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Micrometeorological and Soil Data for Calculating Evapotranspiration for Rainier Mesa, Nevada Test Site, Nevada, 2002–05

Open-File Report 2006-1312

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

Cover: Photograph of the Rainier Brush site looking northwest, Nevada Test Site, Nevada. (Photograph taken by Gary L. Otto, U.S. Geological Survey, date unknown.)

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DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
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Suggested citation:
DeMeo, G.A., Flint, A.L., Laczniak, R.J., and Nylund, W.E., 2006, Micrometeorological and soil data for calculating evapotranspiration for Rainier Mesa, Nevada Test Site, Nevada, 2002–05: U.S. Geological Survey Open-File Report 2006-1312, 12 p.

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Conversion Factors

Multiply	By	To obtain
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
square hectometer (km^2)	247.1	acre
square kilometer (km^2)	0.3861	square mile (mi^2)
cubic hectometer (hm^3)	810.7	acre-foot (acre-ft)
kilopascal (kPa)	0.1450	pound per square inch (lb/in^2)
bar	100	kilopascal (kPa)
meter per second (m/s)	2.237	mile per hour (mi/hr)
meter per second (m/s)	3.281	foot per second (ft/s)

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

°F=(1.8×°C)+32.

Datum

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Symbols and Acronyms

Symbols and Acronyms	Meaning
DVRFS	Death Valley Regional Ground-Water Flow System
E	Rate of water evaporation
ET	Evapotranspiration
G_s	Soil heat flux
H	Sensible heat flux
HDP	Heat-dissipation probe
NOAA	National Oceanic and Atmospheric Administration
NTS	Nevada Test Site
R_n	Net radiation
USGS	United States Geological Survey
WCR	water-content reflectometer
λ	Latent heat of vaporization for water
λE	Latent heat flux (or evaporative flux)

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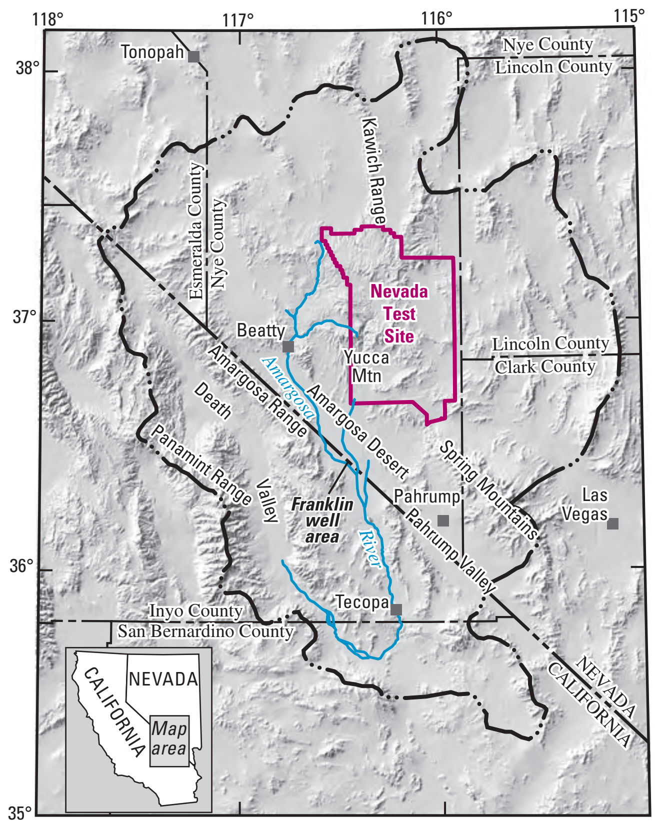
Abstract

Micrometeorological and soil-moisture data were collected at two instrumented sites on Rainier Mesa at the Nevada Test Site, January 1, 2002 – August 23, 2005. Data collected at each site include net radiation, air temperature, and relative humidity at two heights; wind speed and direction; subsurface soil heat flux; subsurface soil temperature; volumetric soil water; and matric water potential. These data were used to estimate 20-minute average and daily average evapotranspiration values. The data presented in this report are collected and calculated evapotranspiration rates.

Introduction

Rainier Mesa, in the north-central part of the Nevada Test Site (NTS), is in the Death Valley Regional Ground-Water Flow System (DVRFS), a major flow system in the Great Basin Regional aquifer system (Harrill and Prudic, 1998; fig. 1). Ground water in this flow system is recharged locally by precipitation that falls on high-altitude areas, such as Rainier Mesa. About 60 underground nuclear devices were detonated in tunnels within unsaturated volcanic rock beneath Rainier Mesa (U.S. Department of Energy, 2000). Radionuclides generated as a consequence of nuclear testing could be carried downward by water infiltrating from the ground surface to the water table. However, few data are available from which to characterize infiltration at Rainier Mesa. A better understanding of the distribution and rate of infiltration is necessary to evaluate the potential for migration of radionuclides.



Base from U.S. Geological Survey digital data, 1:100,000, 1978-89:
Universal Transverse Mercator Projection, Zone 11,
North American Datum of 1983
Shaded relief base from 1:250,000-scale Digital Elevation Model;
sun illumination from northwest at 30 degrees above horizon

EXPLANATION

0 20 40 MILES
0 20 40 KILOMETERS

Death Valley Regional Ground-Water Flow System boundary—Modified from Harrill and others (1988)

Figure 1. Location of Death Valley Regional Ground-Water Flow System and the Nevada Test Site.

Purpose and Scope

This report documents micrometeorological and soil data collected at two instrumented sites on Rainier Mesa, NTS. Twenty-minute micrometeorological data and hourly soil-moisture data were collected from January 1, 2002, to August 23, 2005, and are summarized in Microsoft Excel workbooks (appendix A). These data were used to compute evapotranspiration (ET) rates, volumetric soil-water content, and matric water potential. Plots of daily maxima and minima atmospheric parameters, daily average volumetric soil-water content, matric water potential, and daily ET rates are provided in appendix A.

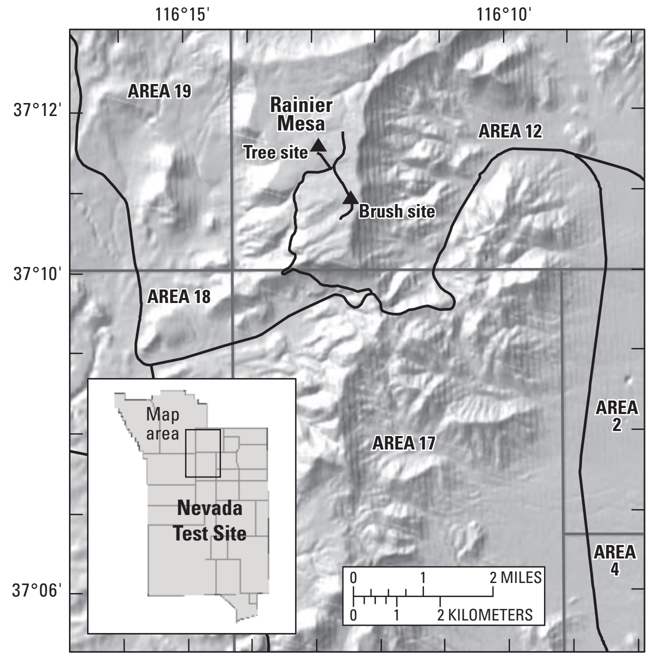
Study Area and Climatic Setting

Rainier Mesa is about 140 km northwest of Las Vegas, Nev. (fig. 2). The mesa covers an area of about 11 km^2 and has an average altitude of 2,200 m (Russell and others, 2001). Vegetation on the mesa is characterized by pinyon pine (*Pinus edulis*) and juniper (*Juniperus sp*.) trees, rabbitbrush (*Chrysothamnus sp.*), perennial grasses, and high-desert scrub brush.

Precipitation on Rainier Mesa principally is from cool-season Pacific storms and from warm-season convective storms when moist tropical air flows northward from the southeastern North Pacific Ocean. Average annual precipitation on Rainier Mesa is approximately 330.0 mm, much of which falls as snow. The maximum recorded annual precipitation for 1964–2005 was 682.5 mm in 1983 and the minimum recorded annual precipitation was 9.6 mm in 2002. Precipitation data and a general description of the NTS climate, which includes a discussion of the higher terrain areas representative of Rainier Mesa, are available at http://www.sord.nv.doe.gov/raingage/Monthly/Rainer_Mesa_Monthly_Data.txt and at http://www.sord.nv.doe.gov/climate/climate.nts.general.pdf (National Oceanic and Atmospheric Administration, 2006).

Description of Instrumentation Sites

Data-collection platforms, equipped with instrumentation that continuously measures and logs micrometeorological and soil-moisture parameters, were installed at two sites. These data were used to compute ET and also can be used to develop infiltration profiles.



Base from USGS digital data 1:100,000 1979-89
Universal Transverse Mercator projection, Zone 11,
North American Datum of 1983.
Shaded-relief base from National Elevation Data (NED);
sun-illumination from northwest at 45 degrees above horizon.

Figure 2. Location of tree and brush sites, Rainier Mesa, Nevada Test Site.

One platform, referred to in this report as the tree site, is in a sparse to moderately dense pinyon and juniper forest. The site is characterized by a vegetation cover of about 20 to 30 percent (fig. 3*A*) and is colocated with a meteorological tower operated by the National Oceanic and Atmospheric Administration (NOAA) Air Resources Laboratory. The site is at a latitude of 37º11'28.5"N and a longitude of 116º12'59.4"W, and at an altitude of 2,283 m above sea level.

A second platform, referred to in this report as the brush site, is in a sparsely vegetated community of perennial grasses and high-desert scrub brush (fig. 3*B*). This site is dominated by rabbitbrush and characterized by a vegetation cover of about 10 to 20 percent. It lies in an open field within a small bowl-shaped valley at a latitude of 37º10'48.4"N and a longitude of 116º12'25.27"W, and at an altitude of 2,290 m above sea level.

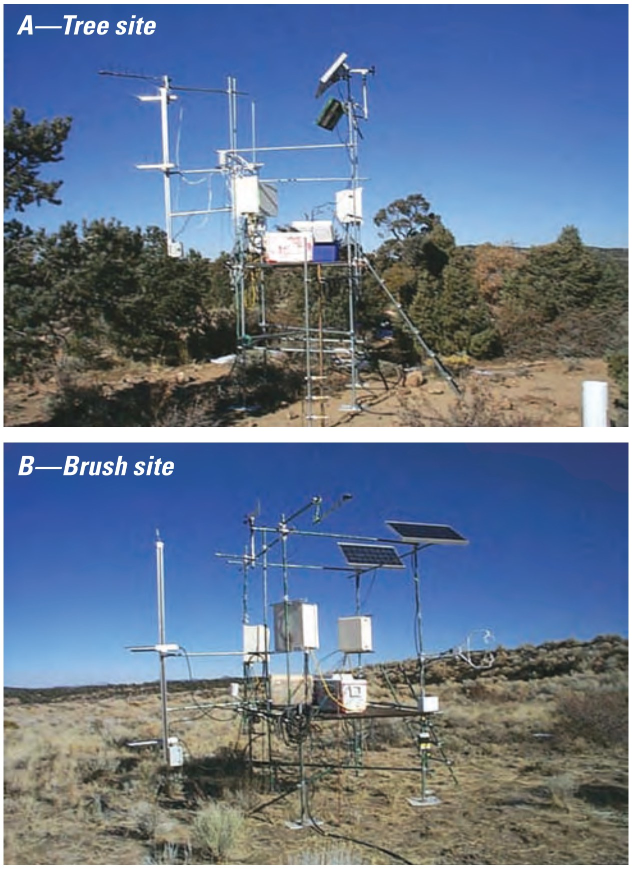


Figure 3. Photographs of (*A*) tree and (*B*) brush sites, Rainier Mesa, Nevada Test Site. Photograph taken by Gary Otto, U.S. Geological Survey, spring 2002.

Micrometeorological and Soil Data

Micrometeorological and soil data were collected at each platform. The data include air temperature, dewpoint temperature, and vapor pressure (measured at two heights above land surface), average relative humidity, net radiation, soil temperature, 20-minute temperature change in soil, soil heat flux (sampled at 30-second intervals), and wind speed and direction (sampled at 10-second intervals) (see appendix A). These data were used to calculate ET using the Bowen ratio method over a 20-minute period. Examples of select maximum and minimum 20-minute averaged micrometeorological data for the brush site are shown in figure 4. Periodic gaps in the data set exist due to adverse weather conditions and instrument failure.

Heat-dissipation-probe (HDP; Campbell Scientific, Inc., 1998) and water-content-reflectometer (WCR; Campbell Scientific, Inc., 1996) instrumentation were used to collect matric water potential and volumetric soil-water content data, respectively (table 1). To collect these data, three shallow holes, approximately 0.30 m deep were dug at each site. Two HDP sensors were placed in each hole between 0.05 and 0.20 m below land surface. Additionally, one WCR sensor was placed in each of the holes with the HDP sensors and inserted into the soil at about a 30 degree angle to collect data from the top 0.15 m of soil. In July 2004, three additional holes, approximately 12.2 m deep, were excavated at each site using a pneumatic rock hammer. Two HDP sensors were placed in each of these holes at about 0.46 and 1.07 m below land surface. These sensors were installed at greater depths than the initial HDP sensors to gain a better understanding of how water moves through the soil. Figure 5 shows the setup of the soil-water sensors in the holes. An example of volumetric soil-water content and matric water potential data at the brush site is shown in figure 6.

During the period of record (2002–05) presented in this report, 20-minute averaged air-temperature data (from the upper temperature probe) ranged from 31.8 to -16.4°C. The recorded maximum 20-minute averaged wind-speed data was 20.7 m/s. The daily average matric water-potential data ranged from a maximum of -0.0001 bars to a minimum of -10,000 bars. The volumetric soil-water content data ranged from 99 to 6.5 percent. Annual precipitation on Rainier Mesa recorded by NOAA ranged from 85.8 to 436.0 mm (fig. 7).

Table 1. Measured parameter and manufacturer name and model number used for the Bowen ratio, eddy covariance, and soil-moisture calculations, Rainier Mesa, Nevada Test Site.

[**Abbreviations:** REBS, Radiation and Energy Balance Systems; RMY, R.M. Young Company; CSI, Campbell Scientific, Inc.; –, not applicable]

Measured parameter	Instrument, manufacturer, and model		
	Bowen ratio	Eddy covariance	Soil moisture
Air temperature	REBS THP-1	Rotronics MP 101A	–
Relative humidity	REBS THP-1	Rotronics MP 101A	–
Net radiation	REBS Q-7.1	REBS Q-7.1	–
Soil heat flux	REBS HFT3	REBS HFT3	–
Wind speed and direction	RMY model 05106 MA	–	–
Soil temperature	CSI TCAV	CSI TCAV	–
Eddy fluxes	–	CSI 3D Sonic anemometer CSI Krypton hygrometer	–
Matric water potential	–	–	CSI HDP
Volumetric soil-water content	CSI CS616	CSI CS616	CSI CS616

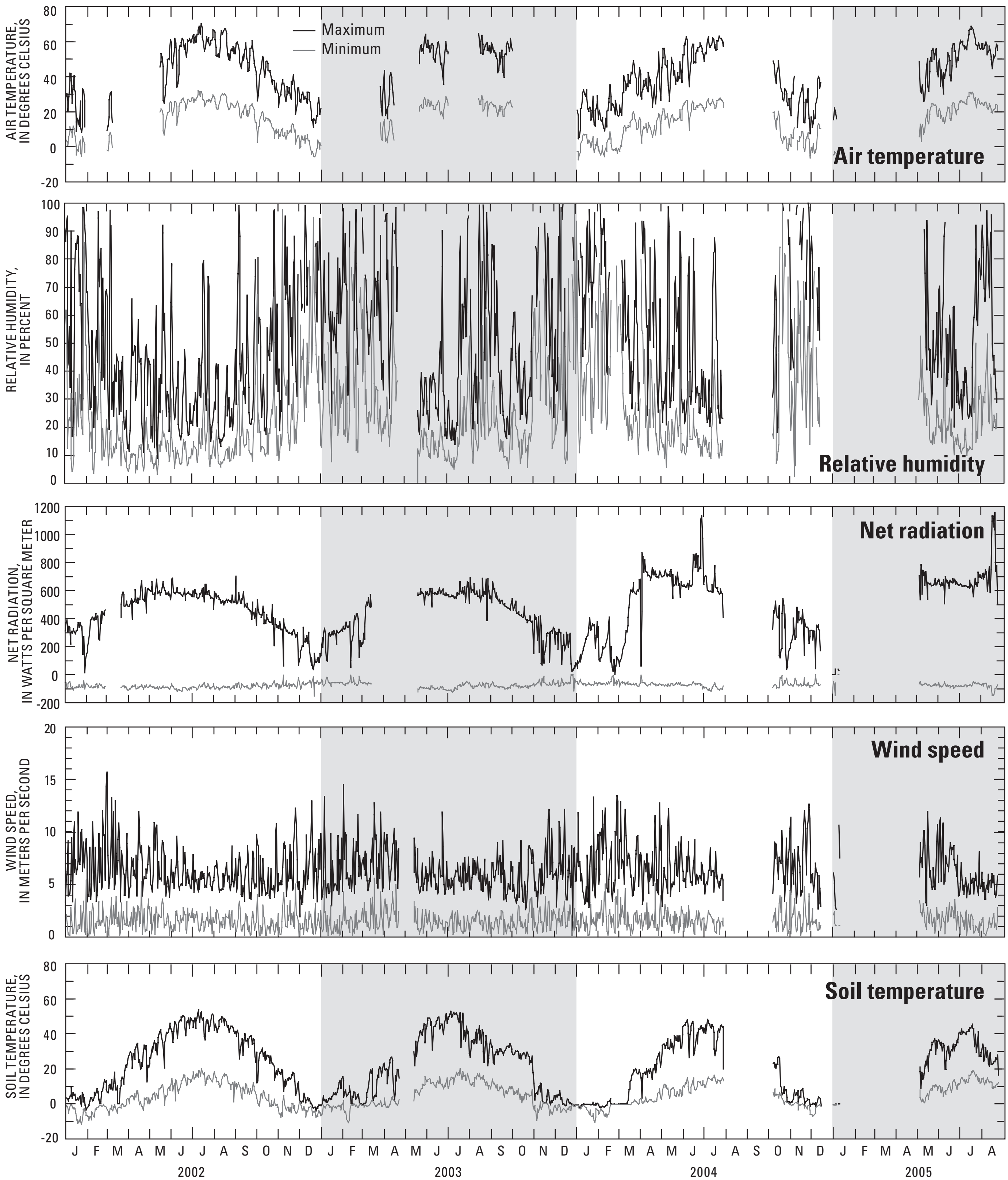


Figure 4. Examples of daily average micrometeorological data collected at brush site, Rainier Mesa, Nevada Test Site, January 1, 2002 – August 23, 2005.

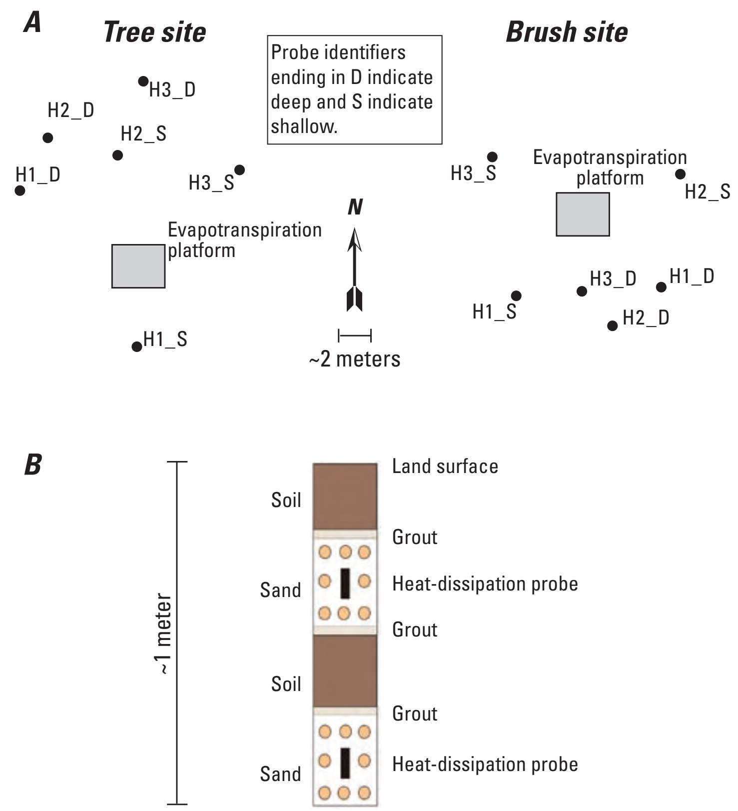


Figure 5. Schematic showing (*A*) placement of soil-water content probes at tree and brush sites and (*B*) vertical structure of deeper hole and placement of heat-dissipation probes used at both sites, Rainier Mesa, Nevada Test Site.

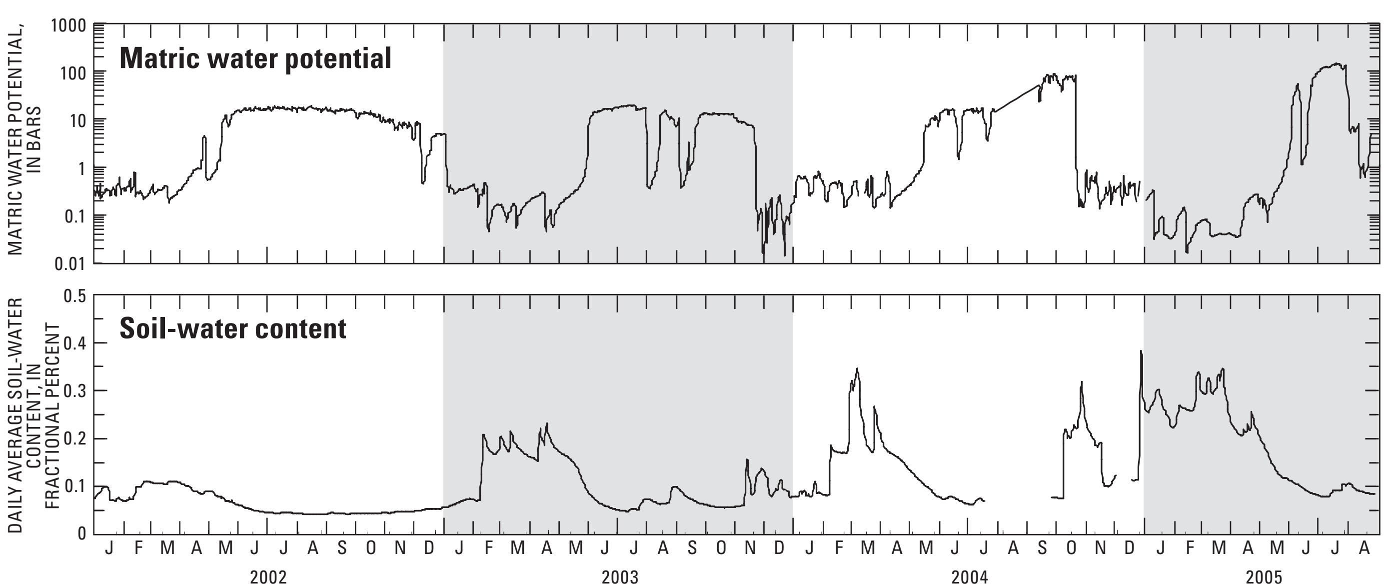


Figure 6. Daily average volumetric soil-water content and daily average matric water potential at the brush site, shallow hole 1, Rainier Mesa, Nevada Test Site, January 1, 2002 – August 23, 2005.

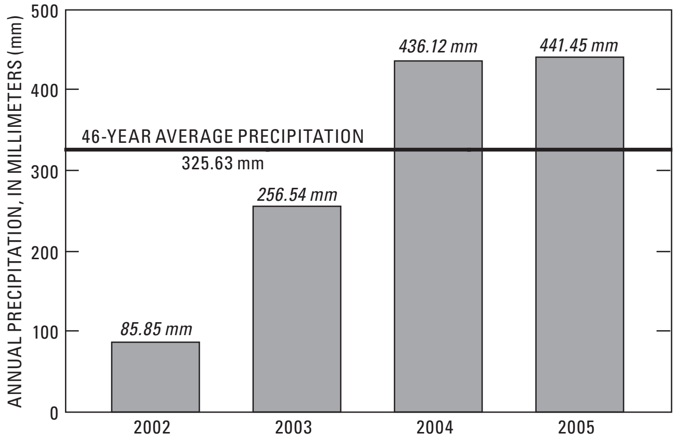


Figure 7. Total annual precipitation measured at Rainier Mesa, Nevada Test Site, 2002–05. Data are from National Oceanic and Atmospheric Administration, Special Operation and Research Division, 2006.

Evapotranspiration Estimates

Evapotranspiration is a process by which water from the Earth's surface is transferred to the atmosphere. The transfer requires that water change from a liquid to a vapor state, which consumes energy. As a result, any change in the rate of water loss by ET is reflected by a change in energy. This relation between water loss and energy consumption is the basis for many of the methods used to estimate ET. Evapotranspiration, as used in this report, includes evaporation from the soil surface, transpiration from plants, and sublimation from snowpack.

Energy at the surface of the Earth can be described as a budget, in which a balance is sought between the incoming and outgoing energy components. The available incoming or net radiation is the energy provided by the sun minus the radiation that is reflected back. This net radiation is equal to the energy used to heat the soil (soil heat flux), plus the energy used to heat the air (sensible heat flux), plus the energy used to evaporate water (latent heat flux). Terms related to the flux of energy can be expressed mathematically as:

$$R_n = G_s + H + \lambda E \ , \tag{1}$$

where

R_n is net radiation, in Watts per square meter,

G_s is soil heat flux, in Watts per square meter,

H is sensible heat flux, in Watts per square meter, and

λE is latent heat flux, in Watts per square meter.

In this study, the Bowen ratio (Bowen, 1926) and eddy covariance (Stull, 1988) methods were applied to calculate ET rates. The Bowen ratio method requires measurements of air temperature and relative humidity at two heights above the ground. These measurements are used to calculate air-temperature and vapor-pressure gradients between the two sample heights (fig. 8*A*, table 1). The Bowen ratio works on the principle that the temperature and vapor-pressure gradients and the available energy regulate the latent heat flux. The eddy covariance method requires measurements of vertical wind speed and fluctuations in water vapor sampled at 0.1-second

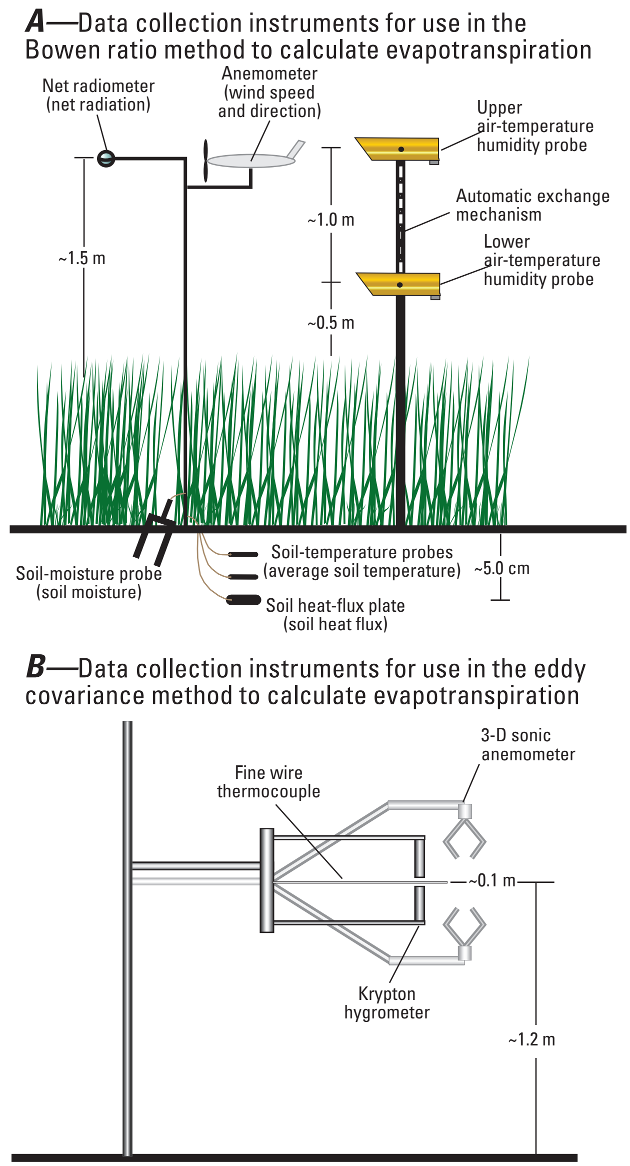


Figure 8. Schematics of (*A*) Bowen ratio and (*B*) eddy covariance instrumentation used at tree and brush sites on Rainier Mesa, Nevada Test Site.

intervals using a three-dimensional sonic anemometer and a krypton hygrometer, respectively (fig. 8*B*, table 1). The eddy covariance method works on the principle that water vapor and heat are transported through the air by turbulence and that estimates of latent heat flux can be calculated by measuring changes in vertical wind speed, air temperature, and water vapor during short intervals of time. Corrections for temperature-induced fluctuations in air density (Webb and others, 1980) and for the sensitivity of the krypton hygrometer to oxygen (Tanner and Greene, 1989) were used to estimate latent heat flux. More detailed discussions on the Bowen ratio and eddy covariance methods are given in Laczniak and others (1999), and DeMeo and others (2003), respectively.

Numerous days of Bowen ratio data were missing at both sites due to the effects of adverse weather conditions and instrumentation failure. In 2003, the tree site was destroyed in a wind storm and no data were collected from January 4 to May 15. A more complete record of ET from the eddy covariance instrumentation was made available due to the robustness of the equipment. Data collection periods from each site, when sufficient data were available to calculate daily ET, are listed in table 2.

Daily ET using the Bowen ratio and eddy covariance methods was determined by summing 20-minute average ET rates for a 24-hour period. Calculated daily ET from 2002 to 2005 for each site is shown in figure 9. Daily ET was summed to calculate monthly and annual ET. Table 3 lists the monthly ET collected at each site during the period of record. Annual ET for the brush site using the eddy covariance method (2002–04) ranged from 243.6 to 347.5 mm. Annual ET for the tree site using the eddy covariance method (2002 and 2004) ranged from 315.0 to 313.0 mm.

Table 2. Number of days per month that evapotranspiration rates are available during the collection period for the Bowen ratio and eddy covariance methods at the tree and brush sites, Rainier Mesa, Nevada Test Site, January 2002 – August 2005.

[**Symbol:** –, missing or bad data]

			Data-collection period											
ET site	**Method**	**Year**	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Brush	Bowen ratio	2002	27	–	–	–	17	30	31	31	30	31	30	31
	Eddy covariance		31	28	31	30	31	30	31	31	30	31	30	29
Tree	Bowen ratio		31	28	31	30	31	12	–	31	30	31	30	31
	Eddy covariance		31	28	31	30	31	30	31	31	30	31	29	28
Brush	Bowen ratio	2003	–	–	–	–	–	–	–	18	30	–	–	–
	Eddy covariance		28	25	30	21	18	30	30	29	30	31	29	26
Tree	Bowen ratio		5	–	–	–	17	30	18	–	7	31	30	24
	Eddy covariance		5	–	–	–	17	30	31	31	30	31	30	24
Brush	Bowen ratio	2004	–	–	–	–	10	3	–	–	–	15	15	14
	Eddy covariance		31	19	24	28	31	30	31	31	30	23	28	12
Tree	Bowen ratio		28	1	8	–	13	30	31	11	9	–	–	–
	Eddy covariance		29	27	31	30	31	30	31	31	19	28	28	27
Brush	Bowen ratio	2005	–	–	–	–	26	30	31	18	–	–	–	–
	Eddy covariance		–	–	–	–	25	30	31	24	–	–	–	–
Tree	Bowen ratio		4	–	–	–	28	30	31	24	–	–	–	–
	Eddy covariance		17	24	31	30	31	30	31	24	–	–	–	–

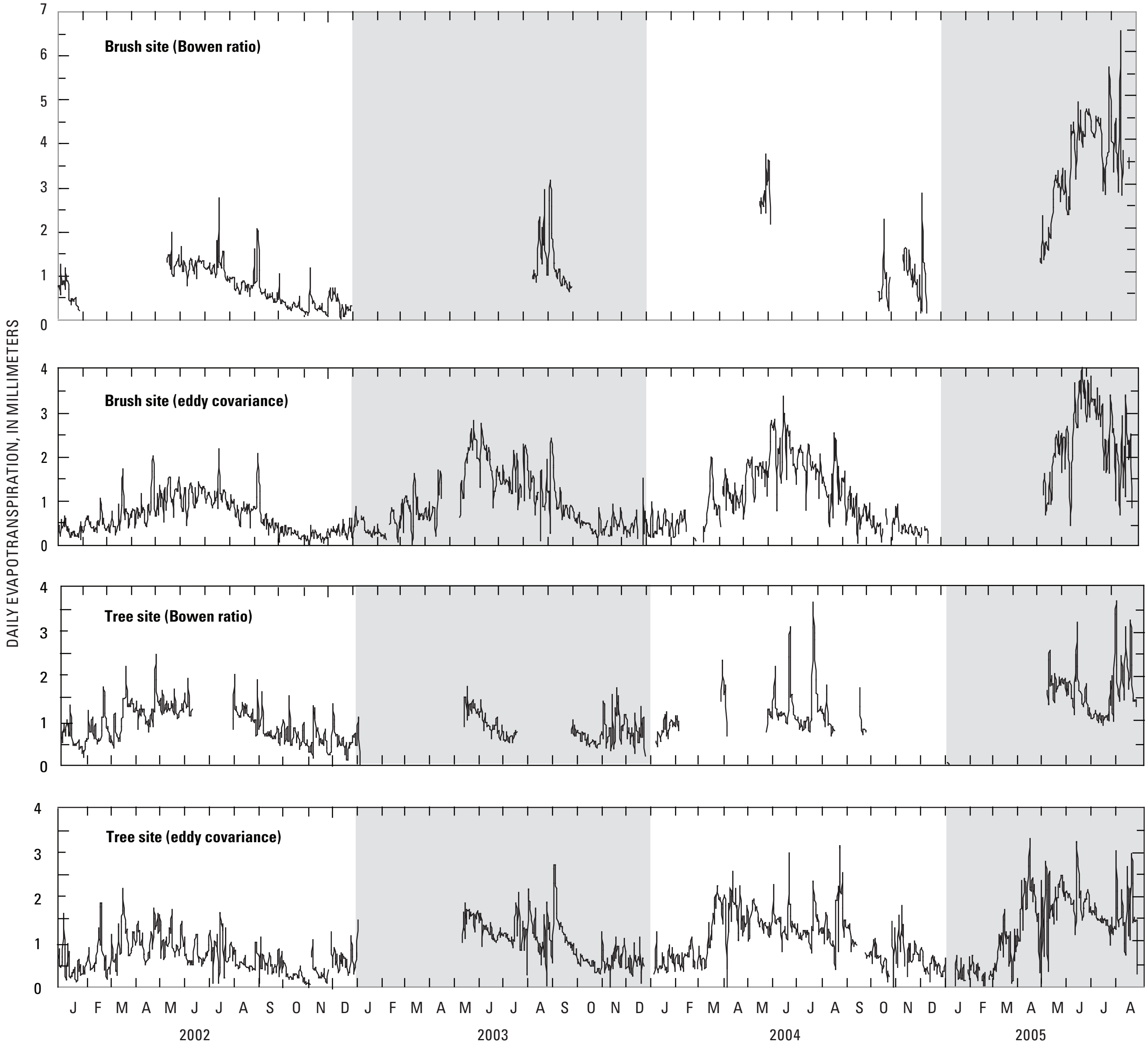


Figure 9. Daily evapotranspiration at brush and tree sites computed from data using eddy covariance and Bowen ratio methods, Rainier Mesa, Nevada Test Site, January 1, 2002 – August 23, 2005.

Table 3. Calculated monthly evapotranspiration at the tree and brush sites, Rainier Mesa, Nevada Test Site, January 2002 – August 2005.

[**Tree site/Brush site:** Evapotranspiration rates only for January 1–August 23, 2005. –, missing or bad data]

Month	Evapotranspiration, in millimeters							
	2002		2003		2004		2005	
	Bowen ratio	Eddy covariance	Bowen ratio	Eddy covariance	Bowen ratio	Eddy covariance	Bowen ratio	Eddy covariance
Tree site								
January	18.3	15.5	3.3	3.6	23.1	16.1	0.1	5.9
February	24.0	19.9	–	–	0.9	17.9	–	7.7
March	32.1	27.0	–	–	13.4	41.1	–	27.2
April	36.8	30.1	–	–	–	46.0	–	54.9
May	40.2	32.3	23.4	27.7	16.5	47.4	49.6	59.2
June	16.3	23.3	27.6	27.7	36.9	42.2	45.9	57.5
July	–	25.0	11.3	37.5	41.9	40.6	42.3	47.5
August	35.5	16.8	–	36.9	10.8	44.2	47.3	38.6
September	24.2	24.5	5.5	39.6	8.7	17.1	–	–
October	20.4	9.4	17.8	16.7	–	18.4	–	–
November	16.9	7.8	27.6	19.7	–	23.3	–	–
December	17.4	18.2	17.2	13.5	–	10.9	–	–
Brush site								
January	16.7	10.6	–	11.0	–	12.8	–	–
February	–	14.5	–	10.4	–	9.2	–	–
March	–	18.9	–	24.9	–	20.2	–	–
April	–	25.6	–	19.0	–	30.0	–	–
May	22.7	34.0	–	34.5	31.3	51.3	63.7	43.9
June	37.1	33.8	–	57.2	9.4	68.8	113.1	82.9
July	38.8	34.8	–	44.1	–	56.8	132.6	90.6
August	24.3	25.2	28.7	39.9	–	44.0	69.0	49.4
September	22.5	20.6	36.6	32.7	–	25.1	–	–
October	11.5	8.9	–	14.9	12.8	11.4	–	–
November	8.7	6.1	–	13.9	20.0	12.2	–	–
December	11.5	10.0	–	11.1	13.1	3.5	–	–

Summary

Micrometeorological and soil data were used to estimate daily, monthly, and annual ET rates at two instrumented sites on Rainier Mesa, January 1, 2002 – August 23, 2005. One site is in an area of brush-dominated vegetation and a second site is in an area dominated by pinyon pines and juniper trees. Micrometeorological, soil, and ET data are presented in this report in Microsoft Excel workbooks. These data include air temperature, vapor pressure, and dew point temperature at two heights; average relative humidity; net radiation; wind speed and direction; soil temperature; 20-minute temperature change in soil; soil heat flux; and ET rates. Data for both sites are presented as 20-minute averages. Volumetric soil-water content and matric water potential are presented as 1-hour intervals and daily averages.

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Appendix A: Micrometeorological, Soil, and Evapotranspiration Data Workbooks

Micrometeorological and soil-moisture data, and evapotranspiration (ET) are presented in Microsoft Excel workbooks as part of this report. Two workbooks are available for each site; one workbook (http://pubs.water.usgs.gov/ofr20061312/data/et.zip) contains the micrometeorological data, energy-budget fluxes, and daily ET values (calculated using both the Bowen ratio and eddy covariance methods) and the other workbook (http://pubs.water.usgs.gov/ofr20061312/data/soil.zip) contains the soil-moisture data.

Microsoft Excel workbook containing the micrometeorological data, energy-budget fluxes, and ET include:

A. Micrometeorological data worksheet (20-minute intervals):

1. Air temperature, vapor pressure, and dew point temperature at two heights,
2. average relative humidity,
3. wind speed and direction, and
4. soil temperature, and time change in air and soil temperature.

B. Bowen ratio energy-budget fluxes and ET worksheet (20-minute intervals):

1. Net radiation,
2. sensible heat flux,
3. latent heat flux,
4. soil heat flux, and
5. ET values.

C. Eddy covariance fluxes and ET worksheet (20-minute intervals):

1. Net radiation,
2. sensible heat flux uncorrected,
3. sensible heat flux Webb (1980) corrected,
4. latent heat flux uncorrected,
5. latent heat flux Webb (1980) corrected,
6. soil heat flux, and
7. ET values.

D. ET worksheet (daily intervals):

1. Bowen ratio and
2. eddy covariance.

E. Plots of daily ET for an annual cycle:

1. Bowen ratio and
2. eddy covariance.

Workbook containing soil-moisture values:

A. Soil-moisture worksheet (hourly intervals):

1. Matric water potential and
2. volumetric water content.

B. Soil-moisture worksheet (daily average values):

1. Matric water potential and
2. volumetric water content.

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For more information concerning the research in this report, contact the
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USGS

DeMeo and others

Micrometeorological and Soil Data for Calculating Evapotranspiration for Rainier Mesa, Nevada Test Site, Nevada, 2002–05

OFR 2006-1312