Comparison of Bowen-Ratio, Eddy-Correlation, and Weighing-Lysimeter Evapotranspiration for Two Sparse-Canopy Sites in Eastern Washington

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
Area		
square meter (m^2)	10.76	square foot
square kilometer (km^2)	0.3861	square mile
Density		
kilogram per cubic meter (kg/m^3)	0.06243	pound per cubic foot
Energy		
joule (J)	9.478×10^{-4}	British thermal unit
Energy-flux density		
watt per square meter (W/m^2)	5.285×10^{-3}	British thermal unit per square foot per minute
Energy and Mass		
joule per gram (J/g)	0.4298	British thermal unit per pound
Flow		
cubic meter per second	15,850	gallons per minute
Length		
millimeter (mm)	0.03937	inch
meter (m)	3.281	foot
kilometer (km)	0.6214	mile
Mass		
gram (g)	2.205×10^{-3}	pound
Power		
watt (W)	3.4129	British thermal unit per hour
Pressure		
kilopascal (kPa)	0.1450	pound per square inch
Resistance		
second per meter (s/m)	0.3048	second per foot
Specific-heat capacity		
joule per gram per kelvin ([J/g]/K)	0.2388	British thermal unit per pound per degrees Fahrenheit
Temperature		
degrees Celsius (°C)	1.8°C + 32	degrees Fahrenheit
kelvin (K)	1.8 K - 459.67	degrees Fahrenheit
Velocity		
meter per second (m/s)	2.237	miles per hour
Volume		
cubic meter (m^3)	35.31	cubic foot

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

SYMBOLS AND EQUATIONS

Symbols used in text:

β	Bowen ratio, unitless
C_p	Specific heat of air, equal to 1.005 joules per gram per degree Celsius
C_s	Specific heat of soil, in joules per kilogram per degree Celsius
C_w	Specific heat of water, in joules per kilogram per degree Celsius
D	Depth, in meters
d	Zero plane displacement height (distance from surface to mean height of heat, vapor, or momentum exchange), in meters
ET	Rate of evapotranspiration, in millimeters per day
e	Vapor pressure, in kilopascals
e_s	Saturated vapor pressure, in kilopascals
ε	Ratio of molecular weight of water to air, equal to 0.622
$FX1$	Soil-heat flux measurement 1, in watts per square meter
$FX2$	Soil-heat flux measurement 2, in watts per square meter
G	Soil-heat flux, in watts per square meter
H	Sensible-heat flux, in watts per square meter
h	Canopy height, in meters
h_r	Relative humidity, in percent
K_h	Height-dependent exchange coefficient (eddy diffusivity) for heat transport, in square meters per second
K_w	Height-dependent exchange coefficient (eddy diffusivity) for water-vapor transport, in square meters per second
k	von Karman's constant, equal to 0.4, unitless
L	Latent-heat of vaporization of water, in joules per gram
LE	Latent-heat flux, in watts per square meter
LE_p	Potential latent-heat flux, in watts per square meter
P	Atmospheric pressure, in kilopascals
ρ_a	Air density, in grams per cubic meter
ρ_b	Soil bulk density, in kilograms per cubic meter
$\Re$	Gas constant for dry air, equal to 0.28704 joules per gram per kelvin
R_n	Net radiation, in watts per square meter

SYMBOLS AND EQUATIONS--CONTINUED

Symbols used in text:

r^2	Square of the correlation coefficient, unitless
S	Flux going into storage as soil heat, in watts per square meter
s	Slope of the saturation vapor-pressure curve at air temperature, in kilopascals per degree Celsius
T	Air temperature, in degrees Celsius
T'	Instantaneous departure from the mean air temperature, in degrees Celsius
T_s	Soil temperature, in degrees Celsius
t	Time, in seconds
u	Wind speed, in meters per second
W	Percentage of water content by weight, in kilograms of water per kilogram of soil
w'	Instantaneous departure from mean vertical wind speed
γ	Psychrometric constant, in kilopascals per degree Celsius

Equations used in study text:

Number	Name and source or derivation	Equation
1.	Energy budget (Brutsaert, 1982, p. 2)	$R_n = LE + H + G$
2.	Latent-heat of vaporization of water (W.D. Nichols, U.S. Geological Survey, written commun., 1990)	$L = \frac{\Re\,[6,788.6 - 5.0016\,(T + 273.15)\,]}{\varepsilon}$
3.	Latent-heat of vaporization of water (Reduction of eq. 2)	$L = 2,502.3 - 2.308\ T$
4.	Soil-heat flux (Campbell Scientific, Inc., 1991, sec. 4, p. 3)	$G = \left(\frac{FX1 + FX2}{2} \right) + S$

Equations used in study text:

Number	Name and source or derivation	Equation
5.	Soil-heat storage (Campbell Scientific, Inc., 1991, sec. 4, p. 3)	$S = \left(\frac{\Delta T_s}{\Delta t}\right) D \rho_b \; [C_s + (W\ C_w)]$
6.	Bowen ratio (Bowen, 1926)	$\beta = \frac{H}{LE}$
7.	Bowen ratio (Rosenberg and others, 1983, p. 255)	$\beta = \frac{P\ C_p\ K_h \frac{dT}{dz}}{L\ \varepsilon\ K_w \frac{de}{dz}}$
8.	Bowen ratio (Tanner, 1988)	$\beta = \frac{P\ C_p\ \Delta T}{L\ \varepsilon\ \Delta e}$
9.	Psychrometric constant, (Rosenberg and others, 1983, p. 255)	$\gamma = \frac{P\ C_p}{L\ \varepsilon}$
10.	Bowen ratio (Substitution of eq. 9 into eq. 8)	$\beta = \gamma \frac{\Delta T}{\Delta e}$
11.	Sensible-heat flux (Rearrangement of eq. 6)	$H = \beta\ LE$
12.	Latent-heat flux (Substitution of eq. 11 for H, then rearrangement of eq. 1)	$LE = \frac{R_n - G}{1 + \beta}$

SYMBOLS AND EQUATIONS--CONTINUED

Equations used in study text:

Number	Name and source or derivation	Equation
13a.	Rate of evapotranspiration (Campbell, 1977, p. 141)	$ET = 86.4 \frac{LE}{L}$
13b.	Latent-heat flux (Rearrangement of equation 13a)	$LE = \frac{ET\ L}{86.4}$
14.	Latent-heat flux, eddy-correlation method (Rosenberg and others, 1983, p. 145)	$LE = -\frac{\varepsilon}{P}\rho_a \overline{w'e'}$
15.	Sensible-heat flux, eddy-correlation method (Rosenberg and others, 1983, p. 145)	$H = -\rho_a C_p \overline{w'T'}$

Comparison of Bowen-Ratio, Eddy-Correlation, and Weighing-Lysimeter Evapotranspiration for Two Sparse-Canopy Sites in Eastern Washington

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ABSTRACT

This report compares evapotranspiration estimated with the Bowen-ratio and eddy-correlation methods with evapotranspiration measured by weighing lysimeters for two sparse-canopy sites in eastern Washington. The sites are located in a grassland area (grass lysimeter site) and a sagebrush-covered area (sage lysimeter site) on the Arid Lands Ecology Reserve in Benton County, Washington. Lysimeter data were collected at the sites from August 1990 to November 1994. Bowen-ratio data were collected for varying periods from May 1993 to November 1994. Additional Bowen-ratio data without interchanging air-temperature and vapor-pressure sensors to remove sensor bias (fixed-sensor system) were collected from October 1993 to June 1994. Eddy-correlation data were collected at the grass lysimeter site from March to April 1994, and at the sage lysimeter site from April to May 1994.

The comparisons of evapotranspiration determined by the various methods differed considerably, depending on the periods of record being compared and the sites being analyzed. The year 1993 was very wet, with about 50 percent more precipitation than average; 1994 was a very dry year, with only about half the average precipitation. The study showed that on an annual basis, at least in 1994, Bowen-ratio evapotranspiration closely matched lysimeter evapotranspiration. In 1993, Bowen-ratio and lysimeter evapotranspiration comparisons were variable. Evapotranspiration estimated with the Bowen-ratio method averaged 5 percent more than evapotranspiration measured by lysimeters at the grass lysimeter site from October 1993 to November 1994, and 3 percent less than lysimeters at the sage lysimeter site from November 1993 to October 1994. From March 24 to April 5, 1994, at the grass lysimeter site, the Bowen-ratio method estimated 11 percent less, the Bowen-ratio method utilizing the fixed sensor system about 7 percent more, and the eddy-correlation method about 28 percent less evapotranspiration than the lysimeters measured. From May 7 to June 18, 1993, however, the Bowen-ratio method estimated only 54 percent of the evapotranspiration measured by lysimeters at the grass lysimeter site. This large difference possibly may be attributed to Bowen-ratio instrument variability or error, to the density of grasses in the lysimeters being greater than in the surrounding area, or to heating effects on the lysimeters. From September 1 to October 31, 1993, the Bowen-ratio method estimated more than 450 percent more evapotranspiration than was measured by lysimeters at the sage lysimeter site. This difference may have been due to conditions in the lysimeters at the sage lysimeter site that were unrepresentative of natural conditions. The Bowen-ratio instruments measured evapotranspiration over sagebrush plants outside the lysimeters, which were blooming very heavily, possibly using supplemental ground water or spring water from nearby upslope areas. The sagebrush plants contained by the lysimeters showed very little evapotranspiration, possibly because they were root-bound and had already used all available water. Also, plants in the lysimeters would not have been able to access any supplemental water available to plants outside the confines of the lysimeters. Earlier in 1993, from June 17 to July 12, the Bowen-ratio method estimated only 1 percent less evapotranspiration than determined for the lysimeters at the sage lysimeter site.

On the basis of lysimeter measurements from August 1990 to November 1994, cumulative evapotranspiration ranged from about 97 to 103 percent of the annual precipitation each year. The evapotranspiration measurements made at the grass and sage lysimeter sites, which were based on weight changes in the lysimeters, showed that storage changes became nearly zero each year some time between August and November as average surface soil moisture decreased to about 2 percent and evapotranspiration rates decreased to less than 0.1 millimeter per day.

INTRODUCTION

Most of the precipitation that falls in semiarid areas of eastern Washington is returned to the atmosphere as evapotranspiration (ET). ET, the amount of water evaporated from soil and other surfaces plus the amount of water transpired by plants, thus plays an important part in the hydrologic cycle for eastern Washington. Combined with precipitation and surface-water discharge data, ET estimates are commonly used to estimate ground-water recharge (Gee and Kirkham, 1984; Gee and Hillel, 1988; Bauer and Vaccaro, 1990). Thus, ET estimates are important to resource managers.

ET is one of the most difficult components of the hydrologic cycle to quantify because of the complexity of collecting the data needed for its computation. Many environmental factors contribute to ET, each of which requires accurate measurement of a number of variables under varied conditions. Some of these variables are particularly difficult to measure in semiarid areas; for example, vapor-pressure gradients may be too small to be accurately measured with available instruments during very dry periods. Also, some instruments cannot be operated in below-freezing air temperatures, or during rain.

Background

In order to better define ET in eastern Washington, an ET investigation was established in August 1989 by the U.S. Geological Survey and the Washington State Department of Ecology. These investigations were continued in 1990, 1991, 1992, and 1993 to form a series of four projects. The objectives of these projects were to make long-term measurements of ET for several sites in eastern Washington and to investigate a method of estimating ET requiring only standard meteorological, or easily collected, data.

The results of these projects are documented in this and three previous reports. The first of these reports describes ET methods and preliminary ET results for a grassland in Snively Basin of the Arid Lands Ecology (ALE) Reserve, Benton County, from May to October 1990 (Tomlinson, 1994). The second report describes ET at the Snively Basin site from May 1990 to September 1991 and for meadow and marsh sites on the Turnbull National Wildlife Refuge near Spokane from May to September 1991 (Tomlinson, 1995). The third report describes ET from six sites in eastern Washington from 1990 to 1992 (Tomlinson, 1996).

Purpose and Scope

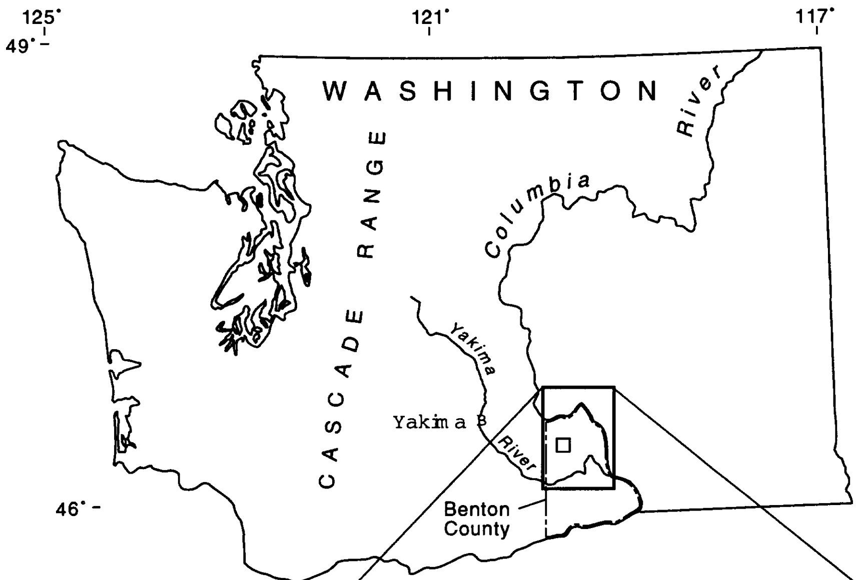
This report presents results of ET research at two sparse-canopy sites on the ALE Reserve. Weighing lysimeters were constructed at these sites in the summer of 1986, and data have been routinely collected from them since November 1987 (Gee and others, 1991). In this study, the Bowen-ratio method, eddy-correlation method, and lysimeters were used to estimate ET at these two sites. The purposes of this part of the series of ET projects were to (1) compare several methods of estimating ET at two semiarid sites in eastern Washington, (2) investigate reasons for different results from these methods, and (3) estimate long-term (more than 1 year) daily ET for two sites. The two sites were chosen because lysimeters were installed and in use at the sites and vegetation was nearly identical to that existing at the project site in Snively Basin described in earlier reports (Tomlinson, 1994; Tomlinson, 1995; Tomlinson, 1996).

Acknowledgments

The author thanks Battelle, Pacific Northwest Laboratories (PNL), especially Randy Kirkham, for their assistance in obtaining permission to install ET instruments on the ALE Reserve, and for providing the U.S. Geological Survey with data they collected from the weighing lysimeters from 1990 to 1994 on the ALE Reserve. Randy Kirkham provided significant technical assistance to the author on interpreting and analyzing the lysimeter data. The author also extends gratitude to Mike Johnson of the USGS Water-Resources Division, Nevada District, who set up eddy-correlation instruments at the grass lysimeter site and helped analyze the eddy-correlation data.

Description of the Study Sites

The study sites are located in semiarid native grass and sagebrush vegetation in eastern Washington (figs. 1 and 2). The sites are situated on the south side of the Rattlesnake Hills on the ALE Reserve of the Hanford Site (also called Hanford Works, Hanford Reservation, or Hanford) in western Benton County, Wash., about 40 kilometers (km) west of Richland and 64 km east of Yakima (fig. 1). The sites are about 450 meters (m) apart on an alluvial fan at an altitude of 293 m (fig. 2). One site is in grassland (grass lysimeter site) and the other is in sagebrush (sage lysimeter site).



Conversion for topographic map in Figure 2

FEET		METERS
600	=	183
800	=	244
1000	=	305
1200	=	366
1400	=	427
1600	=	488
1800	=	549
2000	=	610
2200	=	671
2400	=	732
2600	=	792
2800	=	853
3000	=	914
3200	=	975
3400	=	1,036

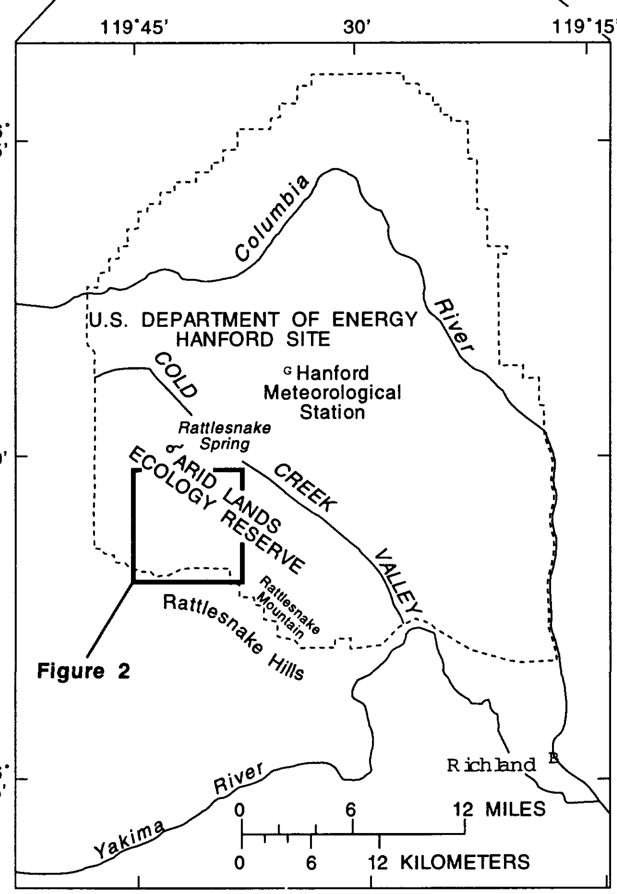


Figure 1.--Location of Arid Lands Ecology Reserve in Washington.

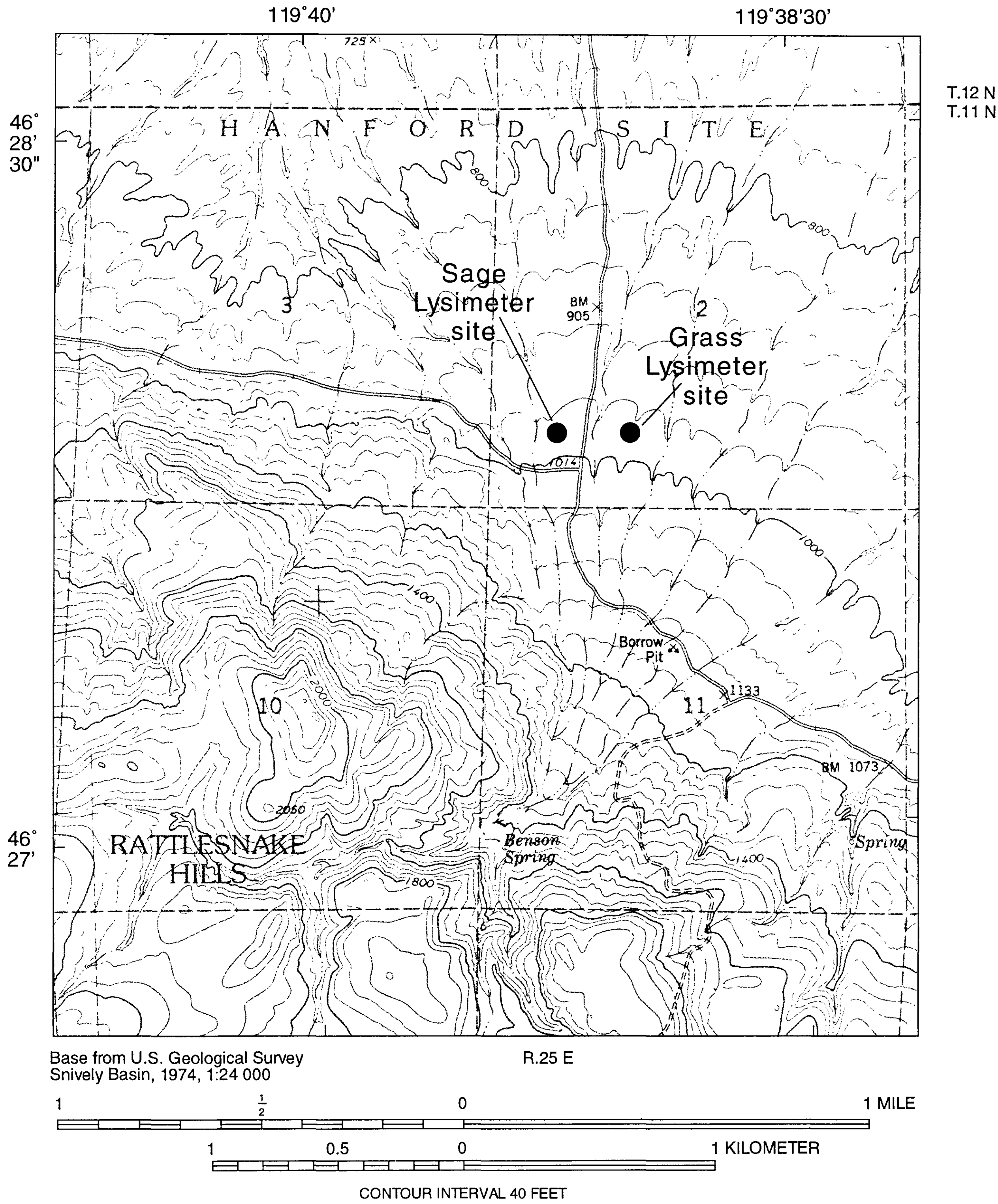


Figure 2.--Location of grass and sage lysimeter sites on Arid Lands Ecology Reserve.

Climate

The semiarid climate of eastern Washington results primarily from the rain-shadow effect of the Cascade Range (fig. 1). The Cascade crest varies between 1,200 and 3,050 m above sea level and forms an effective barrier to storms moving in from the Pacific Ocean. West of the Cascades, Olympia receives 1,270 millimeters (mm) of precipitation annually, while east of the Cascades, Yakima receives only 203 mm a year (Ruffner and Bair, 1987). From Yakima, precipitation gradually increases to the east where Walla Walla receives 383 mm and Spokane 411 mm annually (Ruffner and Bair, 1987).

Average annual precipitation on the ALE Reserve from 1969 to 1980 ranged from 165 mm at the lower altitudes to over 280 mm just north of the Rattlesnake Hills crest (Stone and others, 1983). For the grass and sage lysimeter sites, average annual precipitation is estimated at 209 mm based on an average of two nearby stations reported by Stone and others (1983). More than 75 percent of the annual precipitation falls from October to April, about one-fourth as snow. June to September is normally the driest time of year, although convective storms can produce as much as 20 percent of the annual precipitation (Stone and others, 1983).

Dew is of minor significance and adds only small amounts of water to the annual precipitation at the study sites. No measurements of dew have been made on the ALE Reserve but Rickard and others (1988) estimate dew at less than 5 percent of the annual precipitation on the ALE Reserve on the basis of available meteorological data.

Temperatures at the study sites are primarily continental (influenced more by air masses moving over land rather than over water), but frequent storm fronts move in from the Pacific Ocean, mainly during the winter months, moderating temperatures and bringing precipitation. The average annual temperature at the weather station nearest to the ALE Reserve, located at the Hanford Meteorological Station (HMS) at an altitude of 223 m about 15 km from the study sites, is 11.7 degrees Celsius (°C). Temperature extremes at the HMS range from 46 to -33 °C (Stone and others, 1983).

Vegetation

Vegetation at the grass and sage lysimeter sites is typical of that found over most of the Columbia Plateau. At the grass lysimeter site, bluebunch wheatgrass (*Agropyron spicatum*) and Sandberg's bluegrass (*Poa sandbergii*) predominate. At the sage lysimeter site, these grasses are accompanied by big sagebrush (*Artemesia tridentata*). Cheatgrass (*Bromus tectorum*), an invasive grass introduced to Washington from Europe about 1890 (Franklin and Dyrness, 1988) grows in many areas surrounding the study sites. Vegetation covers 25 to 60 percent of the soil surface at the grass and sage lysimeter sites. The height of the grasses at the grass lysimeter site averages 0.25 m. The sagebrush plants at the sage lysimeter site average 1.0 m in height. No measurements of root depth were made at the study sites, but identical grasses were found to root mostly in the top 0.2 m of soil at a site in Snively Basin (about 5 km to the northeast), with some roots found as deep as 1.1 m. Sagebrush has a taproot that can penetrate 1 to 4 m, but a caliche layer at 2 m at the sage lysimeter site may inhibit rooting below that depth. Other plants occurring with the grasses and sagebrush at the two study sites include rabbitbrush (*Chrysothamnus nauseosus*), bitterbrush (*Purshia tridentata*), Carey's balsamroot (*Balsomorhiza careyana*), showy phlox (*Phlox speciosa*), and lupine (*Lupinus* sp.).

Sagebrush is probably the climax species on the ALE Reserve, but it is fire-sensitive (Franklin and Dyrness, 1988). A major fire in August 1984, which burned 80 percent of the ALE Reserve, eliminated sagebrush from the grass lysimeter site. Grasses cover the soil surface in all directions from 400 m to 3 km or further at the grass lysimeter site. The sage lysimeter site is located at the northeastern edge of a large area of sagebrush. Grasses begin about 30 to 100 m north and east of the sage lysimeter site, probably corresponding with the edge of the 1984 burn. Sagebrush extends over 1 km to the west and south of the sage lysimeter site.

At the ALE Reserve, vegetation grows most rapidly during the wet winter and spring seasons than during the dry summer and fall. Plant growth usually peaks from early March to mid-May, when ET is also at its maximum because of the transpiration from the growing vegetation. Drier weather, beginning in May or June, causes the grasses to go to seed and become dormant. At this time, sagebrush begins to lose a number of leaves in response to the drying conditions. In late summer and early fall, usually the driest time of year, sagebrush blooms while the grasses are completely dormant. Grasses begin growing in fall after the first major precipitation.

Geology and Soils

The study sites are located in the Columbia Plateau physiographic province. The major surficial rock features of this area are numerous layers of basalt, the result of lava flows during the Miocene and Pliocene epochs, with thin sedimentary and volcanic ash interbeds. Silt, gravel, sand, and other alluvial deposits left as a result of the so-called Spokane Flood (actually a series of floods) that swept across the Columbia Plateau during the Pleistocene epoch (Alt and Hyndman, 1984) cover much of the lower altitudes of the Columbia Plateau. Wind-blown loess was deposited over much of the Plateau during the Pleistocene and Holocene epoch. The ALE Reserve lies on the north side of the Rattlesnake Hills within the Pasco Basin. Loess, fine-grained sand, and layers of volcanic ash cover the ALE Reserve (Rockwell International, 1979). Bedrock is basalt.

Warden silt loam is found at the grass and sage lysimeter sites. Permeability is moderate, water-holding capacity is high, and runoff potential is low for this soil type (U.S. Department of Agriculture, 1971). Granite boulders are found in many areas of Warden silt loam, having been carried to the area with glacial ice by the Spokane Flood. Warden silt loam becomes strongly calcareous at about 0.5 m below the surface (U.S. Department of Agriculture, 1971), a characteristic of many soils in arid and semiarid regions. A caliche layer exists in the soil profile at about 2 m below the surface (R. Kirkham, Battelle, Pacific Northwest Laboratories, oral commun., 1995). Soil bulk densities based on collected samples ranged from 1,300 to 1,600 kilograms per cubic meter (kg/m^3) at the grass and sage lysimeter sites. The average soil bulk density was 1,400 kg/m^3.

Hydrology

At the grass and sage lysimeter sites, almost all precipitation is returned to the atmosphere as ET. Thus, there is probably little ground-water recharge except during very wet periods in some winters, when ET is minimal. In a water budget study for a sandy soil on the Hanford Site, Gee and Kirkham (1984) reported that 5 centimeters (cm) of water penetrated 3.5 m below the land surface during wet years. Link and others (1990) found that grass-covered areas of the ALE Reserve held more water at depths of 2.75 m than areas covered with sagebrush. Consequently, grass-covered areas, such as the grass lysimeter site, might be expected to allow more recharge than areas covered with the deeper-rooted sagebrush, which would remove deeper soil moisture. Schwab and others (1979) described 125 springs on the ALE Reserve and found flows ranging from small seeps, with instantaneous discharges estimated at less than 1.6×10^{-5} cubic meters per second (m^3/s), to streams originating from multiple springs, with combined flows of 4.4×10^{-3} m^3/s. Streams fed by discharge from these springs and seasonal snowmelt from higher altitudes of the ALE Reserve flow down to the lower altitudes of the Reserve, where they disappear along losing reaches. In so doing, these springs reportedly recharge a perched water table, which is about 20 m above the true static water table (Harr and Price, 1972). The closest spring to the grass and sage lysimeter sites is Benson Spring (fig. 2). It is located at higher altitudes 2 km south of the sites and flows at an estimated 6.2×10^{-4} m^3/s (Schwab and others, 1979). Although Benson Spring may provide additional soil moisture to plants in ravines and other low-lying areas near the grass and sage lysimeter sites, the spring probably does not affect plants at the lysimeters sites themselves—the plant roots probably do not grow deep enough to access the basalt layers where spring water might be available (R. Kirkham, Battelle, Pacific Northwest Laboratories, oral commun., 1996).

METHODS OF ESTIMATING EVAPOTRANSPIRATION

This section describes the methods of data collection and analysis used in this study to estimate ET. Included is a description of instruments, energy-budgets, Bowen-ratio method, eddy-correlation method, and weighing lysimeters. The Bowen-ratio energy-budget method requires data for net radiation, air temperature and vapor pressure at two heights, soil temperature, and soil-heat flux. The eddy-correlation method requires direct measurement of latent- and sensible-heat fluxes by monitoring fluctuations (instantaneous deviations from the mean) in vertical wind speed, vapor density, and air temperature. Net radiation and soil-heat flux are also often collected with the eddy correlation data to determine energy-budget closure. Use of lysimeters requires measurement of weight changes in the lysimeter to detect ET (weight losses) or precipitation (weight gains). Field personnel collected soil samples during each site visit to determine soil-water content.

In this study, data for estimating ET with the Bowen-ratio method were collected with two instrument setups. In the first setup, air temperature was measured with fine-wire thermocouples, and air from two intakes was routed to a cooled-mirror hygrometer to estimate vapor pressure, eliminating sensor bias. In this report, this fine-wire thermocouple/cooled-mirror setup is referred to as the Bowen-ratio system, or Bowen-ratio instruments. In the second setup, air temperature and relative humidity were measured with two air temperature-relative humidity probes set at two fixed heights; sensor bias was not accounted for. In this report, this setup using sensors at fixed heights is termed the fixed-sensor system, or fixed-sensor instruments. Though the instruments are different in the Bowen-ratio and fixed-sensor systems, both setups collect data to estimate ET with the Bowen-ratio method. The fixed-sensor system allowed the Bowen-ratio method to be used in winter, when the Bowen-ratio system of instruments could not be operated because of the cooled-mirror hygrometer's sensitivity to below-freezing air temperatures. The fixed-sensor system also allowed Bowen-ratio ET estimates to be made when fine-wire thermocouples broke or the cooled-mirror hygrometer failed or provided unreasonable vapor-pressure gradients during the spring, summer, and fall.

Methods and periods of data collection varied at the grass and sage lysimeter sites. At the grass lysimeter site, the Bowen-ratio method was used in May and June 1993, and from March to November 1994. At the sage lysimeter site, the Bowen-ratio method was used from May to November 1993 and from March to October 1994. Additional Bowen-ratio data utilizing a fixed-sensor system of instruments collected data at both sites during the fall, winter, and spring of 1993 to 1994. The eddy-correlation method was used at the grass lysimeter site in late March and early April 1994. Battelle, Pacific Northwest Laboratories collected eddy-correlation data at the sage lysimeter site from April to May 1994 (R. Kirkham, Battelle, Pacific Northwest Laboratories, written commun., 1995). The lysimeters, installed and managed by Battelle, Pacific Northwest Laboratories, operated almost continuously at both study sites during the period of study, August 1990 to November 1994.

Instrumentation

Figure 3 shows the instruments used to collect data needed to estimate ET at the grass and sage lysimeter sites; table 1 describes each of them. Bowen-ratio instruments, fixed-sensor instruments, eddy-correlation instruments, and weighing lysimeters were used at the study sites. More detailed information on the Bowen-ratio and fixed-sensor instruments is presented by Tomlinson (1994), on the eddy-correlation instruments by Bidlake and others (1993, p. 13), on the lysimeters by Gee and others (1991), and on the fixed-sensor instruments following the description of Bowen-ratio instruments in this section. The Bowen-ratio and fixed-sensor instruments collected data at 1 and 10-second intervals and reported averages every 20 minutes during spring, summer, and early fall. During late fall and winter, the fixed-ratio instruments reported data averages every 60 minutes. Eddy-correlation instruments collected data at various intervals and reported averages every 20 minutes. Lysimeters collected data at 10-second intervals and reported averages every 60 minutes.

Bowen-ratio instruments consisted of two fine-wire thermocouples to measure air temperature at two heights, two vapor-pressure intakes connected to one cooled-mirror hygrometer to measure vapor pressure at the same two heights as air temperature, two net radiometers, two soil-temperature thermocouples, and four soil-heat flux transducers. The air from the two intakes was routed alternately at 2-minute intervals to one cooled-mirror. This eliminated sensor bias, which could result if two independent instruments were used. This system was used at the grass and sage lysimeter sites during spring, summer, and fall of 1993 and 1994.

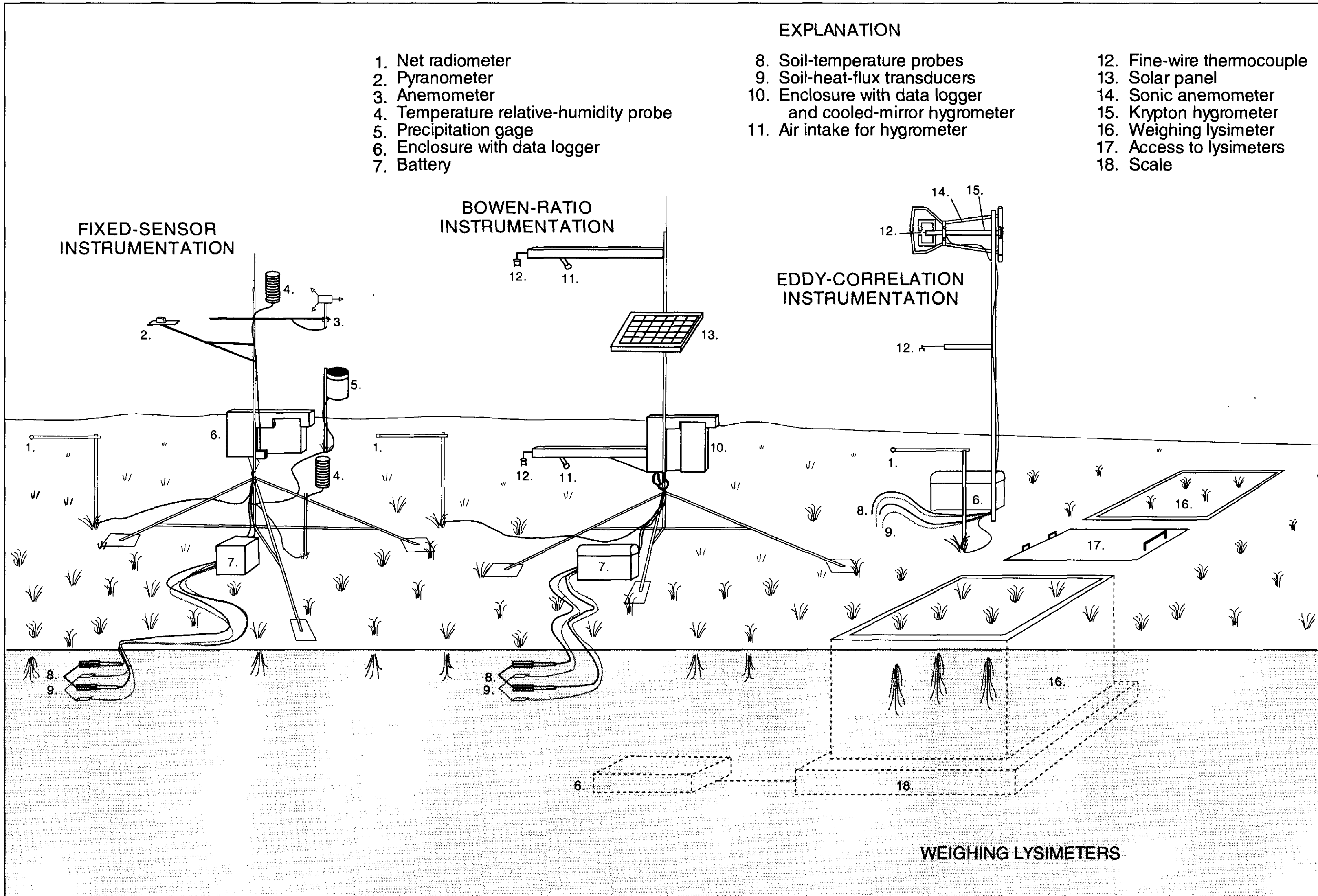


Figure 3.--Evapotranspiration instrumentation setups.

Table 1.--*Instrumentation used at evapotranspiration study sites*

Instrument type	Function	Manufacturer (Model)
Data logger	Scan instruments, record and process data	Campbell Scientific (21X)
Net radiometer	Measure net radiation	Radiation and Energy Balance Systems (Q-6)
Pyranometer	Measure solar and diffuse radiation	LI-COR (LI-200S)
Anemometer	Measure wind speed	Met One (014A)
Temperature-relative humidity probe	Measure air temperature and relative humidity	Campbell Scientific (CR-207)
Precipitation gage	Measure precipitation	Texas Electronics (TE-525)
Soil-temperature thermocouple	Measure average soil temperature	Radiation and Energy Balance Systems (TCAV)
Soil-heat-flux transducer	Measure soil-heat flux	Radiation and Energy Balance Systems (HFT-1)
Cooled-mirror hygrometer	Measure vapor pressure and dew point	General Eastern (DEW-10) and Campbell Scientific (023)
Fine-wire thermocouple	Measure air temperature	Campbell Scientific (FWTC-1, FWTC-3, CA-127)
Krypton hygrometer	Measure vapor density	Campbell Scientific (KH20)
Sonic anemometer	Measure vertical wind-speed fluctuations	Campbell Scientific (CA-27)

At the grass and sage lysimeter sites, numerous problems with the cooled-mirror hygrometer resulted in periods of erroneous data in 1993. Leaks in the cooled-mirror chambers of the instruments at both sites resulted in erroneous vapor-pressure data in March and April 1993. A wiring problem in the cooled-mirror sensor at the grass lysimeter site resulted in erroneous vapor-pressure data from late June to late October 1993. The problem was hard to detect because the cooled mirror provided reasonable vapor-pressure values, but provided erroneous vapor-pressure gradients. At the sage lysimeter site, leaks in the cooled-mirror chamber resulted in erroneous data in March and April 1993. Electrical problems with the cooled-mirror hygrometer at the sage lysimeter site resulted in erroneous vapor-pressure data during most of May and the first half of June 1993. In mid-June 1993, a second Bowen-ratio system was installed at the sage lysimeter site because of the numerous problems with the original one. Unfortunately, inexplicable problems with this cooled-mirror hygrometer resulted in erroneous data from mid-July to late August 1993. During spring, summer, and fall of 1994, however, all Bowen-ratio instruments worked very well, overall; only a few inexplicable problems were encountered with one of the cooled-mirror hygrometers at the sage lysimeter site.

Because the cooled-mirror hygrometers did not operate properly in 1993 and could not be operated during winter because of their sensitivity to freezing temperatures, a fixed-sensor system was set up at each site during the fall of 1993. This fixed-sensor system utilized the Bowen-ratio method with the exception that sensor bias was not eliminated—the air-temperature and relative-humidity sensors (which were used to calculate vapor pressure) were not interchanged. Campbell Scientific CR-207 temperature-relative humidity probes (table 1; fig. 3) were used in the fixed-sensor system. Under many conditions, such as cool air temperatures, high winds, and rain, air-temperature and vapor-pressure data from the Bowen-ratio systems compared very favorably with data from the fixed-sensor systems. These favorable comparisons allowed Bowen-ratio estimates of ET to be made with the fixed-sensor systems during winter as well as during periods when the cooled-mirror hygrometers were not operating properly.

The eddy-correlation systems consisted of three primary sensors that measured the fluctuations in water-vapor density, vertical wind speed, and air temperature. An ultraviolet krypton hygrometer measured instantaneous changes in water-vapor density, while a one-dimensional sonic anemometer with a fine-wire thermocouple measured instantaneous changes in both vertical wind speed and air temperature. The changes in vapor density and air temperature are used to calculate the latent-heat flux, and the changes in vertical wind speed and air temperature are used to calculate the sensible-heat flux. Because the fine-wire thermocouple on each sonic anemometer does not measure absolute air temperatures, an additional sensor was added to the eddy-correlation system to measure ambient air temperature. The ambient air temperature data are used to determine air density, define the proper vapor range of the krypton hygrometer, and calculate latent-heat flux.

Optional sensors were added to the eddy-correlation system to measure net radiation and soil-heat flux, allowing for a check of energy-budget closure in the energy-budget equation (eq. 1). These optional sensors were a net radiometer, two soil-heat flux transducers, and one set of four averaging soil-temperature thermocouples. Also, periodic measurements of soil moisture between the soil-heat flux transducers and the soil surface were taken to find the total soil-heat capacity.

The three primary eddy-correlation sensors are delicate and can be easily damaged. Rainfall is problematic for the eddy-correlation sensors. The krypton hygrometer and sonic anemometer must be dry to make accurate measurements. Prolonged exposure to moisture can damage the seals on the krypton hygrometer and water can damage the unsealed transducers in the sonic anemometer. Additionally, the fine-wire thermocouple may be broken by impacts from raindrops, airborne debris, or insects. Therefore, the eddy-correlation instruments were used only for short periods of time at the study sites—during late March and early April 1994 by the U.S. Geological Survey at the grass lysimeter site and during April and May 1994 by Battelle, Pacific Northwest Laboratories at the sage lysimeter site.

Weighing lysimeters are containers of soil buried flush with the soil surface. The containers are weighed periodically to measure changes in the lysimeter mass. Decreases in mass result mostly from ET, whereas increases result mostly from precipitation or dew. Changes in plant mass are not accounted for separately from ET and precipitation, but they are probably very small and can be ignored.

Energy Budgets and the Bowen-Ratio Method

Energy-budget methods, such as the Bowen-ratio method, use the terms, symbols, and equations outlined at the beginning of the report. Detailed information on the Bowen-ratio method is presented by Tomlinson (1994). Additionally, the Bowen-ratio method is described in great detail in textbooks written by Campbell (1977), Brutsaert (1982), Rosenberg and others (1983), and Monteith and Unsworth (1990). The notation and form of the equations used in these texts may differ from those used in this report, but the principles are the same.

ET involves a phase change of water from liquid to vapor (a process requiring energy) and the movement of that vapor into the atmosphere. ET can be conceptualized by an energy budget, which has four major flux components: net radiation, latent-heat flux, sensible-heat flux, and soil-heat flux. Field measurement of the energy-budget components encompasses a layer with an upper boundary just above the plant canopy and a lower boundary just below the soil surface (fig. 4), in this report called the canopy layer. In the energy-budget equation (eq. 1), net radiation equals the sum of the other three fluxes.

Net radiation, R_n, defined as the sum of all incoming shortwave solar radiation and incoming longwave sky radiation minus the sum of reflected solar radiation and emitted longwave radiation (Haan and others, 1982), provides the major energy source for the energy budget. Net radiation is considered positive when the sum of the incoming radiation fluxes exceeds the sum of the outgoing radiation fluxes.

Latent-heat flux, LE, results from the vaporization and movement of water. It is the product of the latent-heat of vaporization of water (eq. 2, 3) and ET (eq. 13b). In this report, latent-heat flux is considered positive when vapor is transferred upward across the canopy layer.

Sensible-heat flux, H, is a turbulent, temperature gradient-driven heat flux resulting from differences in temperature between soil and vegetative surfaces and the atmosphere. In this report, sensible-heat flux is considered positive when heat is transferred upward from the surface across the upper boundary of the canopy layer. During the daytime, positive sensible-heat flux is often the result of surface heating. At night, sensible-heat flux is often less than zero, the result of surface cooling.

Soil-heat flux, G, represents redistribution of energy by conduction through the soil profile (eq. 4). Soil-heat flux transducers measure the gradient across a material of known thermal conductivity. Although the thermal conductivity of the soil changes with soil-moisture content and may differ from the transducer material, these differences produce small changes in the overall soil-heat flux and are ignored in this study. Soil-heat flux includes the amount of energy that is stored in or comes from the layer of soil between the surface and the point of measurement (eq. 5). In this report, soil-heat flux is considered positive when moving down through the soil from the land surface and negative when moving upward through the soil towards the surface.

The Bowen-ratio method incorporates energy-budget principles and turbulent-transfer theory (Brutsaert, 1982, p. 210-214). The ratio of sensible- to latent-heat flux (eq. 1) is known as the Bowen ratio (Bowen, 1926). Bowen showed that this ratio, β (eq. 6), could be calculated from vertical gradients of temperature and vapor over a surface (eq. 7) under certain conditions. Often the gradients are approximated from air-temperature and vapor-pressure measurements taken at two heights above the canopy. The Bowen-ratio method assumes that there is no net horizontal advection of energy. If there is no net horizontal advection of energy, the coefficients (eddy diffusivities) for heat and water vapor transport, K_h and K_w, respectively, are assumed to be equal. With this assumption (eq. 8) and the combining of several terms to form the psychrometric constant (eq. 9), the Bowen ratio takes the form of equation 10. Once the Bowen ratio is determined, the energy-budget equation (eq. 1) can be solved for the sensible-heat flux (eq. 11) and latent-heat flux (eq. 12).

The rate of ET can then be determined using the latent-heat flux, latent-heat of vaporization of water, and a factor (86.4) that accounts for the conversion of units (eq. 13a). The conversion and factor are derived as follows. Given that LE is in units of Watts per square meter (W/m2), which is equivalent to Joules per second-meter squared (J/sm^2), that L is in units of Joules per gram (J/g), that there are 8.64 x10^4 seconds in a day (24 hours/day x 60 minutes/hour x 60 seconds/hour), and that 1 x 10^{-6} m^3 of water equals 1.0 g, then

$$\left[\left(J/sm^2\right)/(J/g)\right]\left(8.64x10^4 s/d\right)$$
$$\left(1x10^{-6} m^3/g\right)\left(1x10^3 mm/m\right) = 86.4mm/d$$

One of the requirements for using the Bowen-ratio method is that the wind must move over a sufficient distance of similar vegetation and terrain before it reaches the sensors. This distance is termed fetch, and it is generally considered to be 100 times the height of the sensors (Campbell, 1977, p. 40). At the study sites, the maximum height that sensors were placed was 3.2 m above the canopy. Therefore, a distance of 320 m of similar vegetation and terrain should be present at the sites. This requirement was met at the grass lysimeter site but not at the sage lysimeter site. The sage lysimeter site is at the northeastern end of an extensive patch of sagebrush but only 30 to 100 m from an area with grasses but no sagebrush. Winds coming directly from the south or southwest passed over this grassy area before reaching the instruments at the sage lysimeter site, so there may have been times during the study period when fetch requirements were not met. However, to compare Bowen-ratio ET estimates with the lysimeter ET estimates, it was necessary to install the Bowen-ratio instruments in this part of the sagebrush patch so they could collect data adjacent to the lysimeters. Whether the differences between the non-sagebrush area and the sagebrush area were sufficient to affect the data that were collected is not certain. For most of 1994, Bowen-ratio ET at the sage lysimeter site was close to Bowen-ratio ET at the grass lysimeter site, suggesting that the differences between the two sites were small. There were some periods, however, when the differences in ET at the grass and sage lysimeter sites were large.

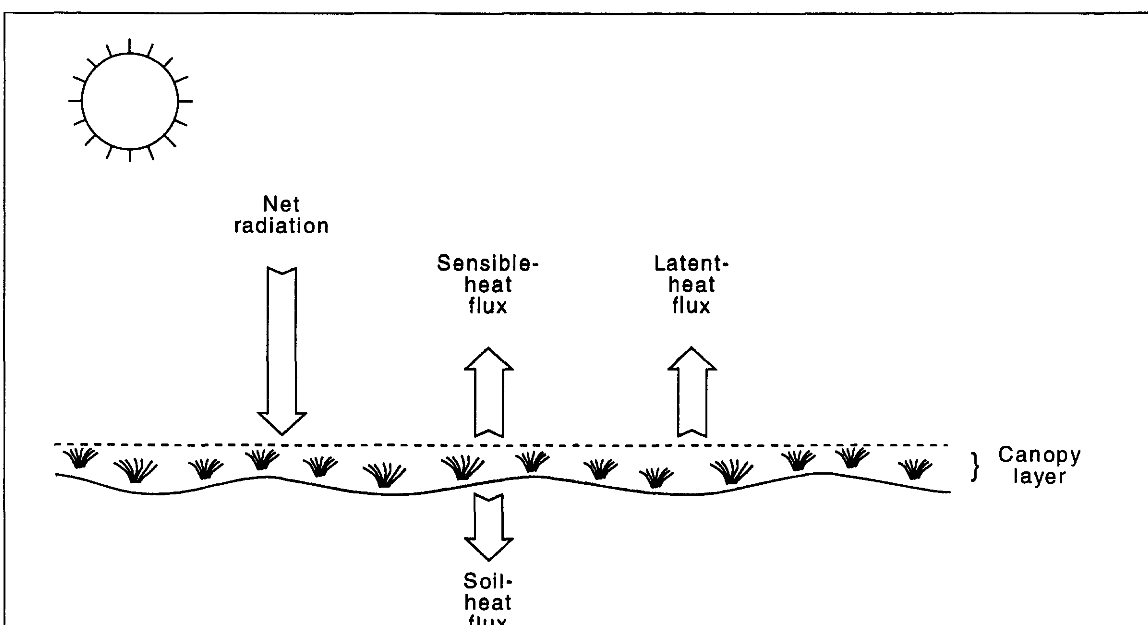


Figure 4.--Energy budget in the canopy layer.

Eddy-Correlation Method

Water vapor is transported in the vertical direction by the upward and downward motion of small parcels of air, called eddies. As air near the surface picks up moisture, the air becomes less dense, moving up while drier, denser air moves down. For a sufficiently long period of time over horizontally uniform terrain, the total quantity of ascending air is about equal to the total quantity of descending air, and the mean value of the vertical velocity will be zero (Rosenberg and others, 1983, p. 145). Latent-heat flux is determined by measuring the covariance of instantaneous departures from the mean values of both vertical wind speed and vapor pressure (eq. 14). Similarly, sensible-heat flux is determined by measuring the covariance of instantaneous departures from the mean values of both vertical wind speed and air temperature (eq. 15). The eddy-correlation method is very useful in semiarid areas, where vapor-pressure gradients are often very small and difficult to measure using the Bowen-ratio method. When air-temperature and vapor-pressure gradients are small, such as over rough surfaces (like the sage lysimeter site), the usually large vertical velocity fluctuations can be measured by eddy-correlation instruments (Rosenberg and others, 1983, p. 146). Along with the eddy-correlation estimates of sensible- and latent-heat flux, net radiation and soil-heat flux are usually also measured to estimate an energy budget. The energy-budget equation (eq. 1) can be used to determine the closure of the eddy-correlation estimates—that is, how close to zero is net radiation minus the sum of soil-heat, latent-heat, and sensible-heat fluxes.

Weighing Lysimeters

Weighing lysimeters provide the most direct method for estimating ET (Kirkham and others, 1991). Weighing lysimeters are, in their simplest form, containers of soil, buried flush with the ground surface, that are weighed periodically. When the lysimeter soil profile and the type and density of vegetation properly represent the surrounding area, lysimeters are considered the standard by which other methods, such as Bowen ratio and eddy correlation, are evaluated.

The lysimeters at the study sites employ a box-within-a-box construction. The inner box contains a monolith of soil and vegetation from the area that is as undisturbed as possible. The inner box rests on a scale for measurements of mass. The outer box acts primarily as a retaining wall for the soil profile surrounding the lysimeter. Changes in lysimeter mass are primarily due to ET losses or precipitation gains. Carbon gain (plant growth) and scale sensitivities to temperature are small and ignored. For shrub deserts (such as the sage lysimeter site), Larcher (1995, p.152) estimates annual vegetative production at only 0.01 to 0.3 kilogram per square meter (kg/m^2) of surface area.

The lysimeters were installed by Battelle, Pacific Northwest Laboratories, at the grass and sage lysimeter sites during the summer of 1986 (Gee and others, 1991). The lysimeters were watered in 1986 to reduce plant shock and to settle the soil monoliths. Data collection began in November 1987. The lysimeters use scales that are sensitive to 50 g, equivalent to 0.02 mm of water (Gee and others, 1991). The surface dimensions of the inner boxes of the ALE Reserve lysimeters are about 1.5 m square and 1.4 to 1.6 m deep (Kirkham and others, 1991).

The scales that weigh the lysimeter monoliths at the grass and sage lysimeter sites produce voltages that are measured every 10 seconds and averaged every hour (Gee and others, 1991). The hourly average voltages are converted to weight in kilograms by adding 1 to the voltage and multiplying the result by a calibration factor (R. Kirkham, Battelle, Pacific Northwest Laboratories, written commun., 1991). The factors, in kilograms per volt (kg/v) are as follows:

Lysimeter number	Site	Calibration factor (kg/v)
1	Grass	4650.2527
2	Grass	4646.3382
3	Sage	4651.5727
4	Sage	4645.2527

The differences between the hourly weights can then be converted to ET (negative weight difference) or precipitation (positive weight difference) in millimeters as follows: divide the weight difference in kilograms per hour by 23,104 square centimeters (cm^2)—the area of each lysimeter; multiply the result by 10,000 mm per kg per cm^2 to obtain a value in millimeters per hour. Sum the hourly weight losses (negative weight differences) to obtain daily ET, and sum weight gains (positive weight differences) to obtain daily precipitation. An alternate method to obtain daily ET is to use midnight-to-midnight voltage values, then subtract daily precipitation.

Estimating ET and precipitation using the lysimeter data was usually fairly straightforward, but there were some exceptions. The process of calculating daily ET and precipitation was normally a simple matter of summing the hourly weight losses (ET) and weight gains (precipitation). However, during short-duration storms, for example, precipitation and ET probably occurred during the same hour and the net hourly result was the greater of ET or precipitation. Weight gains and losses might also have been due to soil or snow movement during windstorms or to animal trespass. Also, during very dry periods, particularly during the fall, the lysimeters tended to gain weight at night and lose weight during the morning, possibly the result of dew formation or heating and cooling effects on the lysimeter monoliths (R. Kirkham, Battelle, Pacific Northwest Laboratories, oral commun., 1993). For instance, from October 30 to November 12, 1993, no precipitation occurred, yet the two lysimeters at the sage lysimeter site averaged a 0.63 mm gain in weight over the period.

RESULTS

ET values, ET comparisons, and water budgets provided both similar and contrasting results at each site. Seasonal patterns of ET were similar at the grass and sage lysimeter sites. Comparisons of daily ET estimated with weighing lysimeters and the Bowen-ratio method at both sites showed there were many daily differences, some of them more than 100 percent, but there were few differences in seasonal or annual totals of ET. Most of the large differences resulted when ET values were low. The major differences may have been due to Bowen-ratio instrument (cooled-mirror hygrometer) variability or error, or to conditions in the lysimeters not representing conditions in the overall landscape. Water budgets for the grass and sage lysimeter sites showed that cumulative ET ranged from 97 to 103 percent of the annual precipitation at the sites during 1993 and 1994.

Using the Bowen-ratio and eddy-correlation methods, sensible- and latent-heat flux were determined. After latent-heat flux was calculated (eq. 1), ET was estimated as part of the latent-heat flux (eq. 13a). For these estimates from the Bowen-ratio and eddy-correlation methods, averages of all net radiometer values and soil-heat flux values at each site were used to provide a more detailed comparison of ET between the methods.

Differences in net radiometers and soil-heat flux transducers were generally small at each of the sites. At the grass lysimeter site, four net radiometers differed by an average of only 3 percent; at the sage lysimeter site, three net radiometers differed by an average of 5 percent. These values are close to the 4-percent instrument difference in net radiation estimated at a grass site in Snively Basin on the ALE Reserve (Tomlinson, 1995, p. 15). Soil-heat flux transducers varied more (about 35 percent) but would produce, at most, an 11-12 percent change in daily ET from using the average soil-heat flux, within range of the 12-percent error due to the instruments themselves (Tomlinson, 1995, p. 15). Thus, the differences between the ET estimated by the methods are due almost entirely to the methods and the associated measurements, not small differences in net radiation or soil-heat flux instruments.

Daily values of ET were estimated from the lysimeters by summing all the hourly incremental lysimeter weight losses for each 24-hour period. To compare the 20-minute Bowen-ratio and eddy-correlation ET with the hourly lysimeter ET, hourly averages of Bowen-ratio and eddy-correlation ET were determined by averaging three 20-minute values. Daily ET estimates were made by averaging all the 20-minute values of ET (Bowen-ratio and eddy-correlation data), or hourly values of ET (lysimeter data).

Energy Budgets

In an energy budget, net radiation equals the sum of the soil-heat, sensible-heat, and latent-heat fluxes (eq. 1). The variability of net radiation and the other fluxes depends on many factors: vegetation (type, height, and extent), stage of plant growth, amount and density of cloud cover, precipitation, wind speed, season of the year, and soil-moisture content. Some plant canopies, such as forests, can also store large amounts of heat that can be part of the energy budget. Canopy heat storage for the grass and sage lysimeter sites was considered negligible because of the sparse nature and short height of the canopies. The variability of energy-budget fluxes for different days depended on several conditions: amount and density of cloud cover, rainfall, wind speed, season of the year, soil-moisture availability, and stage of plant growth. Figures 5-11 show selected energy budget plots for a variety of conditions in the period of study. (Text continued on p. 22.)

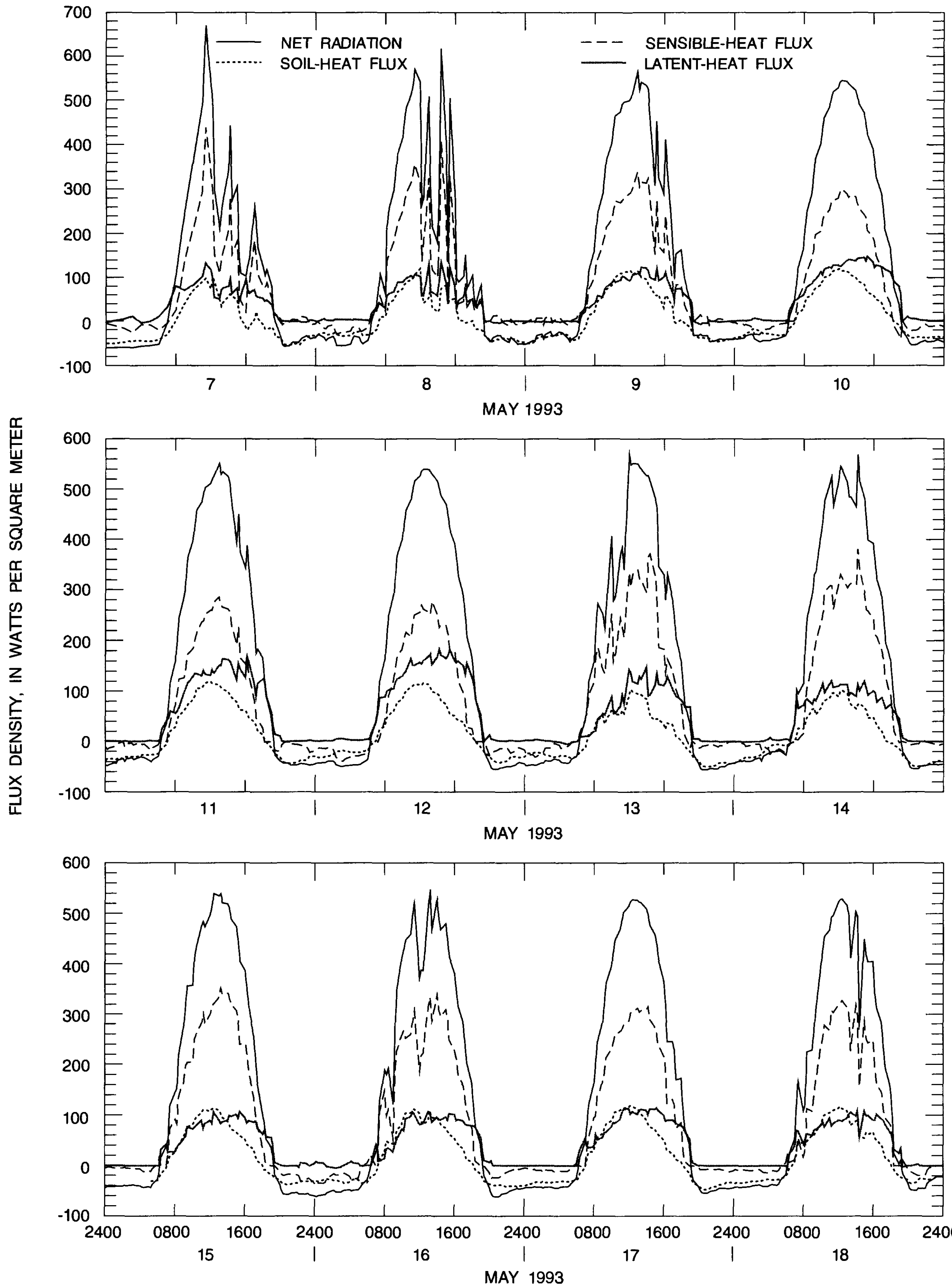


Figure 5.--Energy budget at grass lysimeter site, May 7-18, 1993.

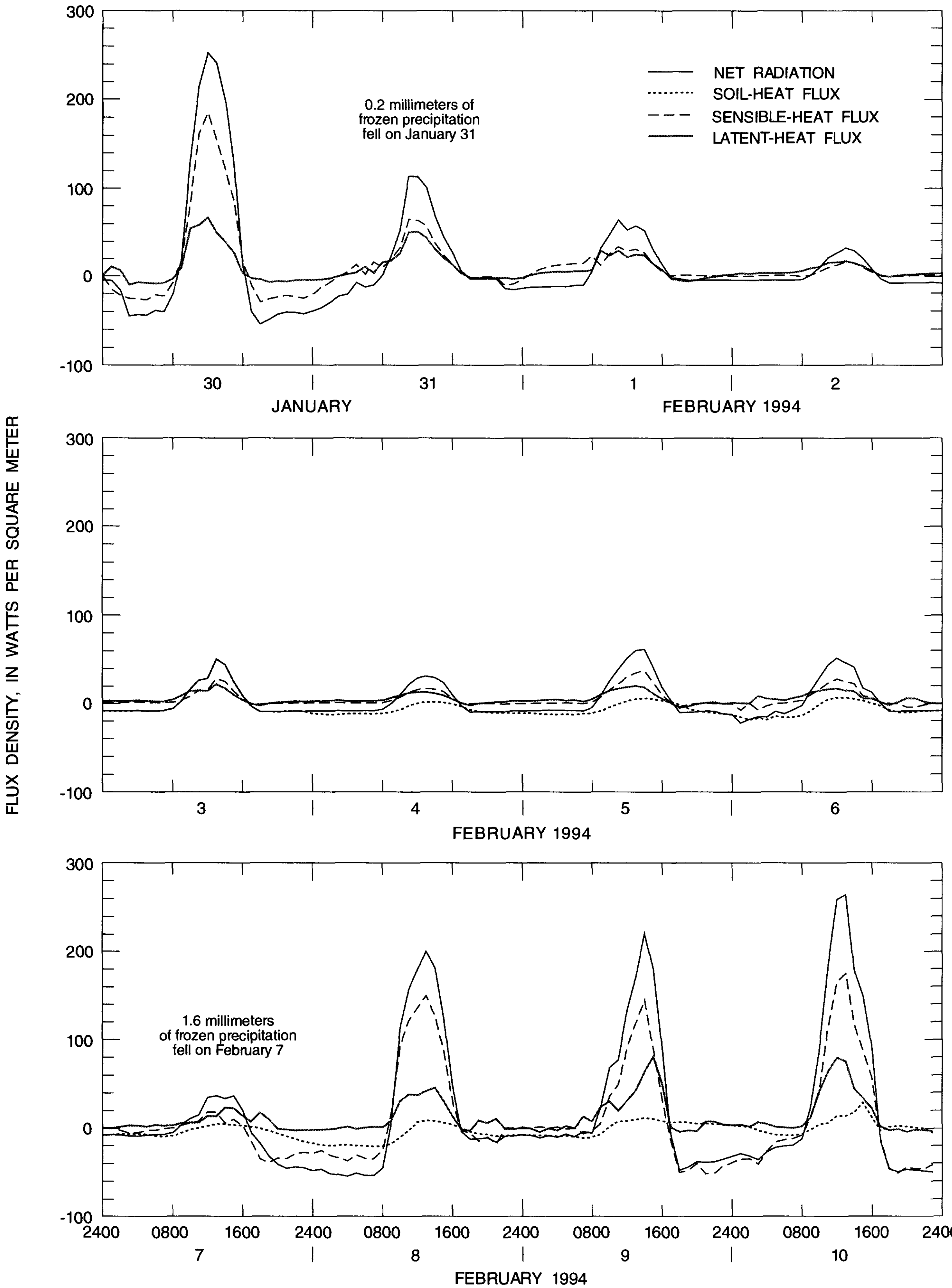


Figure 6.--Energy budget at grass lysimeter site, January 30 to February 10, 1994.

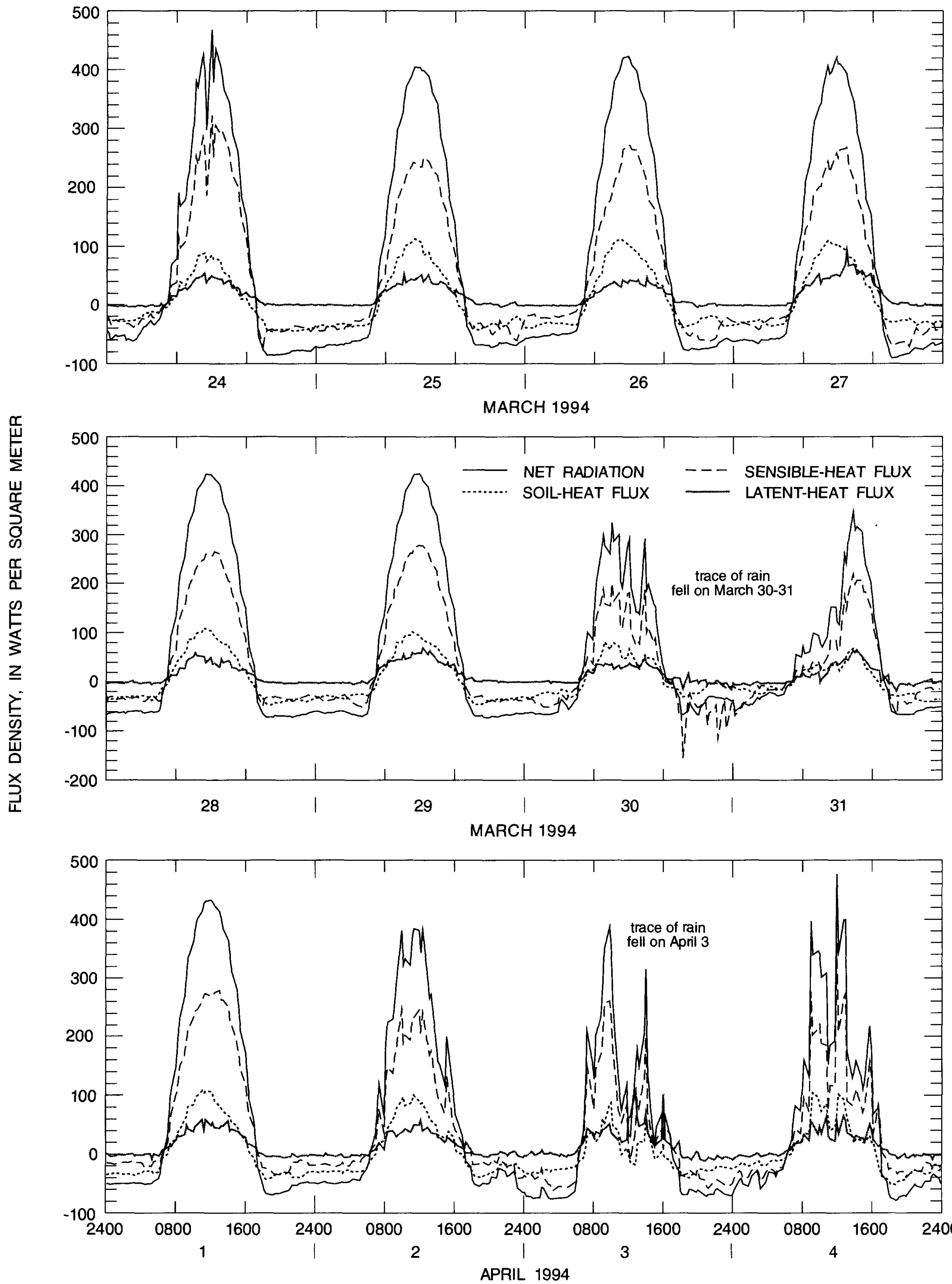


Figure 7.--Energy budget at grass lysimeter site, March 24 to April 4, 1994.

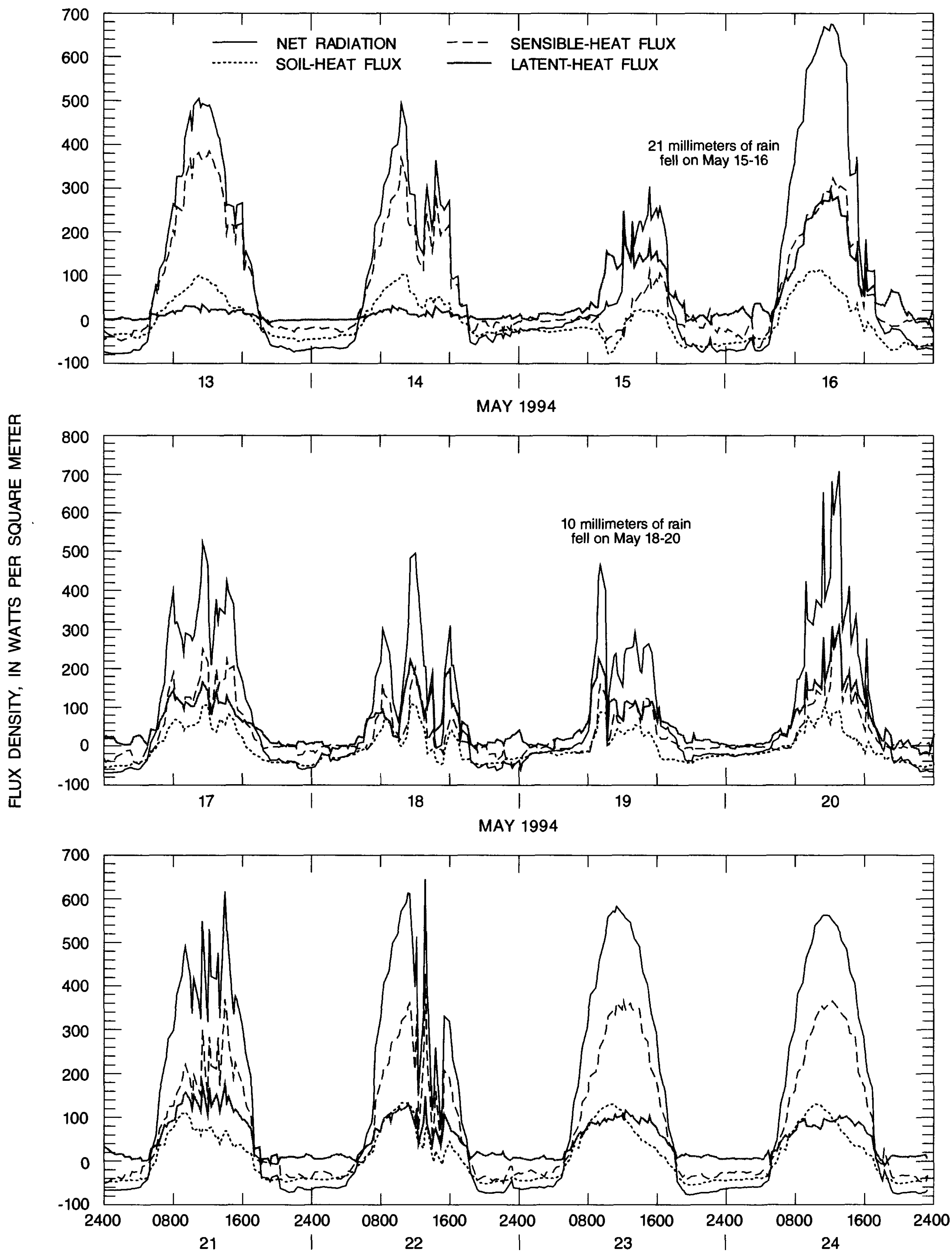


Figure 8.--Energy budget at grass lysimeter site, May 13-24, 1994.

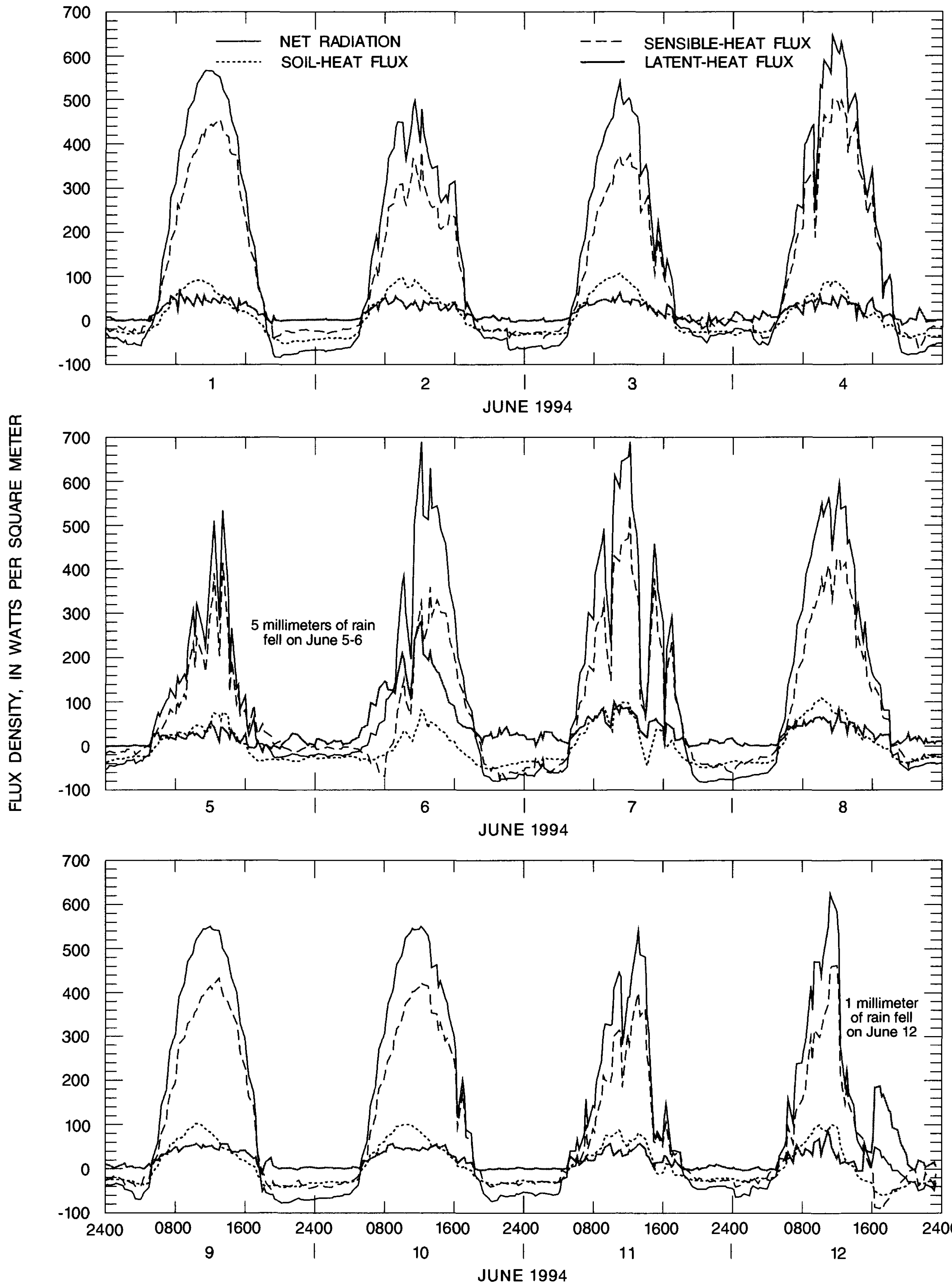


Figure 9.--Energy budget at grass lysimeter site, June 1-12, 1994.

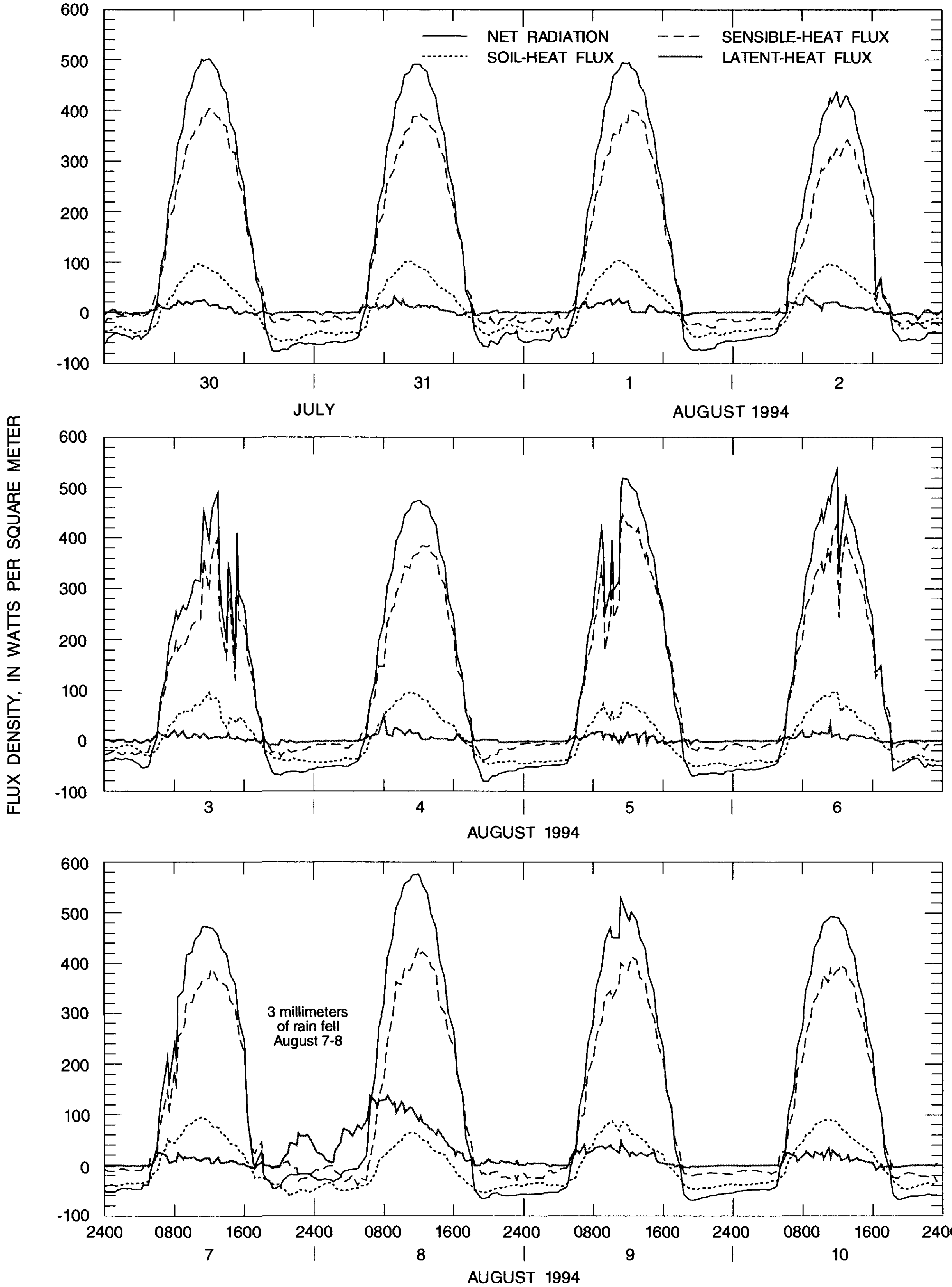


Figure 10.--Energy budget at grass lysimeter site, July 30 to August 10, 1994.

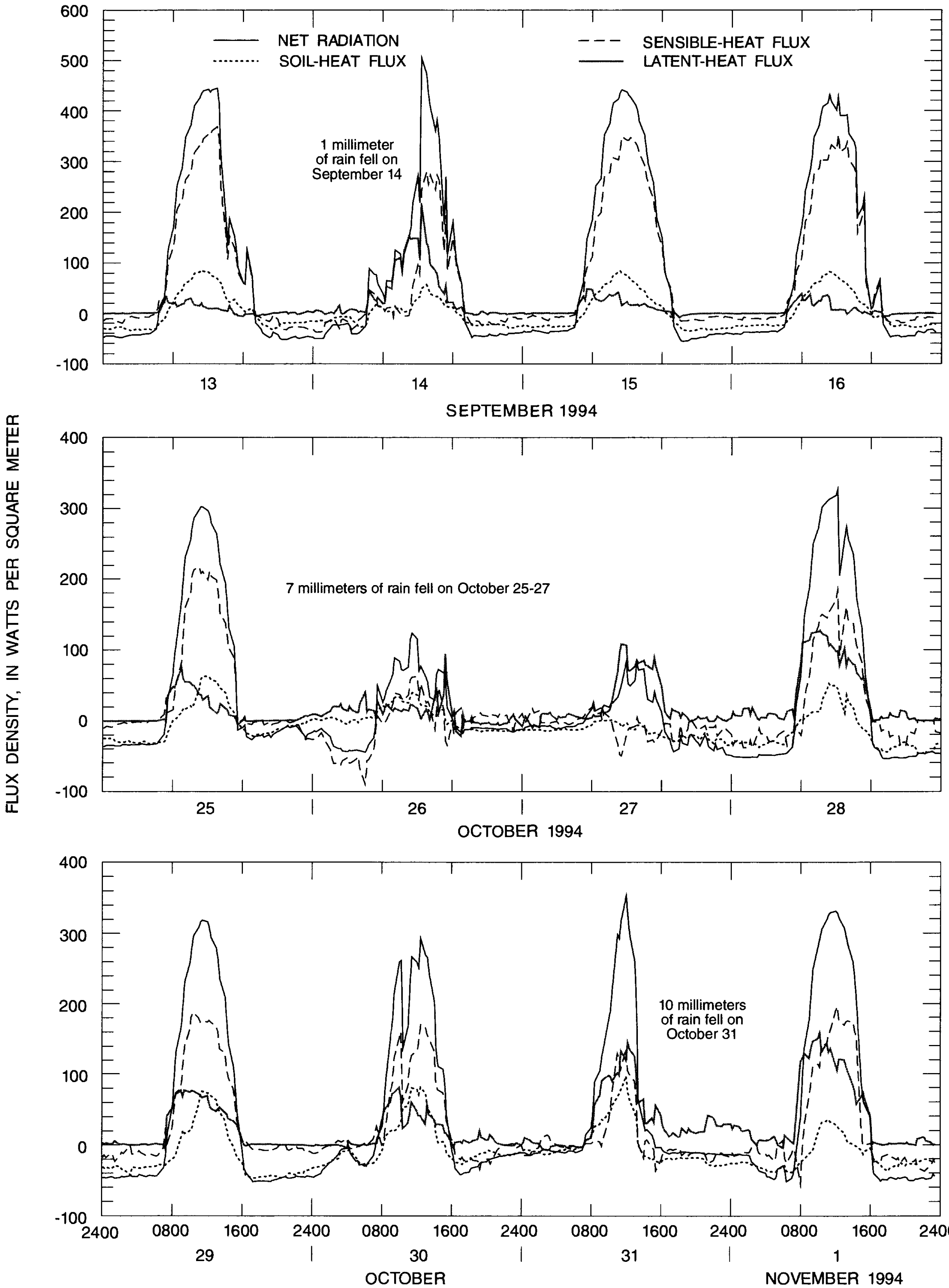


Figure 11.--Energy budget at grass lysimeter site, September 13-16 and October 25 to November 1, 1994.

Net radiation showed considerable variability depending on cloud cover and season of the year. On clear days (March 25-29, 1994, fig 7; May 23-24, 1994, fig 8; and July 30 to August 1, 1994, fig. 10), net radiation peaked around noon and measured near zero at sunrise and sunset. The smoothness of net radiation was also generally reflected in the other fluxes. Net radiation on partly cloudy days (April 2-4, 1994, fig. 7; May 17, 1994, fig. 8; and June 5-8, 1994, fig. 9) was irregular due to clouds passing over the site. On completely cloudy days (May 15 and 18-19, 1994, fig. 8 and October 26-27, 1994, fig. 11), net radiation and other fluxes were low and somewhat irregular, depending on the thickness of the cloud cover. On days of fog (February 2-7, 1994, fig. 6), net radiation and other fluxes were extremely low, less than 50 W/m^2. During days of precipitation (May 15, 1994, fig. 8 and October 26-27, 1994, fig. 11), daytime net radiation and other fluxes remained very low, sometimes less than 100 W/m^2.

The energy-budget plots show strong seasonal differences in net radiation. Net radiation on a clear day in winter (January 30, 1994, fig. 6) is only about 60 percent as much as on a clear day in spring (March 25-29, 1994, fig. 7) or 45 percent as much on a clear day near the summer solstice (June 9-10, 1994, fig. 9). Different angles of the sun above the horizon during the different seasons probably account for most of these seasonal differences in net radiation; for latitude 47 degrees north, the approximate latitude of the grass and sage lysimeter sites, the sun reaches a maximum angle of 20 degrees above the horizon at winter solstice and a maximum angle of 66 degrees above the horizon at summer solstice. Atmospheric transmittance, surface albedo, and air temperature contributed to the lower net radiation values in winter.

During days of precipitation (May 15, 1994, fig. 8 and October 26-27, 1994, fig. 11), soil and atmospheric radiation produced little surface warming so that soil- and sensible-heat fluxes remained low. Most of the energy from net radiation was lost through ET; latent-heat flux approached the net radiation value. Dramatic drops in the fluxes were sometimes noted during late afternoon rainstorms (June 12, 1994, fig. 9).

For periods when the top layer of soil and the air were extremely dry (July 30 to August 6, 1994, fig. 10), most net radiation became sensible-heat flux and, to a lesser extent, soil-heat flux. In these cases, sensible-heat flux approached net radiation, while the latent-heat flux approached zero. Exceptions occurred during these dry periods when a light rainfall produced a short increase in latent-heat flux (August 7-8, 1994, fig. 10 and September 14, 1994, fig. 11).

Latent-heat flux can be high at times without significant precipitation, as a result of plant transpiration and wind-induced evaporation from soil. In spring, when vegetation is in full growth (plant shoots are maturing and seed heads are starting to develop), transpiration is high and is reflected in high latent-heat flux (ET more than 2 mm/d) even in the absence of substantial rainfall for several days (May 10-12, 1993, fig. 5). Winds of more than 12 meters per second (m/s) produced high latent-heat flux at night after 1 mm of rainfall in the late afternoon (June 12, 1994, fig. 9).

Comparison of Weighing-Lysimeter Evapotranspiration at the Grass and Sage Lysimeter Sites

Evapotranspiration estimates based on weight changes in the lysimeters at both the grass and sage lysimeter sites agreed well on a daily and long-term basis at the two sites (fig. 12). The square of the correlation coefficient, r^2, was 0.93. Comparisons were made by averaging daily ET estimates from the two lysimeters at each site to provide one daily ET estimate at each site. From August 19, 1990, to November 4, 1994, the total lysimeter ET at the grass lysimeter site was only 2.2 percent more than that at the sage lysimeter site. This small difference could be due to instrument variability or to environmental effects from the different vegetation. For instance, evaporation of intercepted water would be faster from the sagebrush because of the higher, more open canopy (R. Kirkham, Battelle, Pacific Northwest Laboratories, written commun., 1995). Thus, more ET may occur during or shortly after rain at the sage lysimeter site, compared with the grass lysimeter site. The lysimeter weight gains due to rainfall would have masked this ET, so it would not be accounted for except through lower rainfall totals from the lysimeters, which was observed. From August 19, 1990, to November 4, 1994, about 3.2 percent more precipitation was estimated at the grass lysimeter site than at the sage lysimeter site.

The ET estimates at both sites showed very similar seasonal patterns of ET distribution year to year (fig. 13). ET was greatest in spring and the least in late summer and early fall each year, though there was great variability on a daily basis, depending on variables such as air temperature, cloud cover, soil moisture, precipitation, and wind speed (tables 2 and 3; fig. 13). The high ET rates in spring were due to high evaporation from soils with high moisture content (increase due to the winter precipitation), combined with high transpiration from growing vegetation. During late summer and fall, the surface soil moisture had been depleted to about 2 percent, grasses were dormant, and ET rates were generally very low, often near zero. (Text continued on p. 34.)

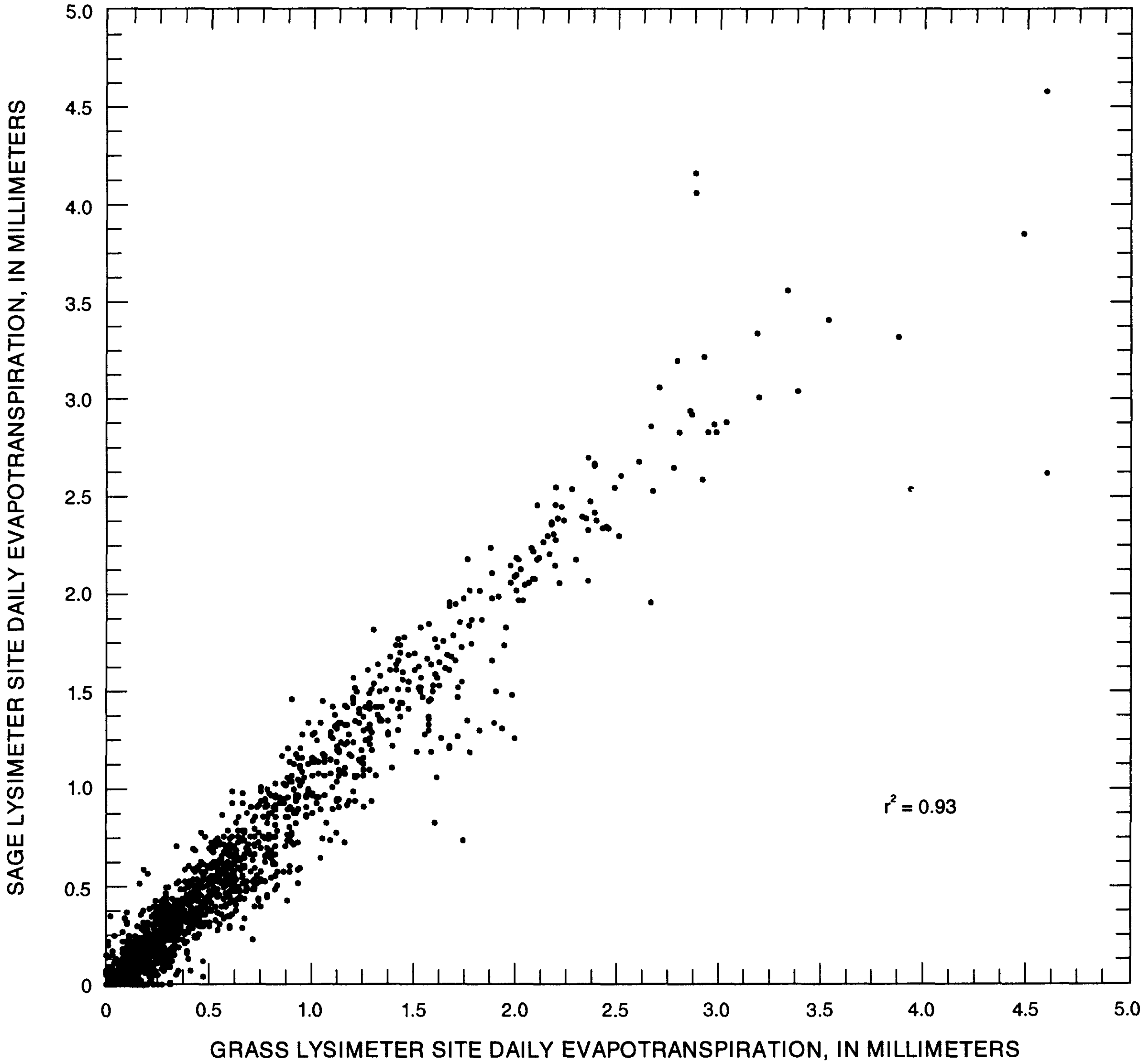


Figure 12.--Weighing-lysimeter daily evapotranspiration at the grass and sage lysimeter sites, August 19, 1990 to November 4, 1994. Evapotranspiration estimates are based on data collected and provided by Batelle, Pacific Northwest Laboratories.

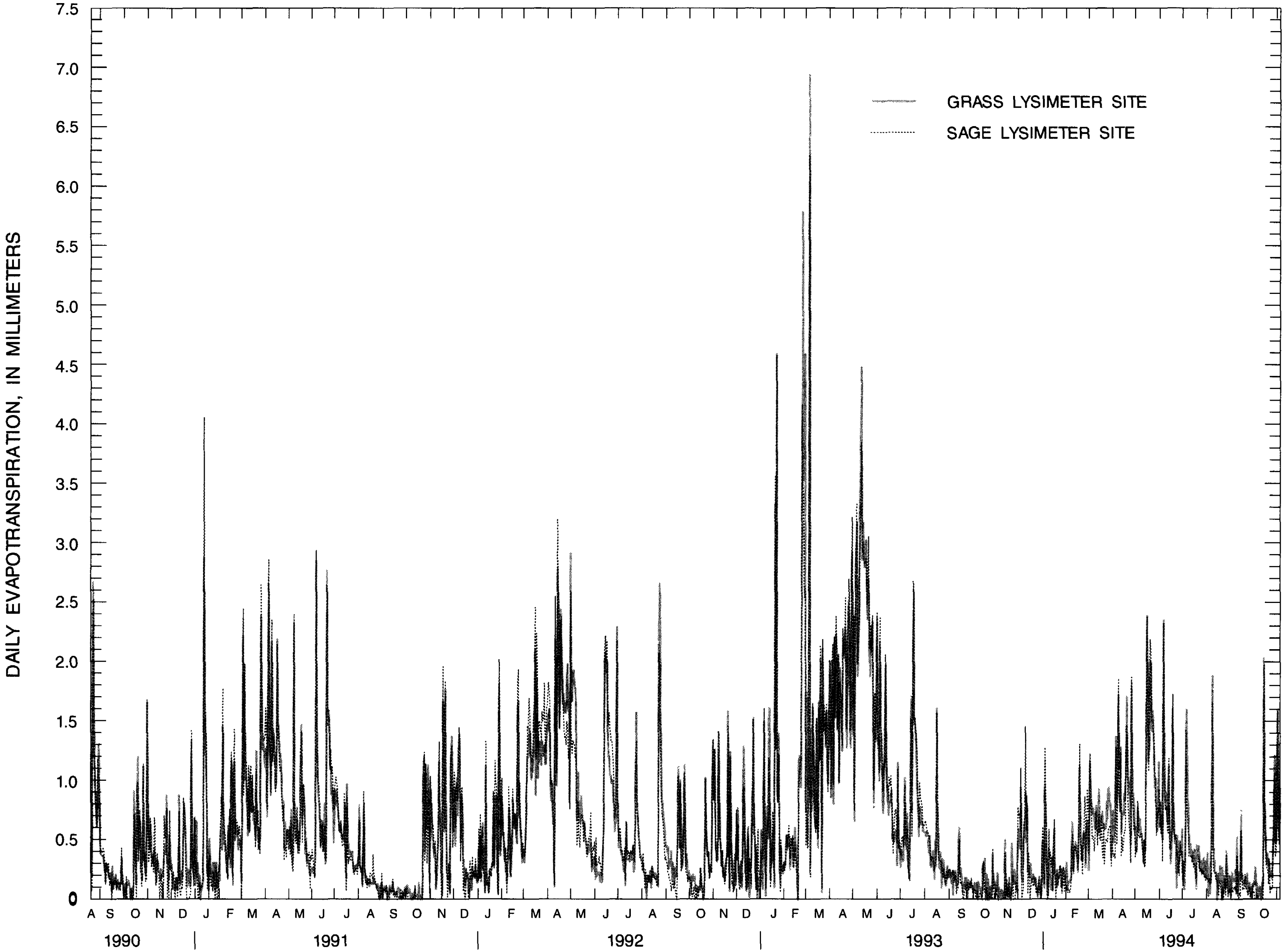


Figure 13.--Daily evapotranspiration at grass and sage lysimeter sites, August 19, 1990 to November 4, 1994. Evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992*

[Precipitation and evapotranspiration estimates for the weighing lysimeters are based on data collected and provided by Battelle, Pacific Northwest Laboratories; mm, millimeters; PRG, average precipitation from two weighing lysimeters at grass lysimeter site; PRS, average precipitation from two weighing lysimeters at sage lysimeter site; ETG, average evapotranspiration from two weighing lysimeters at grass lysimeter site; ETS, average evapotranspiration from two lysimeters at sage lysimeter site; TOT, monthly total of daily precipitation and evapotranspiration; #, partly estimated; --, no value computed]

	August 1990				September 1990				October 1990			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	--	--	--	--	0.00	0.00	0.38	0.42	0.00	0.00	0.02	0.00
2	--	--	--	--	0.00	0.00	0.37	0.41	0.00	0.00	0.13	0.00
3	--	--	--	--	0.00	0.00	0.37	0.39	0.00	0.00	0.01	0.00
4	--	--	--	--	0.00	0.00	0.37	0.44	0.00	0.00	0.10	0.19
5	--	--	--	--	0.00	0.00	0.30	0.40	0.00	0.00	0.12	0.00
6	--	--	--	--	0.00	0.00	0.26	0.32	0.00	0.00	0.16	0.00
7	--	--	--	--	0.00	0.00	0.15	0.13	0.00	0.00	0.14	0.00
8	--	--	--	--	0.00	0.00	0.30	0.31	0.00	0.00	0.11	0 00
9	--	--	--	--	0.00	0.00	0.27	0.31	0.00	0.00	0.00	0.00
10	--	--	--	--	0.00	0.00	0.25	0.26	0.00	0.00	0.09	0.08
11	--	--	--	--	0.00	0.00	0.18#	0.31#	0.00	0.00	0.08	0.00
12	--	--	--	--	0.00	0.00	0.18	0.12	0.00	0.00	0.00	0.00
13	--	--	--	--	0.00	0.00	0.20	0.15	0.00	0.00	0.12	0.00
14	--	--	--	--	0.00	0.00	0.22	0.18	1.90	1.91	0.91	0.72
15	--	--	--	--	0.00	0.00	0.07	0.00	0.00	0.00	0.54	0.53
16	--	--	--	--	0.00	0.00	0.28	0.15	0.00	0.00	0.33	0.15
17	--	--	--	--	0.00	0.00	0.09	0.13	0.00	0.00	0.13	0.00
18	--	--	--	--	0.00	0.00	0.14	0.13	4.50	4.55	0.97	0.96
19	0.51	0.35	0.29	0.08	0.00	0.00	0.18	0.16	0.00	0.00	1.20	0.99
20	0.14	0.12	0.19	0.07	0.00	0.00	0.21	0.18	0.24	0.25	0.43	0.32
21	20.06	20.37	1.32	1.38	0.00	0.00	0.10	0.08	0.61	0.71	0.75	0.70
22	0.00	0.00	2.67	2.53	0.00	0.00	0.14	0.11	0.00	0.17	0.46	0.63
23	0.00	0.00	1.55	1.28	0.00	0.00	0.16	0.13	0.00	0.00	0.24	0.19
24	0.00	0.00	1.03	0.96	0.00	0.00	0.08	0.13	0.00	0.00	0.17	0.11
25	0.00	0.00	0.88	0.86	0.00	0.00	0.10	0.14	1.89	1.83	0.39	0.17
26	0.00	0.00	0.66	0.61	0.00	0.00	0.14	0.07	0.19	0.25	1.12	1.14
27	0.00	0.00	0.62	0.64	0.00	0.00	0.13	0.15	0.08	0.00	0.46	0.32
28	0.00	0.00	0.49	0.58	0.00	0.00	0.15	0.13	0.00	0.00	0.31	0.39
29	1.80	1.53	1.31	1.07	0.00	0.00	0.17	0.14	1.80	1.86	0.21	0.15
30	0.00	0.00	1.06	0.97	0.00	0.00	0.12	0.06	13.22	13.06	0.23	0.17
31	0.00	0.00	0.44	0.51					0.24	0.24	1.66	1.69
TOT	--	--	--	--	0.00	0.00	6.06	6.04	24.67	24.83	11.59	9.60

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

	November 1990				December 1990				January 1991			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	0.00	0.00	1.12	0.94	0.29	0.28	0.27	0.28	0.00	0.00	0.12	0.22
2	0.00	0.00	0.55	0.31	0.00	0.00	0.29	0.09	0.00	0.00	0.66	0.29
3	0.00	0.00	0.42	0.34	0.00	0.00	0.09	0.22	0.00	0.00	0.19	0.23
4	0.12	0.17	0.63	0.69	0.00	0.00	0.14	0.23	0.00	0.00	0.31	0.01
5	0.00	0.00	0.56	0.40	0.00	0.00	0.14	0.07	0.16	0.15	0.11	0.00
6	0.00	0.00	0.40	0.27	0.00	0.00	0.09	0.00	1.70	1.72	0.20	0.15
7	0.00	0.00	0.32	0.37	0.26	0.39	0.18	0.19	2.18	2.23	0.00	0.07
8	0.00	0.00	0.30	0.23	0.11	0.21	0.18	0.18	0.14	0.12	0.07	0.11
9	0.00	0.00	0.43	0.69	4.09	4.14	0.08	0.02	2.68	3.03	0.09	0.10
10	0.00	0.00	0.40	0.61	7.77	7.70	0.18	0.28	3.90	3.94	0.14	0.18
11	0.00	0.00	0.14	0.12	0.00	0.00	0.88	0.74	2.19	2.21	0.20	0.57
12	0.00	0.00	0.24	0.15	0.00	0.00	0.24	0.07	1.31	2.36	2.88	4.06
13	0.00	0.00	0.33	0.39	0.00	0.00	0.13	0.03	0.00	0.00	1.78	1.75
14	0.00	0.00	0.32	0.27	0.00	0.00	0.24	0.11	0.00	0.00	1.23	1.41
15	0.00	0.00	0.23	0.17	0.00	0.00	0.19	0.09	0.00	0.00	1.01	1.29
16	0.00	0.00	0.22	0.01	0.00	0.00	0.24	0.23	0.58	0.47	0.20	0.08
17	0.06	0.10	0.16	0.08	0.00	0.00	0.82	0.86	0.00	0.00	0.24	0.31
18	0.02	0.01	0.26	0.21	2.84	3.03	0.77	0.75	0.00	0.00	0.08	0.01
19	0.00	0.00	0.18	0.00	4.01	4.65	0.59	0.61	0.00	0.00	0.51	0.38
20	0.00	0.00	0.22	0.15	0.00	0.00	0.47	0.12	0.00	0.00	0.33	0.25
21	0.10	0.12	0.21	0.01	0.00	0.00	0.23	0.00	0.00	0.00	0.24	0.11
22	0.10	0.11	0.34	0.71	0.00	0.00	0.11	0.00	0.00	0.00	0.21	0.12
23	0.25	0.23	0.46	0.52	0.00	0.00	0.25	0.00	0.00	0.00	0.11	0.07
24	0.68	0.60	0.38	0.59	0.00	0.00	0.23	0.00	0.00	0.00	0.31	0.23
25	0.62	0.60	0.88	0.77	0.00	0.00	0.11	0.03	0.00	0.00	0.31	0.15
26	0.00	0.00	0.31	0.00	0.00	0.00	0.13	0.05	0.08	0.09	0.08	0.00
27	0.00	0.00	0.30	0.23	0.00	0.00	1.34	1.42	0.00	0.00	0.14	0.11
28	0.00	0.00	0.18	0.00	6.34	7.47	0.26	0.37	0.00	0.00	0.31	0.28
29	0.86	1.08	0.54	0.75	0.00	0.00	0.34	0.25	0.00	0.00	0.11	0.00
30	0.00	0.00	0.43	0.25	2.36	2.39	0.18	0.11	0.00	0.00	0.10	0.02
31					0.52	0.32	0.69	0.69	0.21	0.18	0.23	0.29
TOT	2.81	3.02	11.46	10.23	28.59	30.58	10.08	8.09	15.13	16.50	12.50	12.85

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

	February 1991				March 1991				April 1991			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	0.12	0.07	0.16	0.24	0.13	0.15	0.15	0.00	0.00	0.00	1.27	1.61
2	1.09	1.01	0.50	0.60	6.73	6.87	1.12	0.78	0.22	0.27	1.10	1.42
3	0.43	0.39	0.64	0.86	5.04	5.08	2.22	2.45	0.60	0.62	0.70	0.76
4	3.66	3.57	0.42	0.70	2.17	1.92	1.00	0.88	6.13	5.93	1.69	1.79
5	1.39	1.50	1.45	1.78	0.14	0.02	1.74	1.98	0.00	0.00	2.66	2.86
6	0.14	0.09	0.62	0.71	0.00	0.00	1.18	1.18	0.00	0.00	1.37	1.35
7	0.02	0.08	0.47	0.57	0.00	0.00	1.00	1.16	0.00	0.00	1.13	1.20
8	0.00	0.00	0.47	0.54	0.00	0.00	0.82	0.92	2.41	2.48	0.88	0.90
9	0.00	0.00	0.34	0.42	0.18	0.13	0.54	0.59	0.36	0.31	2.17	2.36
10	0.23	0.31	0.28	0.36	0.00	0.05	0.91	1.13	0.00	0.00	1.25	1.16
11	0.12	0.10	0.19	0.17	1.36	1.20	0.58	0.56	0.00	0.00	1.43	1.37
12	2.32	1.71	0.62	0.58	0.93	0.77	1.03	1.08	0.00	0.00	1.24	1.14
13	2.14	2.12	0.34	0.36	0.00	0.00	0.98	1.13	0.00	0.00	1.23	1.15
14	0.26	0.22	0.70	0.76	0.00	0.00	0.74	0.73	0.53	0.60	0.93	0.90
15	0.00	0.00	0.27	0.43	0.23	0.24	0.93	1.05	5.20	5.15	1.00	0.97
16	0.00	0.00	1.17	1.24	0.00	0.00	0.67	0.74	0.09	0.03	2.19	2.15
17	0.00	0.00	1.06	1.07	0.00	0.00	0.67	0.79	0.00	0.00	1.54	1.47
18	0.00	0.00	0.20	0.12	0.19	0.11	0.59	0.61	0.00	0.00	1.42	1.30
19	0.00	0.00	0.95	1.04	0.75	0.42	0.50	0.44	0.00	0.00	1.25	1.13
20	0.74	0.70	1.16	1.43	0.04	0.05	1.25	1.10	0.00	0.00	1.22	1.07
21	0.00	0.00	0.50	0.55	0.13	0.15	0.59	0.63	0.00	0.00	1.16	1.11
22	0.00	0.00	0.62	0.67	0.00	0.00	0.60	0.75	0.00	0.00	1.04	0.90
23	0.00	0.00	0.60	0.66	0.06	0.06	0.42	0.43	0.22	0.15	0.77	0.66
24	0.00	0.00	0.57	0.62	13.37	12.69	0.50	0.60	0.11	0.12	0.83	0.79
25	0.00	0.00	0.42	0.54	4.47	4.25	0.50	0.38	0.00	0.00	0.43	0.33
26	0.00	0.00	0.51	0.62	0.00	0.00	2.38	2.67	0.00	0.00	0.65	0.45
27	0.00	0.00	0.46	0.52	0.00	0.00	1.78	1.87	0.00	0.00	0.46	0.42
28	0.00	0.00	0.50	0.52	0.00	0.00	1.26	1.42	0.00	0.00	0.47	0.36
29					0.00	0.00	1.33	1.36	0.00	0.00	0.58	0.59
30					0.00	0.00	1.23	1.34	0.00	0.00	0.58	0.51
31					0.00	0.00	1.11	1.38				
TOT	12.66	11.87	16.19	18.68	35.92	34.16	30.32	32.13	15.87	15.66	34.64	34.18

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

	May 1991				June 1991				July 1991			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	0.16	0.07	0.51	0.42	0.00	0.00	0.27	0.42	0.00	0.00	0.79	0.98
2	0.00	0.00	0.61	0.59	0.00	0.00	0.22	0.35	0.00	0.00	0.86	1.03
3	0.35	0.19	0.43	0.38	0.00	0.00	0.27	0.30	0.00	0.00	0.93	0.97
4	0.03	0.04	0.78	0.66	0.00	0.00	0.20	0.18	0.00	0.00	0.77	0.94
5	0.18	0.13	0.45	0.36	0.00	0.00	0.35	0.26	0.00	0.00	0.70	0.67
6	0.00	0.00	0.29	0.27	9.62	9.46	2.85	2.94	0.00	0.00	0.58	0.57
7	1.80	1.68	0.35	0.23	4.12	4.11	1.62	1.53	0.00	0.00	0.62	0.56
8	3.14	3.19	2.32	2.40	0.33	0.35	1.09	1.15	0.00	0.00	0.62	0.66
9	0.00	0.00	0.81	0.63	0.00	0.00	0.91	1.00	0.00	0.00	0.52	0.53
10	0.00	0.00	0.60	0.48	0.00	0.00	0.83	0.96	0.00	0.00	0.54	0.45
11	0.14	0.13	0.52	0.47	0.00	0.00	0.61	0.76	0.00	0.00	0.50	0.45
12	0.36	0.37	0.67	0.78	0.00	0.00	0.44	0.45	0.00	0.00	0.55	0.46
13	0.00	0.00	0.44	0.39	0.57	0.51	0.67	0.61	0.60	0.62	0.82	0.90
14	0.00	0.00	0.54	0.58	0.00	0.00	0.62	0.63	0.00	0.00	0.46	0.38
15	0.00	0.00	0.41	0.39	0.05	0.03	0.41	0.40	0.00	0.00	0.18	0.07
16	4.18	3.96	0.58	0.69	0.08	0.10	0.43	0.48	1.24	1.20	0.97	0.87
17	3.46	3.35	1.25	1.37	0.43	0.22	0.81	0.62	0.00	0.00	0.50	0.43
18	0.58	0.53	1.47	1.41	0.00	0.00	0.30	0.34	0.00	0.00	0.47	0.30
19	0.00	0.00	0.63	0.48	5.77	5.14	0.34	0.33	0.00	0.00	0.38	0.36
20	0.00	0.00	0.97	0.86	12.70	11.98	2.77	2.65	0.00	0.00	0.41	0.33
21	0.00	0.00	0.92	0.97	1.16	1.34	1.47	1.69	0.00	0.00	0.36	0.34
22	0.00	0.00	0.78	0.70	0.38	0.26	1.59	1.53	0.00	0.00	0.39	0.33
23	0.00	0.00	0.38	0.43	0.00	0.00	1.59	1.53	0.00	0.00	0.40	0.33
24	0.00	0.00	0.51	0.48	0.00	0.00	1.13	1.10	0.00	0.00	0.30	0.29
25	0.00	0.00	0.32	0.28	0.00	0.00	1.10	1.26	0.00	0.00	0.23	0.21
26	0.00	0.00	0.34	0.39	0.00	0.00	0.88	1.06	0.00	0.00	0.28	0.22
27	0.00	0.00	0.33	0.36	0.00	0.00	0.94	1.12	0.00	0.00	0.25	0.25
28	0.00	0.00	0.27	0.40	0.10	0.12	0.78	1.00	0.00	0.00	0.29	0.26
29	0.00	0.00	0.20	0.09	0.11	0.30	0.48	0.76	0.00	0.00	0.26	0.24
30	0.00	0.00	0.24	0.37	0.00	0.00	0.92	0.95	0.00	0.00	0.26	0.21
31	0.00	0.00	0.24	0.33					0.40	0.37	0.37	0.34
TOT	14.38	13.64	19.16	18.64	35.42	33.92	26.89	28.36	2.24	2.19	15.56	14.93

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

	August 1991				September 1991				October 1991			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	0.34	0.25	0.80	0.66	0.00	0.00	0.07	0.08	0.00	0.00	0.10	0.06
2	0.00	0.00	0.29	0.27	0.00	0.00	0.10	0.07	0.00	0.00	0.12	0.06
3	0.00	0.00	0.26	0.28	0.00	0.00	0.11	0.09	0.00	0.00	0.05	0.01
4	0.00	0.00	0.22	0.21	0.00	0.00	0.06	0.07	0.00	0.00	0.07	0.00
5	0.00	0.00	0.11	0.12	0.00	0.00	0.11	0.12	0.00	0.00	0.09	0.00
6	1.23	1.42	0.45	0.47	0.00	0.00	0.00	0.06	0.00	0.00	0.03	0.00
7	0.00	0.00	0.81	0.91	0.00	0.00	0.03	0.01	0.00	0.00	0.00	0.00
8	0.00	0.00	0.30	0.33	0.00	0.00	0.03	0.00	0.00	0.00	0.05	0.00
9	0.00	0.00	0.17	0.14	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.19	0.16	0.00	0.00	0.07	0.09	0.00	0.00	0.05	0.03
11	0.00	0.00	0.14	0.10	0.00	0.00	0.06	0.07	0.00	0.00	0.03	0.00
12	0.00	0.00	0.14	0.18	0.00	0.00	0.06	0.07	0.00	0.00	0.09	0.12
13	0.00	0.00	0.13	0.14	0.15	0.15	0.15	0.17	0.00	0.00	0.02	0.00
14	0.00	0.00	0.11	0.13	0.00	0.00	0.10	0.03	0.00	0.00	0.04	0.00
15	0.00	0.00	0.16	0.22	0.00	0.00	0.07	0.08	0.00	0.00	0.04	0.00
16	0.00	0.00	0.13	0.22	0.00	0.00	0.05	0.02	0.00	0.00	0.00	0.00
17	0.00	0.00	0.14	0.20	0.00	0.00	0.04	0.05	0.00	0.00	0.14	0.00
18	0.00	0.00	0.13	0.17	0.00	0.00	0.06	0.07	0.00	0.00	0.04	0.00
19	0.00	0.00	0.18	0.38	0.00	0.00	0.03	0.00	0.00	0.00	0.01	0.00
20	0.00	0.00	0.17	0.20	0.00	0.00	0.10	0.00	0.00	0.00	0.00	0.00
21	0.00	0.00	0.13	0.17	0.00	0.00	0.09	0.02	0.00	0.00	0.00	0.00
22	0.00	0.00	0.13	0.15	0.00	0.00	0.08	0.00	2.05	2.52	0.17	0.00
23	0.00	0.00	0.12	0.10	0.00	0.00	0.01	0.00	0.33	0.04	1.12	0.95
24	0.00	0.00	0.09	0.09	0.00	0.00	0.01	0.09	1.77	2.25	1.20	1.24
25	0.00	0.00	0.13	0.07	0.00	0.00	0.00	0.00	5.25	5.50	0.40	0.32
26	0.00	0.00	0.11	0.03	0.00	0.00	0.02	0.07	2.39	2.47	1.06	1.14
27	0.00	0.00	0.01	0.00	0.00	0.00	0.04	0.01	0.04	0.09	0.71	0.64
28	0.00	0.00	0.02	0.00	0.00	0.00	0.02	0.07	4.08	4.50	0.60	0.30
29	0.00	0.00	0.12	0.05	0.00	0.00	0.10	0.09	0.92	0.63	1.13	0.91
30	0.00	0.00	0.14	0.22	0.00	0.00	0.03	0.04	0.00	0.00	0.82	0.67
31	0.00	0.00	0.01	0.04					5.70	5.94	0.15	0.05
TOT	1.57	1.67	6.04	6.41	0.15	0.15	1.82	1.54	22.53	23.94	8.33	6.50

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

	November 1991				December 1991				January 1992			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	1.04	1.14	0.90	1.04	0.00	0.00	0.93	0.96	0.15	0.13	0.16	0.15
2	0.00	0.00	0.92	0.83	0.00	0.00	0.90	1.07	1.75	1.74	0.42	0.59
3	0.11	0.11	0.54	0.60	0.00	0.00	0.44	0.60	3.90	3.79	0.22	0.17
4	4.84	4.79	0.52	0.63	0.00	0.00	0.75	0.94	0.26	0.37	0.53	0.71
5	5.81	5.83	0.41	0.53	5.87	5.43	1.03	0.96	6.31	6.46	0.15	0.18
6	0.22	0.24	0.35	0.39	2.79	2.67	0.71	0.84	0.00	0.00	0.45	0.61
7	0.27	0.29	0.43	0.49	0.00	0.00	1.29	1.20	0.00	0.00	0.64	0.50
8	0.52	0.49	0.09	0.10	0.00	0.00	1.39	1.45	0.00	0.00	0.26	0.23
9	1.02	1.04	0.18	0.20	0.00	0.00	1.06	1.16	0.00	0.00	0.24	0.21
10	0.09	0.16	0.28	0.40	0.00	0.00	0.48	0.32	0.68	0.81	0.06	0.06
11	0.13	0.10	0.56	0.66	0.00	0.00	0.87	0.86	0.00	0.00	1.12	1.33
12	0.00	0.01	1.16	1.33	0.00	0.00	0.86	0.95	0.00	0.00	0.24	0.12
13	0.49	0.43	0.72	0.67	0.00	0.00	0.35	0.07	0.00	0.00	0.18	0.16
14	0.00	0.00	0.73	0.56	0.00	0.00	0.33	0.18	0.00	0.00	0.09	0.15
15	0.00	0.00	0.23	0.00	0.00	0.00	0.21	0.01	0.00	0.00	0.06	0.05
16	8.59	8.80	0.04	0.03	0.00	0.00	0.12	0.00	4.40	4.24	0.23	0.26
17	0.09	0.08	1.67	1.96	0.13	0.22	0.26	0.25	0.00	0.00	0.21	0.25
18	0.15	0.18	1.00	1.14	2.23	2.27	0.18	0.20	0.00	0.00	0.24	0.19
19	4.89	4.90	0.57	0.59	0.00	0.00	0.22	0.18	0.00	0.00	0.28	0.30
20	0.00	0.00	1.77	1.84	0.00	0.00	0.07	0.00	0.00	0.00	0.30	0.27
21	0.00	0.00	0.82	0.71	3.53	3.46	0.02	0.00	0.00	0.00	0.77	0.91
22	0.00	0.00	0.39	0.22	2.22	2.12	0.18	0.32	0.14	0.11	0.29	0.26
23	0.81	0.79	0.17	0.02	0.00	0.00	0.12	0.20	0.58	0.72	0.85	1.17
24	5.54	5.43	0.19	0.19	0.82	0.83	0.08	0.16	0.00	0.02	0.61	0.99
25	1.85	1.79	0.19	0.30	0.00	0.00	0.27	0.36	0.02	0.00	0.88	0.96
26	10.65	10.64	0.05	0.06	0.00	0.00	0.19	0.19	0.15	0.17	0.20	0.12
27	0.00	0.00	1.12	1.20	0.00	0.00	0.21	0.24	3.82	3.87	0.05	0.04
28	6.92	6.96	1.37	1.29	0.21	0.21	0.18	0.18	4.33	4.19	1.82	2.02
29	0.00	0.00	1.25	1.07	0.15	0.16	0.28	0.34	0.17	0.19	1.21	1.35
30	0.00	0.00	0.57	0.44	0.11	0.10	0.20	0.19	0.00	0.00	0.37	0.41
31					0.04	0.05	0.14	0.21	0.00	0.00	0.66	0.74
TOT	54.03	54.20	19.19	19.49	18.10	17.52	14.32	14.59	26.66	26.81	13.79	15.46

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

	February 1992				March 1992				April 1992			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	0.00	0.00	0.87	1.02	0.37	0.35	0.31	0.36	0.00	0.00	1.53	1.83
2	0.00	0.00	0.55	0.54	0.15	0.18	0.46	0.40	0.00	0.00	1.60	1.77
3	0.00	0.00	0.56	0.52	0.43	0.37	0.64	0.79	0.00	0.00	1.32	1.64
4	0.02	0.03	0.35	0.32	0.00	0.00	0.94	1.04	0.00	0.00	1.01	1.14
5	0.18	0.25	0.34	0.34	0.00	0.00	1.20	1.46	0.00	0.00	0.84	0.96
6	0.26	0.45	0.27	0.43	0.00	0.00	1.20	1.44	0.00	0.00	0.98	1.00
7	1.78	1.74	0.14	0.05	0.00	0.00	1.43	1.70	0.00	0.00	0.64	0.73
8	0.23	0.37	0.24	0.43	0.00	0.00	1.44	1.60	0.04	0.02	0.67	0.67
9	4.96	4.98	0.37	0.41	0.00	0.00	1.23	1.39	8.38	8.29	0.11	0.12
10	0.00	0.00	0.77	0.95	0.00	0.00	1.01	1.15	0.00	0.00	2.19	2.55
11	0.00	0.00	0.50	0.70	0.00	0.00	1.06	1.17	1.93	1.63	1.28	1.41
12	0.00	0.00	0.19	0.20	0.00	0.00	1.09	1.27	1.88	2.60	0.96	1.06
13	0.15	0.15	0.29	0.43	0.00	0.00	1.29	1.51	12.01	11.34	2.79	3.20
14	0.28	0.28	0.47	0.55	0.00	0.00	1.38	1.68	0.00	0.00	2.51	2.61
15	0.46	0.45	0.84	0.93	2.01	2.00	2.10	2.46	0.00	0.00	2.13	2.27
16	0.08	0.08	0.62	0.62	2.02	2.27	0.88	1.21	0.46	0.41	1.44	1.44
17	2.50	2.36	0.60	0.67	0.00	0.00	1.87	2.24	0.00	0.00	2.44	2.35
18	6.78	6.19	0.72	0.72	0.00	0.00	1.42	1.77	0.00	0.00	2.21	2.06
19	8.24	8.04	0.53	0.54	0.00	0.00	1.02	1.25	0.00	0.00	1.94	1.74
20	3.99	3.98	0.47	0.62	0.00	0.00	1.28	1.49	0.00	0.00	1.65	1.62
21	4.96	4.76	1.57	1.85	0.00	0.00	1.33	1.50	0.00	0.00	1.73	1.55
22	0.00	0.00	1.67	1.94	0.00	0.00	1.17	1.42	0.04	0.05	1.57	1.36
23	3.06	2.91	0.72	0.71	0.00	0.00	1.13	1.34	0.02	0.03	1.57	1.37
24	0.58	0.60	0.66	0.98	0.00	0.00	1.33	1.58	0.00	0.00	1.57	1.30
25	0.00	0.00	0.55	0.53	0.00	0.00	1.22	1.50	0.00	0.00	1.90	1.50
26	0.00	0.00	0.46	0.58	0.22	0.26	1.21	1.52	0.00	0.00	1.98	1.48
27	0.33	0.24	0.31	0.35	0.00	0.00	1.30	1.82	0.00	0.00	1.58	1.19
28	0.40	0.35	0.41	0.47	0.00	0.00	1.14	1.24	0.10	0.13	1.71	1.27
29	0.00	0.00	0.32	0.38	0.00	0.00	1.14	1.34	5.30	5.08	0.82	0.76
30					0.00	0.00	1.41	1.61	0.00	0.00	2.91	2.59
31					0.00	0.00	1.41	1.64				
TOT	39.24	38.21	16.36	18.78	5.20	5.43	37.04	43.89	30.16	29.58	47.58	46.54

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

	May 1992				June 1992				July 1992			
Day	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)	PRG (mm)	PRS (mm)	ETG (mm)	ETS (mm)
1	0.00	0.00	1.76	1.35	0.00	0.00	0.17	0.29	0.00	0.00	0.44	0.49
2	0.00	0.00	1.67	1.22	0.00	0.00	0.34	0.52	0.19	0.14	0.55	0.59
3	0.00	0.00	1.89	1.34	0.00	0.00	0.20	0.28	0.00	0.00	0.51	0.60
4	0.00	0.00	1.93	1.31	0.00	0.00	0.23	0.30	0.23	0.28	0.38	0.49
5	0.00	0.00	1.82	1.30	0.00	0.00	0.21	0.31	0.15	0.16	0.41	0.40
6	0.00	0.00	1.77	1.19	0.00	0.00	0.23	0.36	0.00	0.00	0.36	0.41
7	0.00	0.00	1.67	1.21	0.00	0.00	0.15	0.30	0.00	0.00	0.30	0.33
8	0.00	0.00	0.67	0.44	0.00	0.00	0.22	0.31	0.00	0.00	0.24	0.32
9	0.00	0.00	0.83	0.51	0.00	0.00	0.14	0.20	0.00	0.00	0.34	0.43
10	0.00	0.00	1.07	0.83	0.00	0.00	0.17	0.23	0.59	0.63	0.12	0.16
11	0.00	0.00	0.75	0.54	0.72	0.57	0.41	0.46	0.00	0.00	0.65	0.65
12	0.00	0.00	0.65	0.44	22.80	22.69	0.69	0.72	0.00	0.00	0.35	0.41
13	0.00	0.00	0.77	0.63	5.29	4.81	2.00	2.10	0.00	0.00	0.34	0.38
14	0.00	0.00	0.87	0.71	0.00	0.00	2.08	2.22	0.00	0.00	0.33	0.41
15	0.00	0.00	0.72	0.71	1.09	0.98	1.91	1.99	0.00	0.00	0.34	0.34
16	0.00	0.00	0.67	0.60	0.00	0.00	2.01	2.18	0.00	0.00	0.32	0.39
17	0.00	0.00	0.60	0.48	0.00	0.00	1.36	1.51	0.00	0.00	0.40	0.41
18	0.00	0.00	0.65	0.64	0.00	0.00	1.20	1.47	0.09	0.12	0.33	0.38
19	0.00	0.00	0.49	0.54	0.00	0.00	1.20	1.57	0.00	0.00	0.34	0.40
20	0.00	0.00	0.49	0.51	0.00	0.00	1.05	1.45	0.50	0.57	0.44	0.46
21	0.00	0.00	0.39	0.36	0.00	0.00	1.04	1.34	0.00	0.00	0.23	0.36
22	0.00	0.00	0.38	0.38	0.00	0.00	0.98	1.34	0.38	0.47	0.26	0.31
23	0.00	0.00	0.46	0.50	0.00	0.00	1.00	1.28	4.55	4.25	1.09	1.08
24	0.00	0.00	0.40	0.53	0.00	0.00	0.95	1.16	0.00	0.00	1.57	1.33
25	0.36	0.42	0.51	0.53	0.00	0.00	0.75	1.01	0.00	0.00	0.89	0.75
26	0.00	0.00	0.51	0.73	0.00	0.00	0.57	0.68	0.00	0.00	0.67	0.65
27	0.00	0.00	0.34	0.37	0.00	0.00	0.64	0.76	0.00	0.00	0.54	0.49
28	0.00	0.00	0.24	0.28	3.47	3.60	0.68	0.88	0.00	0.00	0.46	0.46#
29	0.00	0.00	0.28	0.44	0.46	0.37	2.29	2.18	0.00	0.00	0.35	0.37
30	0.00	0.00	0.33	0.41	0.00	0.00	0.89	0.91	0.00	0.00	0.37	0.33
31	0.00	0.00	0.36	0.49					0.00	0.00	0.34	0.30
TOT	0.36	0.42	25.94	21.52	33.83	33.02	25.76	30.31	6.68	6.62	14.26	14.88

Table 2.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, August 19, 1990, to September 30, 1992--Continued*

Day	August 1992 PRG (mm)	August 1992 PRS (mm)	August 1992 ETG (mm)	August 1992 ETS (mm)	September 1992 PRG (mm)	September 1992 PRS (mm)	September 1992 ETG (mm)	September 1992 ETS (mm)
1	0.00	0.00	0.31	0.24	0.00	0.00	0.45	0.32
2	0.00	0.00	0.30	0.39	0.00	0.00	0.40	0.29
3	0.00	0.00	0.23	0.20	0.00	0.00	0.44	0.24
4	0.00	0.00	0.20	0.09	0.00	0.00	0.26	0.17
5	0.00	0.00	0.14	0.25	0.00	0.00	0.31	0.16
6	0.00	0.00	0.01	0.22	0.00	0.00	0.28	0.13
7	0.00	0.00	0.18	0.10	0.00	0.00	0.41	0.07
8	0.00	0.00	0.20	0.21	0.00	0.00	0.16	0.15
9	0.00	0.00	0.18	0.14	0.00	0.00	0.31	0.15
10	0.00	0.00	0.21	0.20	0.00	0.00	0.23	0.09
11	0.00	0.00	0.24	0.14	0.00	0.00	0.13	0.15
12	0.00	0.00	0.10	0.16	0.00	0.00	0.27	0.08
13	0.00	0.00	0.27	0.28	0.00	0.00	0.22	0.03
14	0.00	0.00	0.26	0.28	0.53	0.41	0.19	0.00
15	0.00	0.00	0.19	0.19	3.92	3.83	0.50	0.48
16	0.00	0.00	0.22	0.19	0.04	0.17	1.12	1.04
17	0.00	0.00	0.17	0.17	0.00	0.00	0.91	0.88
18	0.00	0.00	0.22	0.17	0.00	0.00	0.62	0.43
19	0.00	0.00	0.16	0.12	0.77	0.69	1.00	0.98
20	0.00	0.00	0.15	0.12	0.00	0.00	0.31	0.23
21	4.29	3.78	0.11	0.13	0.00	0.00	0.26	0.33
22	16.68	10.98	2.35	2.07	0.00	0.00	0.31	0.30#
23	0.00	0.00	2.66	1.96	2.76	2.51	0.66	0.52
24	0.07	0.18	1.63	1.26	0.53	0.47	1.13	1.07
25	0.00	0.00	1.25	0.91	0.00	0.00	0.62	0.48
26	0.00	0.00	0.90	0.73	0.00	0.00	0.27	0.23
27	0.00	0.00	0.80	0.65	0.00	0.00	0.38	0.21
28	0.00	0.00	0.66	0.56	0.00	0.00	0.26	0.14
29	0.00	0.00	0.64	0.44	0.00	0.00	0.17	0.17
30	0.00	0.00	0.53	0.33	0.00	0.00	0.24	0.19
31	0.00	0.00	0.44	0.36				
TOT	21.04	14.94	15.91	13.26	8.55	8.08	12.82	9.71

Comparison of Bowen-Ratio and Weighing-Lysimeter Evapotranspiration

Bowen-ratio and weighing-lysimeter ET values compared favorably on a daily and annual basis at the grass and sage lysimeter sites in 1994; results were mixed in 1993 (table 3; figs. 14 and 15). At the grass lysimeter site from October 29, 1993, to November 1, 1994, Bowen-ratio ET compared well with lysimeter ET ($r^2 = 0.83$) on a daily basis (table 3, fig. 16). During this period at the grass lysimeter site, total Bowen-ratio ET was 4.9 percent more than total lysimeter ET. However, during May and June 1993 at the grass lysimeter site, daily Bowen-ratio ET averaged only 54 percent of daily lysimeter ET (table 3). The reason for this large difference could not be identified. Possibly the difference was due to unaccounted-for Bowen-ratio instrument (cooled-mirror hygrometer) variability or error. Also, the lysimeters may not have been representative of the overall landscape, perhaps because the plant density in the lysimeters was higher than in the surrounding landscape. Additionally, the edges of the lysimeters and the air in the lysimeter access passage beneath the ground could heat the lysimeter soil monolith more than the surrounding soil surface would be heated in nature. Any of these conditions, if true, would cause higher ET rates from the lysimeters than would otherwise be the case. Over much longer periods of time, however, such as 1994, these differences between the two methods appeared to average out. The possibility of Bowen-ratio system variability or error exists because of the numerous problems observed with the cooled-mirror hygrometers in this study and previous studies (Tomlinson, 1994; Tomlinson, 1995; Tomlinson, 1996). The vapor-pressure data from the cooled-mirror hygrometer appeared to be reasonable; however, there was no way to determine its accuracy because no backup Bowen-ratio systems were operating during May and June 1993 at the grass lysimeter site.

Comparisons of Bowen-ratio ET and lysimeter ET on an hourly basis at the grass lysimeter site showed varied results, depending on the season, year, and environmental conditions (figs. 17-19). The Bowen-ratio method estimated ET at only two-tenths to two-thirds of lysimeter ET on clear sunny days in 1993, such as May 9-11 and June 7-10 (fig. 17). On days with rainfall, such as June 11, 1993 (fig. 17), or just after rainfall, such as May 7, 1993 (fig. 17), Bowen-ratio ET agreed more closely with lysimeter ET. On some rainy days, such as May 15, 18, 19, and 20, 1994 (fig. 18), June 6, 1994 (fig. 18), and July 5, 1994 (fig. 19), Bowen-ratio ET exceeded lysimeter ET because of the method of estimating lysimeter ET during rainfall. The lysimeters showed weight gains during these periods; these gains could have masked ET that may have occurred then. Because there was no way to account for this, weight gains were treated entirely as precipitation, and ET was assumed to be zero during these periods. This interpretation of the data shows up as flat periods in the lysimeter ET curves. In fact, ET may not have been zero (as the Bowen-ratio estimates of ET during these periods showed) because the lysimeter weight gain of precipitation over the hour may have masked any ET that may have occurred. During some dry periods, such as June 16-18, 1993 (fig. 17), and May 22-24, 1994 (fig. 18), Bowen-ratio and lysimeter ET agreed reasonably well. On extremely dry days, however, such as July 1-3, 1994 (fig. 19), Bowen-ratio ET and lysimeter ET values were very small, from 0.1 to 0.3 mm, close to the minimum thresholds of instrument precision for the cooled-mirror hygrometer and the lysimeters, and daily averages were very different (table 3). The Bowen-ratio method estimated from 140 to more than 300 percent of the daily ET measured by the lysimeters from July 1-3, 1994. These large percent differences may be due more to instrument variability or error than to true differences between the Bowen-ratio method and the lysimeters. Also, comparison of differences in these very small quantities magnifies the relative percentage differences. Later in the season, such as October 28-30, 1994 (fig. 19), lysimeter ET appeared to agree with, but lag about 2-5 hours behind, Bowen-ratio ET. In this case, perhaps the colder air during the longer nights in fall (compared with spring and summer) cooled the soil by conduction (through the sides of the lysimeters) more quickly than in the surrounding natural soil and retarded the short daytime warming (and resultant ET) of the soil monolith.

Assuming the Bowen-ratio instruments were operating properly and produced accurate ET estimates at the grass lysimeter site from May to mid-June 1993, the large differences between some of the 1993 and 1994 ET comparisons (figs. 17-19) might be explained by the precipitation differences between the 2 years and the different proportion of ET due to evaporation and transpiration, combined with a lysimeter plant density higher than in the overall landscape. The winter of 1992-93 was twice as wet as the average, and plant growth was very lush—in the spring of 1993 grasses were green and flowers were blooming well into June, about a month longer than in 1991 or 1992. If the plant density in the lysimeters was higher than that in the overall landscape, the transpiration (and thus the ET) would have been greater than that estimated with the Bowen-ratio method. Similar differences between Bowen-ratio and lysimeter ET were observed in April and May 1991 at the grass lysimeter site (Tomlinson, 1995), but these differences were thought to be due to leaks in the cooled-mirror hygrometer in the Bowen-ratio system. In contrast to 1992-93, the winter of 1993-94 was extremely dry, with less than half the average precipitation. Grasses senesced the last few days of March and in early April because of the drought. Most of the Sandberg's bluegrass plants turned brown before developing seed heads, and only a few bluebunch wheatgrass plants developed seed heads. Because of the dryness, most of the ET during 1994 was due to evaporation, not transpiration. In 1994, ET may have been nearly the same inside and outside the lysimeters because plants and plant density were not significant factors in ET. If the plant density was higher in the lysimeters than in nature, this may be one reason for the close agreement between Bowen-ratio and lysimeter ET during 1994, but not in 1993. Unfortunately, no firm conclusions could be made from the 1993 data because the Bowen-ratio system's cooled-mirror hygrometer failed in late June 1993. Multiple Bowen-ratio measurements would need to be made after a wet winter, and plant-density studies would need to be undertaken to test the plant-density hypothesis at the grass lysimeter site. Another researcher (Kirkham, 1993) has not found significant differences between Bowen-ratio ET and lysimeter ET during the spring growth period at the grass lysimeter site.

At the sage lysimeter site from November 1, 1993, to October 10, 1994, daily lysimeter ET compared reasonably well with daily Bowen-ratio ET ($r^2 = 0.75$; table 3; fig. 16). During this period at the sage lysimeter site, total Bowen-ratio ET averaged 2.7 percent less than total lysimeter ET (table 3). From June 17 to July 12, 1993, daily lysimeter and Bowen-ratio ET differed by an average of 1 percent at the sage lysimeter site (table 3). However, in September and October 1993, while the sage plants were blooming, daily Bowen-ratio ET averaged over 450 percent more than lysimeter ET (table 3). Also, daily differences between Bowen-ratio and lysimeter ET fluctuated significantly ($r^2 = 0.53$). The large difference in the fall was believed to be due to increased transpiration from heavily blooming sage plants in the natural landscape outside of the lysimeters. Other researchers have also observed this phenomenon. In one case (Black and Mack, 1986), flowering of sage plants was believed to be possible because sage plants conserve water after shedding spring leaf growth, then transpire at high rates during the normally dry summer to produce flower buds. In another case (Evans and Black, 1993), sage plants receiving supplemental water produced more flowers than sage plants that did not. In mid-July 1993, a 20-mm rainfall (in a year of already above-normal precipitation) may have produced the impetus for heavy fall bloom of sagebrush at the sage lysimeter site resulting in ET rates averaging 0.6 mm per day in September and October. The sage plants in the lysimeters appeared stressed and were not blooming profusely, however, and thus did not transpire as much as plants in the surrounding soil. Lysimeter ET averaged only 0.1 mm per day in September and October 1993. Perhaps the constraint on the rooting depth of the lysimeter-contained sage plants did not allow these plants to effectively use or conserve the water available to them, putting the plants in a stressed condition with a resulting sparse bloom and low ET. (Text continued on p. 55)

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994*

[Precipitation and evapotranspiration estimates for the weighing lysimeters are based on data collected and provided by Battelle, Pacific Northwest Laboratories; mm, millimeters; PRG, average precipitation from two weighing lysimeters at grass lysimeter site; ETG, average evapotranspiration from two weighing lysimeters at grass lysimeter site; ETB, evapotranspiration for Bowen-ratio method (fixed sensors, *) at grass lysimeter site; PRS, average precipitation from two weighing lysimeters at sage lysimeter site; ETS, average evapotranspiration from two lysimeters at sage lysimeter site; ETR, evapotranspiration Bowen-ratio method (fixed sensors,*) at sage lysimeter site; TOT, monthly total of daily precipitation and evapotranspiration; #, partly estimated; --, no value computed]

	1992											
	October						November					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.16	--	0.00	0.18	--	0.63	0.84	--	--	--	--
2	0.00	0.04	--	0.00	0.11	--	0.00	1.26	--	--	--	--
3	0.10	0.20	--	0.09	0.14	--	0.00	0.48	--	--	--	--
4	0.00	0.15	--	0.00	0.02	--	3.47	0.41	--	--	--	--
5	0.00	0.21	--	0.00	0.04	--	0.00	0.32	--	--	--	--
6	0.00	0.16	--	0.00	0.10	--	0.21	0.34	--	--	--	--
7	0.00	0.19	--	0.00	0.00	--	0.80	1.41	--	--	--	--
8	0.00	0.08	--	0.00	0.00	--	0.25	1.00	--	--	--	--
9	0.00	0.09	--	0.00	0.13	--	0.00	0.54	--	--	--	--
10	0.00	0.09	--	0.00	0.00	--	0.03	0.45	--	--	--	--
11	0.00	0.09	--	0.00	0.12	--	0.81	0.28	--	--	--	--
12	0.00	0.07	--	0.00	0.02	--	0.18	0.41	--	--	--	--
13	0.00	0.10	--	0.00	0.08#	--	0.16	0.19	--	0.16	0.20#	--
14	0.00	0.08	--	--	--	--	0.00	0.25	--	0.00	0.23	--
15	0.00	0.26	--	--	--	--	0.00	0.16	--	0.00	0.13	--
16	0.00	0.14	--	--	--	--	0.35	0.28	--	0.26	0.19	--
17	0.00	0.09	--	--	--	--	0.08	0.33	--	0.09	0.23	--
18	0.00	0.00	--	--	--	--	0.13	0.38	--	0.06	0.36	--
19	0.00	0.00	--	--	--	--	3.84	1.58	--	3.69	1.46	--
20	0.98	0.17	--	--	--	--	0.00	0.89	--	0.00	0.76	--
21	2.85	1.02	--	--	--	--	12.40	0.07	--	12.89	0.10	--
22	0.06	0.58	--	--	--	--	0.08	1.24	--	0.07	1.20	--
23	0.00	0.47	--	--	--	--	0.00	0.61	--	0.00	0.52	--
24	0.00	0.36	--	--	--	--	0.00	0.40	--	0.00	0.13	--
25	0.00	0.40	--	--	--	--	0.00	0.33	--	0.00	0.15	--
26	0.00	0.18	--	--	--	--	0.00	0.14	--	0.00	0.06	--
27	0.00	0.28	--	--	--	--	5.50	0.09	--	5.59	0.16	--
28	5.26	0.29	--	--	--	--	0.00	0.21	--	0.00	0.39	--
29	2.43	0.23	--	--	--	--	0.00	0.12	--	0.00	0.17	--
30	2.41	1.03	--	--	--	--	0.00	0.72	--	0.00	0.76	--
31	2.72	1.34	--	--	--	--						
TOT	16.81	8.55	--	--	--	--	28.92	15.73	--	--	--	--

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1992						1993					
	December						January					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.38	--	0.00	0.33	--	0.30	0.15	--	0.23	0.01	--
2	0.00	0.77	--	0.00	0.63	--	0.72	0.58	--	0.52	0.41	--
3	0.00	0.23	--	0.00	0.17	--	2.05	0.57	--	1.66	0.34	--
4	0.00	0.14	--	0.00	0.08	--	3.41	0.09	--	3.36	0.34	--
5	0.00	0.19	--	0.00	0.11	--	0.94	0.88	--	0.33	0.74	--
6	0.00	0.32	--	0.02	0.17	--	1.57	1.50	--	1.24	1.61	--
7	5.18	0.10	--	5.16	0.32	--	1.26	0.43	--	1.44	0.58	--
8	4.65	0.36	--	4.40	0.31	--	10.90	0.03	--	11.97	0.09	--
9	0.19	1.29	--	0.00	0.94	--	1.33	0.33	--	0.99	0.40	--
10	17.44	1.21	--	17.41	0.94	--	1.10	0.78	--	1.24	0.67	--
11	0.00	0.58	--	0.00	0.59	--	1.62	0.51	--	1.13	0.56	--
12	0.00	0.22	--	0.00	0.16	--	1.14	1.51	--	0.72	1.19	--
13	0.00	0.07	--	0.00	0.08	--	1.75	1.61	--	0.31	1.06	--
14	0.00	0.31	--	0.00	0.18	--	13.46	0.16	--	12.18	0.10	--
15	0.00	0.61	--	0.00	0.53	--	0.60	0.29	--	0.80	0.43	--
16	6.42	0.09	--	6.42	0.14	--	1.29	0.33	--	1.56	0.29	--
17	0.20	0.02	--	0.09	0.35	--	0.66	0.53	--	0.45	0.74	--
18	0.00	0.14	--	0.00	0.20	--	0.60	0.60	--	0.52	0.62	--
19	5.88	0.10	--	5.64	0.12	--	3.12	0.10	--	3.03	0.15	--
20	1.24	0.80	--	1.22	0.55	--	3.80	3.33	--	3.72	3.56	--
21	0.00	0.89	--	0.00	0.81	--	3.26	1.99	--	3.23	1.26	--
22	0.00	1.53	--	0.00	1.52	--	5.47	4.59	--	5.27	4.58	--
23	0.00	0.55	--	0.00	0.72	--	4.42	0.97	--	4.42	0.97	--
24	0.00	0.50	--	0.00	0.54	--	1.45	0.82	--	1.45	0.82	--
25	0.00	0.15	--	0.00	0.08	--	0.02	1.39	--	0.01	1.22	--
26	0.00	0.39	--	0.00	0.46	--	0.00	0.36	--	0.00	0.30	--
27	5.52	0.08	--	5.31	0.00	--	0.00	0.10	--	0.00	0.06	--
28	2.18	0.18	--	2.20	0.59	--	0.27	0.44	--	0.25	0.50	--
29	9.52	0.11	--	9.54	0.25	--	0.05	0.27	--	0.08	0.24	--
30	0.82	0.01	--	0.79	0.20	--	0.01	0.22	--	0.00	0.24	--
31	6.22	0.16	--	10.00	0.14	--	0.00	0.22	--	0.00	0.24	--
TOT	65.46	12.48	--	68.20	12.21	--	66.57	25.68	--	62.11	24.32	--

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1993											
	February						March					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.32	--	0.00	0.31	--	8.74	0.74	--	5.64	0.44	--
2	0.00	0.28	--	0.00	0.24	--	1.53	1.74	--	1.30	0.74	--
3	0.00	0.29	--	0.00	0.29	--	4.60	0.48	--	4.72	0.44	--
4	0.00	0.54	--	0.00	0.54	--	2.04	0.88	--	1.94	0.43	--
5	0.00	0.42	--	0.00	0.44	--	3.37	2.42	--	3.63	2.34	--
6	0.00	0.44	--	0.00	0.54	--	5.21	6.94	--	4.25	6.27	--
7	0.00	0.54	--	0.00	0.62	--	0.00	0.21	--	0.00	0.19	--
8	0.63	0.52	--	0.64	0.50	--	0.00	0.74	--	0.00	0.92	--
9	0.48	0.25	--	0.40	0.34	--	0.00	0.76	--	0.00	0.86	--
10	0.00	0.39	--	0.00	0.52	--	0.00	1.62	--	0.00	1.65	--
11	0.00	0.39	--	0.00	0.45	--	0.00	1.34	--	0.00	1.35	--
12	0.00	0.51	--	0.00	0.54	--	0.00	0.81	--	0.00	0.76	--
13	0.00	0.27	--	0.00	0.29	--	0.44	0.62	--	0.42	0.62	--
14	0.00	0.39	--	0.00	0.27	--	0.00	0.60	--	0.00	0.56	--
15	0.00	0.61	--	0.00	0.48	--	0.00	1.52	--	0.00	1.52#	--
16	0.00	0.39	--	0.00	0.32	--	3.60	0.64	--	3.27	0.60	--
17	0.00	0.45	--	0.00	0.26	--	0.72	0.44	--	0.66	0.51	--
18	7.74	0.17	--	7.63	0.10	--	0.00	1.67	--	0.00	1.61	--
19	19.31	0.00	--	18.95	0.00	--	1.97	1.19	--	1.68	1.17	--
20	3.68	1.17	--	2.83	0.92	--	2.42	2.02	--	2.36	2.13	--
21	2.10	1.21	--	2.04	1.07	--	0.00	1.29	--	0.00	1.29	--
22	0.85	1.03	--	0.88	1.14	--	14.49	0.06	--	13.60	0.09	--
23	0.91	0.94	--	0.98	1.21	--	2.13	2.11	--	1.68	2.19	--
24	0.99	2.88	--	0.81	4.16	--	0.00	1.42	--	0.00	1.41	--
25	4.18	5.79	--	3.62	3.50	--	0.00	1.52	--	0.00	1.63	--
26	4.54	3.53	--	3.34	3.41	--	0.00	1.44	--	0.00	1.56	--
27	3.82	3.93	--	2.59	2.54	--	0.00	1.28	--	0.00	1.31	--
28	3.20	4.59	--	3.46	2.62	--	0.00	1.58	--	0.00	1.64	--
29							0.00	1.12	--	0.00	1.22	--
30							0.25	0.97	--	0.16	0.91	--
31							0.05	1.57	--	0.05	1.45	--
TOT	52.43	32.24	--	48.17	27.62	--	51.56	41.74	--	45.36	39.81	--

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1993											
	April						May					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	2.49	2.00	--	2.11	2.02	--	0.00	1.38	--	0.00	1.61	--
2	1.27	1.56	--	1.15	1.67	--	0.00	2.20	--	0.00	2.39	--
3	1.54	0.86	--	1.38	0.93	--	2.48	0.66	--	2.18	0.75	--
4	0.00	2.01	--	0.00	1.97	--	1.67	2.15	--	1.44	2.30	--
5	0.00	1.97	--	0.00	2.15	--	0.00	2.94	--	0.00	2.83	--
6	3.56	0.80	--	3.54	0.97	--	1.38	3.18	--	1.08	3.34	--
7	0.00	2.16	--	0.00	2.21	--	0.00	1.88	1.44	0.00	1.98	1.59
8	1.80	1.53	--	1.57	1.57	--	0.00	2.07	1.33	0.00	2.24	1.12
9	0.00	2.23	--	0.00	2.38	--	0.00	2.45	1.51	0.00	2.34	--
10	1.37	2.10	--	1.36	2.18	--	0.00	3.38	2.13	0.00	3.04	--
11	0.25	1.43	--	0.26	1.44	--	0.00	3.87	2.24	0.00	3.32	--
12	0.00	2.06	--	0.00	2.06	--	0.00	4.48	2.56	0.00	3.85	--
13	0.00	0.98	--	0.00	0.99	--	0.00	2.86	1.59	0.00	2.92	--
14	0.00	1.95	--	0.00	1.83	--	0.00	3.19	1.69	0.00	3.01	--
15	0.00	1.64	--	0.00	1.76	--	0.00	2.97	1.40	0.00	2.87	--
16	0.00	1.70	--	0.00	1.66	--	0.00	2.80	1.41	0.00	2.83	--
17	0.07	1.25	--	0.05	1.30	--	0.00	2.98	1.59	0.00	2.83	--
18	0.01	2.19	--	0.01	2.28	--	0.00	3.03	1.46	0.00	2.88	--
19	0.11	2.04	--	0.06	2.05	--	0.00	2.48	1.03	0.00	2.55	--
20	0.00	2.08	--	0.00	2.08	--	3.56	2.36	1.41	3.58	2.48	--
21	0.00	2.27	--	0.00	2.54	--	0.00	2.70	2.07	0.00	3.06	--
22	0.00	1.77	--	0.00	2.02	--	0.00	2.19	1.66	0.00	2.46	--
23	0.00	1.28	--	0.00	1.44	--	0.00	1.88	0.96	0.00	2.11	--
24	0.00	1.76	--	0.00	2.18	--	0.00	2.18	0.84	0.00	2.31	--
25	2.64	2.50	--	2.29	2.30	--	1.04	2.09	1.30	0.86	2.08	--
26	0.00	2.35	--	0.00	2.70	--	0.00	2.34	0.92	0.00	2.39	--
27	0.00	1.70	--	0.00	1.95	--	0.15	1.68	0.60	0.11	1.68	--
28	0.00	1.28	--	0.00	1.42	--	0.00	0.78	0.45	0.00	0.92	--
29	3.17	2.38	--	3.04	2.66	--	0.00	1.43	0.45	0.00	1.74	--
30	0.00	2.92	--	0.00	3.22	--	2.68	1.33	0.87	2.54	1.35	--
31							2.17	1.41	1.12	1.58	1.74	--
TOT	18.28	54.75	--	16.82	57.93	--	15.13	73.32	--	13.37	74.20	--

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1993											
	June						July					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	2.38	1.01	0.00	2.42	--	0.00	0.33	--	0.00	0.40	0.56
2	0.00	1.27	0.48	0.00	1.31	--	0.00	0.27	--	0.00	0.37	0.60
3	0.00	1.28	0.61	0.00	1.33	--	0.00	0.41	--	0.00	0.51	0.68
4	0.16	1.00	0.80	0.12	1.07	0.68	0.00	0.35	--	0.00	0.53	0.58
5	1.44	2.17	1.06	1.39	2.37	1.38	0.00	0.32	--	0.00	0.44	0.60
6	0.00	1.47	0.58	0.00	1.55	1.16	1.03	0.61	--	0.75	0.57	0.63
7	0.00	1.17	0.28	0.00	1.33	0.61	0.00	1.02	--	0.00	0.96	0.63
8	0.00	1.05	0.27	0.00	1.18	0.53	0.00	0.50	--	0.00	0.54	0.27
9	0.00	0.73	0.35	0.00	0.91	0.66	0.75	0.42	--	0.42	0.51	0.41
10	0.00	0.93	0.21	0.00	1.16	--	0.00	0.72	--	0.00	0.60	0.34
11	4.13	1.39	1.32	3.08	1.11	--	0.00	0.30	--	0.00	0.41	0.37
12	0.00	1.97	0.59	0.00	2.06	--	0.00	0.25	--	0.00	0.17	0.23
13	0.00	1.28	0.36	0.00	1.26	--	0.07	0.16	--	0.61	0.52	--
14	0.00	0.92	0.42	0.00	0.94	--	3.57	0.79	--	2.87	0.77	--
15	0.00	0.82	0.31	0.00	0.97	--	0.32	1.71	--	0.04	1.52	--
16	0.00	0.71	0.78	0.00	0.84	--	0.28	0.75	--	0.26	0.53	--
17	0.00	0.82	0.62	0.00	1.03	0.78	20.34	1.50	--	20.26	1.70	--
18	0.00	0.82	0.57#	0.00	0.96	0.93	0.00	2.60	--	0.00	2.68	--
19	0.00	0.89	--	0.00	1.04	0.95	0.82	1.47	--	0.63	1.51	--
20	0.18	0.92	--	0.14	0.88	0.83	0.00	1.52	--	0.00	1.52	--
21	0.29	0.51	--	0.22	0.69	0.52	0.00	1.31	--	0.00	1.42	--
22	0.00	0.49	--	0.00	0.39	0.48	0.44	1.11	--	0.42	1.32	--
23	0.00	0.48	--	0.00	0.58	0.53	0.00	0.89	--	0.00	1.14	--
24	0.00	0.55	--	0.00	0.73	0.69	0.00	0.72	--	0.00	0.80	--
25	0.00	0.57	--	0.00	0.76	0.83	0.00	0.53	--	0.00	0.61	--
26	0.00	0.59	--	0.00	0.69	0.92	0.00	0.75	--	0.00	0.99	--
27	0.00	0.29	--	0.00	0.47	0.50	0.00	0.78	--	0.00	0.86	--
28	1.16	1.15	--	0.90	1.09	1.03	0.00	0.63	--	0.00	0.83	--
29	0.00	0.44	--	0.00	0.43	0.53	0.22	0.66	--	0.21	0.79	--
30	0.00	0.45	--	0.00	0.50	0.67	0.00	0.57	--	0.00	0.60	--
31							0.00	0.58	--	0.00	0.61	--
TOT	7.36	29.51	--	5.85	32.05	--	27.84	24.53	--	26.47	26.73	--

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1993											
	August						September					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.56	--	0.00	0.64	--	0.00	0.19	--	0.00	0.25	1.14
2	0.00	0.56	--	0.00	0.66	--	0.00	0.22	--	0.00	0.23	1.12
3	0.00	0.53	--	0.00	0.63	--	0.00	0.25	--	0.00	0.26	1.11
4	0.00	0.57	--	0.00	0.61	--	0.00	0.18	--	0.00	0.20	1.11
5	0.00	0.55	--	0.00	0.56	--	0.00	0.14	--	0.00	0.20	1.03
6	0.00	0.47	--	0.00	0.56	--	0.00	0.23	--	0.00	0.23	1.34
7	0.00	0.38	--	0.00	0.53	--	0.00	0.04	--	0.00	0.25	1.19
8	0.00	0.53	--	0.00	0.47	--	0.00	0.24	--	0.00	0.16	0.73
9	0.00	0.29	--	0.00	0.39	--	0.00	0.16	--	0.00	0.20	1.20
10	0.00	0.27	--	0.00	0.32	--	0.00	0.24	--	0.00	0.20	0.91
11	0.00	0.29	--	0.00	0.36	--	0.00	0.14	--	0.00	0.05	0.92
12	0.00	0.41	--	0.00	0.35	--	0.00	0.10	--	0.00	0.09	0.73
13	0.00	0.32	--	0.00	0.32	--	0.00	0.15	--	0.00	0.10	0.87
14	0.00	0.17	--	0.00	0.24	--	1.22	0.54	--	1.12	0.28	0.53#
15	0.25	0.50	--	0.06	0.30	--	0.00	0.61	--	0.00	0.51	1.57
16	3.10	0.28	--	2.98	0.32	--	0.00	0.21	--	0.00	0.14	0.98
17	0.00	1.61	--	0.00	1.57	--	0.00	0.26	--	0.00	0.15	0.81
18	0.00	0.77	--	0.00	0.66	--	0.00	0.13	--	0.00	0.12	0.63
19	0.00	0.57	--	0.00	0.44	--	0.00	0.06	--	0.00	0.04	0.63
20	0.00	0.27	--	0.00	0.33	--	0.00	0.13	--	0.00	0.00	0.45
21	0.00	0.26	--	0.00	0.33	--	0.00	0.10	--	0.00	0.05	0.59
22	0.00	0.40	--	0.00	0.33	--	0.00	0.18	--	0.00	0.08	0.71
23	0.00	0.10	--	0.00	0.31	--	0.00	0.16	--	0.00	0.12	0.63
24	0.00	0.34	--	0.00	0.23	--	0.00	0.18	--	0.00	0.00	0.48
25	0.00	0.26	--	0.00	0.19	--	0.00	0.01	--	0.00	0.14	0.66
26	0.00	0.33	--	0.00	0.26	--	0.00	0.16	--	0.00	0.11	0.73
27	0.00	0.19	--	0.00	0.18	--	0.00	0.10	--	0.00	0.08	0.60
28	0.00	0.12	--	0.00	0.13	--	0.00	0.10	--	0.00	0.14	0.75
29	0.00	0.12	--	0.00	0.18	--	0.00	0.15	--	0.00	0.09	0.62
30	0.00	0.23	--	0.00	0.23	--	0.00	0.12	--	0.00	0.18	0.59
31	0.00	0.29	--	0.00	0.17	--						
TOT	3.35	12.54	--	3.04	12.80	--	1.22	5.48	--	1.12	4.65	25.36

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1993											
	October						November					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.12	--	0.00	0.12	0.65	0.00	0.14	0.15*	0.00	0.07	0.20
2	0.00	0.09	--	0.00	0.06	0.59	0.00	0.07	0.02*	0.00	0.04	0.15
3	0.00	0.05	--	0.00	0.07	0.55	0.00	0.22	0.00*#	0.00	0.04	0.24
4	0.00	0.14	--	0.00	0.08	0.46	0.00	0.00	0.26*	0.00	0.00	0.11
5	0.00	0.08	--	0.00	0.09	0.45	0.00	0.10	0.30*	0.00	0.00	0.08
6	0.00	0.07	--	0.00	0.00	0.23	0.00	0.02	0.36*	0.00	0.00	0.25
7	0.00	0.14	--	0.00	0.00	0.48	0.00	0.08	0.24*	0.00	0.00	0.31
8	0.00	0.00	--	0.00	0.07	0.35	0.00	0.01	0.22*	0.00	0.00	0.36
9	0.00	0.15	--	0.00	0.00	0.45	0.00	0.08	0.21*	0.00	0.00	0.28
10	0.00	0.12	--	0.00	0.00	0.34	0.00	0.04	0.18*	0.00	0.01	0.15
11	0.00	0.09	--	0.00	0.05	0.36	0.00	0.01	0.25*	0.00	0.00	0.25
12	0.00	0.07	--	0.00	0.06	0.44	0.00	0.02	0.15*	0.00	0.00	0.31
13	0.00	0.10	--	0.00	0.02	0.30	0.59	0.50	0.38*	0.68	0.39	0.40
14	0.00	0.00	--	0.00	0.00	0.34	0.00	0.14	0.23*	0.00	0.00	0.50
15	0.80	0.28	--	0.69	0.07	0.34	0.00	0.03	0.20*	0.00	0.17	0.24
16	0.00	0.30	--	0.00	0.32	0.73	0.00	0.03	0.12*	0.00	0.00	0.22
17	0.00	0.21	--	0.00	0.08	0.35	0.28	0.12	0.36*	0.27	0.03	0.21*
18	0.00	0.34	--	0.00	0.05	0.36	0.00	0.14	0.31*	0.00	0.19	0.16*
19	0.00	0.00	--	0.00	0.05	0.24	0.00	0.02	0.15*	0.00	0.00	0.16*
20	0.00	0.21	--	0.00	0.10	0.22	0.00	0.09	0.08*	0.00	0.00	0.11*
21	0.00	0.00	--	0.00	0.00	0.23	0.00	0.00	0.48*	0.00	0.06	0.35*
22	0.00	0.17	--	0.00	0.01	0.18	1.01	0.47	0.13*	1.05	0.04	0.11*
23	0.00	0.00	--	0.00	0.05	0.24	0.94	0.24	0.14*	0.78	0.20	0.21*
24	0.00	0.08	--	0.00	0.03	0.35	0.00	0.20	0.06*	0.00	0.00	0.04*
25	0.00	0.11	--	0.00	0.00	0.34	0.00	0.13	0.10*	0.00	0.00	0.10*
26	0.00	0.01	--	0.00	0.00	0.20	0.00	0.25	0.12*	0.00	0.00	0.13*
27	0.00	0.11	--	0.00	0.00	0.14	0.00	0.14	0.28*	0.00	0.15	0.27*
28	0.66	0.38	--	0.67	0.43	0.50	2.17	0.08	0.22*	2.15	0.09	0.11*
29	0.00	0.11	0.39*	0.00	0.10	0.37	1.46	0.06	0.32*	1.40	0.11	0.18*
30	0.00	0.15	0.39*	0.00	0.01	0.45	0.00	0.46	0.56*	0.00	0.78	0.56*
31	0.00	0.09	0.07*	0.00	0.07	0.26						
TOT	1.46	3.77	--	1.36	1.99	11.49	6.45	3.89	6.58	6.33	2.37	6.75

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1993						1994					
	December						January					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	4.37	0.60	0.32*	4.34	0.72	0.15*	4.96	0.49	0.90*	4.82	0.61	0.73*
2	3.16	0.52	0.26*	2.76	0.68	0.00*	1.98	0.29	0.40*	2.03	0.45	0.14*
3	0.00	0.43	0.15*	0.00	0.59	0.12*	3.26	0.10	0.00*	3.19	0.13	0.01*
4	0.00	0.94	0.99*	0.00	1.11	0.42*	1.19	0.95	0.16*	1.17	1.28	0.67*
5	0.00	0.18	0.30*	0.00	0.00	0.16*	0.00	0.70	0.79*	0.00	0.91	0.35*
6	0.00	0.15	0.30*	0.00	0.05	0.27*	0.00	0.34	0.71*	0.00	0.39	0.29*
7	4.59	0.31	0.11*	4.65	0.09	0.13*	0.46	0.04	0.19*	0.59	0.00	0.10*
8	10.33	0.63	0.34*	9.77	0.67	0.20*	0.55	0.03	0.48*	0.51	0.01	0.18*
9	3.53	0.52	0.21*	3.44	0.70	0.00*	0.07	0.43	0.54*	0.09	0.59	0.39*
10	0.00	0.90	0.62*	0.00	1.46	0.68*	0.00	0.26	0.39*	0.00	0.35	0.12*
11	0.00	0.48	0.32*	0.00	0.58	0.11*	0.00	0.23	0.34*	0.00	0.40	0.21*
12	0.00	0.79	0.92*	0.00	0.88	0.16*	0.00	0.08	0.30*	0.00	0.27	0.00*
13	3.30	0.24	0.18*	3.41	0.05	0.14*	0.00	0.17	0.34*	0.00	0.36	0.25*
14	0.44	0.25	0.28*	0.43	0.40	0.26*	0.00	0.08	0.26*	0.00	0.07	0.22*
15	0.00	0.24	0.32*	0.00	0.35	0.16*	0.00	0.40	0.45*	0.00	0.50	0.46*
16	0.00	0.19	0.26*	0.00	0.00	0.14*	0.00	0.59	0.79*	0.00	0.67	0.32*
17	0.00	0.30	0.22*	0.00	0.11	0.09*	0.00	0.21	0.26*	0.00	0.12	0.24*
18	0.00	0.15	0.18*	0.00	0.18	0.10*	0.00	0.16	0.16*	0.00	0.00	0.14*
19	0.00	0.20	0.24*	0.00	0.17	0.04*	0.00	0.10	0.26*	0.00	0.22	0.29*
20	0.00	0.21	0.24*	0.00	0.11	0.09*	0.00	0.25	0.48*	0.00	0.21	0.30*
21	0.00	0.18	0.21*	0.00	0.13	0.07*	0.00	0.17	0.27*	0.00	0.12	0.26*
22	0.00	0.13	0.32*	0.00	0.18	0.02*	0.00	0.19	0.36*	0.00	0.19	0.27*
23	0.00	0.18	0.20*	0.00	0.11	0.20*	0.39	0.19	0.18*	0.36	0.27	0.05*
24	0.00	0.12	0.13*	0.00	0.05	0.06*	0.08	0.27	0.38*	0.10	0.29	0.27*
25	0.00	0.10	0.18*	0.00	0.10	0.04*	0.00	0.11	0.34*	0.00	0.24	0.27*
26	0.00	0.02	0.22*	0.00	0.05	0.04*	0.00	0.11	0.46*	0.00	0.05	0.36*
27	0.00	0.11	0.32*	0.00	0.17	0.06*	0.00	0.25	0.52*	0.00	0.17	0.60*
28	0.00	0.19	0.10*	0.00	0.07	0.03*	0.03	0.26	0.42*	0.02	0.27	0.42*
29	0.00	0.07	0.26*	0.00	0.11	0.03*	0.09	0.24	0.31*	0.13	0.07	0.21*
30	2.72	0.01	0.27*	2.77	0.03	0.09*	0.00	0.20	0.32*	0.00	0.21	0.18*
31	3.31	0.10	0.23*	3.54	0.08	0.14*	0.23	0.12	0.41*	0.23	0.04	0.27*
TOT	35.75	9.44	9.20*	35.11	9.98	4.20*	13.29	8.01	12.17*	13.24	9.40	8.57*

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1994											
	February						March					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.32	0.28*	0.00	0.12	0.22*	0.00	0.59	0.68*	0.00	0.79	0.42*
2	0.00	0.08	0.22*	0.00	0.08	0.19*	0.33	0.25	0.61*	0.29	0.38	0.13*
3	0.00	0.13	0.20*	0.00	0.06	0.17*	0.00	1.16	0.48*	0.00	1.23	0.88*
4	0.00	0.15	0.13*	0.00	0.08	0.12*	0.00	0.98	1.00*	0.00	0.98	0.33*
5	0.00	0.16	0.16*	0.00	0.06	0.34*	0.00	0.80	0.92*	0.00	0.69	0.72*
6	0.00	0.15	0.17*	0.00	0.08	0.32*	0.00	0.72	0.76*	0.00	0.51	0.66*
7	1.59	0.20	0.26*	1.60	0.18	0.21*	0.00	0.77	0.84*	0.00	0.53	1.19*
8	0.00	0.65	0.40*	0.00	0.48	0.51*	0.00	0.72	0.59*	0.00	0.49	0.54
9	0.00	0.50	0.57*	0.00	0.55	0.54*	0.00	0.63	0.46*	0.00	0.41	0.53
10	0.00	0.22	0.44*	0.00	0.24	0.23*	0.00	0.59	0.48	0.00	0.54	0.61
11	0.00	0.42	0.55*	0.00	0.45	0.52*	0.00	0.79	0.62	0.00	0.75	0.57
12	0.00	0.42	0.32*	0.00	0.45	0.13*	0.00	0.70	0.48	0.00	0.58	0.53
13	0.00	0.48	0.52*	0.00	0.41	0.68*	0.00	0.55	0.35	0.00	0.46	0.47
14	0.00	0.42	0.26*	0.00	0.37	0.19*	0.00	0.77	0.61	0.00	0.63	0.51
15	0.00	0.31	0.09*	0.00	0.37	0.00*	0.00	0.93	0.65	0.00	0.73	0.29
16	0.00	0.23	0.18*	0.00	0.25	0.24*	0.00	0.57	0.52	0.00	0.50	0.40
17	3.75	0.72	0.46*	3.58	0.86	0.48*	0.00	0.68	0.48	0.00	0.50	0.75
18	0.00	1.12	0.87*	0.00	1.31	0.49*	0.34	0.68	0.64	0.30	0.70	0.42
19	0.00	0.58	0.46*	0.00	0.47	0.24*	0.00	0.74	0.54	0.00	0.43	0.44
20	0.00	0.45	0.42*	0.00	0.33	0.37*	0.34	0.60	0.64	0.41	0.35	0.55
21	0.00	0.51	0.38*	0.00	0.46	0.14*	0.09	0.64	0.61	0.00	0.64	0.05
22	0.00	0.33	0.34*	0.00	0.21	0.10*	0.00	0.60	0.43	0.00	0.29	0.40
23	0.90	0.56	0.46*	1.21	0.53	0.10*	0.00	0.59	0.45	0.00	0.45	0.47
24	8.07	0.48	0.96*	7.68	0.76	0.92*	0.00	0.61	0.57	0.00	0.51	0.44
25	0.05	0.56	0.90*	0.07	0.87	1.05*	0.00	0.82	0.76	0.00	0.49	0.71
26	1.79	0.27	0.44*	1.59	0.30	0.26*	0.00	0.68	0.74	0.00	0.48	0.76
27	0.34	0.60	0.61*	0.29	0.69	0.50*	0.00	0.93	0.66	0.00	0.59	0.90
28	0.00	0.66	0.58*	0.00	0.93	0.33*	0.00	0.94	0.71	0.00	0.60	0.60
29							0.00	0.82	0.67	0.00	0.62	0.81
30							0.00	0.78	0.61	0.00	0.45	0.50
31							0.00	0.35	0.48	0.00	0.28	0.62
TOT	16.49	11.68	11.63*	16.02	11.95	9.59*	1.10	21.98	19.04	1.00	17.58	17.20

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1994											
	April						May					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.71	0.61	0.00	0.53	0.63	0.00	0.61	0.43	0.00	0.36	0.40#
2	0.00	0.75	0.52	0.00	0.40	0.57	0.00	0.40	0.53	0.00	0.43	0.48#
3	0.00	0.48	0.58	0.00	0.36	0.52	0.07	0.58	0.38	0.14	0.40	0.38#
4	0.00	0.63	0.50	0.00	0.38	0.54	0.59	0.78	0.92	0.57	0.83	0.78#
5	1.31	0.67	0.71	1.16	0.34	0.55	0.00	0.58	0.40	0.00	0.54	0.36#
6	0.00	1.37	1.32	0.04	1.28	1.30	0.00	0.62	0.57	0.00	0.52	0.52#
7	0.00	0.78	0.75	0.00	0.46	0.71	0.00	0.68	0.62	0.00	0.53	0.59#
8	4.35	0.90	1.53	4.47	0.90	1.51	0.00	0.53	0.75	0.00	0.56	0.69#
9	0.14	1.72	1.75	0.00	1.86	1.72	0.00	0.55	0.59	0.00	0.56	0.54#
10	0.00	1.18	1.15	0.00	0.94	1.17	0.00	0.44	0.60	0.00	0.43	0.47
11	0.00	1.09	0.85	0.00	0.74	0.87	0.21	0.41	0.55	0.13	0.31	0.44
12	0.90	1.28	1.25	0.99	1.23	1.23	0.00	0.30	0.45	0.00	0.50	0.43
13	0.00	0.56	0.55	0.00	0.36	0.66	0.00	0.38	0.30	0.00	0.27	0.27
14	0.00	0.73	0.66	0.00	0.52	0.58	0.11	0.45	0.26	0.06	0.30	0.33
15	0.00	0.72	0.62	0.00	0.40	0.57	21.04	1.42	2.00	20.18	1.66	1.65
16	0.00	0.71	0.68	0.00	0.49	0.50	1.05	2.39	3.27	0.86	2.38	2.69
17	0.00	0.89	0.82	0.00	0.58	0.69	0.00	1.73	2.03	0.00	1.73	1.76
18	0.00	0.83	0.80	0.00	0.58	0.81	2.38	1.16	1.86	2.02	1.08	2.08
19	6.26	1.09	1.79	5.77	1.29	1.68#	6.75	1.30	1.90	6.70	1.54	1.71
20	0.00	1.71	1.65	0.00	1.47	1.51#	1.37	2.00	2.49	1.29	2.19	2.14
21	0.00	1.10	0.98	0.00	1.01	0.84#	0.00	1.99	2.16	0.00	2.09	1.87
22	0.00	1.05	0.80	0.00	0.75	0.72#	0.00	1.42	1.63	0.00	1.51	1.54
23	0.00	0.89	0.75	0.00	0.61	0.67#	0.00	1.59	1.62	0.00	1.50	1.52
24	0.30	0.93	0.77	0.16	0.52	0.60#	0.00	1.53	1.49	0.00	1.50	1.35
25	4.07	0.46	1.08	3.98	0.31	0.97#	0.00	1.18	1.28	0.00	1.28	1.18
26	0.00	1.83	1.79	0.00	1.87	1.49#	0.00	0.95	0.98	0.00	1.09	0.96
27	0.00	1.13	1.08	0.00	0.95	0.95#	0.00	1.02	0.87	0.00	0.93	0.83
28	0.00	0.90	0.77	0.00	0.77	0.70#	0.03	0.63	0.72	0.04	0.54	0.85
29	0.00	0.86	0.58	0.00	0.58	0.58#	0.00	0.58	0.61	0.00	0.71	0.70
30	0.02	0.55	0.59	0.04	0.64	0.47#	0.00	0.74	0.69	0.00	0.78	0.70
31							0.64	1.16	1.10	0.48	0.73	1.21
TOT	17.35	28.50	28.28	16.61	23.12	26.31	34.24	30.10	34.05	32.47	29.78	31.42

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1994											
	June						July					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.61	0.73	0.00	0.93	0.64	0.00	0.16	0.32	0.00	0.11	0.48
2	0.00	0.82	0.62	0.00	0.62	0.66	0.00	0.20	0.28	0.00	0.32	0.18
3	0.00	0.66	0.57	0.00	0.55	0.66	0.00	0.08	0.27	0.00	0.22	0.18
4	0.00	0.57	0.66	0.00	0.72	0.65	0.00	0.37	0.30	0.00	0.23	0.19
5	0.53	0.50	0.49	0.53	0.32	0.52	4.68	1.32	2.02	4.48	1.42	1.70
6	5.27	2.35	2.83	4.79	2.33	2.17	0.00	1.60	1.47	0.00	0.83	1.20
7	0.00	1.28	1.24	0.00	1.10	1.03	0.00	1.04	0.91	0.00	0.65	0.64
8	0.00	1.10	0.96	0.00	0.90	0.76	0.00	0.72	0.62	0.00	0.54	0.52
9	0.00	0.76	0.88	0.00	0.76	0.70	0.00	0.48	0.50	0.00	0.36	0.40
10	0.00	0.90	0.77	0.00	0.78	0.70	0.00	0.39	0.39	0.00	0.36	0.31
11	0.00	0.65	0.64	0.00	0.59	0.60	0.00	0.47	0.34	0.00	0.36	0.31
12	1.40	0.82	1.29	1.29	0.56	1.00	0.00	0.36	0.33	0.00	0.37	0.28
13	0.00	1.13	1.38	0.00	1.19	1.31	0.00	0.41	0.31	0.00	0.31	0.26
14	0.00	0.60	0.56	0.00	0.42	0.49	0.00	0.37	0.32	0.00	0.37	0.31
15	0.00	0.45	0.51	0.00	0.43	0.38	0.00	0.31	0.25	0.00	0.27	0.08
16	0.00	0.29	0.53	0.00	0.50	0.47	0.00	0.42	0.26	0.00	0.30	0.09
17	0.03	0.61	0.51	0.06	0.50	0.41	0.00	0.36	0.31	0.00	0.29	0.24
18	2.26	1.61	2.18	2.06	1.73	1.76	0.00	0.08	0.19	0.00	0.18	0.06
19	0.00	0.81	0.86	0.00	0.62	0.65	0.00	0.46	0.24	0.00	0.30	0.00
20	0.00	0.56	0.65	0.00	0.58	0.48	0.00	0.43	0.28#	0.00	0.32	0.00
21	0.00	0.47	0.59	0.00	0.50	0.46	0.00	0.34	0.33#	0.00	0.32	0.12
22	0.00	0.54	0.59	0.00	0.54	0.46	0.00	0.45	0.27#	0.00	0.34	0.19
23	0.00	0.10	0.53	0.00	0.37	0.51	0.00	0.26	0.25#	0.00	0.23	0.09
24	0.00	0.53	0.34	0.00	0.40	0.37	0.00	0.33	0.21#	0.00	0.26	0.12
25	0.00	0.47	0.36	0.00	0.36	0.29	0.00	0.21	0.28#	0.00	0.26	0.02
26	0.00	0.22	0.35	0.00	0.20	0.43	0.00	0.26	0.27#	0.00	0.22	0.01
27	0.00	0.41	0.35	0.00	0.34	0.25	0.00	0.31	0.16	0.00	0.24	0.13
28	0.00	0.49	0.44	0.00	0.45	0.33	0.00	0.35	0.22	0.00	0.19	0.23
29	0.00	0.37	0.34	0.00	0.42	0.33	0.00	0.19	0.14	0.00	0.20	0.08
30	0.00	0.59	0.30	0.00	0.35	0.34	0.00	0.21	0.14	0.00	0.16	0.04
31							0.00	0.32	0.13	0.00	0.19	0.00
TOT	9.49	21.27	23.05	8.73	20.06	19.81	4.68	13.26	12.31	4.48	10.72	8.46

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1994											
	August						September					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.17	0.13	0.00	0.18	0.05	0.00	0.02	0.07	0.00	0.04	0.06
2	0.00	0.39	0.17	0.00	0.16	0.08	0.00	0.23	0.11	0.00	0.11	0.00
3	0.00	0.03	0.10	0.00	0.15	0.09	0.21	0.19	0.30	0.19	0.06	0.24
4	0.00	0.16	0.16	0.00	0.18	0.00	0.00	0.15	0.16	0.00	0.08	0.10
5	0.00	0.05	0.06	0.00	0.13	0.00	0.00	0.16	0.12	0.00	0.11	0.03
6	0.00	0.30	0.13	0.00	0.14	0.00	0.00	0.19	0.14	0.00	0.08	0.09
7	1.91	0.71	0.39	2.07	0.23	0.12	0.00	0.25	0.14	0.00	0.11	0.03
8	1.13	1.88	1.92	0.33	1.66	1.24	0.00	0.05	0.21	0.04	0.06	0.18
9	0.00	0.42	0.42	0.00	0.30	0.15	0.52	0.54	0.53	0.38	0.37	0.34
10	0.00	0.43	0.25	0.00	0.24	0.00	0.00	0.04	0.15	0.00	0.03	0.14
11	0.00	0.23	0.25	0.00	0.23	0.04	0.00	0.14	0.19	0.00	0.00	0.15
12	0.00	0.22	0.18	0.00	0.17	0.09	0.00	0.23	0.15	0.00	0.06	0.04
13	0.00	0.23	0.11	0.00	0.18	0.00	0.00	0.16	0.14	0.00	0.03	0.16
14	0.15	0.00	0.13	0.11	0.15	0.01	1.02	0.75	1.21	0.85	0.58	1.04
15	0.00	0.16	0.12	0.00	0.12	0.12	0.00	0.18	0.29	0.00	0.18	0.10
16	0.00	0.22	0.10	0.00	0.03	0.05	0.00	0.20	0.17	0.00	0.08	0.02
17	0.00	0.15	0.13	0.00	0.15	0.07	0.00	0.13	0.16	0.00	0.10	0.08
18	0.00	0.28	0.11	0.00	0.13	0.00	0.00	0.15	0.17	0.00	0.09	0.06
19	0.00	0.20	0.09	0.00	0.09	0.00	0.00	0.14	0.15#	0.00	0.21	0.03
20	0.00	0.00	0.11	0.00	0.00	0.07	0.00	0.19	0.11#	0.00	0.09	0.06
21	0.00	0.27	0.08	0.00	0.11	0.07	0.00	0.10	0.11	0.00	0.09	0.12
22	0.00	0.05	0.12	0.00	0.00	0.13	0.00	0.22	0.14	0.00	0.06	0.12
23	0.00	0.15	0.12	0.00	0.08	0.02	0.00	0.06	0.11	0.00	0.03	0.04
24	0.00	0.20	0.14	0.00	0.18	0.05	0.00	0.11	0.08#	0.00	0.06	0.01
25	0.00	0.10	0.09	0.00	0.04	0.01	0.00	0.14	0.12#	0.00	0.11	0.14
26	0.33	0.41	0.50	0.36	0.37	0.16	0.00	0.08	0.13#	0.00	0.02	0.07
27	0.00	0.29	0.10	0.00	0.13	0.00	0.00	0.02	0.09#	0.00	0.05	0.10
28	0.00	0.03	0.15	0.00	0.06	0.10	0.00	0.10	0.07#	0.00	0.05	0.05
29	0.00	0.07	0.12	0.00	0.06	0.04	0.35	0.13	0.25#	0.30	0.11	0.38
30	0.00	0.20	0.13	0.00	0.10	0.00	0.00	0.11	0.18#	0.00	0.06	0.17
31	0.00	0.17	0.11	0.00	0.07	0.00						
TOT	3.52	8.17	6.72	2.87	5.82	2.76	2.10	5.16	5.95	1.76	3.11	4.15

Table 3.--*Daily and monthly precipitation and evapotranspiration at grass and sage lysimeter sites, October 1, 1992, to November 4, 1994--Continued*

	1994											
	October						November					
	Grass lysimeter site			Sage lysimeter site			Grass lysimeter site			Sage lysimeter site		
Day	PRG (mm)	ETG (mm)	ETB (mm)	PRS (mm)	ETS (mm)	ETR (mm)	PRG (mm)	ETG (mm)	ETB (mm)	PRG (mm)	ETS (mm)	ETR (mm)
1	0.00	0.13	0.15	0.00	0.07	0.14	0.00	1.60	1.52	0.00	1.59	--
2	0.00	0.19	0.11	0.00	0.00	0.09	0.00	0.62	--	0.00	0.51	--
3	0.00	0.27	0.07	0.00	0.00	0.07	0.01	0.54	--	0.02	0.46	--
4	0.00	0.03	0.08	0.00	0.02	0.06	9.22	0.94	--	9.62	1.02	--
5	0.00	0.14	0.11	0.00	0.03	0.12	--	--	--	--	--	--
6	0.00	0.01	0.11	0.00	0.01	0.09	--	--	--	--	--	--
7	0.00	0.05	0.11	0.00	0.00	0.09	--	--	--	--	--	--
8	0.00	0.11	0.12	0.00	0.00	0.09	--	--	--	--	--	--
9	0.00	0.11	0.10	0.00	0.00	0.10	--	--	--	--	--	--
10	0.00	0.00	0.08	0.00	0.00	0.10	--	--	--	--	--	--
11	0.00	0.02	0.12	0.00	0.00	--	--	--	--	--	--	--
12	0.00	0.19	0.11	0.00	0.00	--	--	--	--	--	--	--
13	2.71	0.12	0.10	1.75	0.02	--	--	--	--	--	--	--
14	6.51	2.03	1.64	7.72	1.97	--	--	--	--	--	--	--
15	0.00	0.81	0.86	0.00	0.63	--	--	--	--	--	--	--
16	0.00	0.60	0.64	0.00	0.45	--	--	--	--	--	--	--
17	0.00	0.42	0.48	0.00	0.29	--	--	--	--	--	--	--
18	0.00	0.30	0.39	0.00	0.27	--	--	--	--	--	--	--
19	0.00	0.38	0.34	0.00	0.26	--	--	--	--	--	--	--
20	0.00	0.28	0.40	0.00	0.13	--	--	--	--	--	--	--
21	0.00	0.32	0.31	0.00	0.35	--	--	--	--	--	--	--
22	0.00	0.25	0.27	0.00	0.05	--	--	--	--	--	--	--
23	0.00	0.21	0.34	0.00	0.10	--	--	--	--	--	--	--
24	0.00	0.18	0.30	0.00	0.09	--	--	--	--	--	--	--
25	0.30	0.19	0.39	0.33	0.12	--	--	--	--	--	--	--
26	0.49	0.44	0.42	0.63	0.37	--	--	--	--	--	--	--
27	6.54	0.80	0.79	6.47	0.88	--	--	--	--	--	--	--
28	0.00	1.21	1.28	0.00	1.06	--	--	--	--	--	--	--
29	0.00	0.47	0.71	0.00	0.36	--	--	--	--	--	--	--
30	0.00	0.48	0.57	0.00	0.42	--	--	--	--	--	--	--
31	9.95	1.26	1.20	9.91	1.25	--	--	--	--	--	--	--
TOT	26.50	12.00	12.70	26.81	9.20	--	--	--	--	--	--	--

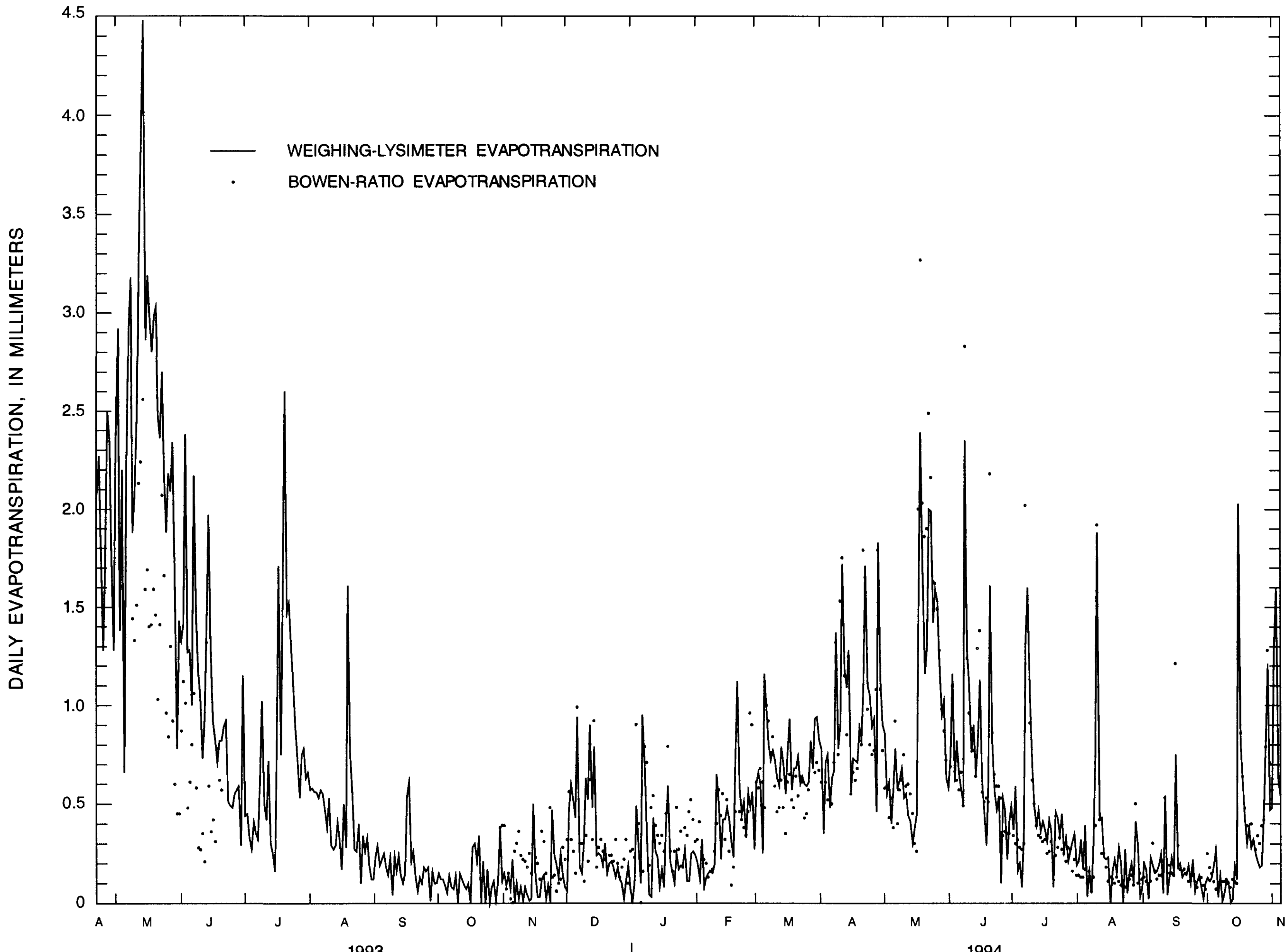


Figure 14.--Daily weighing-lysimeter and Bowen-ratio evapotranspiration at grass lysimeter site, April 20, 1993 to November 4, 1994. Weighing-lysimeter evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

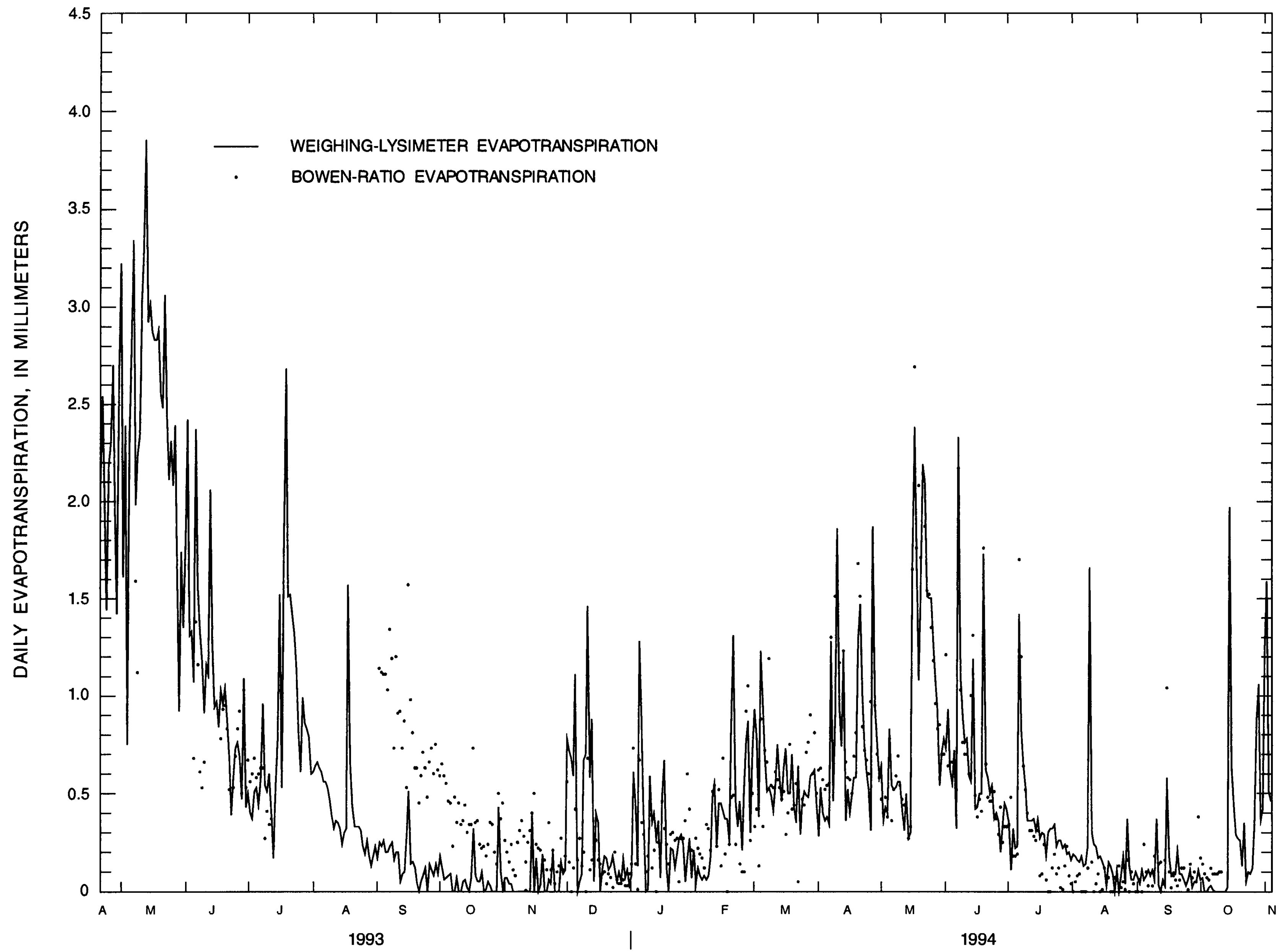


Figure 15.--Daily weighing-lysimeter and Bowen-ratio evapotranspiration at sage lysimeter site, April 20, 1993 to November 4, 1994. Weighing-lysimeter evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

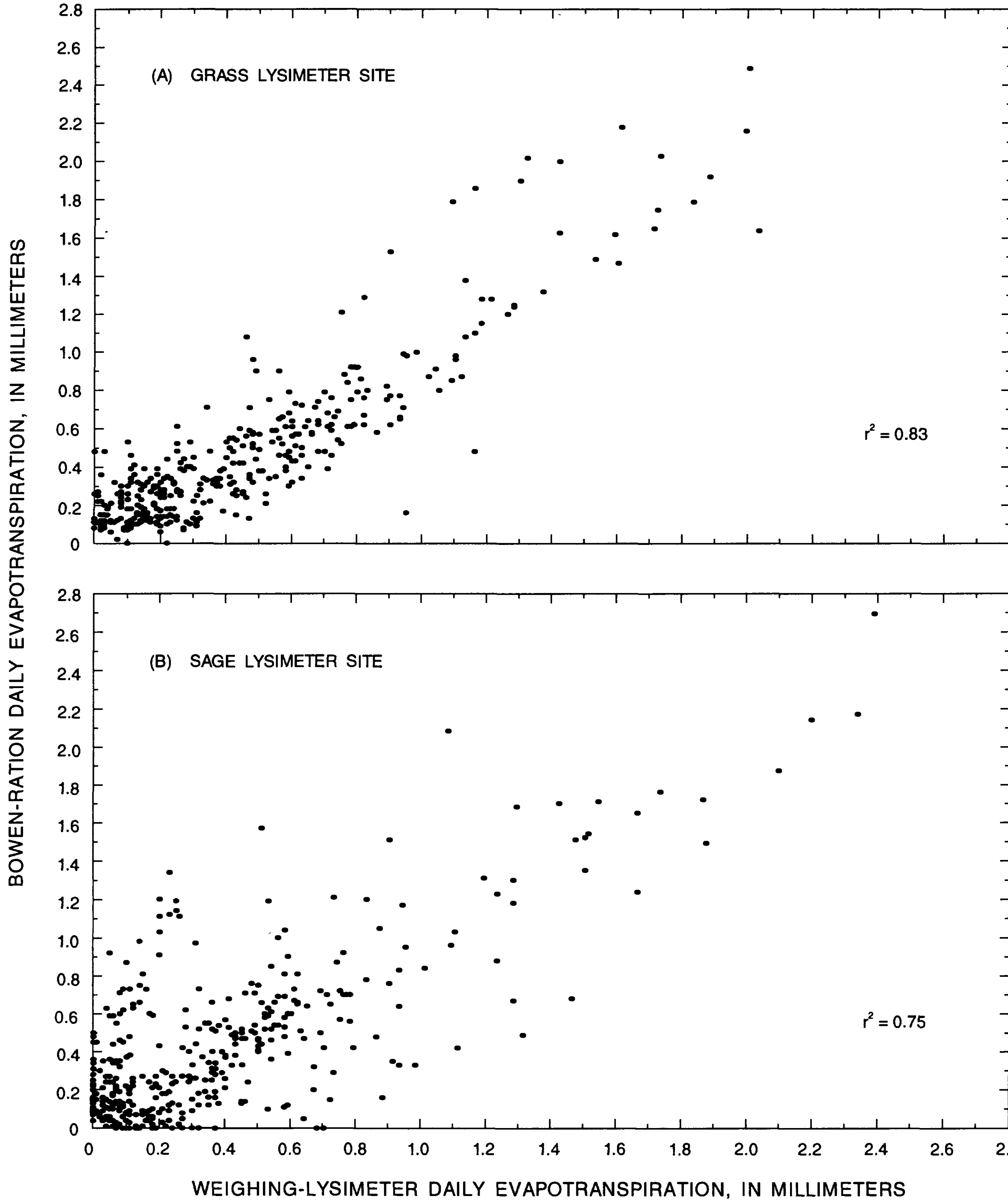


Figure 16.--Weighing-lysimeter and Bowen-ratio daily evapotranspiration at (A) grass lysimeter site, October 29, 1993 to November 1, 1994, and (B) sage lysimeter site, November 1, 1993 to October 10, 1994. Weighing-lysimeter evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

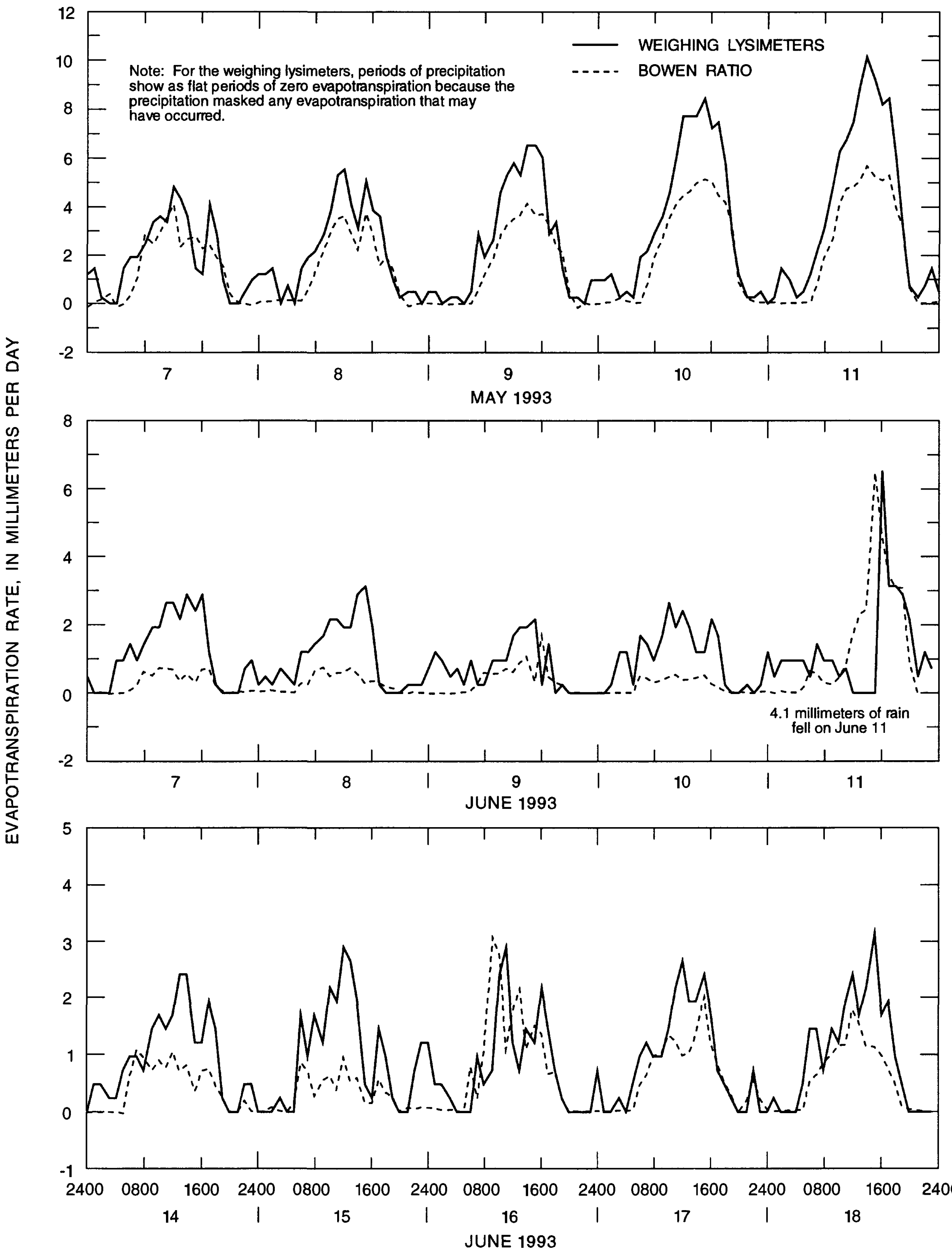


Figure 17.--Hourly evapotranspiration at the grass lysimeter site estimated with weighing lysimeters and the Bowen-ratio method, May 7-11, June 7-11, and June 14-18, 1993. Weighing-lysimeter evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

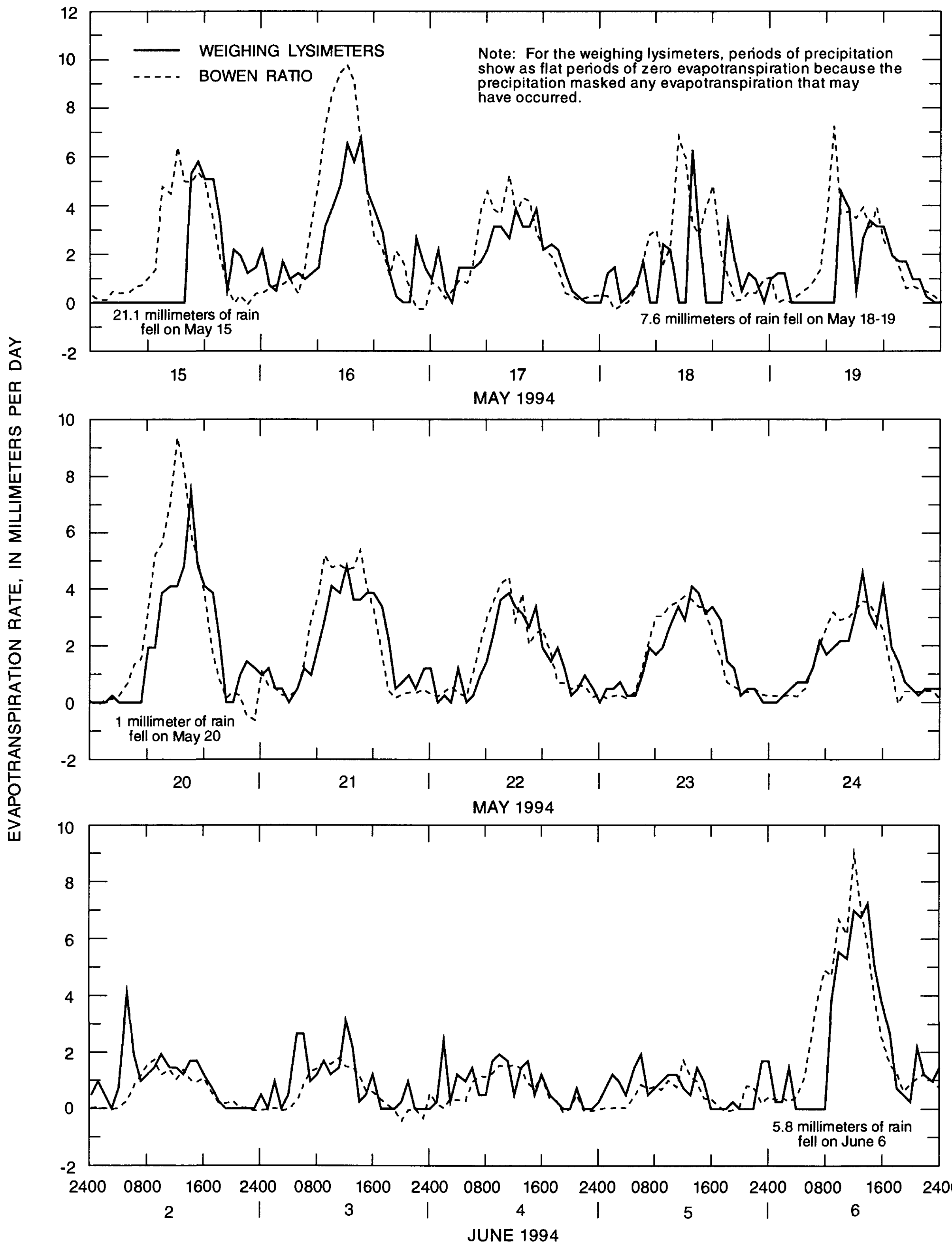


Figure 18.--Hourly evapotranspiration at the grass lysimeter site estimated with weighing lysimeters and the Bowen-ratio method, May 15-24 and June 2-6, 1994. Weighing-lysimeter evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

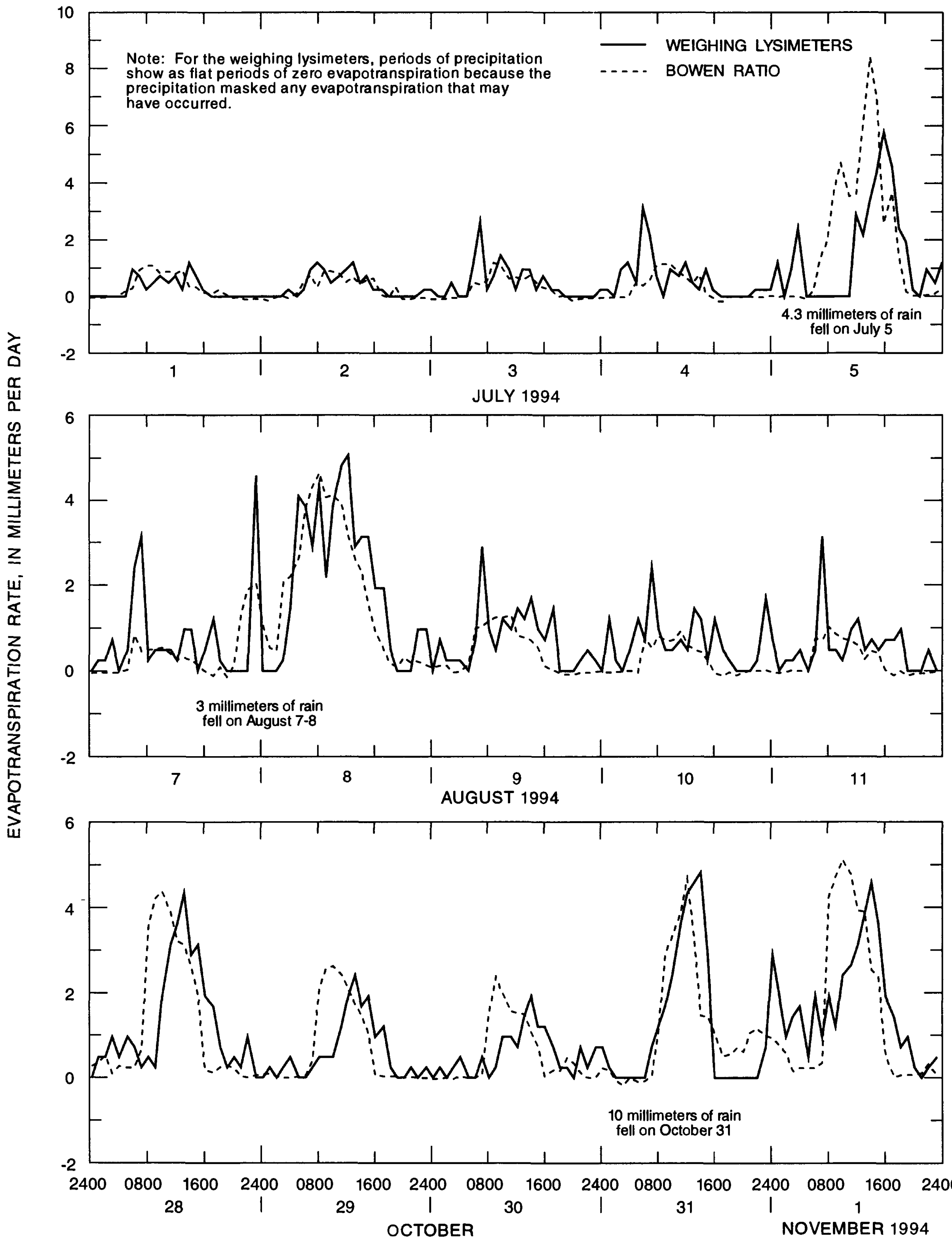


Figure 19.--Hourly evapotranspiration at the grass lysimeter site estimated with weighing lysimeters and the Bowen-ratio method, July 1-5, August 7-11, and October 28 to November 1, 1994. Weighing-lysimeter evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

Comparison of Latent-Heat Fluxes from Bowen-Ratio and Fixed-Sensor Systems

In 1993 and 1994, latent-heat flux from the fine-wire thermocouple/cooled-mirror hygrometer Bowen-ratio system compared favorably with that from the fixed-sensor system at the grass and sage lysimeter sites under many conditions (clouds, cool temperatures, rainfall, and high winds) during the fall, winter, and spring. During periods such as May 15-21, 1994 (fig. 20), latent-heat fluxes estimated with the Bowen-ratio system were consistent with those estimated with the fixed-sensor system. Because of this consistency, the fixed-sensor system was used to estimate ET with the Bowen-ratio method when the fine-wire thermocouple/cooled-mirror Bowen-ratio system could not be used because of instrument failure or adverse weather conditions, such as freezing air temperatures during winter. The fixed-sensor system also worked well after heavy rainfalls even during the summer. There are many conditions in which sensor bias may be small compared with air-temperature and vapor-pressure gradients. In these cases, sensor bias can be ignored and the fixed-sensor system data can be used as an alternate to the Bowen-ratio system data to estimate daily ET.

There were some cases, however, in which the Bowen-ratio system results did not agree well with the fixed-sensor system results. When conditions became warm and dry, such as May 22-26, 1994 (fig. 20), the fixed-sensor system sometimes produced unreasonable or erroneous values of latent-heat flux compared with the Bowen-ratio system. This was sometimes represented by extremely negative gradients which resulted in negative latent-heat fluxes, such as on May 23-25, 1994 (fig. 20). These unreasonable results may have been due to inadequate ventilation of the fixed sensors or uneven heating of the fixed sensors, which would have affected both the air-temperature and relative-humidity measurements. Not only would this have caused erroneous data to be collected, but it could have introduced uneven instrument bias between the upper and lower sensors. Many close, as well as some dissimilar, comparisons between Bowen-ratio and fixed-sensor results were also noted at sites outside the present study area (S. Tomlinson, U.S. Geological Survey, written commun., 1995).

Comparison of Evapotranspiration Methods from March 24 to April 5, 1994

Table 4 shows daily ET from March 24 to April 5, 1994 at the grass lysimeter site estimated with the two weighing lysimeters, two eddy-correlation systems, the Bowen-ratio system (DEW-10 cooled-mirror hygrometer and fine-wire thermocouples), and the fixed-sensor system (two fixed RH-207 air-temperature and relative-humidity probes). Total ET from March 24 to April 5 varied within about 30 percent, using the different systems and methods. Total ET for the period differed by only 4 percent for the two lysimeters. The Bowen-ratio method averaged 89 percent of the ET measured by the two lysimeters, within the 12-percent error that might be expected due to the instruments (Tomlinson, 1995). The Bowen-ratio method utilizing the fixed-sensor system estimated 107 percent of lysimeter ET. The eddy-correlation method estimated about 80 percent of Bowen-ratio ET and 72 percent of lysimeter ET. Differences between lysimeter, Bowen-ratio, and eddy-correlation ET were often small on an hourly basis (fig. 21). Lysimeter ET showed the most hourly variability, compared with Bowen-ratio and eddy-correlation ET, but most of this variability averaged out over the day.

Two eddy-correlation systems collected data from March 23 to April 6, 1994, providing daily ET estimates form March 24 to April 5. The first eddy-correlation system (eddy correlation #1) was set at 2.5 m above the land surface adjacent to the Bowen-ratio system. The 2.5-meter height corresponded exactly with the average height of the two Bowen-ratio system arms that collected air-temperature and vapor-pressure data. The second eddy-correlation system (eddy correlation #2) was set up 0.5 m above the land surface adjacent to the lysimeters to test for spacial differences between the ET measured by the lysimeters and the Bowen-ratio system. Eddy-correlation #1 ET averaged 86 percent of the Bowen-ratio ET and 77 percent of the lysimeter ET. Eddy-correlation system #2 ET averaged 86 percent of eddy-correlation #1 ET, 74 percent of Bowen-ratio ET, and 66 percent of lysimeter ET. The two eddy-correlation systems may have estimated different amounts of ET because of instrument variability or site differences. In all cases, the differences between the methods were consistent with the better comparisons between Bowen-ratio and lysimeter ET in 1993 and the rest of 1994. Other researchers comparing Bowen-ratio with eddy-correlation ET (Duell, 1990; Wilson and others, 1992) and Bowen-ratio with lysimeter ET (Kirkham, 1993) in semiarid areas have not found significant differences between the methods.

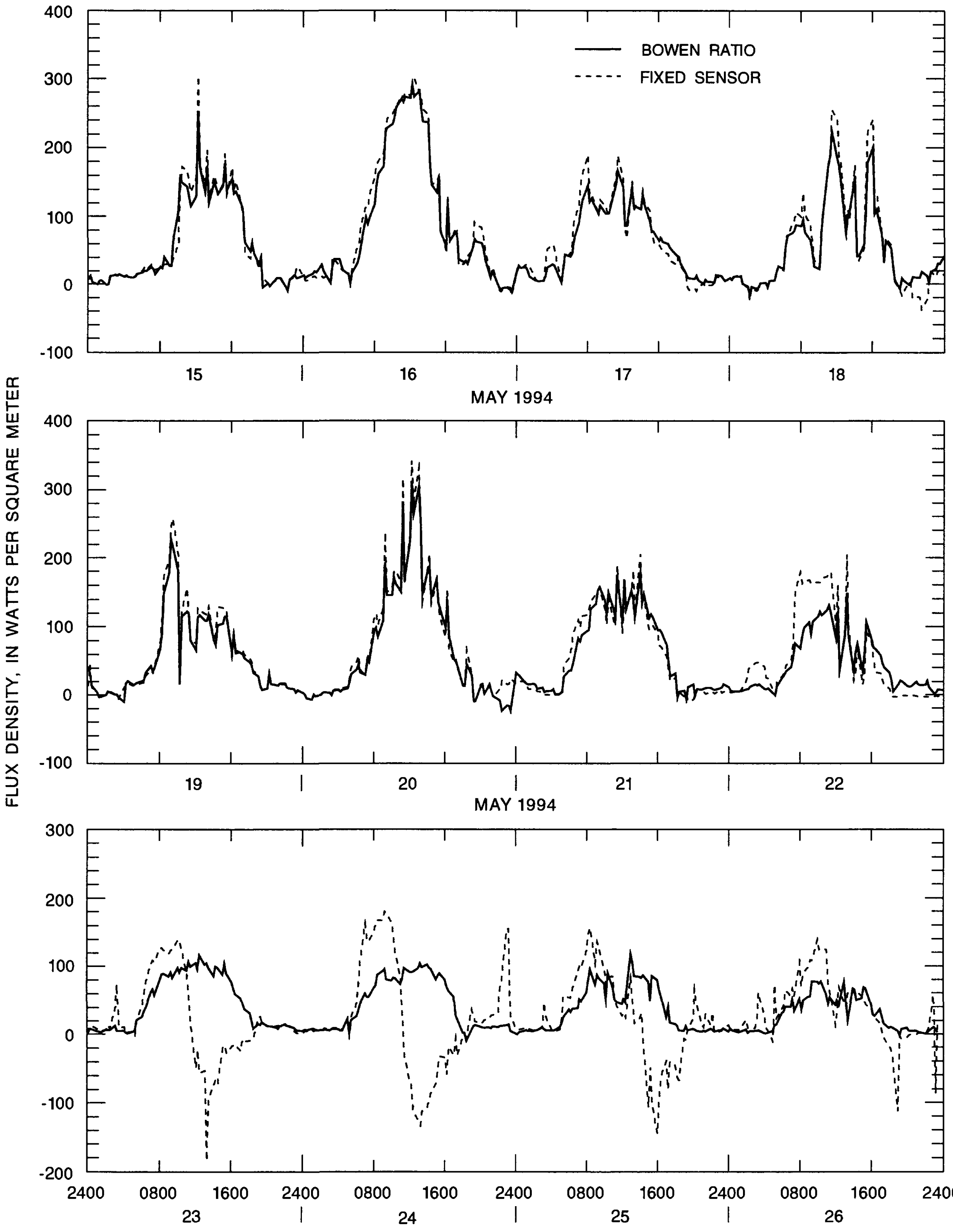


Figure 20.--Bowen-ratio latent-heat flux at the grass lysimeter site from Bowen-ratio and fixed-sensor instruments, May 15-26, 1994.

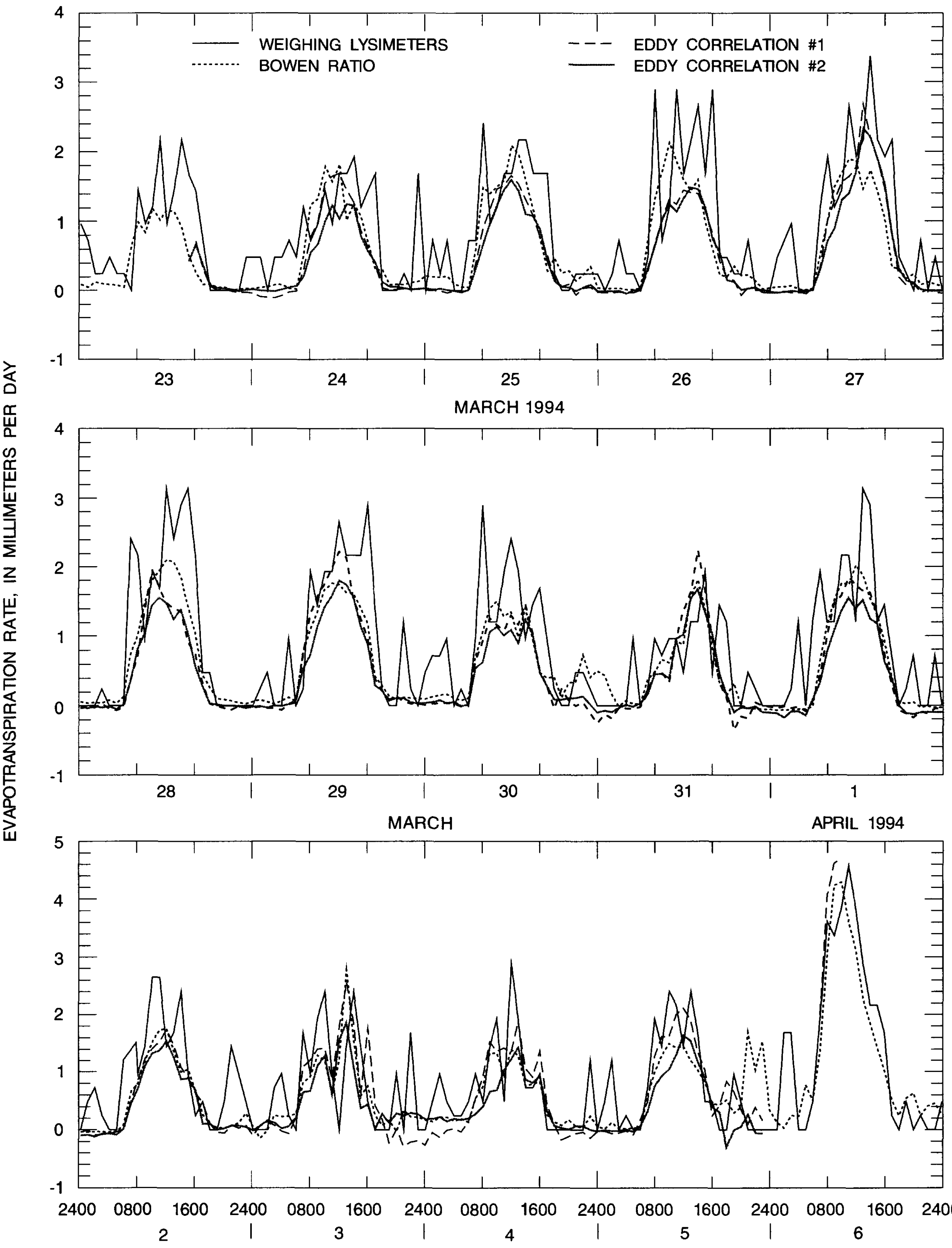


Figure 21.--Evapotranspiration at the grass lysimeter site estimated with weighing lysimeters, the Bowen-ratio method, and the eddy-correlation method, March 23 to April 6, 1994. Weighing-lysimeter evapotranspiration estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

Table 4.--*Daily and total evapotranspiration at the grass lysimeter site from weighing lysimeters, the Bowen-ratio method, and the eddy-correlation method, March 24 to April 5, 1994*

[Evapotranspiration estimates for the weighing lysimeters are based on data collected and provided by Battelle, Pacific Northwest Laboratories; all values in millimeters; WL1, evapotranspiration from weighing lysimeter 1; WL2, evapotranspiration from weighing lysimeter 2; BR, evapotranspiration from Bowen-ratio method; EC1, evapotranspiration from eddy-correlation method at 2.0 meters; EC2, evapotranspiration from eddy-correlation method at 0.5 meters; FX, evapotranspiration from Bowen-ratio method using fixed sensors]

Date	WL1	WL2	BR	EC1	EC2	FX
March						
24	0.56	0.66	0.57	0.47	0.39	0.57
25	.87	.78	.72	.53	.48	.80
26	.60	.76	.65	.48	.48	.82
27	.91	.95	.66	.71	.65	.79
28	.97	.90	.71	.50	.46	.83
29	.70	.95	.67	.68	.56	.88
30	.83	.74	.79	.47	.43	1.16
31	.20	.50	.48	.39	.38	.28
April						
1	.74	.68	.61	.54	.43	1.07
2	.76	.74	.52	.48	.42	.82
3	.48	.48	.58	.60	.49	.55
4	.64	.62	.50	.49	.45	.41
5	.74	.60	.71	.69	.45	.82
Total	9.00	9.36	8.17	7.03	6.07	9.80

Some researchers have found, however, that the eddy-correlation method consistently underestimated the Bowen-ratio method (Bidlake and others, 1993, p. 22; D. Stannard, U.S. Geological Survey, oral commun., 1994; M.J. Johnson, U.S. Geological Survey, oral commun., 1995). These trends may be present in short-term investigations, but possibly not in long-term investigations. In the present study, although the eddy-correlation ET estimates were lower than the Bowen-ratio ET estimates on 10 of the 13 days from March 24 to April 5, 1994 (table 4), this trend may not have continued if eddy-correlation measurements had been made into May. Lysimeter ET was greater than Bowen-ratio ET for 10 of the 13 days during the March-April 1994 period, but this trend did not continue. For example, the Bowen-ratio method estimated more ET than the lysimeters measured on 20 out of the 31 days in May 1994, so Bowen-ratio ET averaged 13 percent more than lysimeter ET for the month (table 3).

To help check on the accuracy of the eddy-correlation measurements, energy-budget closure was determined using measured net radiation and soil-heat flux, along with the eddy-correlation #1 estimates of latent-heat flux and sensible-heat flux. Energy-budget closure was obtained by subtracting the sum of soil-heat, latent-heat, and sensible-heat fluxes from the net radiation. An ideal closure would be zero. The best closure from March 24 to April 5, 1994, was obtained on cloudy or rainy days, whereas the worst closure was obtained on sunny days (fig. 22). Because the latent-heat flux and ET estimates made with the eddy-correlation method agreed reasonably well with the Bowen-ratio and lysimeter ET estimates, the eddy-correlation estimates of sensible-heat flux on sunny days were presumed to be in error. Eddy-correlation sensible-heat fluxes averaged about 50 to 80 percent of Bowen-ratio sensible-heat fluxes on clear, sunny days. Furthermore, using sensible-heat flux estimates from the Bowen-ratio method with latent-heat flux estimates from the eddy-correlation method with net radiation and soil-heat flux common to both methods resulted in closure near zero (fig. 22). The closure results help substantiate that the eddy-correlation sensible-heat flux estimates were often in error on sunny days, but the results provide no reason for the error. Possible reasons for the error include

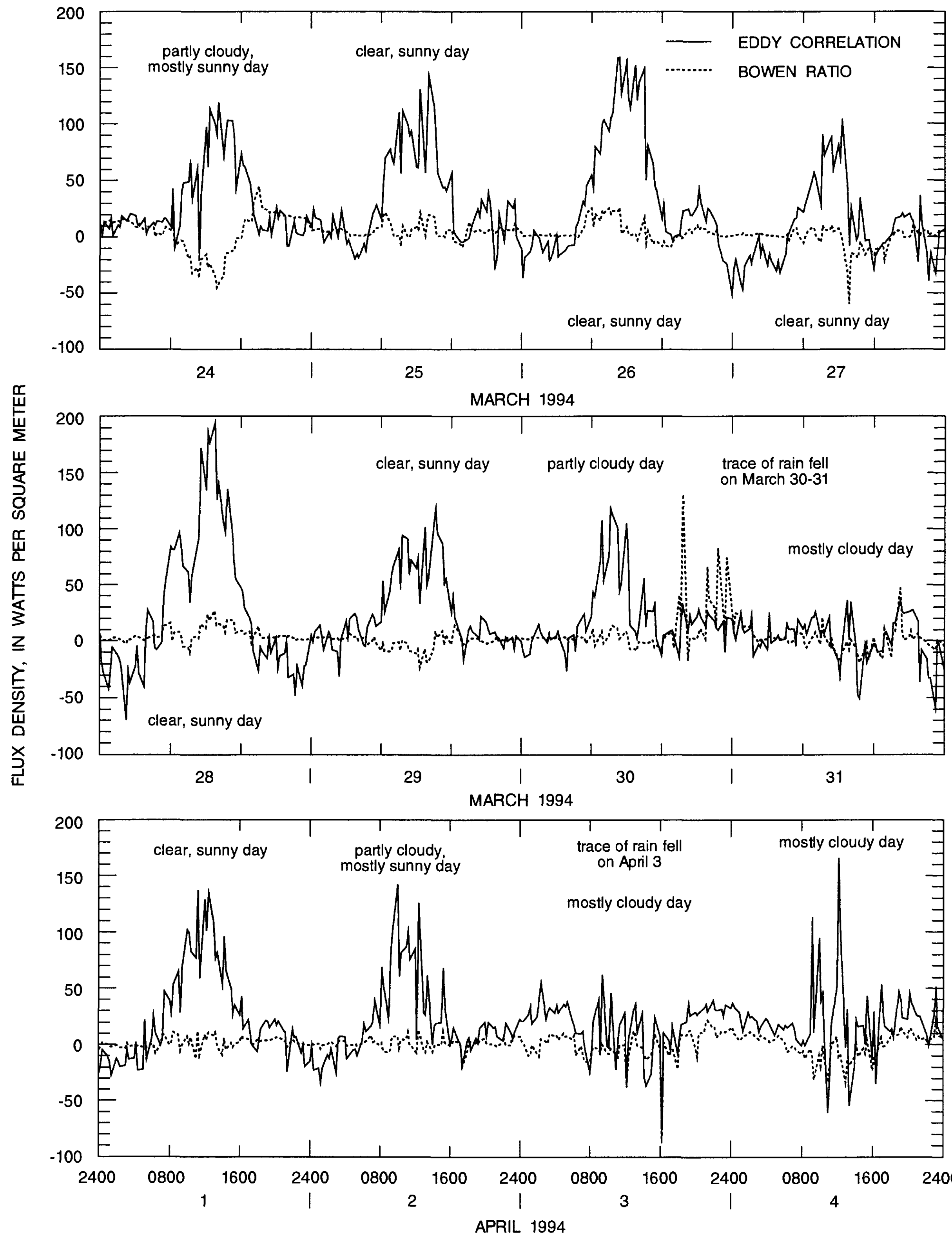


Figure 22.-- Energy-budget closure from eddy-correlation sensible-heat flux and Bowen-ratio sensible-heat flux at grass lysimeter site, March 24 to April 4, 1994. Energy-budget closure =net radiation– soil-heat flux– sensible-heat flux– latent-heat flux.

either different calculations of air density for changing covariances between vertical wind speed and air temperature, or to the measurement of instantaneous fluctuations in air temperature (M.J. Johnson, U.S. Geological Survey, written commun., 1995). Other researchers have found poor energy-budget closure with the eddy-correlation method, but the suspected errors were with the latent-heat flux or net radiation (Bidlake and others, 1993, p. 20-22).

Table 4 also shows that the fixed-sensor system worked quite well, even under conditions of drought, so long as air temperatures were not high. The total fixed-sensor ET for the period March 24 to April 5, 1994 averaged only 7 percent more than that measured by the lysimeters (table 4). Daily air temperatures averaged 12°C during the March-April period, compared with an average of 21°C from May 23-25, 1994, when the fixed-sensor system failed to produce reasonable ET results compared to the estimates made with the Bowen-ratio system.

Comparison of Latent-Heat Fluxes from Identical Bowen-Ratio Instruments

Figures 23 and 24 show latent-heat flux for several periods in 1994 estimated with identical Bowen-ratio instruments at the grass and sage lysimeter sites. Two sets of Bowen-ratio instruments were located at the sage lysimeter site and one set at the grass lysimeter site. Bowen-ratio latent-heat flux at the two sites agreed reasonably well on most days, but there were some exceptions. On April 1, 2, and 3, 1994 (fig. 23), for instance, Bowen-ratio system #2 at the sage lysimeter site showed negative latent-heat fluxes while sage lysimeter site Bowen-ratio system #1 and the grass lysimeter site Bowen-ratio system showed positive, closely matching latent-heat fluxes. The discrepancy at the sage lysimeter sites is puzzling because they agreed on many days, such as May 25 to June 9, 1994 (figs. 23-24). ET estimated with the three Bowen-ratio systems varied by an average of 14 percent during the May 25 to June 9 period, close to the 12 percent instrument difference estimated at a nearby site in 1991 (Tomlinson, 1995). Bowen-ratio system #1 at the sage lysimeter site estimated ET within 5 percent of ET estimated by the grass lysimeter site Bowen-ratio system. The largest difference in ET, 18 percent, existed between the two Bowen-ratio systems at the sage lysimeter site. Possible explanations for the differences in April and May 1994 include advective processes affecting one set of instruments but not the other, instrument error, or vapor-pressure gradients beyond the sensitivities of some cooled-mirrors. Eddy-correlation measurements that were made at the sage lysimeter site during April and May by Battelle, Pacific Northwest Laboratories showed positive latent-heat fluxes (R. Kirkham, Battelle Pacific Northwest Laboratories, written commun., 1995). Negative latent-heat fluxes have been observed in a number of instances at other sites as well (Tomlinson, 1994; Tomlinson, 1995, Tomlinson, 1996).

Because the eddy-correlation data showed positive fluxes and two Bowen-ratio systems showed positive fluxes, this might suggest that instrument error of some form is the reason for the negative fluxes on the sage lysimeter site Bowen-ratio system #2. The cooled-mirror hygrometers may be biased towards negative vapor-pressure gradients when vapor-pressure gradients are very small. The eddy-correlation method may make more accurate estimates of ET than the Bowen-ratio method when vapor-pressure gradients are very small, which often occurs over rough surfaces (Rosenberg and others, 1983, p. 146), such as exists at the sage lysimeter site. Large negative gradients were not observed at the grass lysimeter site.

Water Budgets

At the grass and sage lysimeter sites, practically all the precipitation that falls annually is returned to the atmosphere as ET. Periods of near-zero soil-moisture change and near-zero ET occur every year in late summer or in fall at the grass (fig. 25) and sage (fig. 26) lysimeter sites. For the purpose of estimating water budgets for the grass and sage lysimeter sites for this study, August 19, 1990, was chosen as a starting point when the soil-moisture storage change in the lysimeter monoliths was assumed to be zero. The weight of the lysimeters was at its lowest point in 1990 on August 19, and there had been no rain for 18 days beforehand. In fact, there had been no daily precipitation greater than 3.2 mm since May 23. In addition, daily maximum air temperatures exceeded 33°C on 28 of the 38 days from July 10 to August 16, 1990, which helped evaporate most soil moisture from the lysimeters at the grass and sage lysimeter sites. A 20-mm rainfall occurred on August 21, ending the dry period. Surface runoff was assumed to be zero at the sites because soils were usually very dry and were able to absorb all the rainfall that occurred.

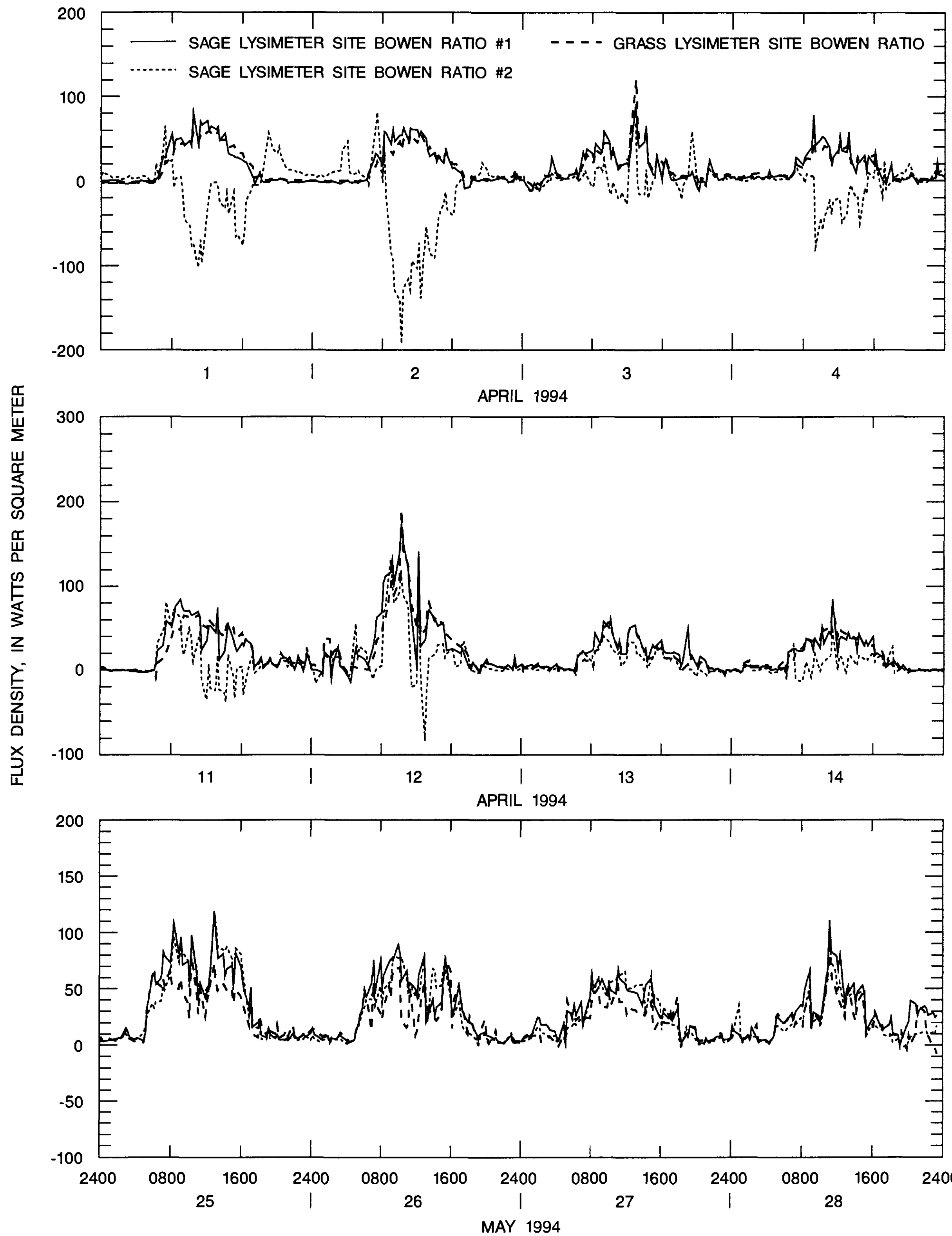


Figure 23.--Latent-heat flux at the sage and grass lysimeter sites from the Bowen-ratio method, April 1-4, April 11-14, and May 25-28, 1994.

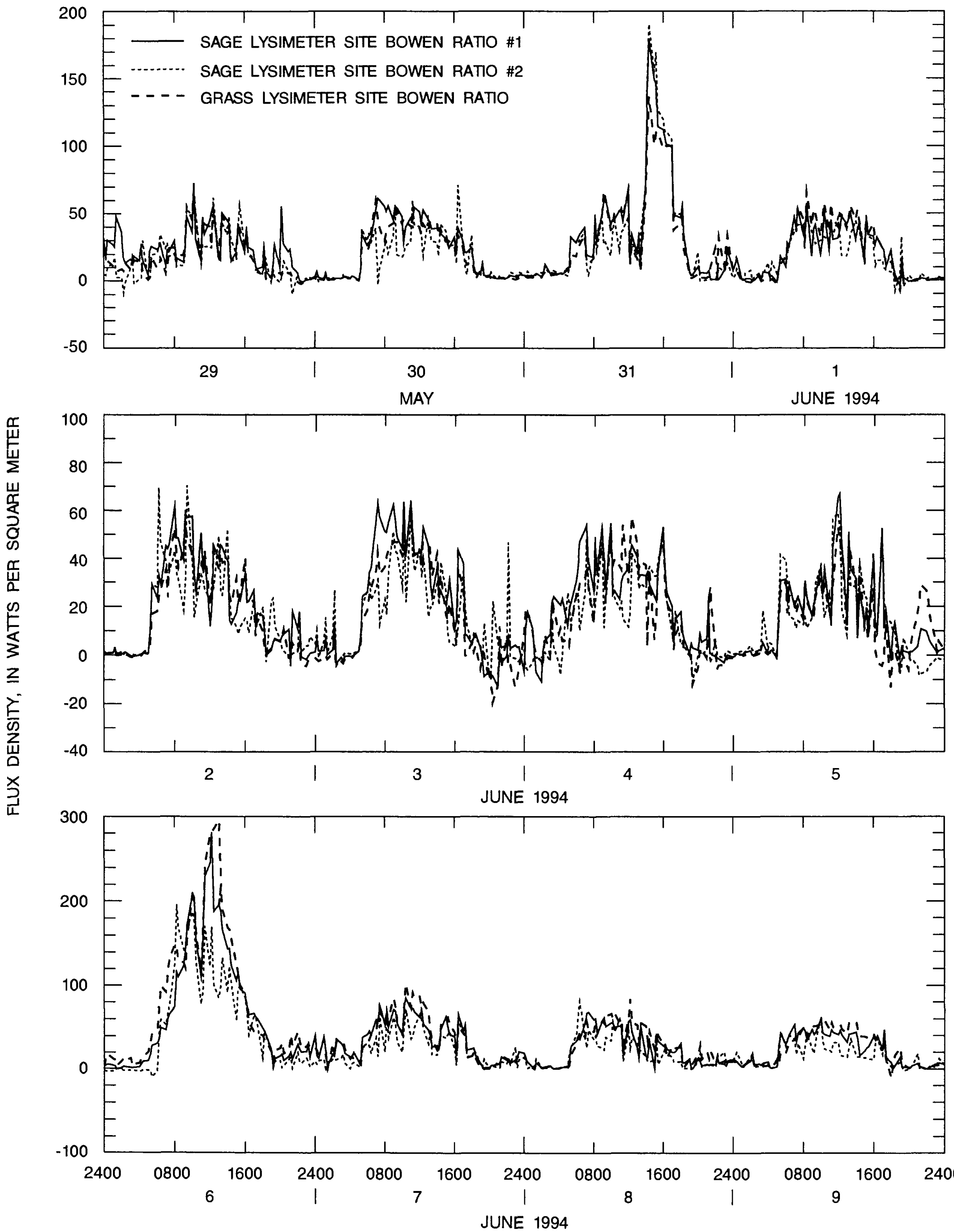


Figure 24.-- Latent-heat flux at the sage and grass lysimeter sites from the Bowen-ratio method, May 29 to June 9, 1994.

Water budgets were estimated in two ways. In the first method, daily totals of ET and precipitation were accumulated at each site for the period August 19, 1990, to November 4, 1994, and compared (figs. 25-26). In the second method, lysimeter weights at the driest point in every year were compared to the weights on August 19, 1990. The latter is probably a more accurate method to determine the water budget as it does not have to take into account occasional anomalies in the lysimeter measurements, such as animal trespass or drifting snow. When daily lysimeter estimates of ET and precipitation were added up, such anomalies could not always be accounted for, so some errors were introduced in the ET and precipitation estimates. These errors are not believed to be large because most weight-gain anomalies were always followed by weight-loss anomalies of the same magnitude and therefore cancelled out.

In the first method, ET and precipitation were tallied at each lysimeter (tables 2 and 3), then the ET-to-precipitation ratio was noted for each day from August 19, 1990, to November 4, 1994. Dates with the highest ET-to-precipitation ratios were noted for each year from 1991 to 1994. For the grass and sage lysimeter sites, respectively, these ratios were 101 and 101 percent on October 12, 1991; 98.4 and 101 percent on August 20, 1992; 96.7 and 103 percent on November 21, 1993; and 99.0 and 103 percent on October 21, 1994. The values above 100 percent were probably due to unaccounted-for weight gains and losses in the lysimeters, particularly in fall when unaccounted-for dew may have augmented precipitation. For instance, the lysimeters on some days in late summer and in fall showed overall weight gains, even though there was no precipitation. ET was estimated at zero rather than a negative number for those days. The overall error of about 3 percent (103 percent, compared with 100) is within the 5 percent of the precipitation on the ALE Reserve that might be dew (Rickard and others, 1988), so dew augmentation may be a plausible explanation.

Using the actual lysimeter weights on each of the same dates in the first method gave the following ET-to-precipitation ratios for the grass and sage-lysimeter sites, respectively: 1991, 100 and 99.9 percent; 1992, 99.8 and 100 percent; 1993, 98.9 and 99.8 percent; and 1994, 99.6 and 100 percent. Water budgets using only the Bowen-ratio ET estimates were not possible because of intermittent data gaps throughout the period.

Both methods show that practically no water became recharge in any of the years from 1990 to 1994. During this period, the only year in which some recharge may have occurred was 1993, a wet year, when the lysimeters showed between 97 and 99 percent of the precipitation became ET at the grass lysimeter site. Both water budget methods show that precipitation from late summer storms (August 21, 1990, and August 22, 1992) may be held over in the soil profile until the following spring, when it is consumed by plants through ET. On the basis of lysimeter weight changes for all 4 years, the two methods showed that 99.0 to 99.6 percent of precipitation became ET at the grass lysimeter site, and 100 percent became ET at the sage lysimeter site. This helps substantiate the hypothesis that the sage plants are root-bound in the lysimeters and, therefore, use all the water that is available to them. However, the difference is so small that instrument or experimental error could not be ruled out.

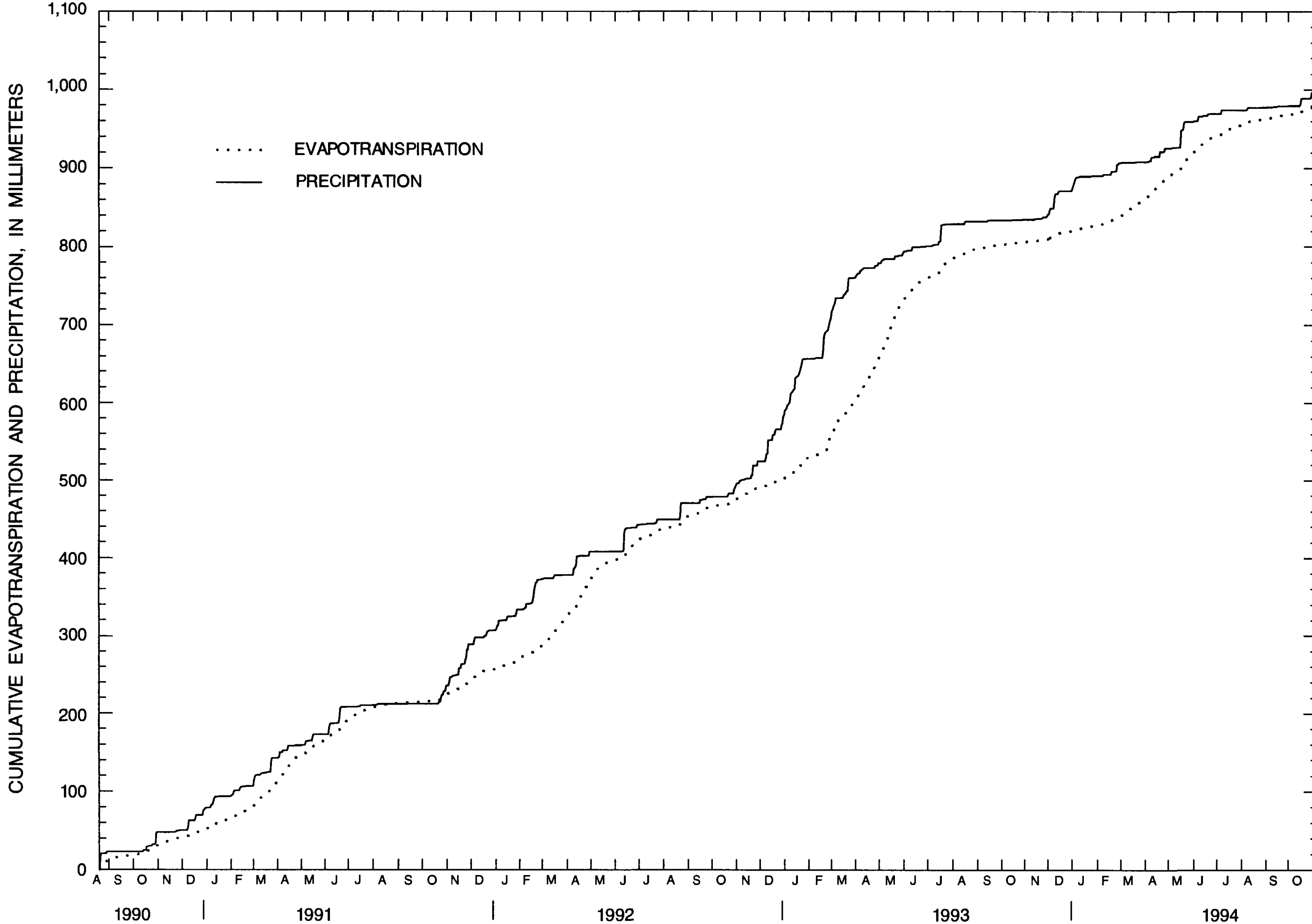


Figure 25.--Cumulative evapotranspiration and precipitation at grass lysimeter site, August 19, 1990 to November 4, 1994. Evapotranspiration and precipitation estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

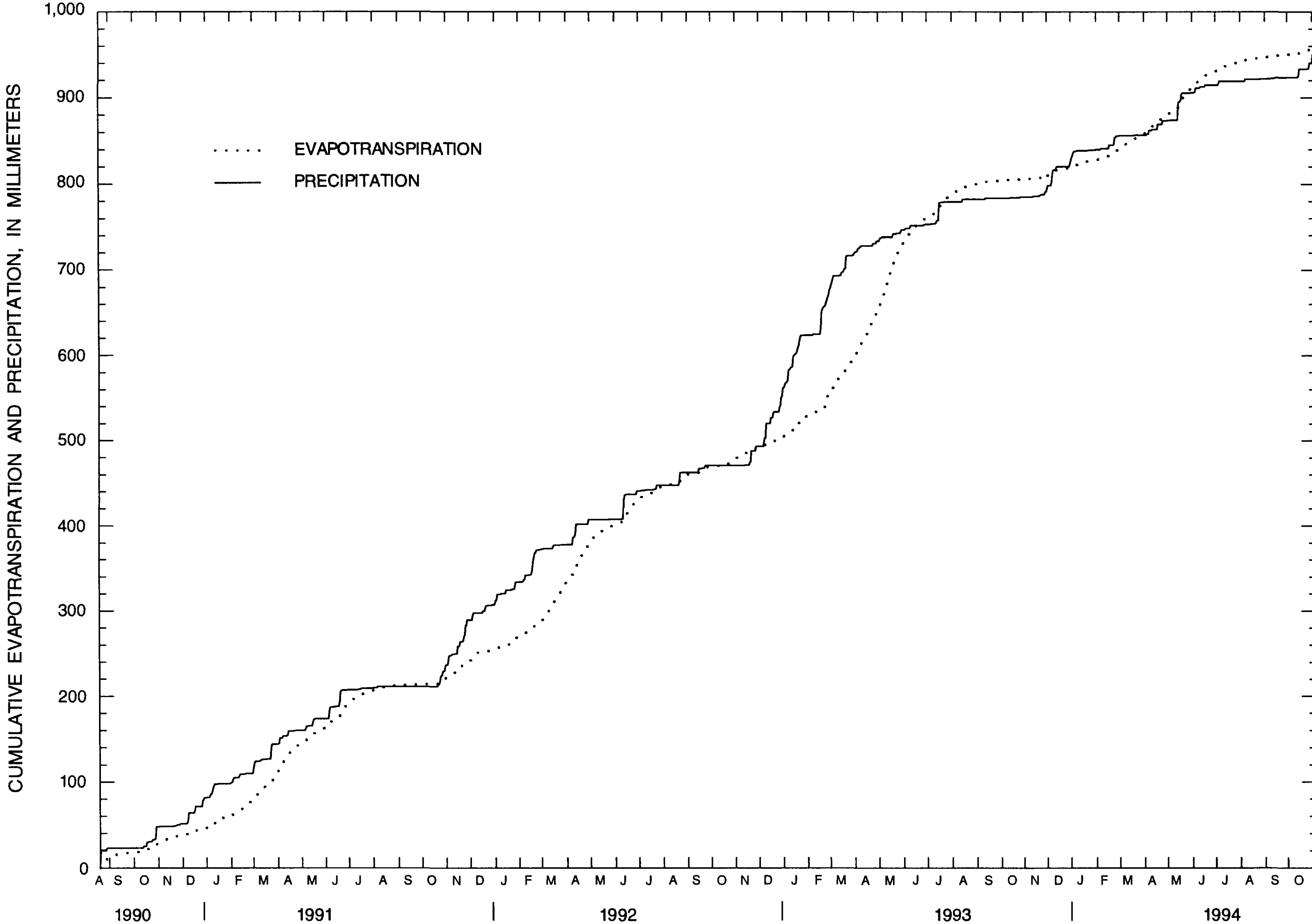


Figure 26.--Cumulative evapotranspiration and precipitation at sage lysimeter site, August 19, 1990 to November 4, 1994. Evapotranspiration and precipitation estimates are based on data collected and provided by Battelle, Pacific Northwest Laboratories.

SUMMARY AND CONCLUSIONS

The comparison of Bowen-ratio, eddy-correlation, and weighing-lysimeter evapotranspiration for two sparse-canopy sites in eastern Washington points to three conclusions. First, although there were sometimes large differences among the Bowen-ratio method, eddy-correlation method, and lysimeters for small periods of time such as a day, week, or month, the differences between the methods (at least between the Bowen-ratio method and lysimeters) were small when averaged out over a year or longer. Second, periods of large differences among the methods were usually due to either instrument variability or error, or to conditions in the lysimeters not representing conditions in the overall landscape. Further studies would be required to determine if the lysimeter monoliths heat or cool more quickly than soil in the surrounding landscape, if plant density in the lysimeters is higher than in the surrounding landscape at the grass lysimeter site, or if the sage plants in the lysimeters at the sage lysimeter site are root-bound. Third, lysimeter estimates of ET and precipitation showed that practically no precipitation became recharge from August 1990 to November 1994 at the grass and sage lysimeter sites. Almost 100 percent of the precipitation that fell at the grass and sage lysimeter sites became ET.

The conclusions for this report are based on ET and precipitation results from several methods and periods of data collection at the grass and sage lysimeter sites on the Arid Lands Ecology Reserve in Benton County, Washington. ET estimates were made with weighing lysimeters from August 1990 to November 1994. The Bowen-ratio method was used to estimate ET from May to July 1993 and September 1993 to November 1994. A variation of the Bowen-ratio method utilizing fixed sensors estimated ET during the fall, winter, and spring of 1993-94. The eddy-correlation method was used to estimate ET at the grass lysimeter site in March and April 1994.

Comparisons among the different methods varied, depending on the periods of record being compared and the sites being analyzed. The year 1993 was very wet, with about 50 percent more precipitation than the annual average; 1994 was a very dry year, with only about half the average annual precipitation. From August 1990 to November 1994, lysimeter ET at the grass lysimeter site averaged only 2.2 percent more than lysimeter ET at the sage lysimeter site ($r^2 = 0.93$). From October 1993 to November 1994, Bowen-ratio ET averaged 4.9 percent more than lysimeter ET ($r^2 = 0.83$) at the grass lysimeter site. However, from May to June 1993, Bowen-ratio ET was only 54 percent of lysimeter ET at the grass lysimeter site. At the sage lysimeter site, Bowen-ratio ET averaged 1 percent less than lysimeter ET in June and July 1993 and 2.7 percent less than lysimeter ET from November 1993 to October 1994 ($r^2 = 0.75$). However, Bowen-ratio ET averaged 450 percent more than lysimeter ET in September and October 1993 ($r^2 = 0.53$).

The 54-percent difference between Bowen-ratio and lysimeter ET at the grass lysimeter site in 1993 may have been due to inexplicable Bowen-ratio cooled-mirror instrument error (though the vapor-pressure data from the cooled-mirror appeared reasonable) or to the lysimeters not representing conditions in the overall landscape. Possibly, grass plant density is higher in the lysimeters than in nature, or the lysimeter sides heat the soil more than the soil would be heated in nature—both of these situations could cause ET to occur at a higher rate than outside the lysimeters, especially in spring when grasses are in peak growth.

The 450-percent difference between Bowen-ratio and lysimeter ET at the sage lysimeter site in September and October 1993 may have been due to the lysimeters not representing conditions in the overall landscape. The lysimeters limit the rooting depth of sage plants in the lysimeters to the depth of the lysimeters, while in the surrounding landscape the plants may root more deeply and access stored water. Because sage plants transpire when developing flower buds and blooming in late summer and early fall, significant ET would be expected at this time. Furthermore, supplemental water in summer increases the intensity of bud development and bloom. In 1993, a 20-mm rainfall in July after an already wet winter may have spurred the sage plants outside the lysimeters to bud and bloom heavily, resulting in ET rates averaging 0.6 mm per day in September and October. The sage plants in the lysimeters appeared stressed, bloomed sparsely compared with the plants outside the lysimeters, and averaged 0.1 mm per day in ET. Annual water budgets of lysimeter ET and precipitation at the sage lysimeter site from 1991 to 1994 showed about 100 percent of the precipitation became ET each year, possibly indicating a root-bound condition in the lysimeters.

From March 24 to April 5, 1994, at the grass lysimeter site, the Bowen-ratio method, the eddy-correlation method, and lysimeters estimated ET within about 30 percent of each other. ET estimated by the two lysimeters differed by only 4 percent. The Bowen-ratio method using the fine-wire thermocouple/cooled-mirror system estimated 89 percent and the Bowen-ratio method using the fixed-sensor system estimated 107 percent of the ET estimated with two lysimeters. Two eddy-correlation systems estimated ET at 66 to 77 percent of lysimeter ET. The differences between the eddy-correlation system ET estimates may have been due to instrument differences or to site differences. Whether the eddy-correlation method would continue to estimate ET about 30 percent less than lysimeter ET is unclear. Bowen-ratio ET did not continue to be lower than lysimeter ET at the grass lysimeter site during the rest of 1994. For instance, in May 1994, Bowen-ratio ET averaged 113 percent of lysimeter ET. From October 1993 to November 1994, Bowen-ratio ET averaged only 4.9 percent more than lysimeter ET. Thus, there may be daily, weekly, or monthly differences between different ET methods that may average out over longer periods of time.

From May 25 to June 9, 1994, ET estimated with one set of Bowen-ratio instruments at the grass lysimeter site and two sets of instruments at the sage lysimeter site varied by an average of 14 percent. The largest difference was between the two Bowen-ratio instruments at the sage lysimeter site, indicating that instrument differences or errors were the most likely reasons for the variability. On some days in April and May 1994, one set of Bowen-ratio instruments at the sage lysimeter site showed large negative latent-heat fluxes while the other set of Bowen-ratio instruments and eddy-correlation instruments showed positive latent-heat fluxes. Although it is possible advection of air from other areas might explain the negative fluxes, the data from the assembly of instruments at the grass and sage lysimeter sites indicate instrument variability or error was probably responsible.

Using lysimeter measurements from August 19, 1990, to November 4, 1994, cumulative ET ranged from about 97 to 103 percent of the annual precipitation each year. Surface runoff was estimated at zero. The lysimeter weight changes at the grass and sage lysimeter sites showed that soil-moisture storage changes became nearly zero each year some time between August and November, when average surface soil moisture decreased to about 2 percent and ET rates decreased to less than 0.1 mm per day. No recharge was estimated at the grass lysimeter site for any year in the August 1990 to November 1994 period except for 1993, when the lysimeters showed between 97 and 99 percent of the precipitation became ET. No recharge was estimated for any year in the period at the sage lysimeter site because the lysimeters indicated that 100 percent of the annual precipitation became ET.

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