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# Nevada Test Site
# 2005 Waste Management Monitoring Report
# Area 3 and Area 5 Radioactive Waste Management Sites

**August 2006**

**Prepared for:**

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

**Prepared by:**

**National Security Technologies, LLC**
**Las Vegas, Nevada**

**Disclaimer**

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# ACRONYMS and ABBREVIATIONS

| | |
|---|---|
| AGL | above ground level |
| | |
| 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) |
| | |
| DCG | Derived Concentration Guide |
| DOE | U.S. Department of Energy |
| | |
| E | evaporation |
| ET | evapotranspiration; evapotranspirative |
| | |
| °F | degrees Fahrenheit |
| ft | feet or foot |
| | |
| GCD | greater confinement disposal |
| | |
| in. | inch(es) |
| | |
| km | kilometer(s) |
| | |
| LLW | low-level waste |
| | |
| m | meter(s) |
| MDC | minimum detectable concentration |
| MEDA | Meteorological Data Acquisition |
| mi | mile(s) |
| mm | millimeter(s) |
| mph | mile(s) per hour |
| mR | milliroentgen |
| mrem | millirem |
| m/s | meter(s) per second(s) |
| $m^3$ | cubic meters |
| µCi | microcurie(s) |
| | |
| NPCF | Neutron Probe Calibration Facility |
| NTS | Nevada Test Site |

## ACRONYMS and ABBREVIATIONS

| | |
|---|---|
| PA | Performance Assessment |
| PET | potential evapotranspiration |
| | |
| REECo | Reynolds Electrical & Engineering Co., Inc. |
| RREMP | Routine Radiological Environmental Monitoring Plan |
| RWMS | Radioactive Waste Management Site |
| | |
| SC | specific conductance |
| | |
| TDR | time domain reflectometry |
| TLD | thermoluminescent dosimeter |
| TOC | total organic carbon |
| TOX | total organic halides |
| | |
| VWC | volumetric water content |

# EXECUTIVE SUMMARY

Environmental monitoring data were collected at and around the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs) at the Nevada Test Site. These data are associated with radiation exposure, air, groundwater, meteorology, vadose zone, subsidence, and biota. This report summarizes the 2005 environmental data to provide an overall evaluation of RWMS performance and to support environmental compliance and performance assessment activities. Some of these data (e.g., radiation exposure, air, and groundwater) are presented in other reports (U.S. Department of Energy, 2005; Grossman, 2005; Bechtel Nevada, 2006).

Direct radiation monitoring data indicate that exposure levels around the RWMSs are at or below background levels. Air monitoring data at the Area 3 and Area 5 RWMSs indicate that tritium concentrations are slightly above background levels. There is no detectable man-made radio-activity by gamma spectroscopy, and concentrations of americium and plutonium are only slightly above detection limits at the Area 3 RWMS. Measurements at the Area 5 RWMS show that radon flux from waste covers is no higher than natural radon flux from undisturbed soil in Area 5. Groundwater monitoring data indicate that the groundwater in the uppermost aquifer beneath the Area 5 RWMS is not impacted by facility operations. Precipitation during 2005 totaled 219.1 millimeters (mm) (8.63 inches [in.]) at the Area 3 RWMS and 201.4 mm (7.93 in.) at the Area 5 RWMS. Soil-gas tritium monitoring continues to show slow subsurface migration consistent with previous results. Moisture from precipitation at Area 5 has percolated to the bottom of the bare-soil weighing lysimeter, but this same moisture has been removed from the vegetated weighing lysimeter by evapotranspiration. Vadose zone data from the operational waste pit covers show that precipitation from the fall of 2004 and the spring of 2005 infiltrated past the deepest sensors at 188 centimeters (6.2 feet) and remains in the pit cover. Precipitation did not infiltrate to the deepest sensor on the vegetated final cover at U-3ax/bl. Water drained from all Area 3 drainage lysimeters that received three times natural precipitation, but there was no drainage from the lysimeters that received only natural precipitation. Biota monitoring data show that tritium is the primary radionuclide accessible to plants and animals. Other human-produced radionuclides in the tissues of plant and animal samples from both RWMSs were not found at concentrations higher than in biota samples collected at control locations. This suggests that sampled animals did not intrude into the waste and that waste did not move to where it is accessible to plants or animals.

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# INTRODUCTION

This document summarizes the calendar year 2005 waste management environmental monitoring data for the Area 3 and Area 5 Radioactive Waste Management Sites (RWMSs). The *Integrated Closure and Monitoring Plan for the Area 3 and Area 5 Radioactive Waste Management Sites at the Nevada Test Site* (Bechtel Nevada [BN], 2005) describes details of the RWMS monitoring program. This report summarizes environmental data monitored for various media, 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 Emissions 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 confirm that Area 5 RWMS activities are not affecting the aquifer.
- Vadose zone monitoring - conducted to assess the water balance of the RWMSs, confirm the assumptions made in the Performance Assessments (including no downward pathway), and evaluate the performance of the operational monolayer-evapotranspirative (ET) waste covers.
- Soil-gas monitoring for tritium - conducted to evaluate tritium movement at waste containment cell GCD-05U.
- Biota monitoring for tritium - 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 BN as required by BN/DOE Contractual Work Smart Standards, which include various DOE Orders and regulations from the Code of Federal Regulations (CFR). For a detailed description of these regulatory drivers, refer to the *Integrated Closure and Monitoring Plan for the Area 3 and Area 5 Radioactive Waste Management Sites at the Nevada Test Site* (BN, 2005). These regulatory drivers exist to mitigate risk to the public and environment and include: DOE Order 435.1 (Radioactive Waste Management), DOE Order 450.1 (Environmental Protection Program), DOE Order 5400.1 (General Environmental Protection Program), DOE Order 5400.5 (Radiation Protection of the Public and the Environment), 40 CFR 61 (EPA: National Emission Standards for Hazardous Air Pollutants), 40 CFR 264 (EPA: Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities), and 40 CFR 265 (EPA: Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities).

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

# SITE DESCRIPTIONS

## Area 3 RWMS

The Area 3 RWMS is located on Yucca Flat within the Nevada Test Site (NTS). 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 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 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 the several primary underground nuclear test areas and most of the length of the valley is marked with subsidence craters.

The thickness of the unsaturated zone at the Area 3 RWMS is estimated to be 488 m (1,600 ft), and the water table is assumed to occur in Tertiary tuff, based on data from surrounding bore-holes. The tuff-alluvium contact is estimated to occur at a depth of between 305 and 457 m (1,000 and 1,500 ft) below land surface (BN, 1996).

Daily air temperatures can vary from -18 degrees Celsius ($^{o}$C) (0 degrees Fahrenheit [F]) to 24$^{o}$C (75$^{o}$F) in winter and from 16$^{o}$C (60$^{o}$F) to 42$^{o}$C (108$^{o}$F) in summer. During 2005, the temperature range was -14.4$^{o}$C (6.1$^{o}$F) to 41.3$^{o}$C (106$^{o}$F). The climate of Yucca Flat is arid. The average annual precipitation based on a 45-year record (1961-2005) at a location 4.5 km (2.8 mi) northwest of the Area 3 RWMS is 165.3 millimeter (mm) (6.51 inches [in.]) (Air Resources Laboratory [ARL], 2006). The average annual precipitation based on the ten-year record (1996-2005) collected at the Area 3 RWMS is 167.4 mm (6.59 in.). Precipitation is highly variable at the Area 3 RWMS. The standard deviation of the ten-year record of annual precipitation is 97.6 mm (3.84 in.); the maximum annual precipitation was 374.1 mm (14.73 in.) in 1998 and the minimum was 26.2 mm (1.03 in.) in 2002. Average annual potential evapotrans-piration (PET) at the Area 3 RWMS, calculated using local meteorology data, is approximately ten times the annual average precipitation (Desotell et al., 2006).

## 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 NTS. 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 (see Figure 1). The valley floor slopes gently toward a central playa. 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 (774 ft) at the southeast corner of the RWMS (Well UE5PW-1), 256.6 m (842 ft) at the northeast corner (Well UE5PW-2), and 271.5 m (891 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) (Reynolds Electrical & Engineering Co., Inc. [REECo], 1994). The water table beneath the Area 5 RWMS is extremely flat. The average groundwater elevation measured at these wells is 733.7 m (2,407 ft) AMSL.

Air temperatures can vary from -15°C (5°F) to 24°C (75°F) in winter and from 16°C (60°F) to 45°C (113°F) in summer. During 2005, the temperature range was -13.1°C (8.4°F) to 43.6°C (110°F). The climate of Frenchman Flat is arid. The average annual precipitation based on a 43-year record (1963-2005) at a location 6.4 km (4 mi) south of the Area 5 RWMS is 125.9 mm (4.96 in.) (ARL, 2006). The average annual precipitation based on the 11-year record (1995-2005) collected at the Area 5 RWMS is 135.9 mm (5.35 in.). Precipitation is highly variable at the Area 5 RWMS. The standard deviation of the 11-year record of annual precipitation is 65.0 mm (2.56 in.); the maximum annual precipitation was 258.9 mm (10.19 in.) in 1998 and the minimum was 37.7 mm (1.48 in.) in 2002. Average annual PET 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, the annual average temperature at Area 3 is about 2°C (4°F) cooler than at Area 5, and soils at Area 3 are generally finer grained than at Area 5.

## Hydrologic Conceptual Model of the Area 3 and Area 5 RWMSs

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 contents 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 pore 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 static region begins between approximately 49 to 119 m (160 to 390 ft) in Area 3, and between approximately 40 to 90 m (131 to 295 ft) 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). Stable isotope compositions of pore 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 Performance Assessments (PAs) (Shott et al., 1997, 1998; Levitt et al., 1999; Levitt and Yucel, 2002; and 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). In addition, monitoring data from a bare-soil weighing lysimeter located in Area 5 indicate that the soil water storage has increased slowly with time and water is beginning to accumulate at the bottom of the lysimeter.

# PROJECT DESCRIPTION

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

## 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). Disposal in the U-3ax crater began in the late 1960s. Disposal began in U-3bl 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 closure cover that is at least 2.4 m (8 ft) thick. For details of the final closure plan of CAU 110, refer to BN (2001a). 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 NTS and approved off-site generators. Crater U-3bh was originally used for disposal of contaminated soils from the Tonopah Test Range in 1997 and has been used for waste disposal from other approved generators. The remaining two craters are not in use (Figure 3). For a detailed description of the facilities at the Area 3 RWMS, refer to Shott et al. (1997).

## 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 4). Some previous documents list fewer landfill cells, but new cells continue to be constructed and Trench 4 was separated into T04C and T04C-1 (BN, 2005). 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 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 (2005) and Cochran et al. (2001).

There are currently eight pits receiving waste at the Area 5 RWMS. The open pits include P03U, P06U, P09U, P12C, P13U, P14U, P15U, and P16C. Construction of P16C was completed and P03U was graded in 2005. The only active mixed waste disposal cell is P03U. All other active units contain LLW except P06U, which contains asbestiform LLW. Landfill cells that have been closed to date include all 16 trenches and eight pits. The eight closed pits are P01U, P02U, P04U, P05U, P07U, P08U, P10C, and P11U.

# ENVIRONMENTAL MONITORING DATA

## Types of RWMS Environmental Data

Area 3 RWMS monitoring locations are shown in Figure 3, and Area 5 RWMS monitoring locations are shown in Figures 4 and 5. This report provides a general description and graphical representations of some of these data. Monitoring data currently being collected include:

### *Radiation Exposure Data*

- Quarterly thermoluminescent dosimeter (TLD) measurements

### *Air Monitoring Data*

- Weekly alpha concentrations
- Weekly beta concentrations
- Biweekly tritium concentrations
- Monthly gamma concentrations
- Monthly americium concentrations
- Monthly plutonium concentrations
- Radon flux measurements from waste covers

### *Groundwater Monitoring Data*

- Quarterly water-level measurements (manual)

- Semiannual Indicators of Contamination:
    - pH (field measurement)
    - Specific conductance (SC) (field measurement)
    - Total organic carbon (TOC)
    - Total organic halides (TOX)
    - Tritium ($^{3}H$)

- 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 as $^{238}Pu$ and $^{239+240}Pu$

### *Meteorology Monitoring Data*

- Daily Meteorology Data:
    - Average air temperature at heights of 3.0 m (9.8 ft) and 9.5 m (31.1 ft) above ground level (AGL)

- Maximum air temperature at heights of 3.0 m and 9.5 m AGL
- Minimum air temperature at heights of 3.0 m and 9.5 m AGL
- Average relative humidity at heights of 3.0 m and 9.5 m AGL
- Maximum relative humidity at heights of 3.0 m and 9.5 m AGL
- Minimum relative humidity at heights of 3.0 m and 9.5 m AGL
- Average wind speed at heights of 3.0 m and 9.5 m AGL
- Maximum wind speed at heights of 3.0 m and 9.5 m AGL
- Average barometric pressure
- Maximum barometric pressure
- Minimum barometric pressure
- Total precipitation

- Hourly Meteorology Data:
  - Average air temperature at heights of 3.0 m and 9.5 m AGL
  - Average relative humidity at heights of 3.0 m and 9.5 m AGL
  - Average wind speed at heights of 3.0 m and 9.5 m AGL
  - Average wind direction at heights of 3.0 m and 9.5 m 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-05U gas sampling ports (nine depths)

- Daily Weighing Lysimeter Data (Area 5):
  - Daily E from the bare-soil weighing lysimeter
  - Daily ET from the vegetated weighing lysimeter

- Daily Drainage Lysimeter Data (Area 3):
  - Soil volumetric water content (VWC), soil matric potential, and temperature with depth
  - Total soil water storage

- Daily Automated Vadose Zone Monitoring System Data:
  - Soil VWC with depth in waste covers
  - Soil VWC beneath waste cells
  - Soil matric potential with depth in waste covers
  - Soil temperature with depth in waste covers
  - Soil temperature beneath waste cells

- Periodic Subsidence Monitoring Data : Locations and description of subsidence features on waste covers

- Biota Monitoring Data: Periodic analysis of plant and animal samples for tritium concentrations.

## Radiation Exposure Data

The goals of direct radiation monitoring are to assess the state of the external radiation environment, to detect changes in that environment, and to measure gamma radiation levels near potential exposure sites. Performance objectives in DOE Order 435.1 state that LLW disposal facilities shall be sited, designed, operated, maintained, and closed so it is reasonable to expect that the total effective dose equivalent from all exposure pathways, except the dose from radon, to representative members of the public shall not exceed 25 millirem/year (mrem/yr). Because the RWMSs are located well within the NTS boundaries, no members of the public 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 were used to measure ionizing radiation exposure from all sources, including natural and man-made radioactivity. The TLD used was the Panasonic UD-814AS, consisting of four elements housed in an air-tight, water-tight, ultraviolet-light-protected case. A slightly shielded lithium borate element was used to check low-energy radiation levels and the average of three calcium sulfate elements was used to measure penetrating gamma radiation.

Figures 3, 4, and 5 show TLD monitoring locations. At each location, a pair of TLDs was placed at 1 ± 0.3 m (28 to 51 in.) AGL and were exchanged for analysis on a quarterly basis. TLDs were analyzed quarterly using automated TLD readers that were calibrated and maintained by the BN Radiological Control Department. Reference TLDs were exposed to 100 milliroentgen (mR) from a $^{137}$Cs radiation source under very controlled conditions and were analyzed along with TLDs collected from the environment to scale their response.

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 and, therefore, 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 compared with the average exposures at the fence line or in Area 3 outside the fence line.

Annual radiation exposures during 2005 at locations inside and near the Area 3 RWMS are shown in Figure 6. The monitoring locations are RWMS Center, RWMS North, RWMS East, RWMS South, RWMS West, T3, T3 West, T3A, and U-3CO North (see Figure 3). The exposures measured inside Area 3 RWMS and three of four measurements at the boundary were within the range of background exposures. The TLD locations outside the Area 3 RWMS boundary and RWMS South have higher exposures. The locations with higher exposures are associated with historic aboveground nuclear weapon test locations. Given this, current Area 3 RWMS operations would have contributed negligible external exposure to a hypothetical person residing at the Area 3 RWMS boundary during 2005.

Twenty-five nuclear weapons tests were conducted within 6.3 km (3.9 mi) of the Area 5 RWMS between 1951 and 1971. Fifteen of these were atmospheric tests and nine of the remaining tests released radioactivity to the surface which contributes to exposures in the area. No nuclear weapons testing occurred within the boundaries of the Area 5 RWMS. During 2005, estimated annual exposures from TLD measurements at the Area 5 RWMS were within the range of exposures measured at NTS background locations.

Comparisons of 1998–2005 direct radiation exposure data using TLDs from the two RWMSs and NTS background locations are presented in Figures 7 and 8. These data indicate that direct radiation exposure at the Area 3 and Area 5 RWMSs is low.

## Air Monitoring Data

### *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 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 is drawn across a desiccant during a two-week period to collect atmospheric moisture. The moisture is distilled from the desiccant and the tritium activity is measured by liquid scintillation.

The tritium monitoring locations at the Area 3 RWMS are U-3bh N and U-3ah/at S RWMS (see Figure 3). The Area 5 RWMS monitoring locations are DoD (approximately 1.0 km [0.6 mi] north of the Area 5 RWMS) and Sugar Bunker (approximately 1.5 km [0.9 mi] south of the Area 5 RWMS). These Area 5 monitoring locations are in the prevailing downwind directions from the RWMS and provide adequate environmental monitoring for the Area 5 RWMS. Tritium concentrations at the Area 3 and Area 5 RWMSs are below the DOE Derived Concentration Guide (DCG) for tritium (Figure 9). The DCG is the concentration of a radio-nuclide in air that could be inhaled for one year and not exceed the DOE radiation standard of 100 mrem/yr committed effective dose equivalent to the public (DOE Order 5400.5).

The higher-than-normal tritium concentrations from DoD and Sugar Bunker on December 28, 2005, are suspected of being caused when a buried Sealand® shipping container was being retrieved on December 19, 2005. Forty drums of tritium-laden waste were in this Sealand® container which was punctured either when it was buried in April 2005 or when it was being retrieved.

### *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 2005 analysis results indicate that no man-made radioactivity was detected by gamma spectroscopy. However, concentrations of americium and plutonium near the minimum detectable concentrations (MDCs) of the measurements were detected (Figures 10, 11, and 12).

The americium and plutonium concentrations at the Area 3 RWMS were slightly higher than at the Area 5 RWMS. Due to historical testing adjacent to the Area 3 RWMS, it is not possible to determine whether waste operations contributed anything to these measured concentrations. All measured concentrations of americium and plutonium were below the DCG for each radionuclide.

#### *Radon*

The performance objective (DOE Order 435.1), and regulatory limit (40 CFR 61, Subpart Q) for radon emissions from DOE facilities is 20 picoCurie per square meter per second. Radon flux measurements were made during 2005 on the Area 5 RWMS for comparison with the regulatory limit. Radon flux was measured on the P01U cover because P01U has a high inventory of radium. Radon flux was also measured on the north end of the P13Uand P14U covers because these pits contain thorium-bearing waste. Radon flux was also measured at an undisturbed site outside the RWMS. Figure 13 shows the measurement locations. Measurements were made December 19 through 21, 2005. Measurements were made using radon flux domes (Rad Elec, Inc.) placed on the ground surface. Electrets inserted in the domes measure radon flux from the ground.

Radon flux results during 2000–2005 are summarized in Figure 14. All radon flux measurements were at least five times lower than the regulatory limit. Measured radon flux from the pit covers is not higher than the measured radon flux from the undisturbed location.

### Groundwater Monitoring Data

Three pilot wells, UE5PW-1, UE5PW-2, and UE5PW-3, were drilled around the perimeter of the Area 5 RWMS in 1993 (see Figure 5). The groundwater at these wells is sampled twice a year. SC, pH, TOC, TOX, and tritium are measured as indicators of contamination migration. 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 Test Site 2005 Data Report: Groundwater Monitoring Program, Area 5 Radioactive Waste Management Site* (BN, 2006).

Groundwater elevation measurements are taken quarterly using an electronic tape. All groundwater elevation data from manual measurements taken since the wells were drilled in 1993 are shown in Figure 15. These data indicate that the water table beneath the Area 5 RWMS is flat, with little or no groundwater flow.

### Meteorology Monitoring Data

Meteorology monitoring data collected in 2005 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) from Well UE5PW-1 (see Figures 3 and 4).

### *Air Temperature*

Air temperatures at the Area 3 RWMS are slightly cooler than air temperatures at the Area 5RWMS. The 2005 average recorded temperatures at 3 m (10 ft) are 13.3ºC (55.9ºF) at the Area 3 RWMS, and 15.4ºC (59.7ºF) at the Area 5 RWMS. The 2005 maximum and minimum temperatures at 3 m (10 ft) are 41.3ºC (106.3ºF) and -14.4ºC (6.1ºF) at the Area 3 RWMS and 43.6ºC (110.5ºF) and -13.1ºC (8.4ºF) at the Area 5 RWMS (Figure 16).

### *Relative Humidity*

Measured relative humidity at the Area 3 RWMS and the Area 5 RWMS are similar. The average relative humidity during 2005 at these two sites is 42.4 percent (Figure 17).

### *Barometric Pressure*

Average daily barometric pressure measured at the Area 3 RWMS and the Area 5 RWMS show very similar patterns (Figure 18). The difference in barometric pressure readings between the two locations is caused by the 261 m (856 ft) difference in elevation.

### *Wind Speed and Direction*

The average wind speed is slightly higher at the Area 3 RWMS than at the Area 5 RWMS. During 2005, the average wind speed at the Area 3 RWMS was 2.8 meters per second (m/s) (6.3 miles per hour [mph]) and the maximum gust was 19.6 m/s (43.8 mph). During 2005, the average wind speed at the Area 5 RWMS was 2.4 m/s (5.4 mph) and the maximum gust was 20.4 m/s (45.6 mph). Daily maximum and average wind speeds are in Figures 19 and 20.

Wind rose diagrams provide wind direction and wind speed distribution in each direction using hourly wind data measured at a height of 3 m AGL. Generally, lower wind speeds come from the north and higher wind speeds come from the south. Wind roses from the Area 3 and Area 5 RWMS are presented in Figures 21 and 22, respectively. The one-year wind roses presented here are very similar to the multiple-year wind roses.

### *Precipitation*

Rainfall at the Area 3 RWMS in 2005 was above average, totaling 219.1 mm (8.62 in.). The maximum daily rainfall at the Area 3 RWMS was 26.8 mm (1.06 in.) on August 14, 2005. The annual average precipitation measured at the Area 3 RWMS for 1996 to 2005 is 167.4 mm (6.59 in.). Rainfall at the Area 5 RWMS in 2005 was also above average, totaling 201.4 mm (7.93 in.). The maximum daily rainfall at the Area 5 RWMS was 28.6 mm (1.12 in.) on April 28, 2005. The annual average precipitation measured at the Area 5 RWMS for 1995 to 2005 is 135.9 mm (5.35 in.). Figures 23 and 24 depict the 2005 daily total precipitation at the Area 3 and Area 5 RWMSs. Precipitation at the Area 3 RWMS and the Area 5 RWMS during January and February 2005 was well above average. This followed high precipitation in October and December 2004.

Historical precipitation data recorded at the Buster-Jangle Y (BJY) station (located about 3 km [2 mi] northwest of the Area 3 RWMS) and at the Area 3 RWMS are in Figure 25. The BJY station is a Meteorological Data Acquisition (MEDA) station operated by the ARL Special Operations and Research Division (ARL/SORD). The 45-year average annual precipitation at BJY from 1961 to 2005 is 165.3 mm (6.51 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 the Area 5 RWMS are provided in Figure 26. The Well 5B station is also an ARL/SORD MEDA station. The 43-year average annual precipitation at Well 5B from 1963 to 2005 is 125.9 mm (4.96 in.).

### *PET*

The total calculated PET in 2005 at the Area 3 RWMS is 1,517.2 mm (59.7 in.) and at the Area 5 RWMS is 1,577.8 mm (62.1 in.). Total PET is derived using a modified version of the radiation-based equation of Doorenbos and Pruitt (1977). This equation calculates PET 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 employed 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 PET to precipitation in 2005 at the Area 3 RWMS is 6.92, and the ratio of PET to precipitation in 2005 at the Area 5 RWMS is 7.73. The ratio of PET to precipitation is lower than normal because there was above-average rainfall in 2005 and annual PET is fairly constant.

## Vadose Zone Monitoring Data

### *Monitoring Strategy*

Vadose zone monitoring is conducted at the Area 3 and Area 5 RWMSs to demonstrate compliance with DOE Orders 5400.1 and 435.1, and confirm the assumptions made in the PA for each RWMS (e.g., hydrologic conceptual models including soil water contents, upward and downward flux rates, 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 current vadose zone monitoring program at the RWMSs is designed based on an understanding of the vadose zone system acquired through extensive characterization studies (BN, 1998; Blout et al., 1995; REECo, 1993a, 1993b, 1994; Schmeltzer et al., 1996; Shott et al., 1997, 1998; Tyler et al., 1996) and modeling studies (Levitt et al., 1999).

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 PET values (the driving force of upward flow), directly measuring ET and bare-soil E at the Area 5 RWMS weighing lysimeter facility, 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 well GCD-05U located near the center of Area 5 RWMS (see Figure 4).

### *Soil Gas Tritium*

Soil gas tritium monitoring is conducted via soil gas sampling at Well GCD-05U. This 3-m- (10-ft)-diameter borehole has a large tritium inventory (~2.2 million curies at time of disposal) which is buried from 20 to 37 m (65 to 120 ft) below ground surface. Two strings of nine soil gas sampling ports are buried at depths of 3.0 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. Approximately 30 liters of soil gas sample provides approximately 0.3 grams of water. Tritium sampling at GCD-05U provides a direct measure of changes in tritium activity with depth due to degradation of waste containers, advection, and diffusion. Sampling started in 1990 and has continued at least annually through 2005.

Soil gas tritium was sampled from the nine GCD-05U sampling depths in August 2005. The 16-year trend in results indicates that upward migration of tritium through soil from the waste level is extremely slow. Tritium concentrations have remained constant and low from the surface down to 12.2 m (40 ft). Tritium concentrations at 15.2 m (50 ft) slowly increased through 1997, but have since leveled off. The sample ports at depths of 19.8, 25.9, 33.5, and 36.3 m (65, 85, 110, and 119 ft) are adjacent to the tritium source. Tritium concentrations at these depths have increased by a factor of three since 1990. The highest measured soil gas tritium concentration of 304 microcuries (µCi) per $m^3$ 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 Figures 27 and 28.

### *Area 5 Weighing Lysimeter Facility*

The Area 5 Weighing Lysimeter Facility consists of two precision weighing lysimeters located about 400 m (0.25 mi) southwest of the Area 5 RWMS (see Figure 5). Each lysimeter is a 2 × 4 m (6.6 × 13 ft) by 2-m- (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 loadcell. Each loadcell can measure approximately 0.1 mm (0.004 in.) of precipitation or ET. One lysimeter is vegetated with native plant species at the approximate density of the surrounding desert, and the other lysimeter is kept bare to simulate the bare operational waste covers at the Area 5 RWMS. The load cells have been monitored continuously since March 1994 and provide an accurate data set of the surface water balance at the Area 5 RWMS.

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, 2005, is illustrated in Figure 29.

The vegetated lysimeter is considerably drier than the bare-soil lysimeter, despite the small number of plants on the vegetated lysimeter (about 15 percent plant cover). Soil water storage decreases rapidly in the vegetated lysimeter following high rainfall periods. Increases in soil water storage observed early in the data record in the vegetated lysimeter are a result of irrigation conducted to ensure that transplanted vegetation survived.

No water has ever accumulated at the bottom of the vegetated lysimeter. Heavy precipitation and low E rates during the period from October 2004 to February 2005 combined with initially higher water contents, resulted in water accumulating at the bottom of the bare lysimeter starting in March 2005. Long-term numerical simulations (30 years) using a unit gradient bottom boundary were used to determine the amount of drainage that would have occurred if water could drain from the lysimeters. These simulations indicate an average of 1.0 cm/year of water reaches the bottom of the bare lysimeter and that essentially no water reaches the bottom of the vegetated lysimeter (Desotell et al, 2006).

During 2005, E from the bare lysimeter was lower than ET from the vegetated lysimeter, and soil water storage decreased in both lysimeters (Figure 30). The vegetated lysimeter dried out as cumulative ET exceeded cumulative precipitation after April 3. The bare-soil lysimeter dried out, but cumulative E did not exceed cumulative precipitation until August 23. ET was greater than E in March, April, and May (Figure 31).

### *Automated Waste Cover Monitoring System*

In 1998, an automated monitoring system was installed in Area 5 adjacent to Well UE5PW-1 at the Neutron Probe Calibration Facility (NPCF). Time-domain reflectometry (TDR) sensors are used to measure water content around different types of casings used in neutron probe access holes. These measured water contents are used for calibrating neutron probes. This TDR system has 36 TDR probes buried at depths of 30, 60, and 90 cm (1, 2, and 3 ft) around four different neutron probe access hole casing types. There are three replicate TDR sensors at each depth for each casing type. In 2005, precipitation infiltrated into the soil and percolated below 0.9 m (3 ft) at the NPCF. No neutron probes were calibrated during 2005.

In 1998, TDR probes were buried 1.2 m (4 ft) beneath the floor of open Pit 5 at the Area 5 RWMS. Approximately 4.4 m (14 ft) of waste and then approximately 2.3 m (8 ft) of operational cover were placed above these probes during disposal operations. The total depth of these probes is now approximately 8.9 m (29 ft). Measured volumetric water content in the floor of Pit 5 has remained constant at approximately 10 percent (Figure 32). 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 two sites (north and south) at depths ranging from 10 to 180 cm (0.3 to 5.9 ft). The precipitation events, beginning in October 2004, infiltrated into the operational cover and percolated below the deepest probe at 180 cm at both the north location (Figure 33) and the south location (Figure 34) in early March 2005. This moisture is below the range of substantial surface E and the gradual drying at these locations is most likely due to downward percolation. This is the deepest observed moisture percolation in the Pit 3 operational cover.

In 2000, TDR probes were installed in the operational covers of Pits 4 and 5 at depths ranging from 20 to 180 cm (0.7 to 5.9 ft). The 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 (Figure 35) and at Pit 5 in April 2005 (Figure 36). Similar to Pit 3, this moisture is below the range of substantial surface E and the gradual drying at these pits is most likely due to downward percolation. This is the deepest observed moisture percolation in the Pit 4 and Pit 5 operational covers.

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. Eight vertically arranged TDR probes were installed at four locations at depths ranging from 30 to 244 cm (1.0 to 8.0 ft). Measured soil water contents for one location (East Nest A) in the U-3ax/bl waste cover are shown in Figure 37. The TDR data indicate 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 U3ax/bl and percolated deeper than 152 cm (5.0 ft) by March 2005. This moisture was removed from the cover and returned to the atmosphere by ET by September 2005. Unlike the bare-soil operational covers on Pit 3, Pit 4, and Pit 5, moisture did not percolate deeper than where plants could remove it by ET.

Vegetation on the cover of U-3ax/bl is critical to its effectiveness. In the native environment, vegetative cover is about 12 percent. Vegetative cover is defined as the percent area covered by living 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 on the soil cap. A quantitative analysis of the vegetative cover on the U-3ax/bl soil cap is conducted annually in the spring. The percent cover for the established U-3ax/bl cover has ranged from 13 percent in 2004 to 20 percent in 2005.

### *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 (see Figure 3). This facility is designed to collect saturated gravity drainage from eight 3.05-m- (10-ft)-diameter by 2.44-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 (1.0 ft), 61 cm (2.0 ft), 91 cm (3.0 ft), 122 cm (4.0 ft), 183 cm (6.0 ft), and 244 cm (8.0 ft) deep. Measured water contents 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 Russian thistle, halogeton, and tumble mustard), and native species (primarily shadscale, winterfat, ephedra, and Indian rice grass). The climate treatments are natural precipitation and three times natural precipitation. The three times natural precipitation lysimeters receive natural precipitation and are irrigated with an amount equal to two times natural precipitation.

The eight lysimeters are identified as Lysimeter A through Lysimeter H. Lysimeter A is bare-soil with natural precipitation, Lysimeter B is bare-soil with three times natural precipitation, Lysimeter C is invader species with natural precipitation, Lysimeter D is invader species with three times natural precipitation, Lysimeter E is native species with natural precipitation, Lysimeter F is native species with three times natural precipitation, Lysimeter G is invader species with natural precipitation, and Lysimeter H is invader species with three times natural precipitation (Table 1).

In 2005, there was 219.1 mm (8.6 in.) of precipitation at the Area 3 Drainage Lysimeter facility. An additional 508.2 mm (20.0 in.) of irrigation was applied to the irrigated Lysimeters B, D, F, and G. Also an irrigation solenoid failed and 507.9 mm (20.0 in.) was accidentally applied to Lysimeter F between June 1, 2005 and June 15, 2005.

No drainage occurred from any of the four nonirrigated lysimeters, but moisture accumulated at the bottom of the bare-soil lysimeter (Lysimeter A) and the native plant lysimeter (Lysimeter E). There was drainage from every irrigated lysimeter. There was 358.7 mm (14.1 in.) of drainage from the irrigated bare-soil lysimeter (Lysimeter B). This is 49 percent of the combined precipitation and applied irrigation. There was 58.2 mm (2.3 in.) and 123.3 mm (4.8 in.) of drainage from the two irrigated lysimeters with invader species (Lysimeters D and H). These are 8.0 percent and 16.9 percent of the combined precipitation and applied irrigation. There was 292.6 mm (11.5 in.) of drainage from the irrigated native species lysimeter (Lysimeter F). This is 23.7 percent of the combined precipitation and applied irrigation. Almost 40 percent (114.5 mm [4.5 in.]) of the drainage from Lysimeter F occurred between June 7 and July 4, 2005. This was during and immediately following the period when this lysimeter was accidentally flooded with 507.9 mm (20.0 in.) of irrigation.

Volumetric water contents at all measurement depths through time are illustrated in Figure 38 for bare-soil natural precipitation lysimeter (Lysimeter A), and in Figure 39 for the native species, natural precipitation lysimeter (Lysimeter E). Lysimeter A mimics bare-soil operational soil covers, and Lysimeter E mimics final monolayer-ET covers. During 2005, moisture from natural precipitation has percolated to the bottom of Lysimeter A, 244 cm (8 ft) deep. Moisture has accumulated at the bottom of this lysimeter and is being very slowly removed by surface E. Also during 2005, moisture from natural precipitation percolated to the bottom of Lysimeter E, but most of this moisture was removed from the lysimeter by ET.

Figure 40 shows the calculated total water storage for all eight lysimeters using TDR data. In 2005, plants on the vegetated lysimeters (both native and invaders species cells) removed the accumulated moisture in the lysimeters by ET. Lysimeter F had more water storage during the summer of 2005 because it was accidentally flooded. The two bare-soil lysimeters (Lysimeters A and B) could not remove the accumulated moisture by only E resulting in greater water storage.

### *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. Waste Operations personnel observe and repair subsidence features. The locations of subsidence features observed at the Area 5 RWMS in 2005 are shown in Figure 41. Subsidence occurred on the cover of Pits 4 and 5 where 12 separate subsidence locations were recorded. Altogether, 27 $m^3$ (953 $ft^3$) of fill dirt were required to cover the cracks and depressions that occurred due to soil settling.

## Biota Monitoring Data

Plant and animal (biota) monitoring at the Area 3 RWMS and Area 5 RWMS help characterize and define trends in potential transport of radionuclides from buried waste. Tritium is predominantly observed due to its high mobility as tritiated water. The primary mechanisms that transport tritium upward through waste covers and into the atmosphere are gaseous diffusion, gaseous advection, bioturbation, plant uptake and transpiration, and soil E. Sampling plant water for tritium provides a direct measure of the plant uptake of tritium. Analysis of plant tissues for gamma-emitting radionuclides, $^{90}$Sr, and alpha-emitting radionuclides provides information on potential plant intrusion into the waste and uptake of radionuclides.

Biota sampling took place between April 12 and May 26, 2005. A total of seven plants and six small mammals were sampled from the Area 3 RWMS (U-3ax/bl) (Figure 42 and Table 2). Forty-five plants and six small mammals were sampled from the Area 5 RWMS (Figure 43 and Table 2). Ant and small mammal burrows were also recorded in the Area 5 RWMS as a record of bioturbation (see Figure 43). Control plant and small mammal samples were collected in Area 22 within 500 m (1,640 ft) of the Army Water Well to provide background radionuclide concentration data for biota. Water was extracted from the samples by distillation and each sample was screened for tritium content by BN Environmental Technical Services using liquid scintillation. Tritium concentrations are displayed in Figures 44 and 45. Samples were then composited as shown in Table 2 and analyzed for gamma-emitting radionuclides, $^{90}$Sr, $^{238}$Pu, $^{239+240}$Pu, and $^{241}$Am. Detected man-made radionuclides are listed in Table 3. Tritium concentrations are much higher than any other detected radionuclide and, in fact, all other radionuclides except tritium are not different from the concentrations measured at the control site (see Table 3). Tritium concentrations were also much higher in the Area 5 RWMS compared with the Area 3 RWMS (U-3ax/bl). The higher concentrations in the Area 5 RWMS are expected because more tritium is disposed at the Area 5 RWMS. The lack of other radionuclides in biota suggests sampled biota did not intrude into the waste and that waste did not move to where it is accessible to plants or animals. Tritium concentrations observed during 2005 were within the range of values observed during recent sampling periods (BN, 2001b; 2002; 2003). Continued monitoring of biota can provide data to support PA efforts in predicting potential radionuclide movement over time.

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# CONCLUSIONS

The 2005 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. 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 at GCD-05U indicates 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 during the past ten years of their operation. Biota monitoring data show that tritium is the primary radionuclide accessible to plants and animals. All 2005 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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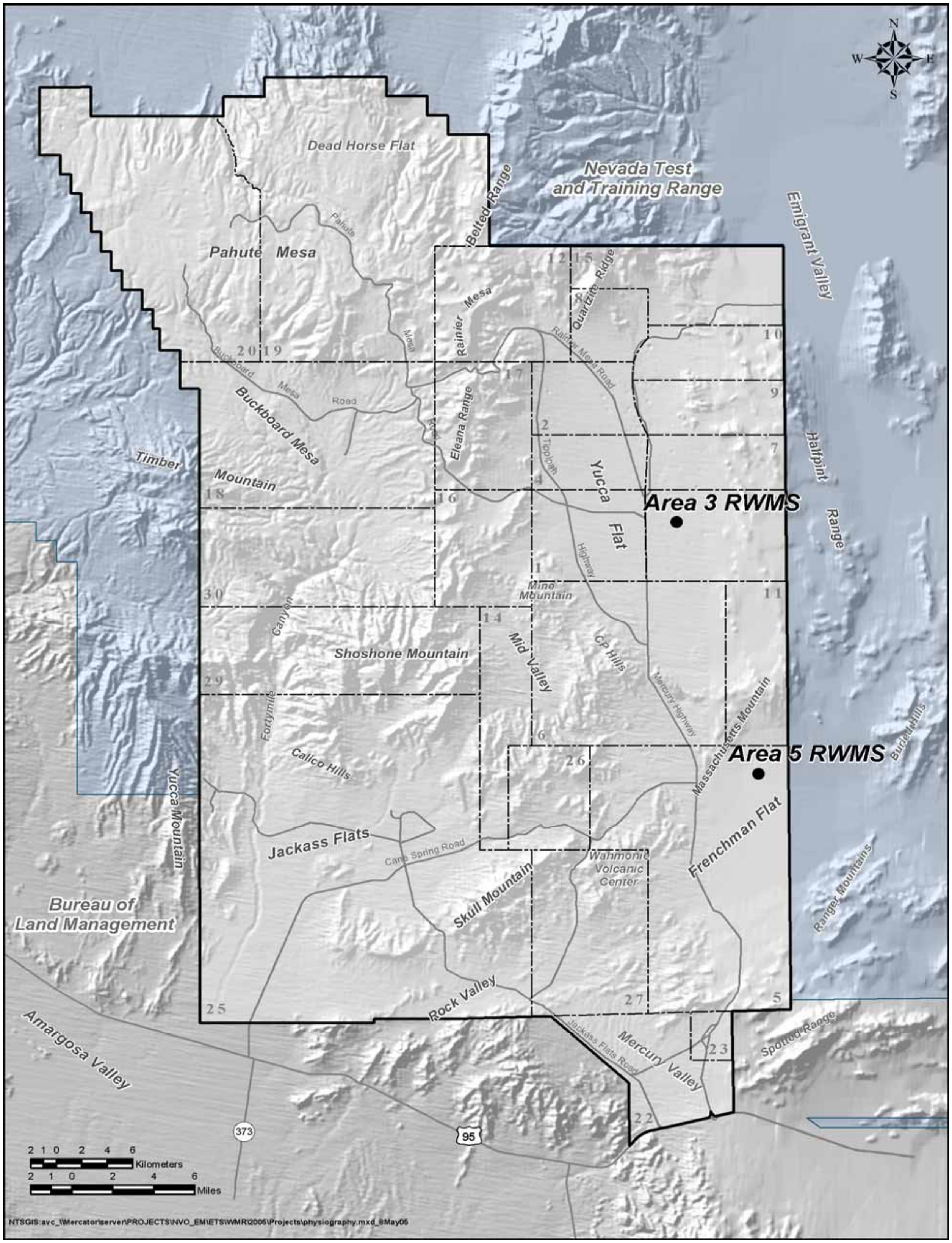



Figure 1. Location of the Area 3 and Area 5 RWMSs on the NTS

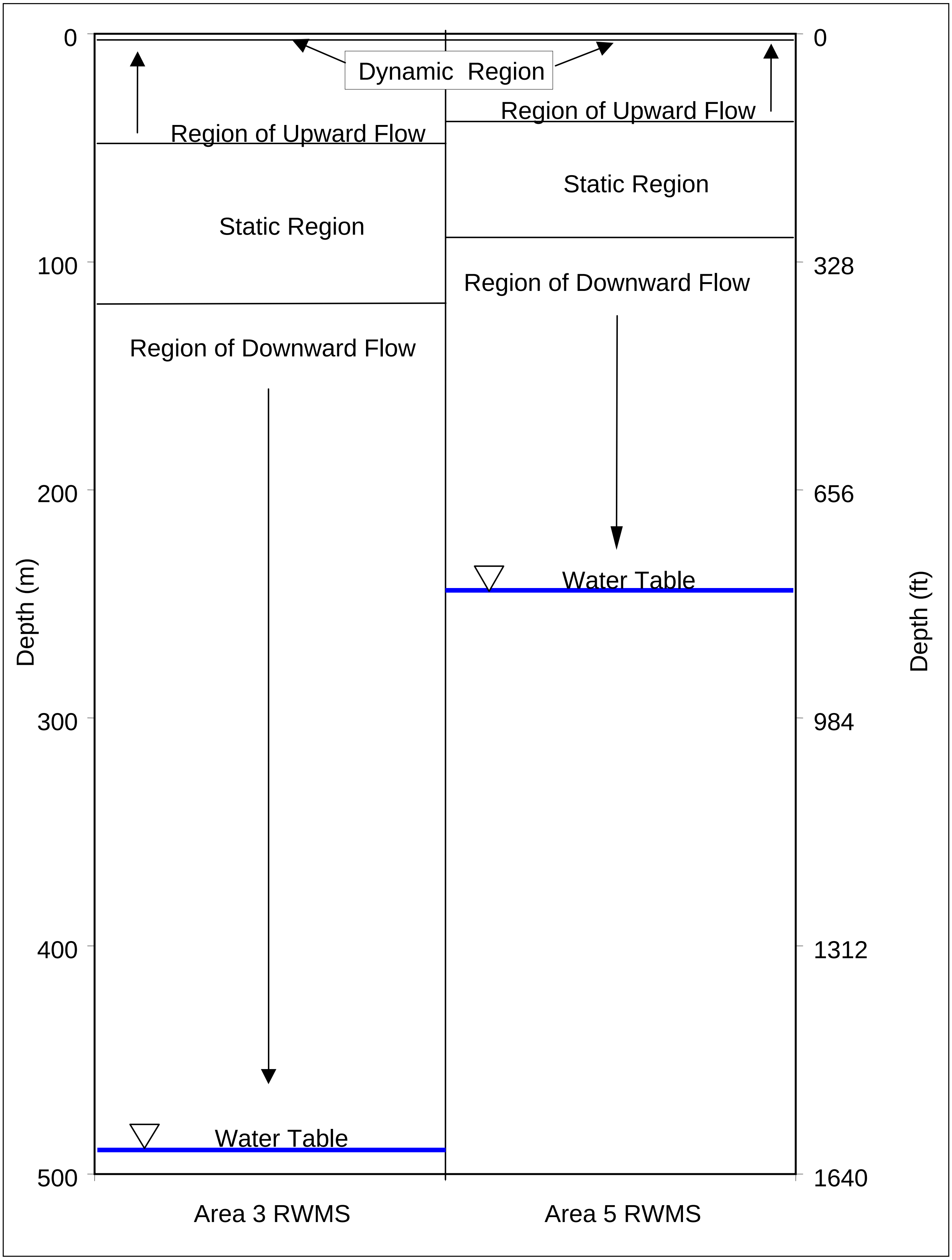



Figure 2. Vadose zone hydrologic conceptual models of the Area 3 and Area 5 RWMSs

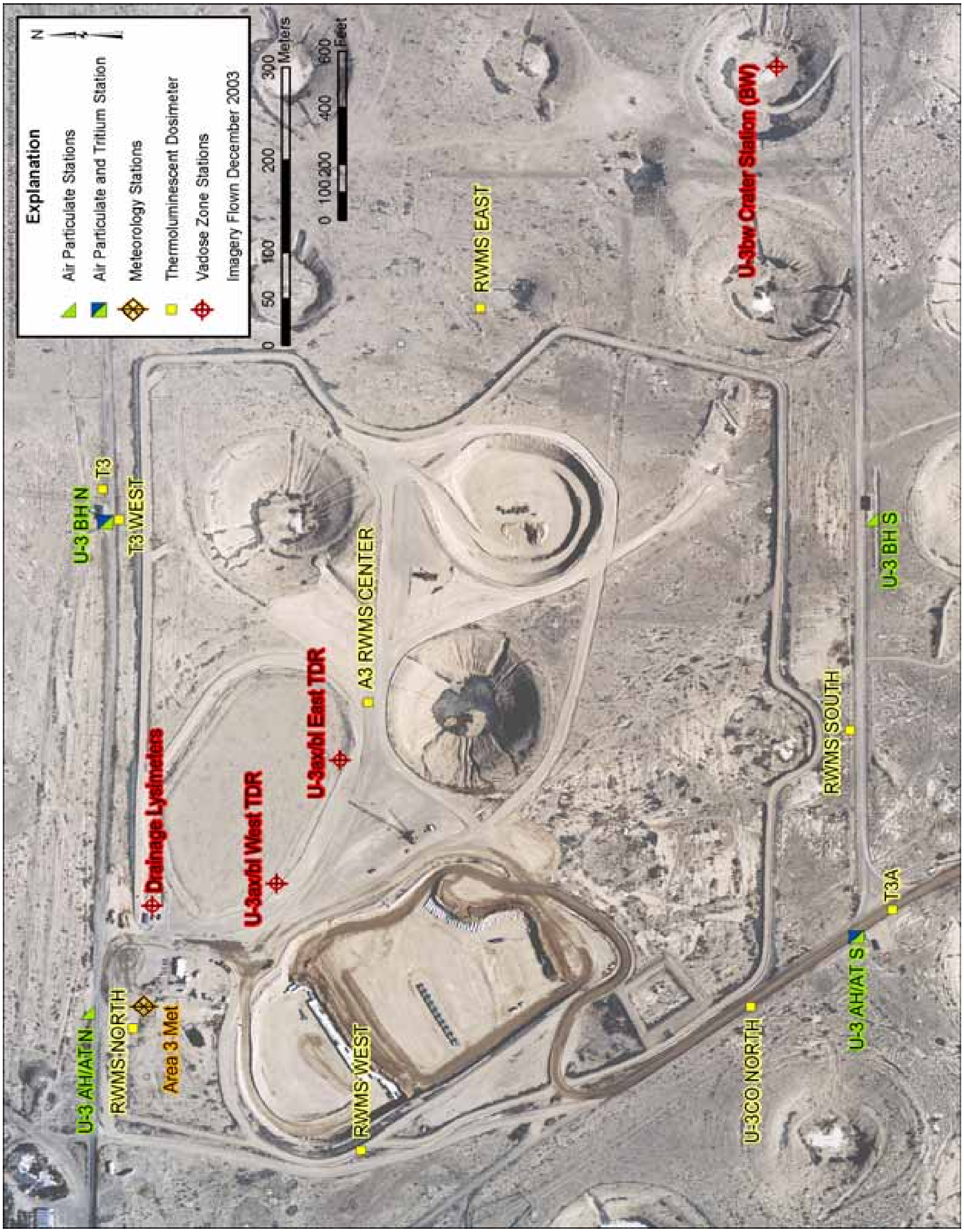



**Figure 3 Monitoring locations at the Area 3 RWMS**

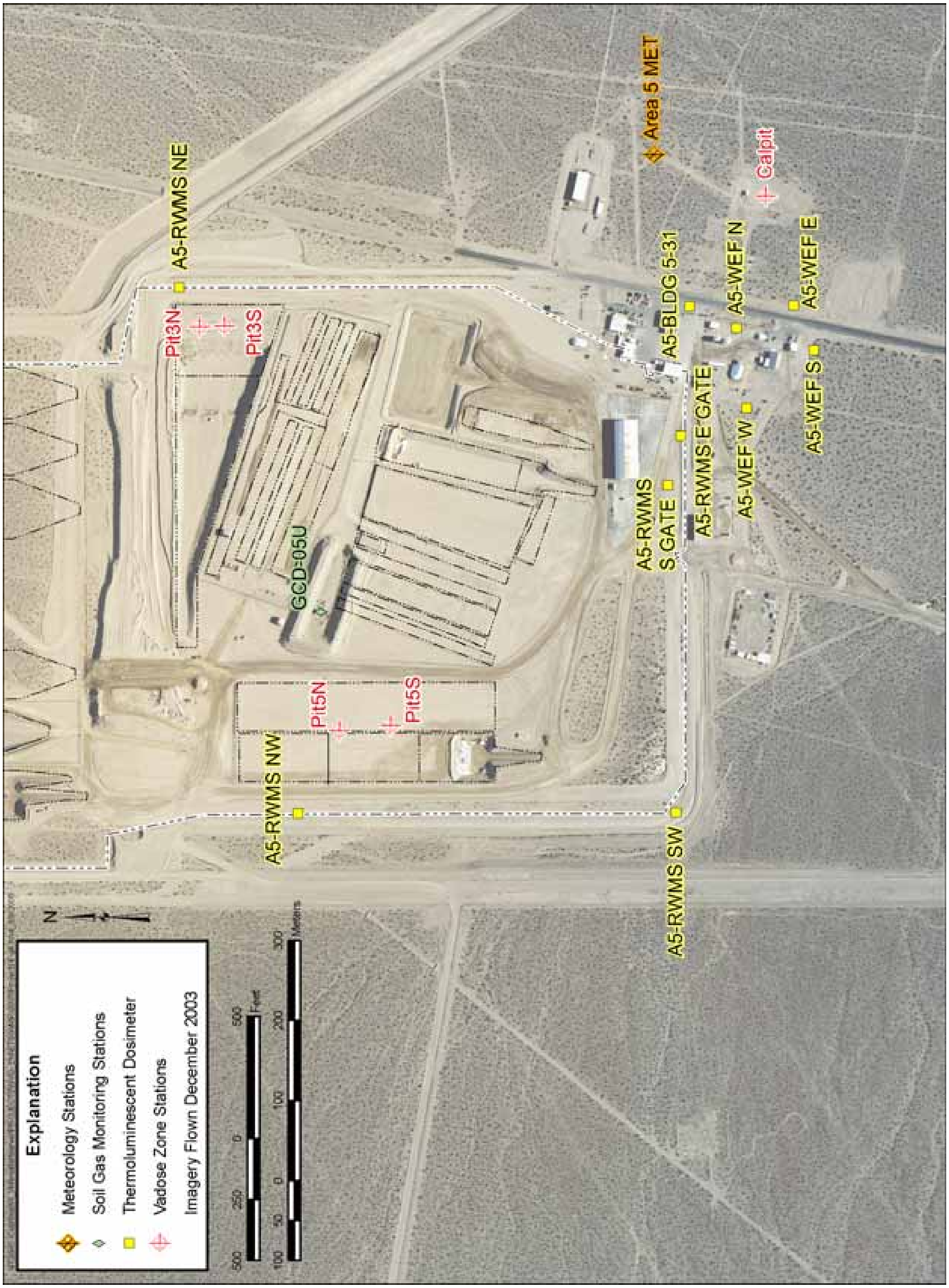



**Figure 4 Monitoring locations at the Area 5 RWMS**

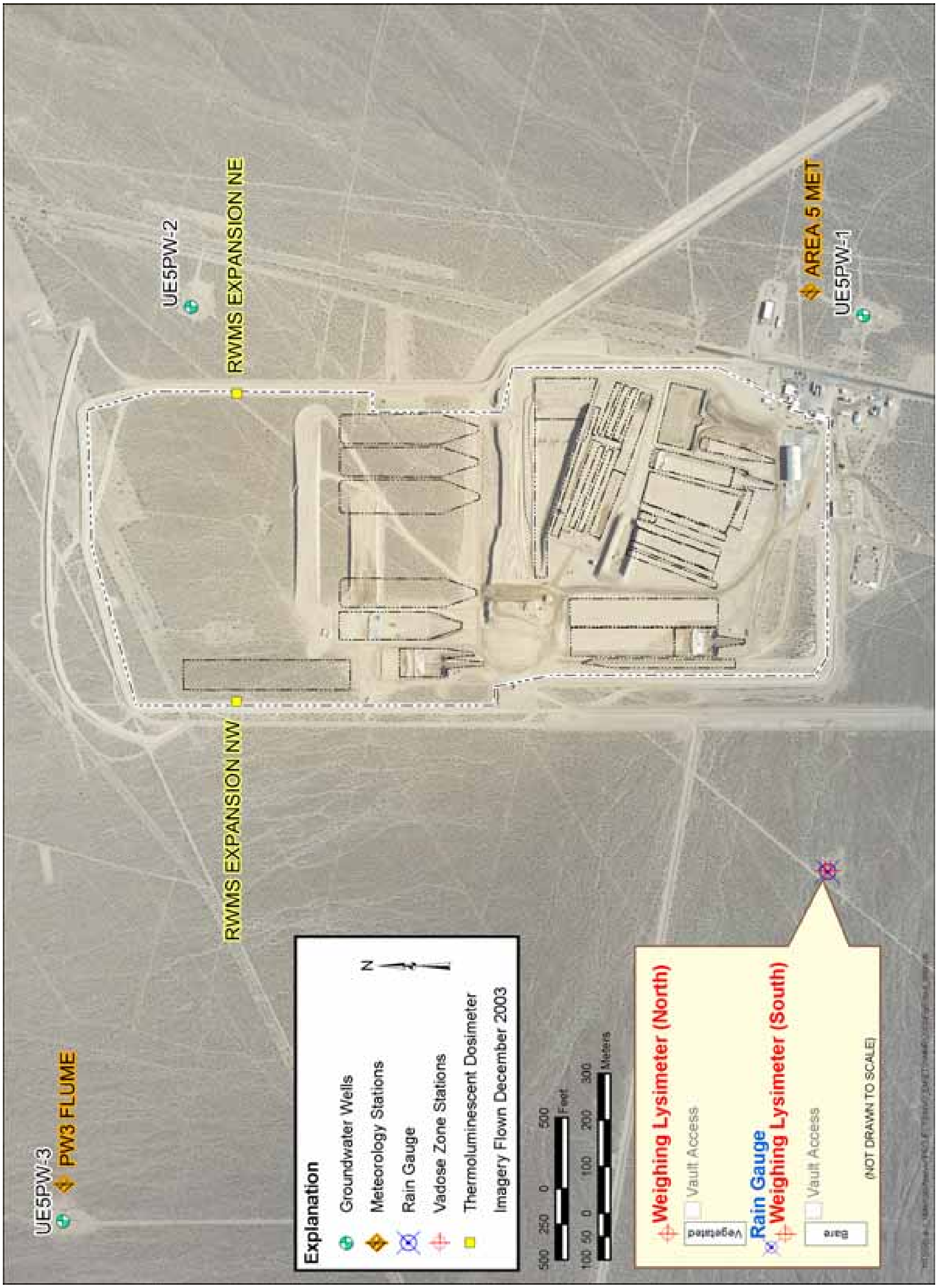



**Figure 5 Location of the Area 5 RWMS pilot wells and Weighing Lysimeter Facility**

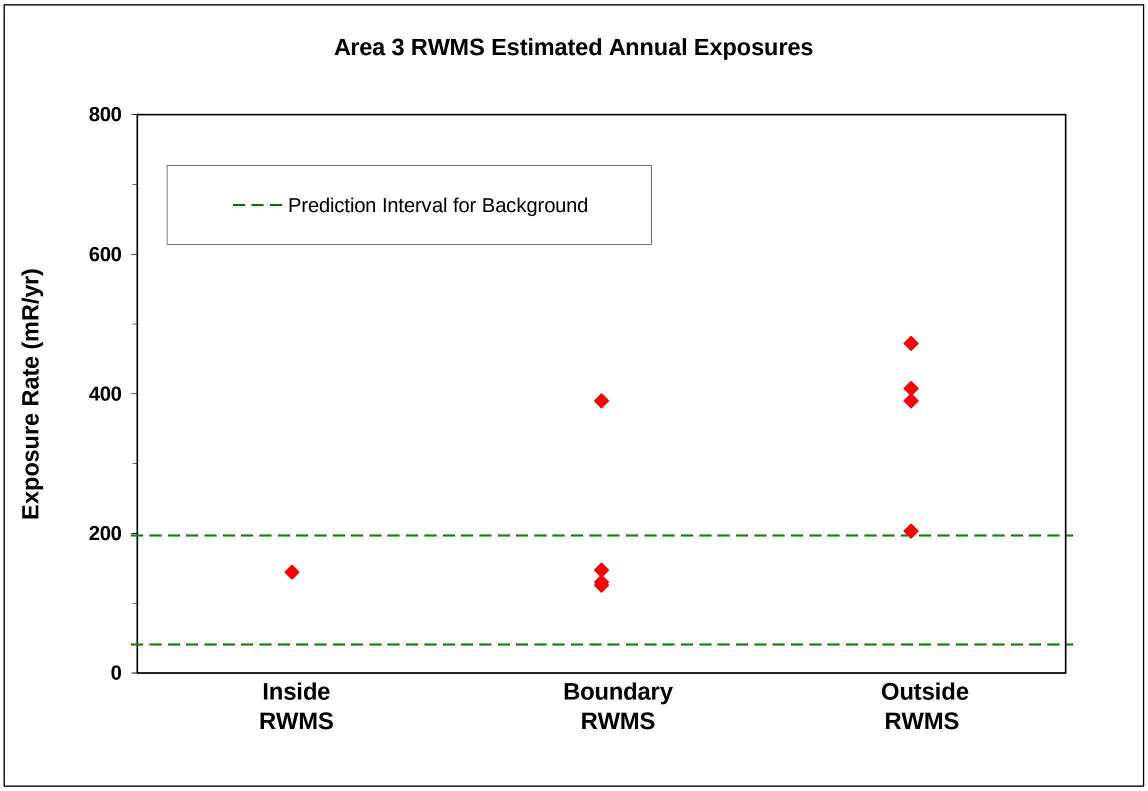



Figure 6. Annual exposure rates at the Area 3 RWMS during 2005

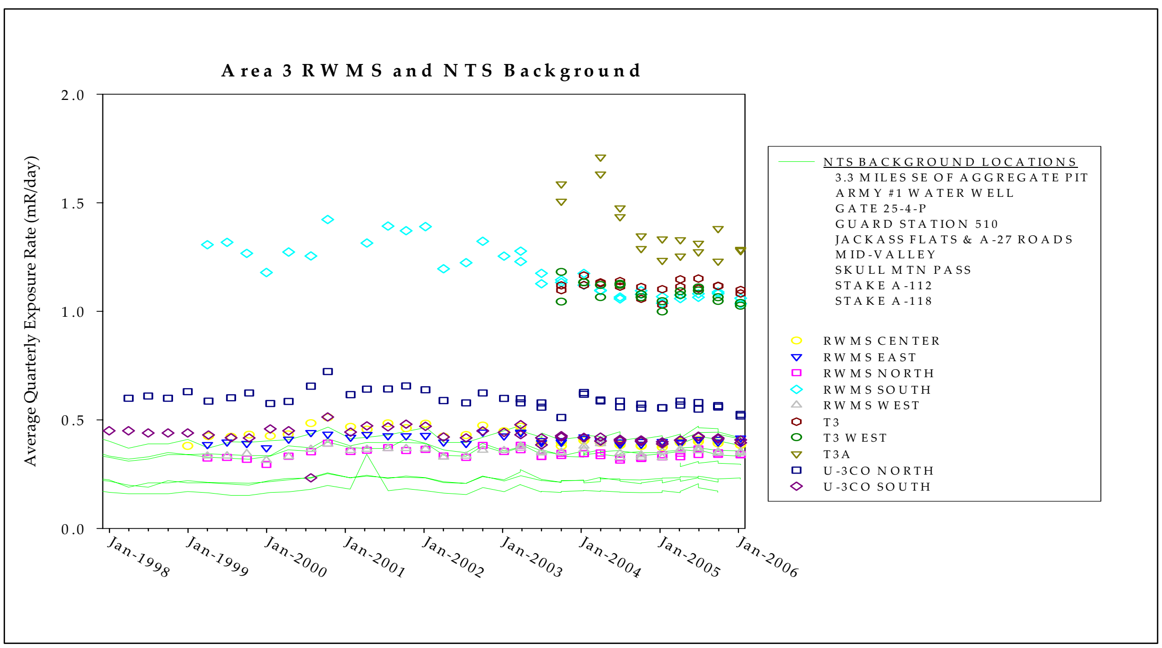



Figure 7. Quarterly average daily exposure rates at Area 3 RWMS and NTS background TLD locations, 1998–2005

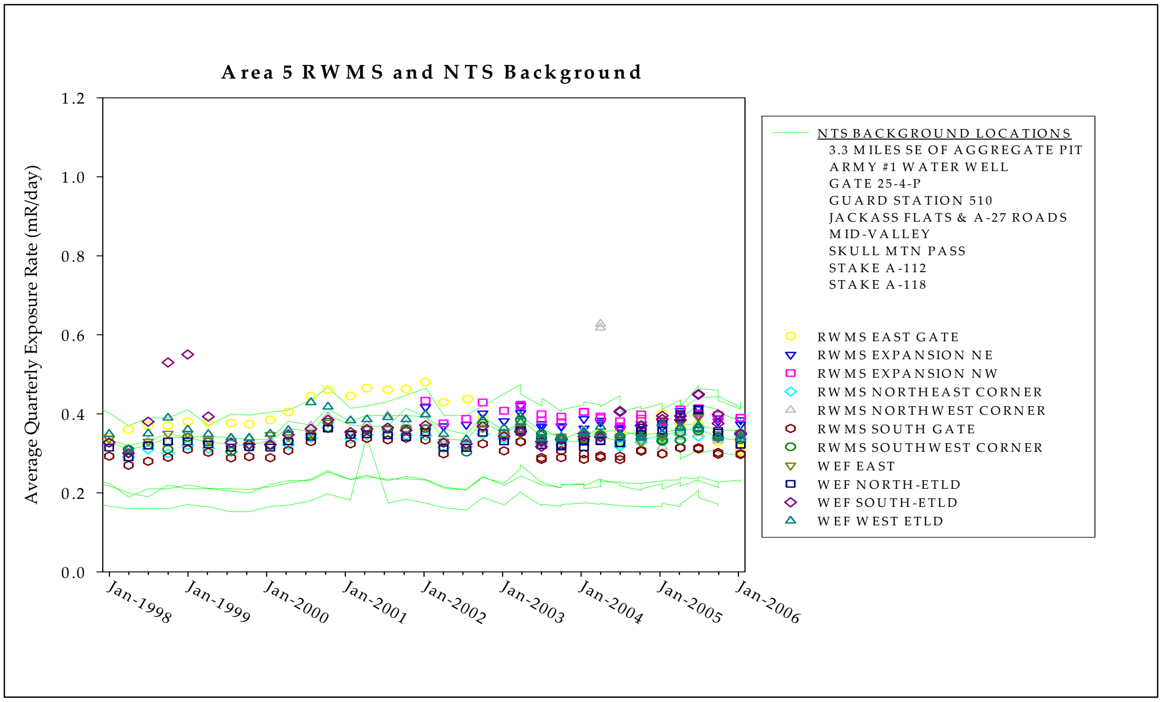



Figure 8. Quarterly average daily exposure rates at Area 5 RWMS and NTS background TLD locations, 1998–2005

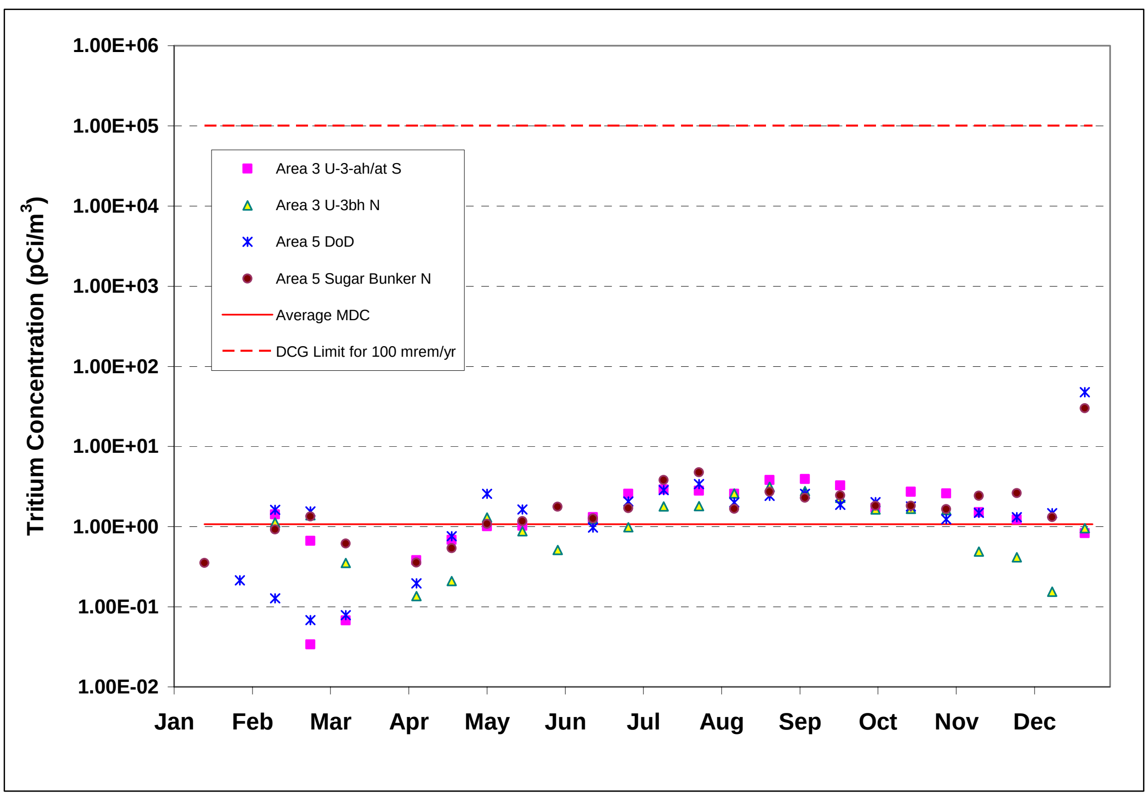



Figure 9. Tritium concentrations in air

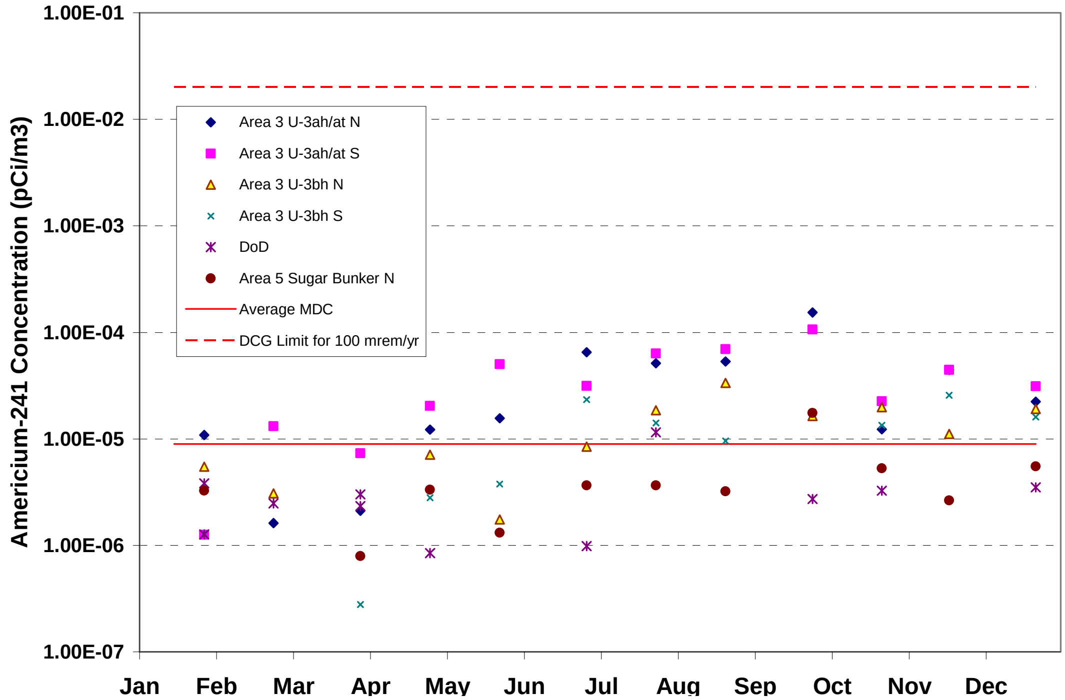



Figure 10. Americium-241 concentrations in air at the RWMSs and other locations

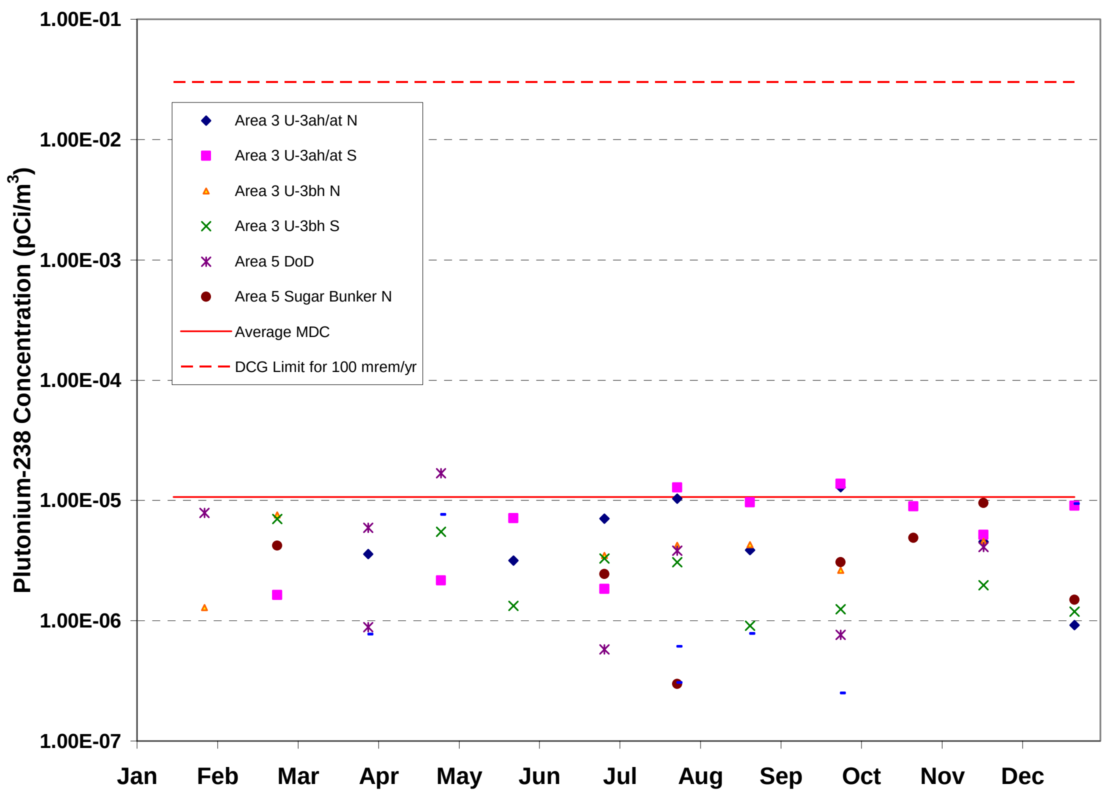



Figure 11. Plutonium-238 concentrations in air at the RWMSs and other locations

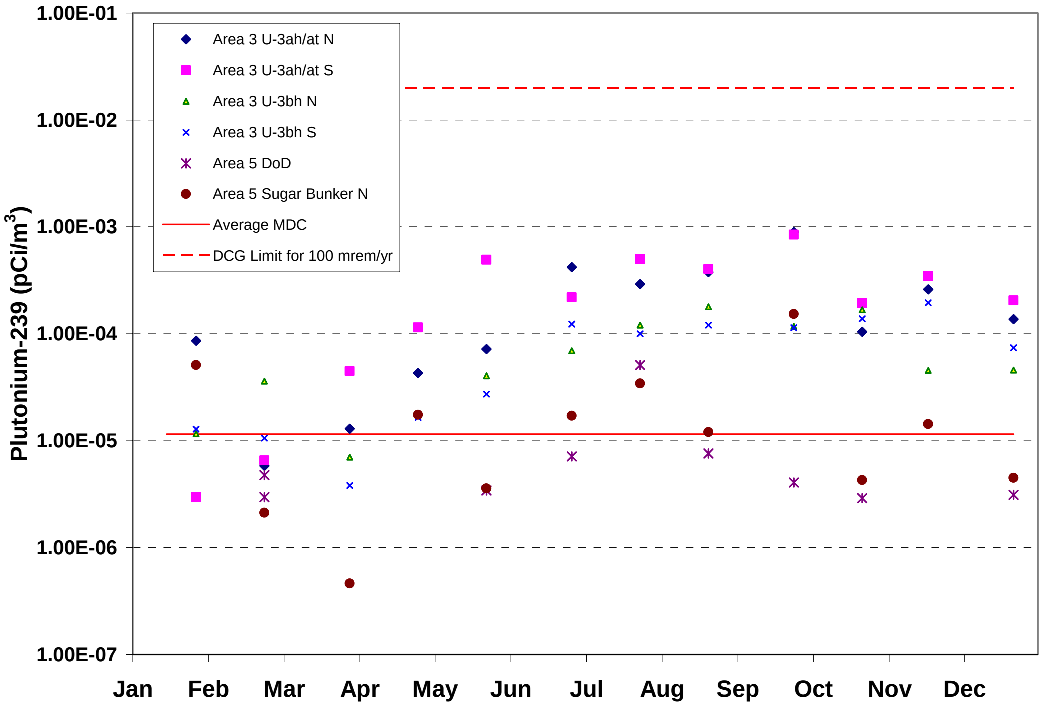



Figure 12. Plutonium-239 concentrations in air at the RWMSs and other locations

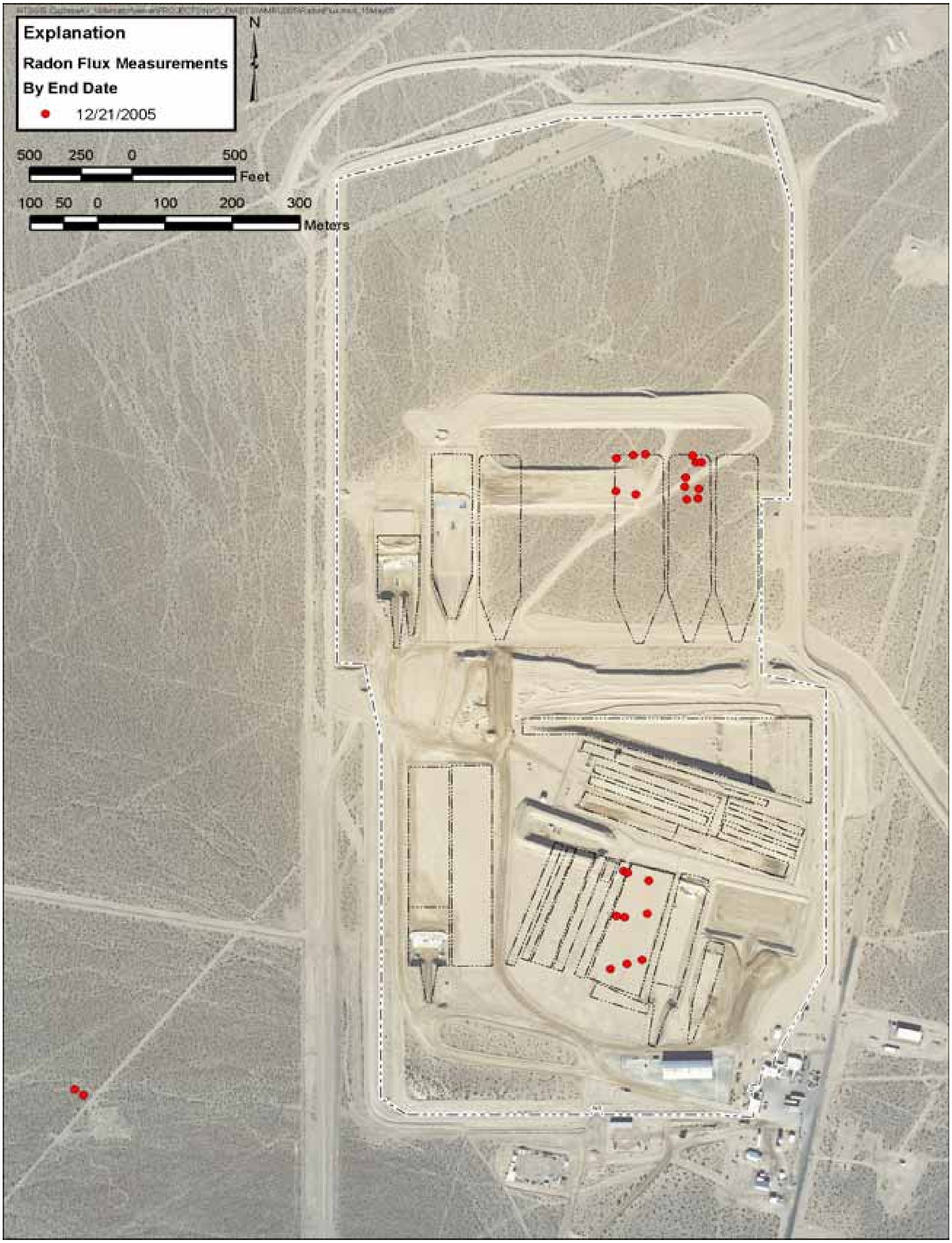



Figure 13. Radon flux measurement locations

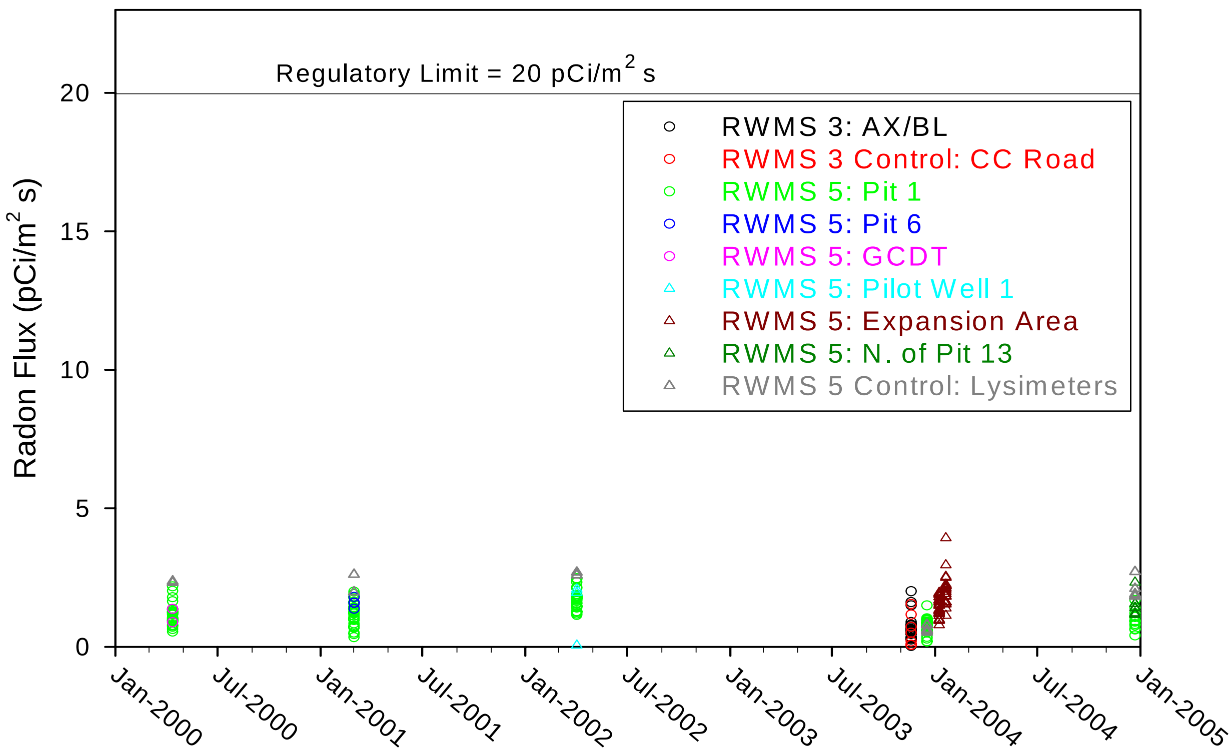



Figure 14. Radon flux results 2000-2005

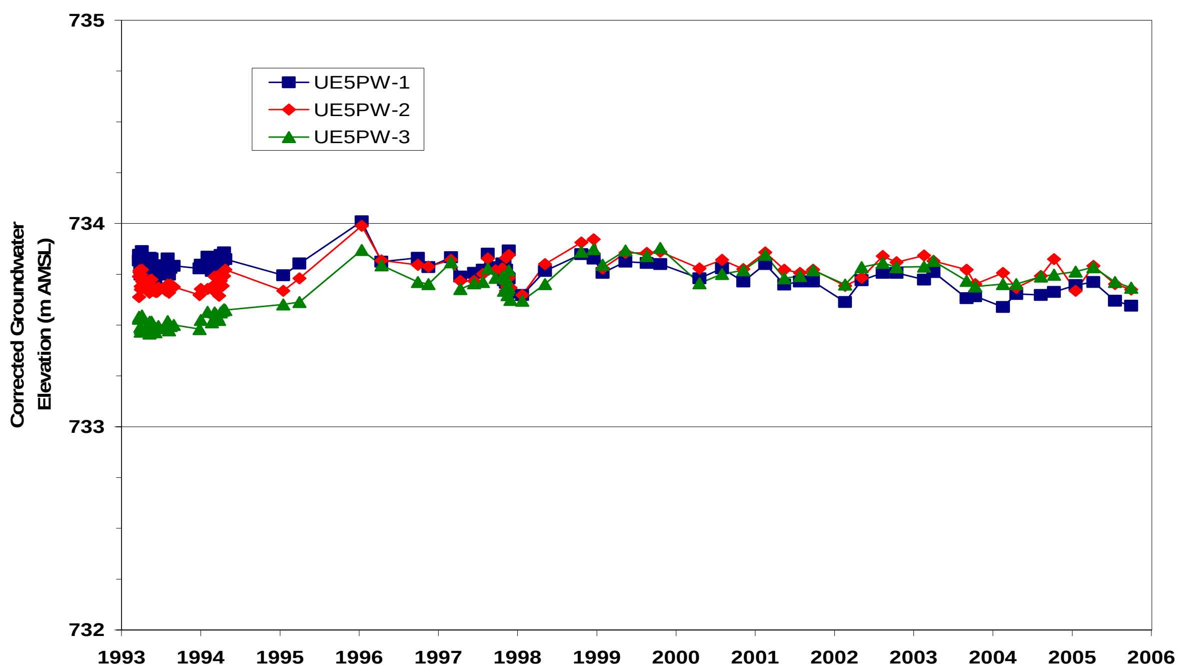



Figure 15. Groundwater elevation measurements recorded at the three Area 5 RWMS pilot wells by tagging

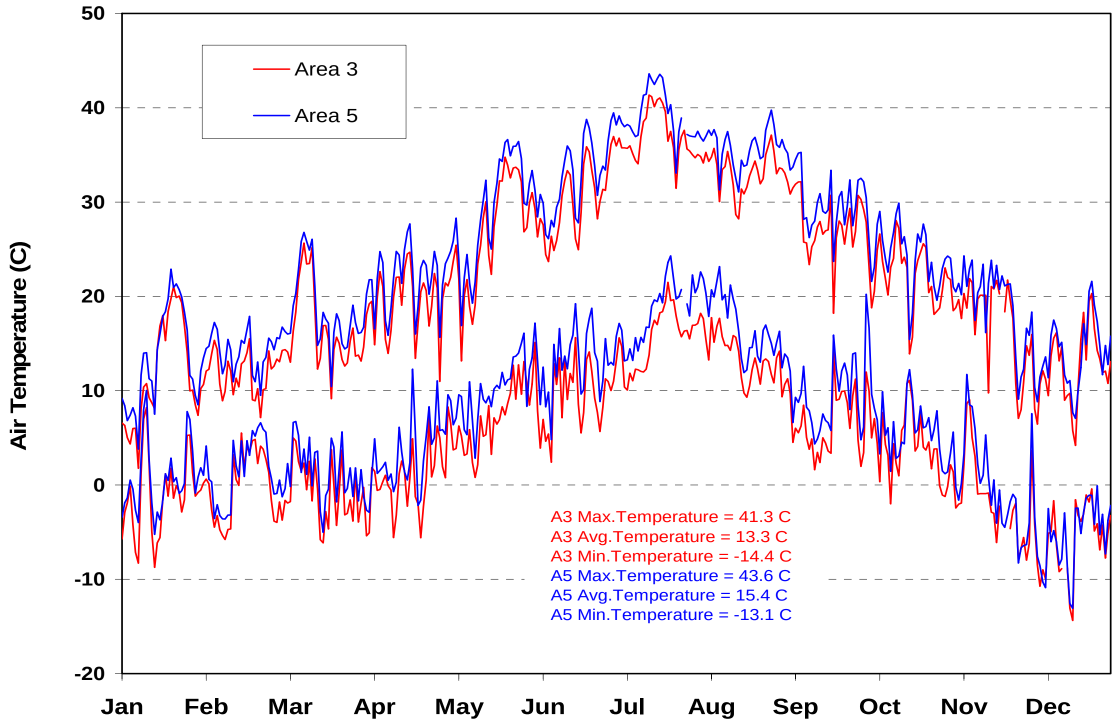



Figure 16. Daily maximum and minimum air temperatures at Area 3 and Area 5 RWMS

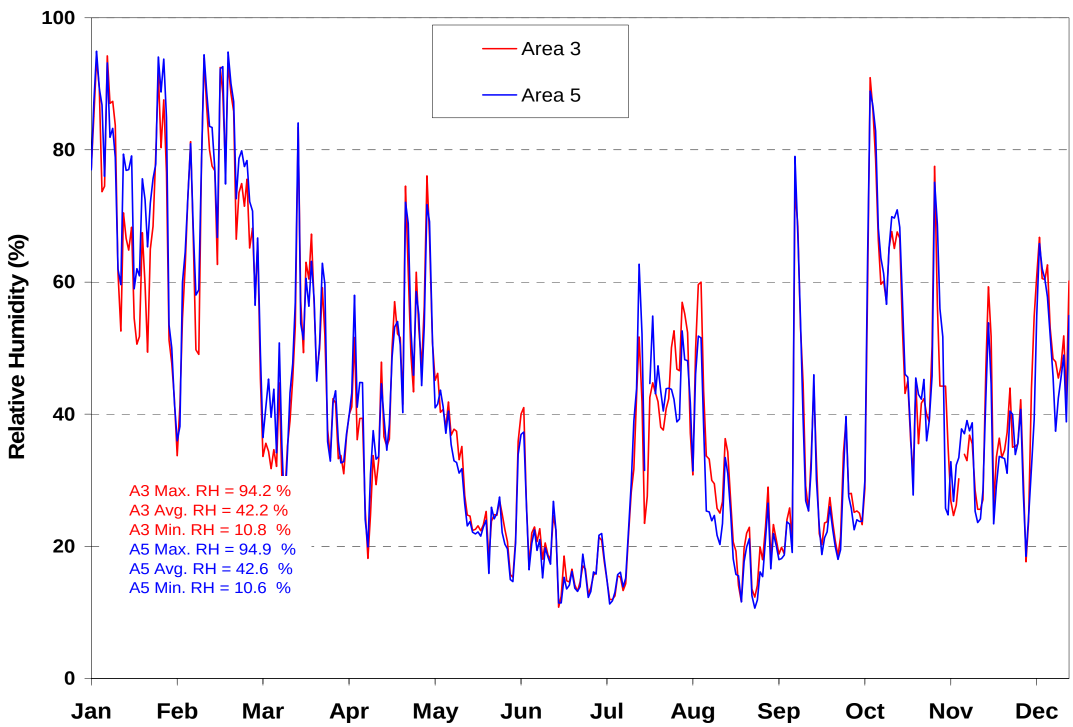



Figure 17. Daily average humidity recorded at Area 3 and Area 5 RWMS Meteorology Stations

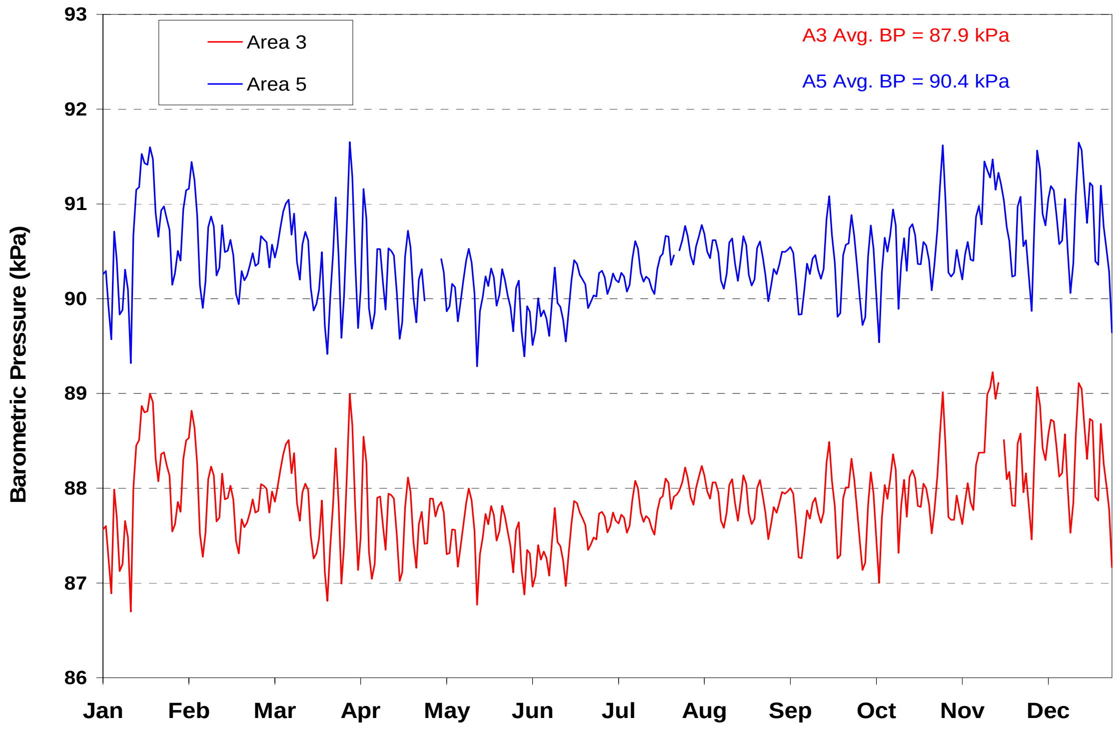



Figure 18. Daily average barometric pressure recorded at Area 3 and Area 5 RWMS Meteorology Stations

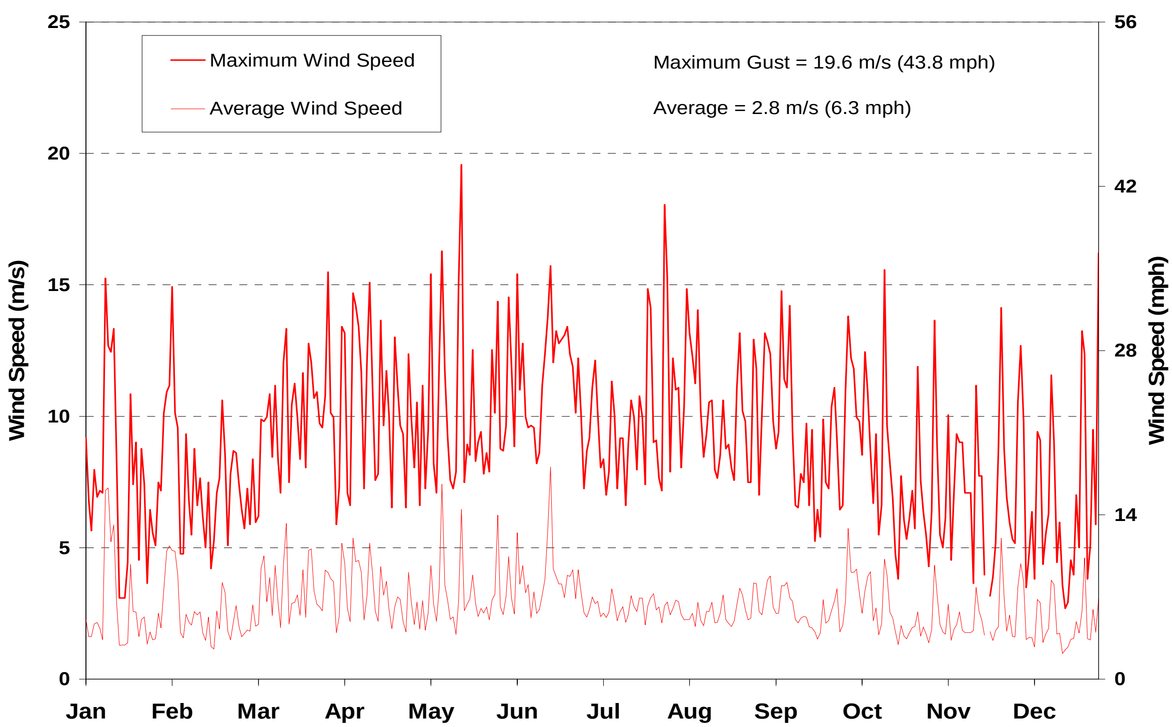



Figure 19. Daily wind speed recorded at Area 3 RWMS Meteorology Station at a height of 3 m

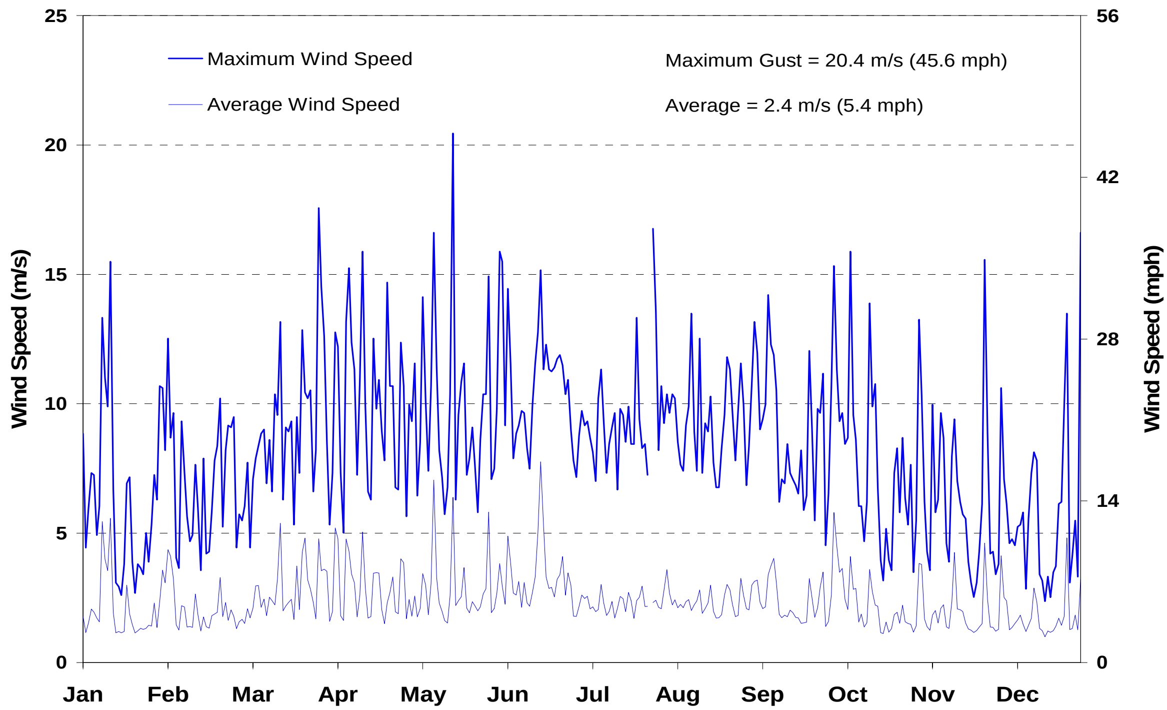



Figure 20. Daily wind speed recorded at Area 5 RWMS Meteorology Station at a height of 3 m

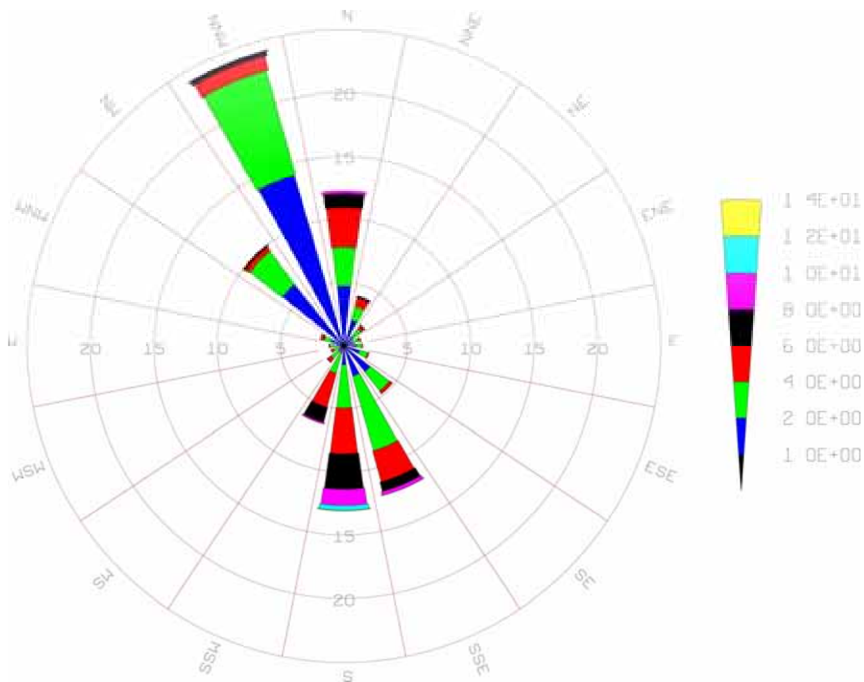



Figure 21. Wind rose diagram for the Area 3 RWMS Meteorology Station

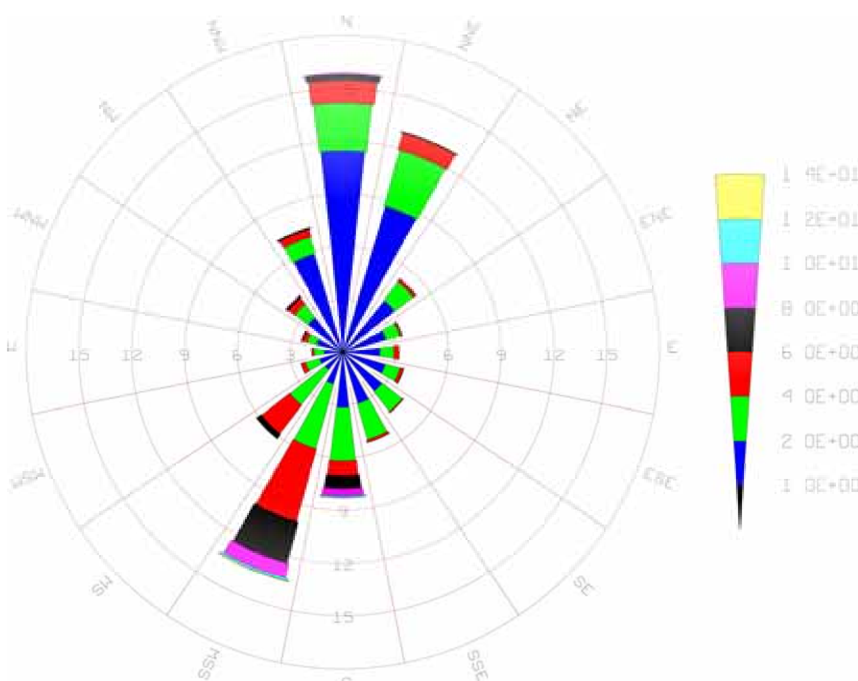



Figure 22. Wind rose diagram for the Area 5 RWMS Meteorology Station

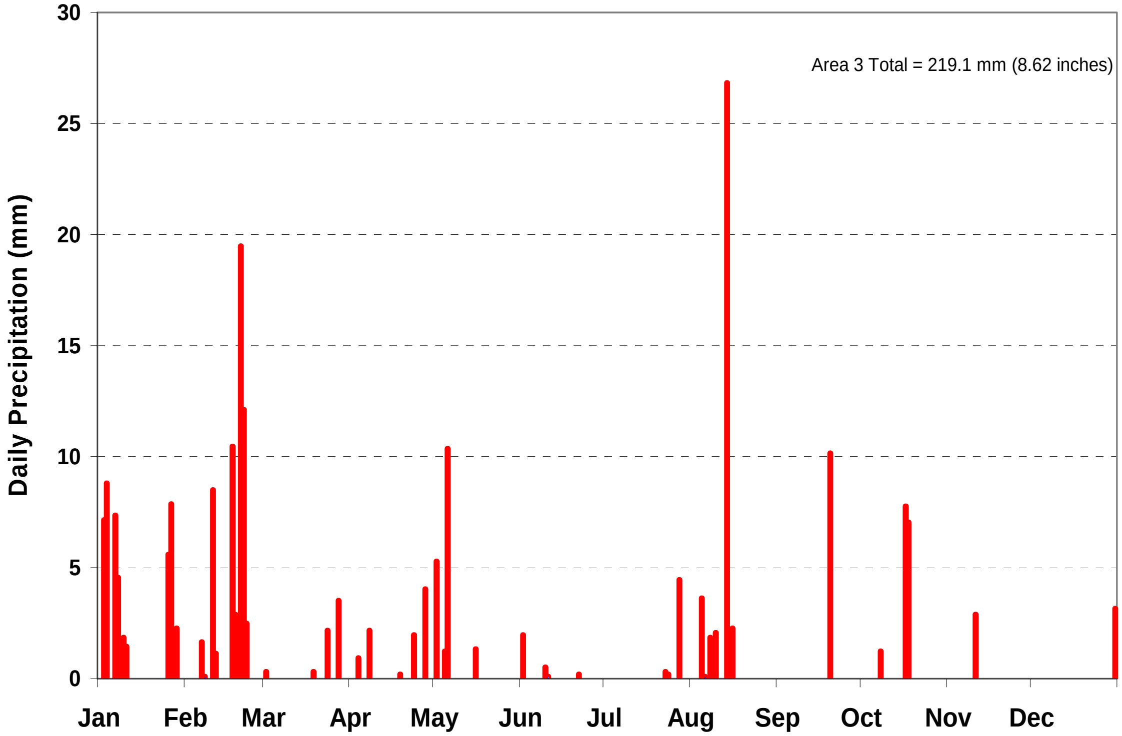



Figure 23. Daily precipitation recorded at Area 3 RWMS Meteorology Station

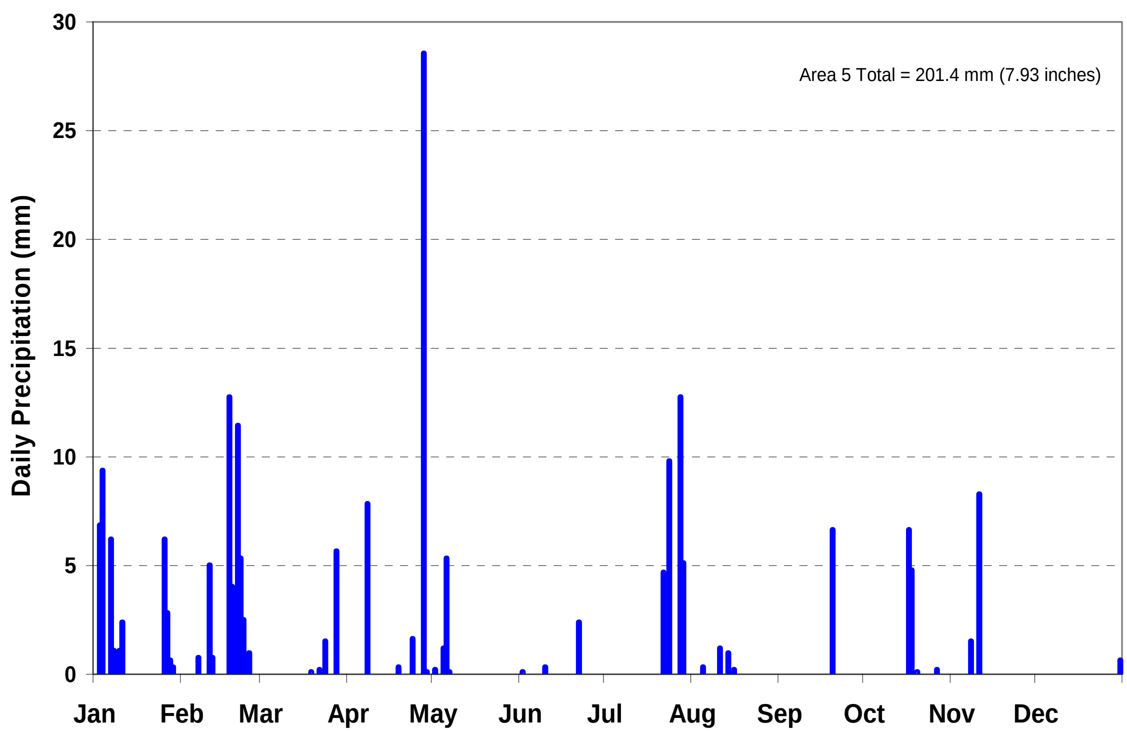



Figure 24. Daily precipitation recorded at Area 5 RWMS Meteorology Station

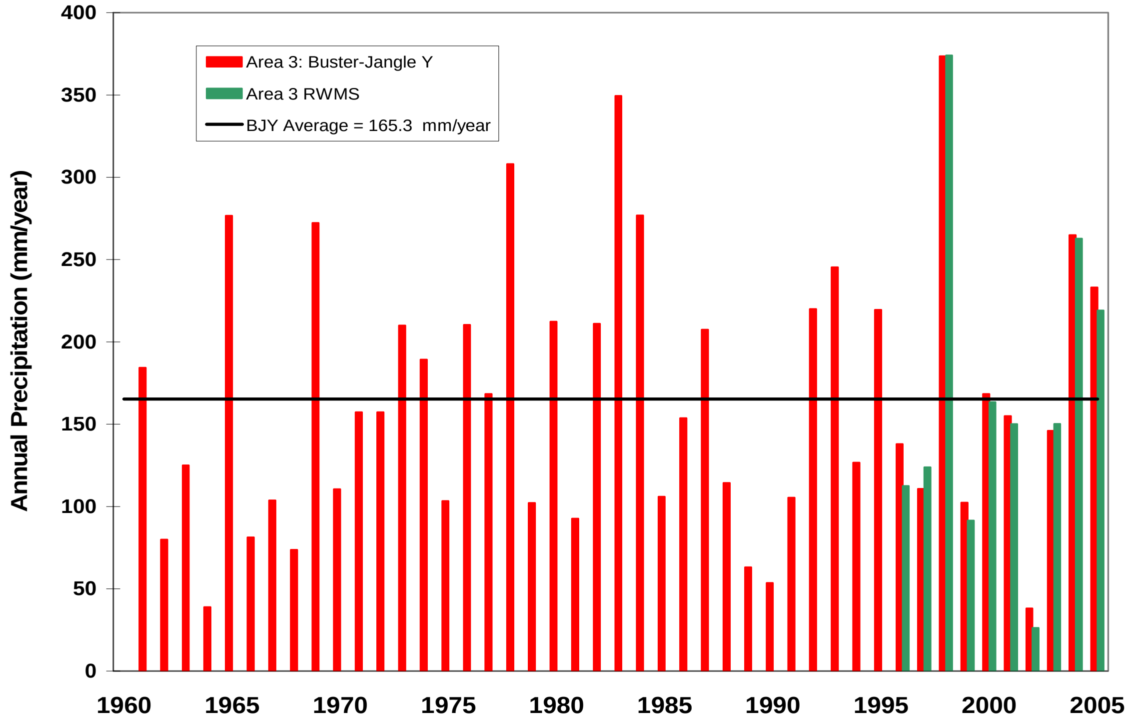



Figure 25. Historical precipitation record for Area 3 Buster-Jangle Y and Area 3 RWMS

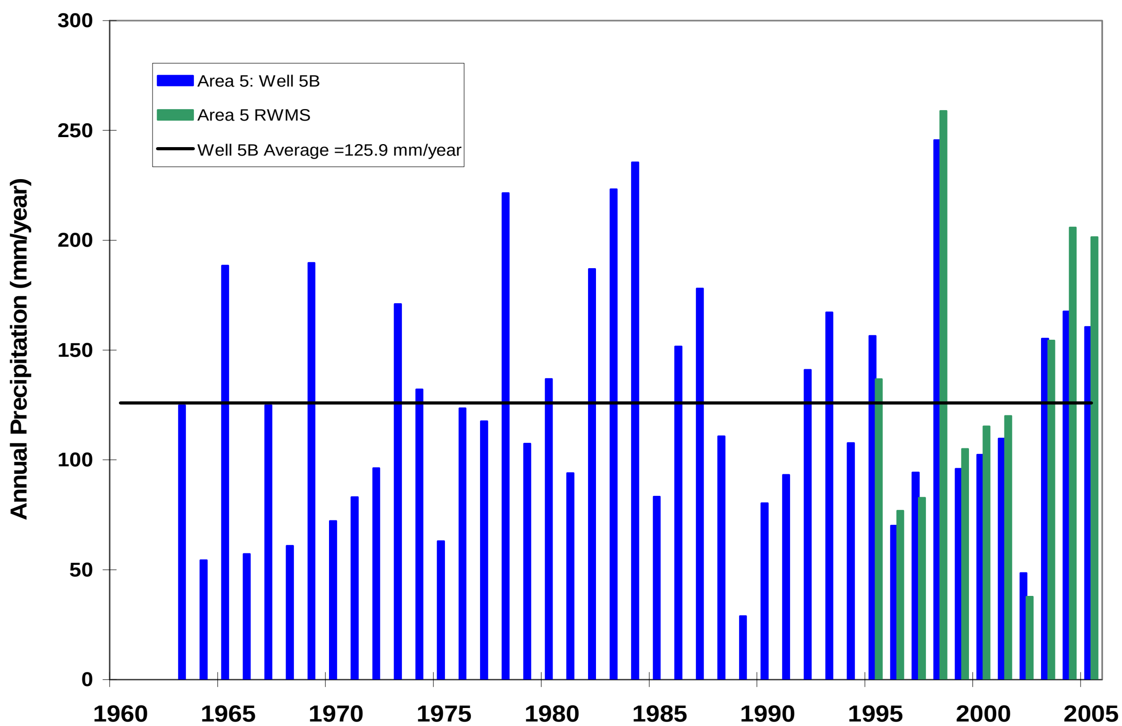



Figure 26. Historical precipitation record for Area Well 5B and Area 5 RWMS

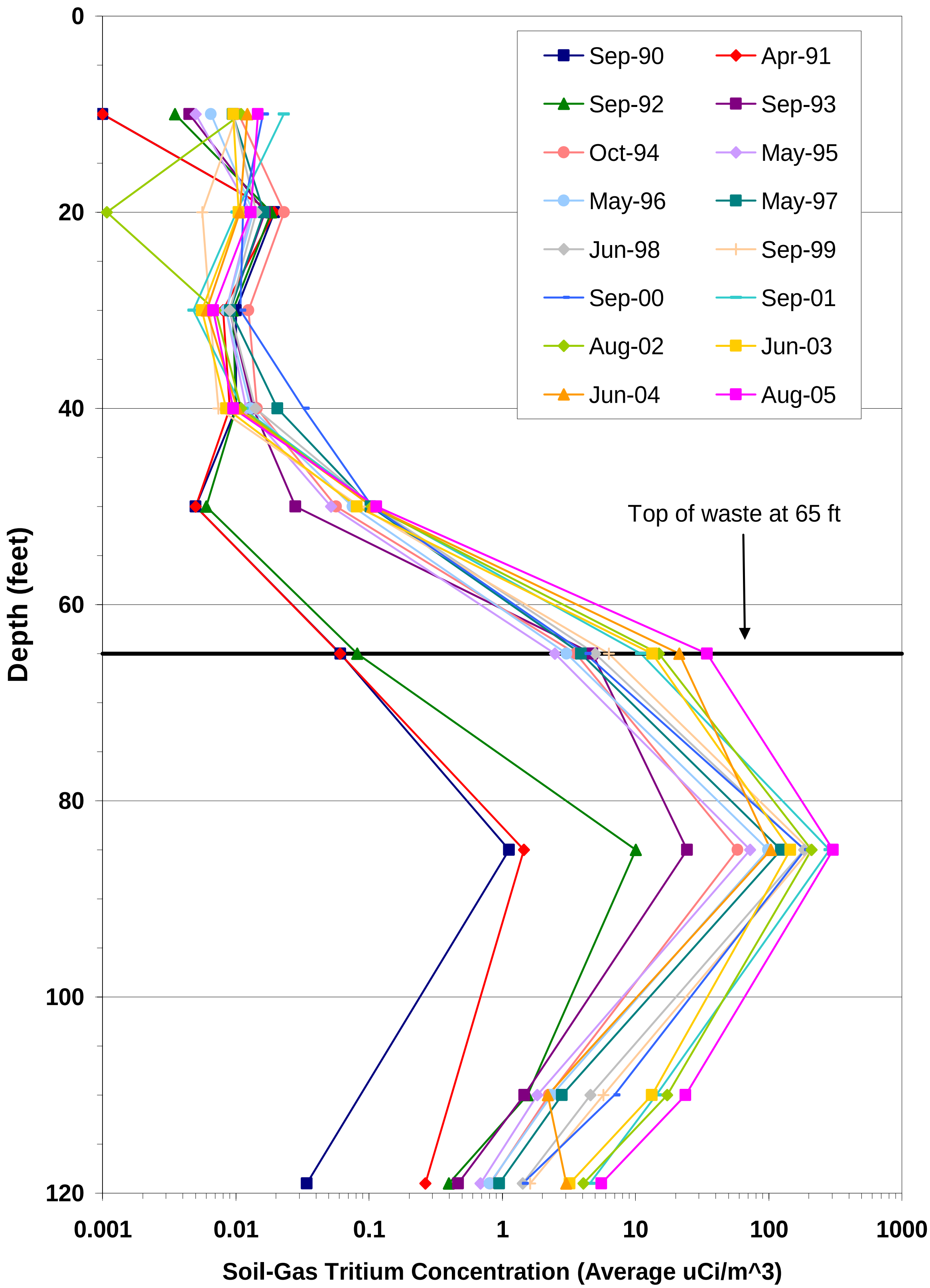



Figure 27. Soil gas tritium concentrations with depth at GCD-05U

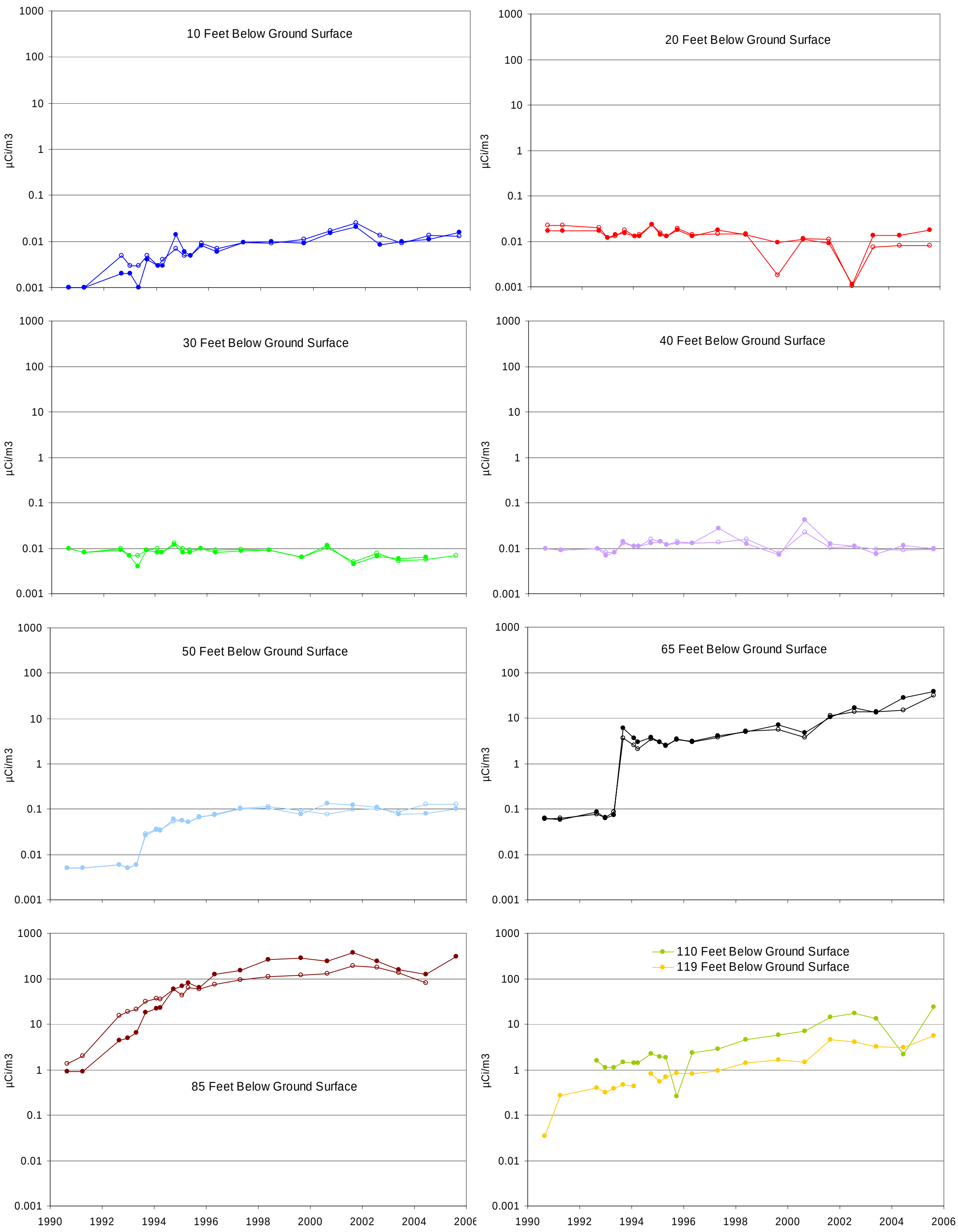



Figure 28. Soil gas tritium concentrations at each depth in GCD-05U

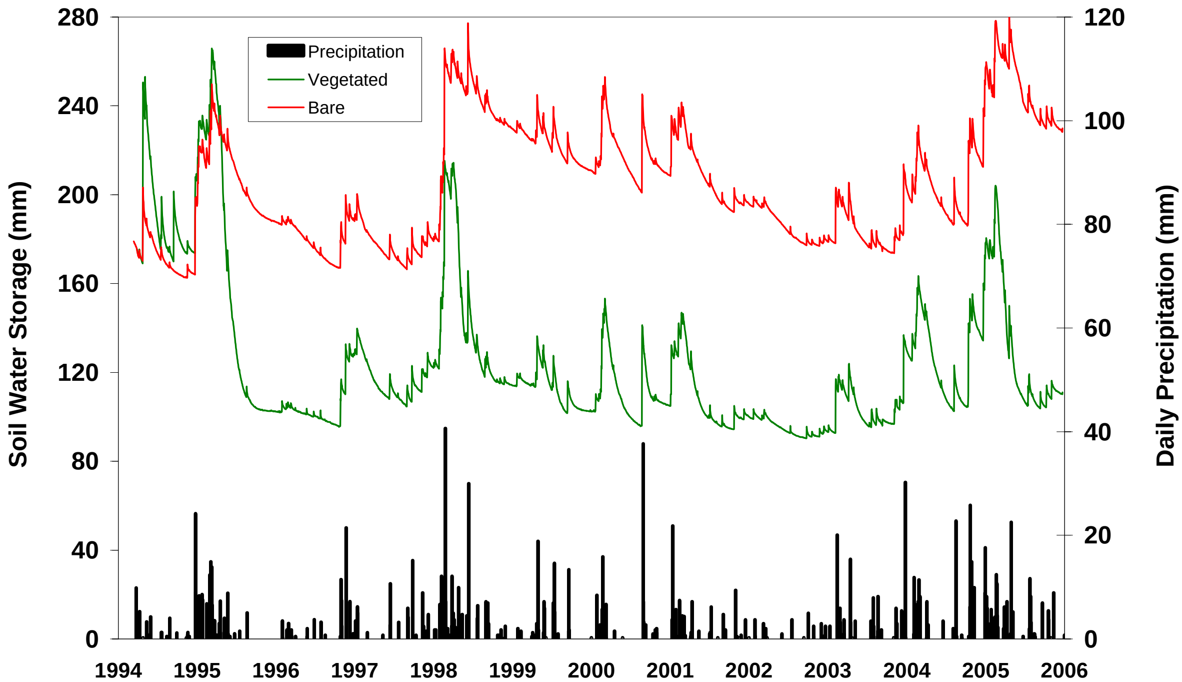



Figure 29. Weighing lysimeter and precipitation data from March 1994 to December 2005

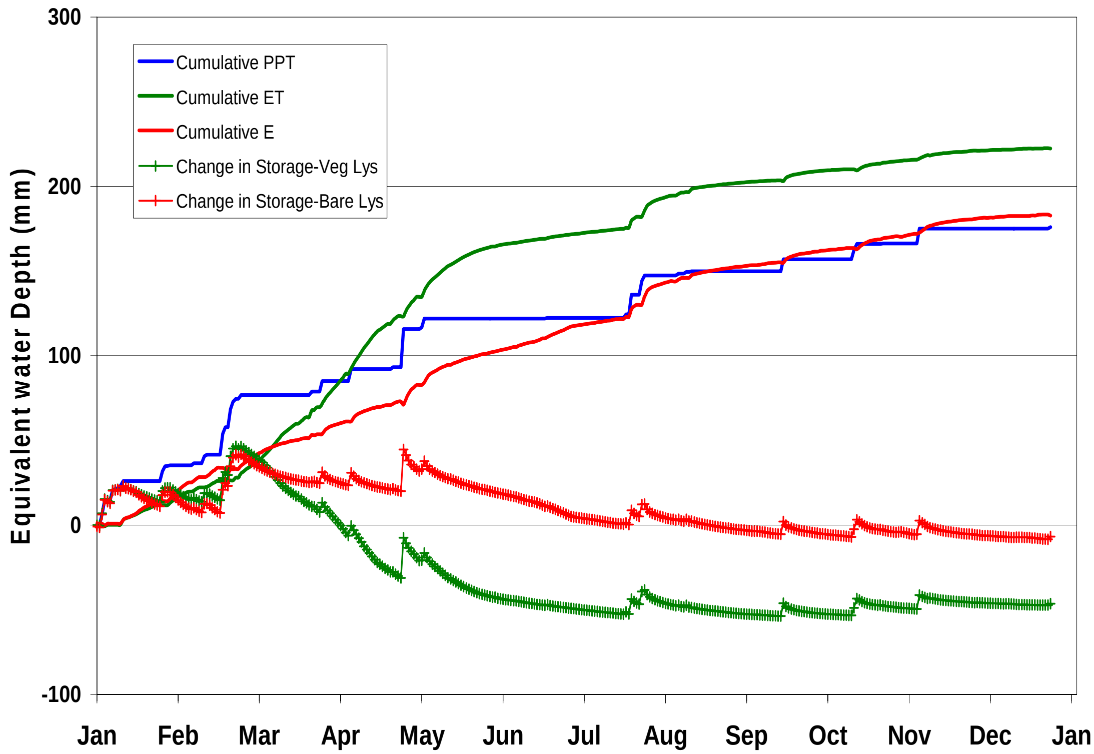



Figure 30. Cumulative precipitation, ET, E, and change in storage for the weighing lysimeters in 2005

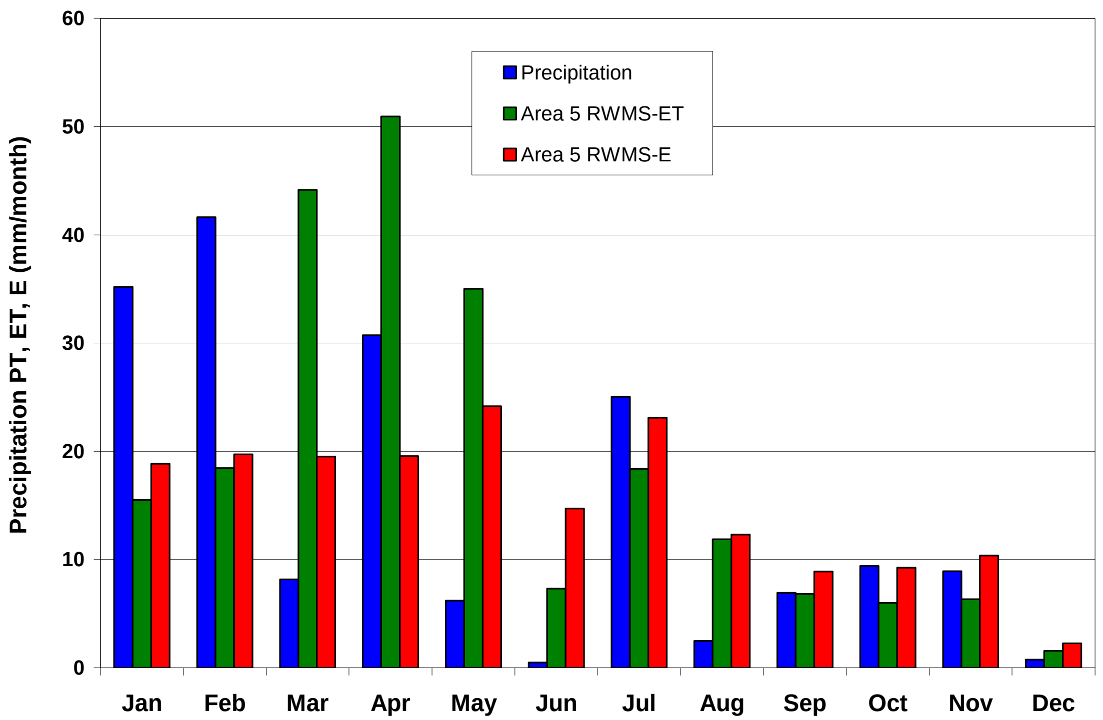



Figure 31. Monthly precipitation, E, and ET measured in weighing lysimeters in 2005

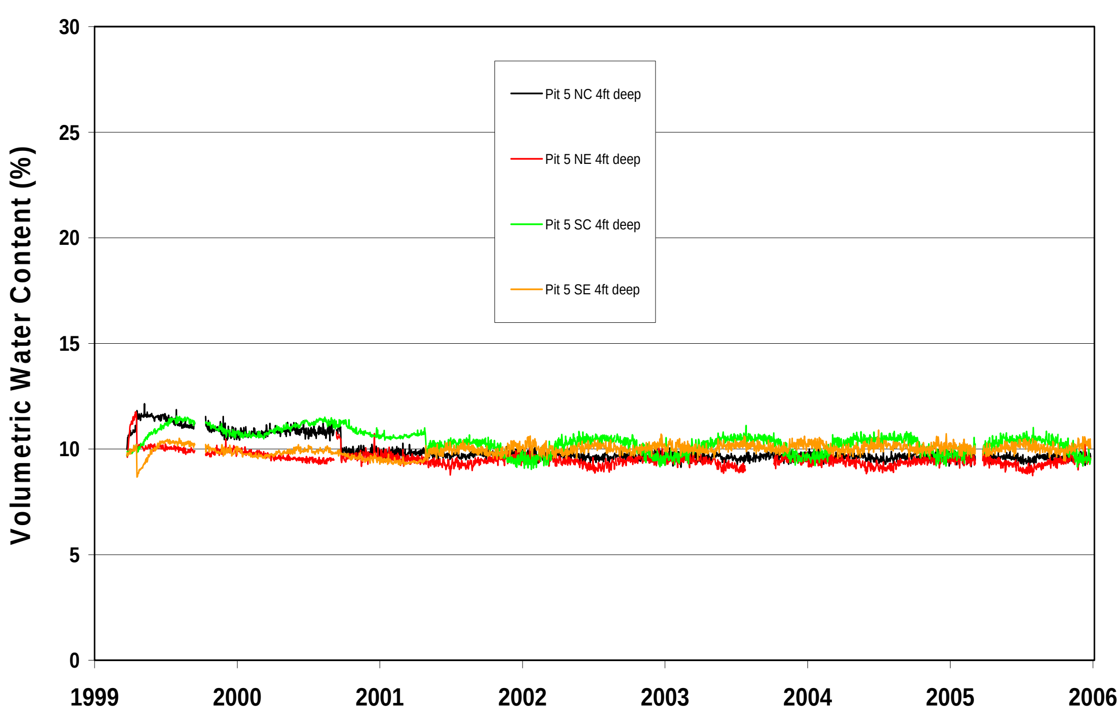



Figure 32. Soil water content in Pit 5 floor using automated TDR systems

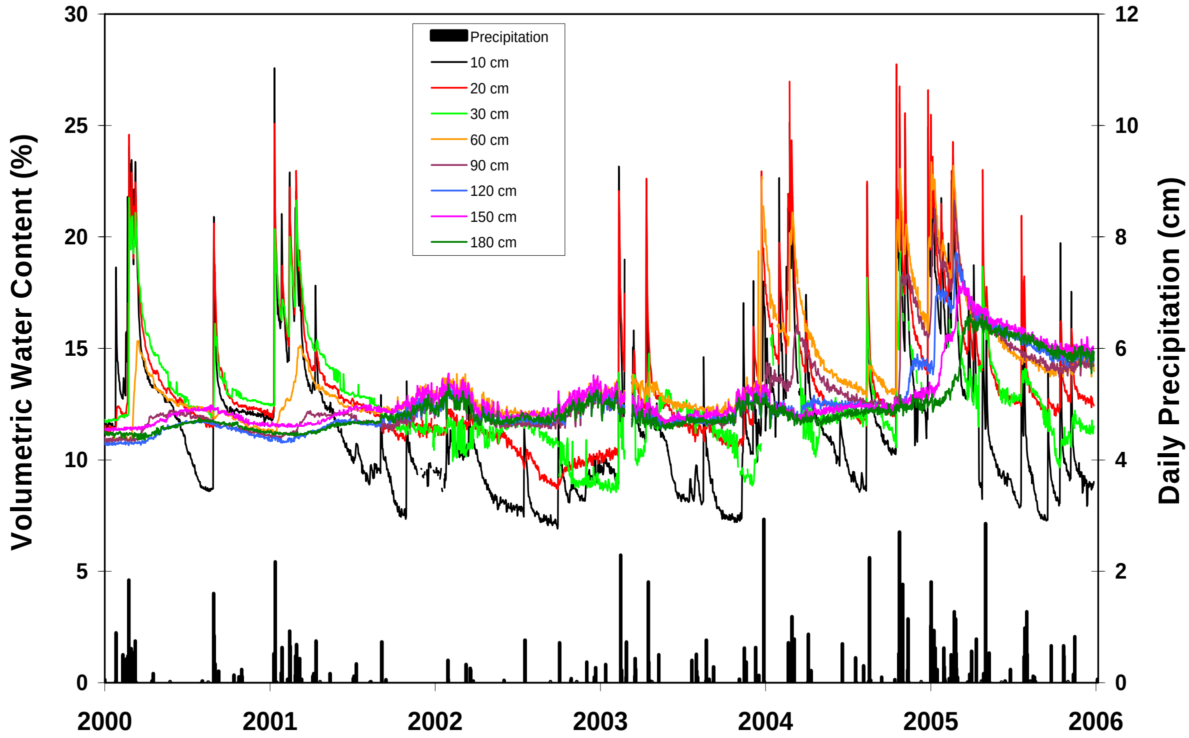



Figure 33. Soil water content Pit 3 waste cover (north site) using an automated TDR system

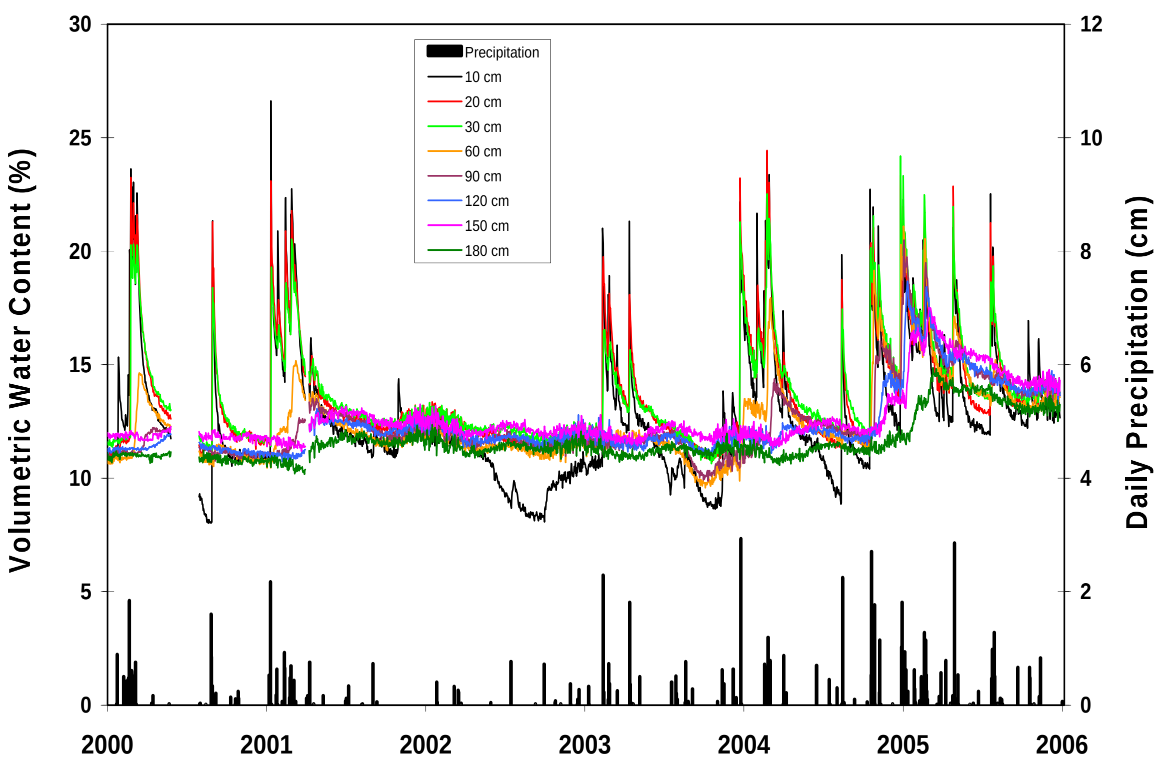



Figure 34. Soil water content Pit 3 waste cover (south site) using an automated TDR system

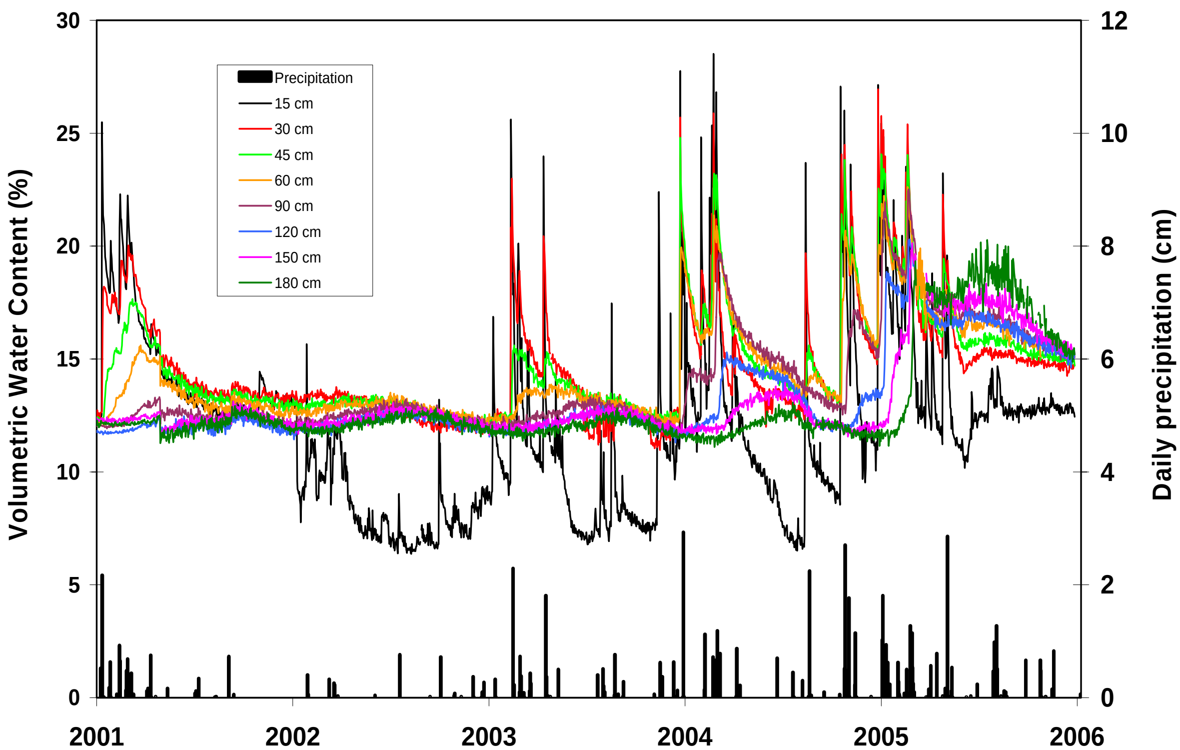



Figure 35. Soil water content in Pit 4 waste cover using an automated TDR system

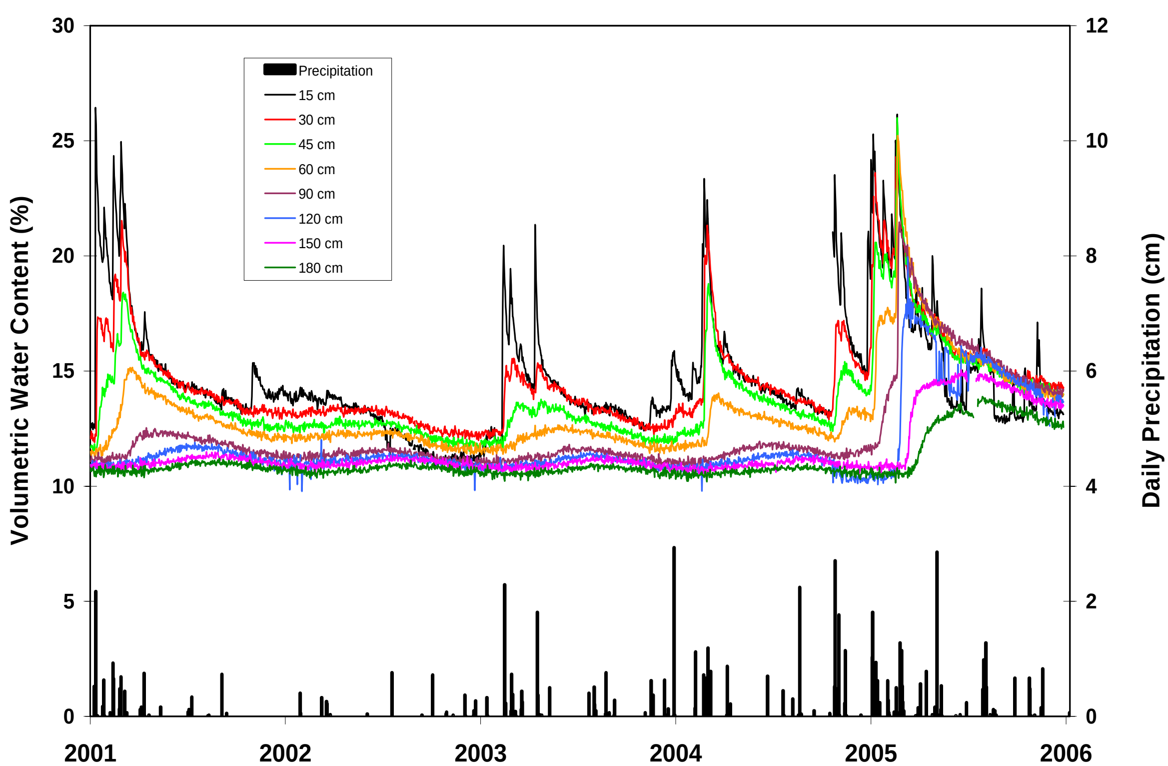



Figure 36. Soil water content in Pit 5 waste cover using an automated TDR system

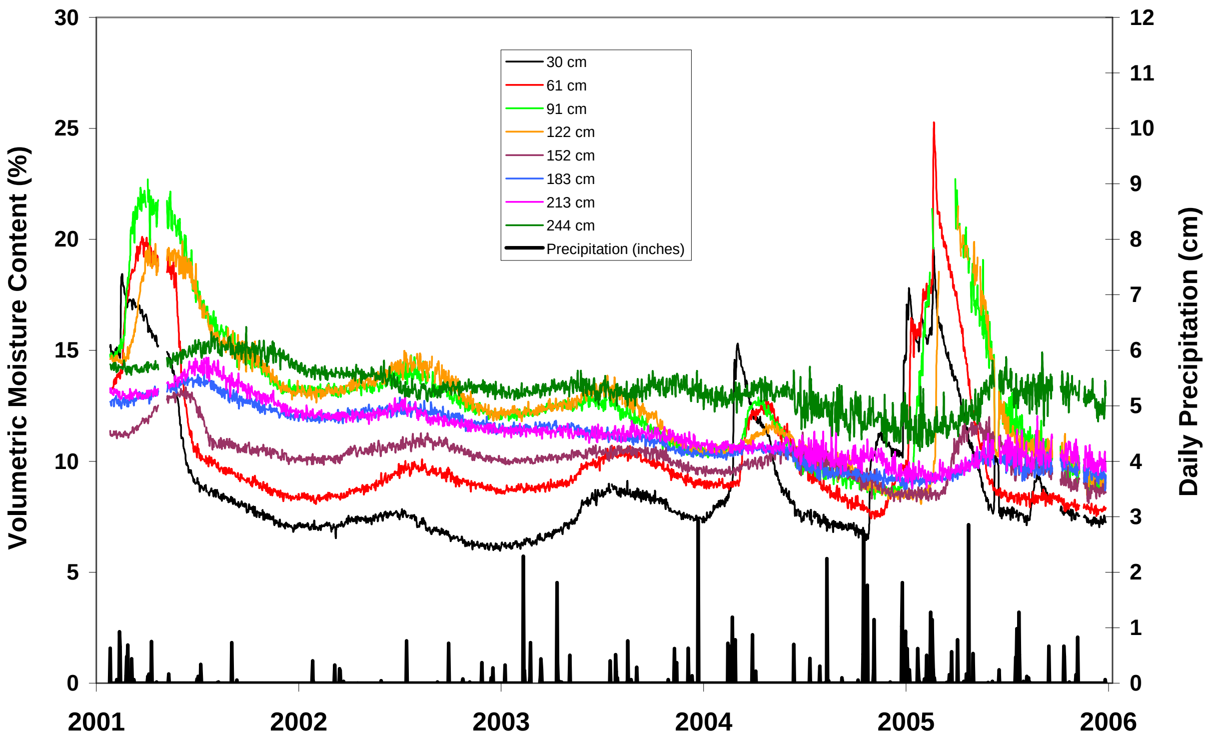



Figure 37. Soil water content in U-3ax/bl waste cover (East Nest A) using a TDR system

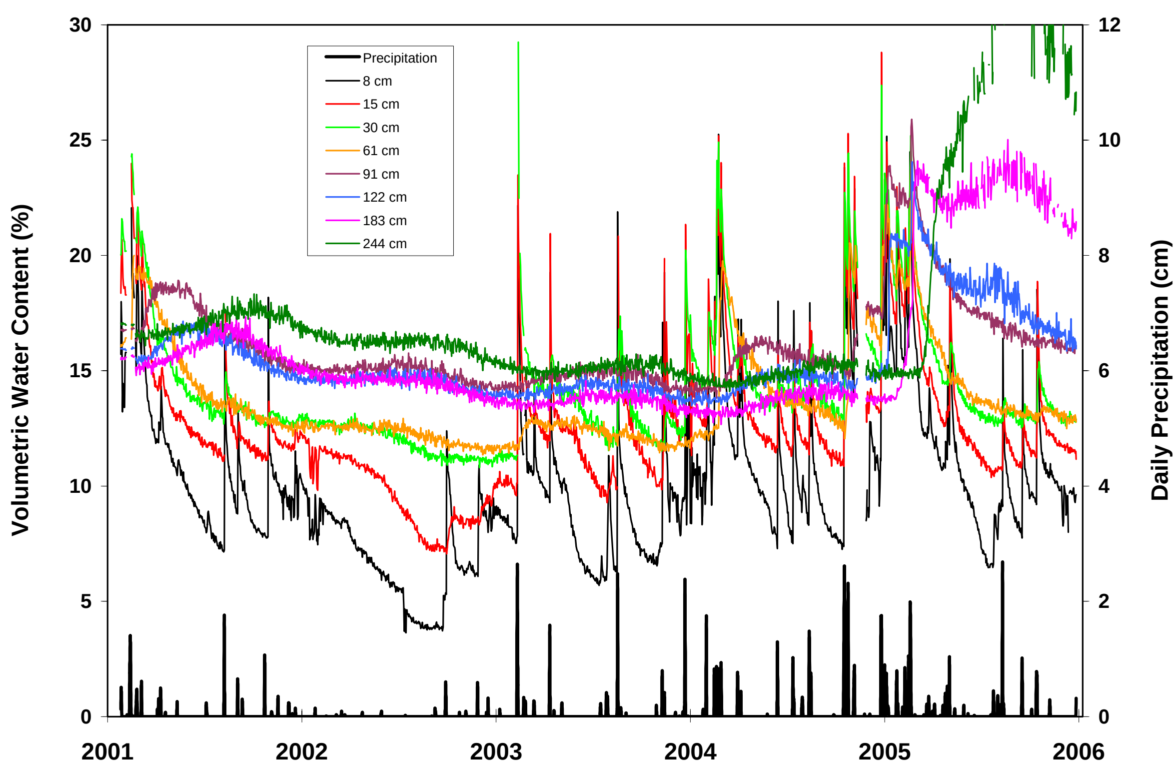



Figure 38. Soil water content in bare drainage lysimeter (A) using a TDR system

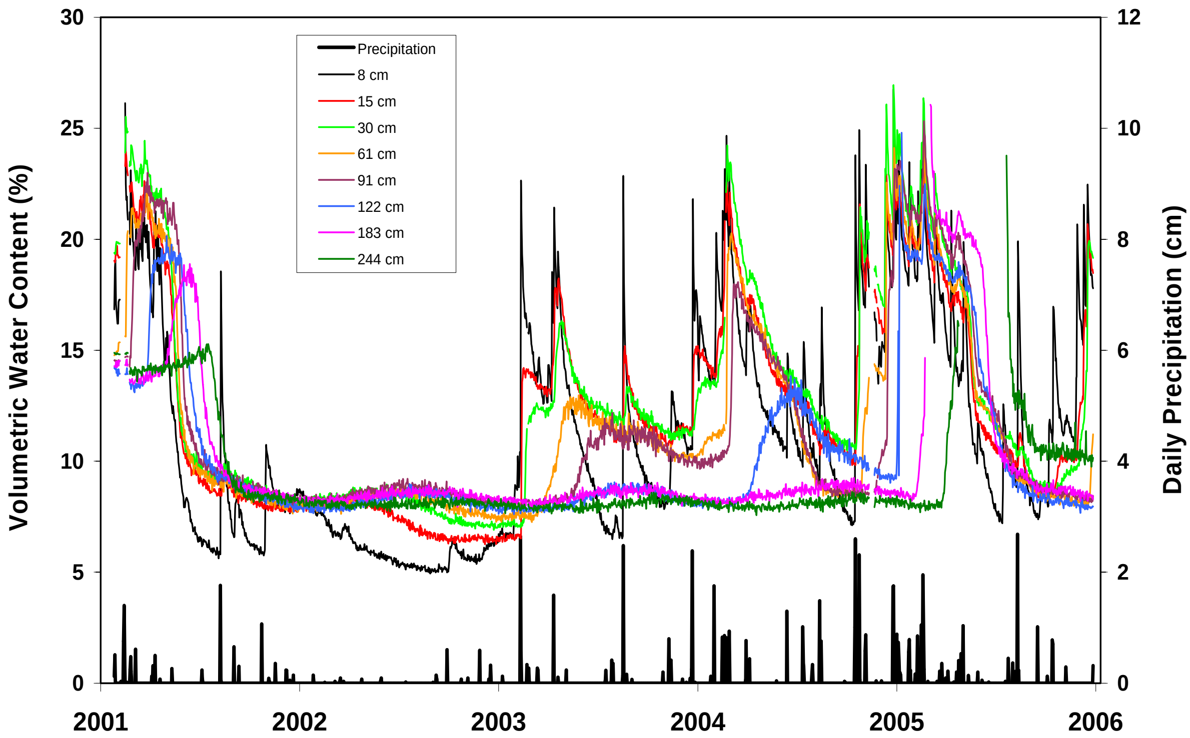



Figure 39. Soil water content vegetated drainage lysimeter (E) using TDR system

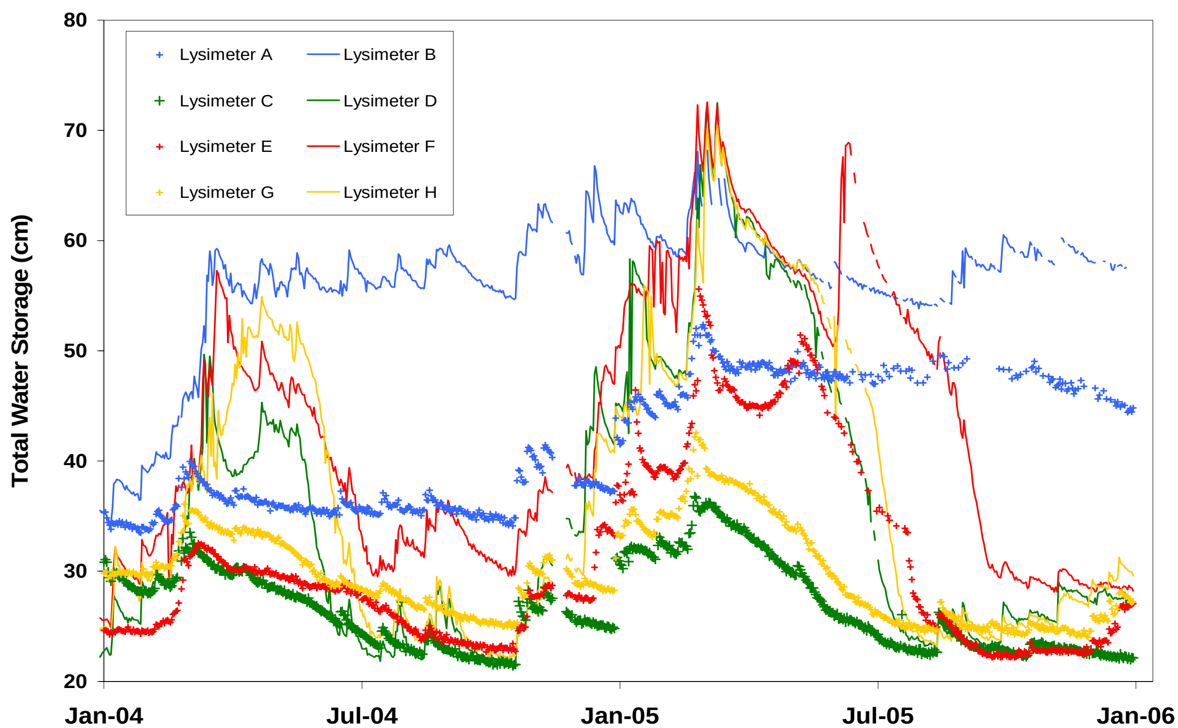
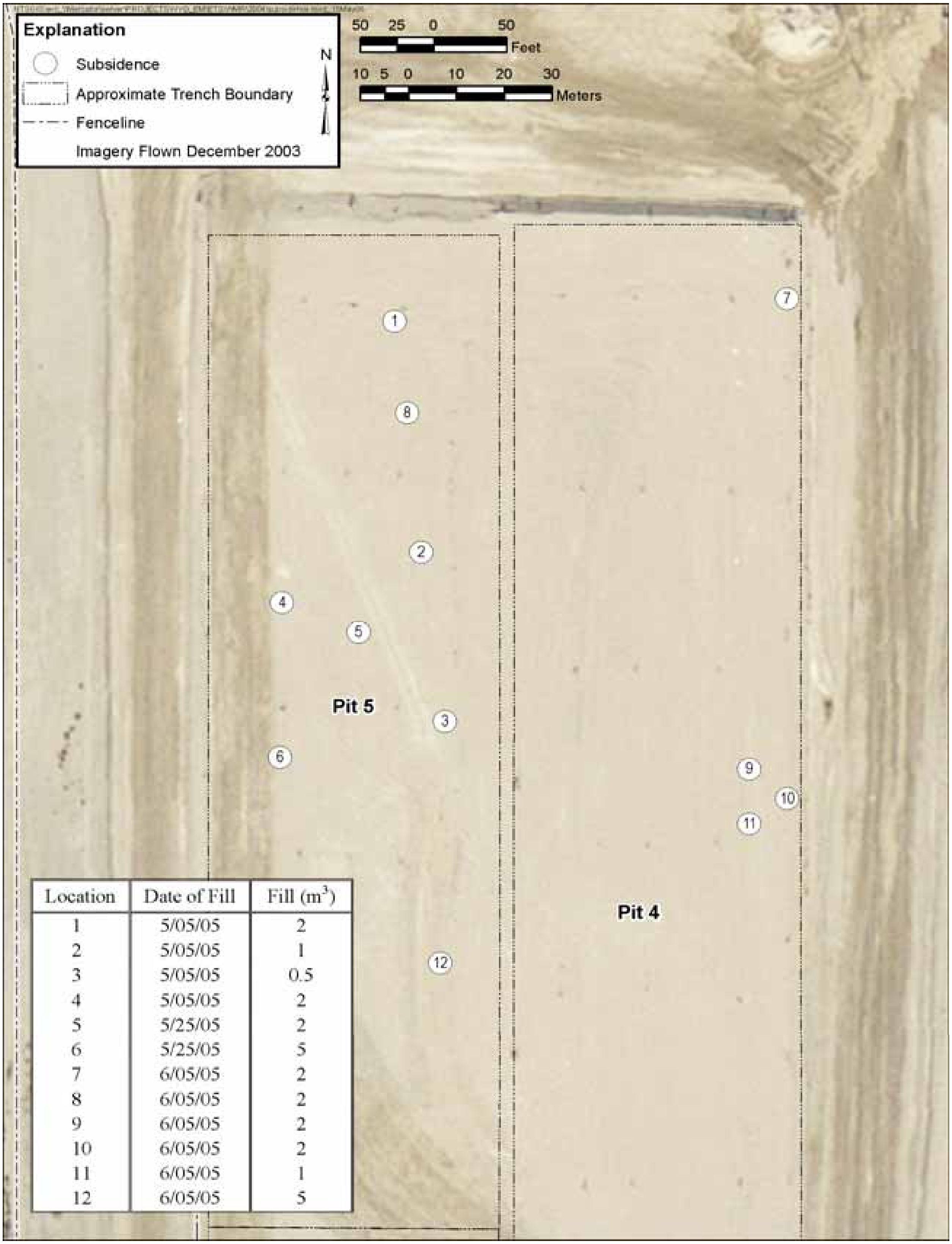



Figure 40. Soil water storage in drainage lysimeters




| Location | Date of Fill | Fill ($m^3$) |
|---|---|---|
| 1 | 5/05/05 | 2 |
| 2 | 5/05/05 | 1 |
| 3 | 5/05/05 | 0.5 |
| 4 | 5/05/05 | 2 |
| 5 | 5/25/05 | 2 |
| 6 | 5/25/05 | 5 |
| 7 | 6/05/05 | 2 |
| 8 | 6/05/05 | 2 |
| 9 | 6/05/05 | 2 |
| 10 | 6/05/05 | 2 |
| 11 | 6/05/05 | 1 |
| 12 | 6/05/05 | 5 |

Figure 41. Subsidence locations in 2005

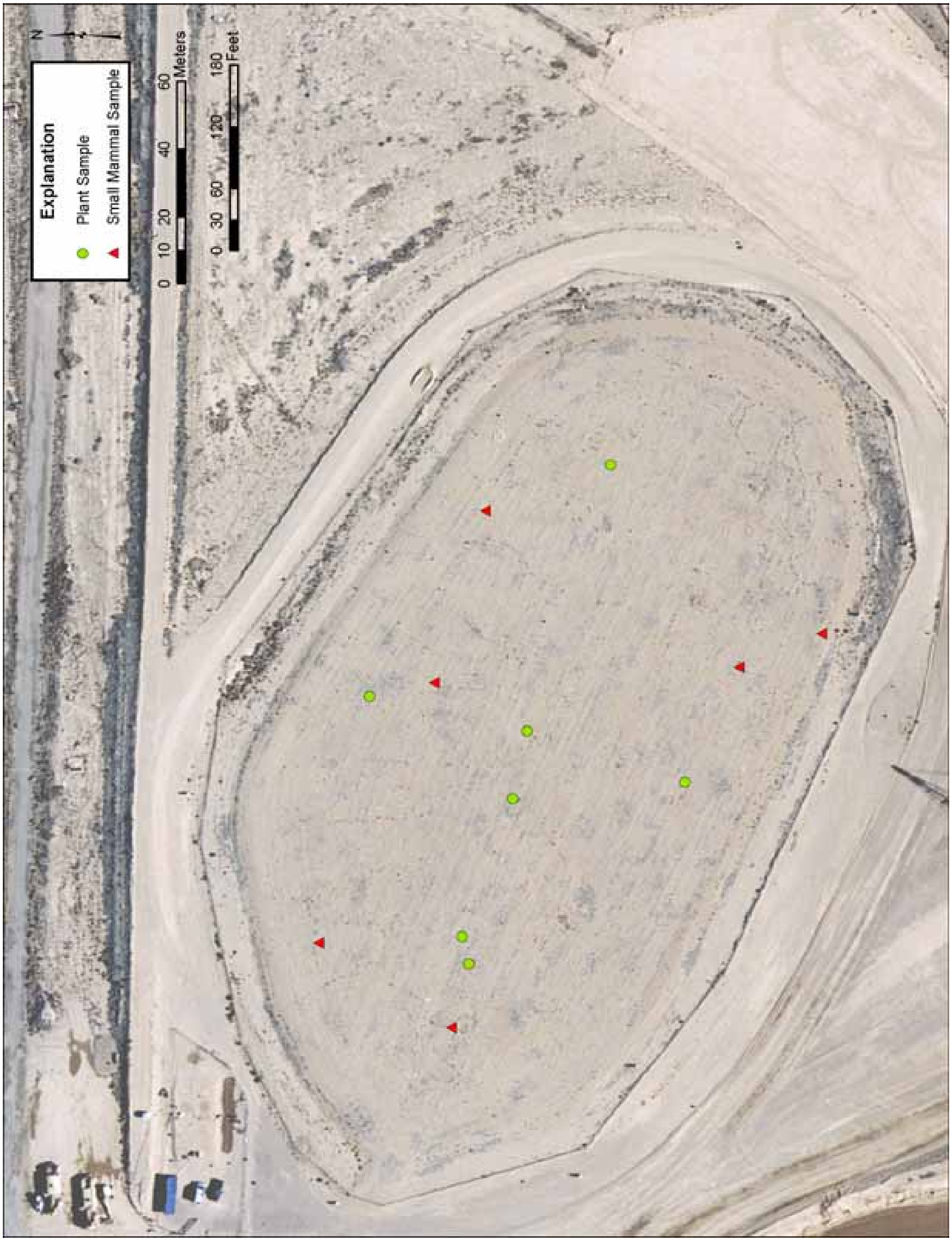



**Figure 42 Locations of biota samples collected at the Area 3 RWMS (U-3ax/bl) in 2005**

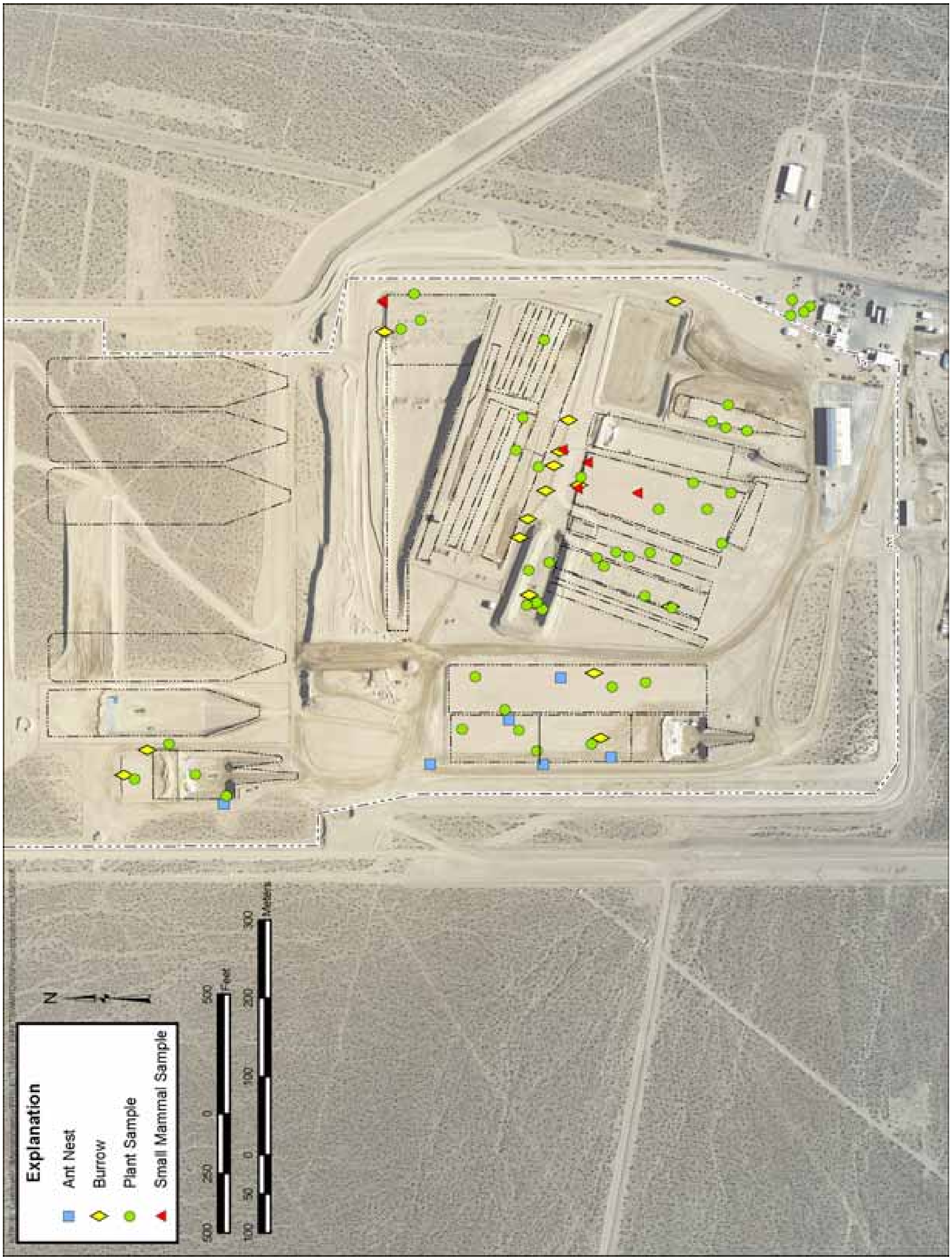



**Figure 43. Locations of ant and small mammal burrows and biota samples collected at the Area 5 RWMS in 2005**

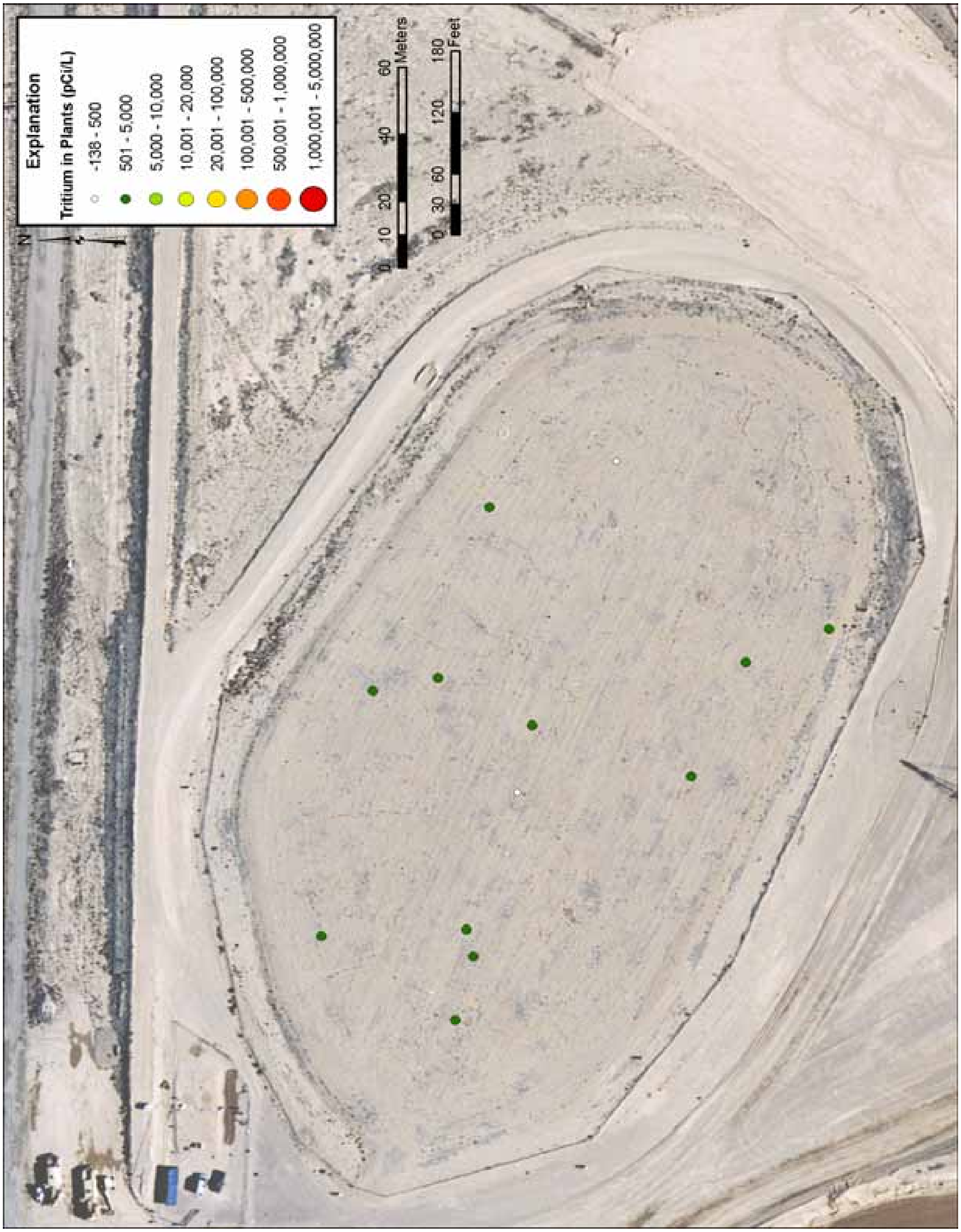



**Figure 44. Tritium concentrations in Area 3 RWMS biota samples in 2005**

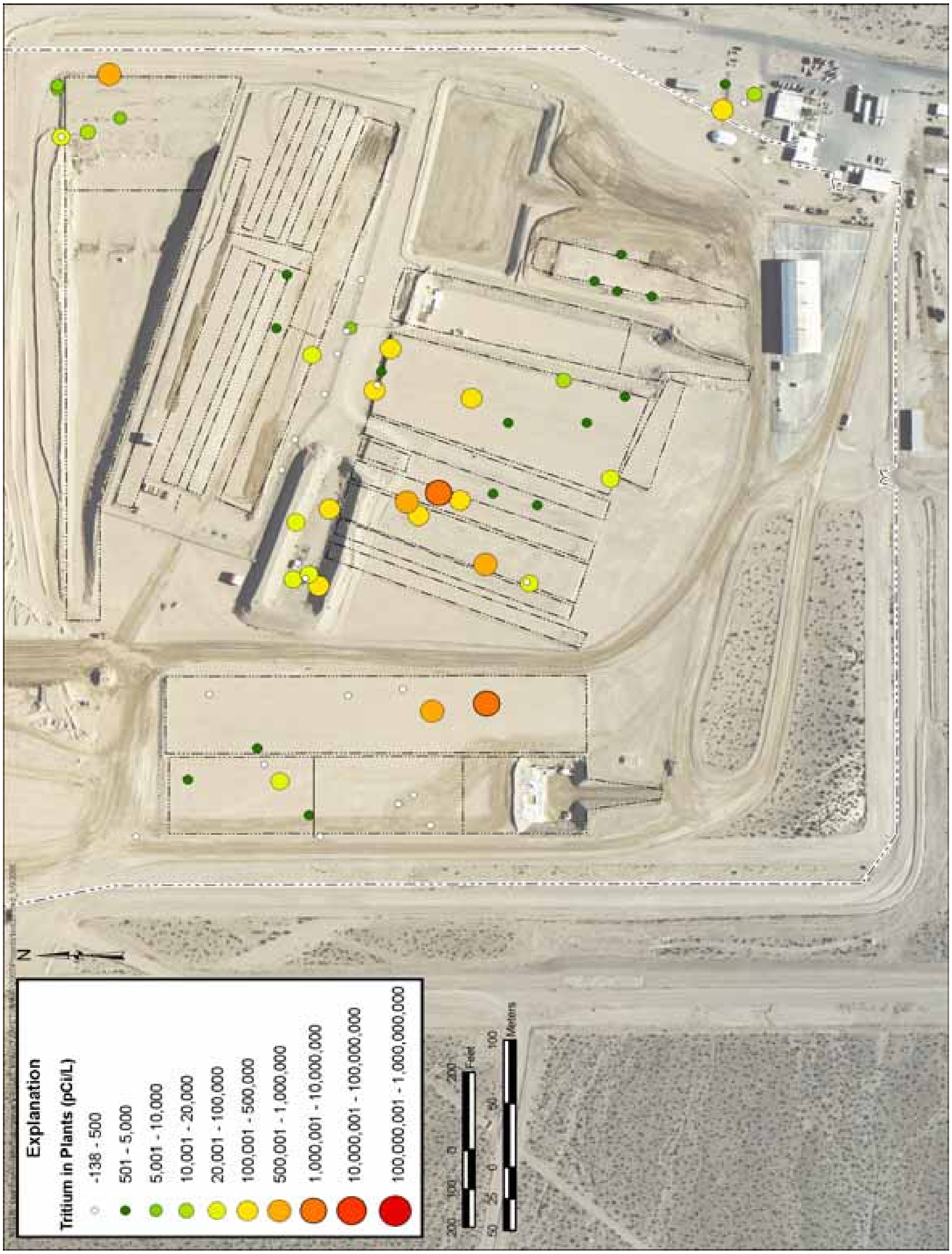



**Figure 45. Tritium concentrations in Area 5 RWMS biota samples in 2005**

Table 1. Area 3 drainage lysimeter treatments

| Lysimeter | Climate | Surface Vegetation |
|---|---|---|
| A | natural precipitation | Bare-soil |
| B | 3 times natural precipitation | Bare-soil |
| C | natural precipitation | invader species |
| D | 3 times natural precipitation | invader species |
| E | natural precipitation | Native species |
| F | 3 times natural precipitation | Native species |
| G | natural precipitation | invader species |
| H | 3 times natural precipitation | invader species |

Table 2. Biota samples collected at RWMS and control locations in 2005

| Location | Sampling Date | Species (number sampled) | Comments |
|---|---|---|---|
| **Plant Samples** | | | |
| Area 3 RWMS | May 24 | *Atriplex canescens* (fourwing saltbush) (1) | 1 Composite Sample |
| | | *Atriplex confertifolia* (shadscale saltbush) (6) | |
| Area 5 RWMS | May 23 | *Achnatherum hymenoides* (Indian ricegrass) (1) | |
| | | *Atriplex canescens* (fourwing saltbush) (2) | |
| | | *Atriplex polycarpa* (cattle saltbush) (12) | 11 Composite Samples |
| | | *Halogeton glomeratus* (saltlover) (6) | |
| | | *Larrea tridentata* (creosote bush) (1) | |
| | | *Salsola* (Russian thistle) (21) | |
| | | *Stephanomeria pauciflora* (wirelettuce) (1) | |
| | | Unknown annual (1) | |
| Control (Area 22) | May 26 | *Stephanomeria pauciflora* (Wirelettuce) (6) | 1 Composite Sample |
| **Animal Samples** | | | |
| Area 3 RWMS | April 13 | *Dipodomys merriami* (Kangaroo Rat) (6) | 1 Composite Sample |
| Area 5 RWMS | May 24 | *Dipodomys merriami* (Kangaroo Rat) (6) | 2 Composite Samples |
| Control (Area 22) | May 26 | *Neotoma lepida* (Desert Woodrat) (2) | 1 Composite Sample |

Table 3. Detected man-made radionuclide concentrations (excluding tritium) in biota samples collected at RWMS and control locations in 2005

| Location | Radionuclide Concentration | | | | |
|---|---|---|---|---|---|
| | $^{3}H^{a}$ | $^{90}Sr^{b}$ | $^{238}Pu^{b}$ | $^{239+240}Pu^{b}$ | $^{241}Am^{b}$ |
| **Plant Samples** | | | | | |
| Control (Area 22) | | | | | |
| Composite (6 Plants) | 292 ± 187 | 0.011 ± 0.005 | 0.004 ± 0.008 | -0.003 ± 0.007 | 0.001 ± 0.008 |
| RWMS 3 | | | | | |
| Composite (7 Plants) | 1180 ± 215 | 0.014 ± 0.023 | -0.001 ± 0.009 | 0.001 ± 0.006 | 0.004 ± 0.009 |
| RWMS 5 | | | | | |
| Composite #1 (4 Plants) | 1300 ± 224 | -0.007 ± 0.024 | 0.000 ± 0.007 | -0.003 ± 0.005 | 0.003 ± 0.008 |
| Composite #2 (4 Plants) | 9340 ± 423 | 0.013 ± 0.019 | 0.001 ± 0.006 | -0.003 ± 0.005 | -0.007 ± 0.006 |
| Composite #3 (4 Plants) | 1970000 ± 51200 | -0.010 ± 0.015 | -0.002 ± 0.005 | -0.003 ± 0.005 | -0.005 ± 0.004 |
| Composite #4 (4 Plants) | 54200 ± 1430 | 0.017 ± 0.019 | 0.002 ± 0.006 | 0.002 ± 0.005 | 0.007 ± 0.006 |
| Composite #5 (4 Plants) | 273000 ± 7110 | 0.003 ± 0.018 | 0.004 ± 0.006 | -0.004 ± 0.005 | 0.003 ± 0.008 |
| Composite #6 (5 Plants) | 380000 ± 9890 | -0.009 ± 0.021 | 0.001 ± 0.006 | -0.002 ± 0.003 | -0.002 ± 0.004 |
| Composite #7 (6 Plants) | 11400 ± 474 | 0.018 ± 0.024 | 0.007 ± 0.007 | -0.001 ± 0.006 | 0.000 ± 0.005 |
| Composite #8 (4 Plants) | 1430 ± 228 | 0.007 ± 0.026 | -0.002 ± 0.006 | -0.003 ± 0.006 | 0.002 ± 0.007 |
| Composite #9 (4 Plants) | 331000 ± 8620 | 0.003 ± 0.017 | 0.001 ± 0.006 | -0.003 ± 0.004 | 0.000 ± 0.008 |
| Composite #10 (3 Plants) | 36700 ± 976 | 0.011 ± 0.039 | -0.001 ± 0.002 | -0.005 ± 0.005 | -0.010 ± 0.007 |
| Composite #11 (3 Plants) | 169000 ± 4390 | 0.034 ± 0.019 | 0.000 ± 0.004 | -0.006 ± 0.005 | 0.004 ± 0.007 |
| **Animal Samples** | | | | | |
| Control (Area 22) | | | | | |
| Composite (2 animals) | 350 ± 208 | 0.093 ± 0.023 | -0.002 ± 0.005 | 0.001 ± 0.005 | 0.001 ± 0.002 |
| RWMS 3 | | | | | |
| Composite (6 animals) | 2160 ± 269 | 0.109 ± 0.031 | 0.002 ± 0.003 | 0.020 ± 0.011 | 0.005 ± 0.005 |
| RWMS 5 | | | | | |
| Composite #1 (3 animals) | 8640 ± 418 | 0.079 ± 0.026 | 0.003 ± 0.003 | 0.003 ± 0.006 | -0.002 ± 0.004 |
| Composite #2 (3 animals) | 139000 ± 3640 | 0.055 ± 0.023 | 0.000 ± 0.005 | 0.006 ± 0.006 | -0.005 ± 0.005 |
| Average MDC: | 610 | 0.045 | 0.011 | 0.012 | 0.013 |

Results are ± two standard deviations. Shaded results are greater than the sample specific MDC

[a] pCi/L in water distilled from sample

[b] p i/g – dry weight

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