DOE/NV/25946--1226

NEVADA NATIONAL SECURITY SITE
2010 WASTE MANAGEMENT MONITORING REPORT
AREA 3 AND AREA 5 RADIOACTIVE WASTE MANAGEMENT SITES

June 2011

Prepared for:

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

Prepared by:

National Security Technologies, LLC
Las Vegas, Nevada

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EXECUTIVE SUMMARY

Environmental monitoring data were collected at and around the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs) at the Nevada National Security Site (NNSS). These data are associated with radiation exposure, air, groundwater, meteorology, vadose zone, subsidence, and biota. This report summarizes the 2010 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, 2010a; 2010b; 2011).

Direct radiation monitoring data indicate exposure levels at the RWMSs are within the range of background levels measured at the NNSS. Air monitoring data at the Area 3 and Area 5 RWMSs indicate that tritium concentrations are slightly above background levels. All gamma spectroscopy results for air particulates collected at the Area 3 and Area 5 RWMS were below the minimum detectable concentrations, and concentrations of americium and plutonium are only slightly above detection limits. The measured levels of radionuclides in air particulates and moisture are below derived concentration guides for these radionuclides. Groundwater monitoring data indicate that the groundwater in the uppermost aquifer beneath the Area 5 RWMS is not impacted by facility operations. The 246.9 millimeters (mm) (9.72 inches [in.]) of precipitation at the Area 3 RWMS during 2010 is 56 percent above the average of 158.7 mm (6.25 in.), and the 190.4 mm (7.50 in.) of precipitation at the Area 5 RWMS during 2010 is 50 percent above the average of 126.7 mm (4.99 in.). Soil-gas tritium monitoring at borehole GCD-05 continues to show slow subsurface migration consistent with previous results. Water balance measurements indicate that evapotranspiration from the vegetated weighing lysimeter dries the soil and prevents downward percolation of precipitation more effectively than evaporation from the bare-soil weighing lysimeter. Data from the automated vadose zone monitoring system for the operational waste pit covers show that moisture from precipitation did not percolate below 90 centimeters (cm) (3 feet [ft]) before being removed by evaporation. Moisture from precipitation did not percolate below 61 cm (2 ft) in the vegetated final mono-layer cover on the U-3ax/bl disposal unit at the Area 3 RWMS before being removed by evapotranspiration. During 2010, there was no drainage through 2.4 meters (8 ft) of soil from the Area 3 drainage lysimeters that received only natural precipitation. Water drained from both the bare-soil drainage lysimeter and the invader species drainage lysimeter that received 3 times natural precipitation.

All 2010 monitoring data indicate that the Area 3 and Area 5 RWMSs are performing within expectations of the model and parameter assumptions for the facility PAs.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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
C	carbon
CAU	Corrective Action Unit
CFR	Code of Federal Regulations
Ci	curie(s)
cm	centimeter(s)
Cs	cesium
DCG	Derived Concentration Guide
DOE	U.S. Department of Energy
E	evaporation
ET	evapotranspiration
ET_{ref}	reference evapotranspiration
°F	degrees Fahrenheit
ft	foot; feet
ft^3	cubic feet
GCD	greater confinement disposal
IL	investigation level
in.	inch(es)
km	kilometer(s)
kPa	kilopascal(s)
LLW	low-level waste
$\mu Ci/m^3$	microcurie(s) per cubic meter
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)
mm	millimeter(s)
mmhos/cm	millimho(s) per centimeter

mph	mile(s) per hour
mR	milliroentgen(s)
mR/day	milliroentgen(s) per day
mR/yr	milliroentgen(s) per year
mrem	millirem(s)
mrem/yr	millirem(s) per year
NNSS	Nevada National Security Site
NSTec	National Security Technologies, LLC
PA	Performance Assessment
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
RREMP	Routine Radiological Environmental Monitoring Plan
RWMS	Radioactive Waste Management Site
SC	specific conductance
Sr	strontium
TDR	time-domain reflectometry
Tc	technetium
TLD	thermoluminescent dosimeter
TOC	total organic carbon
TOX	total organic halides
VWC	volumetric water content

1.0 INTRODUCTION

This document summarizes the calendar year 2010 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], 2007) 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 *Integrated Closure and Monitoring Plan for the Area 3 and Area 5 Radioactive Waste Management Sites at the Nevada Test Site* (BN, 2005c) 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 confirm compliance with National Emission Standards for Hazardous Air Pollutants
- Groundwater monitoring conducted, 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 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 operational monolayer-evapotranspirative waste covers
- Soil-gas monitoring for tritium conducted to evaluate tritium movement at waste containment cell GCD-05
- Biota monitoring for tritium and other radionuclides conducted to evaluate the upward pathway through the waste covers
- Subsidence monitoring conducted to ensure that subsidence features are repaired to prevent the development of preferential pathways through the covers

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 Integrated Closure and Monitoring Plan (BN, 2005c) and the Area 5 RWMS Closure Plan (NSTec, 2008). These regulatory drivers exist to mitigate risk to the public and environment and include the following:

- DOE O 435.1, “Radioactive Waste Management”
- DOE O 450.1A, “Environmental Protection Program”
- DOE O 5400.5, “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 long axis extends approximately 27 kilometers (km) (17 miles [mi]), and the 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, the Massachusetts Mountains 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, 2007).

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 (1,200 and 1,500 ft) (BN, 2005b).

Based on a 21-year record from 1981 to 2001 at location Buster-Jangle Y (BJY) (4.5 km 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 50-year period from 1961 through 2010 is 163.4 millimeters (mm) (6.43 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 (Air Resources Laboratory, Special Operations and Research Division [ARL/SORD], 2011). 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).

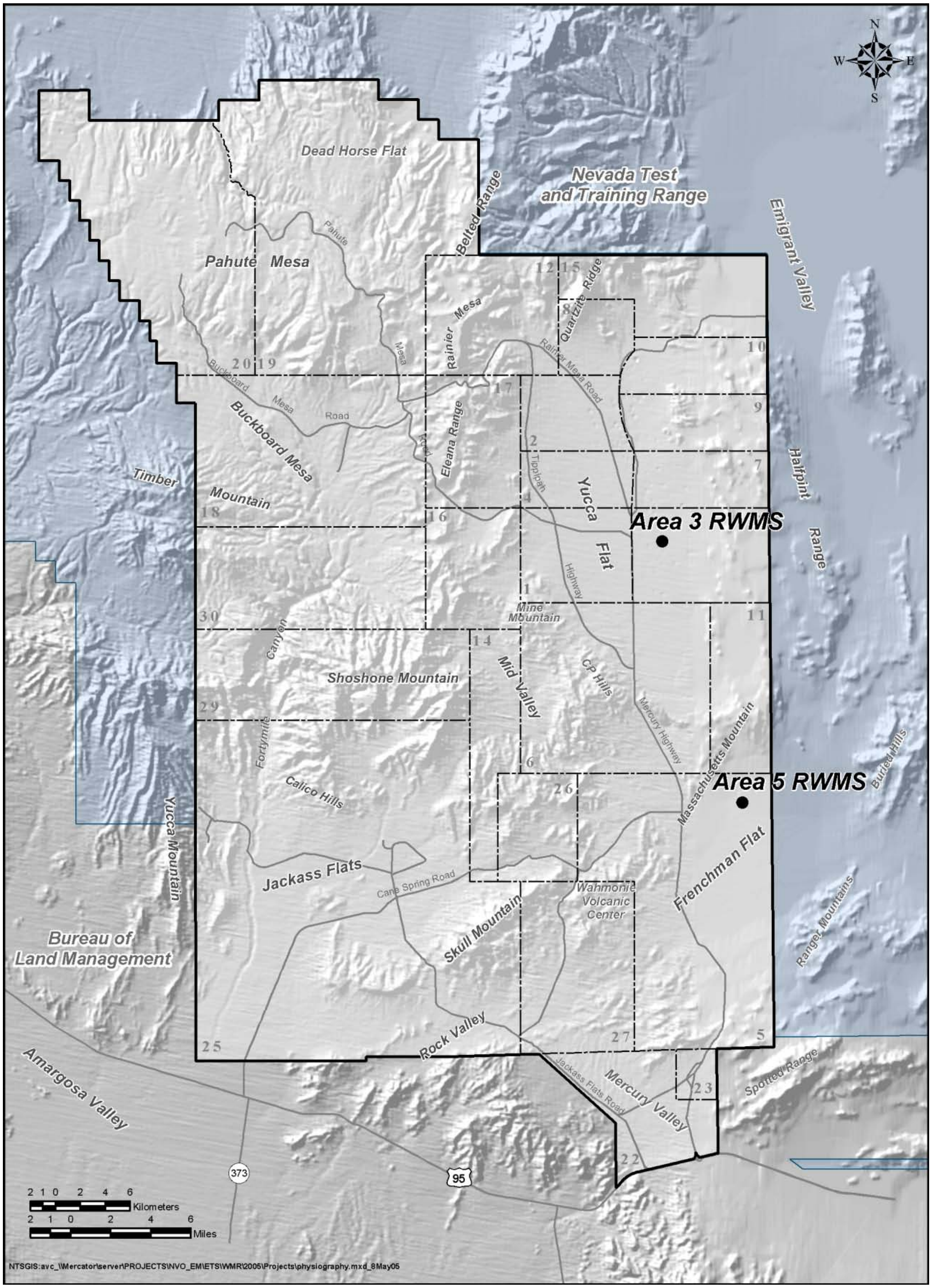

Figure 2-1. Location of the Area 3 and Area 5 RWMSs

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 the Massachusetts Mountains 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 235.8 m (773.6 ft) at the southeast corner of the RWMS (Well UE5PW-1), 256.4 m (841.2 ft) at the northeast corner (Well UE5PW-2), and 271.5 m (890.7 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, 2005a). 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 2010 is 733.6 m (2,406.8 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 48-year period from 1963 through 2010 is 123.9 mm (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 (ARL/SORD, 2011). Annual ET_{ref} at the Area 5 RWMS, calculated using local meteorology data, is approximately 13 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 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 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 160 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 (160 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). 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), 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).

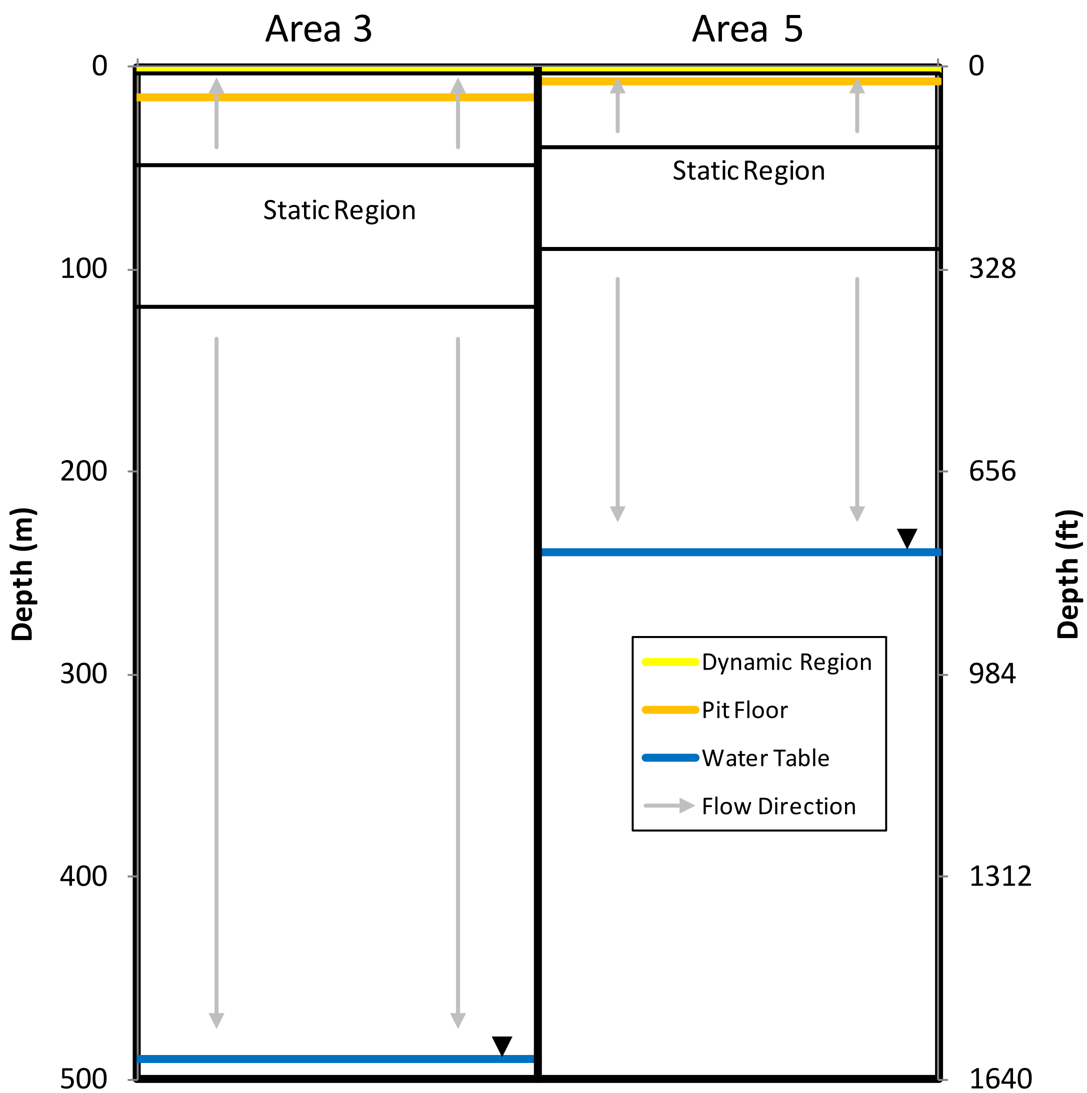

Figure 2-2. Vadose Zone Conceptual Models of the Area 3 and Area 5 RWMSs

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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 waste that is generated at the NNSS, from DOE offsite locations, and from other approved offsite generators.

3.1 AREA 3 RWMS

Waste disposal cells within the Area 3 RWMS are subsidence craters resulting from underground nuclear testing. The seven craters within the Area 3 RWMS ranged from 122 to 177 m (400 to 580 ft) in diameter and from 14 to 32 m (46 to 105 ft) in depth at the time of formation (Plannerer, 1996). Five of these craters have been used for waste disposal. 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. Craters U-3ax and U-3bl were combined to form the U-3ax/bl disposal unit (Corrective Action Unit [CAU] 110), which is now covered with a vegetated, native alluvium, evapotranspiration (ET) cover that is at least 2.4 m (8 ft) thick. The cover was constructed in 2000. For details of the final closure plan of CAU 110, refer to BN (2001). Disposal in the combined unit U-3ah/at began in 1988. Disposal cell U-3ah/at has been used for disposal of bulk LLW from the NNSS and approved offsite generators. Crater U-3bh was originally used for disposal of contaminated soils from the Tonopah Test Range in 1997 and has been used since for waste disposal from other approved generators. The remaining two craters are not in use (Figure 2-1). For a detailed description of the facilities at the Area 3 RWMS, refer to Shott et al. (1997) and NSTec (2007). No waste has been disposed at the Area 3 RWMS since 2006.

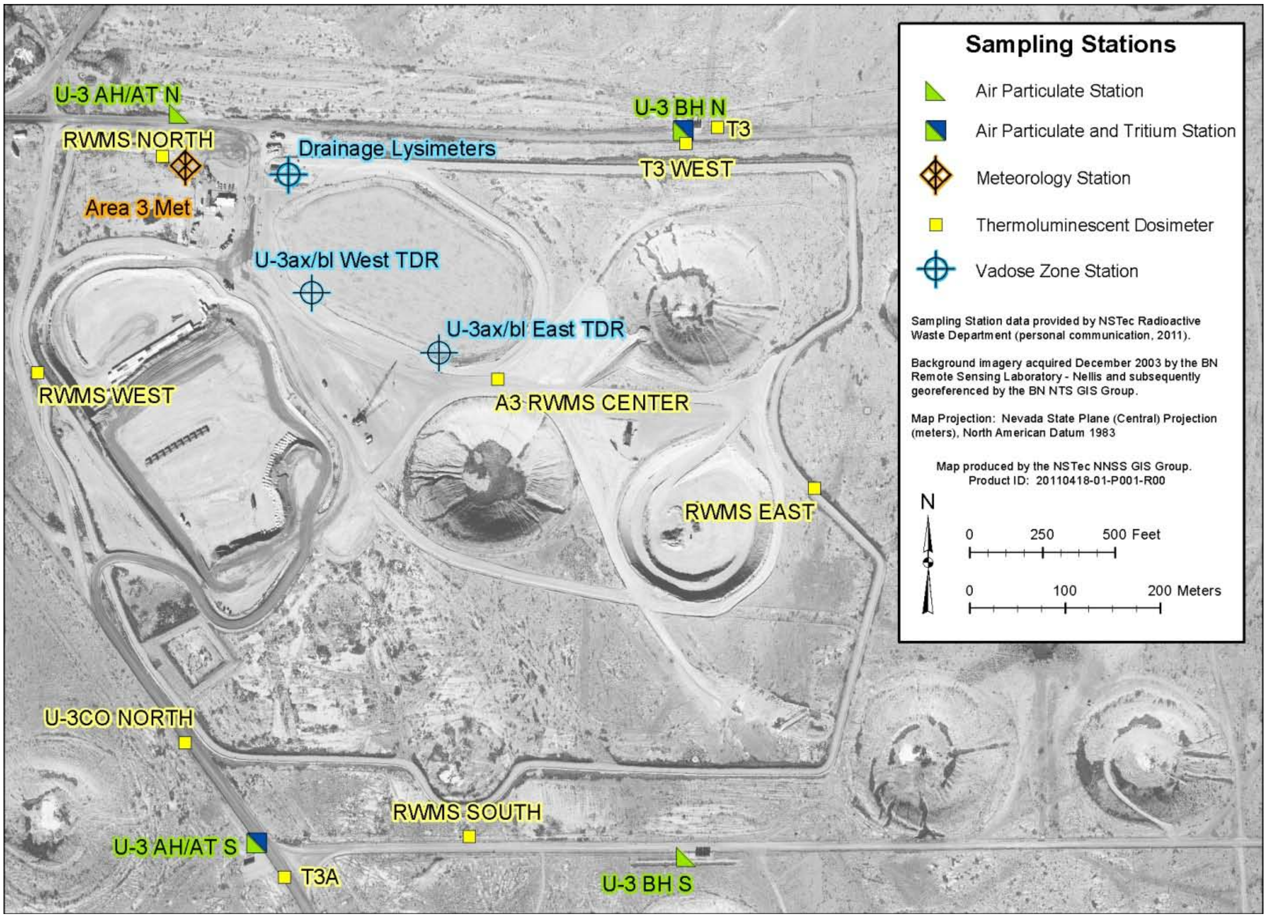

Figure 3-1. Monitoring Locations at the Area 3 RWMS

3.2 AREA 5 RWMS

Waste disposal has occurred at the Area 5 RWMS since the early 1960s. The Area 5 RWMS consists of 32 landfill cells (pits and trenches) and 13 greater confinement disposal (GCD) boreholes (Figure 3-2 and Figure 3-3). Some previous documents list fewer landfill cells, but new cells continue to be constructed, and Trench 4 was separated into T04A and T04A1 (BN, 2005c). Pits and trenches range in depth from 4.6 to 15 m (15 to 48 ft). The unlined 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 (2005c; 2006) and Cochran et al. (2001).

Waste was disposed in nine pits at the Area 5 RWMS during 2010. The pits that received waste are P03, P06, P10, P12, P13, P14, P15, P16, and P17. P03 was the only active mixed waste disposal cell during 2010, and P06 contains asbestiform LLW. All other active pits contain LLW. P03, P06, and P15 received their last waste in 2010. Landfill cells that have been operationally closed to date include all 16 trenches and 11 pits. The 11 closed pits are P01, P02, P03, P04, P05, P06, P07, P08, P09, P11, and P15. All 13 GCD boreholes are inactive and have not received waste since 1989. Seven GCD boreholes are operationally closed (GCDT, GCD01, GCD02, GCD03, CGD04, GCD05, and GCD10). These boreholes are filled with waste to approximately 20 m (65 ft) below the surface and backfilled with native soil to the surface. Boreholes GCD06 and GCD07 are partially filled, and GCD08, GCD09, GCD11, and GCD12 are empty.

Preliminary closure work for the approximately 92-acre area in the southern portion of the Area 5 RWMS began in 2010. Fencing, signs, monuments, and utilities were removed from this area. Casing was removed from approximately 50 shallow boreholes, and these boreholes were filled with cement. GCD06, GCD07, GCD08, GCD09, GCD11 and GCD12 were backfilled to the surface with native soil, and the sampling apparatus for GCD05 was removed. Preliminary grading for final closures started.

Construction was completed on P18, P19, and P20, but no waste was disposed in these cells in 2010. P18 is a Resource Conservation and Recovery Act–compliant, lined mixed waste cell. P19 and P20 are unlined LLW cells.

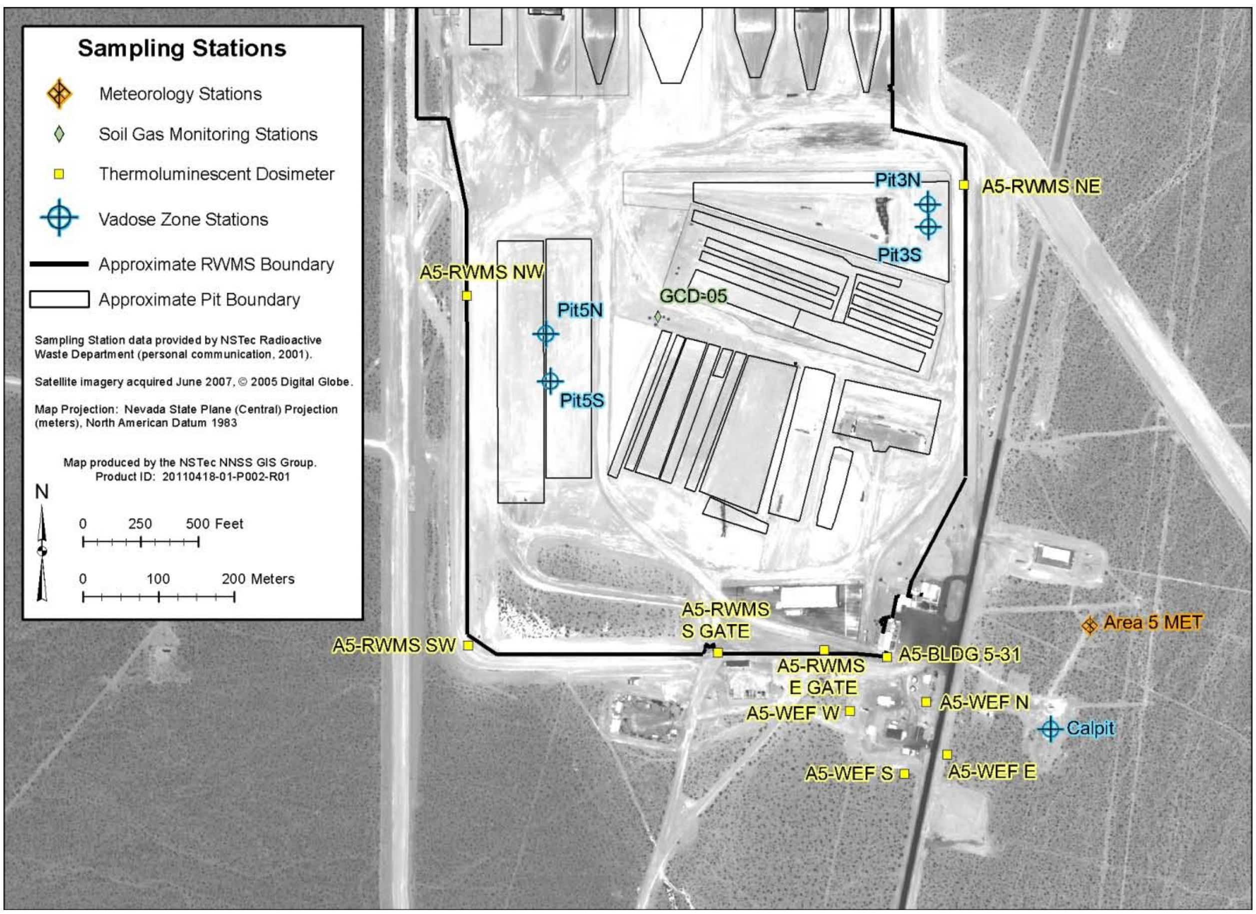

Figure 3-2. Monitoring Locations at the Area 5 RWMS

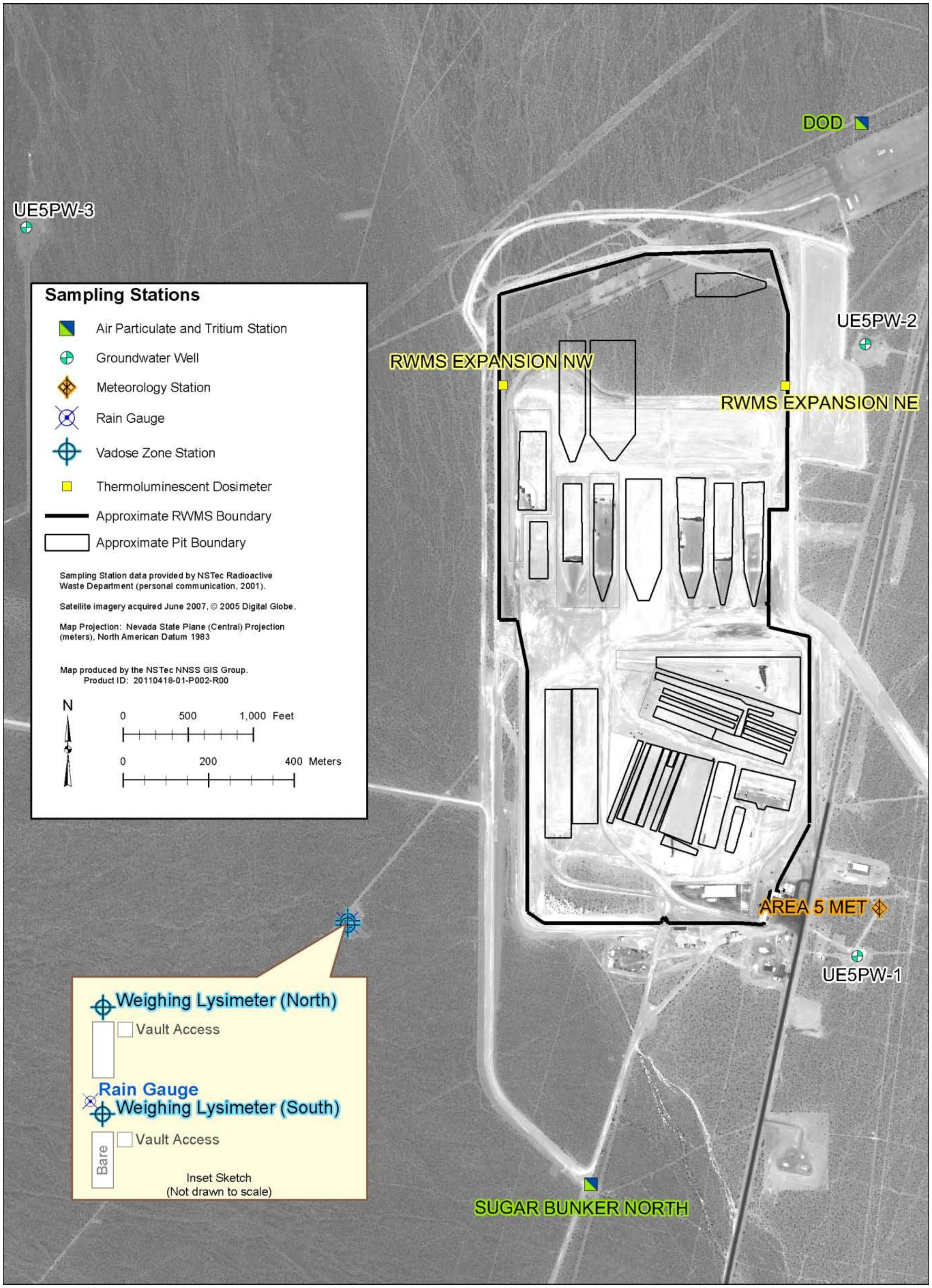

Figure 3-3. Pilot Wells, Weighing Lysimeters, and Air Monitoring at the Area 5 RWMS

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 and Figure 3-3. This report provides a general description and graphical representations of some of these data. Monitoring data being collected include:

- Radiation Exposure Data
  - Quarterly thermoluminescent dosimeter (TLD) measurements
- Air Monitoring Data
  - Weekly Data
    - Alpha concentrations
    - Beta concentrations
  - Biweekly Data
    - Tritium concentrations
  - Monthly Data
    - Gamma concentrations
    - Americium (Am) concentrations
    - Plutonium (Pu) concentrations
  - Periodic radon flux measurements from waste covers
- Groundwater Monitoring Data
  - Quarterly Water-Level Measurements
  - Semiannual Indicators of Contamination
    - pH (field measurement)
    - Specific conductance (SC) (field measurement)
    - Total organic carbon (TOC)
    - Total organic halides (TOX)
    - Tritium
  - Semiannual General Water Chemistry Parameters
    - Total calcium, iron, magnesium, manganese, potassium, sodium, silicon
    - Total sulfate, chloride, fluoride
    - Alkalinity
  - Biennial RREMP Analyses
    - Gross alpha
    - Gross beta
    - Gamma spectroscopy
    - Plutonium (^{238}Pu and $^{239+240}$Pu)
  - Triennial RREMP Analyses for Specific Radionuclides
    - Strontium-90 (^{90}Sr)
    - Technetium-99 (^{99}Tc)
    - Carbon-14 (^{14}C)

- Meteorology Monitoring Data
  - Daily Meteorology Data
    - Average air temperature at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) above ground level (AGL)
    - Maximum air temperature at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Minimum air temperature at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Average relative humidity at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Maximum relative humidity at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Minimum relative humidity at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Average wind speed at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Maximum wind speed at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Average barometric pressure
    - Maximum barometric pressure
    - Minimum barometric pressure
    - Total precipitation
  - Hourly Meteorology Data
    - Average air temperature at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Average relative humidity at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Average wind speed at 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Average wind direction 3.0 m (9.8 ft) and 9.5 m (31.1 ft) AGL
    - Average barometric pressure
    - Average solar radiation
    - Total precipitation
- Vadose Zone Monitoring Data
  - Annual Soil Gas Monitoring Data (soil gas tritium concentrations measured at GCD-05 gas sampling ports [nine depths])
  - Weighing Lysimeter Data (Area 5)
    - Daily and hourly E from the bare-soil weighing lysimeter
    - Daily and hourly ET from the vegetated weighing lysimeter
    - Daily and hourly precipitation and 5-minute precipitation rates
    - Daily soil volumetric water content (VWC) and soil water potential
    - Hourly soil temperature with depth
  - Drainage Lysimeter Data (Area 3)
    - Daily Soil VWC, soil water potential, and water storage with depth
    - Hourly temperature with depth
    - Daily and hourly drainage from each lysimeter
  - Daily Automated Vadose Zone Monitoring System Data
    - Soil VWC with depth in waste covers
    - Soil VWC beneath waste cells
    - Soil water potential with depth in waste covers
    - Soil temperature with depth in waste covers

- Periodic Subsidence Monitoring Data: Locations and descriptions of subsidence features on waste covers
- Biota Monitoring Data: Periodic analysis of plant and animal samples for tritium and other radionuclide concentrations

4.2 RADIATION EXPOSURE DATA

The goals of direct radiation monitoring are to assess the external radiation environment, to detect changes in that environment, and to measure gamma radiation levels near potential exposure sites. Performance objectives in DOE O 435.1 require that LLW disposal facilities be sited, designed, operated, maintained, and closed, so it is reasonable to expect a less than 25 millirem per year (mrem/yr) total effective dose equivalent to representative members of the public from the facility. The effective dose equivalent is from all exposure pathways associated with the facility, but does not include the dose from radon and the background dose. Because the RWMSs are located well within the NNSS boundaries, 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 year-round 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. These elements are used to 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, Figure 3-2, and Figure 3-3 show TLD monitoring locations near the Area 3 and Area 5 RWMSs. At each location, a pair of TLDs is placed at 1 ± 0.3 m (28 to 51 in.) AGL and are 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. Waste pits in the Area 3 RWMS are subsidence craters from seven subsurface tests that are being filled with LLW. 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 in milliroentgen per year (mR/yr) during 2010 at locations inside and near the Area 3 RWMS are shown in 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 historical aboveground nuclear weapons test locations in close proximity to these locations. Given this, radionuclides in the Area 3 RWMS contributed negligible external exposure to a hypothetical person residing at the Area 3 RWMS. Estimated daily exposure rates in milliroentgen per day (mR/day) from the quarterly exposure rate data at the Area 3 RWMS are presented in 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. Estimated daily exposure rates from the quarterly exposure data at the Area 5 RWMS are within the range of exposures measured at NNSS background locations (Figure 4-3).

Comparisons of 1998 to 2010 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).

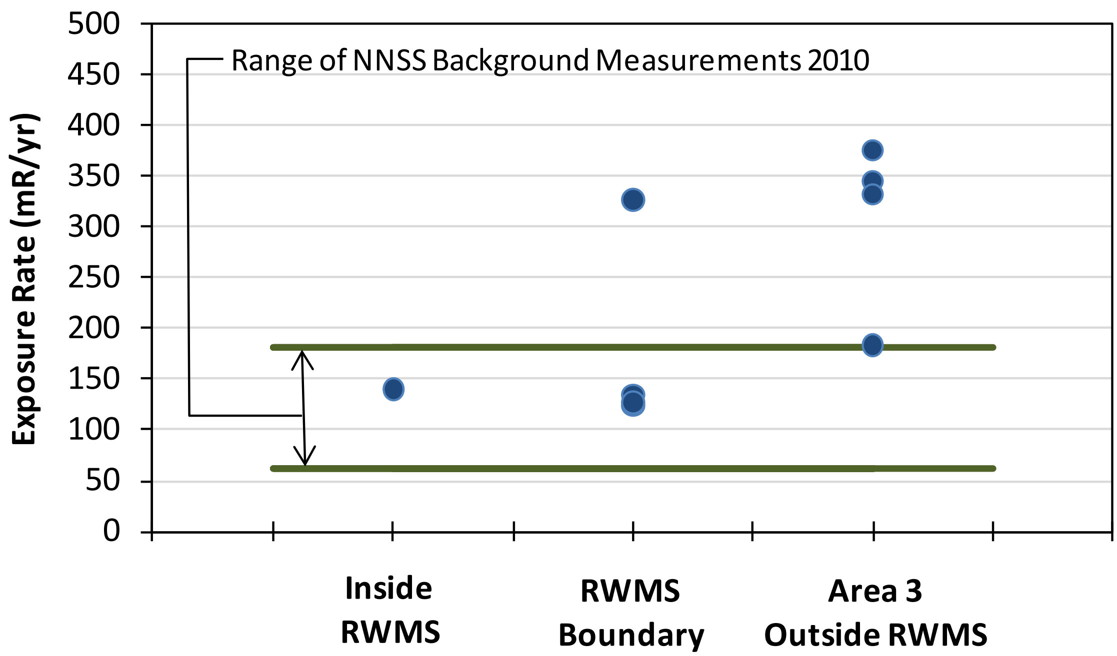

Figure 4-1. Annual Radiation Exposure Rates at the Area 3 RWMS

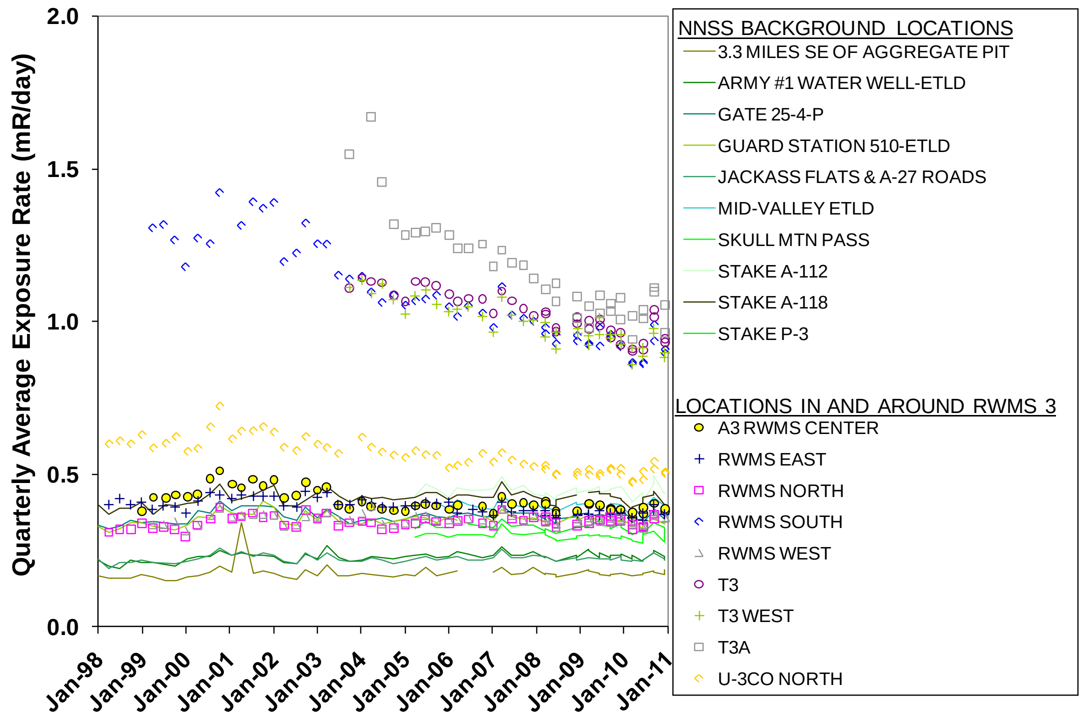

Figure 4-2. Quarterly Average Daily Exposure Rates at the Area 3 RWMS and NNSS Background TLD Locations from 1998 to 2010

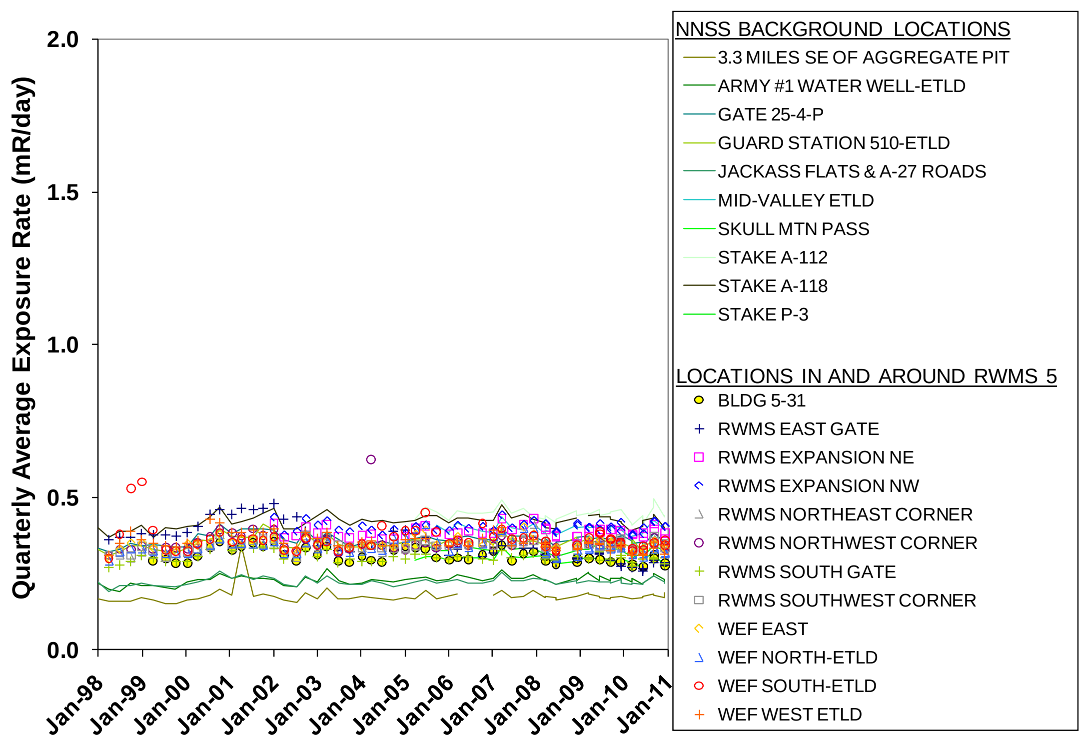

Figure 4-3. Quarterly Average Daily Exposure Rates at the Area 5 RWMS and NNSS Background TLD Locations from 1998 to 2010

4.3 AIR MONITORING DATA

4.3.1 Tritium

Tritium is a highly mobile isotope of hydrogen that acts as a conservative tracer and is therefore 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. The moisture is distilled from the desiccant, and the tritium activity is measured by liquid scintillation.

The two tritium monitoring locations at the Area 3 RWMS are U-3bh N and U-3ah/at S (Figure 3-1). The two Area 5 RWMS monitoring locations are DoD, which is approximately 1.0 km (0.6 mi) north of the Area 5 RWMS, and Sugar Bunker, which is approximately 1.5 km (0.9 mi) south of the Area 5 RWMS (Figure 3-3). These monitoring locations are in the prevailing downwind directions to provide adequate environmental monitoring for each RWMS.

During 2010, tritium concentrations at the Area 3 and Area 5 RWMSs ranged from −0.73 to 3.72 picocuries per cubic meter (pCi/m^3) with all results well below the DOE Derived Concentration Guide (DCG) (DOE O 5400.5) for tritium adjusted to the 25 mrem/yr exposure specified in DOE O 435.1. In general, higher tritium concentrations occur in June through October (Figure 4-4).

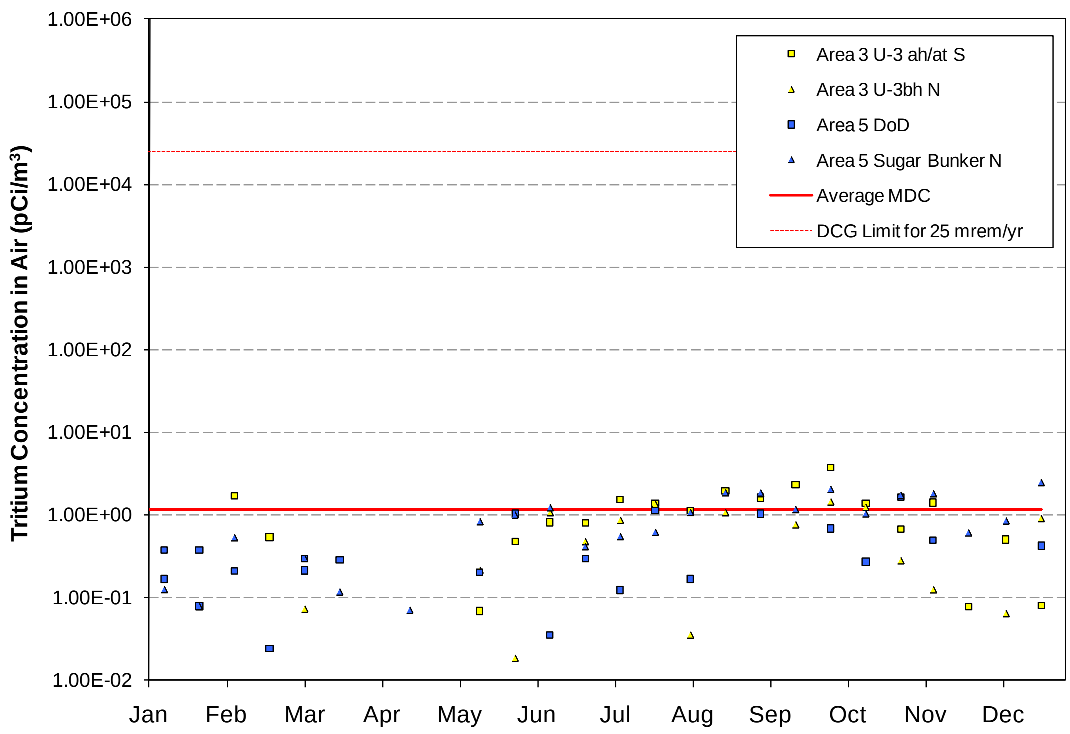

Figure 4-4. Tritium Concentration in Air at the Area 3 and Area 5 RWMSs during 2010

4.3.2 Particulates

Air particulate samples are collected weekly on glass-fiber filters near each RWMS and are screened for gross alpha and gross beta radioactivity to provide early detection of any change in environmental concentrations of airborne radioactivity. Monthly composites of the filters from each sampling location are analyzed by gamma spectroscopy for gamma-emitting radioactivity and by radiochemical analyses for americium and plutonium.

The four air particulate monitoring locations at the Area 3 RWMS are U-3bh N, U-3bh S, U-3ah/at N, and U-3ah/at S (Figure 3-1). The two air particulate monitoring locations at the Area 5 RWMS are DoD and Sugar Bunker (Figure 3-2).

All gamma spectroscopy results for man-made radionuclides from 2010 are below their associated sample-specific minimum detectable concentration (MDC). The alpha spectroscopy results from 2010 for each location are above the MDCs in 33 to 75 percent of the samples for ^{241}Am (Figure 4-5), above the MDCs in 8 to 33 percent of samples for ^{238}Pu (Figure 4-6), and above the MDCs in 17 to 92 percent of samples for $^{239+240}$Pu (Figure 4-7). The americium and plutonium concentrations at the Area 3 RWMS are slightly higher than at the Area 5 RWMS. There is no indication that RWMS operations contributed americium or plutonium activity above normal variability observed at all locations. All measured concentrations of americium and plutonium were below the DCG, adjusted to 25 mrem/yr for each radionuclide.

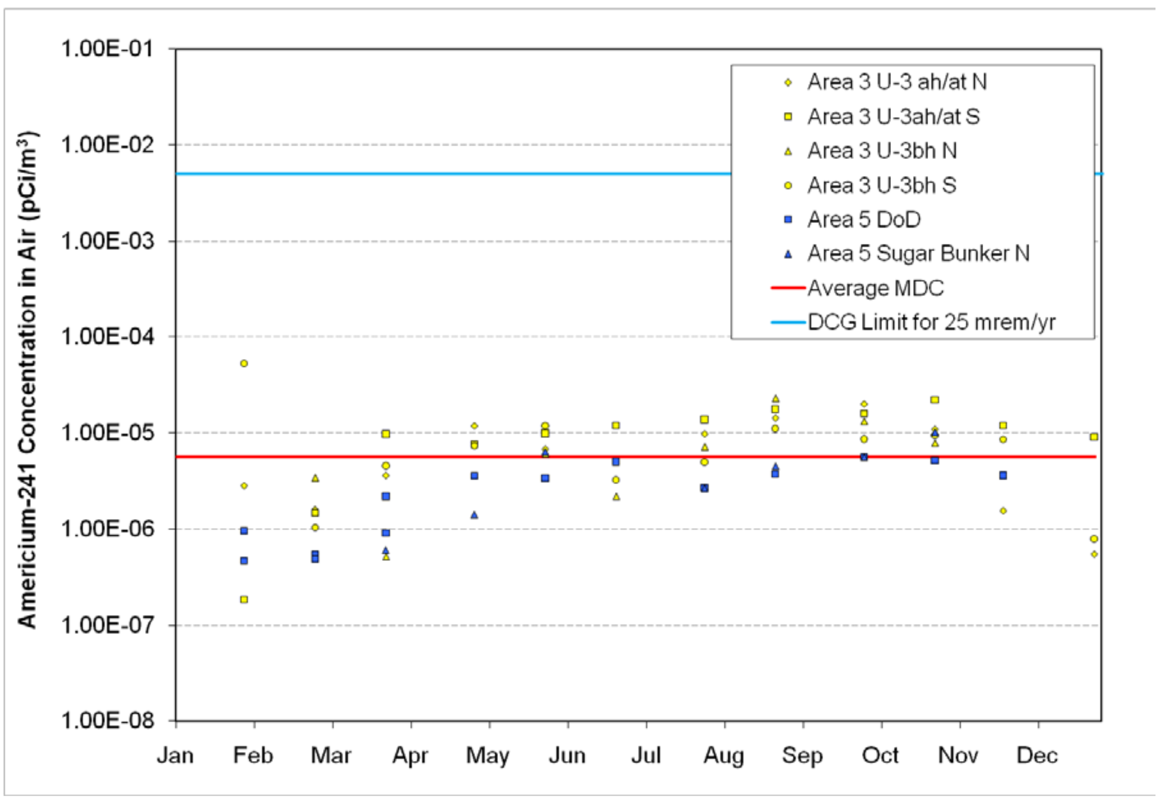

Figure 4-5. Concentration of ^{241}Am in Air at the Area 3 and Area 5 RWMSs during 2010

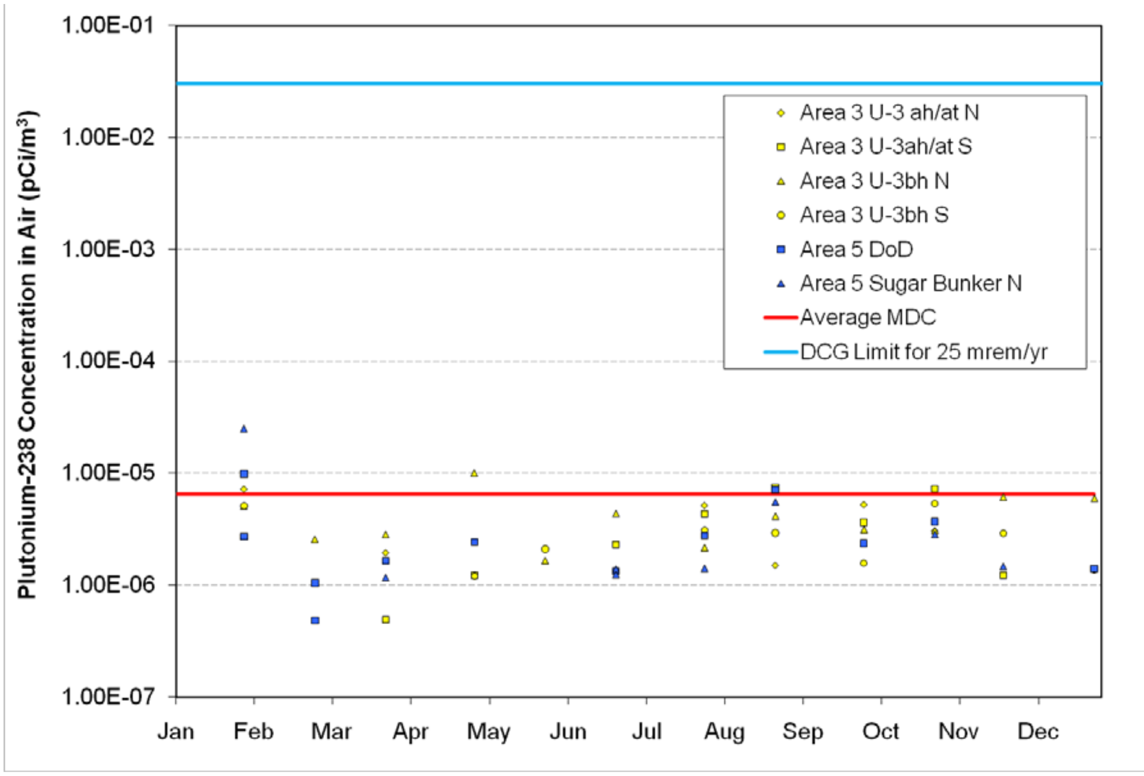

Figure 4-6. Concentration of ^{238}Pu in Air at the Area 3 and Area 5 RWMSs during 2010

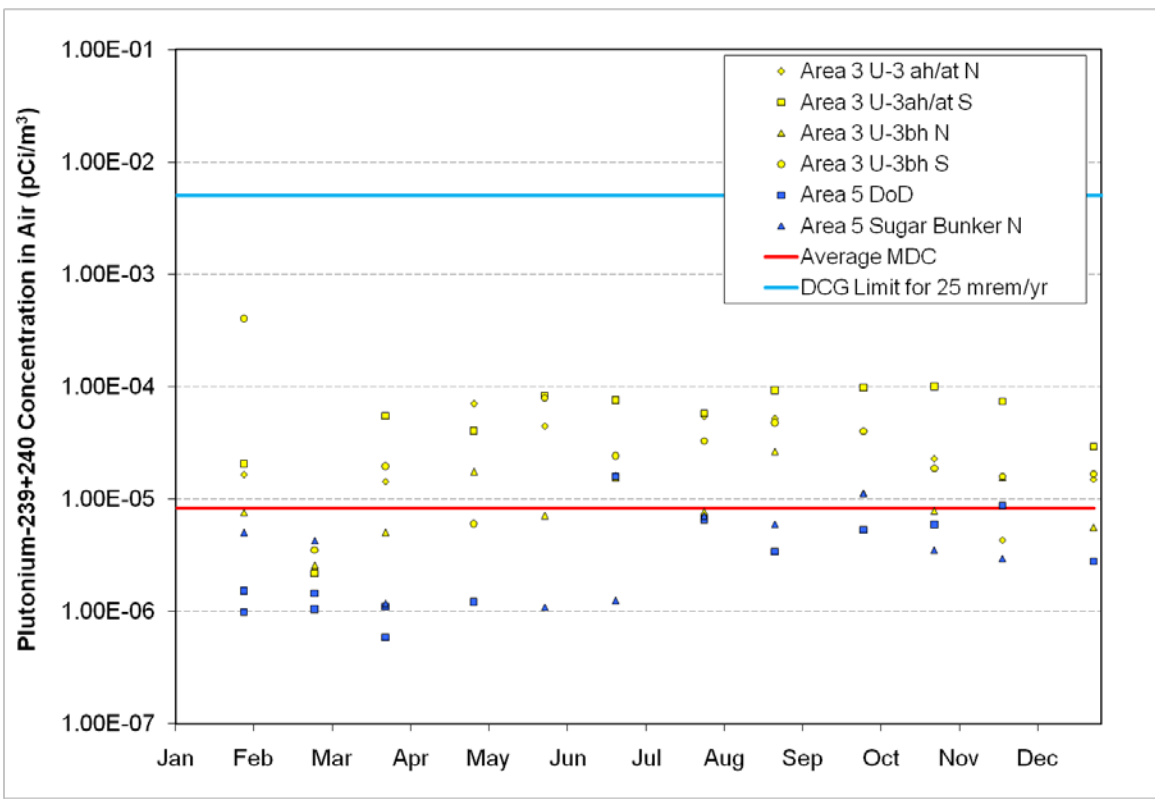

Figure 4-7. Concentration of $^{239+240}$Pu in Air at the Area 3 and Area 5 RWMSs during 2010

4.3.3 Radon

No radon flux measurements were made at the Area 3 and Area 5 RWMSs during 2010.

4.4 GROUNDWATER MONITORING DATA

Three wells (UE5PW-1, UE5PW-2, and UE5PW-3) were drilled around the perimeter of the Area 5 RWMS in 1993 (see Figure 3-3). These wells are sampled twice a year to monitor the groundwater below the Area 5 RWMS. During 2010, these wells were sampled in March and August. 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 2010 are summarized in Table 1. General water chemistry parameters are also measured.

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 2010 Data Report: Groundwater Monitoring Program, Area 5 Radioactive Waste Management Site* (NSTec, 2011).

Table 1. Investigation Levels and Results from 2010 Groundwater Monitoring

Indicator Parameter	Investigation Level	Results
pH	<7.6 or >9.2	8.13 to 8.39
SC	0.440 mmhos/cm	0.345 to 0.379 mmhos/cm
TOX	1 mg/L	<0.5 to 0.76 mg/L
TOC	50 µg/L	<5 to <5.9 µg/L
Tritium	2,000 pCi/L	-25.2 to 2.08 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).

Groundwater elevation is measured quarterly using an electronic tape. All groundwater elevation data since the wells were drilled in 1993 are shown in Figure 4-8. The 2010 average depths to groundwater from the top of casing are 235.82 m (773.69 ft) at UE5PW-1, 256.43 m (841.30 ft) at UE5PW-2, and 271.54 m (890.75 ft) at UE5PW-3. The average groundwater elevations are 733.55 m (2406.65 ft) AMSL at UE5PW-1, 733.69 m (2407.11 ft) AMSL at UE5PW-2, and 733.69 (2407.11 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 0.10 m/year (0.33 ft/year) to the south.

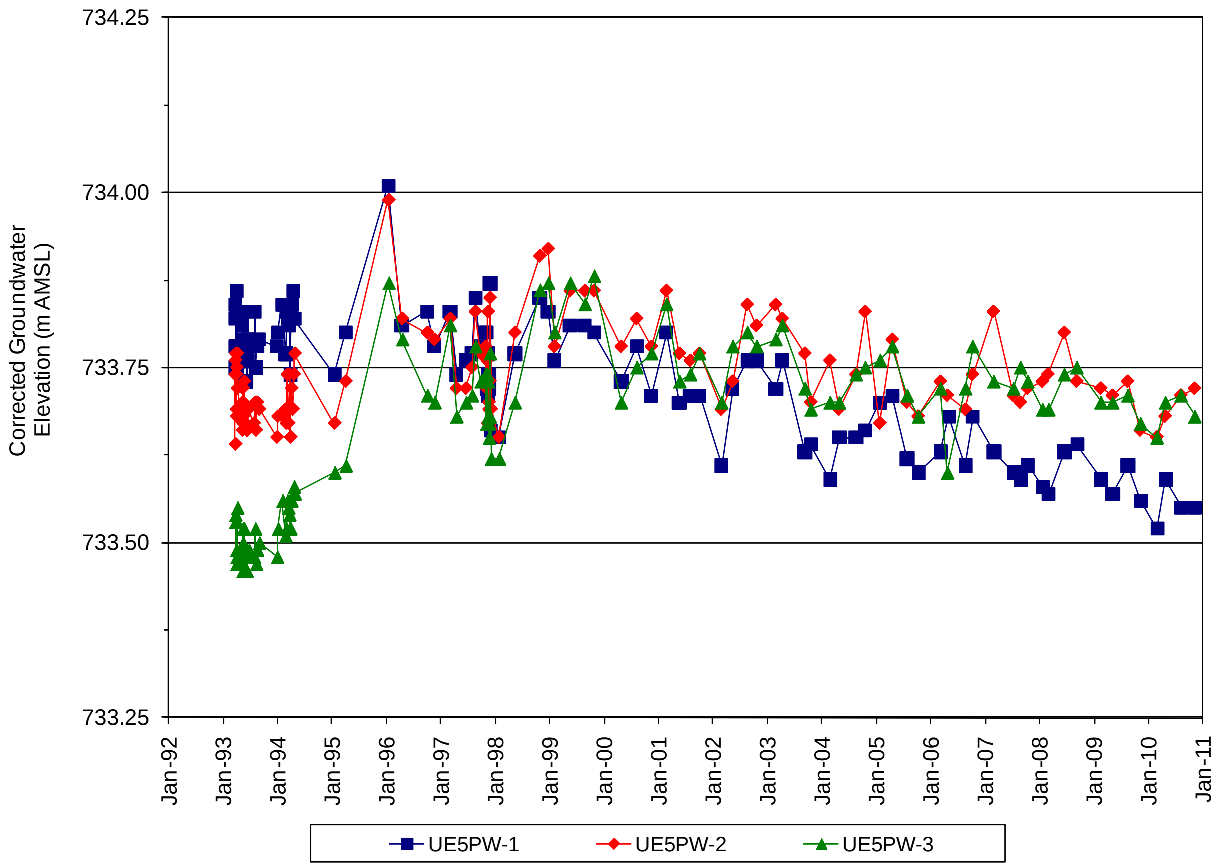

Figure 4-8. Groundwater Elevation at the Three Area 5 RWMS Pilot Wells

4.5 METEOROLOGY MONITORING DATA

Meteorology monitoring data collected in 2010 include precipitation, air temperature, humidity, wind speed and direction, barometric pressure, and incoming solar radiation. 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 (see 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 2010 average recorded temperatures at 3 m (10 ft) are 13.5°C (56.3°F) at the Area 3 RWMS and 15.8°C (60.4°F) at the Area 5 RWMS. The 2010 maximum and minimum temperatures at 3 m (10 ft) are 39.7°C (103.5°F) on July 15, 2010, and −13.4°C (−7.9°F) on December 31, 2010, at the Area 3 RWMS and 41.9°C (107.4°F) on July 15, 2010, and −12.1°C (10.2°F) on November 27, 2010, at the Area 5 RWMS (Figure 4-9).

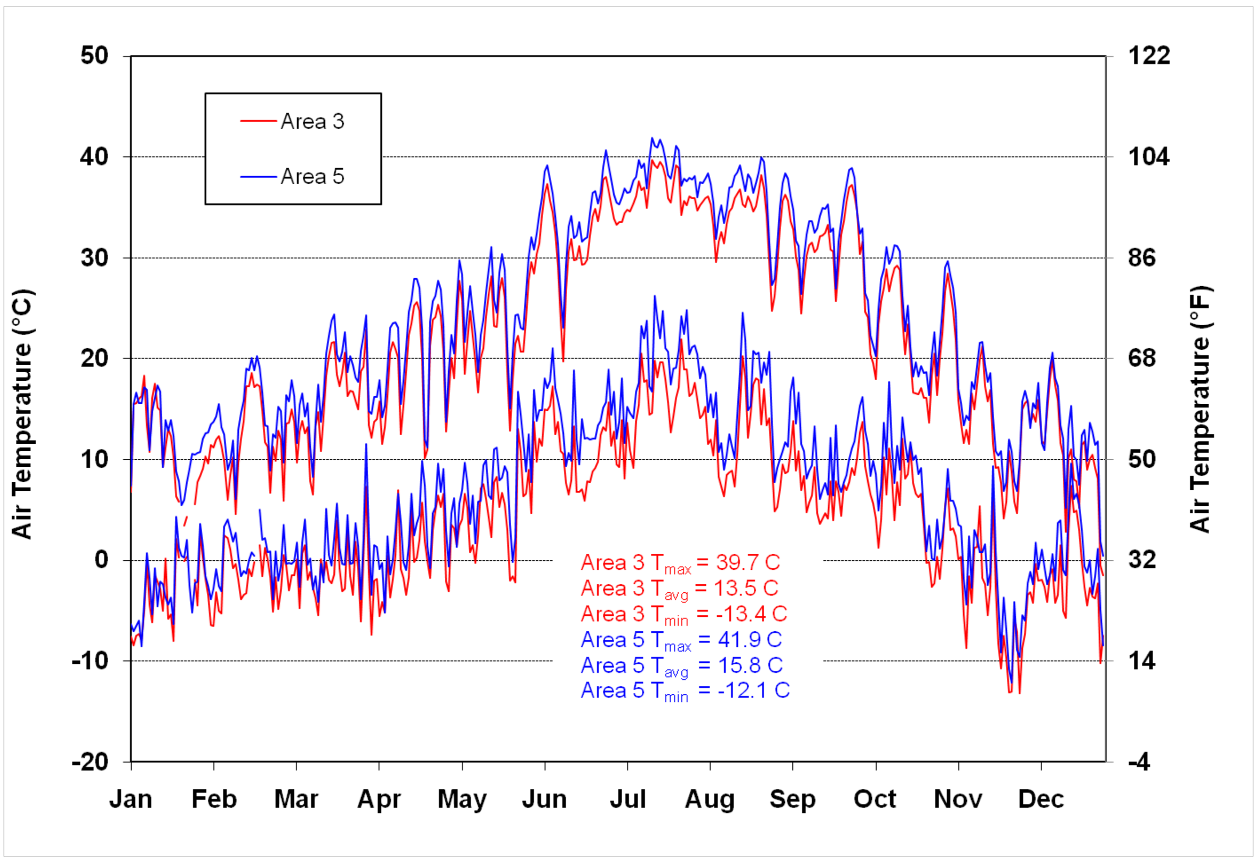

Figure 4-9. Daily Maximum and Minimum Temperature at the Area 3 and Area 5 RWMSs

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 2010 at these two sites is 40.3 percent for Area 3 and 37.5 percent for Area 5 (Figure 4-10). Measured relative humidity ranged from 6.8 to 98.4 percent.

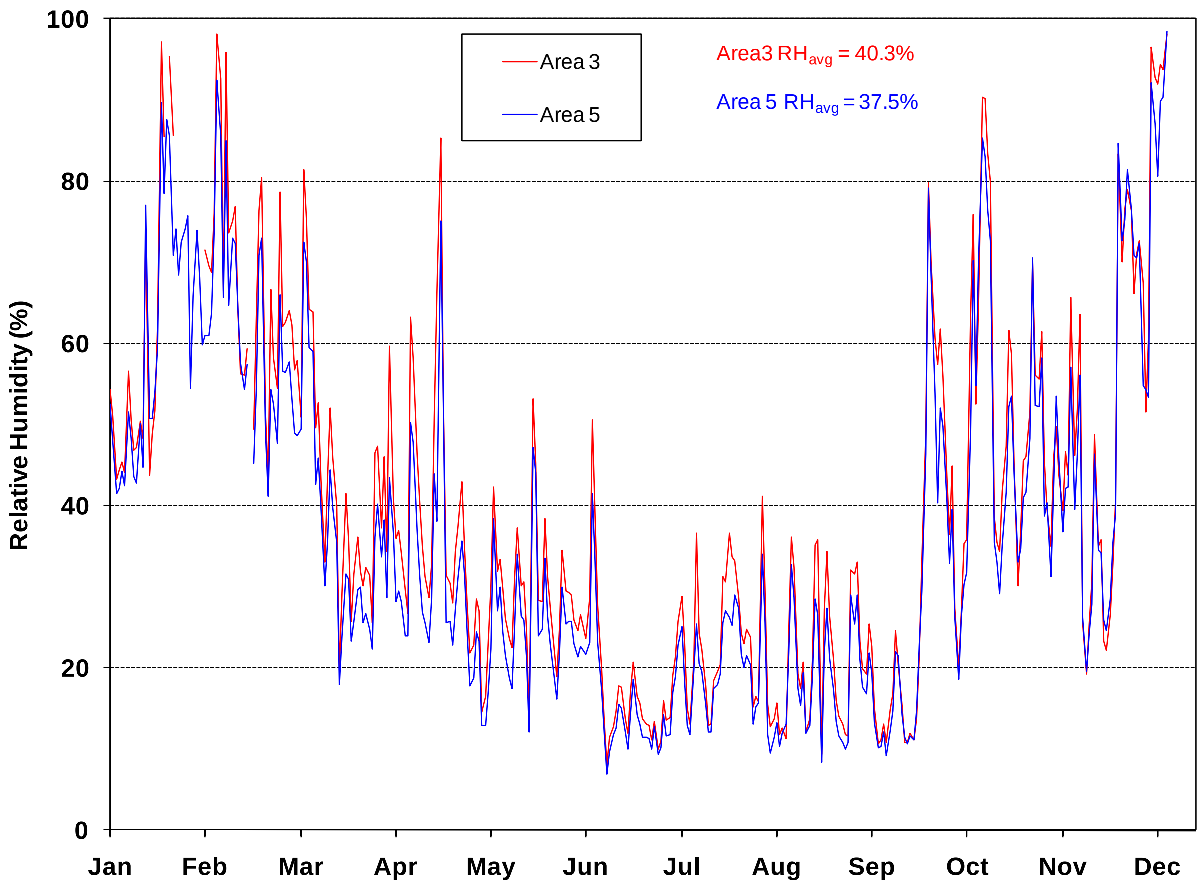

Figure 4-10. Daily Average Relative Humidity at the Area 3 and Area 5 RWMSs

4.5.3 Barometric Pressure

Average daily barometric pressure measured at the Area 3 RWMS and the Area 5 RWMS show very similar patterns (Figure 4-11). The average barometric pressure at the Area 3 RWMS is 87.7 kilopascals (kPa) (12.71 pounds per square inch [PSI]), and the average barometric pressure at the Area 5 RWMS is 90.4 kPa (13.11 PSI). The difference in barometric pressure readings between the two locations is caused by the 261 m (856 ft) difference in elevation.

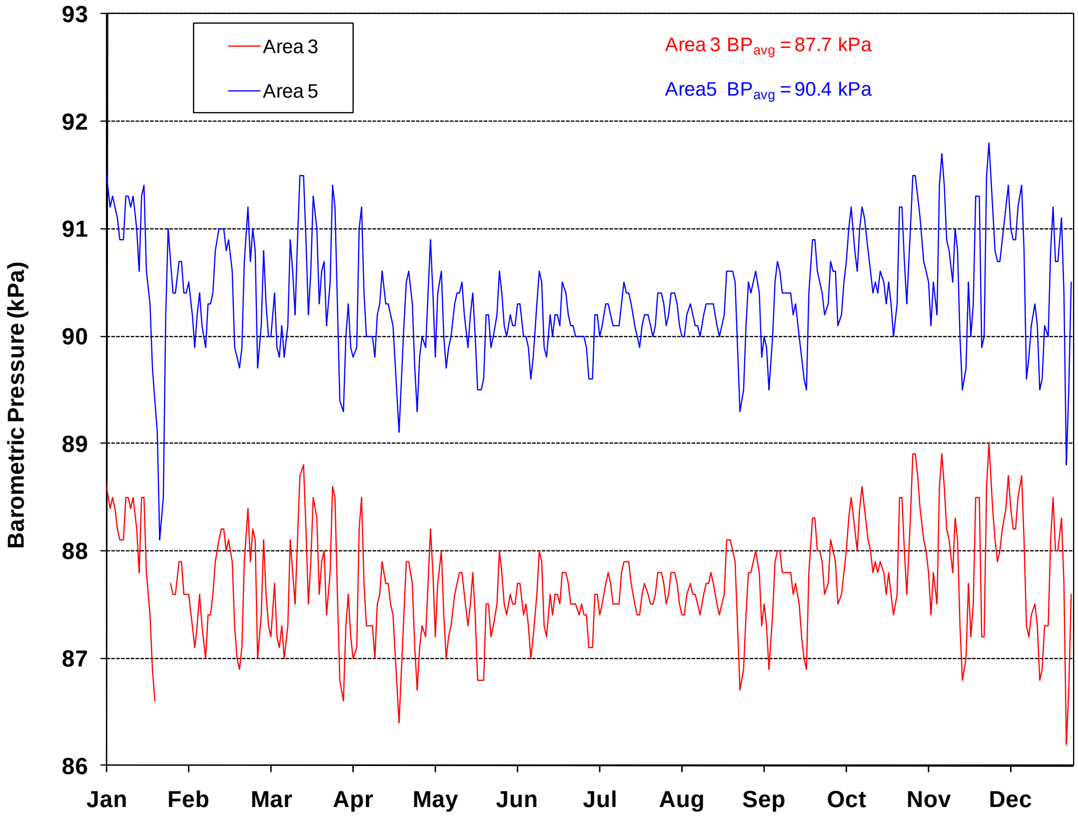

Figure 4-11. Average Barometric Pressure at the Area 3 and Area 5 RWMSs

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 2010, the average wind speed at the Area 3 RWMS was 3.1 m/s (6.9 mph), and the maximum gust was 18.5 m/s (41.4 mph) on March 31. During 2010, the average wind speed at the Area 5 RWMS was 3.3 m/s (7.4 mph), and the maximum gust was 23.7 m/s (53.0 mph) on December 29. Daily maximum and average wind speeds are in Figure 4-12 and Figure 4-13.

Wind rose diagrams illustrate wind direction and wind speed distribution in each direction using hourly wind data measured at a height of 3 m AGL. Generally, more wind comes from the north and higher wind speeds come from the south. Wind roses from the Area 3 and Area 5 RWMSs are presented in Figure 4-14 and Figure 4-15, respectively. The 1-year wind roses presented here are very similar to the multiple-year wind roses.

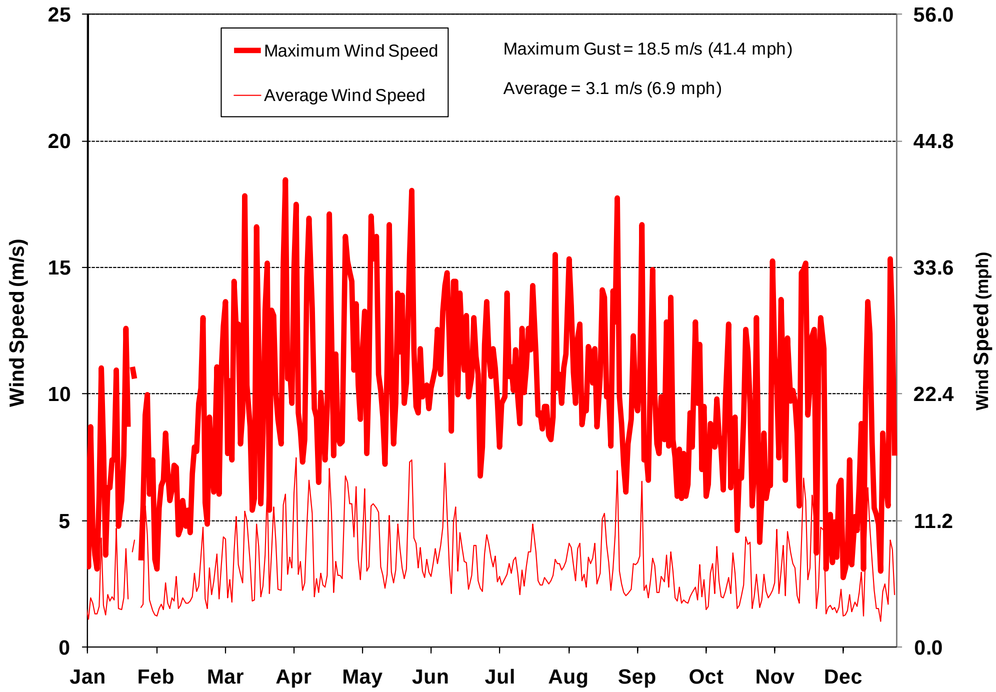

Figure 4-12. Daily 3 m Wind Speed at the Area 3 RWMS

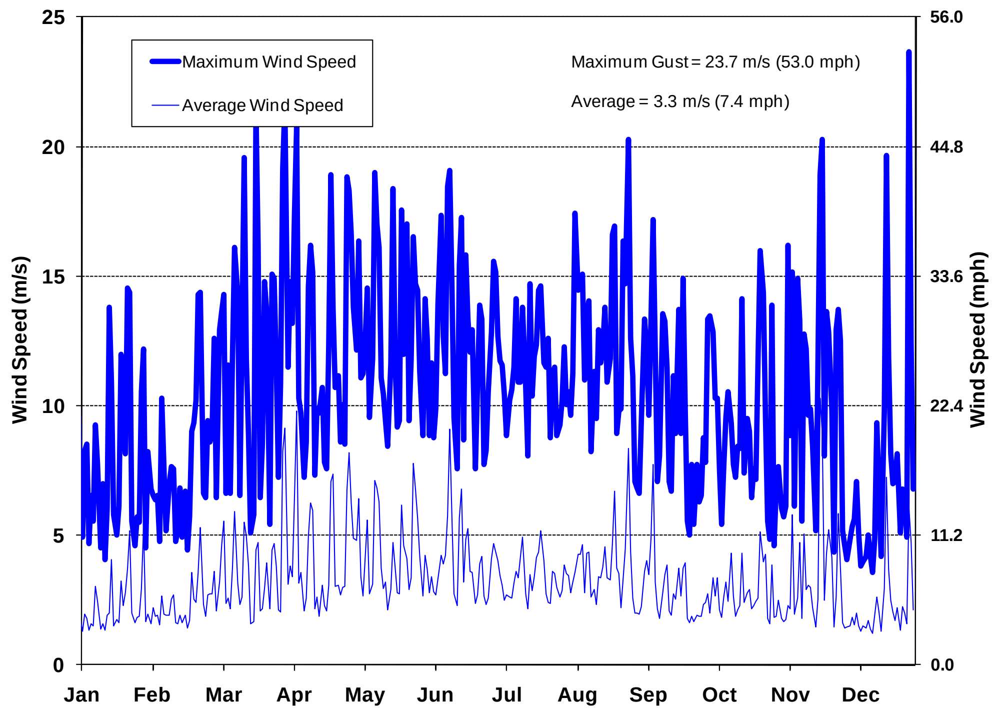

Figure 4-13. Daily 3 m Wind Speed at the Area 5 RWMS

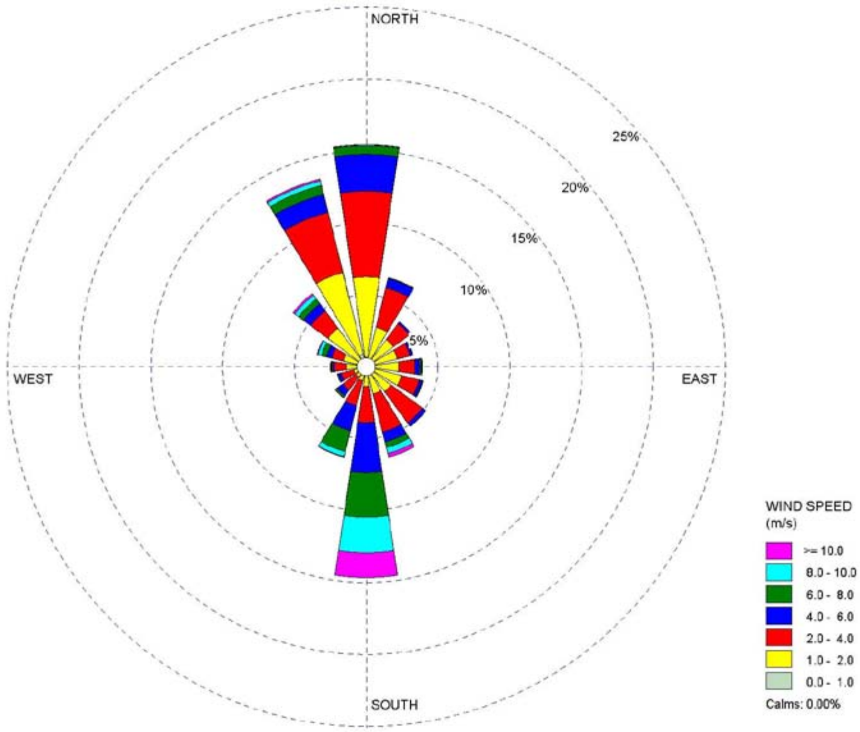

Figure 4-14. Wind Rose Diagram for the Area 3 RWMS

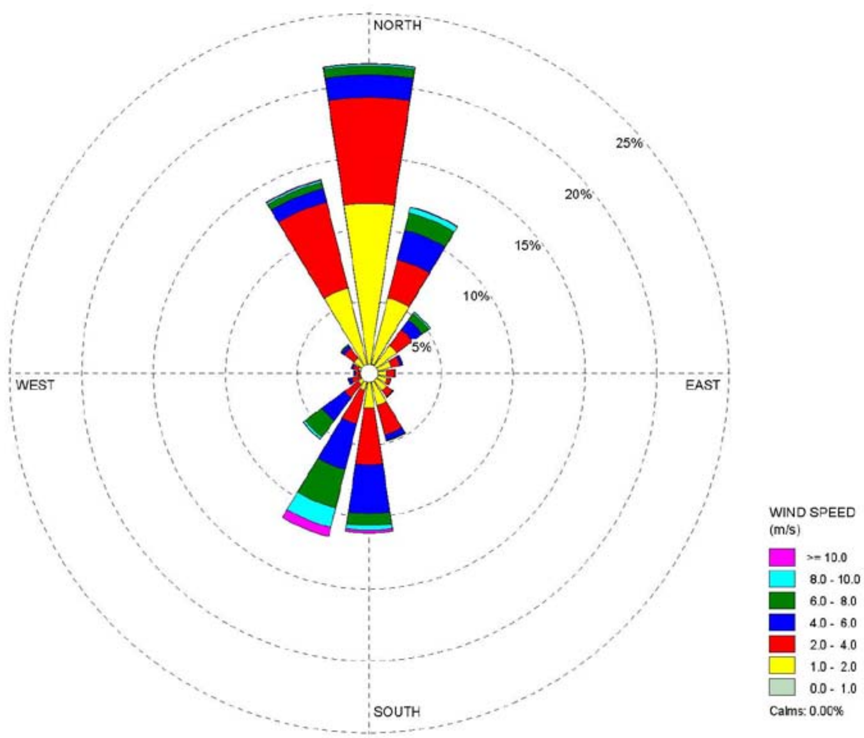

Figure 4-15. Wind Rose Diagram for the Area 5 RWMS

4.5.5 Precipitation

Rainfall at the Area 3 RWMS in 2010 was 56 percent above average, totaling 246.9 mm (9.72 in.). This is the third wettest year since measurements began at the Area 3 RWMS in 1996. The average annual precipitation measured at the Area 3 RWMS for 1996 to 2010 is 158.7 mm (6.25). The maximum daily rainfall at the Area 3 RWMS during 2010 was 32 mm (1.26 in.) on December 22. Precipitation was measured on 58 days during 2010 at the Area 3 RWMS (Figure 4-16).

Rainfall at the Area 5 RWMS in 2010 was 50 percent above average, totaling 190.4 mm (7.49 in.). This is the fourth wettest year since measurements began at the Area 5 RWMS in 1995. The average annual precipitation measured at the Area 5 RWMS for 1995 to 2010 is 126.7 mm (4.99 in.). The maximum daily rainfall at the Area 5 RWMS during 2010 was 29.1 mm (1.15 in.) on December 22. Precipitation was measured on 47 days during 2010 at the Area 5 RWMS (Figure 4-17).

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 4-18. The BJY station is a Meteorological Data Acquisition (MEDA) station operated by ARL/SORD. The 50-year average annual precipitation at BJY from 1961 to 2010 is 163.7 mm (6.43 in.). 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 4-19. The Well 5B station is also an ARL/SORD MEDA station. The 48-year average annual precipitation at Well 5B from 1963 to 2010 is 123.9 mm (4.88 in.).

4.5.6 Reference Evapotranspiration

The calculated 2010 ET_{ref} at the Area 3 RWMS is 1,522 mm (59.9 in.) and at the Area 5 RWMS is 1,571 mm (61.9 in.). ET_{ref} is the rate that readily available soil water is vaporized 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 2010 at the Area 3 RWMS is 6.2, and the ratio ET_{ref} to precipitation in 2008 at the Area 5 RWMS is 8.2. The low ratio of ET_{ref} to precipitation during 2010 is caused by the very high precipitation.

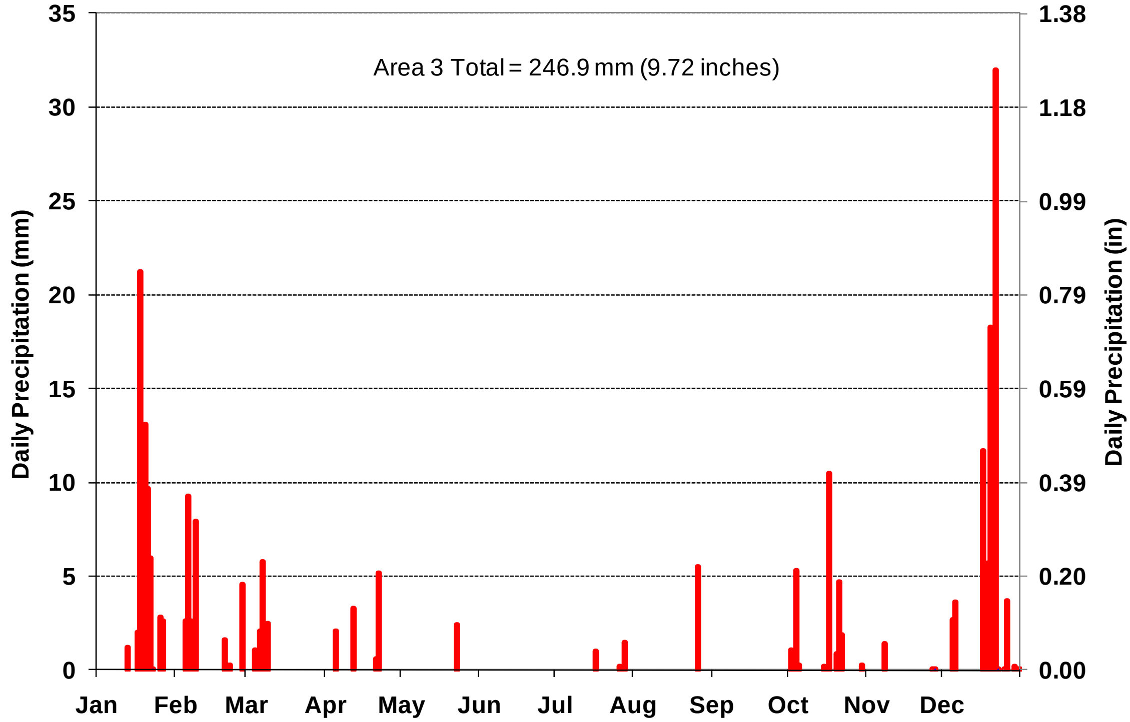

Figure 4-16. Daily Precipitation at the Area 3 RWMS

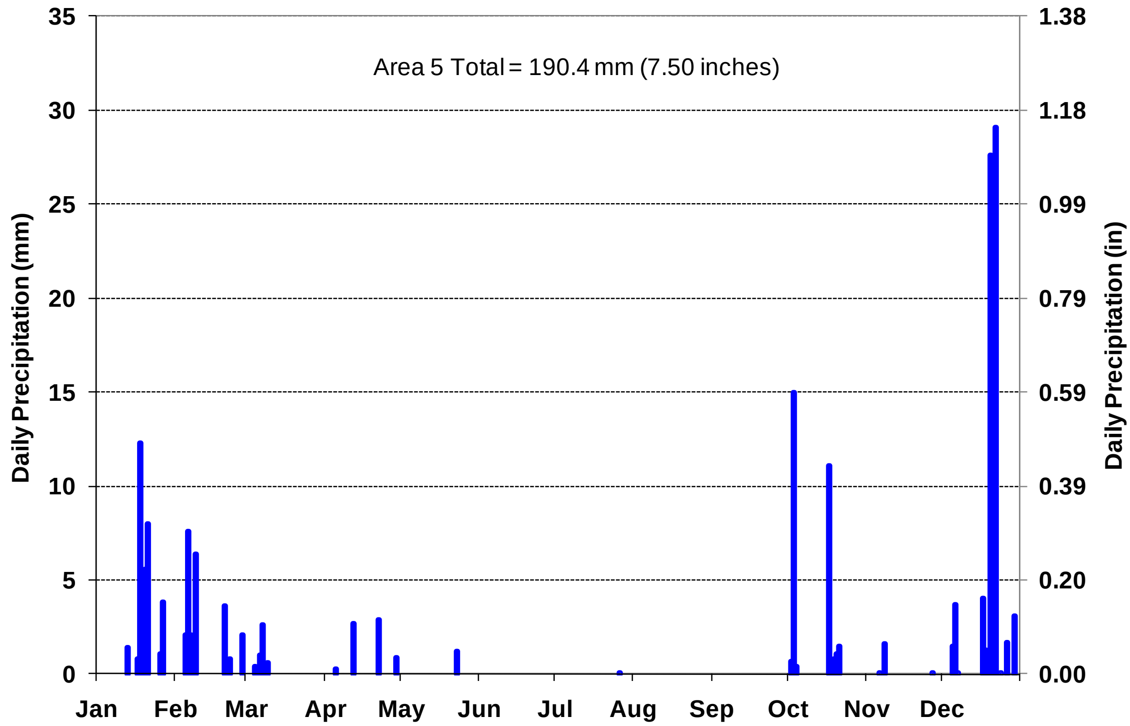

Figure 4-17. Daily Precipitation at the Area 5 RWMS

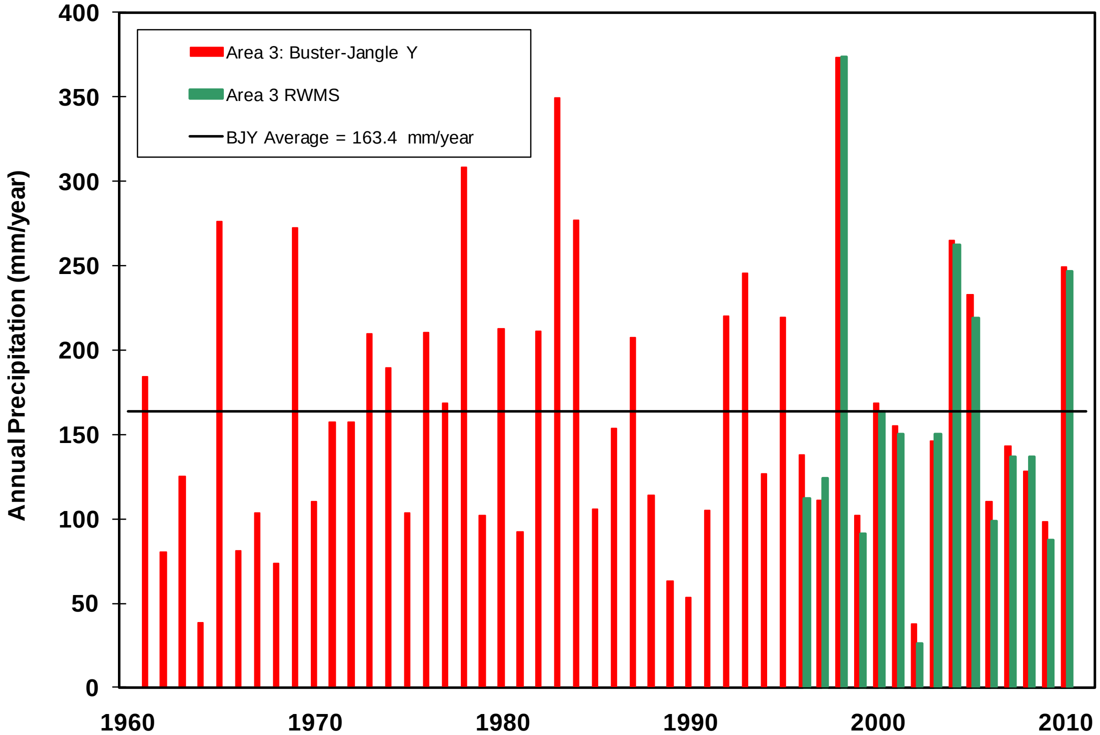

Figure 4-18. Historical Precipitation Record for Buster-Jangle Y and the Area 3 RWMS

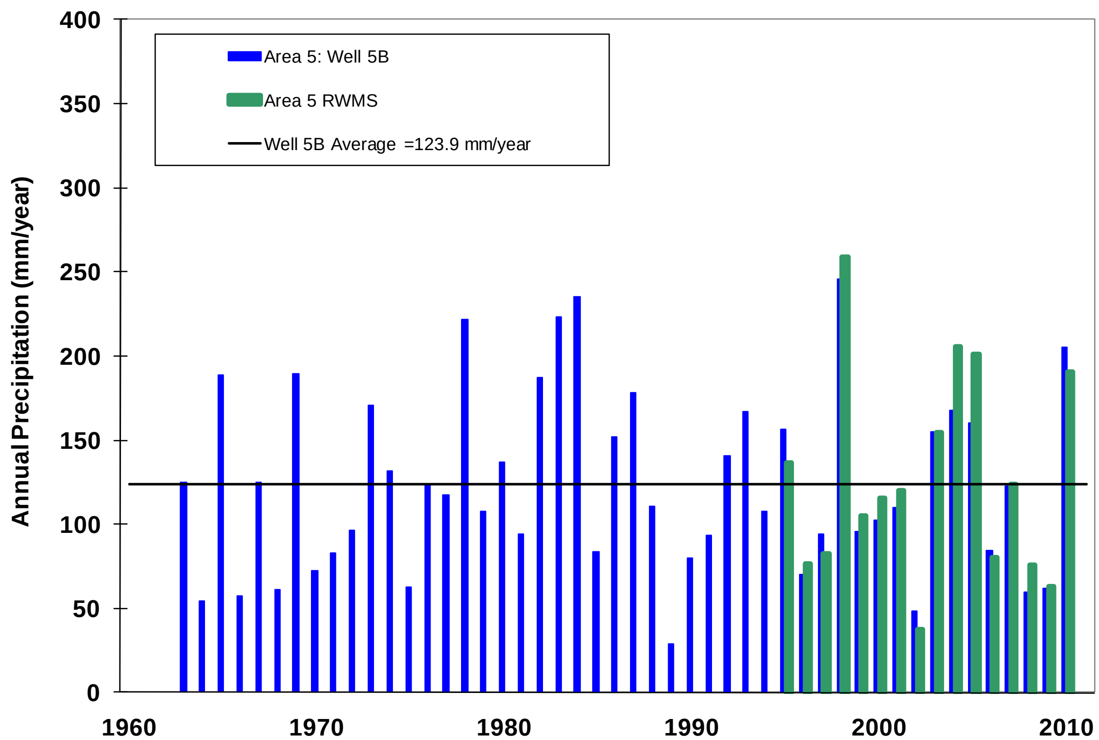

Figure 4-19. Historical Precipitation Record for Well 5B and the Area 5 RWMS

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 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). The 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 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. The vadose zone monitoring strategy also evaluates the subsurface migration of tritium by sampling soil gas for the presence of tritium at borehole GCD-05 located near the center of Area 5 RWMS (see Figure 3-2).

4.6.2 Soil Gas Tritium

Soil gas tritium monitoring is conducted via soil gas sampling at borehole GCD-05. This 3 m (10 ft) diameter borehole has a large tritium inventory (~2.2 million curies [Ci] at time of disposal) buried from 20 to 37 m (65 to 120 ft) below ground surface. Two separate strings of nine soil gas sampling ports are buried in the borehole. The sampling ports are at depths of 3 m (10 ft), 6.1 m (20 ft), 9.1 m (30 ft), 12.2 m (40 ft), 15.2 m (50 ft), 19.8 m (65 ft), 25.9 m (85 ft), 33.5 m (110 ft), and 36.3 m (119 ft) below ground surface. Soil gas is pumped from the sampling ports to the surface at a low flow rate (2 cubic centimeters per minute). A cold trap removes water vapor from the air stream, and the tritium activity of the water is measured by liquid scintillation. Typically 25 liters of soil gas sample provide approximately 0.35 grams of water. Tritium sampling at borehole GCD-05 provides a direct measure of changes in tritium activity with depth due to degradation of waste containers and transport by advection and diffusion. Sampling started in 1990 and has continued at least annually through 2010.

Soil gas tritium was sampled from the nine GCD-05 sampling depths in June 2010. The 21-year trend in results indicates that upward migration of tritium through soil from the waste level is extremely slow. Tritium concentrations have remained low from the surface down to 15.2 m (50 ft). Tritium concentrations at 6.1 m (20 ft), 9.1 m (30 ft), and 12.2 m (40 ft) increased in 2010. The sample ports at depths of 19.8 m (65 ft), 25.9 m (85 ft), 33.5 m (110 ft), and 36.3 m (119 ft) are adjacent to the tritium source. Tritium concentrations at these depths have increased since 1990. The highest measured soil gas tritium concentration of 363.9 microcuries per cubic meter ($\mu Ci/m^3$) indicates that most of the 2.2 million Ci originally buried at the site remains contained. Soil gas tritium concentrations with depth and time are illustrated in Figure 4-20 and Figure 4-21.

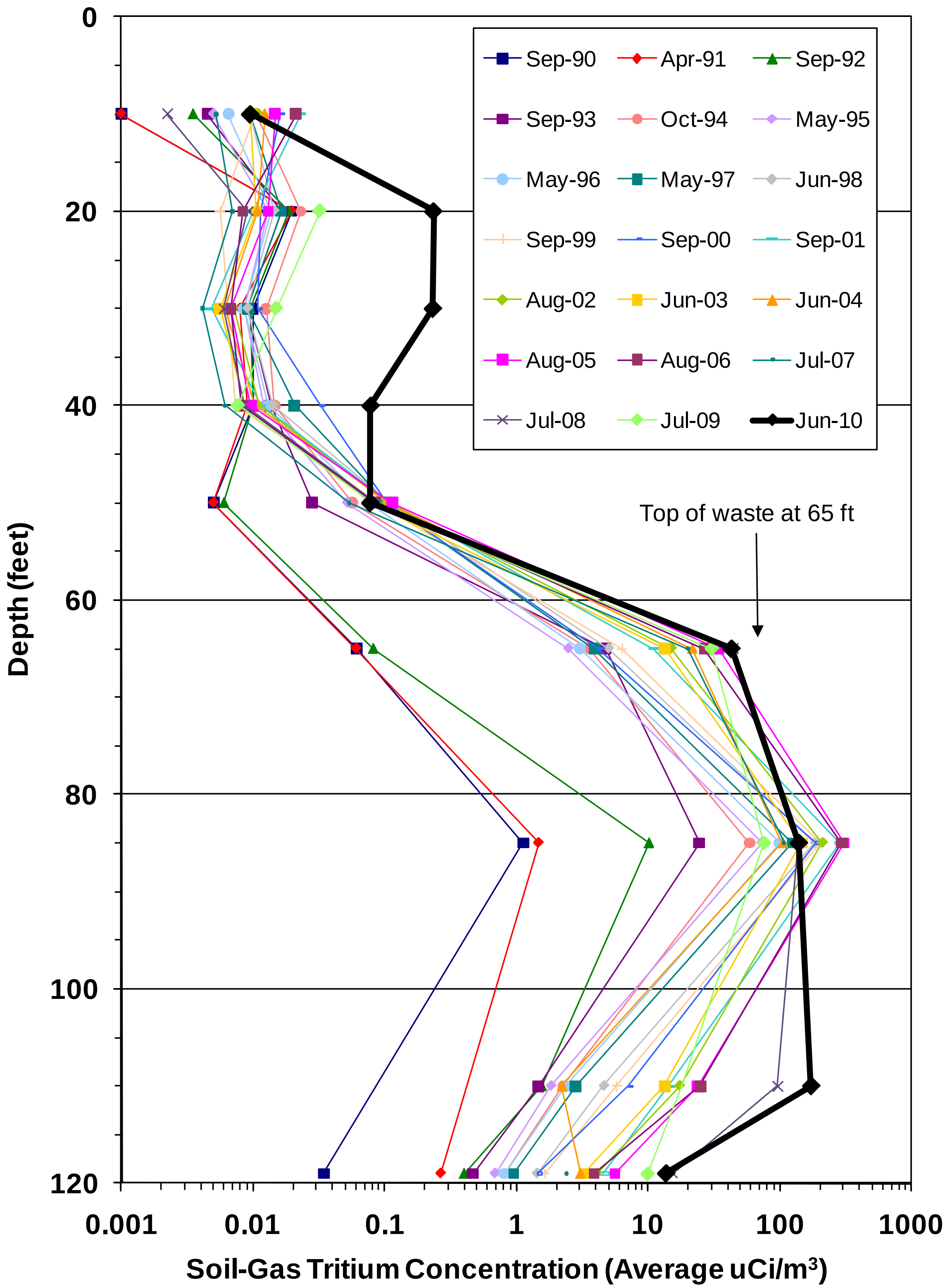

Figure 4-20. Soil-Gas Tritium Concentration Depth Profiles at GCD-05

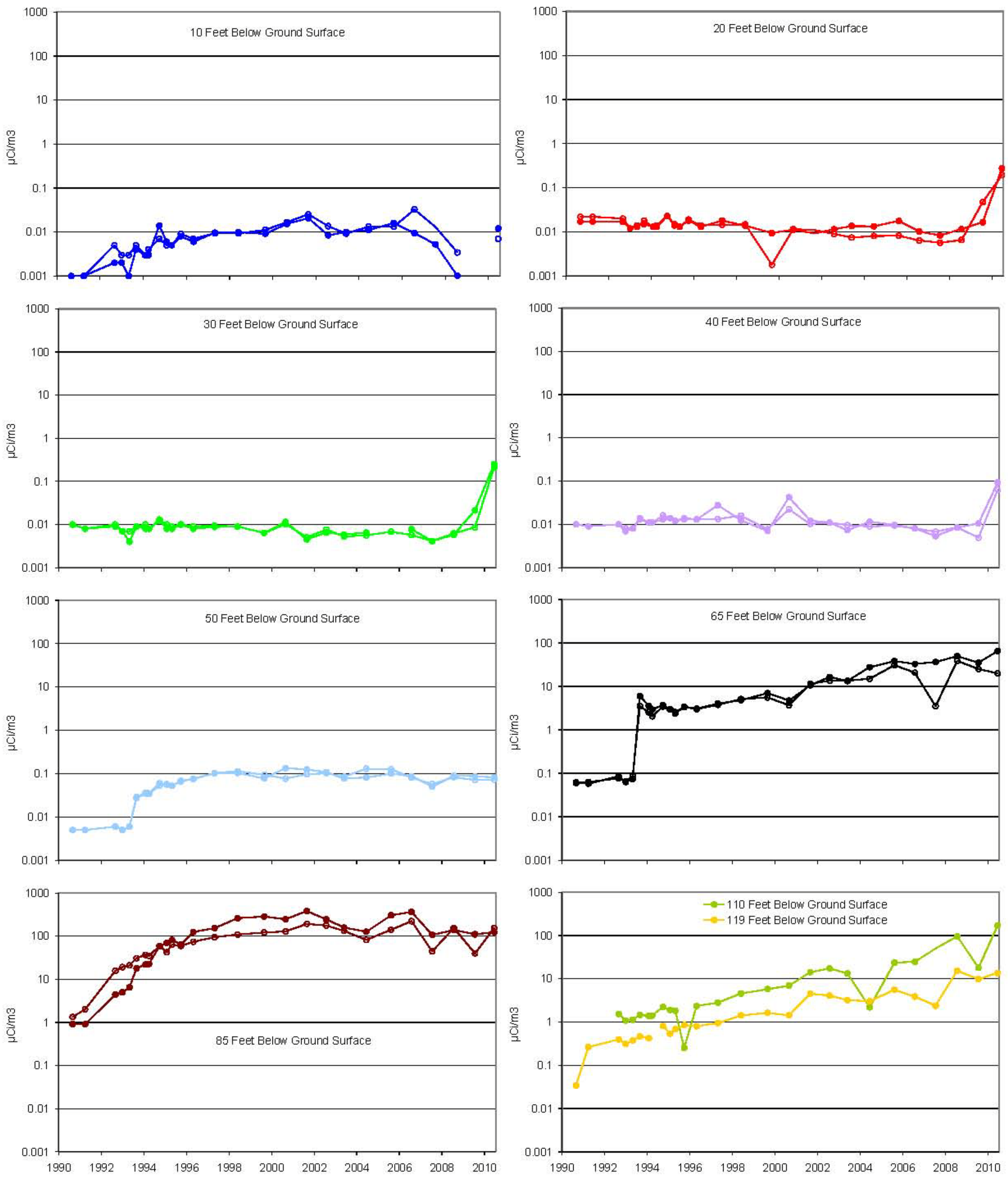

Figure 4-21. Soil-Gas Tritium Concentration for Each Depth at GCD-05

4.6.3 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 (see Figure 3-3). Each lysimeter is a 2 m wide by 4 m long by 2 m deep (6.6 ft wide by 13 ft long by 6.6 ft deep), open-top steel box 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 andersonii* (Anderson's wolfberry), 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 centimeter (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, 2010, is illustrated in Figure 4-22.

The vegetated lysimeter is considerably drier than the bare-soil lysimeter, despite the small number of plants on the vegetated lysimeter (about 27 percent plant cover). The average soil water storage depth in the vegetated lysimeter from January 1, 1996, to December 31, 2010, is 116 mm (4.6 in.). This is equivalent to an average VWC of 5.8 percent. For the same period, the average soil water storage depth in the bare lysimeter is 206 mm (8.1 in.), which is equivalent to an average VWC of 10.3 percent. During 2010, the average soil water storage depth in the vegetated lysimeter was 115 mm (4.5 in.), and the average water storage depth in the bare lysimeter was 204 mm (8.0 in.).

Following high rainfall periods in the winter, soil water storage decreases in the vegetated lysimeter due to ET from rapid plant growth in the spring. As the vegetated lysimeter dries out, plant growth and ET 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 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 from May 5, 2008, to June 19, 2008; from March 2, 2009, to May 12, 2009; and from February 3, 2010, to April 27, 2010. No water effluent was collected from the suction candles during this period. 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 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 2010, E from the bare lysimeter was 120.3 mm (4.7 in.) and ET from the vegetated lysimeter was 119.7 mm (4.7 in.). E and ET are approximately equal to the 119.0 mm (4.7 in.) precipitation in 2010 through December 16, 2010. An additional 83.8 mm (3.3 in.) precipitation after December 16, 2010, caused a very large water storage increase in both lysimeters (Figure 4-23). Precipitation exceeded both E and ET in January, February, October, and December 2010, and ET exceeded E in March, April, and May 2010 (Figure 4-24).

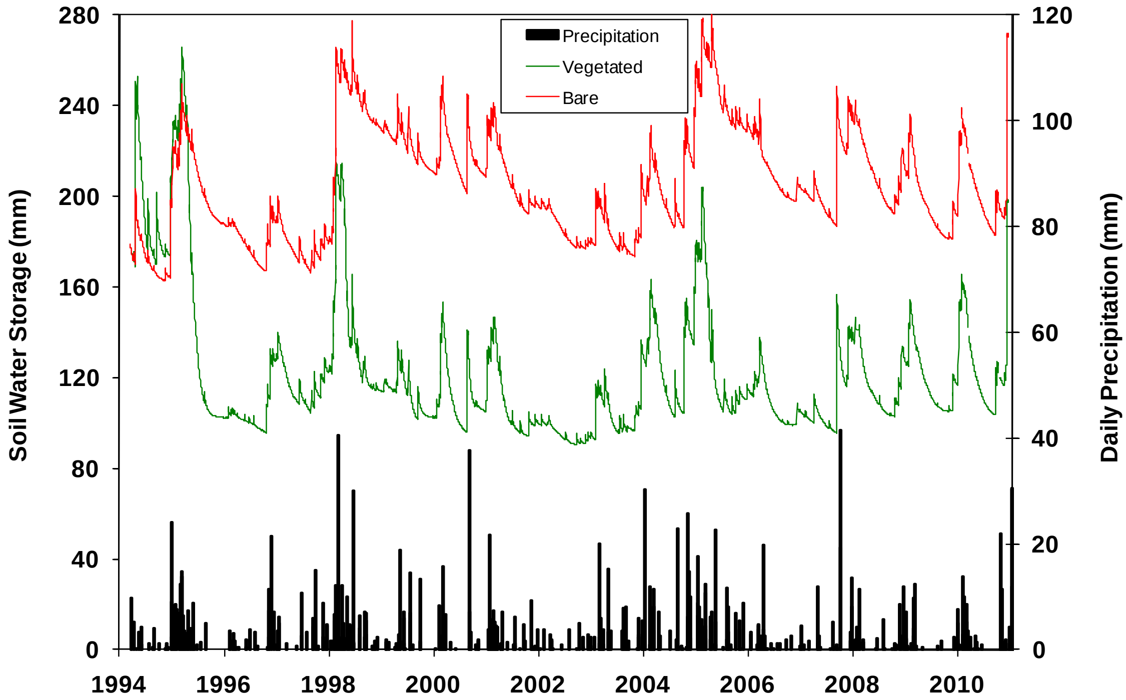

Figure 4-22. Weighing Lysimeter Data from March 1994 to December 2010

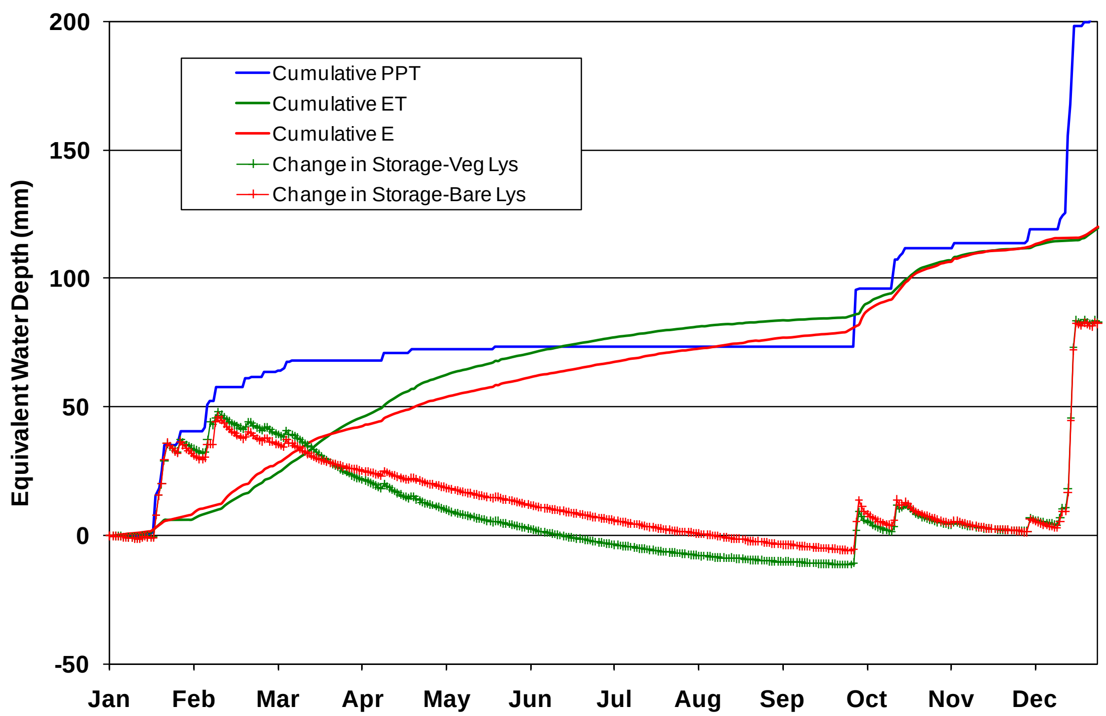

Figure 4-23. Precipitation, ET, E, and Storage for the Weighing Lysimeters during 2010

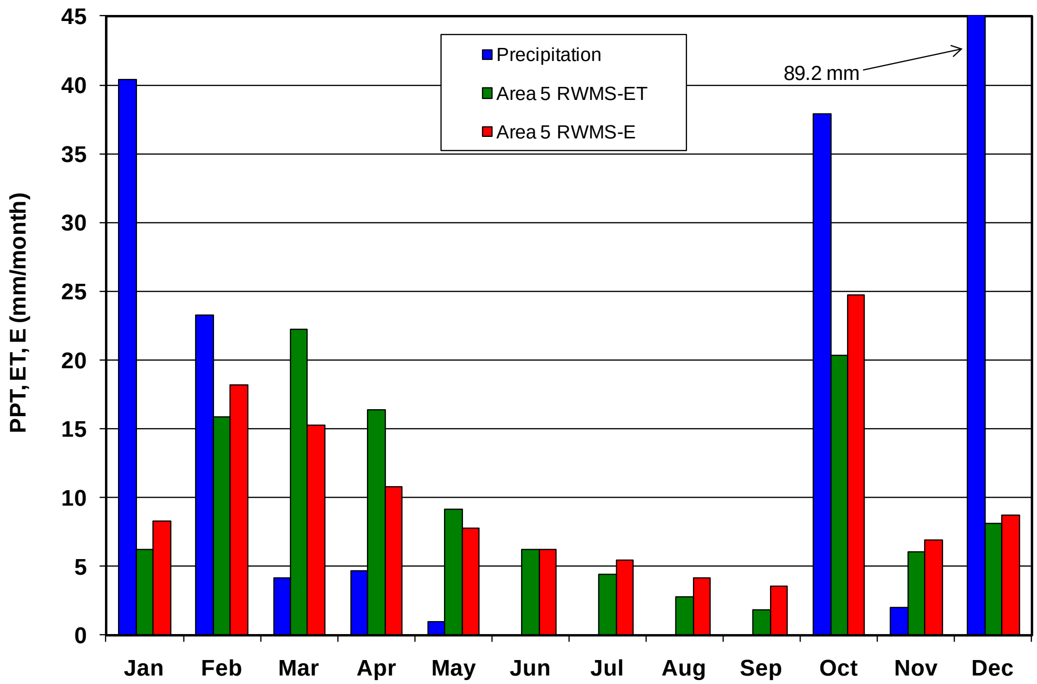

Figure 4-24. Monthly Precipitation, E, and ET during 2010

4.6.4 Automated Waste Cover Monitoring System

In 1998, time-domain reflectometry (TDR) probes were buried 1.2 m (4 ft) beneath the floor of open Pit 5 at the Area 5 RWMS. The four probes are adjacent to the Pit 5N and Pit 5S monitoring locations with one probe buried near the Pit 5 center line and one probe near the eastern edge of Pit 5 at the two monitoring locations (Figure 2-2). 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 Pit 5 has remained constant at approximately 10 percent (Figure 4-25). The constant measured water content indicates that no moisture has percolated to 1.2 m (4 ft) below the waste.

In 1999, TDR probes were also installed in the operational cover of Pit 3 at monitoring locations Pit 3N and Pit 3S (Figure 3-2). At each location probes were buried at depths ranging from 10 to 180 cm (0.3 to 5.9 ft). Precipitation events, beginning in October 2004, infiltrated into the operational cover and percolated below the deepest probe at 180 cm (5.9 ft) at both the north and south location in March 2005 (Figure 4-26). This moisture is below the range of substantial surface E. By September 2007, the VWC at 180 cm (5.9 ft) at both sites had returned to approximately 12 percent. A 58.1 mm (2.29 in.) precipitation event occurred on September 21 and September 22, 2007. Water contents increased to 90 cm depth at Pit 3N and to 120 cm depth at Pit 3S after this storm. By May 2008, this moisture was removed from the Pit 3 operational cover by E without any percolation below 120 cm. Moisture contents at 150 cm and 180 cm depths had returned to the approximate moisture contents prior to October 2004 by December 2009 (Figure 4-26). Precipitation during January and February 2009 and during January and February 2010 increased water contents to 90 cm depth in both the Pit 4 and Pit 5 operational covers.

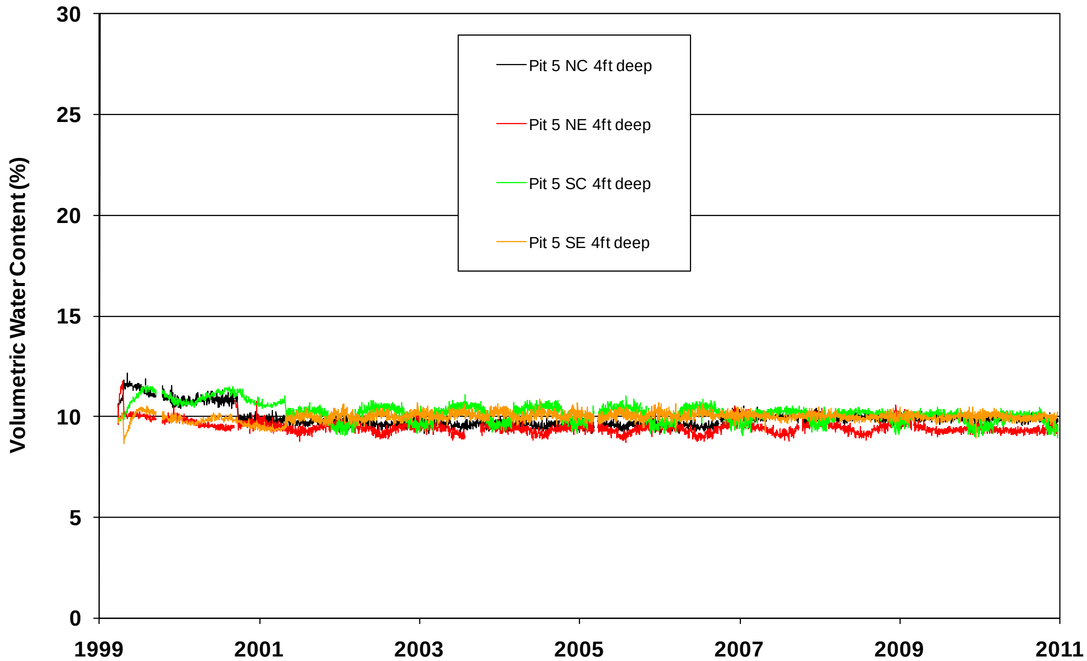

Figure 4-25. Soil Water Content in the Pit 5 Floor

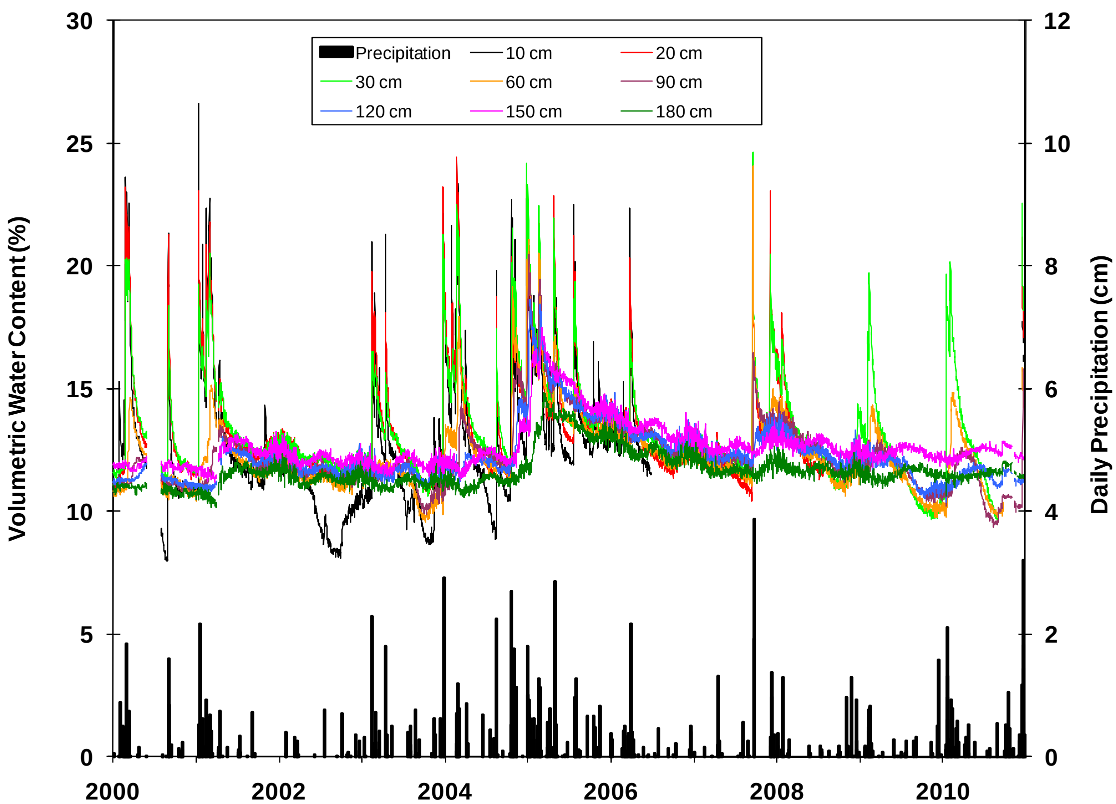

Figure 4-26. Soil Water Content in the Pit 3 Waste Cover at Pit 3S

In 2000, TDR probes were installed in the Pit 4 operational cover at location Pit 5S and in the Pit 5 operational cover at Pit 5N (Figure 3-2). At each location the probes are buried at depths ranging from 20 to 180 cm (0.7 to 5.9 ft). Precipitation events beginning in October 2004 infiltrated into the operational cover of Pit 4 and Pit 5, and percolated deeper than the deepest probe at 180 cm (5.9 ft) at Pit 4 in March 2005 and at Pit 5 in April 2005 (Figure 4-27). Because this moisture is below the range of substantial surface E, the gradual drying is most likely due to downward percolation. The 58.1 mm (2.29 in.) precipitation event on September 21 and September 22, 2007, increased water contents to 60 cm depth in both the Pit 4 and Pit 5 operational covers. Precipitation during January and February 2009 and during January and February 2010 increased water contents to 90 cm depth in both the Pit 4 and Pit 5 operational covers (Figure 4-27).

In December 2000, TDR probes were installed in 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 244 cm (1 to 8 ft). Measured soil water content values for one location (East Nest A) in the U-3ax/bl waste cover are shown in Figure 4-28. From 2001 to 2005, the TDR data indicate that the soil water content in the cover generally decreased over time as the vegetation on the cover grew. The precipitation events beginning in October 2004 infiltrated into the final cover of U-3ax/bl, but the moisture has been removed without percolating below the 244 cm (8 ft) deep sensor. Unlike the bare-soil operational covers on Pit 3, Pit 4, and Pit 5, the moisture at U-3ax/bl was removed by ET before reaching 244 cm (8 ft). The wetting front from 6.6 cm (2.6 in.) precipitation event on September 21 and September 22, 2007, only reached 30 cm (1 ft) deep as compared to 90 to 120 cm (3 to 4 ft) deep in the bare operational covers. Precipitation during January and February 2009 increased water contents to 30 cm depth. Precipitation during January and February 2010 and precipitation in December 2010 increased water contents to 61 cm.

Initial water contents are lower in the vegetated U-3ax/bl cover, so more moisture is stored per unit depth as the wetting front moves down. 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. A quantitative analysis of the vegetative cover on the U-3ax/bl cover is conducted annually in the spring. The percent cover for the established U-3ax/bl cover has ranged from 20.2 percent in 2005, to 19.6 percent in 2006, to 10.6 percent in 2007, to 26.8 percent in 2008, to 12.2 percent in 2009, to 19.8 percent in 2010. The dominant perennial plant on the U-3ax/bl cover is *Atriplex confertifolia* (shadscale saltbush), which accounted for 14.6 percent cover.

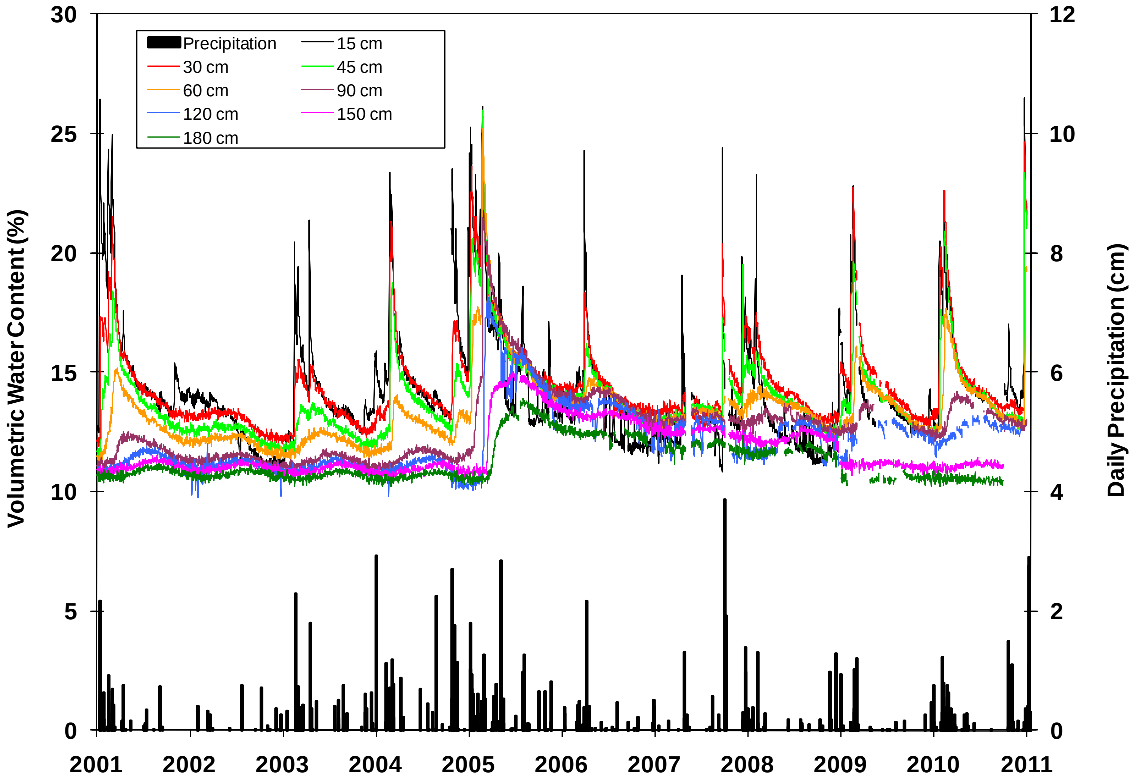

Figure 4-27. Water Content in the Pit 5 Waste Cover at Pit 5N

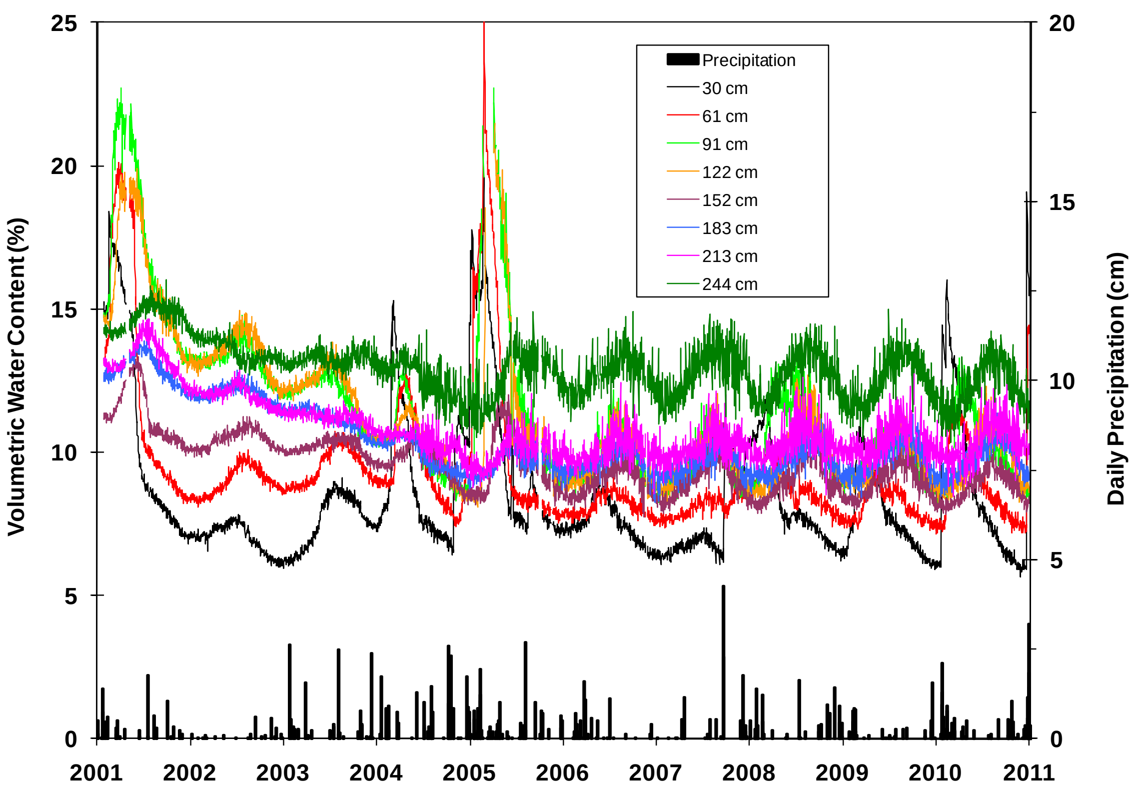

Figure 4-28. Soil Water Content in the U-3ax/bl Cover

4.6.5 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 3 m (10 ft) diameter by 2.4 m (8 ft) deep lysimeters. Each lysimeter is filled with native soil and 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 7.6 cm (0.25 ft), 15 cm (0.5 ft), 30 cm (1 ft), 61 cm (2 ft), 91 cm (3 ft), 122 cm (4 ft), 183 cm (6 ft), and 244 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 needs including reducing uncertainty in the expected performance of monolayer-ET closure covers under various surface vegetation treatments and climatic change scenarios such as 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] and *Halogeton glomeratus* [halogeton]), and native species (primarily *Atriplex confertifolia* [shadscale saltbush], *Krascheninnikovia lanata* [winterfat], *Ephedra nevadensis* [Nevada jointfir], *Achnatherum hymenoides* [Indian ricegrass], 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 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 2010 precipitation at the drainage lysimeters was 247 mm (9.7 in.). The 2010 irrigation applied to Lysimeters B, D, F, and H is 500 mm (19.7 in.). The 2010 lysimeter treatments are summarized in Table 2.

There were 1,679 liters (444 gallons) of drainage from Lysimeter B and 53 liters (14 gallons) of drainage from Lysimeter D during 2010. The equivalent depths of this drainage are 23.0 cm (9.1 in.) for Lysimeter B and 0.7 cm (0.3 in.) for Lysimeter D (Table 2). Drainage from Lysimeter B occurred from January 25, 2010, to August 20, 2010, and from December 24, 2010, to December 31, 2010. The Lysimeter B drainage is 31 percent of total precipitation and applied irrigation. Drainage from Lysimeter D occurred from March 23, 2010, to April 29, 2010. The Lysimeter D drainage is 0.1 percent of total precipitation and applied irrigation. There was no drainage from any other lysimeter during 2010. Drainage has only occurred from the irrigated lysimeters. Total cumulative drainage from each irrigated lysimeter is 116.1 cm (45.7 in.) from Lysimeter B, 6.5 cm (2.6 in.) from Lysimeter D, 29.3 cm (11.5 in.) from Lysimeter F, and 12.3 cm (4.8 in.) from Lysimeter H (Figure 4-29).

Cover was measured for each of the eight drainage lysimeters on May 18, 2010. The results are summarized in Table 3. *B. tectorum* accounts 20.0 percent cover on Lysimeter D. Dead *B. tectorum* accounts for much of the litter percent cover.

Table 2. Area 3 Drainage Lysimeter Treatments in 2010

Lysimeter	Climate	Precipitation (mm)	Irrigation (mm)	Drainage (mm)	Surface Vegetation
A	Natural precipitation	247	0	0	Bare-soil
B	3 times natural precipitation	247	500	230	Bare-soil
C	Natural precipitation	247	0	0	Invader species
D	3 times natural precipitation	247	500	7.2	Invader species
E	Natural precipitation	247	0	0	Native species
F	3 times natural precipitation	247	500	0	Native species
G	Natural precipitation	247	0	0	Native species
H	3 times natural precipitation	247	500	0	Native species

Table 3. Area 3 Drainage Lysimeter Percent Cover

Lysimeter	Plant Cover (percent)	Bare (percent)	Gravel (percent)	Litter (percent)
A	15.0	32.5	52.5	0.0
B	7.5	15.0	70.0	7.5
C	47.5	20.0	20.0	12.5
D	20.0	2.5	0.0	77.5
E	27.5	0.0	2.5	70.0
F	47.5	0.0	0.0	52.5
G	40.0	2.5	0.0	57.5
H	52.5	0.0	0.0	47.5

Figure 4-30 shows the total water storage for all eight lysimeters from 2004 through 2010. Water storage is calculated using TDR data. The two bare-soil lysimeters (Lysimeters A and B) have the highest water storage. Evaporation and drainage are the only processes that remove water from these two lysimeters. Water storage in the other irrigated lysimeters (Lysimeters D, F, and H) was elevated at the beginning of 2010. ET removed most of this water in the spring and summer.

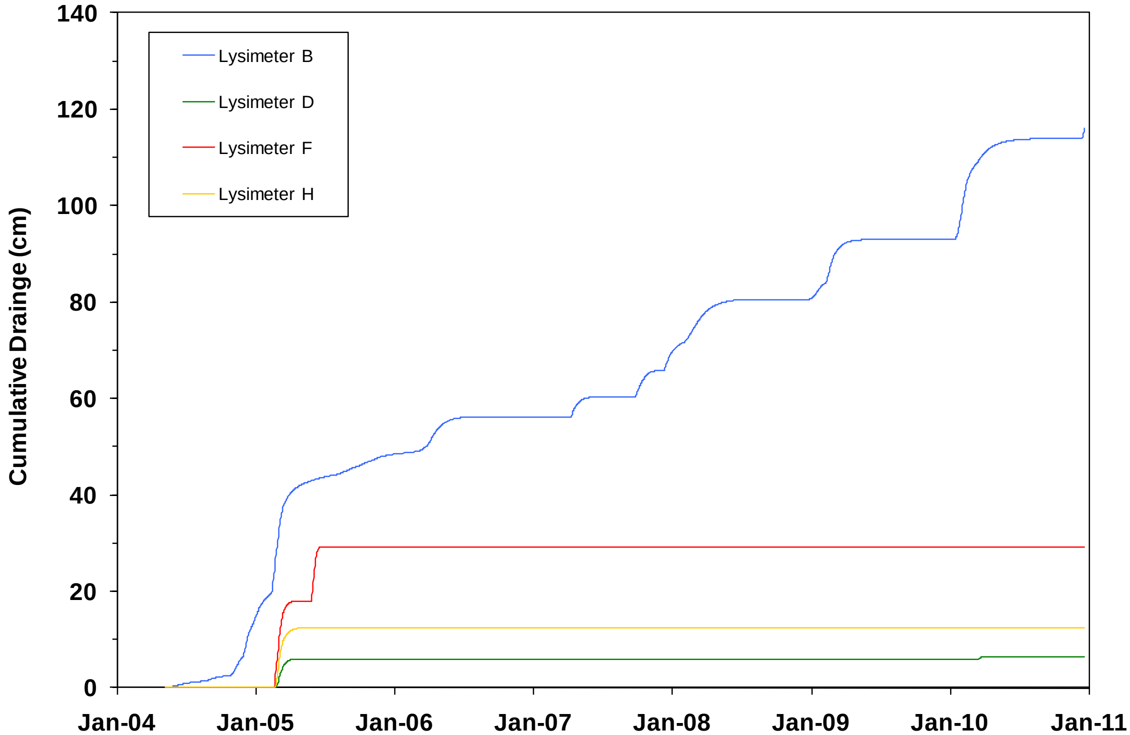

Figure 4-29. Cumulative Drainage from the Drainage Lysimeters

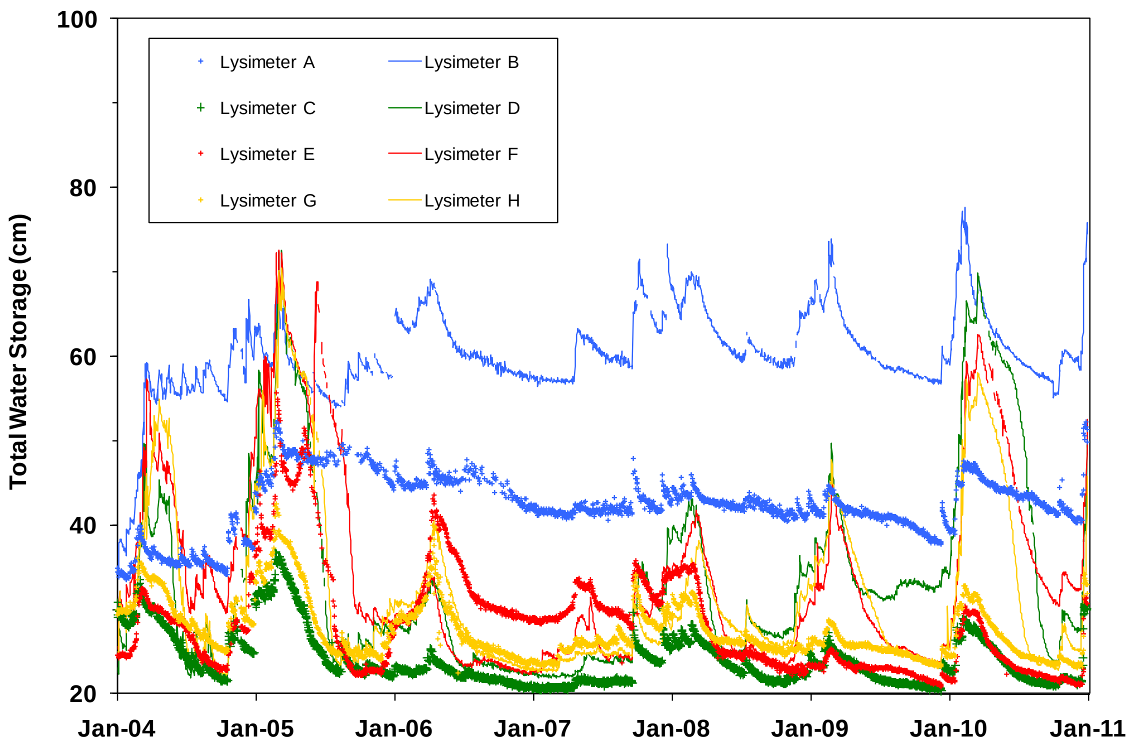

Figure 4-30. Soil Water Storage in the Drainage Lysimeters

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. Subsidence monitoring also helps ensure that vadose zone monitoring data are representative of the entire RWMS. Typically as small depressions or cracks are observed in the covers, they are filled before large subsidence features develop. No large subsidence features were observed during 2010.

4.8 BIOTA MONITORING DATA

No biota monitoring data was collected during 2010.

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5.0 CONCLUSIONS

The 2010 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. Soil gas monitoring data at GCD-05 indicate little natural migration of tritium away from the waste at this disposal borehole. 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 2010 monitoring data indicate that the Area 3 and Area 5 RWMSs are performing within expectations of the model and parameter assumptions for the facility PAs.

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