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Selected Micrometeorological, Soil-Moisture, and Evapotranspiration Data at Amargosa Desert Research Site in Nye County near Beatty, Nevada, 2001–05

Data Series 284

U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors and Datum

Conversion Factors

Multiply	By	To obtain
becquerel per liter (Bq/L)	27.027	picocurie per liter
centimeters (cm)	0.3937	inch
cubic meter (m^3)	35.31	cubic foot
kilometer (km)	0.6214	mile
kilopascal (kPa)	0.1450	pound-force per square inch
liter (L)	0.2642	gallon
meter (m)	3.281	foot
meter per second (m/s)	3.281	foot per second
micrometer (µm)	0.000039	inch
millibar (mbar)	0.0145	pound per square inch
millimeter (mm)	0.03937	inch
millimeter per day (mm/d)	0.0397	inch per day
millimeter per hour (mm/h)	0.03937	inch per hour
Watts per square meter (W/m^2)	0.005290	British Thermal Unit per square foot per minute

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Radiation: A unit of activity is a Curie (Ci), which is equivalent to 3.7×10^{10} disintegrations per second (dps); the standard disintegration rate of 1 gram of Radium. In International Units a Becquerel (Bq) is equivalent to 1 disintegration per second (dps). Thus, 1 Curie (Ci) equals 3.7×10^{10} Becquerels (Bq) or 37 gigaBecquerels (GBq).

Datum

In this report, “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929, formerly called “Sea-Level Datum of 1929”), which is derived from a general adjustment of the first-order leveling networks of the United States and Canada.

Selected Micrometeorological, Soil-Moisture, and Evapotranspiration Data at Amargosa Desert Research Site in Nye County near Beatty, Nevada, 2001–05

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Abstract

Selected micrometeorological and soil-moisture data were collected at the Amargosa Desert Research Site adjacent to a low-level radioactive waste and hazardous chemical waste facility near Beatty, Nevada, 2001–05. Evapotranspiration data were collected from February 2002 through the end of December 2005. Data were collected in support of ongoing research to improve the understanding of hydrologic and contaminant-transport processes in arid environments.

Micrometeorological data include solar radiation, net radiation, air temperature, relative humidity, saturated and ambient vapor pressure, wind speed and direction, barometric pressure, precipitation, near-surface soil temperature, soil-heat flux and soil-water content. All micrometeorological data were collected using a 10-second sampling interval by data loggers that output daily and hourly mean values. Daily maximum and minimum values are based on hourly mean values. Precipitation data output includes daily and hourly totals. Selected soil-moisture profiles at depth include periodic measurements of soil volumetric water-content measurements at nine neutron-probe access tubes to depths ranging from 5.25 to 29.25 meters. Evapotranspiration data include measurement of daily evapotranspiration and 15-minute fluxes of the four principal energy budget components of latent-heat flux, sensible-heat flux, soil-heat flux, and net radiation. Other data collected and used in equations to determine evapotranspiration include temperature and water content of soil, temperature and vapor pressure of air, and covariance values. Evapotranspiration and flux estimates during 15-minute intervals were calculated at a 0.1-second execution interval using the eddy covariance method.

Data files included in this report contain the complete micrometeorological, soil-moisture, and evapotranspiration field data sets. These data files are presented in tabular Excel spreadsheet format.

This report highlights selected data contained in the computer generated data files using figures, tables, and brief discussions. Instrumentation used for data collection also is described. Water-content profiles are shown to demonstrate variability of water content with depth. Time-series data are plotted to illustrate temporal variations in micrometeorological, soil-water content, and evapotranspiration data.

Introduction

Research at the Amargosa Desert Research Site (ADRS) is intended to develop a fundamental understanding of hydrologic and contaminant-transport processes in arid environments. Research objectives are to advance the understanding of hydrologic science and to provide scientific information for those making decisions concerning waste isolation and water management in desert environments. Information on ADRS is available on the internet at http://nevada.usgs.gov/adrs/.

In support of ongoing research, micrometeorological, soil-moisture, and evapotranspiration (ET) data were collected at the ADRS adjacent to a low-level radioactive and hazardous-chemical waste facility near Beatty, Nev. The waste facility has been used for the burial of low-level radioactive waste from 1962 through 1992 and hazardous-chemical waste from 1970 to present. The ADRS was incorporated into the U.S. Geological Survey (USGS) Toxic Substances Hydrology Program in 1997. Research at the ADRS began in 1983 and has produced long-term benchmark data on hydrologic characteristics and soil-water movement in undisturbed conditions and in simulated waste-disposal conditions in arid environments (Andraski and Stonestrom, 1999).

This report includes selected micrometeorological, soil-moisture, and ET data collected during 2001–05. Instrumentation used to collect the data is described herein. This report is the eighth in a series of meteorological reports published for the ADRS (Wood and Fischer, 1991, 1992; Wood and others, 1992; Wood and Andraski, 1992, 1995; Wood, 1996, Johnson and others, 2002). These previous reports include meteorological data collected during 1986–92 and during 1998–2000. Meteorological data were not reported for 1993–97.

The micrometeorological data collected for 2001–05 include solar radiation, net radiation, air temperature, relative humidity, saturated and ambient vapor pressure, wind speed and direction, barometric pressure, precipitation, near-surface soil temperature, soil-heat-flux and soil-water content. Soil-moisture profiles collected periodically during 2001-05 consist of volumetric soil-water content measurements made using a neutron probe. ET data were collected from February 14, 2002, through December 31, 2005, and included daily totals and 15-minute energy fluxes of net radiation, soil-heat flux, latent-heat flux, and sensible-heat flux along with other soil and air parameters collected and used in equations to derive ET.

Data files that contain the complete micrometeorological (appendixes A–F), soil-moisture (appendixes G and H), and ET (appendixes I–M) field data sets are summarized in this report. These data consist of 13 tabular files (in Excel spreadsheet format) with about 62 megabytes of information. Appendix A lists daily mean micrometeorological data and daily total precipitation for 2001–05. Appendixes B–F list hourly mean micrometeorological and hourly precipitation data for 2001–05. Appendix G lists soil-water content by date and depth at four experimental sites. Appendix H lists soil-water content by date and depth for each neutron-probe access tube. Appendix I lists the daily ET. Appendixes J–M list the 15-minute fluxes and other variables for each year (2002–05).

Site Description

The ADRS is near a waste-burial facility about 17 km south of Beatty, Nev., and 20 km east of Death Valley, Calif. (fig. 1*A*). The ADRS is in the Mojave Desert ecosystem, one of the most arid regions in the United States. Vegetation in the area is sparse, covering about 6 to 8 percent of the land surface at the ADRS (Andraski and others, 2005) based on 2001 and 2003 data collected using the line-transect method (Smith, 1974). Creosote bush (*Larrea tridentata*), an evergreen shrub, is the dominant species. At the site, creosote bush averages about 0.7 m in height, with a major and minor axial diameter of 1 m and 0.7 m, respectively. The Amargosa Desert is in the Basin and Range physiographic province. Sediments beneath the study area and the waste-burial facility primarily are basin fill consisting of unconsolidated alluvial fan, fluvial, and marsh deposits (Clebsch, 1968). The basin fill is estimated to be more than 170-m thick (Nichols, 1987, p. 8). Depth to the water table ranges from 85 to 115 m below land surface (Fischer, 1992, p. 12).

Other studies at the ADRS facility have been established to support research of flow and transport processes within the thick unsaturated zone above the water table. The research site has two fenced areas; one encloses a vertical, 13.7-m instrument shaft (figs. 1*B* and 2; Fischer, 1992), and the other encloses simulated waste trenches (figs. 1*B* and 3; Andraski, 1990). A weather station, two precipitation gages, and three neutron-probe access tubes are within the instrument-shaft area (fig. 2). The instrument-shaft area is used for monitoring soil-water content in a vegetated, native-soil profile. Six neutron-probe access tubes and a single precipitation gage are within the simulated waste-trench area (fig. 3). The tubes are used to measure soil-water content under nonvegetated, simulated waste-trench conditions and under devegetated, but undisturbed native-soil conditions. Ground-water levels have been measured periodically since 1987 at well MR-3 (fig. 1*B*). Throughout the thick unsaturated zone, deep test holes (UZB-1, 2, and 3; fig. 1*B*) have been used for obtaining measurements of soil temperature, water potential, air pressure, and for collecting soil-gas samples (Prudic and Striegl, 1995; Andraski and Prudic, 1997; Prudic and others, 1999; Mayers and others, 2005). An ET station (fig. 1*B*) is located approximately 200 m south of the fenced area enclosing the instrument shaft area. Not shown in the figures is an array of soil-gas sampling tubes that are used for periodic collection and analysis of the chemical composition of unsaturated-zone air to a depth of about 1.5 m (Striegl and others, 1998; Healy and others, 1999). Similarly, numerous plant-sampling sites have been established to evaluate soil-plant-atmosphere interactions and ultimately to determine how those interactions affect the potential release of contaminants (Andraski and others, 2005).

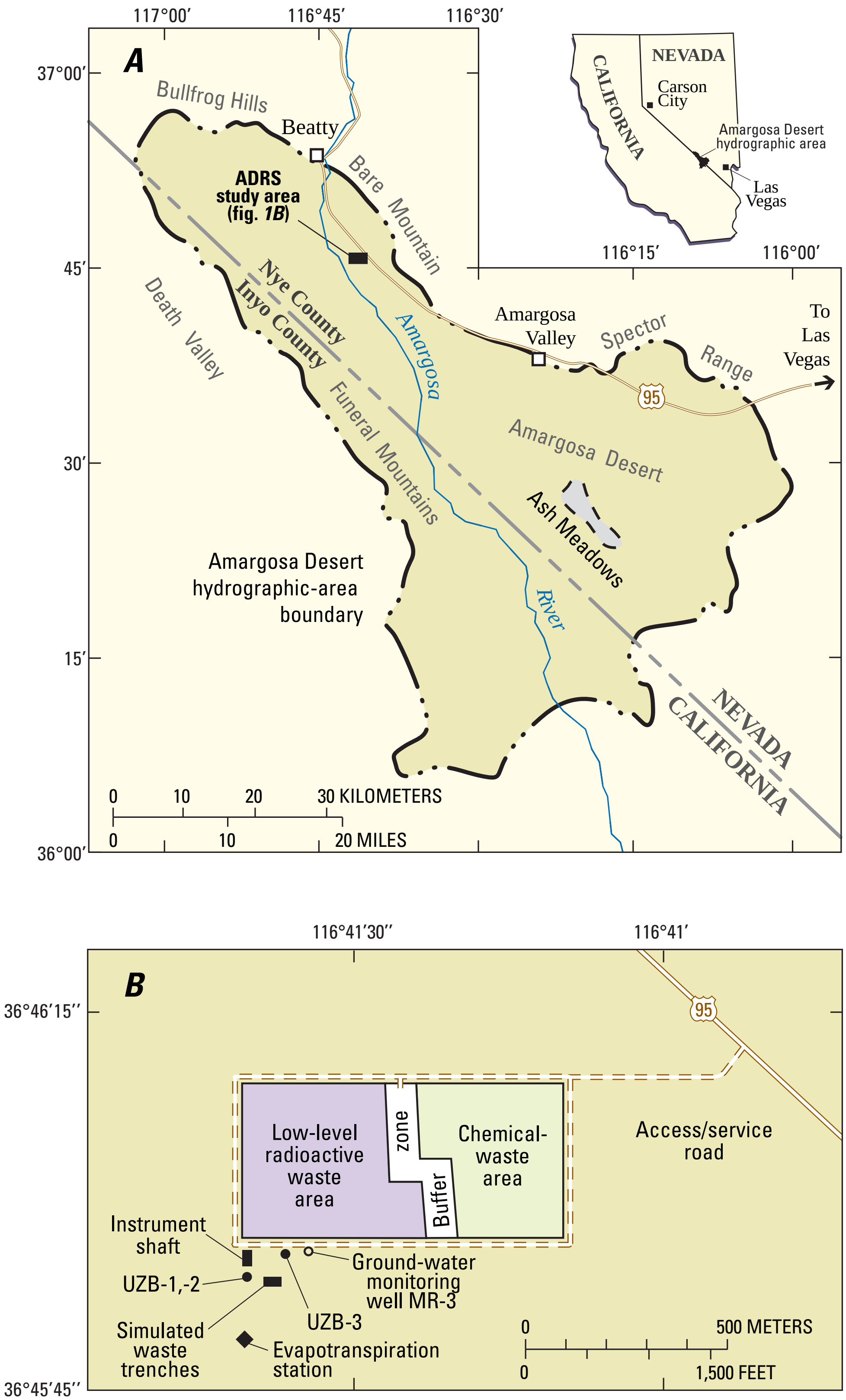

Figure 1. Location of (*A*) Amargosa Desert Research Site (ADRS) near Beatty, Nevada, and (*B*) instrument shaft and simulated waste trenches adjacent to waste-disposal facility.

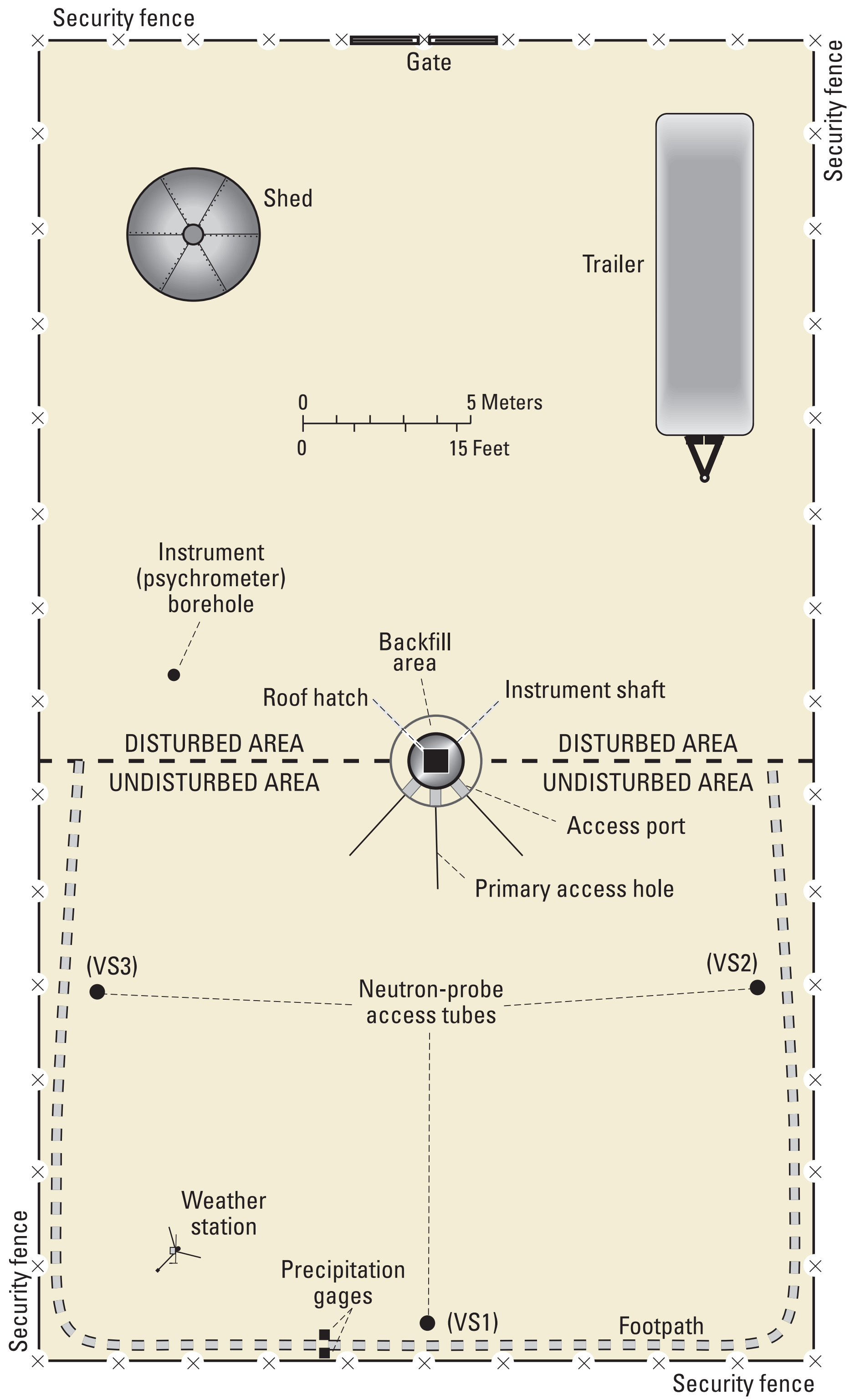

Figure 2. Fenced area of instrument shaft, location of weather station, neutron-probe access tubes VS1, VS2, and VS3 in vegetated native soil, and precipitation gages at Amargosa Desert Research Site near Beatty, Nevada.

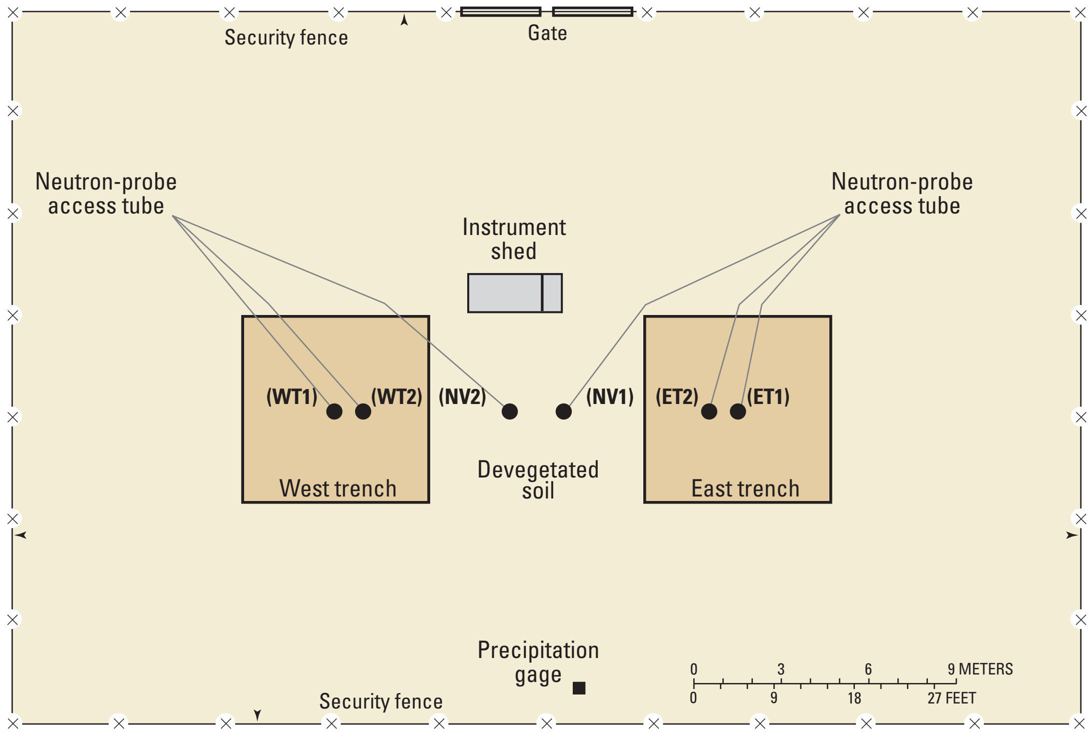

Figure 3. Fenced area of simulated waste trenches and location of neutron probe access tubes NV1 and NV2 in devegetated native soil; neutron-probe access tubes ET1, ET2, WT1, and WT2 in simulated waste trenches; and precipitation gage at Amargosa Desert Research Site near Beatty, Nevada.

Micrometeorological Instrumentation

Micrometeorological sensors consisting of a tipping-bucket precipitation gage, an air-temperature and relative-humidity probe, a barometric-pressure sensor, a pyranometer, and an anemometer with wind vane were installed in December 1997. A net radiometer was installed at the site in July 1998. Soil-temperature probes and two soil-heat-flux plates were installed in September 1999. A soil-moisture probe was installed in January 2002. Data from two accumulating precipitation gages periodically were read after storm events to verify the data values obtained by the tipping-bucket precipitation gage.

Data from all the sensors were recorded using a Campbell Scientific, Inc. (CSI), 23X data logger using a 10-second sampling interval. The logger was programmed to output data in three formats: daily mean values (except for precipitation where only daily accumulated totals are output); hourly mean values (except for precipitation where only hourly accumulated totals are output); and 5-minute totals for precipitation (to define storm event timing rather than to collect data values and are not included in this data report). The data logger is interfaced to a telephone modem permitting automated communication and data retrieval using an off-site computer. The data logger reference is Pacific Standard Time (PST) throughout the year.

The air-temperature relative-humidity sensor, pyranometer, and anemometer with wind vane are mounted on a CM10 tripod at heights of 1.5 m, 3 m, and 3 m above the ground surface, respectively. The barometric-pressure sensor is mounted 1 m above the ground and housed with the data logger in a shed approximately 30 m north of the tripod (fig. 2). The net radiometer is mounted 1.5 m above the ground and approximately 10 m from the tripod. The net radiometer monitors principally bare soil radiation within the undisturbed vegetated area. The precipitation tipping-bucket precipitation gage was installed on its own mount approximately 5 m from the tripod at a height of 1 m. Adjacent to the tipping-bucket precipitation gage is an accumulating plastic precipitation gage made by Tru-Chek mounted at a height of 1 m along the south fence of the instrument shaft area (fig. 2), and a second Tru-Chek precipitation gage was at the south end of the waste-trench area (fig. 3). Two soil-heat-flux plates are buried in the near-surface soil at a depth of about 0.08 m approximately 2 m from the weather-station tripod. Between the flux plates and the soil surface, the averaging soil-temperature probes are buried at depths of 0.02 and 0.06 m. The soil-moisture probe is buried to measure average soil moisture in the depth interval between the flux plate depth of 0.08 m and the soil surface. The probe has two 0.3 m rods spaced about 0.03 m apart. The rods are inserted into the ground at a slight angle to integrate the water content of soil over the depth interval.

The accuracy of the data is dependent on the sensors being used. Instrumentation manuals from the manufacturers (vendors) contained the following sensor specifications. The tipping-bucket precipitation gage is a WeatherMeasure model P-501 with a resolution of 0.25 mm representing one tip of the bucket, and an accuracy of 0.5 percent at 12.7 mm/h. The air-temperature relative-humidity sensor is a Vaisala HMP35C from CSI with a temperature accuracy of ±0.4°C over a range of -24 to 48°C, and measures a relative humidity accuracy of ±2 percent within the range from 0 to 90 percent and ±3 percent within the range from 90 to 100 percent. The Vaisala temperature and humidity sensor is mounted inside a 12-plate gill radiation shield. Solar radiation is measured with a LI-COR LI200X silicon pyranometer calibrated against an Eppley Precision Spectral Pyranometer, and has a maximum error of ±5 percent. The net radiometer is a Radiation and Energy Balance Systems (REBS) Q7.1 net radiometer, which has a spectral response from 0.25 to 60 µm, with a nominal resistance of 4 ohms. Wind speed and direction are measured by a Met One 034A-L Windset with a wind speed accuracy of ±0.12 m/s, a threshold of 0.28 m/s, and wind direction accuracy of ±4 degrees. The barometric-pressure sensor is a CSI SBP270 with a pressure range from 800 to 1,100 mbar and an accuracy of ±0.2 mbar. Soil temperature is measured with a TCAV-L averaging soil-temperature probe manufactured by CSI with two junctions at two depths and constructed using a Type-E thermocouple (chromel-constantan) wire. The four thermocouples and associated reference temperature define an averaged soil temperature with a typical uncertainty of 0.5°C, but the uncertainty can be as high as 1.6°C. The soil-heat flux is measured with two REBS HFT3.1 heat-flow transducer plates with a nominal resistance of 2 ohms and a thermal conductivity of 1.00 Watt per meter per degrees Kelvin (W/m/K). The soil-heat-flux plates have an error of about ±5 percent. The near-surface soil moisture is measured using a CS615 water content reflectometer designed to measure volumetric water content derived from the probe sensitivity to the unique dielectric content of the soil which changes with changing moisture conditions. The soil-moisture probe has an accuracy of ±2 percent when calibrated for a specific soil. The soil moisture values have been calibrated to the specific soil at the site by periodic field sampling of soil between the 8-cm flux-plate depth and the soil surface. Samples were analyzed to determine gravimetric water, bulk density, and volumetric water content.

Soil-Moisture Profile Instrumentation

Measurements of soil-water content were collected at depth from neutron-probe access tubes using a CPN 503 Hydroprobe manufactured by Campbell Pacific Nuclear International, Inc. The probe uses a 50 mCi Americium-241: Beryllium neutron source, or in System International units, a 1.85 GBq source. This source emits fast neutrons that are not detected by the neutron detectors in the probe. The fast neutrons propagate through the soil, collide with hydrogen atoms in soil water, become thermalized or slowed, and are then reflected back as slow neutrons. The reflected slow neutrons are detected in the tube of the probe and the surface electronic sensor counts each slow neutron event. Counts are accumulated for a specified time interval and recorded. Soil-water content is proportional to the number of slow neutron reflections counted. Because the neutron source and its detector tube can vary in radiation-flux emissions and detections with time, count ratios are used to normalize the field counts for a given set of measurements. Count ratios are calculated by dividing the field counts by standard counts obtained while the neutron probe is within its shield above the ground.

Access tubes at both the vegetated, native soil profile (VS1, VS2, and VS3; fig. 2) and the devegetated, native soil profile (NV1 and NV2; fig. 3) are large-steel tubes with a 140-mm outside diameter and a 6.4-mm wall thickness. These access tubes were installed at the vegetated, native soil site (July 1984) and the devegetated, native soil site (September 1988) using a pneumatically driven downhole-hammer system (Tyler, 1988). Access tubes at the two simulated waste trenches (ET1, ET2, WT1, and WT2; fig. 3) are small-steel tubes with a 51-mm outside diameter and 3.0-mm wall thickness. These access tubes were installed during trench construction (September 1987) with tubes placed in holes that were hand-augured below the trench floor prior to backfilling (Andraski, 1996). Three access tubes (VS1, VS2, and VS3; fig. 2) were used at the vegetated, native soil profile with the neutron probe reaching a maximum recording depth of 13.75, 29.75, and 13.75 m, respectively. Two access tubes were used at each of the other sites (fig. 3) with a maximum neutron probe depth of about 5.25 m.

Neutron counts were accumulated for 30-second time interval at each depth selected within the individual access tubes. At the vegetated, native soil profile (within the instrument shaft area; fig. 2), single readings were obtained at each depth, and readings were obtained at intervals of 0.25 m to a depth of 10.75 m and then 0.5 m below that depth. At the devegetated, native soil profile and the two trenches (within the simulated trench area; fig. 3), two readings were obtained at each depth, and readings typically were obtained at intervals of 0.25 m.

Using count ratios, calibration equations were developed with coefficients of determination greater than 0.96 (Andraski, 1997, p. 1904). The standard error of estimate for small-diameter tubes ranged from 0.017 m^3/m^3 for measurements at the 0.15 m depth to 0.012 m^3/m^3 for measurements at depths greater than 0.15 m. For large-diameter tubes, the standard error of estimate was less than 0.009 m^3/m^3 at all depths.

Evapotranspiration Instrumentation

ET instrumentation consists of a CSI eddy covariance system which includes a CSAT3 three-dimensional sonic anemometer, a KH20 krypton hygrometer, and a FW05 fine-wire thermocouple (type E, 0.0005 inch diameter). These instruments measure two main energy budget components: the transfer of water vapor (latent-heat flux) and the transfer of heat (sensible-heat flux) through the atmosphere, using the eddy covariance technique. Additional sensors were added to this instrumentation to document the two other principal energy budget components of net radiation and soil-heat flux. Net radiation is measured by a REBS Q7.1 net radiometer. Soil-heat flux is calculated by measurements obtained from ground sensors consisting of two REBS HFT3.1 heat-flow transducer plates, a TCAV-L (CSI) averaging soil-temperature probe, and a CS616 water content reflectometer. The eddy covariance system uses a HMP45C Vaisala temperature and relative humidity probe to derive other necessary variables for the eddy covariance technique.

The anemometer, hygrometer, and fine-wire thermocouple were mounted on their own tripod with cables running to a second tripod used to mount the net radiometer, Vaisala temperature and relative humidity probe, cellular phone antenna, and enclosure box containing a CSI 23X data logger, storage module, cellular phone and other terminals and controls. The installation geometry of the soil sensors is the same as at the weather station. The net radiometer was mounted 3 m above the ground and 3 m out from the tripod; this sensor placement was selected to provide a representative measurement of the land surface consisting of sparse plant canopy and bare soil. The temperature and humidity probe along with the anemometer, hygrometer, and fine-wire thermocouple were mounted 2 m above the ground surface.

The ET station was operated using a field program (flx232_3.csi, version 2.3, 22 March 2001) obtained from Campbell Scientific, Inc. (Ed Swiatek, Campbell Scientific, Inc., written commun., 2002). The field program was modified to the specific sensors used at the ADRS. The eddy covariance fluxes are computed for a 15-minute covariance period based on a 0.1-second execution or sampling interval. Other sensors generally sample data for a 1-second sampling interval and output data every 15 minutes.

Selected Micrometeorological Data

Complete micrometeorological data sets are available in appendixes A–F of this report. Appendix A lists daily mean micrometeorological data and daily total precipitation for 2001–05. Hourly mean micrometeorological and hourly precipitation data for 2001–05 are listed in appendixes B–F.

Appendix A lists daily mean values of micrometeorological data computed from instantaneous readings sampled every 10 seconds during the day (8,640 samples). These daily mean values are equivalent to daily mean values computed by averaging hourly mean values (appendixes B-F) computed from (the same) instantaneous readings sampled every 10 seconds during the hour (360 samples). In this report, daily mean values are included only in appendix A. Any reference to daily mean values computed from hourly mean values can be looked up in appendix A. However, daily maximum and minimum values of micrometeorological data computed from instantaneous readings sampled every 10 seconds throughout a day are not equivalent to daily maximum and minimum values computed from hourly mean values of the same data. In this report, discussions of micrometeorological data will focus on the daily mean values (appendix A) with reference to daily maximum and minimum values from hourly mean values (appendixes B–F).

Solar Radiation

Daily maximum and mean solar radiation computed from hourly averaged values at ADRS are shown in figure 4. Complete daily and hourly solar-radiation data are in appendixes A–F. Solar radiation is the amount of incident radiation from the sun that reaches the surface of the earth at the point of detection. Both daily and hourly mean and maximum solar-radiation data in this report and solar-radiation data presented in the previous report (Johnson and others, 2002) are based on instantaneous readings sampled every 10 seconds. Earlier ADRS publications (Wood and Fischer, 1991, 1992; Wood and others, 1992; Wood and Andraski, 1992, 1995; Wood, 1996) also reported daily mean and maximum solar radiation derived from hourly mean values based on instantaneous readings sampled every 10 seconds.

The daily maximum and mean solar-radiation curves (fig. 4) show the annual solar-energy cycle and the difference between the daily mean and maximum for any given day of the year. The maximum radiation for the year occurs during the summer solstice in late June during clear sky days with maximum daily values generally averaging about 1,020 W/m^2 during the 5 years of record. Conversely, during the winter solstice period in late December during clear sky days maximum daily values generally average about 580 W/m^2 during the 5 years of record. The downward spikes in figure 4 show days where average daily solar radiation is reduced during extended periods of cloud cover. As indicated in figure 4, the difference between the daily maximum and daily mean time-series values varies from more than 720 W/m^2 during the summer to an average of about 410 W/m^2 during the winter.

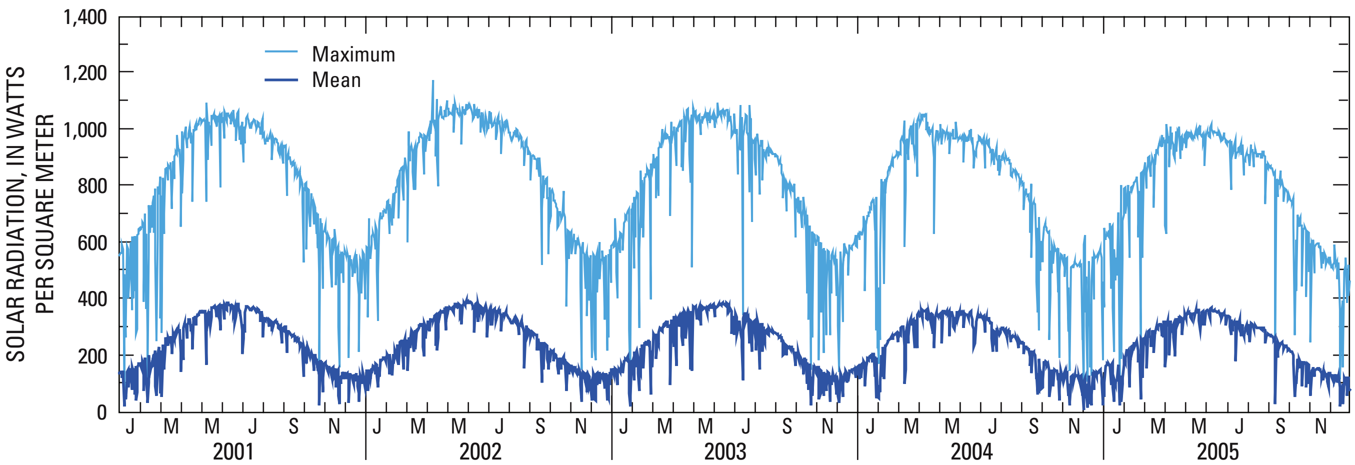

Figure 4. Daily maximum and mean solar radiation computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Figure 4 shows a shift in the data set, which occurred on May 5, 2004, with the replacement of one pyranometer with another. The shift is about 5 percent of the maximum expected absolute error in natural daylight for this kind of sensor. During any given 1-year period an individual sensor can range ±2 percent.

Net Radiation

Daily maximum and mean net radiation computed from hourly averaged values are shown in figure 5. Complete daily and hourly net-radiation data are in appendixes A–F. Net radiation is the difference between all downward and upward radiation fluxes of both short- and long-wave radiation. Net radiation is a measure of the energy available at the surface of the Earth that can be partitioned into such energy-consuming processes as heating the soil and air, ET, and plant growth. By convention, net radiation is defined as positive when downward components (incoming radiation) exceed upward components (outgoing radiation), and this typically occurs after sunrise and before sunset. Allocation of this net radiative energy varies with seasonal surface conditions. For example, in late spring after a rainstorm, more energy is used to evaporate water from wet soils and for plant transpiration than is used to heat the air and soil. Later in the summer under dry conditions almost all the net radiative energy goes to heat the air and soil.

During 2001–05, the daily mean net radiation generally ranged from about 20 W/m^2 in early winter to about 160 W/m^2 in early summer (fig. 5; appendix A). The daily maximum generally ranged from a low of about 290 W/m^2 in early winter to a high of about 570 W/m^2 in early summer. The mean net radiation that occurs from 8 a.m. to 4 p.m. PST also is shown in figure 5 to illustrate that a large part of daily net radiation available to the site occurs during the 4 hours before and after noon. This daily 8 a.m. to 4 p.m. mean radiation often is within 100 W/m^2 of the daily maximum radiation.

Variations in measured net radiation values can occur over time as the transparent polyethylene shields on the net radiometer age and become less translucent from the UV radiation component of solar radiation or from the scouring from wind driven particles. Cracks in the shield will cause abrupt changes in net radiation values as shown in figure 5 from August 14, 2004, to October 25, 2004, when the shield was replaced. UV radiation can dry the polyethylene shield to the point where the shield is shattered from heavy rains during summer thunderstorms or from wind driven particles such as sand. Radiation values can increase or decrease when the radiometer is not level, such as when birds damage the shields or tilt the sensor head. An example of an abnormal increase in radiation can be seen from July 3, 2001, to September 5, 2001 (fig. 5). Most sensor problems can be easily fixed by replacing shields and leveling the sensors. The extended periods of poor-quality data reflect the timing of the occurrence of sensor problems with the scheduled field visits limited to quarterly visits.

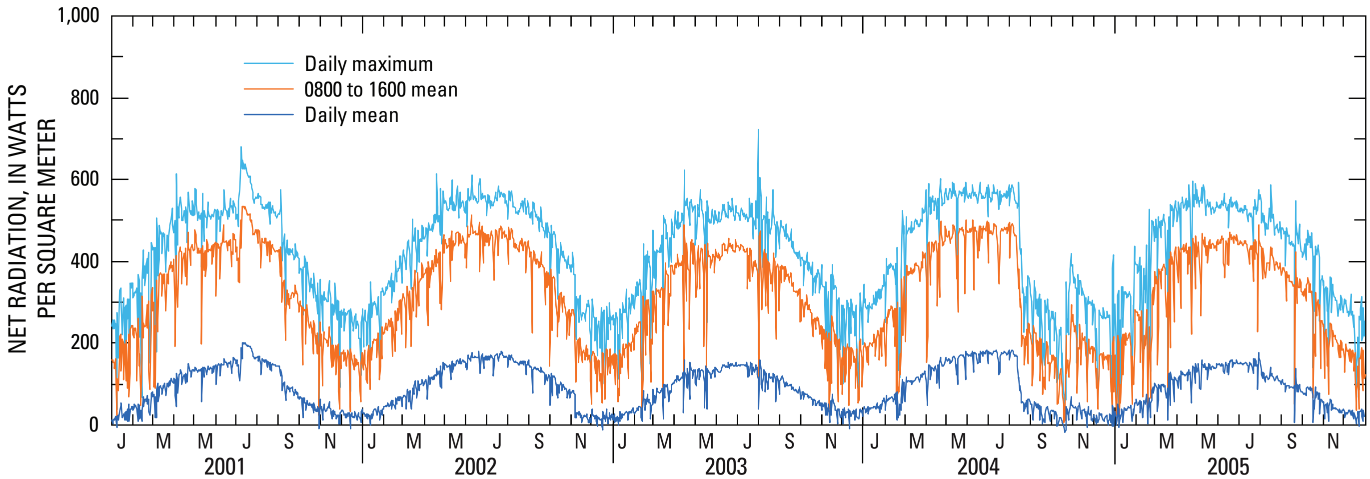

Figure 5. Daily maximum and mean net radiation compared to mean from 8 a.m. to 4 p.m. of net radiation computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Air Temperature

Monthly maximum, minimum, and mean air temperatures computed from hourly averaged values are listed in table 1. Daily maximum, minimum, and mean air temperatures are shown in figure 6. Complete data for daily and hourly air temperatures are in appendixes A–F. During 2001–05, air temperatures averaged 18.3°C with the warmest month averaging 31.7°C during July and the coldest month averaging 6.4°C during December. From 2001 through 2005, the maximum hourly average temperature recorded was 44.7°C in July 2005 and the minimum temperature recorded was -8.5°C in January 2002.

Daily and seasonal temperature fluctuations are large at the study site. Differences between daily maximum and minimum temperatures commonly exceed 20°C as shown in figure 6. Differences between winter minimum and summer maximum temperatures exceed more than 40°C, and sometimes more than 50°C. The desert environment, with its high percentage of clear skies, has a large heating capacity from incoming solar (short-wave) radiation during the day, and a proportionally large heat discharge by terrestrial (long-wave) radiation during the night. The large gains and losses in energy on a daily basis and their relative variation on a seasonal basis are what regulate the temperatures that occur in this environment.

Relative Humidity

Daily maximum, minimum, and mean relative-humidity computed from hourly averaged values is shown in figure 7. Complete daily and hourly relative-humidity data are in appendixes A–F. Relative humidity is the ratio of the amount of water vapor in the air at a specific temperature (vapor pressure) to the maximum amount of water vapor that the air can hold at that temperature (saturated vapor pressure), expressed as a percent. Daily mean values ranged from 5 to 95 percent. In contrast, hourly mean values ranged from 1 percent during the drier summer months to 100 percent during winter storms. During mid-day hours in the summer, relative-humidity values of less than 10 percent are common in the Amargosa Desert where prevailing high summer temperatures lower the relative-humidity measurements of available vapor content of the air relative to what saturated levels would be if maximum water vapor were available in the area.

Table 1. Monthly, maximum, minimum, and mean air temperatures computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

[Temperatures are in degrees Celsius. Maximum and minimum based on hourly mean values. Monthly mean obtained by averaging mean daily values]

Month	Air temperatures in degrees C				
	Maximum	Day	Minimum	Day	Mean
2001					
January	21.4	3	-3.7	21	5.7
February	23.6	4	-5.2	9	6.9
March	27.6	31	-0.4	1	14.2
April	32.3	30	0.3	9	15.3
May	39.0	24	8.8	3	25.7
June	40.8	30	11.2	14	28.5
July	43.4	2	16.6	23	29.5
August	42.1	18	16.2	22	30.9
September	36.6	24	12.9	9	26.0
October	35.7	2	6.5	25	19.9
November	26.5	3	-4.5	28	11.8
December	17.4	31	-5.9	16	5.8
2002					
January	20.3	13	-8.5	17	5.9
February	24.6	23	-8.4	1	9.4
March	29.6	30	-4.2	17	11.4
April	33.5	14	3.8	21	18.2
May	39.0	30	5.9	21	22.4
June	40.9	30	14.1	12	29.0
July	44.7	9	18.7	28	32.7
August	43.2	14	15.1	31	29.7
September	38.6	2	10.5	8	25.6
October	32.5	8	3.6	30	17.1
November	25.4	20	-0.7	2	12.2
December	19.0	5	-7.4	19	6.3
2003					
January	26.0	31	-1.2	16	10.5
February	23.4	1	-5.4	8	8.7
March	26.7	31	-0.9	3	13.3
April	27.7	10	0.9	6	14.5
May	41.3	28	7.3	9	22.6
June	40.6	28	15.5	25	29.1
July	43.8	12	16.8	1	32.9
August	40.6	18	16.5	7	29.9
September	38.9	27	11.7	19	26.8
October	35.0	21	2.5	31	21.6
November	19.2	11	-4.0	25	8.3
December	19.9	2	-4.8	16	5.8

Month	Air temperatures in degrees C				
	Maximum	Day	Minimum	Day	Mean
2004					
January	20.4	14	-7.3	26	6.1
February	22.3	17	-4.4	13	7.1
March	32.1	21	2.3	1	16.6
April	33.1	27	3.3	18	17.5
May	36.3	31	8.4	12	23.0
June	39.9	5	9.7	10	28.4
July	40.6	19	16.4	2	31.1
August	42.4	11	14.9	28	29.1
September	39.2	1	8.5	23	24.3
October	32.0	8	2.2	29	16.7
November	25.3	6	-7.0	30	9.6
December	21.2	10	-4.7	25	7.0
2005					
January	23.2	19	-2.5	7	8.0
February	18.4	17	-1.3	9	8.8
March	27.4	9	-0.6	15	12.3
April	29.1	17	1.0	1	15.1
May	37.4	26	8.8	13	22.7
June	39.4	22	11.1	8	26.0
July	44.7	18	18.1	5	32.4
August	40.7	28	15.4	30	29.3
September	37.0	2	8.5	13	22.7
October	32.3	2	5.0	11	17.9
November	25.2	19	-3.6	28	12.1
December	22.7	23	-6.1	17	6.8

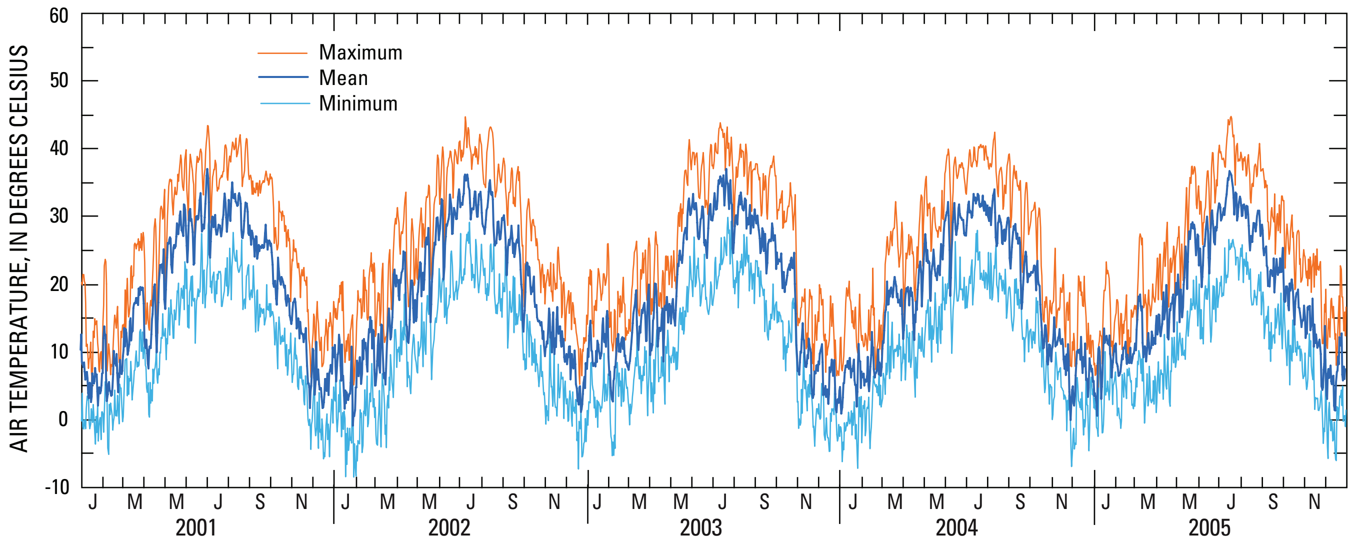

Figure 6. Daily maximum, minimum, and mean air temperature computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

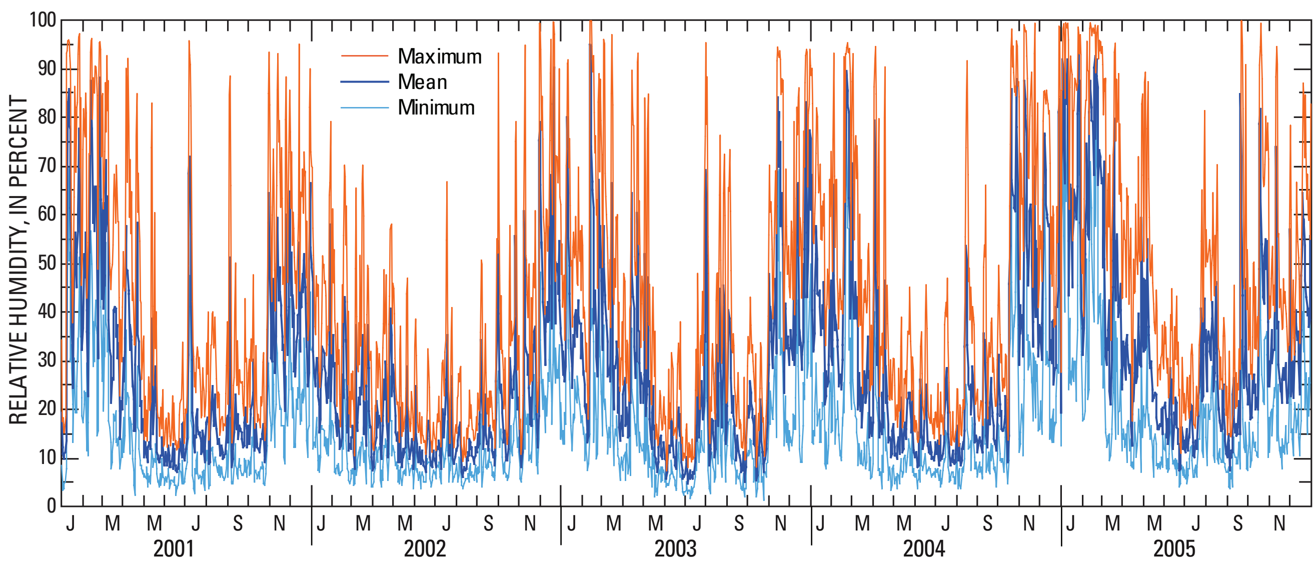

Figure 7. Daily maximum, minimum, and mean relative humidity computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Saturated and Ambient Vapor Pressure

Daily mean vapor pressures computed from hourly averaged values are shown in figure 8. Complete daily and hourly vapor pressure data are in appendixes A–F. Ambient vapor pressure is the partial pressure exerted by water vapor present in the air and indicates the water-vapor content of the air under prevailing atmospheric conditions. The ambient vapor pressure is the product of the saturated vapor pressure and the relative humidity. Saturated vapor pressure is the highest concentration of water vapor that can exist in equilibrium over a free-water surface at that temperature. The data logger calculates the saturated vapor pressure in kilopascals from measured air temperature using an algorithm from Lowe (1977).

The mean saturated vapor pressures are higher during the summer months and lower during winter months (fig. 8) because warm air can potentially hold considerably more water vapor than cold air. For this reason, the summer rain events cause generally somewhat higher ambient vapor pressures than the larger winter precipitation. Figure 8 generally shows these higher ambient vapor pressures predominantly during the summer months. However, the mean ambient vapor pressure during the months of June through August average only about 0.15 kPa more than the mean ambient vapor pressure during the months of December through February, or about 0.60 kPa and 0.45 kPa, respectfully. Daily variations in ambient maximum and minimum vapor pressure from the mean vapor pressure typically are less than 0.15 kPa. During 2001–05, ambient-vapor pressures averaged about 0.5 kPa with daily means ranging from 0.08 to 2.1 kPa, while saturated-vapor pressures averaged 2.6 kPa with daily means ranging from 0.6 to 6.5 kPa. This large difference between saturated and ambient vapor pressure is an indication of the large water deficit that exists in this desert environment.

Wind Speed and Direction

Daily mean wind speeds are shown in figure 9. Complete daily and hourly wind speed data are in appendixes A–F. Annual mean wind speed computed from daily mean wind speeds for the 5 years of record (2001–05) was 2.8, 2.9, 2.8, 3.0, and 2.7 m/s, respectively. During these 5 years, the mean wind speed was 2.8 m/s, and the maximum daily mean wind speed was 8.8 m/s on February 2, 2003 (fig. 9). The maximum hourly mean wind speed was 13.0 m/s and occurred on February 2, 2003. The distribution of hourly mean wind speed for the 5-year monitoring period is shown in figure 10. For example, 4 percent of the time the wind speed was below 1.0 m/s, and about 80 percent of the time the wind speed was less than 4.0 m/s. Winds of less than the anemometer threshold of 0.28 m/s are set to zero by the field recorder to indicate they are not measurable. Hourly mean wind speeds of less than 0.28 m/s occurred less than 0.6 percent of the time during the 5 years of record, as shown in figure 10. However, most days had at least one 10-second sampling interval with wind speeds below the instrument threshold giving most days a daily minimum based on a 10-second sampling interval of 0.0 m/s.

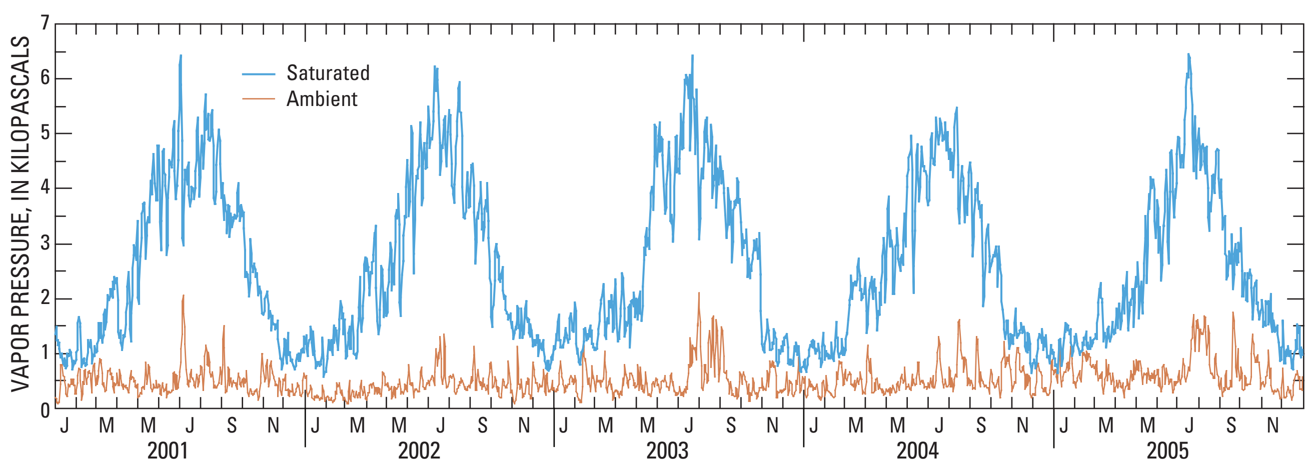

Figure 8. Daily mean saturated and ambient vapor pressure from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

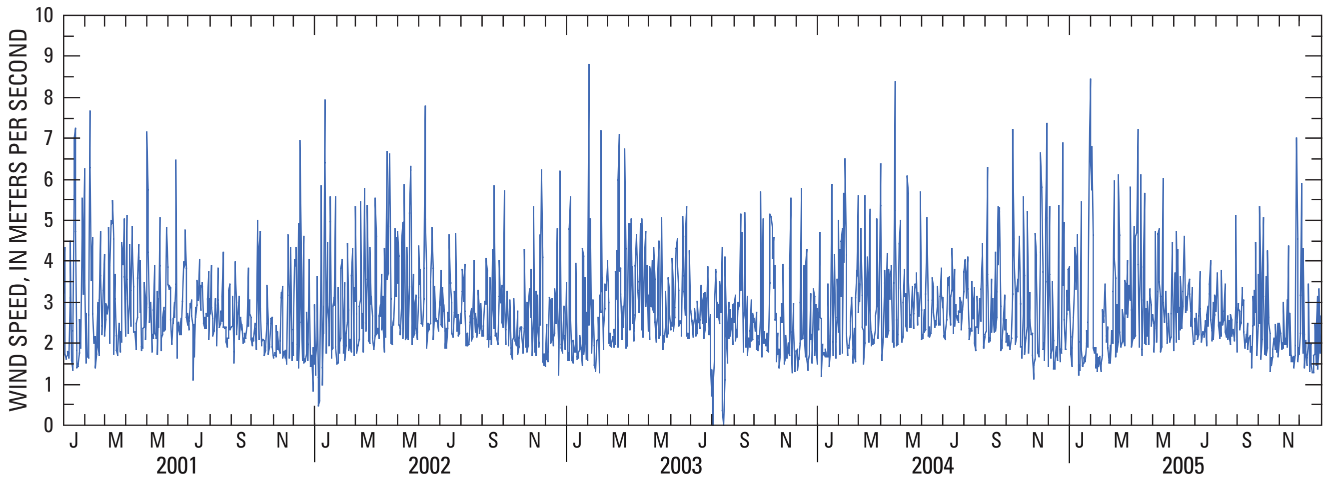

Figure 9. Daily mean wind speed computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

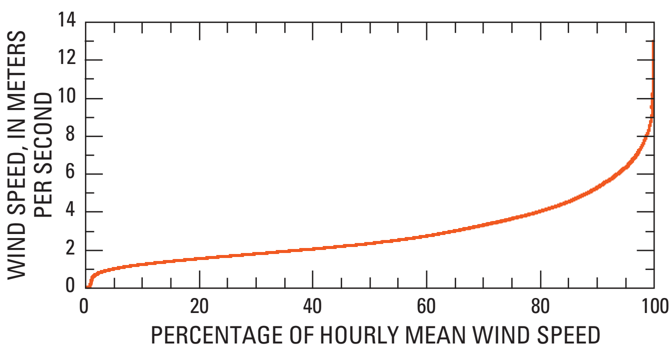

Figure 10. Distribution of hourly mean wind speed as a percentage of all hourly mean values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Daily and hourly mean wind-vector directions in degrees Azimuth of true north with standard deviation are listed in appendixes A–F. Mean horizontal wind-vector direction was calculated by vectorially summing the individual wind vectors consisting of wind magnitude and direction using available data logger commands. The daily mean wind-vector directions are shown in figure 11. Daily wind directions indicate seasonal variability and annual recurrent patterns for 2001–05. Wind at the ADRS predominantly was from the northwest from September through February, and generally associated with regional frontal systems moving in from the west coast during the autumn and winter seasons. Winds from March to September are more evenly distributed from the northwest, southwest, and southeast. The ill-defined summer to autumn winds have at times been observed (D.I. Stannard, U.S. Geological Survey, oral commun., 2006) to be strongly katabatic, blowing up the valley during the day and down the valley at night. Southwest and southeast winds typically are associated with the counter-clockwise rotation of subtropical lows moving inland from the west coast of Mexico or southern California.

Barometric Pressure

Daily mean barometric pressure and hourly mean barometric pressure data are listed in appendixes A–F. Barometric pressures at the ADRS facility are corrected to sea level using an altitude of 847.2 m. Daily mean barometric-pressure values from hourly averaged values are shown in figure 12. The mean barometric pressure for 2001–05 was about 101.5 kPa. Higher pressures generally occurred during clear winter days and lower pressures occurred during storm periods and summer. An hourly reading of 103.77 kPa occurred on February 10, 2002, and an hourly reading of 99.48 kPa occurred on April 15, 2002.

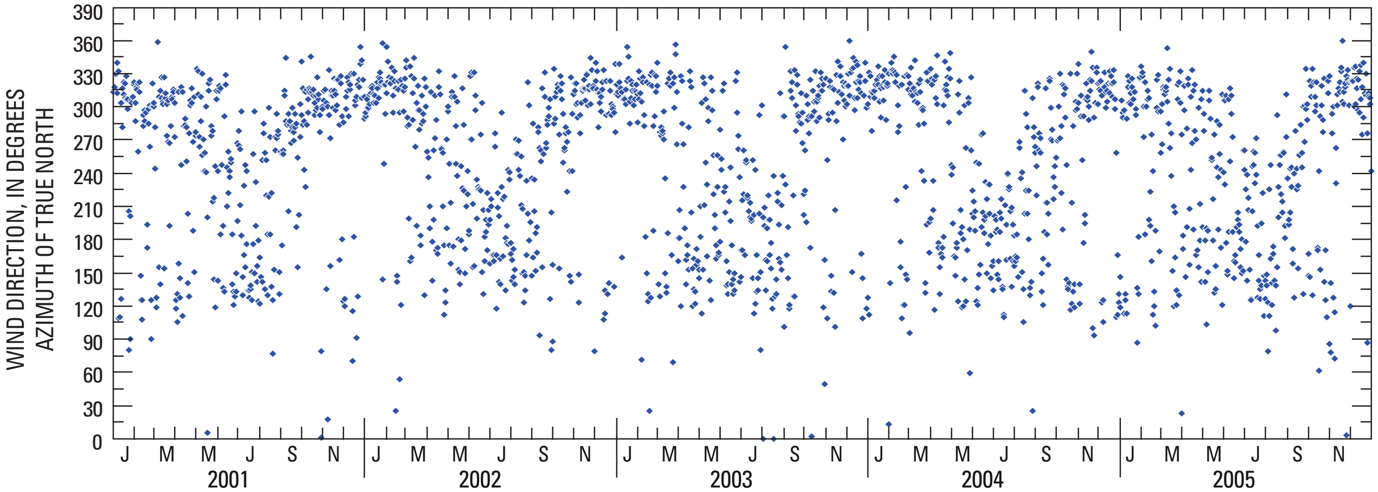

Figure 11. Daily mean wind-vector direction in degrees Azimuth of true north at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

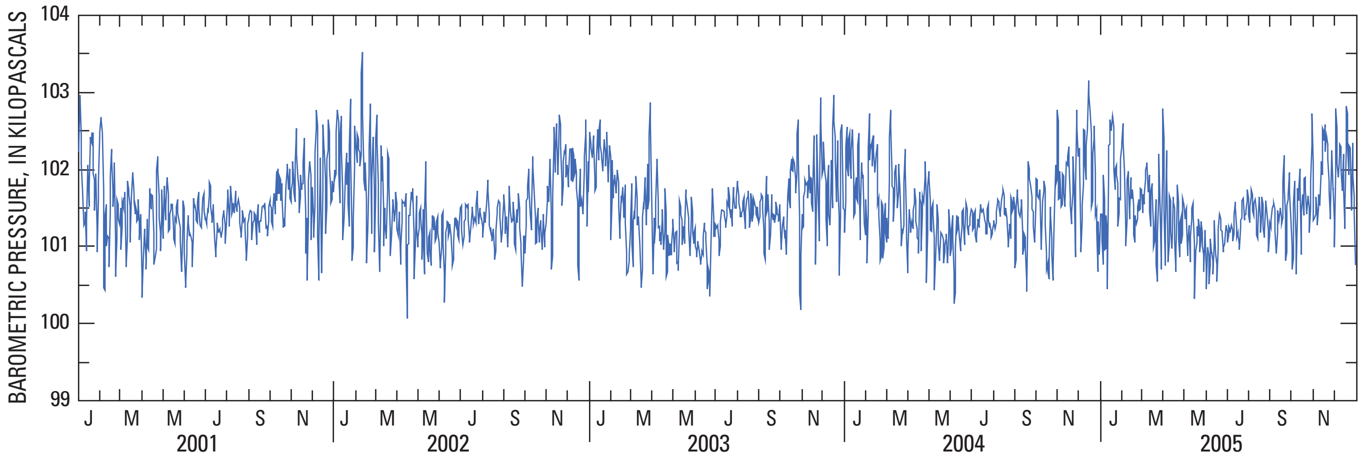

Figure 12. Daily mean barometric pressure from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Precipitation

Daily total precipitation is summarized in table 2 (from appendix A), and monthly total precipitation is shown in figure 13. Hourly precipitation is listed in appendixes B–F. During the times that the tipping-bucket precipitation gage malfunctioned, precipitation volumes from the waste-facility precipitation gage adjacent to ADRS were used. These substituted volumes for individual storm events were accurately measured and only the time distribution was estimated for one to several days. The procedure for estimating daily precipitation followed technical guidelines established by the U.S. Geological Survey[1].

[1] Collection, Quality Assurance, and Presentation of Precipitation Data: U.S. Geological Survey, Office of Surface Water Technical Memorandum, No. 2006.01, December 28, 2005, 29 p.

Total annual precipitation averaged 130.3 mm for the 5 years of record (2001–05) with measured totals of 164.8 mm in 2001, 3.5 mm in 2002, 131.8 mm in 2003, 173.6 mm in 2004, and 177.7 mm in 2005 (table 2). Based on a combination of waste-facility and ADRS precipitation records for 25 years (1981–2005), the long-term average annual precipitation was 112 mm at ADRS. Annual precipitation for the previous 20 years of record (1981–2000) averaged 108 mm (Johnson and others, 2002). Precipitation during the 5 years of record (2001–05) was about 147, 3, 117, 115, and 158 percent, respectively, of the 25-year long-term average. The low annual precipitation in 2002 was associated with a La Niña event which occurred along the eastern Pacific Ocean during that year. Winter frontal systems typically account for 70 percent of ADRS precipitation (Andraski and Stonestrom, 1999, p. 459), whereas summer storms typically account for 30 percent of precipitation. In the Amargosa Desert, the predominant winter precipitation comes from regional winter frontal systems moving in from the west coast.

Table 2. Daily total precipitation at Armagosa Desert Research Site near Beatty, Nevada, 2001–05.

[Values are in millimeters. No precipitation was recorded on unlisted dates]

Date	Julian day	Daily total precipitation
2001		
01-08	8	7.62
01-10	10	1.38
01-11	11	15.13
01-26	26	8.33
01-27	27	2.08
02-12	43	14.00
02-13	44	6.32
02-25	56	9.12
02-26	57	8.15
03-06	65	7.87
04-05	95	8.57
04-07	97	0.57
04-11	101	1.27
04-21	111	6.60
05-12	132	0.25
07-06	187	32.90
07-07	188	2.66
09-03	246	18.03
10-30	303	1.02
11-12	316	5.16
11-13	317	1.19
11-24	328	2.29
12-14	348	4.32
Annual total precipitation		164.8
2002		
01-27	27	0.76
06-02	153	0.25
07-17	198	0.76
10-01	274	1.02
11-30	334	0.25
12-20	354	0.51
Annual total precipitation		3.5
2003		
02-12	43	17.27
02-24	55	0.51
02-27	58	0.76
03-15	74	4.57
2003—Continued		
04-14	104	14.73
04-22	112	1.27
05-07	127	1.52
07-28	209	1.67
07-30	211	6.03
07-31	212	14.40
08-19	231	11.18
08-21	233	7.62
08-26	238	7.62
09-02	245	5.39
09-05	248	0.45
11-12	316	12.70
11-15	319	2.79
11-16	320	8.38
12-11	345	2.03
12-25	359	10.92
Annual total precipitation		131.8
2004		
02-03	34	8.26
02-18	49	3.81
02-22	53	22.44
02-23	54	1.18
02-25	56	8.98
02-26	57	3.36
02-27	58	1.12
03-01	61	1.42
03-02	62	5.69
04-02	93	0.39
04-03	94	9.27
04-17	108	0.51
08-13	226	0.42
08-14	227	3.39
10-19	293	16.81
10-20	294	10.87
10-27	301	15.49
11-07	312	19.91
11-08	313	2.95
11-20	325	0.25
12-28	363	22.02
12-29	364	14.05
12-31	366	1.01
Annual total precipitation		173.6
2005		
01-03	3	20.43
01-04	4	4.21
01-07	7	4.57
01-08	8	1.34
01-09	9	3.34
01-10	10	1.00
01-11	11	0.67
01-25	25	1.52
01-26	26	13.80
01-27	27	2.21
01-28	28	2.40
01-29	29	0.40
02-11	42	9.06
02-12	43	0.85
02-18	49	7.64
02-19	50	2.41
02-20	51	0.20
02-21	52	13.53
02-22	53	11.05
02-23	54	11.05
02-24	55	0.51
02-26	57	1.01
03-04	63	2.79
03-22	81	1.02
03-28	87	0.25
04-28	118	2.29
05-02	122	1.27
05-06	126	0.25
07-28	209	5.33
08-04	216	3.27
08-14	226	0.56
08-15	227	1.11
08-16	228	6.96
09-20	263	31.24
10-17	290	3.30
11-10	314	4.06
11-11	315	0.76
Annual total precipitation		177.7

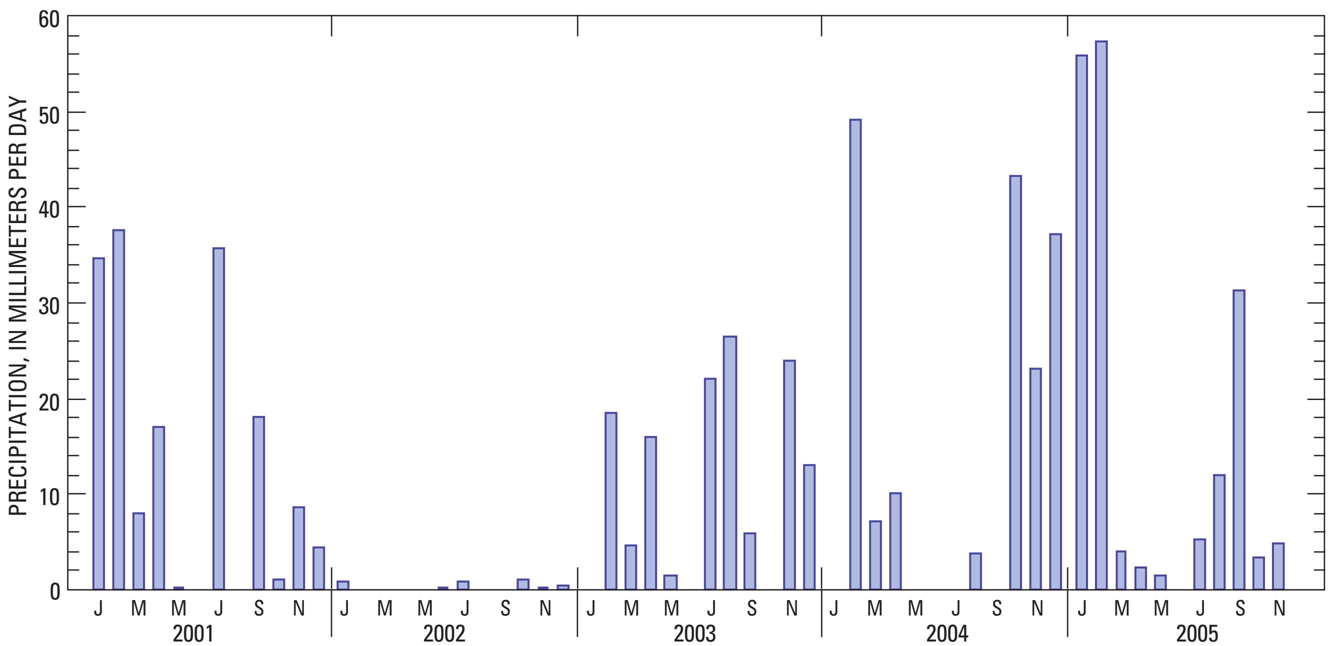

Figure 13. Monthly total precipitation computed from accumulated daily totals at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

However, in this desert environment, precipitation is scant and unpredictable because of the rain shadow effect of the Sierra Nevada Mountains, which similarly shadow Death Valley west of the Amargosa Desert. Summer precipitation, mainly from localized convective storms, is even more uncertain within different locations of the Amargosa Desert. Summer storms are dependent on water vapor transported into the area by southwesterly winds, which bring water vapor primarily from subtropical low-pressure systems from off the west coast of either Mexico or Southern California. Previous comparisons between the ADRS weather station and two National Oceanic and Atmospheric Administration (NOAA) sites (Wood and Andraski, 1995, p. 15) indicate monthly values also differ considerably between sites within the Amargosa Desert.

Monthly total precipitation is highly variable from year to year for a given month, and from month to month in a given year as shown in figure 13. For example, significant precipitation fell during January 2001 and 2005, but not during intervening Januarys. Other months also show monthly variability. In 2002, precipitation was minimal for the 12-month period, defining the driest year for the 25-years of record at the ADRS, although the other 4 years were wetter than normal and increased the long-term average annual precipitation.

Near-Surface Soil Temperature, Soil-Heat Flux, and Soil-Water Content

Daily and hourly mean values of near-surface soil temperature and soil-heat flux are listed in appendixes A–F. Daily mean soil temperatures and soil-heat-flux values are shown in figures 14 and 15, respectively. The averaging soil-thermocouple probe measures the temperature in soil between the soil surface and the 8-cm depth. The soil-heat-flux plates measure thermal energy that enters or leaves the soil. As the thermal energy enters the soil and moves downward, the soil-heat flux is defined as positive, and as the thermal energy leaves the soil the soil-heat flux is defined as negative. The mean soil temperature for 5 years of record (2001–05) was 21.4°C. Daily mean soil temperatures ranged from 42.9°C on July 23, 2003, to -0.4°C on January 4, 2004 (fig. 14). The mean values of soil-heat flux for the 5 years of record were 1.3 W/m^2. Daily mean soil-heat flux ranged from 16.0 W/m^2 on July 10, 2001, to -19.0 W/m^2 on October 21, 2004 (fig. 15).

Daily and hourly mean values of near-surface soil-water content are listed in appendixes A–F. Daily mean values of soil-water content are shown in figure 16. The mean soil-water content for 5 years of record (2001-05) was 0.05 m^3/m^3 (5 percent). The near-surface soil-water content ranged from a low daily mean of less than 0.016 m^3/m^3 (1.6 percent) during June, July, and August 2002 to a high of about 0.31 m^3/m^3 (31 percent) on January 4, 2005 (fig. 16). Spikes in the soil-water content shown in figure 16 are indications of rain events occurring at the research site (fig. 13).

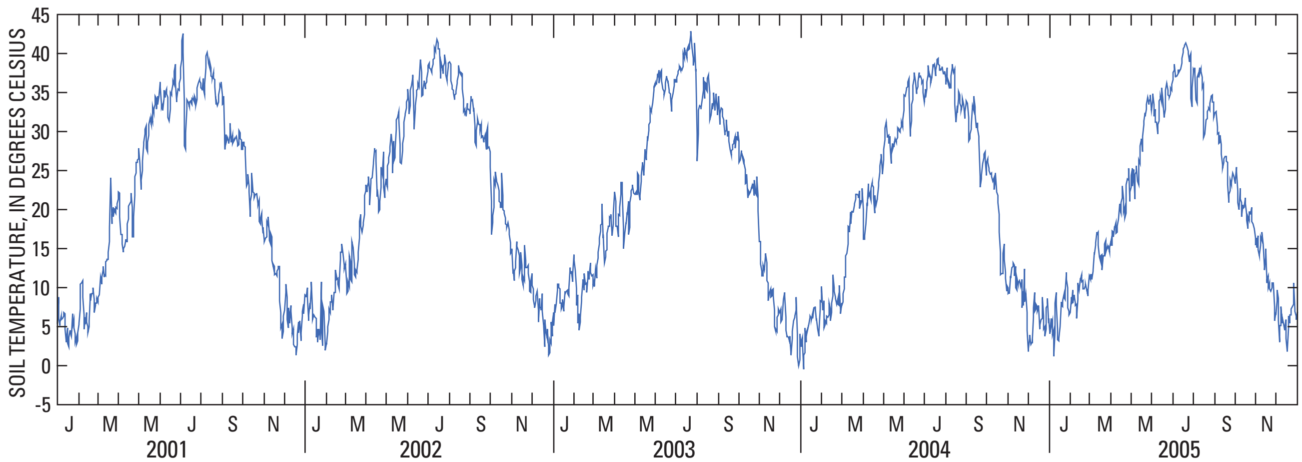

Figure 14. Daily mean soil temperature computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

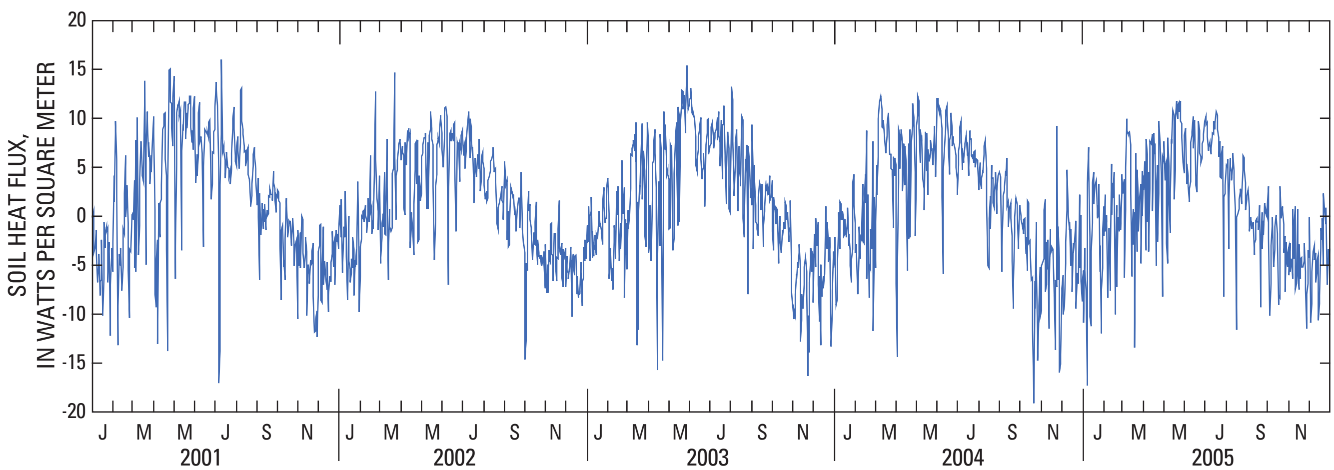

Figure 15. Daily mean soil-heat flux computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

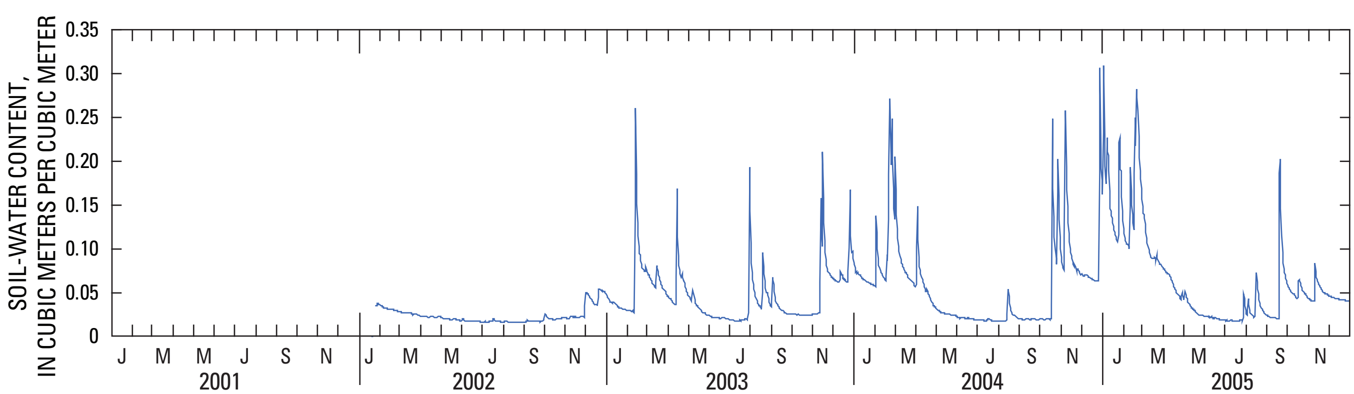

Figure 16. Daily mean soil-water content in upper 0.08 meters of soil computed from hourly averaged values at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

When power availability is low, the soil-moisture probe does not operate and data loss occurs. The soil-moisture probe requires higher levels of power than the other sensors used at the weather station. Hourly averaged soil-water content values were obtained only during daytime when solar energy met power requirements (appendix B and start of appendix C). High resistance wiring and the solar panel were replaced on January 17, 2002. The new equipment enabled the batteries to meet the soil-moisture probe power requirements and continued soil-water content monitoring.

Selected Soil-Moisture Data At Depth

At depth, soil-water content under natural-site and simulated waste-site conditions was monitored at four experimental sites: one vegetated, native soil profile; one devegetated, native soil profile; and two non-vegetated, simulated waste trenches with disturbed soil used as backfill (figs. 2 and 3). The simulated waste trenches have 208-L soil-filled drums buried at depths from 1.5 to 2.5 m and 3.5 to 4.5 m; soil-water content is not determined for these depths because of the influence of simulated waste on neutron-probe readings. Soil-water content is reported in volumetric units of cubic meter per cubic meter (volumetric water content).

Complete soil-water content data and the associated calibration equations are available in appendixes G–H. Volumetric water-content data by date and depth for each of the four experimental sites are listed in appendix G, and volumetric water-content data by date and depth for each individual neutron-probe access tube located at the experimental sites are listed in appendix H.

Volumetric Water-Content Profiles

Variations in volumetric water content with depth were measured periodically at ADRS to define moisture levels at the different depths within the sedimentary geology and to identify temporal changes in the profile. The deepest access tube (VS2, fig. 2) at ADRS measures a vegetated native-soil profile to a depth of 29.75 m. Figure 17 shows selected water content profiles obtained during the 5-year data collection period at the vegetated, native soil profile. Within the upper 1 m of the soil profile, water content ranged from a low of about 0.02 m^3/m^3 to a high of about 0.12 m^3/m^3 as shown by profiles of August 4, 2004, and January 25, 2005, respectively. For the 5-year data set (appendix G), the average volumetric water content within the upper 1 m of soil at the vegetative native-soil profile averaged about 0.05 m^3/m^3. The devegetated native-soil profile and the two non-vegetated simulated waste trench sites averaged about 0.07 m^3/m^3 within the upper 1 m of soil. The difference in average volumetric water content between the vegetated site and the three sites without

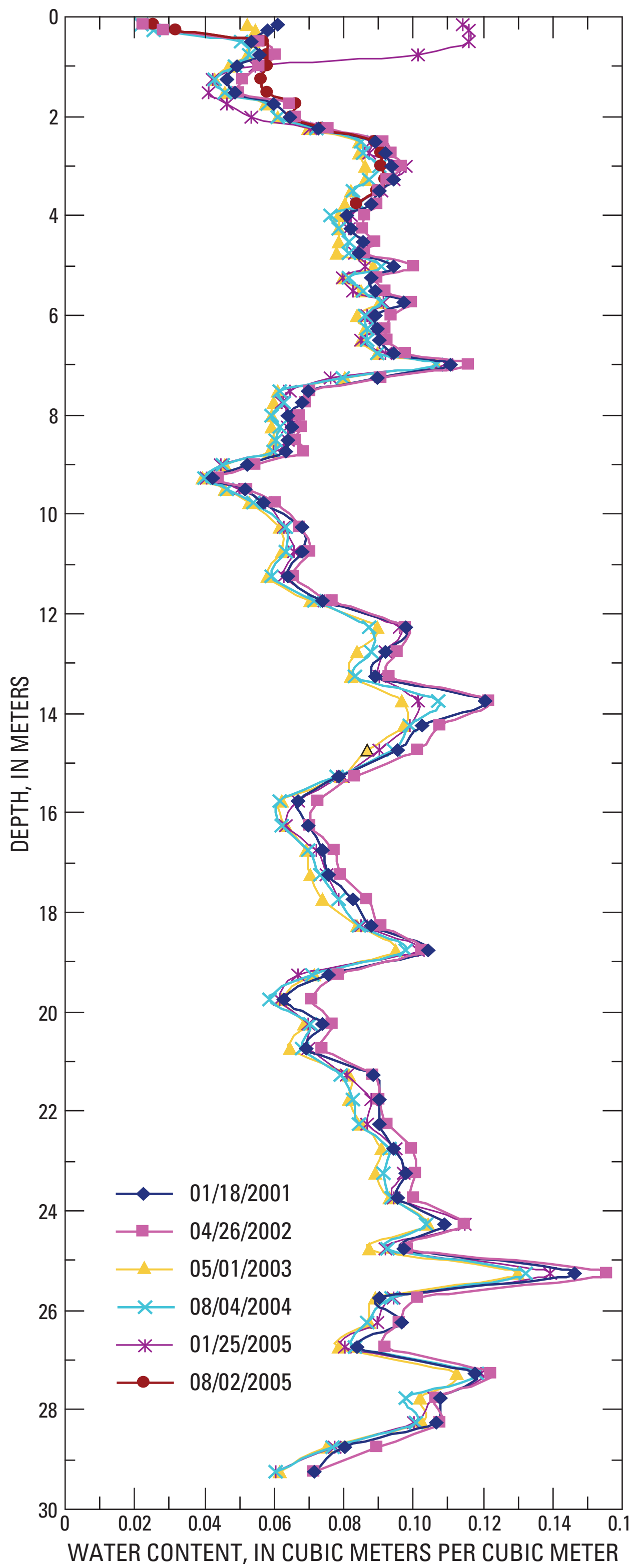

Figure 17. Water content variations to 30 meters below land surface for selected dates for the vegetated, native soil profile at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

vegetation is attributed primarily to loss of root-zone soil-moisture by plant transpiration. The highest water content in the vegetated native-soil profile averaged about 0.14 m^3/m^3 at a depth of 25.25 m. At depth, moisture retention appears to be primarily a function of grain size within the varying basin fill. Clay lenses in sediments tend to have higher water content, whereas gravel layers have lower water content.

Figure 17 shows that temporal changes in soil moisture with depth are limited to the upper profile, generally in the upper 1 m, whereas below several meters the variation with depth reflects changes in lithology that does not appreciably change in time. Below several meters the profiles in figure 17 show profile changes of less than 0.02 m^3/m^3 at any given depth, and these changes are within the measurement error estimated at 0.017 m^3/m^3 based on calibration uncertainties (Andraski, 1997). In the upper 1 m of the soil profile, substantial moisture is derived from local rain events. Variations in soil moisture in the upper 1 m can be accounted for by the downward redistribution of water from precipitation, which infiltrates the soils after a storm event and by increased soil-water discharge by ET.

Figure 18 shows in more detail the temporal variations in soil moisture within the upper 5.5 m for each of the four experimental sites from May 2004 through August 2005. Figure 19 compares the water content between the four experimental sites at selected depths over time (2001–05).

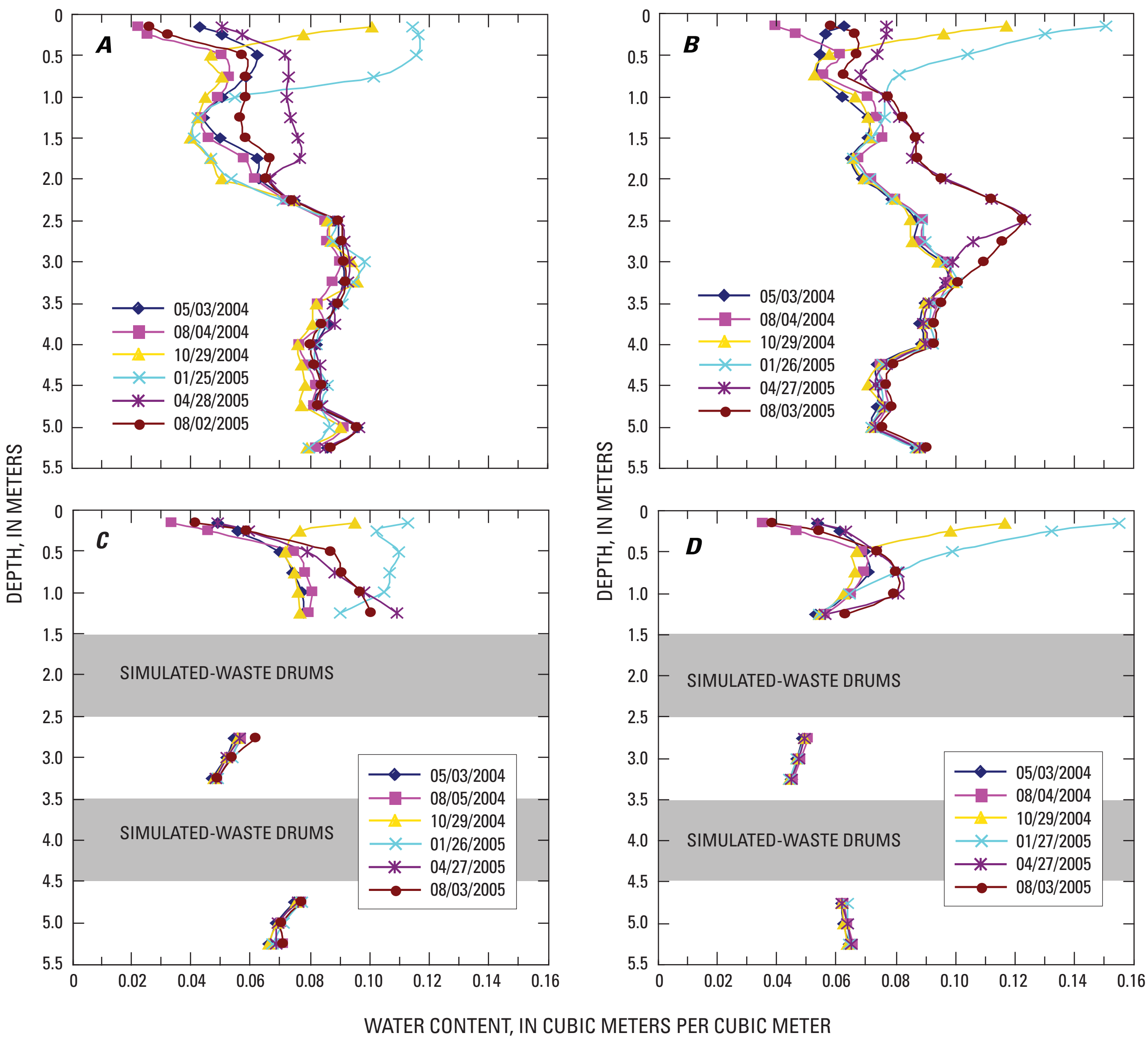

Figure 18. Water content variations with depth in upper 5.5 meters of soil for selected dates at four experimental sites: (*A*) vegetated, native soil profile; (*B*) devegetated, native soil profile; (*C*) non-vegetated east trench; and (*D*) non-vegetated west trench at Amargosa Desert Research Site near Beatty, Nevada, May 2004 to August 2005.

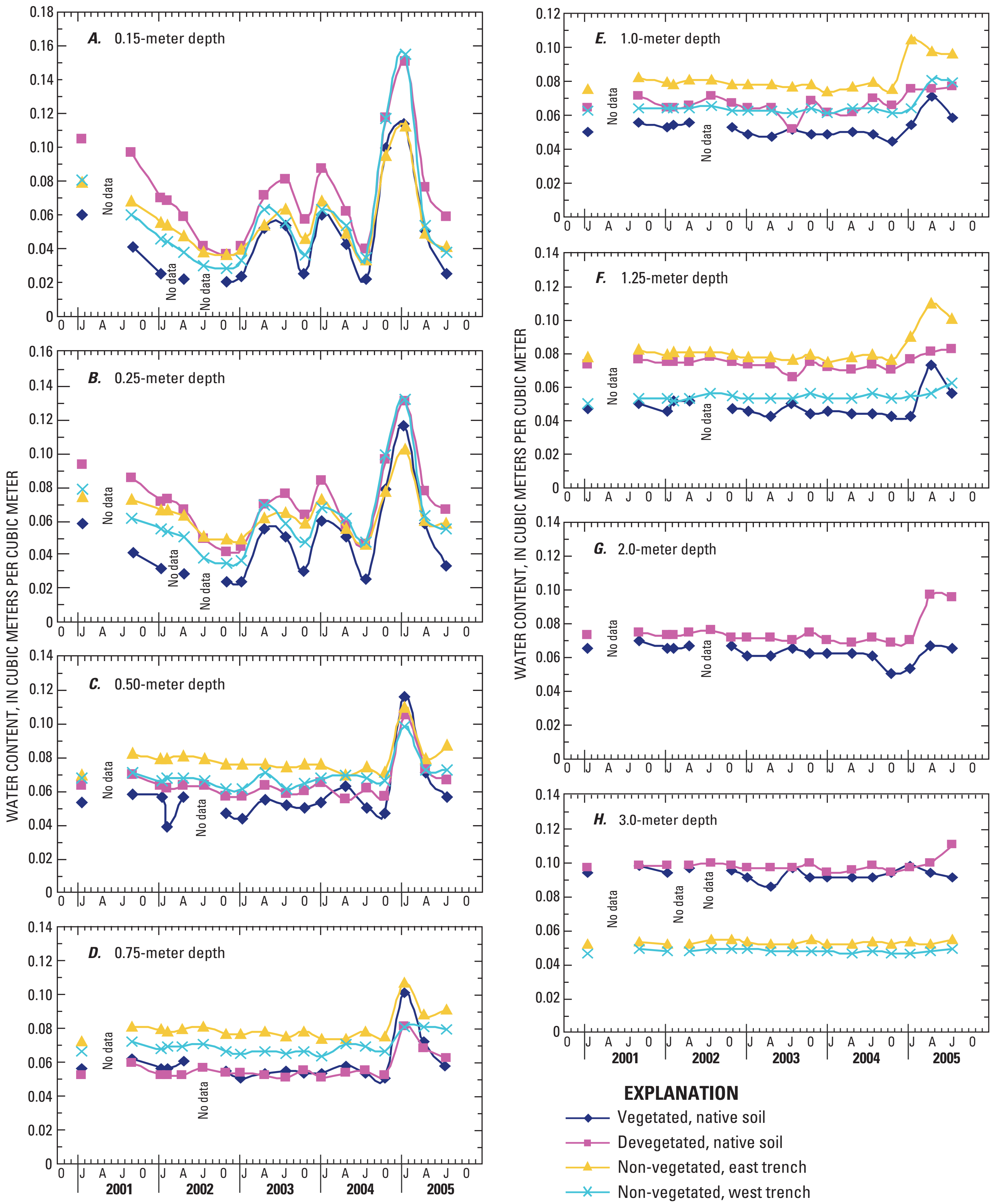

Figure 19. Cumulative changes in water content with time for selected depth at four experimental sites: (*A*) 0.15 –meter depth; (*B*) 0.25-meter depth; (*C*) 0.5-meter depth; (*D*) 0.75-meter depth; (*E*) 1.0-meter depth; (*F*) 1.25-meter depth; (*G*) 2.00-meter depth; and (*H*) 3.0-meter depth at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Significant rain events occurred during the 5 months from October 2004 through February 2005 that totaled about 217 mm of precipitation (fig. 13). These rain events are first indicated by the October 2004 profile in figure 18. All four experimental sites show measurable temporal variations in soil-water content in response to precipitation recharge in the upper 1.25 m of the soil profile. The August 2005 profile indicates that water from winter precipitation reached a depth of 2.75 m at the devegetated, native soil site (fig. 18*B*), although for the same profile at the vegetated native-soil site (fig. 18*A*), winter precipitation penetrated the soil to a depth of 1.75 m. Below these depths, downward movement of water from precipitation cannot be substantiated given that profile differences are equal to or less than the inherent uncertainty of the soil moisture measurements. The change in water content profiles from August 2004 to August 2005 at the devegetated native-soil site (fig. 18*B*) graphically illustrates the maximum recorded downward redistribution of soil moisture at the four experimental sites. This is the deepest documented temporal variation in soil-water content at the ADRS since soil moisture research began in 1983.

Selected Evapotranspiration Data

ET data sets are available in appendixes I–M. Daily ET measurements are listed in appendix I. Appendixes J–M list the four principal energy budget components of latent-heat flux, sensible-heat flux, soil-heat flux, and net radiation during 15-minute intervals for 2002–05. Other field data, including air temperature, air-vapor pressure, soil-heat flux at individual flux plates, and soil-temperature and soil-water content above the flux plates, were collected and used to derive variable coefficients used in the calculations (appendixes J-M).

Daily Evapotranspiration and Energy Fluxes

Daily total ET is summarized in appendix I and is shown graphically in figure 20 for 2002–05. ET data collection started on February 13, 2002. Total recorded ET was 48 mm (based on 321 days) for 2002, 148 mm for 2003, 198 mm for 2004, and 233 mm for 2005 (appendix I). ET totals for each year in this desert environment are highly variable and dependent on available moisture primarily from precipitation and precipitation-derived water stored in the upper soil profile. A much smaller component of ET is supplied by water moving upward through the deep unsaturated zone to the land surface. ET totals also can include the net effect of daily recycling of atmospheric moisture and surface dew. In addition, moisture from localized convective storms can be advectively transported by katabatic winds over the ADRS. Thus, measured ET will include moisture inputs that are not limited to just precipitation measured at the site.

ET in 2002 (fig. 20) is limited throughout the year by a lack of precipitation (fig. 13). In figure 20, daily ET spikes after a rainstorm and gradually decreases until the next rain event. Elevated ET right after a storm is derived from evaporation of surface and near-surface soil moisture that supplements the increased plant transpiration. This high rate of evaporation can last for one to several days depending on the amount of precipitation. Depending on the duration and intensity of the rain event, deeper soil-moisture percolation may occur and maintain the decreasing daily ET curve for longer periods. This more sustained daily ET is attributed primarily to loss of root-zone soil-moisture by plant transpiration.

During 2002, available soil moisture sustained daily ET of less than 0.2 mm/d during summer when there is maximum energy available for ET. In late autumn 2002, with less energy available, daily ET was estimated at less than 0.05 mm/d indicating a lower base discharge, though these values are within the measurement error. In contrast to 2002 (fig. 20), with an average daily ET of 0.15 mm/d for the period of record, ET in 2003–05 (figs. 20) averaged about 0.5 mm/d. During 2003–05, ET increased substantially due to increased precipitation at the site or in the basin near the site that introduced moisture directly or through advection. Because 2002 was an extremely low precipitation year with maximum depletion of the upper several meters of soil moisture, data from 2003 can provide a comparison of measured ET to precipitation from a water budget perspective. Average daily ET for 3 years of record (2003–05) exceeded the available precipitation measured at the site by 0.086 mm/d. On an annual basis, ET during those three years averaged about 193 mm exceeding average precipitation of 161 mm by about 32 mm. ET uncertainty, (conservatively) estimated to be about 0.05 mm/d, or on an annual basis about 18 mm, would not account for all the excess water. This excess water between ET and measured precipitation needs to be attributed to some combination of long-term, upward-moving soil moisture from depth, additional ET from advection of precipitation moisture near the site but not recorded by the precipitation gage, and measurement uncertainties.

Figures 21*A* and *B* show the change in energy budget fluxes before and after a rain event of 22.1 mm, which occurred at the end of July 2003. The results of those changes on the daily ET (fig. 20) are shown for three days before (July 25–27) and the three days after (August 1–3) the rain event of July 28–31. Prior to the rain event, there was a fairly stable but low latent-heat flux with most available energy being used as sensible-heat flux (fig. 21). Latent-heat flux is the energy used to drive the ET process and the sensible-heat flux is the energy used to heat the air. Both the latent-heat flux and the sensible-heat flux partition the total available energy (net radiation at the surface of the earth less energy used to heat the soil).

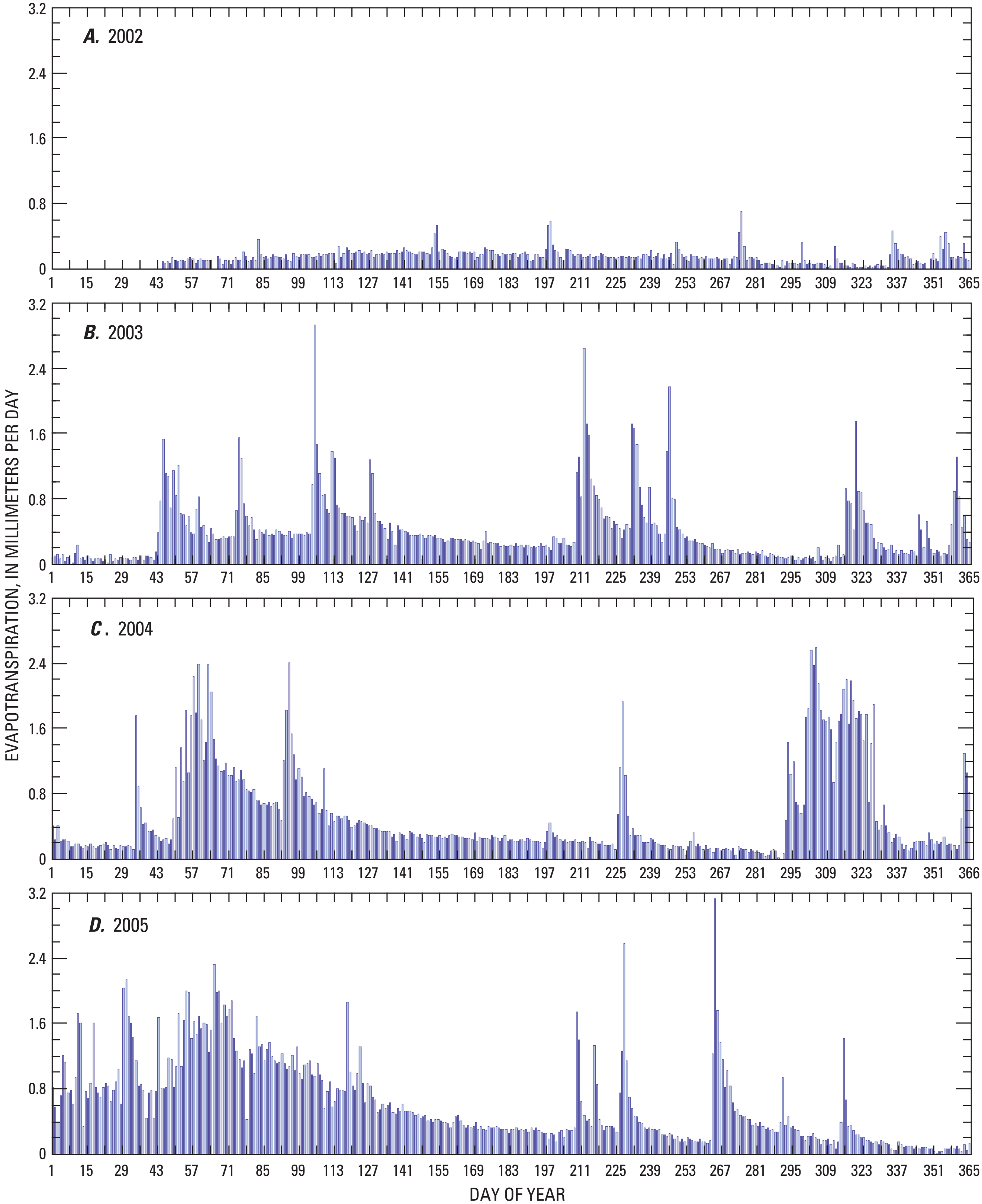

Figure 20. Daily evapotranspiration at the Amargosa Desert Research Site near Beatty, Nevada, 2002–05.

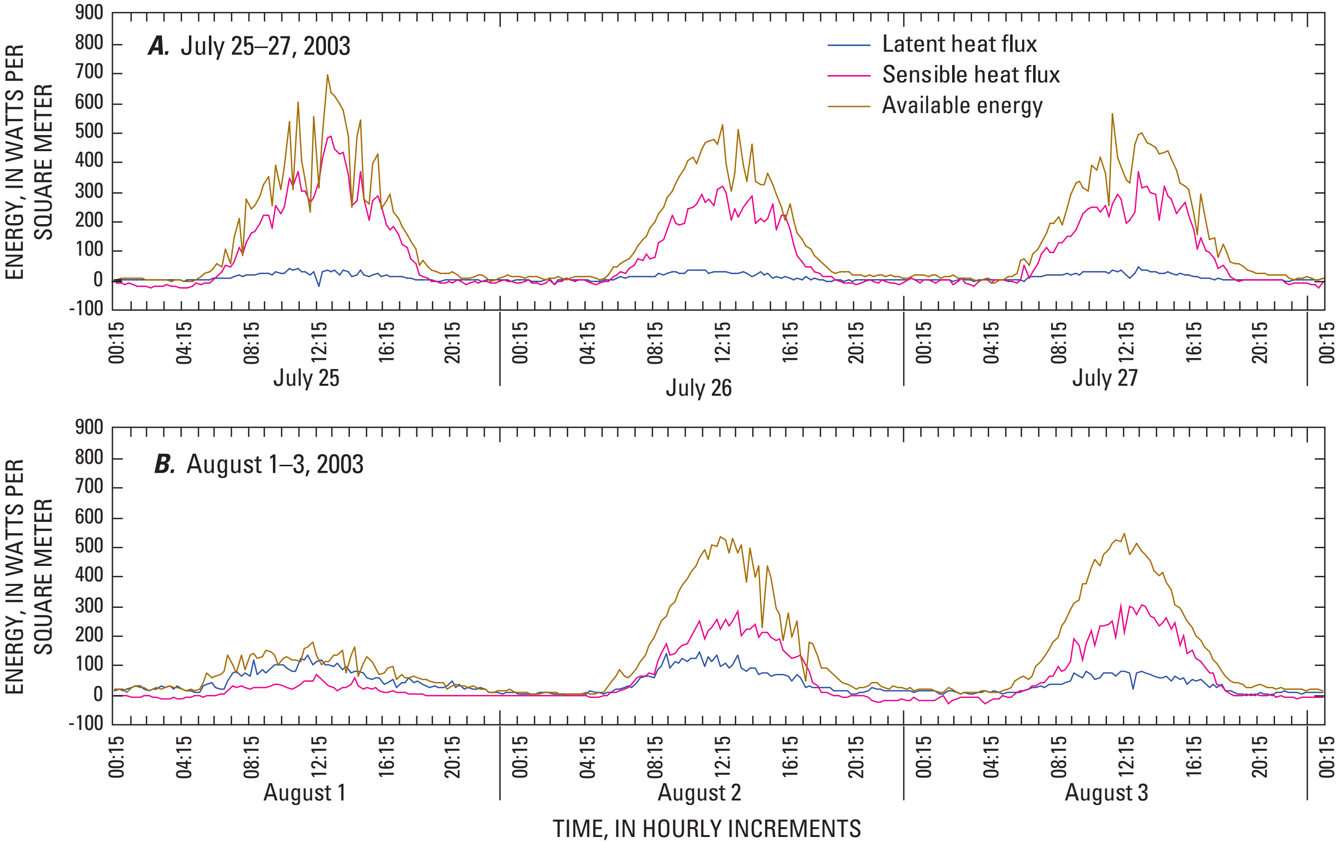

Figure 21. Energy fluxes 3 days before and after a rain event during July 28-31, 2003, at Amargosa Desert Research Site near Beatty, Nevada, 2003.

With little soil moisture for plant transpiration or soil evaporation, the energy used for sensible-heat flux would nearly equal the available energy. Conversely, with sufficient moisture the energy used for latent-heat flux would dominate. As shown in figure 21, under dry desert conditions (July 25-27), the latent-heat flux during mid-day is about 20 to 30 W/m^2, which is less than one-twelfth the sensible-heat flux, generating about 0.2 mm of daily ET (fig. 20). After the rain event, the latent-heat flux on August 1 dominates the sensible-heat flux on a cloudy day with limited available energy (fig. 21*B*). During the 3 days after the rain event (and for many days after), latent-heat flux levels were above pre-rain levels. During the 3 days, mid-day latent-heat flux decreased from about 130 to 80 W/m^2 and daily ET decreased from 1.7 to 1.0 mm as shown in figure 20 (for days 213, 214, and 215). The highest daily ET of about 2.6 mm (fig. 20) occurred during the last day of the rain event ending on calendar day 212 (July 31). During this day, rain ended at 1000 hours followed by clear skies with mid-day latent-heat flux energy exceeding 400 W/m^2, sensible-heat flux less than 130 W/m^2, and wet surfaces evaporating water and drying.

Summary

Micrometeorological and soil-moisture data were collected at the Amargosa Desert Research Site facility adjacent to a low-level radioactive and hazardous-chemical waste facility near Beatty, Nevada, 2001–05. Evapotranspiration (ET) data were collected from February 14, 2002, through December 31, 2005. Data were collected in support of ongoing research to improve the understanding of hydrologic and contaminant-transport processes in arid environments.

Micrometeorological data include solar radiation, net radiation, air temperature, relative humidity, saturated and ambient vapor pressure, wind speed and direction, barometric pressure, precipitation, and near-surface soil temperature, soil-heat flux, and soil-water content. All micrometeorological data were collected using a 10-second sampling interval by data loggers that output daily and hourly mean values. Daily maximum and minimum values are based on hourly mean values. Precipitation data output included daily and hourly totals. Selected soil-moisture profiles at depth include periodic measurements of soil volumetric water-content measurements at nine neutron-probe access tubes to depths ranging from 5.25 to 29.25 m. ET data include measurements of daily ET and 15-minute fluxes of the four principal energy budget components of latent-heat flux, sensible-heat flux, soil-heat flux, and net radiation. Time-series data are plotted to illustrate temporal variations in micrometeorological, soil-water content, and ET data.

Total annual precipitation for 2001–05 averaged 130.3 mm with measured totals of 164.8 mm in 2001, 3.5 mm in 2002, 131.8 mm in 2003, 173.6 mm in 2004, and 177.7 mm in 2005. The 25-year (1981–2005) long-term average annual precipitation averaged 112 mm at the ADRS. The low annual precipitation in 2002 was associated with a La Niña event along the eastern Pacific Ocean. After significant winter rains that totaled 217 mm from October 2004 through February 2005, changes in soil moisture were recorded in early August 2005 to a depth of at least 2.75 m at the devegetated native-soil site and 1.25 m at the vegetated native-soil site. This is the deepest downward percolation of soil moisture documented at ADRS since investigations began in 1983. Recorded annual ET was 48 mm (based on 321 days) for 2002, 148 mm for 2003, 198 mm for 2004, and 233 mm for 2005.

ET consumes available moisture from plants and soil, and depends on precipitation to replace depleted soil moisture in this desert environment. During drought conditions, with maximum available energy during the summer months of 2002, daily ET typically was less than 0.2 mm/d. With less energy available during drought conditions in late autumn 2002, daily ET was estimated at less than 0.05 mm/d indicating a lower base discharge, although these values are within the measurement error. In contrast to 2002 (fig. 20), with an average daily ET of 0.15 mm/d for the period of record, ET in 2003–05 averaged about 0.5 mm/d. With precipitation to infiltrate soils, daily ET abruptly increased to as much as several millimeters per day and quickly decreased over several days or weeks, but maintained higher base levels of water discharge for extended periods after a storm event. Annual ET during 2003–05 exceeded precipitation measured at the site. ET in excess of precipitation may be attributed to some combination of long-term upward-moving soil moisture from depth, additional moisture inputs from dew formation and advection of unrecorded precipitation-derived moisture near the site, and measurement uncertainties.

References Cited

Andraski, B.J., 1990, Water movement and trench stability at a simulated arid burial site for low-level radioactive waste near Beatty, Nevada: La Grange Park, Ill., American Nuclear Society, Nuclear Waste Isolation in the Unsaturated Zone, Las Vegas, Nev., September 1989, Proceedings, p. 166–173.

Andraski, B.J., 1996, Properties and variability of soil and trench fill at an arid waste-burial site: Soil Science Society of America Journal, v. 60, p. 54–66.

Andraski, B.J., 1997, Soil-water movement under natural-site and waste-site conditions—A multiple-year field study in the Mojave Desert, Nevada: Water Resources Research, v. 33, no. 9, p. 1901–1916.

Andraski, B.J., and Prudic, D.E., 1997, Soil, plant, and structural considerations for surface barriers in arid environments—Application of results from studies in the Mojave Desert near Beatty, Nevada, in Barrier Technologies for Environmental Management, Summary of a Workshop: Washington, D.C., National Academy Press, p. D50–D60.

Andraski, B.J., and Stonestrom, D.A., 1999, Overview of research on water, gas, and radionuclide transport at the Amargosa Desert Research Site, Nevada, *in* Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Charleston, South Carolina, March 8–12, 1999—Volume 3 of 3—Subsurface Contamination from Point Sources: U.S. Geological Survey Water-Resources Investigations Report 99–4018–C, p. 459–466.

Andraski, B.J., Stonestrom, D.A., Michel, R.L., Halford, K.J., and Radyk, J.C., 2005, Plant-based plume-scale mapping of tritium contamination in desert soils: Vadose Zone, v. 4, p. 819–827.

Clebsch, Alfred, Jr., 1968, Geology and hydrogeology of a proposed site for burial of solid radioactive waste southeast of Beatty, Nye County, Nevada, *in* Morton, R.J., Land burial of solid radioactive wastes—Study of commercial operations and facilities: Atomic Energy Commission, NTIS Report WASH-1143, p. 70–100.

Fischer, J.M., 1992, Sediment properties and water movement through shallow unsaturated alluvium at an arid site for disposal of low-level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Water-Resources Investigations Report 92–4032, 48 p.

Healy, R.W., Striegl, R.G., Michel, R.L., Prudic, D.E., and Andraski, B.J., 1999, Tritium in water vapor in shallow unsaturated zone at the Amargosa Desert Research Site, *in* Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Charleston, South Carolina, March 8–12, 1999—Volume 3 of 3—Subsurface Contamination from Point Sources: U.S. Geological Survey Water-Resources Investigations Report 99–4018–C, p. 485–490.

Johnson, M.J., Mayers, C.J., and Andraski, B.J., 2002, Selected micrometeorological and soil-moisture data at Amargosa Desert Research Site in Nye County near Beatty, Nevada, 1998–2000: U.S. Geological Survey Open-File Report 02–348, 14 p.

Lowe, P.R., 1977, An approximating polynomial for computation of saturation vapor pressure: Journal of Applied Meteorology, v. 16, p. 100–103.

Mayers, C.J., Andraski, B.J., Cooper, C.A., Wheatcraft, S.W., Stonestrom, D.A., and Michel, R.L., 2005, Modeling tritium transport through a deep unsaturated zone in an Arid Environment: Vadose Zone Journal, v. 4, p. 967–976.

Nichols, W.D., 1987, Geohydrology of the unsaturated zone at the burial site for low-level radioactive waste near Beatty, Nye County, Nevada: U.S. Geological Survey Water-Supply Paper 2312, 57 p.

Prudic, D.E., and Striegl, R.G., 1995, Tritium and radioactive carbon (14C) analyses of gas collected from unsaturated sediments next to a low-level radioactive-waste burial site south of Beatty, Nevada, April 1994 and July 1995: U.S. Geological Survey Open-File Report 95–741, 7 p.

Prudic, D.E., Striegl, R.W., Healy, R.G., Michel, R.L., and Hass, H., 1999, Tritium and 14C concentrations in unsaturated-zone gases at test hole UZB-2, Amargosa Desert Research Site, 1994-98, *in* Morganwalp, D.W., and Buxton, H.T., eds., U.S. Geological Survey Toxic Substances Hydrology Program—Proceedings of the Technical Meeting, Charleston, South Carolina, March 8–12, 1999—Volume 3 of 3—Subsurface Contamination from Point Sources: U.S. Geological Survey Water-Resources Investigations Report 99–4018–C, p. 475–483.

Smith, R.L., 1974, Ecology and field biology (2d ed.): New York, Harper and Row.

Striegl, R.G., Healy, R.W., Michel, R.L., and Prudic, D.E., 1998, Tritium in unsaturated zone gases and air at the Amargosa Desert Research Site, and in spring and river water, near Beatty, Nevada, May 1997: U.S. Geological Survey Open-File Report 97–778, 13 p.

Tyler, S.W., 1988, Neutron moisture meter calibration in large diameter boreholes: Soil Science Society of America Journal, v. 52, p. 890–893.

Wood, J.L., 1996, Selected meteorological and micrometeorological data for an arid site near Beatty, Nye County, Nevada, calendar year 1992: U.S. Geological Survey Open-File Report 96–434, 33 p.

Wood, J.L., and Andraski, B.J., 1992, Selected meteorological data for an arid site near Beatty, Nye County, Nevada, calendar year 1989: U.S. Geological Survey Open-File Report 92–484, 27 p.

Wood, J.L., and Andraski, B.J., 1995, Selected meteorological data for an arid site near Beatty, Nye County, Nevada, calendar years 1990-91: U.S. Geological Survey Open-File Report 94–489, 49 p.

Wood, J.L., and Fischer, J.M., 1991, Selected meteorological data for an arid site near Beatty, Nye County, Nevada, calendar year 1986: U.S. Geological Survey Open-File Report 91–189, 27 p.

Wood, J.L., and Fischer, J.M., 1992, Selected meteorological data for an arid site near Beatty, Nye County, Nevada, calendar year 1987: U.S. Geological Survey Open-File Report 92–59, 27 p.

Wood, J.L., Hill, K.J., and Andraski, B.J., 1992, Selected meteorological data for an arid site near Beatty, Nye County, Nevada, calendar year 1988: U.S. Geological Survey Open-File Report 92–61, 27 p.

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Appendixes

Data files that contain the complete micrometeorological (appendixes A–F), soil-moisture (appendixes G and H), and ET (appendixes I–M) field data sets are presented in 13 Microsoft© Excel spreadsheets. The appendixes can be accessed and downloaded at URL http://pubs.water.usgs.gov/ds284/.

Appendix A. Summary of Daily Mean Micrometeorological Data Collected at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Appendix B. Summary of Hourly Mean Micrometeorological Data Collected at Amargosa Desert Research Site near Beatty, Nevada, 2001.

Appendix C. Summary of Hourly Mean Micrometeorological Data Collected at Amargosa Desert Research Site near Beatty, Nevada, 2002.

Appendix D. Summary of Hourly Mean Micrometeorological Data Collected at Amargosa Desert Research Site near Beatty, Nevada, 2003.

Appendix E. Summary of Hourly Mean Micrometeorological Data Collected at Amargosa Desert Research Site near Beatty, Nevada, 2004.

Appendix F. Summary of Hourly Mean Micrometeorological Data Collected at Amargosa Desert Research Site near Beatty, Nevada, 2005.

Appendix G. Volumetric Water-Content Data at Depth for Each Experimental Site at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Appendix H. Volumetric Water-Content at Depth for Each Neutron-Probe Access Tube at Amargosa Desert Research Site near Beatty, Nevada, 2001–05.

Appendix I. Daily Evapotranspiration Rates at Amargosa Desert Research Site near Beatty, Nevada, 2002–05.

Appendix J. 15-minute Evapotranspiration Data—Energy Flux Rates and Other Field Data Parameters at Amargosa Desert Research Site near Beatty, Nevada, 2002.

Appendix K. 15-minute Evapotranspiration Data—Energy Flux Rates and Other Field Data Parameters at Amargosa Desert Research Site near Beatty, Nevada, 2003.

Appendix L. 15-minute Evapotranspiration Data—Energy Flux Rates and Other Field Data Parameters at Amargosa Desert Research Site near Beatty, Nevada, 2004.

Appendix M. 15-minute Evapotranspiration Data—Energy Flux Rates and Other Field Data Parameters at Amargosa Desert Research Site near Beatty, Nevada, 2005.

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