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NEVADA NATIONAL SECURITY SITE
2016 WASTE MANAGEMENT MONITORING REPORT
AREA 3 AND AREA 5 RADIOACTIVE WASTE
MANAGEMENT SITES

August 2017

Prepared for:

U.S. Department of Energy
National Nuclear Security Administration
Nevada Field Office

Prepared by:

National Security Technologies, LLC
Las Vegas, Nevada

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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). These data include direct radiation exposure, as well as radiation from the air, groundwater, meteorology, and vadose zone. This report summarizes the 2016 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 (National Security Technologies, LLC, 2016; 2017a; 2017b).

Direct radiation monitoring data indicate exposure levels at the 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 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 were all below established investigation levels. Leachate samples collected from the leachate collection system at the mixed low-level waste cell were below established contaminant regulatory limits. During 2016, precipitation at the Area 3 RWMS was 8% below average, and precipitation at the Area 5 RWMS was 8% above average. Water balance measurements indicate that evapotranspiration from the vegetated weighing lysimeter dries the soil and prevents downward percolation of precipitation more effectively than evaporation as measured from the bare-soil weighing lysimeter. Vadose zone monitoring on Area 5 and Area 3 RWMS cell covers shows no evidence of precipitation percolating through the covers to the waste. Moisture from precipitation did not percolate below 150 centimeters (cm) (5 feet [ft]) in the vegetated final cover on the U-3ax/bl disposal unit at the Area 3 RWMS. During 2016, 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. Forty-four percent of the applied precipitation and irrigation drained from the bare-soil drainage lysimeter, which received 3 times the natural precipitation.

All 2016 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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LIST OF ACRONYMS AND ABBREVIATIONS

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	degrees Celsius
CAU	Corrective Action Unit
CFR	Code of Federal Regulations
cm	centimeter(s)
Cs	cesium
DCS	Derived Concentration Standard
DOE	U.S. Department of Energy
E	evaporation
EPA	U.S. Environmental Protection Agency
ET	evapotranspiration
ET_{ref}	reference evapotranspiration
°F	degrees Fahrenheit
ft	foot; feet
ft^3	cubic feet
GCD	greater confinement disposal
g/m^3	gram(s) per cubic meter
HDPE	high-density polyethylene
IL	investigation level
in.	inch(es)
km	kilometer(s)
kPa	kilopascal(s)
lb/A	pound(s) per acre
LLW	low-level waste
µg/L	microgram(s) per liter
m	meter(s)
m^3	cubic meter(s)
m/s	meter(s) per second
MDC	minimum detectable concentration
MEDA	Meteorological Data Acquisition
mg/L	milligram(s) per liter
mi	mile(s)

MLLW	mixed low-level waste
mm	millimeter(s)
mmhos/cm	millimho(s) per centimeter
mph	mile(s) per hour
mR	milliroentgen(s)
mR/yr	milliroentgen(s) per year
mrem	millirem(s)
mrem/yr	millirem(s) per year
NNSA/NFO	U.S. Department of Energy, National Nuclear Security Administration Nevada Field Office
NNSA/NSO	U.S. Department of Energy, National Nuclear Security Administration Nevada Site Office
NNSS	Nevada National Security Site
NSTec	National Security Technologies, LLC
PA	performance assessment
PCB	polychlorinated biphenyls
pCi/L	picocurie(s) per liter
pCi/m^3	picocurie(s) per cubic meter
pCi/m^2/s	picocurie(s) per square meter per second
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(s)
RTG	radioisotope thermoelectric generator(s)
RWMS	Radioactive Waste Management Site
SC	specific conductance
Sr	strontium
TDR	time-domain reflectometry
TLD	thermoluminescent dosimeter
TOC	total organic carbon
TOX	total organic halides
VWC	volumetric water content

1.0 INTRODUCTION

This document summarizes the calendar year 2016 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 location, setting, 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 defined below:

- Direct radiation monitoring conducted to confirm that RWMS activities do not result in significant exposure above background levels
- Air monitoring conducted 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 conducted, as required by U.S. Environmental Protection Agency (EPA) 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 conducted 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 monolayer-evapotranspirative waste covers
- Subsidence monitoring conducted to assess waste cover stability
- Biota monitoring to assess the engineered, planted, vegetated, final cover on closed waste cells and to evaluate the upward biological pathway for radionuclides

These data are collected by NSTec, 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). These regulatory drivers exist to mitigate risk to the public and the environment and include the following:

- 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 what and how technically defensible environmental monitoring data are collected.

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 (10 mi). Yucca Flat is bound 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 (3,900 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 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 is 4°C (40°F), and the average summer temperature is 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 is 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 has 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 has 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 56-year period from 1961 through 2016 is 160.0 millimeters (mm) (6.30 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).

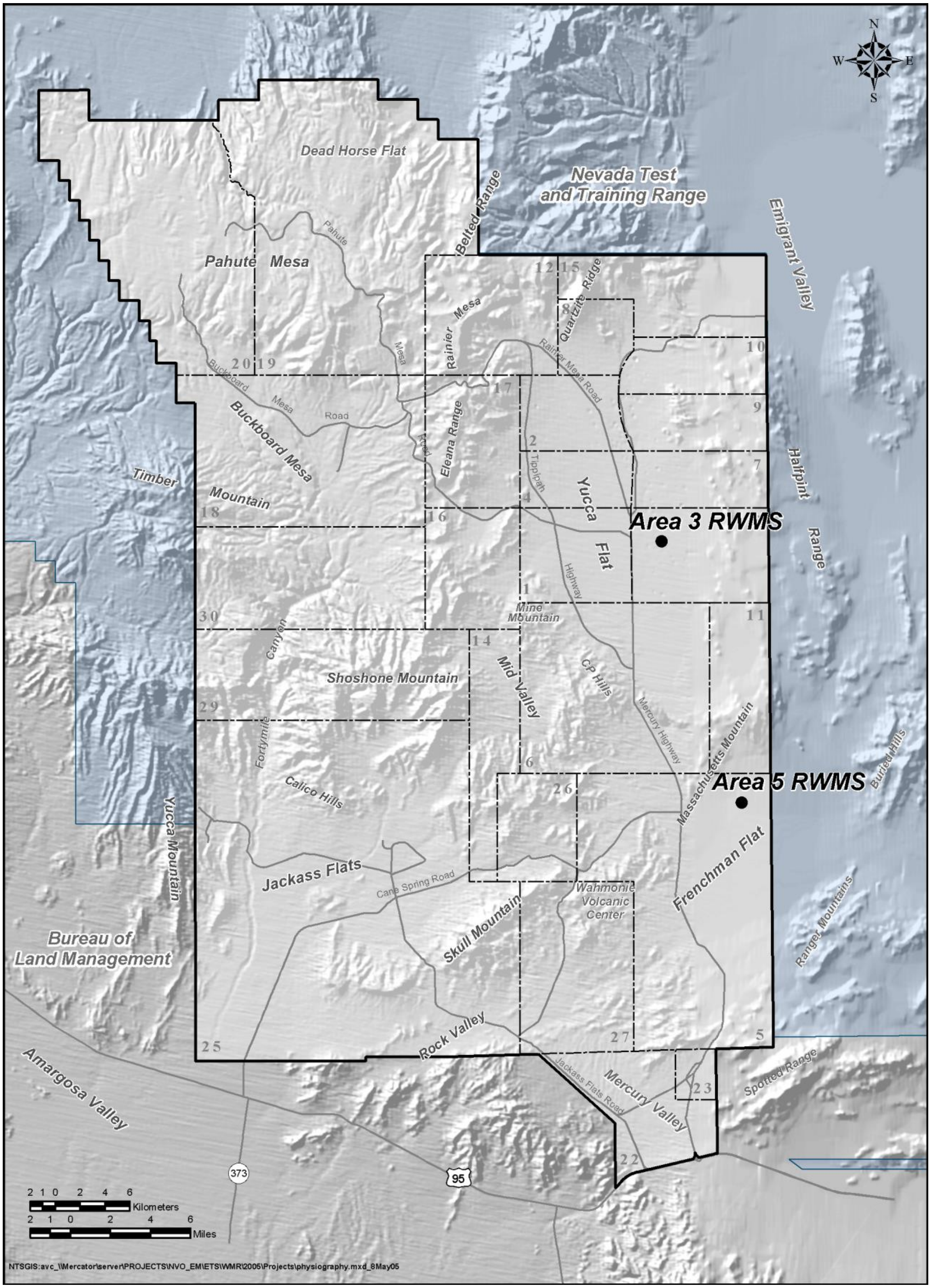

Figure 2-1. Location of the Area 3 and Area 5 RWMSs

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 bound 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 m (3,077 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 962 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 0.1 m/year (0.33 ft/year). The average groundwater elevation measured at these wells in 2016 is 733.6 m (2,407 ft) AMSL.

Based on a 21-year record from 1981 to 2001 at location Well 5B (6.4 km [4 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 is 5°C (41°F), and the average summer temperature is 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 is 46% at 4:00 PST, 25% at 10:00 PST, 20% at 16:00 PST, and 37% at 22:00 PST. January has 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 has 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 53-year period from 1964 through 2016 is 123.0 mm (4.84 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, except for slight differences in air temperature, precipitation, and soil texture. Area 3 receives approximately 30% 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 MODEL OF THE AREA 3 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 extends to depths from approximately 3 to 49 m (10 to 161 ft) in Area 3, and from approximately 3 to 40 m (10 to 131 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 between approximately 49 and 119 m (161 to 390 ft) deep in Area 3, and between approximately 40 and 90 m (131 to 295 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% of the annual rainfall at Area 5, based on one-dimensional modeling results (Desotell et al., 2006).

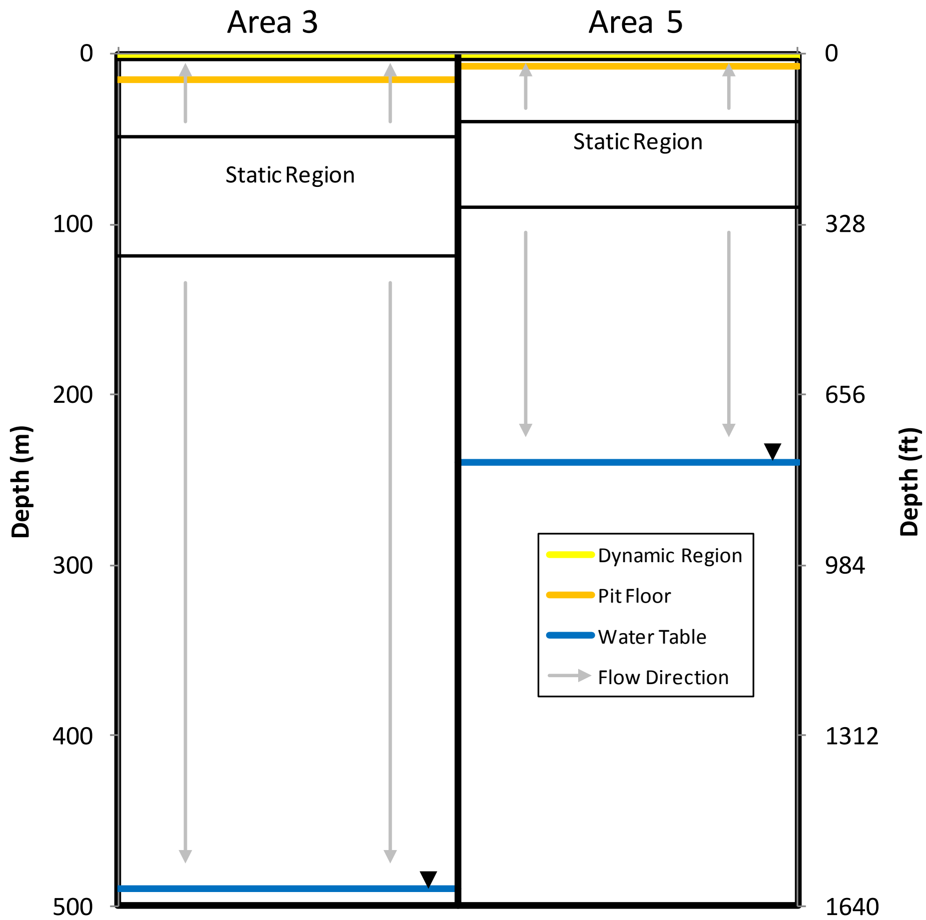

Figure 2-2. Vadose Zone Conceptual Models of the Area 3 and Area 5 RWMSs

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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 (126 acres). The area enclosed by a fence is used for waste disposal operations and covers approximately 49 hectares (121 acres). 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 105 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 are operational and can accept unclassified LLW but have not received any waste since 2006. U-3bh was originally used for disposal of contaminated soils from the Tonopah Test Range during 1997 and was later used for waste disposal 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-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 between the Nevada Division of Environmental Protection and DOE. 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. For details of the closure of CAU 110, refer to U.S. Department of Energy, Nevada Operations Office (2000; 2001) and BN (2001).

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

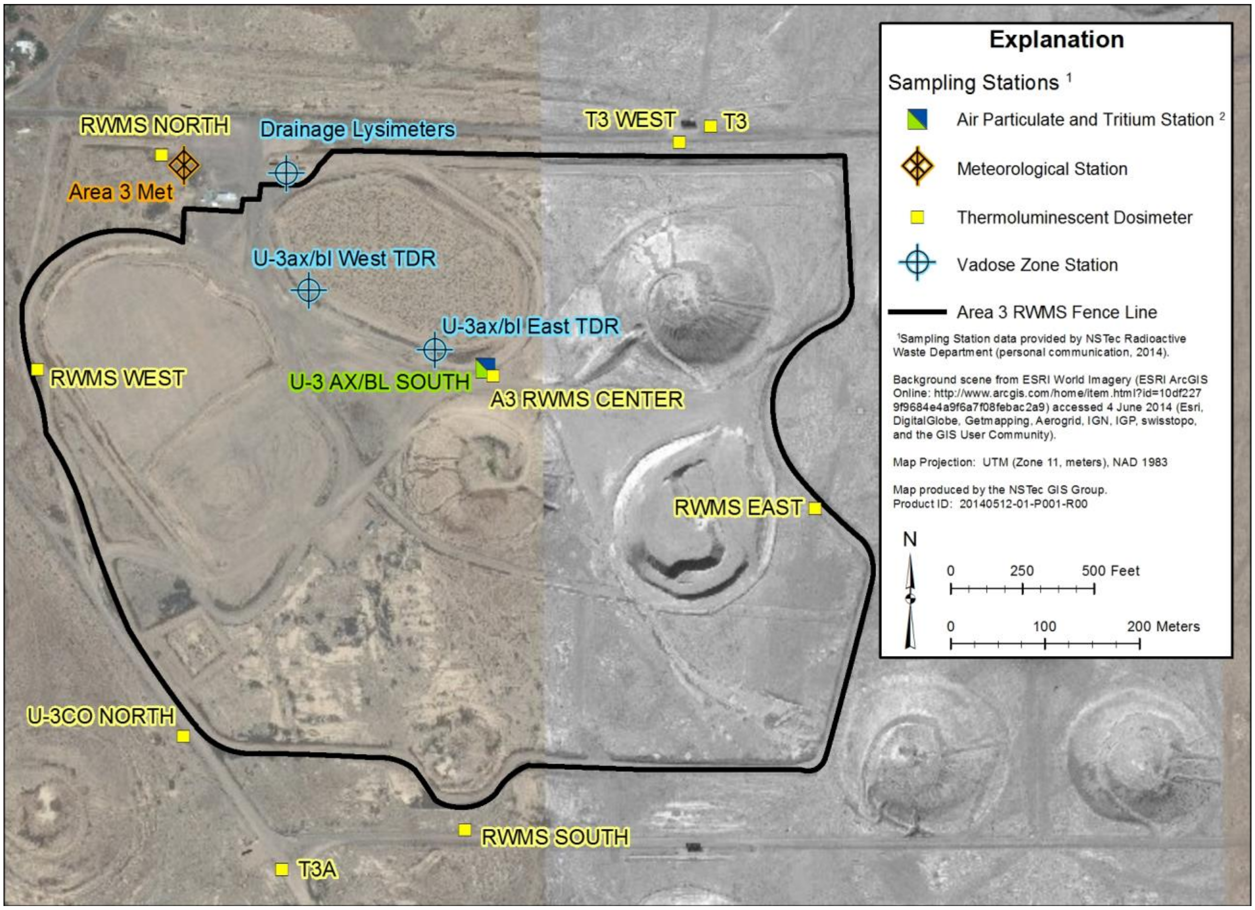

Figure 3-1. Monitoring Locations at the Area 3 RWMS

3.2 AREA 5 RWMS

The Area 5 RWMS (NNSS Area 5A) covers approximately 300 hectares (741 acres) with approximately 100 hectares (247 acres) 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) was built with a RCRA-compliant double liner and leachate collection system over a geosynthetic clay liner. All other cells are unlined. GCD boreholes are 36 m (118 ft) deep, 3 to 3.7 m (10 to 12 ft) diameter uncased boreholes.

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 complex 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 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 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 2016, waste was disposed in seven cells at the Area 5 RWMS: P18, P19, P20, P21, P22, P27, and T13. No waste was disposed of in P14 and P17 in 2016 and P28, a new cell, was opened. All active cells contain LLW, and P18 also contains MLLW.

The approximately 92-Acre Area in the southern portion of the Area 5 RWMS was permanently closed by constructing an engineered, monolayer, vegetated evapotranspiration (ET) cover with a minimum 2.5 m (8.2 ft) thickness over the waste cells. The 92-Acre ET cover 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, CGD-04, GCD-05, GCD-06, GCD-07, GCD-08, GCD-09, GCD-10, GCD-11, and GCD-12); and the CWI Trenches. P26 was also closed by the ET cover, but it is completely within P03. Four cells outside the 92-Acre Area (P08, P10, P12, and P15) are operationally inactive.

After grading and soil preparation was completed, the cover surface was disked and 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 cover, 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 [NNSA/NSO], 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 cover by sampling forty 100-m (328-ft) transects. Successful establishment of the seeded species was very low, and there were very high concentrations of invasive weed species (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 cover.

The 92-Acre site comprises three areas separated by drainage channels and access roads. The three areas are designated as the North Cover, the South Cover, and the West Cover. The first remedial trial was done on the northern section of the North Cover with planting in October 2013. Results indicated that broadcast seeding may be the preferred method of seeding and that it is questionable whether mulching provides benefit. It was also noted that the impact of rabbits grazing on the new seedlings will be 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 the germination of the creosote seed. A total of 107 mm of irrigation was provided along with 37 mm of natural precipitation for a total of 144 mm, just less than the 174 mm 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 done and there were only a few *Atriplex canescens* [four-wing saltbush] from earlier seeding and no newly seeded species showed up in the sampling along several 100-m transects. It is presumed the young seedlings seen in March were eaten by rabbits that were observed inside the fence and also evidenced by the number of rabbit pellets documented in the March inspection. The only species observed on the June survey were of Russian thistle and halogeton. These two weed species covered 34% of the irrigated sites and 2% 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 done; it was noted that no new four-wing saltbush plants were growing, but the ones seen from the previous survey were still there and continue to grow.

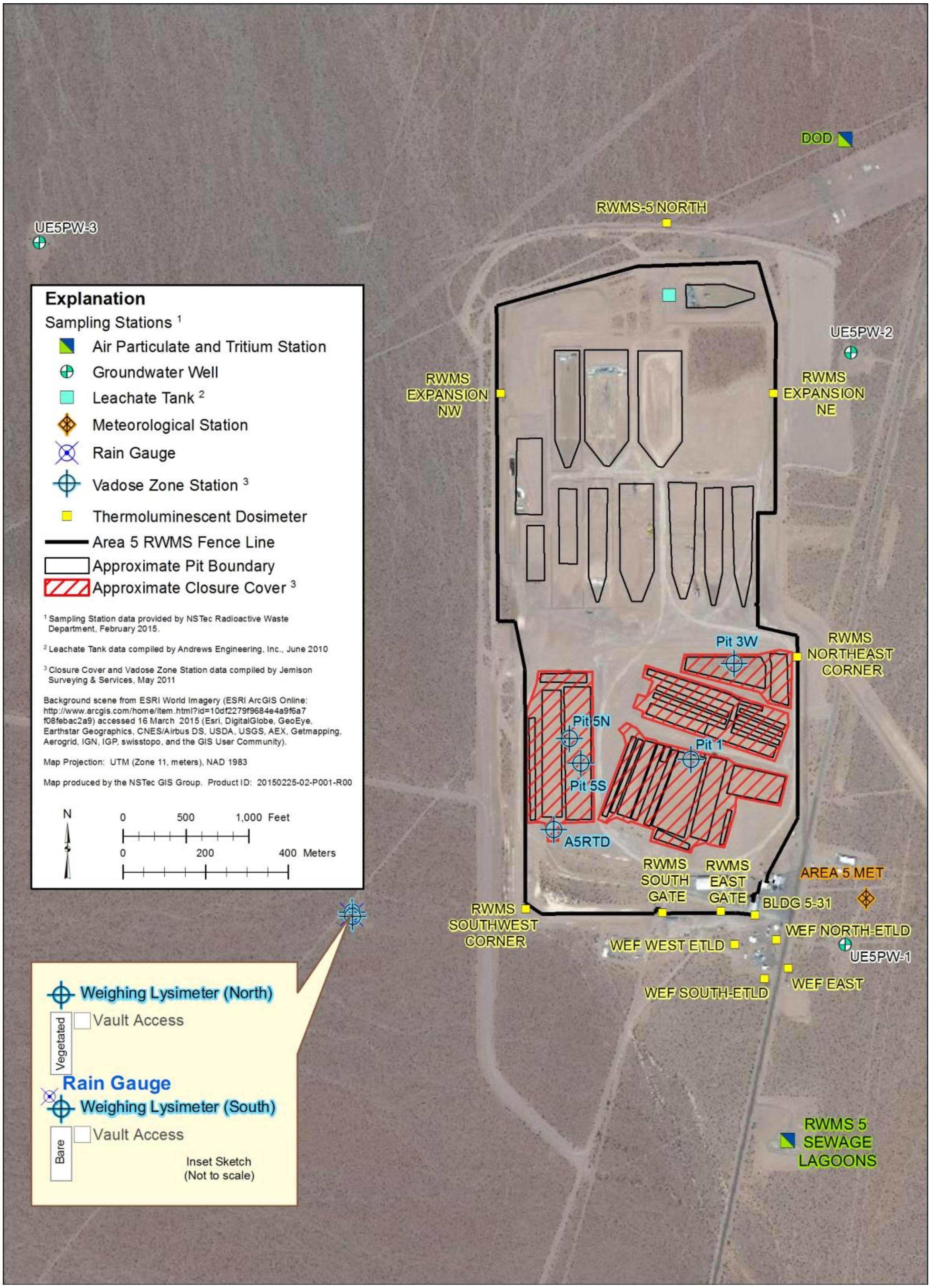

Figure 3-2. Monitoring Locations at the Area 5 RWMS

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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—gamma-emitting radionuclides, americium (Am), and plutonium (Pu) concentrations
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 and 9.5 m • Relative humidity at 3.0 m and 9.5 m • Vapor pressure at 3.0 and 9.5 m • Wind speed and direction at 3.0 and 9.5 m • Barometric pressure • Precipitation—hourly, daily, and 5-minute rate • Solar radiation • Energy balance for ET calculation—net solar radiation, soil heat flux, soil temperature, soil water content

Vadose Zone	• Drainage lysimeters
	  ○ 8 lysimeters at 1 location
	  ○ 3 vegetation treatments (bare soil, invader species, and native species) with 2 irrigation treatments (precipitation and 3-times precipitation)
	  ○ 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 for tritium and radionuclides • Annual plant density and plant cover measurements for drainage lysimeters • Plant density and plant cover measurements for the U-3ax/bl cover every five years
Subsidence	• 8 surveyed subsidence monuments on U-3ax/bl cover with 2-year measurement interval • Cover inspections at 3-month interval

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

Monitoring	Description
Radiation Exposure	• 3-month measurement interval at 12 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—gamma-emitting radionuclides, Am, and Pu concentrations
Radon Flux	• Periodic radon flux measurements • Various locations on waste covers
Groundwater	• 3 wells surrounding Area 5 RWMS • Water level measurement at 3-month interval • Groundwater samples at 6-month interval • Analysis for indicators of contamination—Field measurements of pH and specific conductance (SC), total organic carbon (TOC), total organic halides (TOX), and tritium • Analysis of water chemistry—calcium, magnesium, potassium, sodium, iron, manganese, sulfate, chloride, fluoride, and silicate • Alkalinity • Chemical analysis of P18 MLLW disposal cell leachate • Sampling and analysis when leachate collection tank is full
Meteorology	• Daily and hourly measurements at 1 location • Air temperature at 3.0 m and 9.5 m • Relative humidity at 3.0 m and 9.5 m • Vapor pressure at 3.0 and 9.5 m • Wind speed and direction at 3.0 and 9.5 m • Barometric pressure • Precipitation—hourly, daily, and 5-minute rate • Solar radiation • Energy balance measurements for ET calculation—net solar radiation, soil heat flux, soil temperature, soil water content

Vadose Zone	• 2 weighing lysimeters—bare soil and vegetated at 1 location
	    ○ Direct measurement of ET
	    ○ Daily water content, water potential, and temperature profiles at each lysimeter
	• Daily water content, water potential, and temperature profiles in 92-Acre Area cover at 4 locations
	• Daily water content below closed disposal cell at 4 locations
	• Soil temperature around radioisotope thermoelectric generators (RTGs)

Biota	• Periodic sampling of vegetation, small mammals, and animal burrow spoils for tritium, and particulate radionuclides • Annual plant density and plant cover measurements on each weighing lysimeter and the 92-Acre Area cover
Subsidence	• 52 surveyed subsidence monuments on the 92-Acre Area cover at 1-year measurement interval • Quarterly subsidence inspections

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,” (U.S. Department of Energy ,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 millirem 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. 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 RWMS.

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. 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. A pair of TLDs is placed 1 ± 0.3 m (28 to 51 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 NSTec Radiological Control Department. Reference TLDs exposed to 100 milliroentgen (mR) from a cesium-137 (^{137}Cs) radiation source under controlled conditions are used to scale the response of the measurement TLDs. Direct radiation exposure is usually reported in the unit 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 boundary. Fourteen of these tests were atmospheric tests, which left 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 2016 at nine locations inside and near the Area 3 RWMS range from 126 to 303 mR/yr (Figure 4-1). The Area 3 monitoring locations are (1) inside the Area 3 RWMS (RWMS Center), (2) on the RWMS boundary (RWMS North, RWMS East, RWMS South, RWMS West), and (3) 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 are within the range of background exposures.

The four TLD locations outside the Area 3 RWMS boundary and RWMS South (boundary location) 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/day from the quarterly exposure rate data at the Area 3 RWMS are 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 are within the range of background levels measured on the NNSS.

Comparisons of 2006 to 2016 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).

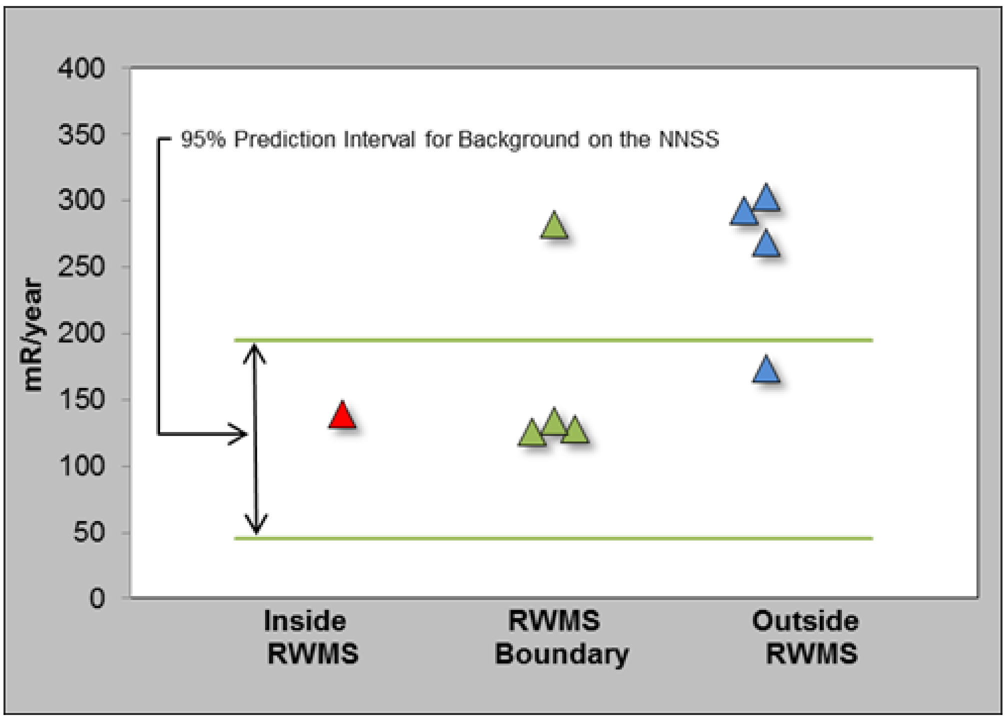

Figure 4-1. Annual Radiation Exposure Rates at the Area 3 RWMS

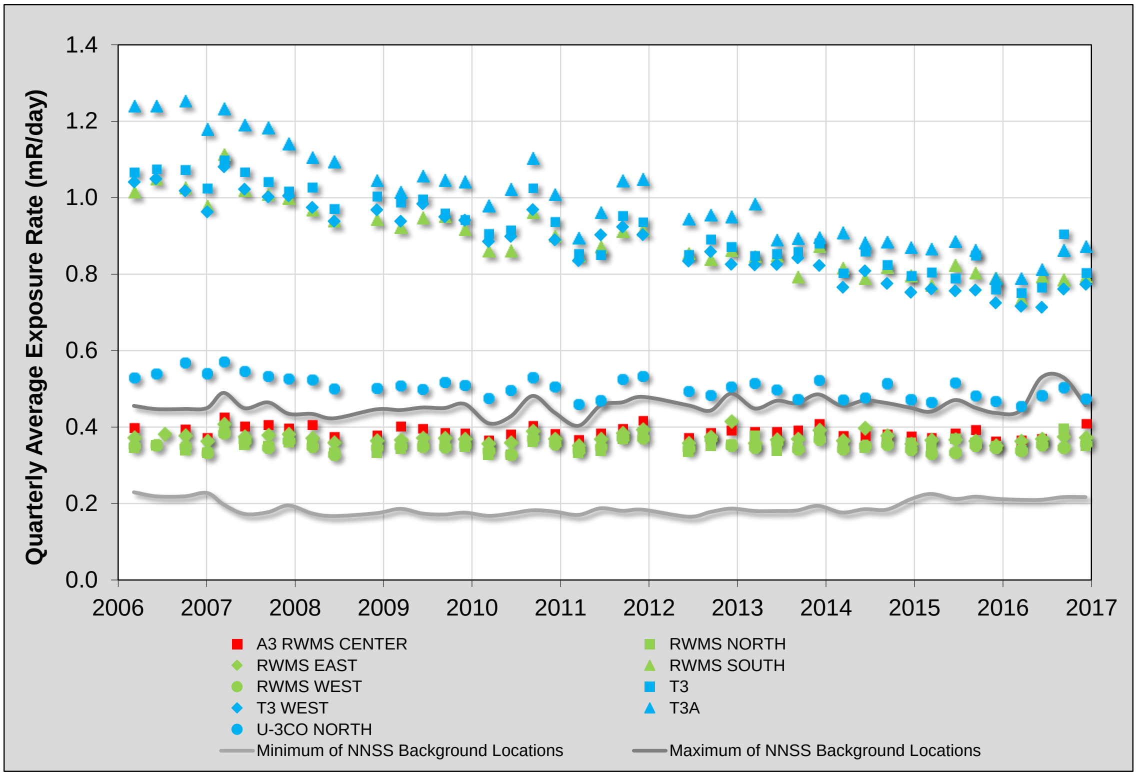

Figure 4-2. Quarterly Average Daily Exposure Rates at the Area 3 RWMS

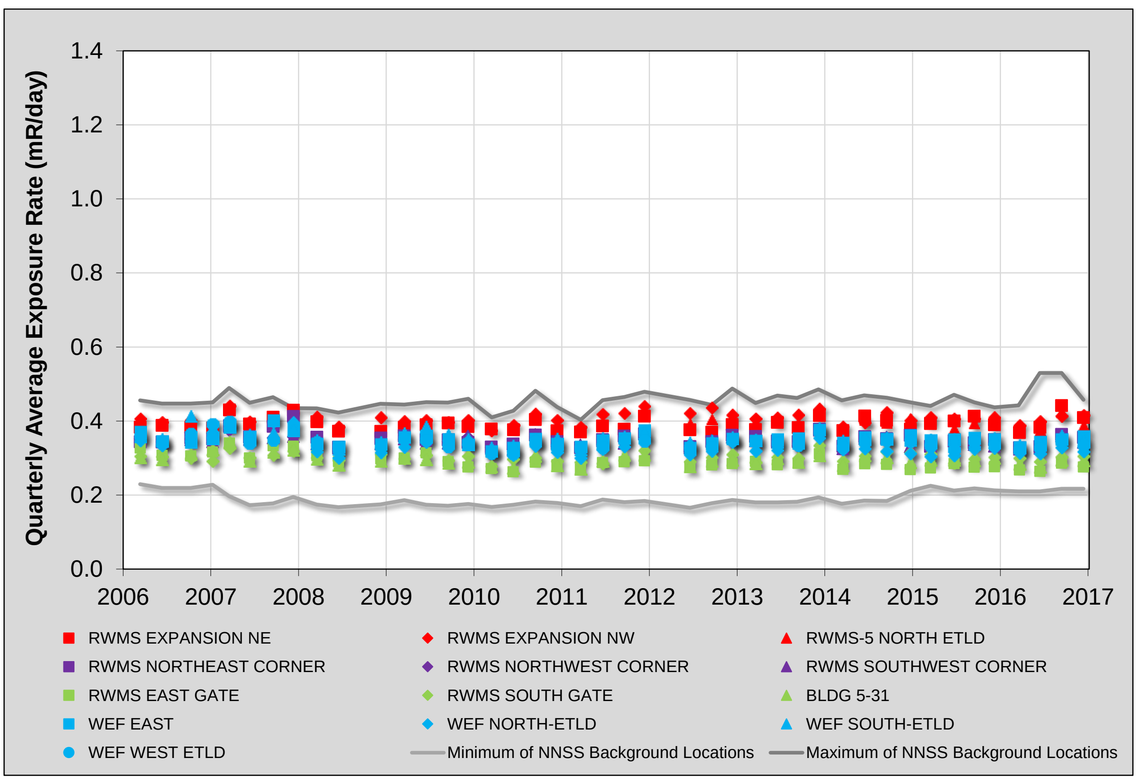

Figure 4-3. Quarterly Average Daily Exposure Rates at the Area 5 RWMS

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 cubic feet [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 areas during 2016 (Figure 3-1). These locations are U-3ax/bl South, Bilby Crater, and Kestrel Crater N. U-3ax/bl South measures radionuclide concentrations near the center of the Area 3 RWMS while Bilby Crater and Kestrel Crater N measure radionuclide concentrations in the prevailing wind directions at the Area 3 RWMS. Bilby Crater is approximately 1.2 km (0.75 mi) north of the Area 3 RWMS and Kestrel Crater N is approximately 1.5 km (0.9 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 2016 (Figure 3-2). These locations are Department of Defense (DoD) and RWMS 5 Lagoons. The DoD station is approximately 1.0 km (0.6 mi) north-northeast of the center of the Area 5 RWMS, and the RWMS 5 Lagoons station is approximately 1.5 km (0.9 mi) south-southeast of the center of the Area 5 RWMS (Figure 3-2). These monitoring locations are generally in the prevailing wind directions and provide adequate environmental monitoring for the Area 5 RWMS.

During 2016, tritium concentrations at the Area 3 and Area 5 RWMSs ranged from −0.38 to 3.26 picocuries per cubic meter (pCi/m^3). The highest concentrations were observed at the RWMS 5 Lagoons location which peaked between September 8 and October 20 (Figure 4-4). Most results from Area 3 are below the MDC for the entire year. All results are well below the DOE Derived Concentration Standard (DCS) for tritium adjusted to the 10 mrem/yr dose limit specified in DOE M 435.1 (DOE, 2001a) 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.

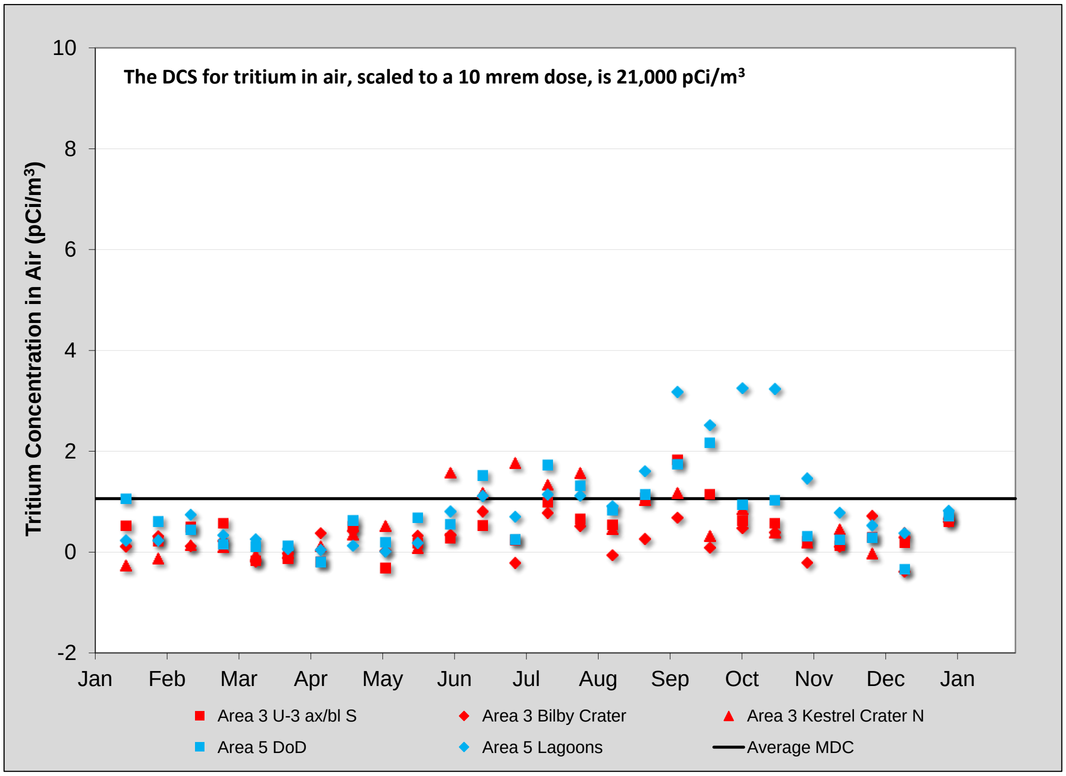

Figure 4-4. Tritium Concentration in Air at the Area 3 and Area 5 RWMSs

4.3.2 Particulates

Air particulate samples were collected every 2 weeks during 2016 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 (60,035 ft^3) of air through a glass-fiber filter with a collection efficiency of 99.99%. The air particulates are 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 were generally higher during the third quarter. This is likely a result of high winds that occurred during that time. No Cesium-137 (^{137}Cs) was detected in Area 3 or Area 5 RWMS samples during 2016, and all results are well below the 10 mrem/year adjusted DCS for each radionuclide.

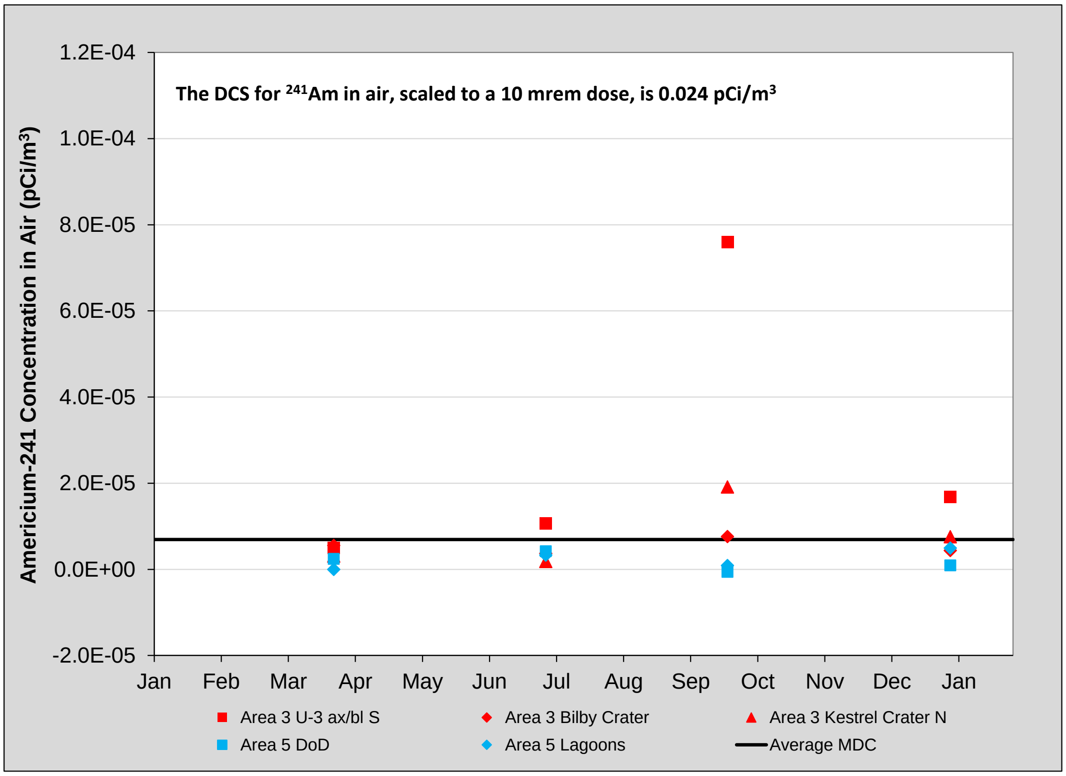

Figure 4-5. Concentration of ^{241}Am in Air at the Area 3 and Area 5 RWMSs

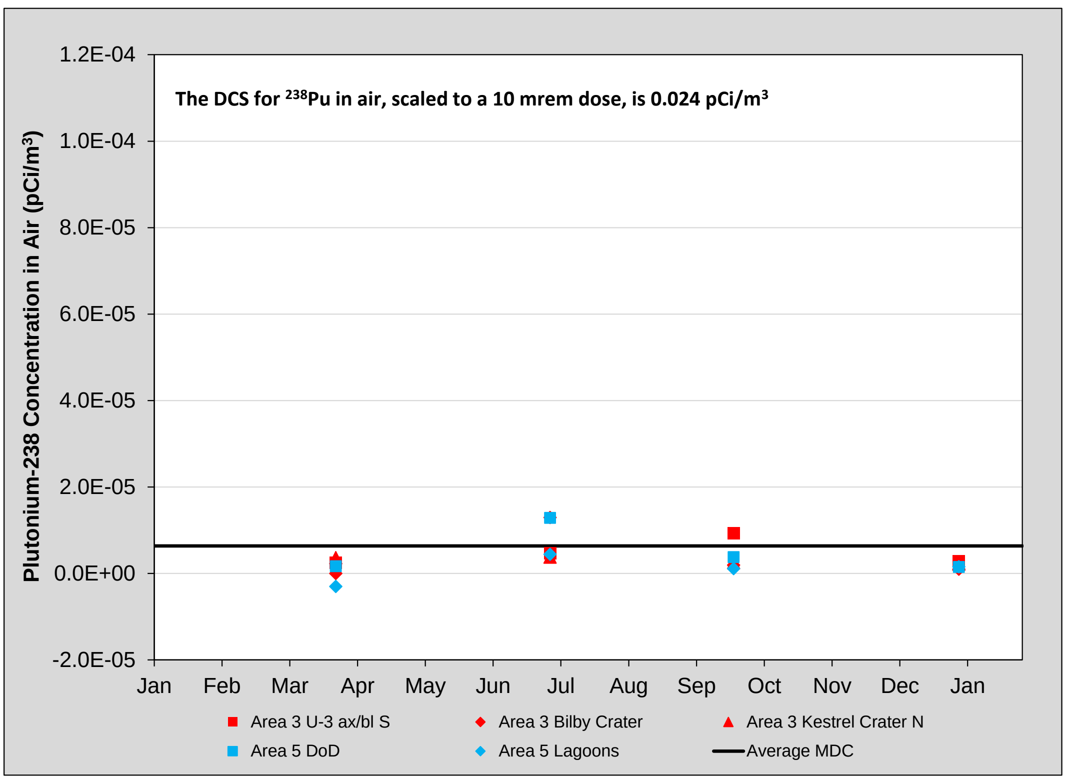

Figure 4-6. Concentration of ^{238}Pu in Air at the Area 3 and Area 5 RWMSs

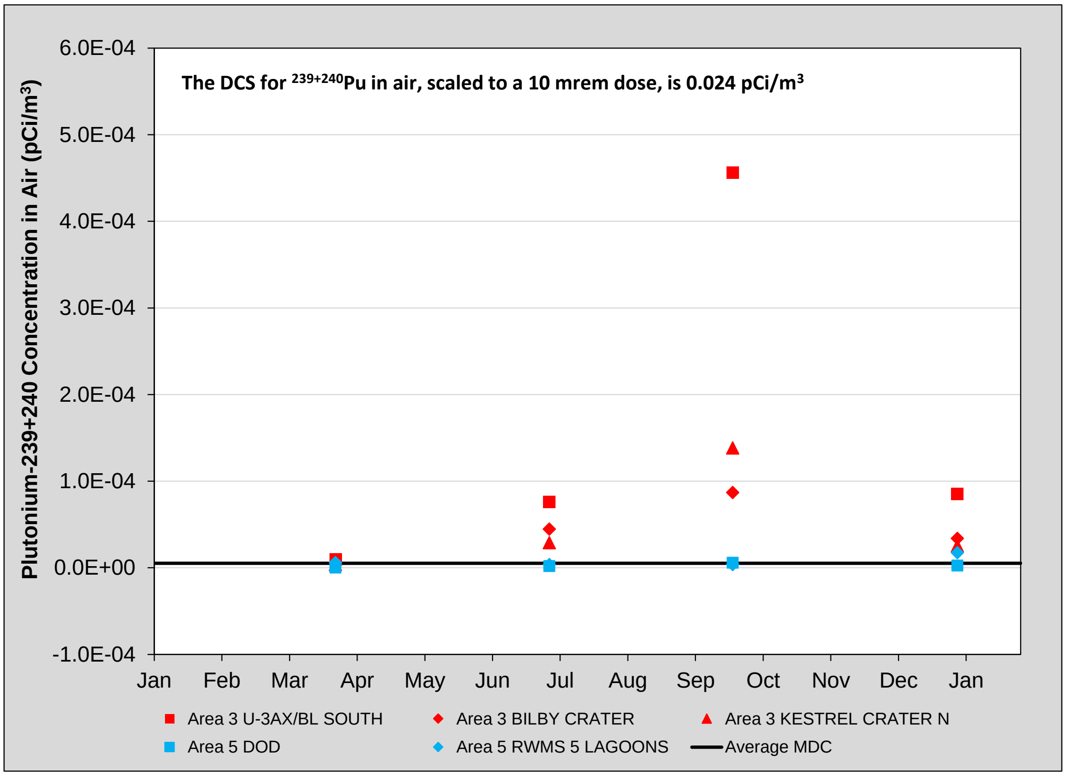

Figure 4-7. Concentration of $^{239+240}Pu$ in Air at the Area 3 and Area 5 RWMSs

4.3.3 Radon

The performance objective from DOE M 435.1-1, (DOE, 2001a) for radon emissions from DOE radioactive waste facilities is 20 picocuries per square meter per second (pCi/m^2/s). Radon emissions from waste covers in both the Area 3 and Area 5 RWMSs have been measured in previous years and have consistently been less than 25% of the performance objective. Radon emissions were not measured during 2016 but will be repeated in the future to verify continued low emissions.

4.4 GROUNDWATER MONITORING DATA

4.4.1 Groundwater Monitoring at the Pilot Wells

Three wells (UE5PW-1, UE5PW-2, and UE5PW-3) were drilled around the perimeter of the Area 5 RWMS in 1993 (see 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 15, August 16, and August 17, 2016. 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 2016 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 2016 Data Report: Groundwater Monitoring Program, Area 5 Radioactive Waste Management Site* (NSTec, 2017).

Table 4-3. Investigation Levels and Results from 2015 Groundwater Monitoring

Indicator Parameter	Investigation Level	Results
pH	<7.6 or >9.2	8.15 to 8.41
SC	0.440 mmhos/cm	0.348 to 0.374 mmhos/cm
TOC	1 mg/L	All <0.33 mg/L
TOX	50 µg/L	All <3.33 µg/L
Tritium	2000 pCi/L	<−132 to <159 pCi/L

Units are millimhos per centimeter (mmhos/cm), milligrams per liter (mg/L), micrograms per liter (µg/L), and picocuries per liter (pCi/L). < indicates the result is less than the provided sample specific MDA.

Groundwater elevations at the pilot wells are measured quarterly using an electronic tape. Groundwater elevations were measured on March 7, June 6, August 15, and October 24, 2016. All groundwater elevation data since the wells were drilled in 1993 are shown in Figure 4-8. The 2016 average depths to groundwater from the top of casing are 235.89 m (773.93 ft) at UE5PW-1, 256.48 m (841.47 ft) at UE5PW-2, and 271.59 m (891.05 ft) at UE5PW-3. The average groundwater elevations are 733.49 m (2,406.45 ft) AMSL at UE5PW-1, 733.61 m (2,406.87 ft) AMSL at UE5PW-2, and 733.70 m (2,407.16 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 less than 0.08 m/year (0.26 ft/year) to the southeast.

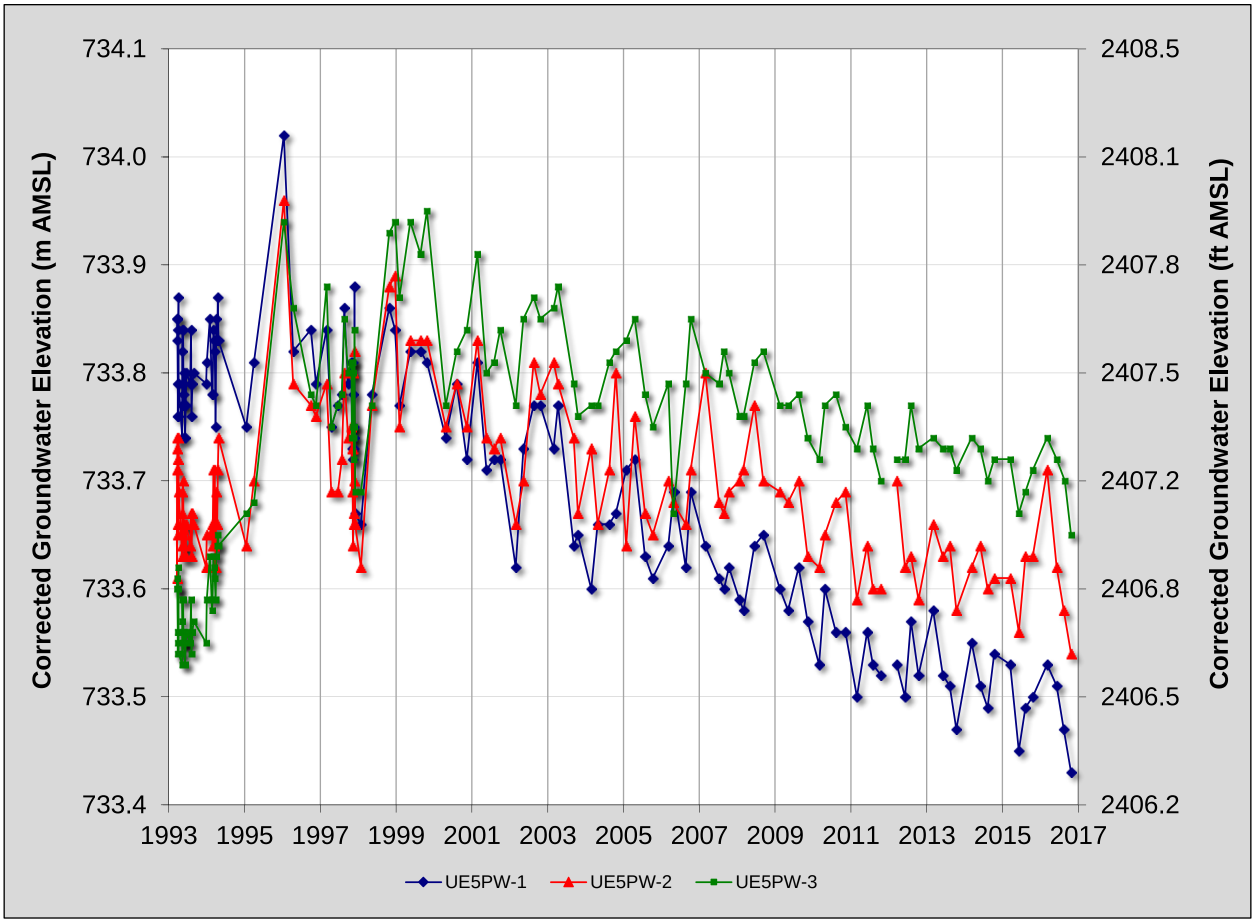

Figure 4-8. Groundwater Elevations at the Area 5 Pilot Wells

4.4.2 Leachate Monitoring at P18

Cell 18 is a lined, mixed waste disposal cell located in the northeastern corner of the Area 5 RWMS. It was constructed during 2010 and began receiving waste in January 2011. The Cell 18 liner is a RCRA-compliant double liner with a leachate collection and leak detection system placed over a geosynthetic clay liner. The double liner is 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. The primary liner is 80-mil textured high-density polyethylene (HDPE), and the secondary liner is 60-mil textured HDPE. The 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 1.35-hectare (3.33-acre) 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 Cell 18. Any water leaking through the primary liner would percolate to the secondary liner and eventually drain into the secondary sump in the floor of Cell 18. Water collected in the primary sump is pumped from the sump to a 3,000-gallon tank (leachate tank) on the surface above the cell. On February 25, 2016, 2,440 liters (644 gallons) were pumped from the secondary liner sump to the leachate tank.

The total volume pumped from the primary sump into the leachate collection tank from January 2011 through December 2016 is 285,348 liters (75,381 gallons) (Figure 4-9). From January 2011 through December 2016, there was 69.6 cm (27.4 in.) of precipitation 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 is 2.12 cm (0.83 in.). Neglecting additional water applied to Cell 18 for dust control, leachate is approximately 3.0 percent of the precipitation. The total volume pumped from the primary sump into the leachate collection tank in 2016 is 102,093 liters (26,970 gallons). In 2016 there was 13.4 cm (5.28 in.) of precipitation 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 is 0.76 cm (0.30 in.). Neglecting additional water applied to Cell 18 for dust control, leachate is approximately 5.7 percent of the 2016 precipitation.

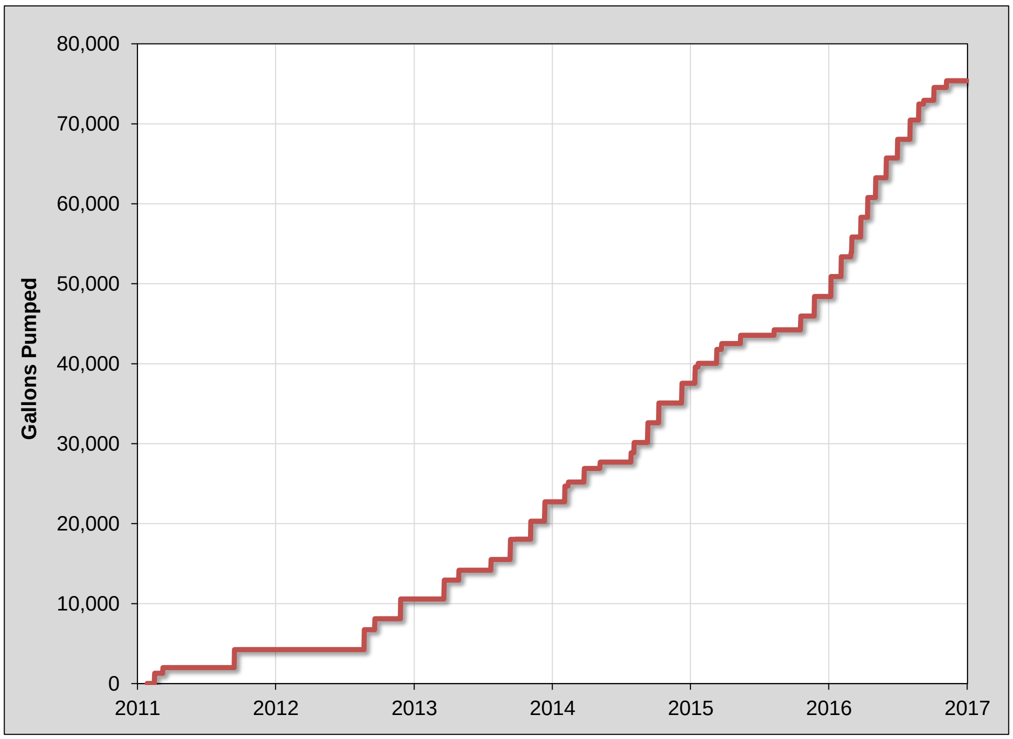

Figure 4-9. Leachate Volume Pumped from Cell 18 Primary Sump

When the tank approaches its 3,000-gallon capacity, leachate samples are collected from the tank and analyzed for the toxicity characteristic contaminants listed in Table 1 of 40 CFR 261.24 (2003), polychlorinated biphenyls (PCB), pH, and SC. Since Cell 18 opened in 2011 through 2016, leachate samples have been collected thirty-two times and the tank emptied thirty-two times. During 2016, leachate samples were collected eleven times (January 13, February 9, March 9 and 29, April 18, May 10, June 15, July 13, August 4, September 14, and November 8), and the tank was emptied twelve times (January 6 and 26, February 25, March 24, April 12, May 3 and 31, June 30, August 2 and 25, October 4, and November 22). Typically there is approximately a 2-week delay between sampling and emptying the leachate tank. The tank was emptied on January 6, 2016, based on results from leachate samples collected during 2015. Detailed results for the leachate are presented in the *Nevada National Security Site 2016 Data Report: Groundwater Monitoring Program, Area 5 Radioactive Waste Management Site* (NSTec, 2017).

Indicators of contamination monitored for leachate:

- Toxicity characteristic contaminants
    - Metals – arsenic, barium, cadmium, chromium, lead, selenium, 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, 2,4,6-trichlorophenol
    - Volatiles – benzene, carbon tetrachloride, chlorobenzene, chloroform, 1,2-dichloroethane, 1,1-dichloroethylene, methyl ethyl ketone, tetrachloroethylene, trichloroethylene, vinyl chloride
    - Organochlorine pesticides – chlordane, endrin, heptachlor (and its epoxide), lindane, methoxychlor, toxaphene
    - Chlorinated herbicides – 2,4-D, 2,4,5-TP (Silvex)
- PCBs
- pH
- SC

Through 2016, no regulatory limits for toxicity characteristic contaminants were exceeded, and no PCBs exceeded the analysis method quantification limit. During 2016, the leachate average specific conductance was 3,967 mmhos/cm, and the leachate average pH was 7.45. After leachate analysis results are evaluated, the leachate is pumped from the collection tank and used for dust control in Cell 18.

4.5 METEOROLOGY MONITORING DATA

Meteorology monitoring data collected in 2016 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 are 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 from 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 2016 average recorded temperatures at 9.5 m (31 ft) above ground level were 15.1°C (59.2°F) at the Area 3 RWMS and 17.2°C (63.0°F) at the Area 5 RWMS. The 2016 maximum and minimum temperatures at 9.5 m (31 ft) at the Area 3 RWMS were 40.2°C (104.4°F) on July 27, 2016, and −9.8°C (14.4°F) on December 17, 2016. The 2016 maximum and minimum temperatures at 9.5 m (31 ft) at the Area 5 RWMS were 42.5°C (108.5°F) on June 27, 2016, and −11.5°C (11.3°F) on December 18, 2016 (Figure 4-10).

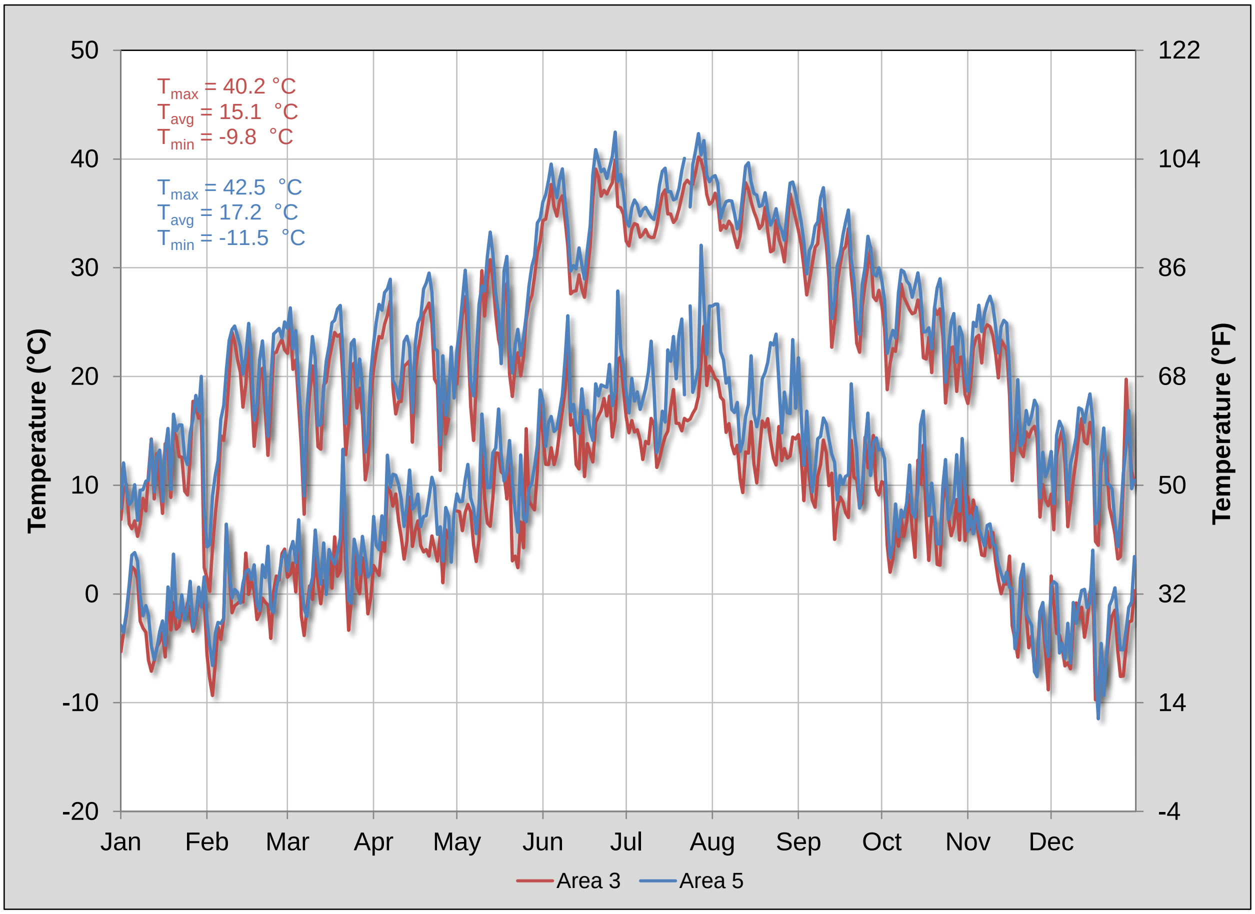

Figure 4-10. Daily Maximum and Minimum Air Temperature at the Area 3 & Area 5 RWMSs

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 2016 at 9.5 m (31 ft) above ground level was 33.4% for Area 3 and 32.4% for Area 5 (Figure 4-11). Measured daily average relative humidity ranged from 5.99% to 95.9%.

Vapor 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 vapor density during 2016 was 3.7 g/m^3 at Area 3 and 4.0 g/m^3 at Area 5 (Figure 4-12). The measured daily average vapor density ranged from 1.1 g/m^3 to 11 g/m^3.

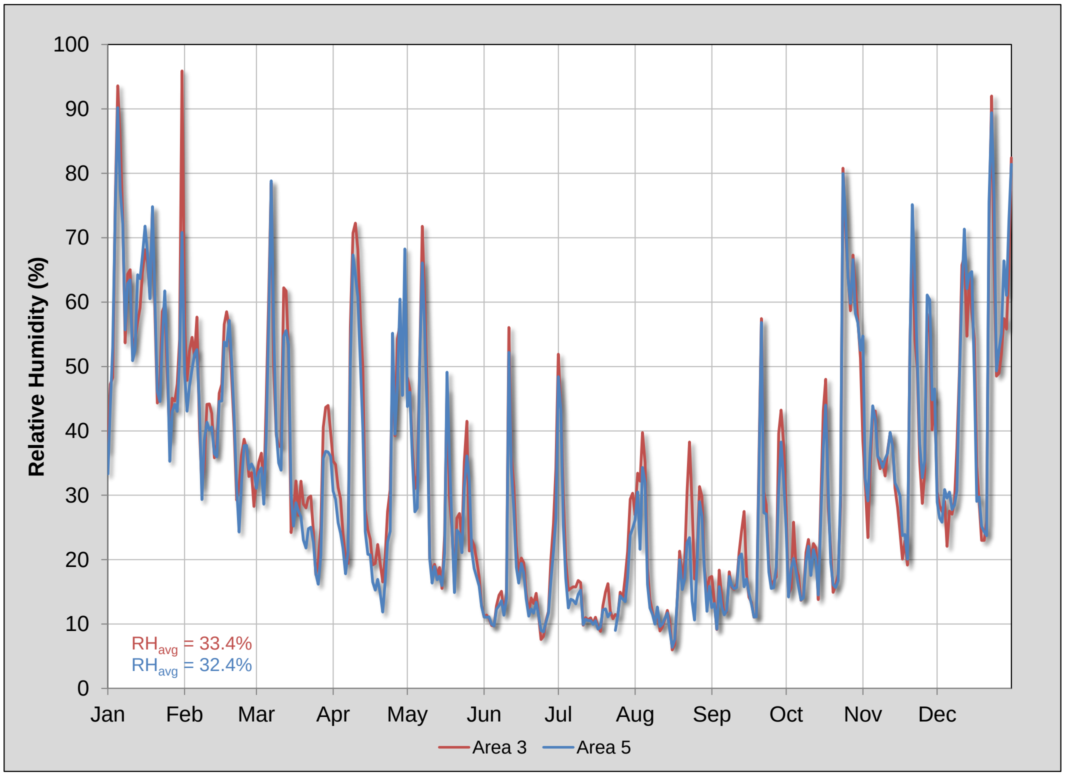

Figure 4-11. Daily Average Relative Humidity at the Area 3 and Area 5 RWMSs

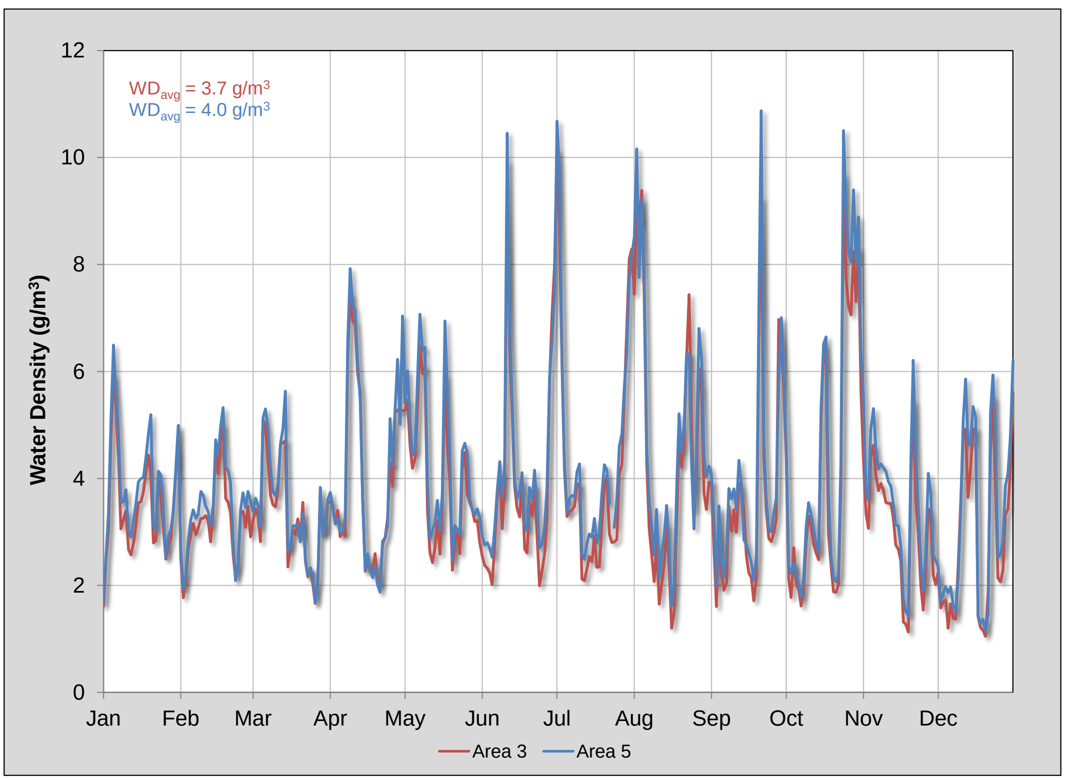

Figure 4-12. Daily Average Atmospheric Water Density at the Area 3 and Area 5 RWMSs

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 4-13). The average barometric pressure at the Area 3 RWMS was 87.8 kilopascals (kPa) (12.7 pounds per square inch [PSI]). The average barometric pressure at the Area 5 RWMS 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.

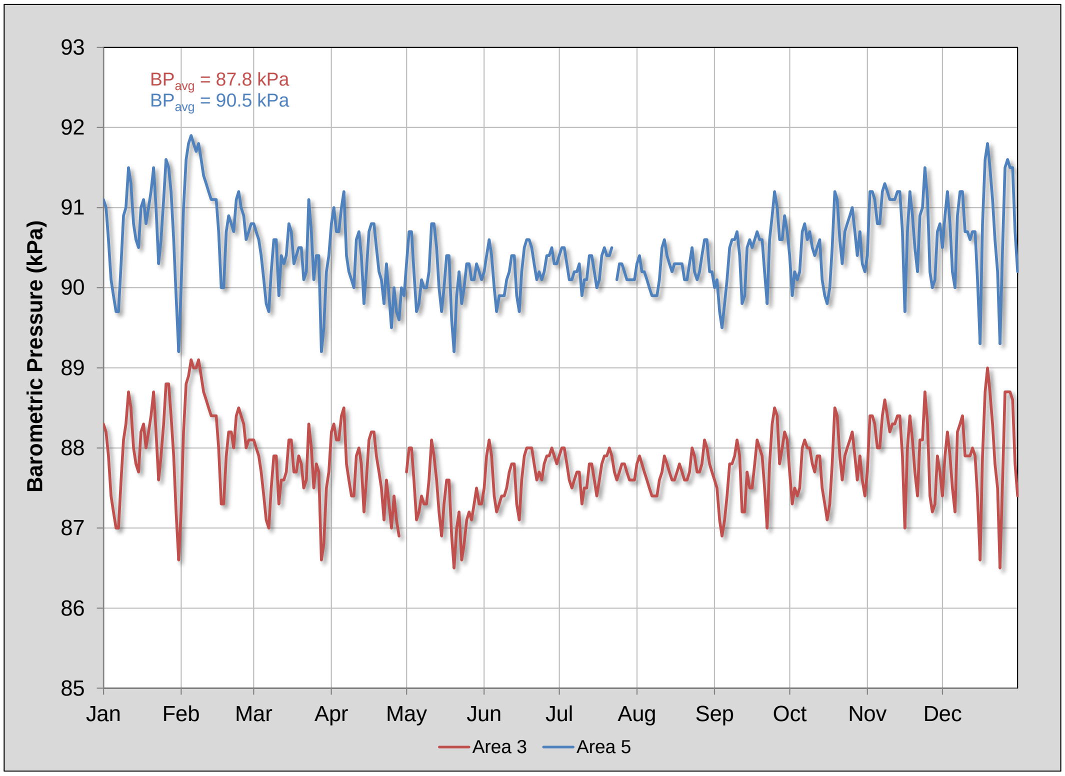

Figure 4-13. Average Barometric Pressure at the Area 3 and Area 5 RWMSs

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 2016, the average daily wind speed at the Area 3 RWMS at 9.5 m (31 ft) was 3.7 m/s (8.3 mph), and the maximum gust was 22.7 m/s (50.8 mph) on April 22. During 2016, the average daily wind speed at the Area 5 RWMS at 9.5 m (31 ft) was 3.2 m/s (7.2 mph), and the maximum gust was 22.1 m/s (49.4 mph) on March 28. Daily maximum and average wind speeds at the Area 3 and Area 5 RWMSs are in Figure 4-14 and Figure 4-15, 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 4-16 and Figure 4-17, respectively. The 1-year wind roses presented here are very similar to the multiple-year wind roses.

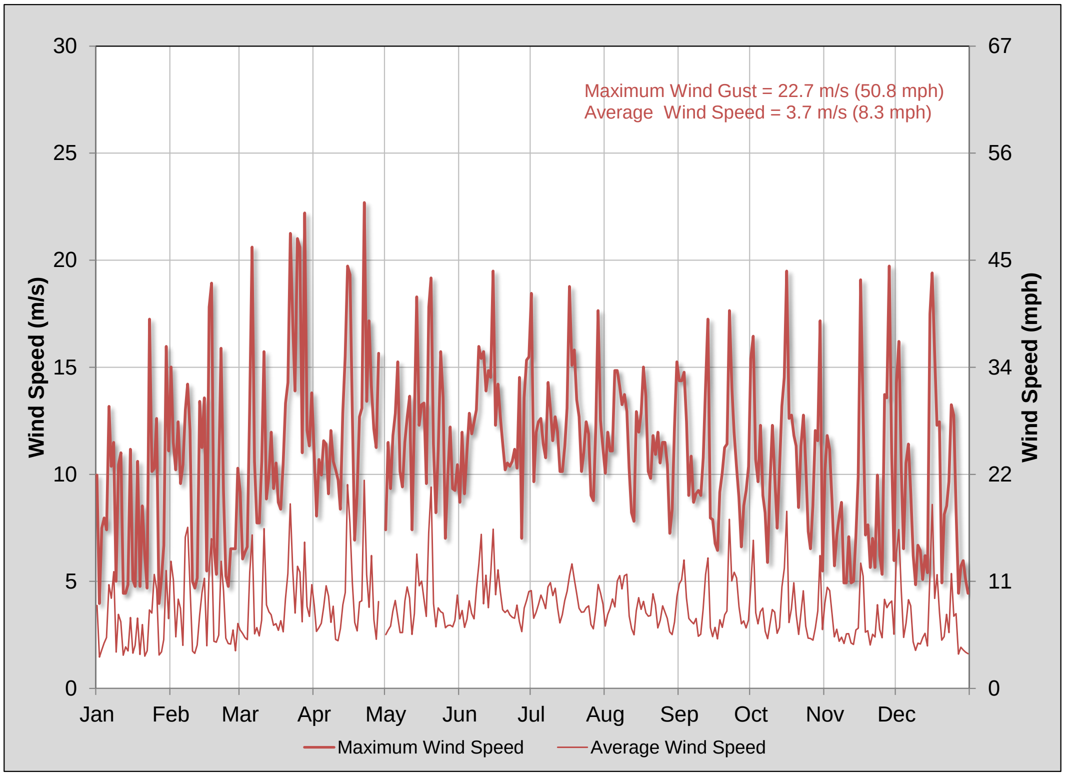

Figure 4-14. Daily Wind Speed at the Area 3 RWMS

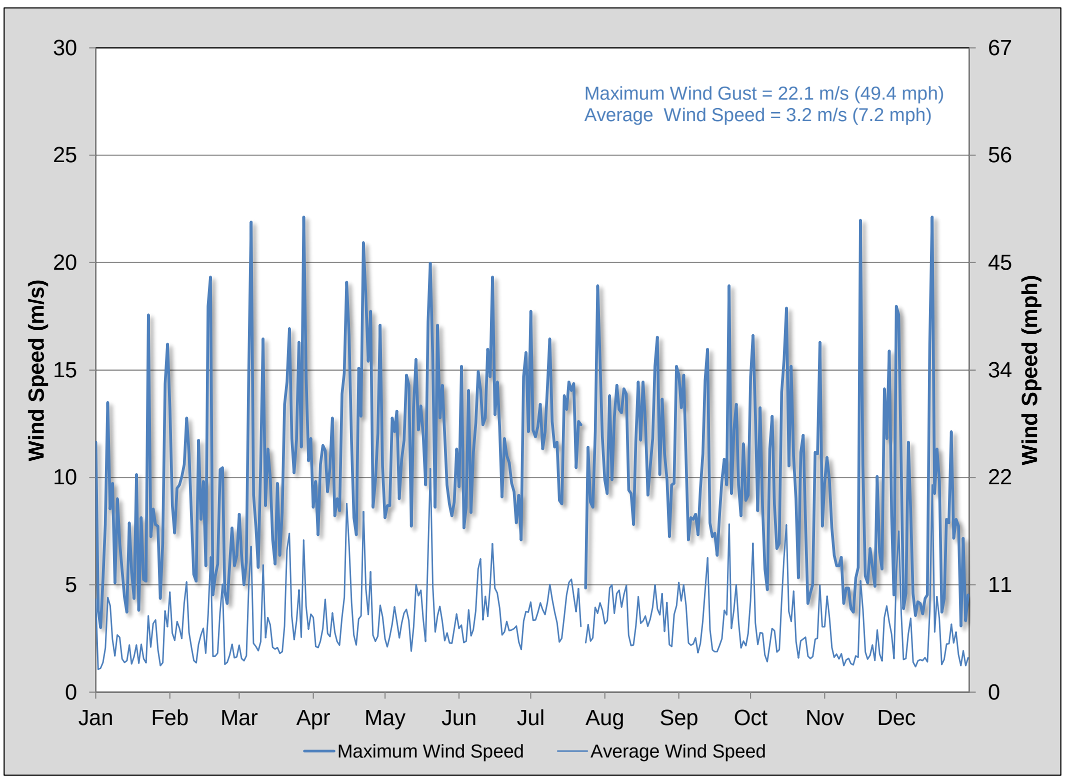

Figure 4-15. Daily Wind Speed at the Area 5 RWMS

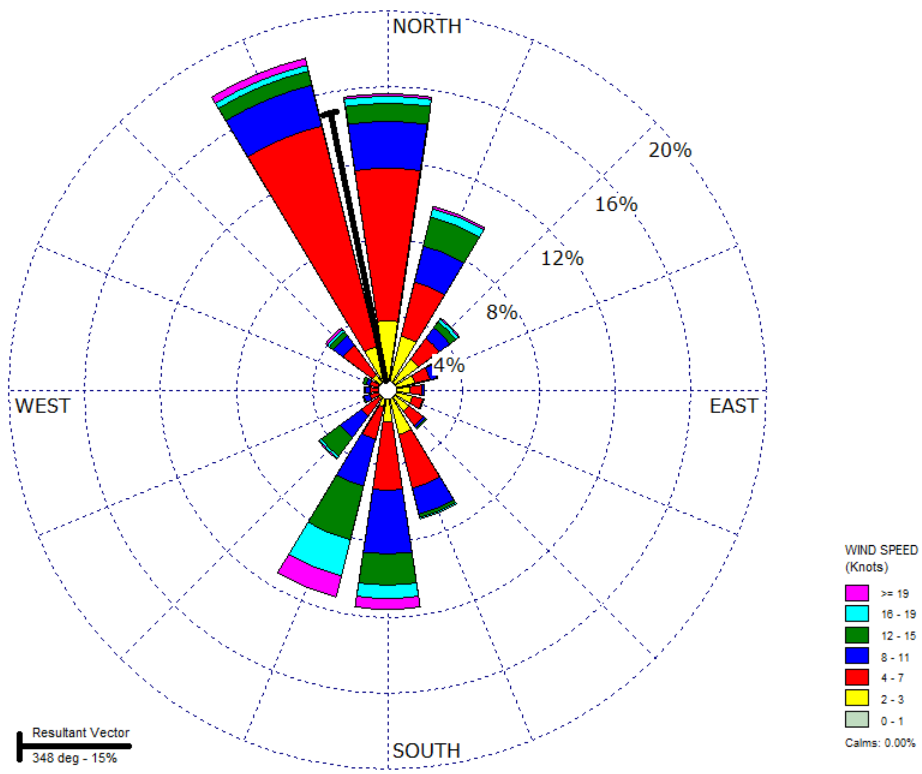

Figure 4-16. Wind Rose Diagram for the Area 3 RWMS

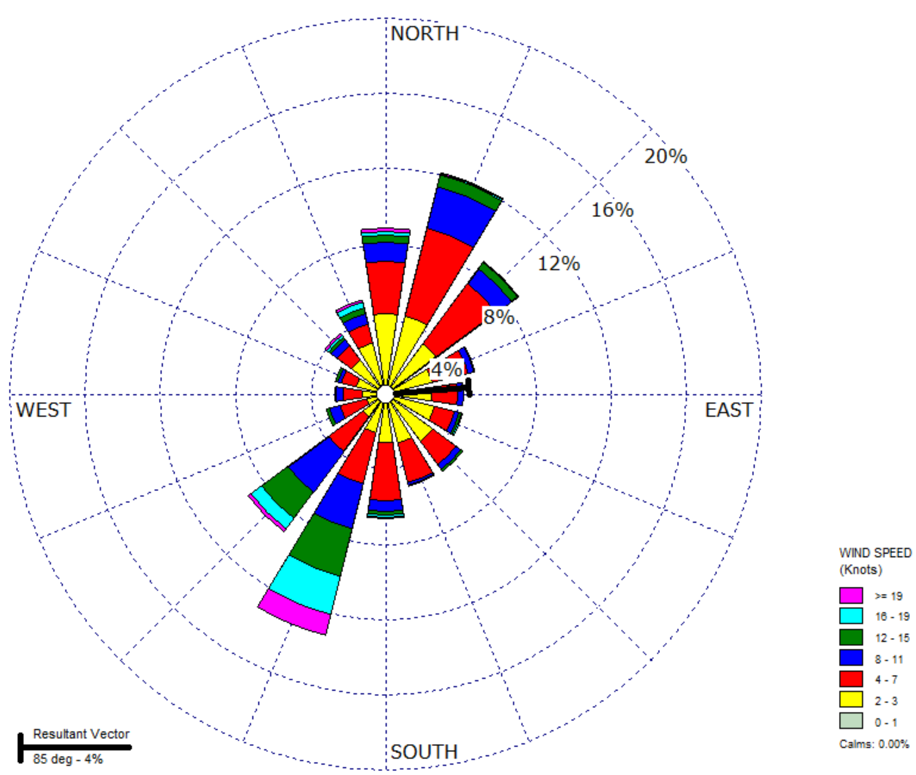

Figure 4-17. Wind Rose Diagram for the Area 5 RWMS

4.5.5 Precipitation

Rainfall at the Area 3 RWMS in 2016 was 8% below the 20 year average, totaling 138.9 mm (5.47 in.). The average annual precipitation measured at the Area 3 RWMS from 1996 through 2016 is 150.0 mm (5.91 in.). The maximum daily rainfall at the Area 3 RWMS during 2016 was 20.3 mm (0.8 in.) on January 5. Figure 4-18 compares the highest, lowest, average, and the 2016 precipitation amounts for the last 16 years in Area 3. Rainfall in January was close to triple the average for the month and the rest of the year was close to average with August and September being below average. Precipitation was measured on 52 days during 2016 at the Area 3 RWMS.

Rainfall at the Area 5 RWMS in 2016 was 8% above the 21 year average, totaling 133.5 mm (5.26 in.). The average annual precipitation measured at the Area 5 RWMS from 1995 through 2016 is 123.9 mm (4.88 in.). The maximum daily rainfall at the Area 5 RWMS during 2016 was 14.0 mm (0.55 in.) on January 5. Figure 4-19 compares the highest, lowest, and average precipitation amounts for the last 21 years, along with the 2016 amount in Area 5. Rainfall in January was more than double the average amount and the rest of the year was close to average with August and September being below average. Precipitation was measured on 38 days during 2016 at the Area 5 RWMS.

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 in Figure 4-20. The BJY station is a Meteorological Data Acquisition (MEDA) station operated by ARL/SORD. The 56-year average annual precipitation at BJY from 1961 to 2016 is 160 mm (6.30 in.) (ARL/SORD, 2017). 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 4-21. The Well 5B station is also an ARL/SORD MEDA station. The 53-year average annual precipitation at Well 5B from 1964 to 2016 is 123 mm (4.84 in.) (ARL/SORD, 2017).

4.5.6 Reference Evapotranspiration

The calculated 2016 ET_{ref} at the Area 3 RWMS is 1,604 mm (63.1 in.) and at the Area 5 RWMS is 1,606 mm (63.2 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 evapotranspiration 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 2016 at the Area 3 RWMS was 11.5, and the ratio of ET_{ref} to precipitation in 2016 at the Area 5 RWMS was 12.0.

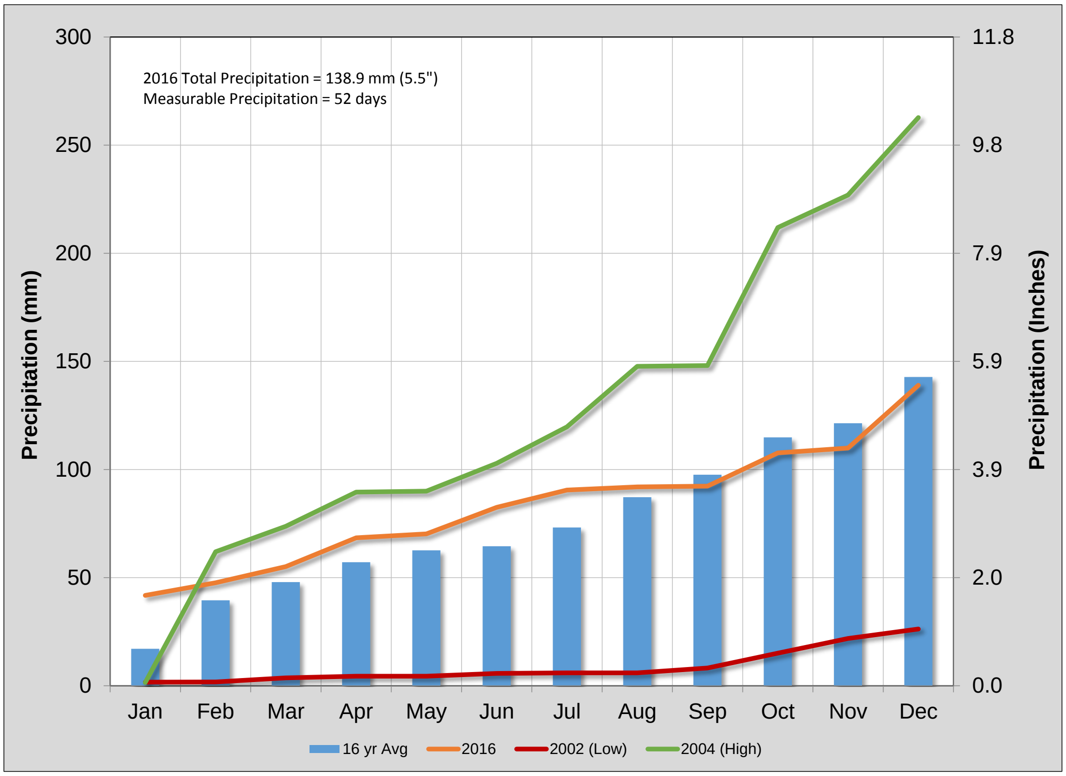

Figure 4-18. Precipitation at the Area 3 RWMS

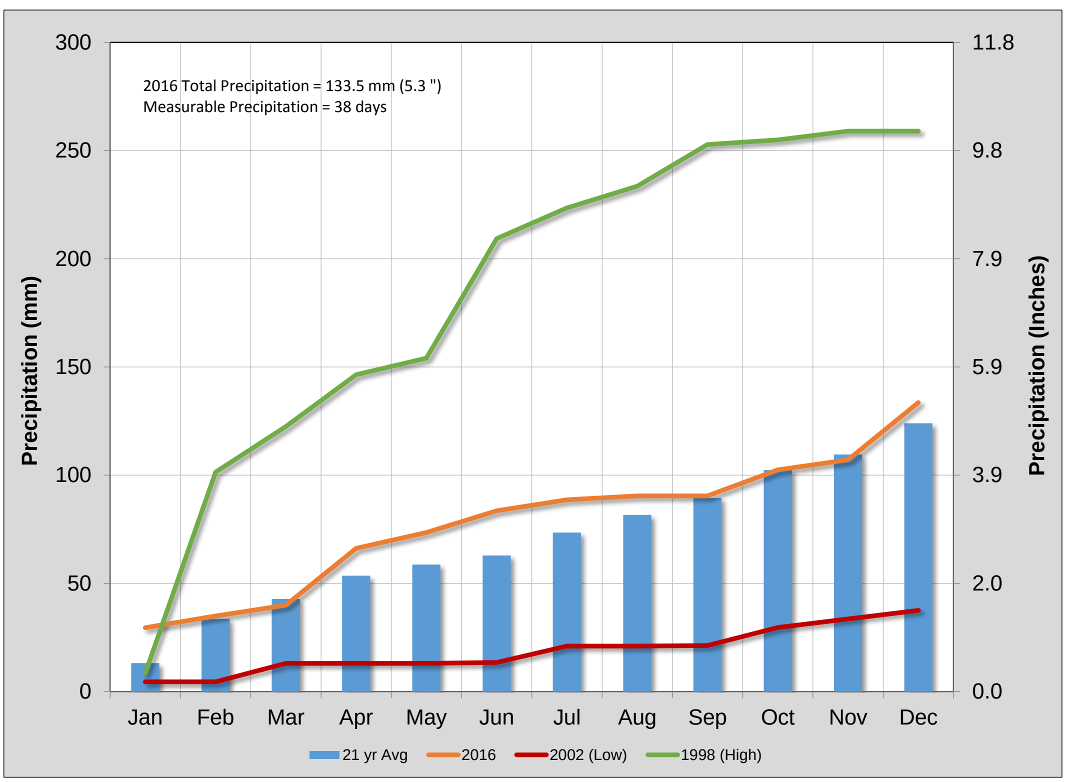

Figure 4-19. Precipitation at the Area 5 RWMS

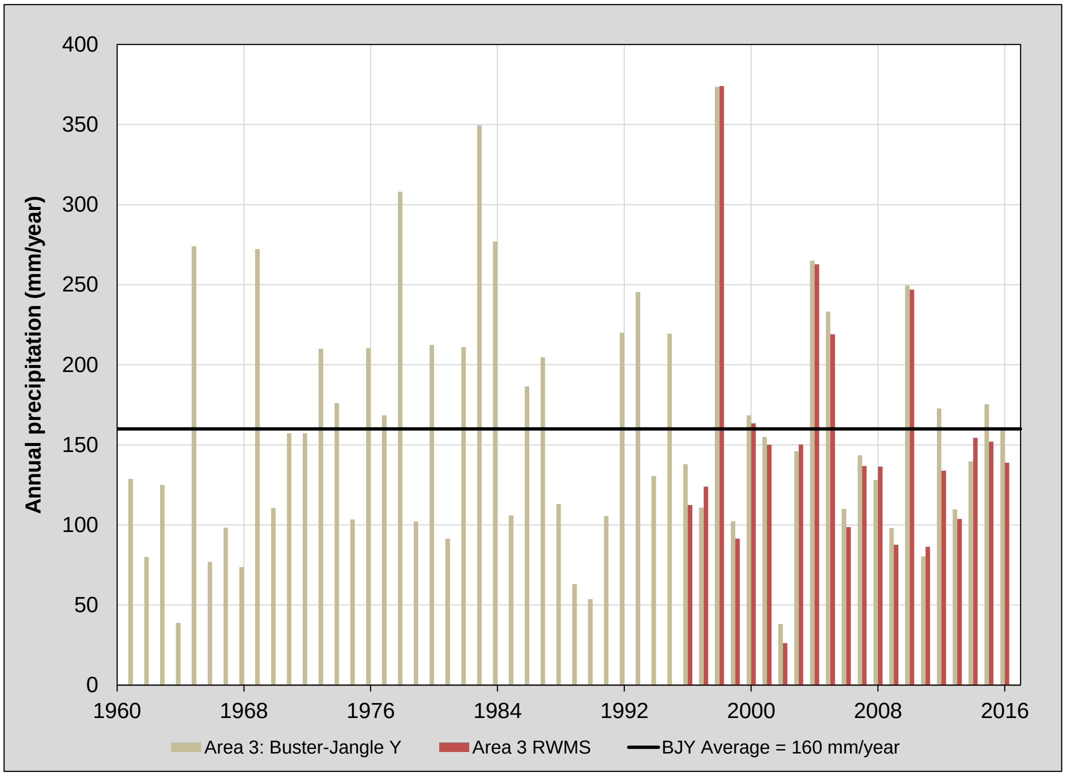

Figure 4-20. Historical Precipitation Record for Buster-Jangle Y and Area 3 RWMS

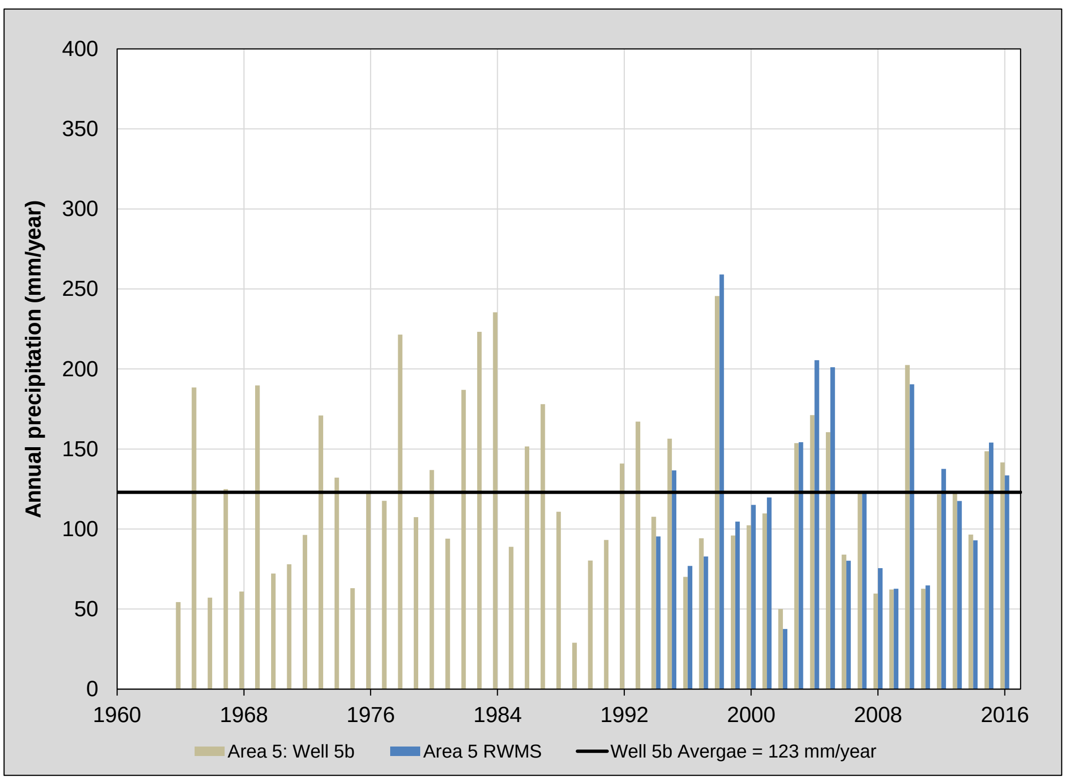

Figure 4-21. Historical Precipitation Record for Well 5B and Area 5 RWMS

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 the operational monolayer 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 evaporation (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 about 400 m (1,312 ft) southwest of the Area 5 RWMS (Figure 3-2). Each lysimeter is an open-top steel box, measuring 2 m wide by 4 m long by 2 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 (1 in.) lip around the edge of the lysimeters prevents run-on and runoff. Total soil water storage for the period of March 30, 1994, through December 31, 2016, is provided in Figure 4-22.

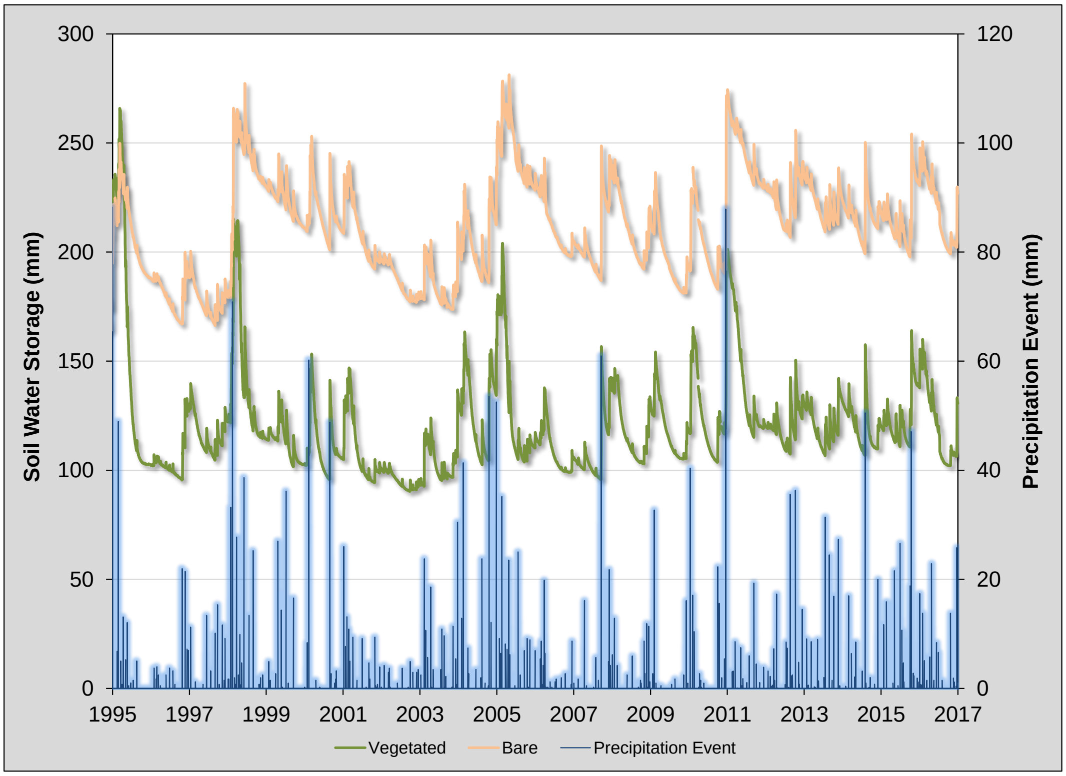

Figure 4-22. Weighing Lysimeter Data from January 1995 thru December 2016

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% plant cover. Cover was measured for both the vegetated and bare-soil weighing lysimeters on May 25, 2016, using an ocular projection device. Plant cover on the vegetated lysimeter did not change much from 2015 and consisted of 4 shrubs; two *Larrea tridentate* [Creosote]; two *Lycium pallidum* [Pale desert thorn], and roughly 225 small annual grasses, *Schismus arabicus* [Arabian schismus.] The results are summarized in Table 4-4.

Table 4-4. Weighing Lysimeters Percent Cover

Lysimeter	Plant Cover (percent)	Bare (percent)	Gravel (percent)	Litter (percent)
Vegetated	30	10	58	2
Bare Soil	0	15	85	0

The average soil water storage depth in the vegetated lysimeter from January 1, 1996, through December 31, 2016, was 118 mm (4.6 in.). This is equivalent to an average volumetric water content (VWC) of 5.9%. For the same period, the average soil water storage depth in the bare lysimeter was 211 mm (8.3 in.), which is equivalent to an average VWC of 10.6%. During 2016, the average soil water storage depth in the vegetated lysimeter was 122 mm (4.8 in.), and the average water storage depth in the bare lysimeter was 220 mm (8.7 in.). Rains in late winter and early spring promote plant growth, which removes water by evapotranspiration. 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 (Figure 4-22).

No water has ever accumulated at the bottom of the vegetated lysimeter. Heavy precipitation during the 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. A suction of −8.0 kPa (−1.2 PSI) was applied to the porous suction candles on the bottom of the bare lysimeter 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 1.0 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 2016, E from the bare lysimeter was 133.2 mm (5.2 in.) and ET from the vegetated lysimeter was 137.0 mm (5.4 in). Water content in the vegetated lysimeter decreased during 2016 because annual ET from the vegetated lysimeter was greater than the 129.6 mm of precipitation. Water content in the bare lysimeter also decreased during 2016.

During 2016, following a wet January and April, ET from the vegetated lysimeter was greater or equal to E from the bare lysimeter from February through July. Plant growth slowed August through December and E exceeded ET while the water storage was fairly constant until large precipitation events in December (Figure 4-24).

Monthly precipitation was less than ET and E in all but four months: January, April, October, and December, thus reducing the water content in each lysimeter except for those four months. The overall yearly water storage was a deficit until the large precipitation amount in December, which brought the net storage for the year to almost zero (Figure 4-24).

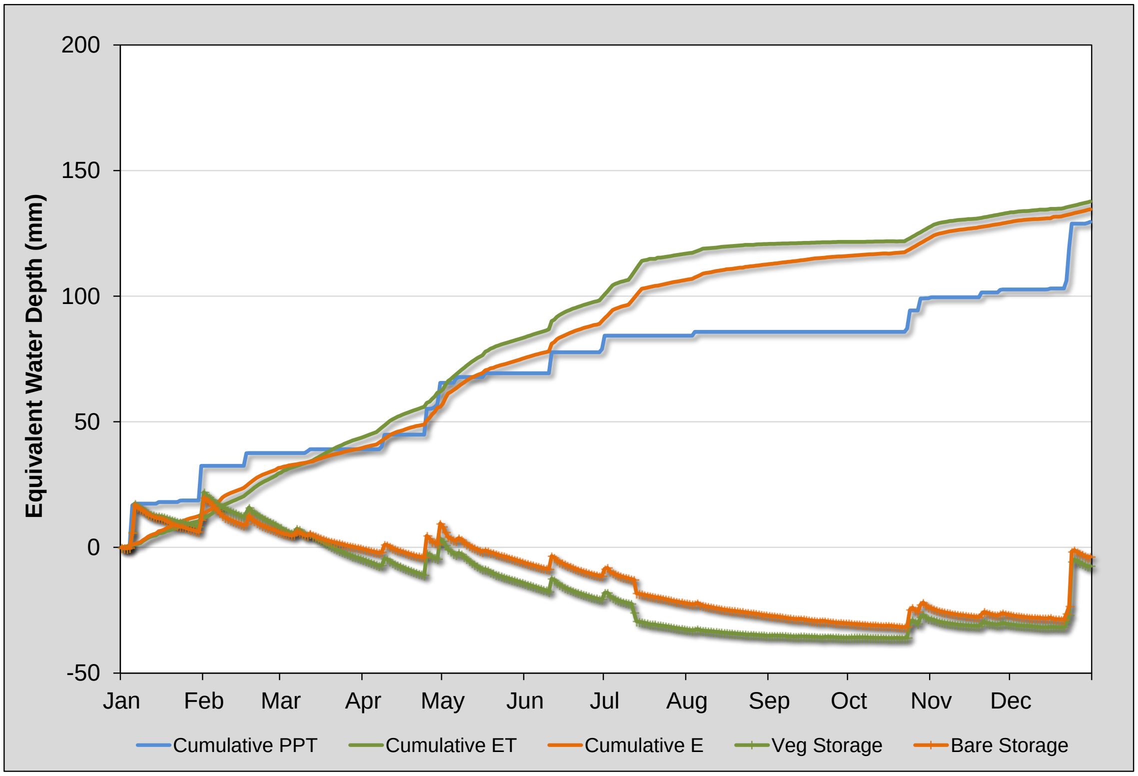

Figure 4-23. Precipitation, ET, E, and Storage for the Weighing Lysimeters

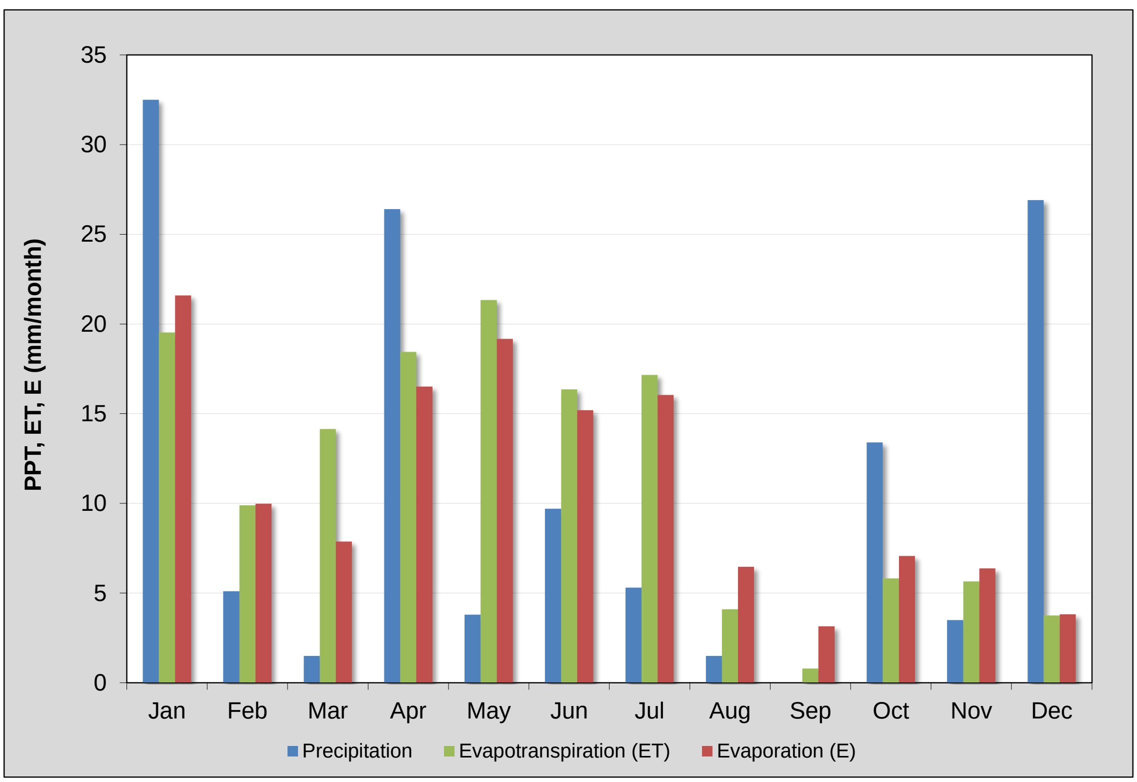

Figure 4-24. Monthly Precipitation, E, and ET

4.6.3 Automated Waste Cover Monitoring System

In 1998, time-domain reflectometry (TDR) probes were buried 1.2 m (4 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 (8 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% since measurements began in early 1999 (Figure 4-25). The constant measured water content indicates that no moisture has percolated to 1.2 m (4 ft) below the waste. The missing data in 2011 are from during the construction of the final cover. The original TDR probes placed on the cell floor were used after the final cover was completed, but the data appear slightly more variable. This variability may be related to construction of the cover or damage to the probes during construction. The original probes in the temporary cover were abandoned and left in place.

Figure 4-25. Soil Water Content in the Cell 5 Floor

TDR probes were installed in the final cover 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 the four locations at depths ranging from 15 to 180 cm (0.5 to 6 ft). The measured VWC profiles are similar at the four locations. Measured VWC values for Cell 5N are shown in Figure 4-26. From January 2012 to June 2012, 9.7 cm (3.8 in) of water was applied to help establish vegetation and the VWC approached 10%. Once irrigation stopped, the VWC below 45 cm (18 in) quickly decreased and settled around 7% until late 2015. Precipitation events in 2013 and again in 2014 wetted the soil to 45 cm indicated by the rising gold line, but this moisture was removed by E and possibly ET without moving below 60 cm. In 2015, precipitation events in July wetted the soil to 45 cm, and in September 1.8 inches of precipitation wetted the soil to 180 cm (6 ft) shown by the slightly rising purple line. In 2016 there were several smaller precipitation events that wetted the top 45 cm (18 in), but by the summer the VWV at all levels approached 7%.

In 2015 precipitation wetted Cell 5S to the 180-cm level while in 2016 the 180 cm TDR was at 15% until the summer when it dropped to around 10% VWC. Cell 5N and 5S both had weeds growing on the cover in 2016.These may provide some ET during the spring, but none of the native perennial desert species capable of providing year-round ET when large precipitation events occur at these cells. TDR probes at Cell 1 indicate wetting down to the 45-cm level in 2016 while probes at Cell 3W indicate wetting down to 90 cm after precipitation in May.

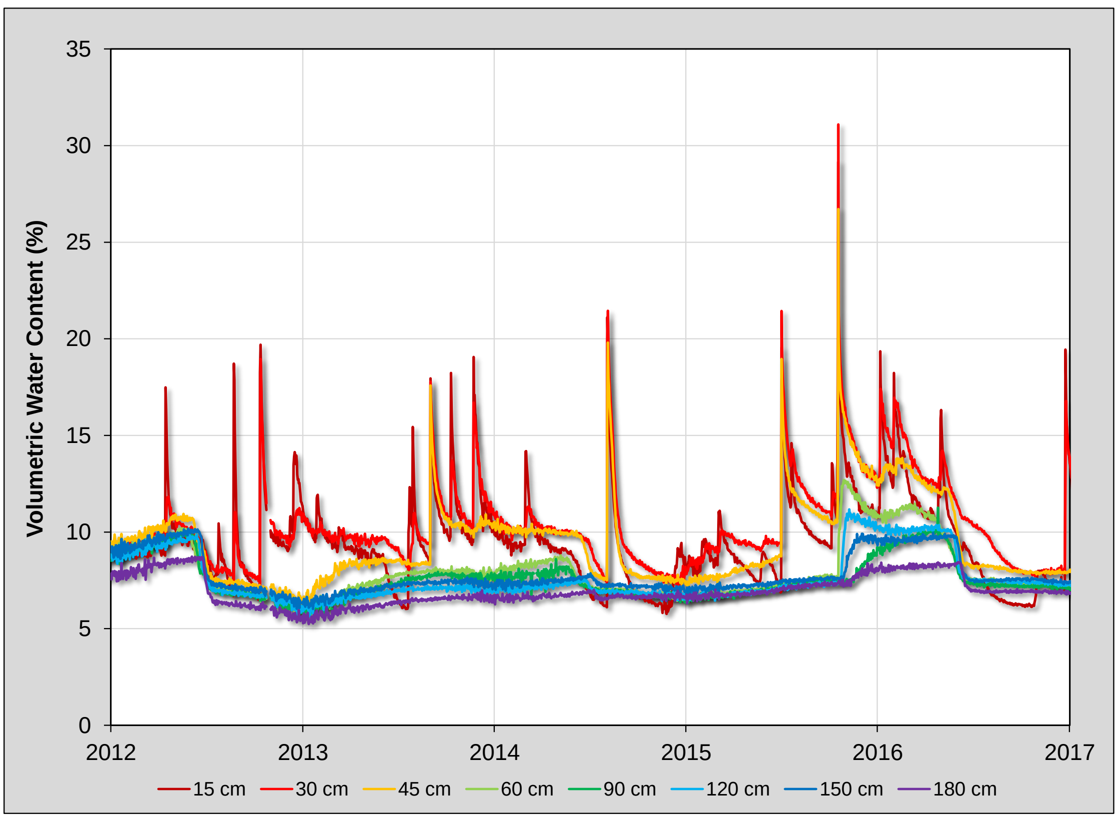

Figure 4-26. Soil Water Content in the 92 Acre Cover at Cell 5 N

Four strontium-90 (^{90}Sr) radioisotope thermoelectric generators (RTGs) were disposed at 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 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 4-27 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. Data gaps in Figure 4-27 are from sensor malfunction. 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 (9.1 ft) below the ground surface are not affected by the heat flux from the RTGs.

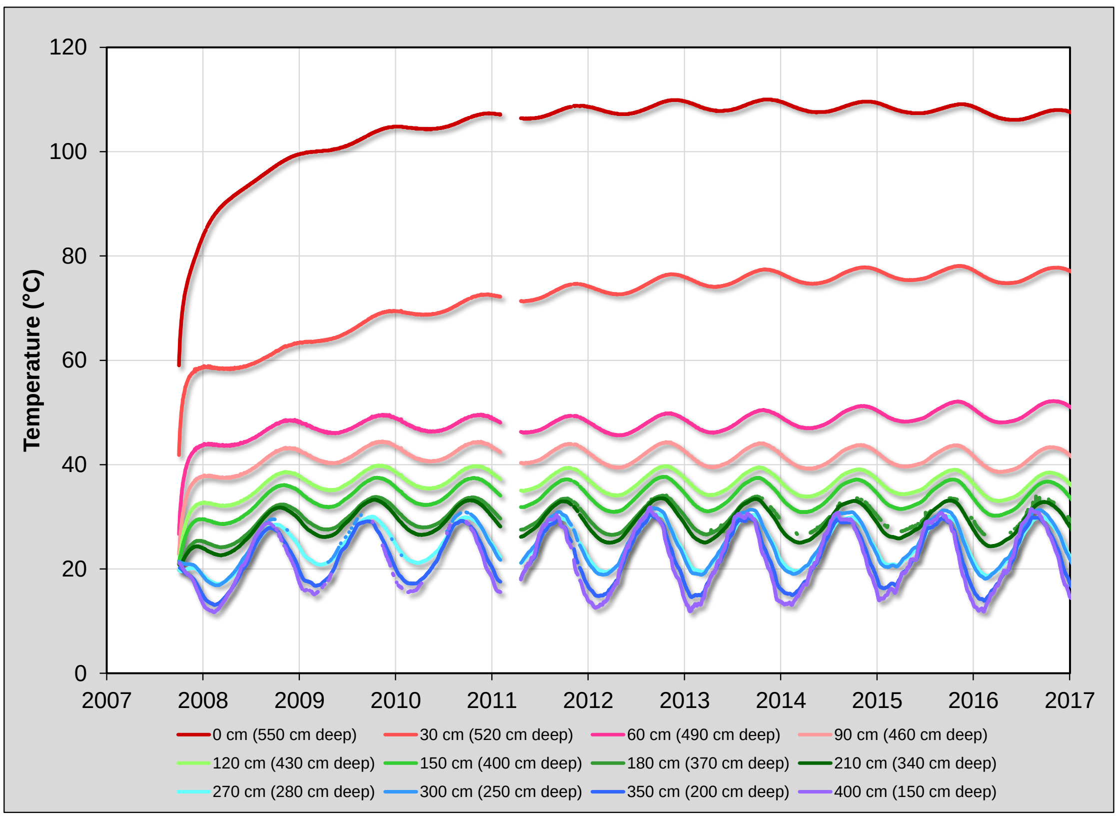

Figure 4-27. Temperatures above an RTG at Cell 5

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 to 8 ft). Measured soil water content values for one location (West Nest B) in the U-3ax/bl waste cover are shown in Figure 4-28. From 2001 to 2009, 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 (4 ft). Precipitation in late 2015 and into 2016 caused wetting down to 150 cm (4.9 ft) shown by the green line in Fig 4-28 reaching 15% VWC.

Vegetation is critical to the effectiveness of the U-3ax/bl cover. In the native environment, about 12% of the surface area is covered by plant material. Obtaining 12% 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% of the vegetation cover in 2014. A quantitative plant survey at the U-3ax/bl cover was not done in 2016, and the interval was increased from annually to every 5 years. The next scheduled plant survey will be in 2019.

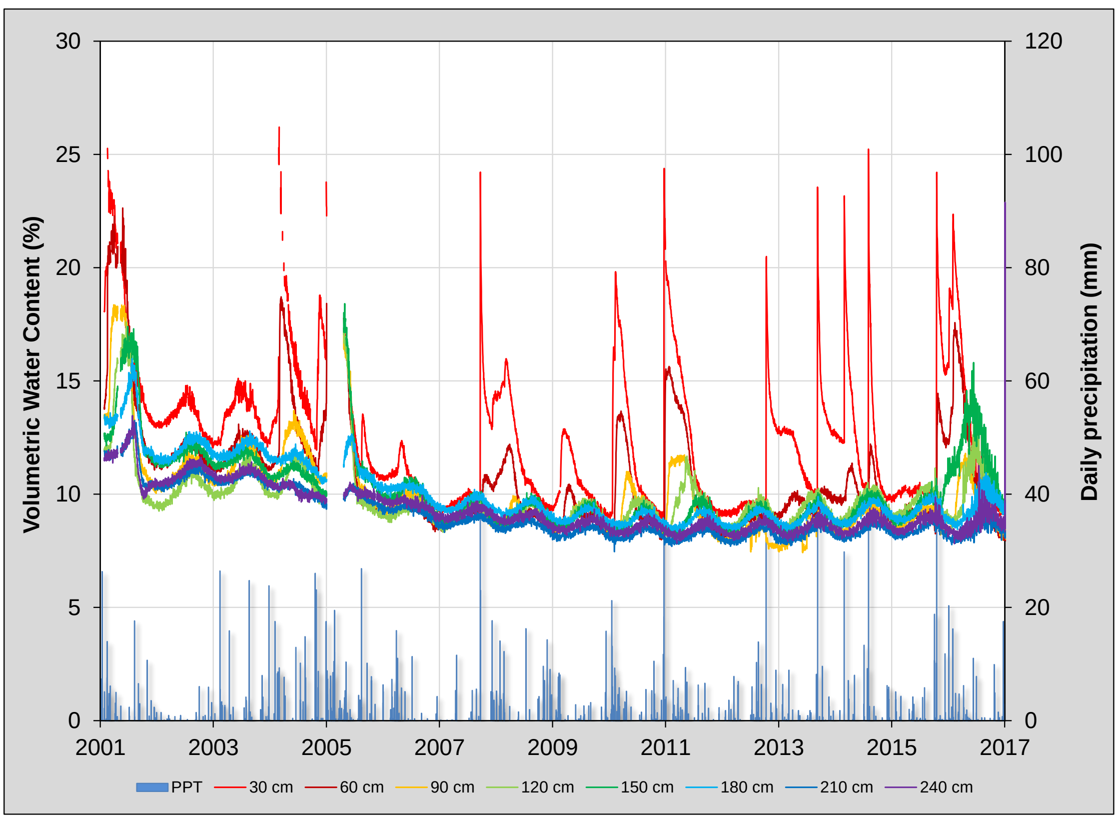

Figure 4-28. Soil Volumetric Water Content in the U-3 ax/bl Cover

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 (8 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 cm (0.25 ft), 15 cm (0.5 ft), 30 cm (1 ft), 60 cm (2 ft), 90 cm (3 ft), 120 cm (4 ft), 180 cm (6 ft), and 240 cm (8 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 fulfill data needed to reduce uncertainty in the expected performance of monolayer-ET closure covers 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 3-times natural precipitation. The 3-times natural precipitation lysimeters receive natural precipitation and are irrigated with an amount equal to 2-times natural precipitation.

The 2016 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 3-times natural precipitation; Lysimeter C is invader species with natural precipitation; Lysimeter D is invader species with 3-times natural precipitation; Lysimeters E and G are native species with natural precipitation; and Lysimeters F and H are native species with 3-times natural precipitation.

The 2016 precipitation at the drainage lysimeters was 156 mm (6.1 in.). The 2016 irrigation applied to Lysimeters B, D, F, and H was 254 mm (10.0 in.). The last ten days of 2016 saw several precipitation events and the required 2-times irrigation was not applied until 2017. There were 1,303 liters (344 gallons) of drainage from Lysimeter B during 2016. The equivalent depth of this drainage is 17.9 cm (7.0 in.). Drainage from Lysimeter B ended on October 3, 2016. The 2016 Lysimeter B drainage is 44% of total 2016 precipitation and applied irrigation.

There were 467 liters (123 gallons) of drainage from Lysimeter D during 2016. The equivalent depth of this drainage is 6.4 cm (2.5 in.). Drainage from Lysimeter D ended March 29, 2016. The 2016 Lysimeter D drainage is 16% of total 2016 precipitation and applied irrigation.

For the first time since 2005 there was drainage from Lysimeter F. There were 165 liters (44 gallons) of drainage from Lysimeter F starting on February 29, 2016, and ending on March 30, 2016. The equivalent depth of this drainage is 2.3 cm (0.9 in.). The 2016 Lysimeter F drainage is 5.5% of total 2016 precipitation and applied irrigation.

There was no drainage from any other lysimeter during 2016. Drainage has only occurred from the irrigated lysimeters. Total cumulative drainage from the beginning of the measurements for each irrigated lysimeter is 184.7 cm (72.7 in.) from Lysimeter B, 16.1 cm (6.4 in.) from Lysimeter D, 28.4 cm (11.2 in.) from Lysimeter F, and 11.0 cm (4.3 in.) from Lysimeter H (Figure 4-29).

Plant cover was measured for each of the eight drainage lysimeters on May 25, 2016. The results are summarized in Table 4-6. Invader species (annual forbs) dominated all the plots except for the two bare-soil ones during most of 2016. The native species Nevada ephedra is healthy and appears on plots E, F, G, and H, while Winterfat is growing on plots F and H but it does not appear healthy. There are no native shrubs on the non-irrigated plots E and G and revegetation will be required.

Table 4-5. Area 3 Drainage Lysimeter Treatments in 2016

Lysimeter	Climate	Surface Vegetation	Precipitation & Irrigation (mm)	Drainage (mm)	Drainage (%)
A	Natural precipitation	Bare-soil	156	0	0%
B	3-times natural precipitation	Bare-soil	410	179	44%
C	Natural precipitation	Invader	156	0	0%
D	3-times natural precipitation	Invader	410	64	16%
E	Natural precipitation	Native	156	0	0%
F	3-times natural precipitation	Native	410	23	5.5%
G	Natural precipitation	Native	156	0	0%
H	3-times natural precipitation	Native	410	0	0%

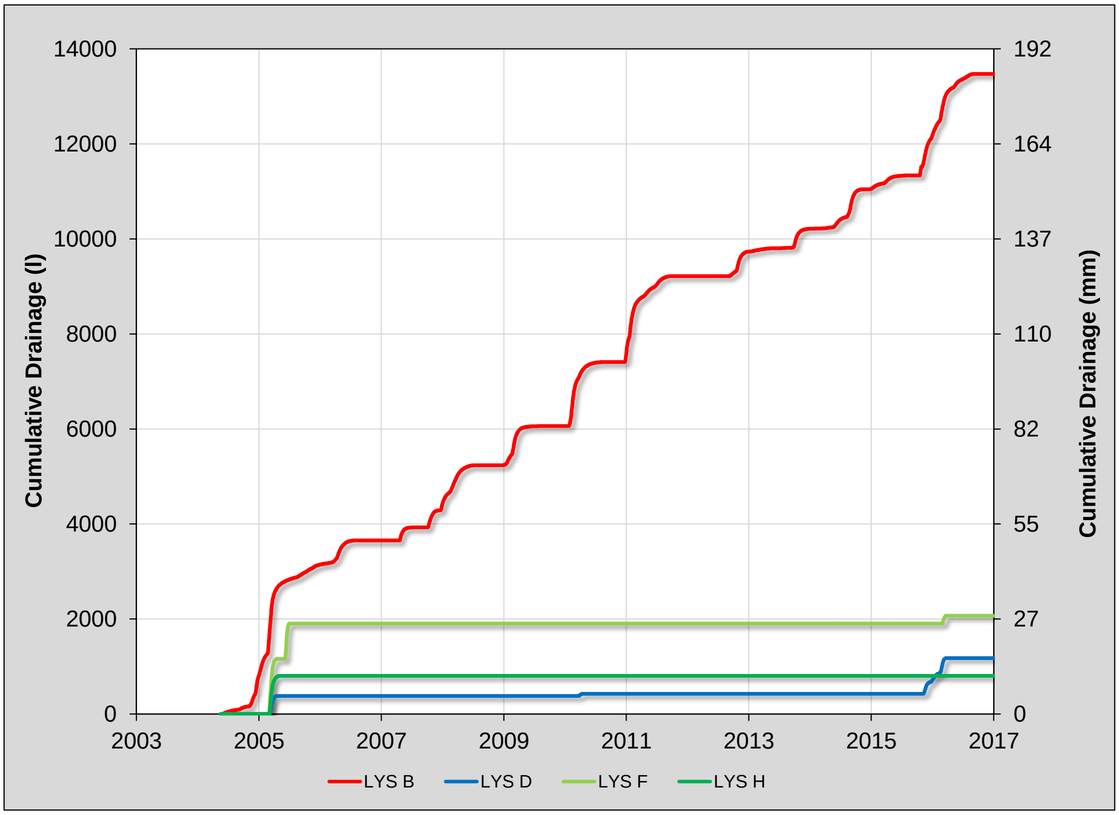

Figure 4-29. Cumulative Drainage from the Drainage Lysimeters

Table 4-6. Area 3 Drainage Lysimeter Percent Cover in 2016

Lysimeter	Plant Cover (percent)	Bare (percent)	Gravel (percent)	Litter (percent)
A	0	30	68	2
B	0	30	68	2
C	38	25	32	5
D	90	0	0	10
E	63	12	2	23
F	75	5	0	20
G	55	23	2	20
H	75	7	0	18

Figure 4-30 shows the total water storage for all eight lysimeters from 2006 through 2016. 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, 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 bare-soil Lysimeter B (3x precipitation) generally fluctuates between 60 and 70 cm of storage, while Lysimeter A (natural precipitation) fluctuates between 40 and 50 cm of storage. These simulate a bare-soil waste cover and only dry out to a certain depth. The invader species Lysimeter C (heavy green line) has performed about the same as the native species lysimeters (heavy red and gold lines) at removing water, but invader Lysimeter D with 3x precipitation (light green line) did not evapotranspirate as much water as the native species lysimeters (light red and gold lines). This was especially evident in 2015 when the evader species on plot D were virtually non-existent from the summer of 2014 into the dry spring of 2015. This is shown by the plot D green line rising and eventually reaching a water storage level that produced drainage out the bottom of the lysimeter. After the large September 2015 rain event, the native plant lysimeters with natural precipitation appear to be performing much as they did after the other large rain events in the spring of 2010 and 2011 when they reached a storage depth above 30 cm and then after several months approached a storage depth of 20 cm.

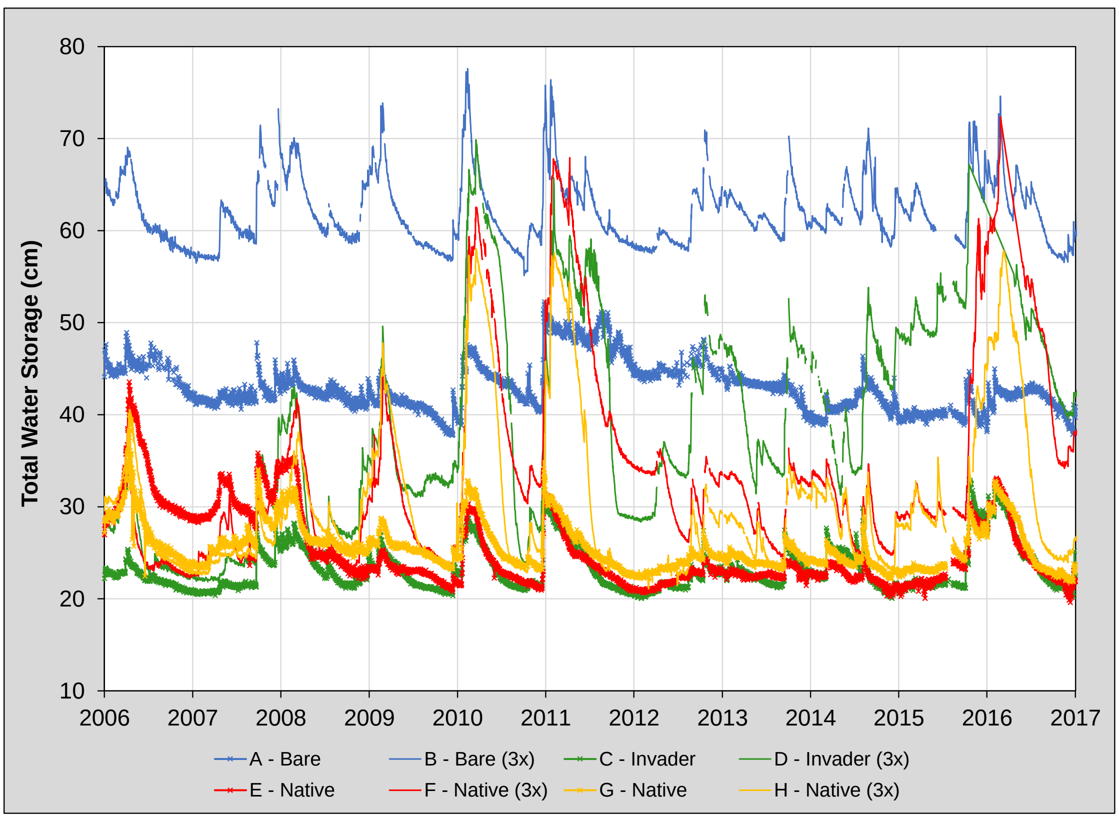

Figure 4-30. Soil Water Storage in the Drainage Lysimeters

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 entire RWMS. Typically, as small depressions or cracks are observed in operational covers, they are filled before large subsidence features develop.

Inspections of the U-3ax/bl final ET cover were changed from quarterly in 2015 to bi-annual in 2016 and check for evidence of cracks, settling, erosion, and subsidence. Inspections were done on June 22 and December 6, 2016. No repairs were needed after the June inspection. On the December inspection, three use restriction signs were faded and illegible and were required to be replaced.

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 done 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 [NNSA/NFO], 2014). The last survey of the U-3ax/bl cover was done on June 27, 2016. The measured subsidence at each marker was 1.5, 1.6, 0.8, 2.0, 4.1, 1.6, and 1.9 cm (0.05, 0.05, 0.03, 0.07, 0.13, 0.05, and 0.06 ft) for an average subsidence of 1.9 cm (0.06 ft).

Quarterly inspections of the 92-Acre Area final ET cover check for evidence of cracks, settling, erosion, and subsidence. This cover is also inspected when more than 2.5 cm (1.0 in.) of precipitation occurs during a day. Quarterly inspections were done on March 2, June 22, September 19, and December 6. After the March inspection, a crack on the north cover and several areas of subsidence and cracking on the south and west covers were repaired on April 20, 2016. After the June inspection, cracks on the west and south covers and erosion on the south cover were repaired on August 4, 2016. After the September inspection, cracks on the west cover were repaired on October 26, 2016. After the December inspection, cracks and subsidence on the west, south, and north covers were repaired on January 26, 2017.

Fifty-two subsidence markers were installed in the 92-Acre Area cover, and an initial elevation survey of these markers was completed in January 2012. Subsidence was last measured at each marker in May 2016. The average subsidence at the 52 subsidence markers was 1.2 cm (0.04 ft), and the median subsidence was 0.9 cm (0.03 ft).

4.8 BIOTA MONITORING DATA

The U-3ax/bl cover was seeded with native vegetation during December 2000. Quantitative analyses of the vegetative cover on the U-3ax/bl cover have been conducted annually in the spring from 2001 until 2014. After the 2014 inspection, the interval was increased from annually to every five years. A qualitative survey was done on July 14, 2016, and Shadscale (Atriplex confertifolia) continues to be the most abundant shrub species on the closure cover. None of the plants observed showed signs of stress. Current annual growth, evidenced by new leaves and stems, was good. Nevada jointfir (Ephedra nevadensis), the second most common perennial species showed good growth. The other shrubs occasionally encountered on the closure cover, winterfat (Krascheninnikovia lanata) and fourwing saltbush (Atriplex canescens), also showed signs of significant annual growth.

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5.0 CONCLUSION

The 2016 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 any 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 2016 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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