0
B	0.0	12.5	70.0	17.5
C	32.5	35.0	30.0	2.5
D	62.5	12.5	12.5	12.5
E	62.5	22.5	7.5	7.5
F	85.0	2.5	0.0	12.5
G	67.5	7.5	5.0	20.0
H	80.0	10.0	2.5	7.5

Figure 4-31 shows the total water storage for all eight lysimeters from 2009 through 2019. Water storage is calculated using TDR data. The two bare-soil lysimeters (Lysimeters A and B, blue lines) generally have the highest water storage. Evaporation and drainage are the only processes that remove water from these two lysimeters. The invader species (Lysimeters C and D, green lines) grow quickly in the spring, have shallow root systems, and transpire water before setting seed and dying in the early summer. The native species (Lysimeters E, F, G, and H, red and gold lines) mostly consist of perennial shrubs that grow year round and have deep, dense root systems that survive during periods of drought.

The end of 2018 and the start of 2019 was very wet. Of the three times precipitation lysimeters, it appears Lysimeter D and F (light green and light red lines) performed similarly, but Lysimeter D had drainage, so the native plants on Lysimeter F with deep roots removed water, where the invasive species on Lysimeter D did not. Lysimeter H (light gold line) had even less storage, and that may be accounted for in that the plants on Lysimeter H are older and more established than on Lysimeter F. Lysimeter A (heavy blue line), the bare lysimeter with normal precipitation, consistently has storage levels above the three times precipitation lysimeters with plants and would likely percolate downward if not for the bottom in the lysimeter, but it is not enough to drain.

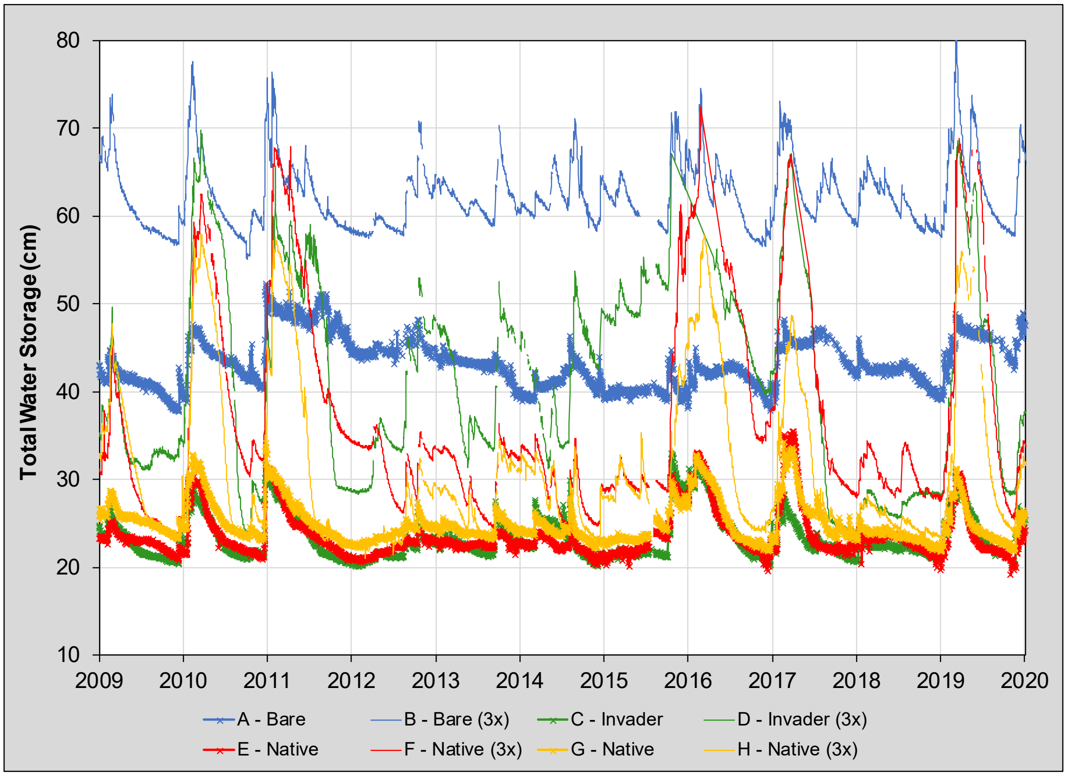

Figure 4-31. Soil Water Storage in the Drainage Lysimeters

4.7 WASTE COVER SUBSIDENCE

Subsidence monitoring is conducted to ensure that subsidence features are repaired to prevent the development of preferential water migration pathways through the waste covers and also to help ensure that vadose zone monitoring data are representative of the Area 3 and Area 5 RWMSs. Typically, as small depressions or cracks are observed in operational covers, they are filled before large subsidence features develop.

Visual inspections of the U-3ax/bl final ET cover were changed from quarterly in 2015 to twice per year in 2016 and checked for evidence of cracks, settling, erosion, and subsidence. Inspections were performed on June 13 and December 18, 2019. During the June inspection, two areas of subsidence were noted and repaired on August 7, 2019. During the December inspection, three areas of subsidence were noted and repaired on February 25, 2020.

Seven subsidence markers were installed in the U-3ax/bl cover, and an initial elevation survey of these markers was completed in December 2000. Subsidence surveys were performed twice a year through March 2012, and the interval was increased to every 2 years after the March 2012 survey (U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office 2014). In 2018 the average subsidence at the 7 subsidence markers was 1.9 cm (0.75 in.), and the median subsidence was 1.5 cm (0.59 in.). A subsidence survey was not required in 2019.

Quarterly inspections of the 92-Acre Area final ET covers include checking for evidence of cracks, settling, erosion, and subsidence. This covers are also inspected when more than 25 mm (1.0 in.) of precipitation occurs during a 24-hour period. Quarterly inspections were performed on March 12, June 13, September 12, and December 18, 2019. During the March inspection, subsidence and animal burrows was noted on four covers and repaired on May 14, 2019. During the June inspection, subsidence was noted on two covers and repaired on August 7, 2019. During the September inspection, subsidence cracks was noted on three covers and repaired on November 25, 2019. During the December inspection, subsidence cracks was noted on three covers and repaired on February 4, 2020.

Fifty-two subsidence markers were installed in the 92-Acre Area covers, and an initial elevation survey of these markers was completed in January 2012. Subsidence was measured at each marker in May 2019. The average subsidence at the 52 subsidence markers was 1.8 cm (0.70 in.), and the median subsidence was 0.91 cm (0.36 in.).

4.8 BIOTA MONITORING DATA

Plants, animals, and soil excavated by ants or small mammals sampled on top of waste covers may be used to assess the integrity of radioactive waste containment. No biota samples were collected in 2019.

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5.0 CONCLUSION

The 2019 environmental and operational monitoring data from the Area 3 and Area 5 RWMSs indicate that these facilities are performing as expected for the long-term isolation of buried waste. Direct radiation exposure data indicate a rate that is well below any dose of concern, and air monitoring data indicate that concentrations of radioactive materials in air remain below concentrations of concern. Groundwater and vadose zone monitoring data indicate that the groundwater beneath the Area 5 RWMS is unaffected by the waste disposal operations. Vadose zone monitoring data indicate that vegetation prevents infiltrating precipitation from percolating deep into the soil by returning the moisture to the atmosphere by ET. Long-term vadose zone monitoring data from the weighing lysimeters indicate no drainage through the bottoms of the vegetated lysimeters. All 2019 monitoring data indicate that the Area 3 and Area 5 RWMSs are performing within expectations of the model and parameter assumptions for the facilities' PAs.

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