Data Report: Meteorological and Evapotranspiration Data from Sagebrush and Pinyon Pine/Juniper Communities at Pahute Mesa, Nevada National Security Site, 2011-2012

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Nevada Site Office
National Nuclear Security Administration
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Las Vegas, Nevada

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ABSTRACT

Pahute Mesa is a groundwater recharge area at the Nevada National Security Site. Because underground nuclear testing was conducted at Pahute Mesa, groundwater recharge may transport radionuclides from underground test sites downward to the water table; the amount of groundwater recharge is also an important component of contaminant transport models. To estimate the amount of groundwater recharge at Pahute Mesa, an INFIL3.0 recharge-runoff model is being developed. Two eddy covariance (EC) stations were installed on Pahute Mesa to estimate evapotranspiration (ET) to support the groundwater recharge modeling project. This data report describes the methods that were used to estimate ET and collect meteorological data. Evapotranspiration was estimated for two predominant plant communities on Pahute Mesa; one site was located in a sagebrush plant community, the other site in a pinyon pine/juniper community. Annual ET was estimated to be 310±13.9 mm for the sagebrush site and 347±15.9 mm for the pinyon pine/juniper site (March 26, 2011 to March 26, 2012). Annual precipitation measured with unheated tipping bucket rain gauges was 179 mm at the sagebrush site and 159 mm at the pinyon pine/juniper site. Annual precipitation measured with bulk precipitation gauges was 222 mm at the sagebrush site and 227 mm at the pinyon pine/juniper site (March 21, 2011 to March 28, 2012). A comparison of tipping bucket versus bulk precipitation data showed that total precipitation measured by the tipping bucket rain gauges was 17 to 20 percent lower than the bulk precipitation gauges. These differences were most likely the result of the unheated tipping bucket precipitation gauges not measuring frozen precipitation as accurately as the bulk precipitation gauges. In this one-year study, ET exceeded precipitation at both study sites because estimates of ET included precipitation that fell during the winter of 2010-2011 prior to EC instrumentation and the precipitation gauges started collecting data in March 2011.

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LIST OF ACRONYMS

AGC	automatic gain control
d	day
DOE	U.S. Department of Energy
EC	Eddy Covariance
ET	Evapotranspiration
H	Sensible heat
H_2O	Water
Hz	Hertz
IRGA	infrared gas analyzer
kg	kilogram
kPa	kilopascal
LE	Latent energy
m	meter
mm	millimeter
NNSS	Nevada National Security Site
NSO	Nevada Site Office
NV	Nevada
PAR	photosynthetically active radiation
PFD	photon flux density
RH	Relative humidity
VPD	Vapor pressure deficit
UGTA	Underground Test Area
WPL	Webb, Pearman, Leuning

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INTRODUCTION

Pahute Mesa is located in the northwest portion of the Nevada National Security Site (NNSS) (Figure 1). Pahute Mesa is a groundwater recharge area for aquifers found at the NNSS. Because underground nuclear testing was conducted at Pahute Mesa, groundwater recharge may transport radionuclides from underground test sites downward to the water table. Quantifying the amount of groundwater recharge at Pahute Mesa is also important because groundwater flow and contaminant transport models are sensitive to groundwater recharge from Pahute Mesa (U.S. Department of Energy, 2009).

To estimate the amount of groundwater recharge at Pahute Mesa, the U.S. Department of Energy (DOE), Nevada Site Office (NSO), Environmental Restoration Program (ERP), Underground Test Area (UGTA) project is developing an INFIL recharge-runoff model (Hevesi *et al.*, 2003). INFIL3.0 is a grid-based, disturbed-parameter, deterministic, water-balance, watershed model that calculates the temporal and spatial distribution of daily net infiltration of water across the lower boundary of the root zone (U.S. Geological Survey, 2008). The daily water balance simulated with INFIL3.0 includes estimates of evapotranspiration (ET) from the root zone. To provide data for the Pahute Mesa INFIL3.0 recharge model, two eddy covariance (EC) stations were installed on Pahute Mesa to estimate ET. The EC method was used to estimate ET for one year at two predominant plant communities (sagebrush and pinyon pine/juniper) on Pahute Mesa.

DATA COLLECTION SITES

Two study sites were selected at Pahute Mesa that contain sagebrush (*Artemisia tridentate*) and pinyon pine (*Pinus edulis*)/juniper (*Junipera sp.*) plant communities. The sagebrush site was located at 37°14'30.09" N, 116° 28'32.22" W (elevation 1915 m), and the pinyon pine/juniper site was located at 37°12'51.39"N, 116°19'58.59"W (elevation 2223 m) (Figure 1). Average annual precipitation at a long-term precipitation gauge on Pahute Mesa (PM1) (http://www.sord.nv.doe.gov/raingage/Monthly/Pahute_Mesa_Monthly_Data.txt) between 1964 and 2011 was 193 mm with a range of 67 mm (2002) to 368 mm (1999). The gauge at PM1 was a universal weighing rain gauge until September, 2011 when it was replaced with an M29 electronic tipping bucket gauge. The PM1 precipitation gauge is located at 37°15'23.6"N, 116°26'07.06"W (elevation 1996 m) and was approximately 4 km from the sagebrush site and 10 km from the pinyon pine/juniper site.

EDDY COVARIANCE INSTRUMENTATION AND CALCULATIONS

Eddy covariance, energy balance, and meteorological instruments were installed at the sagebrush and pinyon pine/juniper sites on February 18, 2011, but initial data collection was not initiated until March 26, 2011 (Figure 1 and Figure 2). A 3 m tower was installed at the sagebrush site while a 10 m tower was installed at the pinyon pine/juniper site so that the eddy covariance (EC) instrumentation was above the taller the pinyon pine/juniper vegetation; these
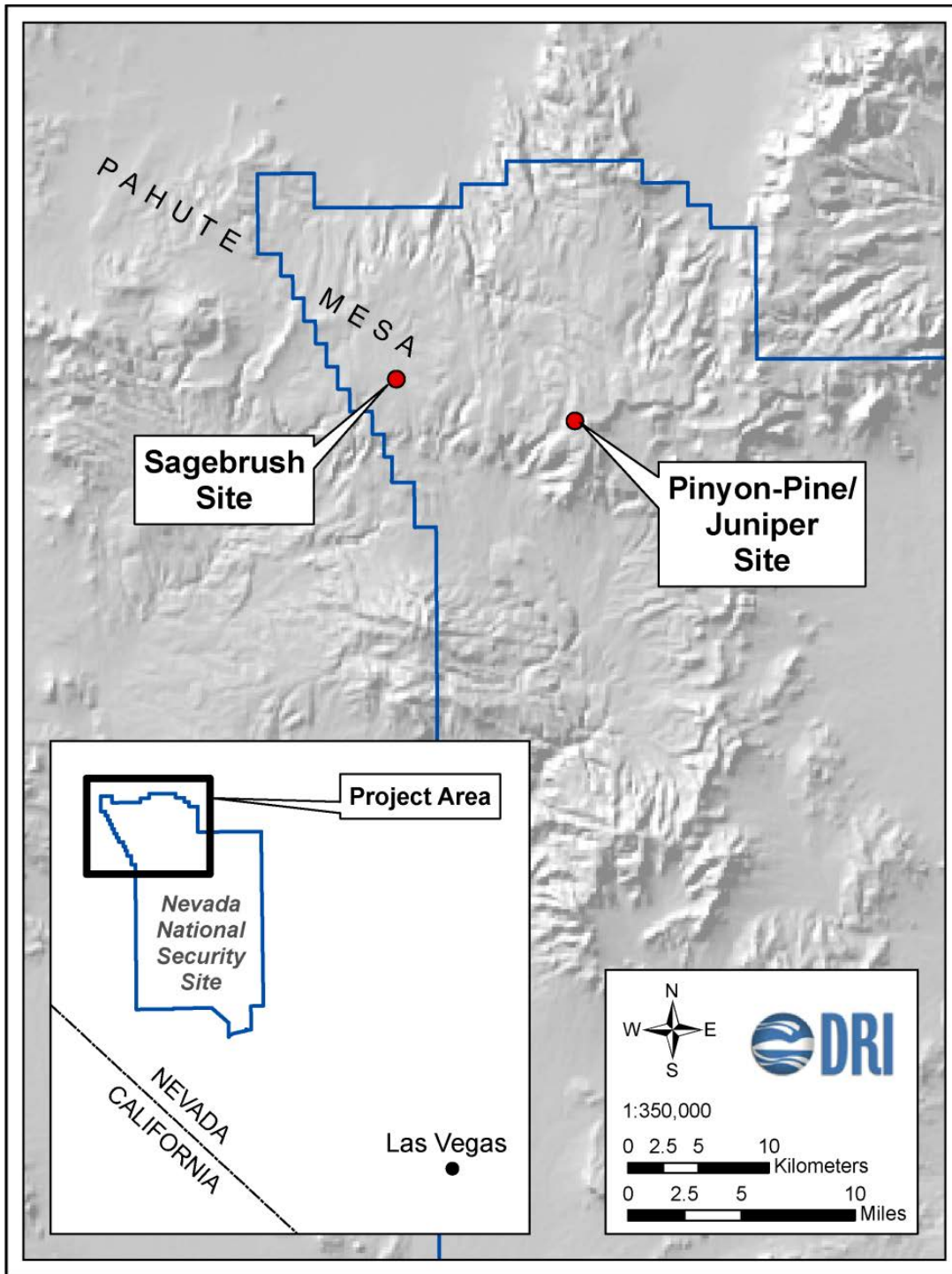
Figure 1. Map showing the location of the sagebrush (37°14'30.09" N, 116° 28'32.22" W; elevation 1915 m) and pinyon pine/juniper (37°12'51.39"N, 116°19'58.59"W; elevation 2223 m) eddy covariance evapotranspiration sites at Pahute Mesa, Nevada National Security Site.
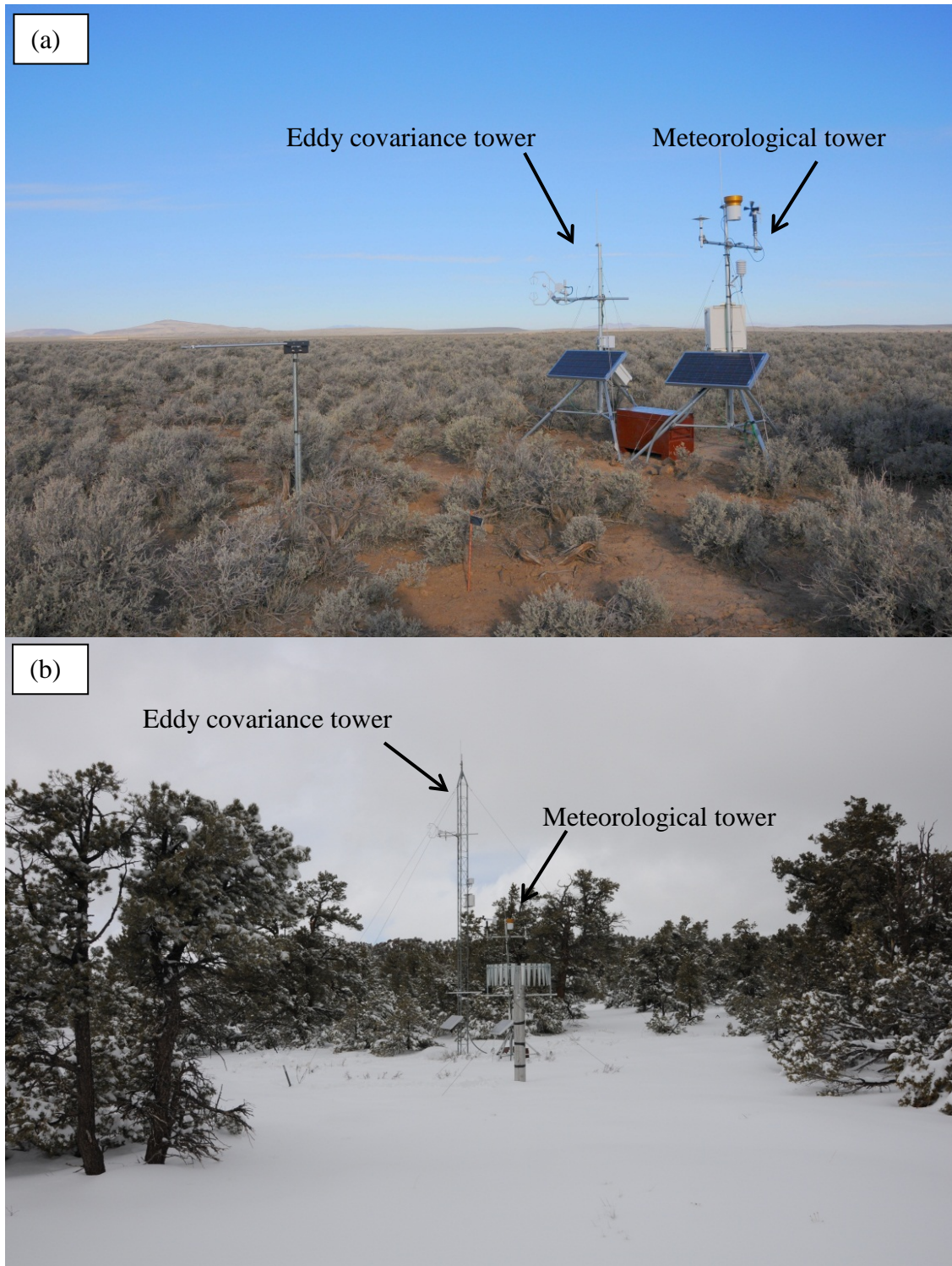
Figure 2.   Photographs of the sagebrush (a) and pinyon pine/juniper (b) eddy covariance and meteorological instrumentation located at Pahute Mesa. Photographs were taken by Brad Lyles of the Desert Research Institute on February 18, 2011 for the sagebrush site and on March 24, 2011 for the pinyon pine/juniper site.

EC towers were installed to estimate ET from the dominant vegetation cover at each site. Eddy covariance instrumentation consisted of a three-dimensional sonic anemometer (CSAT3, Campbell Scientific Inc., Logan, Utah, USA) to measure the three wind components and an open-path infrared gas analyzer (IRGA) to measure H_2O molar density (LI-7500, LI-COR Inc., Lincoln, Nebraska, USA). The EC instrumentation was mounted 1.4 and 2.7 m above mean vegetation height on the south (predominant wind direction) side of the sagebrush and pinyon pine/juniper towers, respectively. The sensor heights above mean vegetation height were selected to increase the number of points within the area of interest/footprint (sagebrush or pinyon pine/juniper communities) and to avoid interference from sources outside of this area. The ensuing larger high-frequency flux contributions and unavoidable low-pass filtering caused by the sensor heights were accounted for during post-processing using the method described by Massman (2000).

Meteorological instruments at both sites were mounted on an adjacent 3 m tower and consisted of a shielded air temperature and humidity sensor (HMP-45C, Viasala, Finland; mounted 2.0 m above ground surface), a wind vane anemometer (RM Young Wind Sentry, RM Young Company, Traverse City, MI, USA; mounted 1.5 and 2.1 m above ground surface at the sagebrush and pinyon pine/juniper sites, respectively), a net radiometer (NR-Lite, Kipp & Zonen, The Netherlands; mounted 1.8 m above ground surface), a photosynthetically active radiation sensor (Q-190-SB, LI-COR Inc.; PAR, 400-700 nm; mounted 2.5 m above ground surface), an unheated tipping bucket rain gauge (TE525, Texas Electronics, Dallas, TX, USA; mounted 2.5 m above ground surface), and a bulk precipitation gauge (bulk gauges were fabricated as part of this project from 20 cm diameter stainless steel pipe and fitted with a standard alter shield [model 260-952, NovaLynx Corporation, Grass Valley, CA, USA]). The gauge orifice was approximately 1.8 m above the ground surface, and the top of the alter shield was about 5 cm above the gauge orifice. Soils instrumentation included two soil heat flux plates (Hukseflux HFP01SC, HuksefluxUSA, Manoville, NY; inserted at 8 cm soil depth), soil temperature thermocouple probes (TCAV averaging soil thermocouple probes, Campbell Scientific; installed at 2 and 6 cm soil depth adjacent to the soil heat flux plate), and a water content reflectometer (CS-616, Campbell Scientific; installed at a depth of 4 cm). Data from the EC instrumentation were recorded at a frequency of 10 Hz (10 times per second) while data from the other instrumentation were recorded as 30-min averages, and both sets of data were logged using a CR5000 data logger (Campbell Scientific). Both the 10 Hz data and 30-min average data were stored on a compact flash card. Data from the compact flash card were downloaded monthly when instruments were checked and maintained.

Eddy fluxes were calculated as the covariance between turbulent fluctuations of the vertical wind speed and water vapor density derived from Reynolds (block) averaging of 30-min blocks of data. The sonic anemometer's coordinate system was numerically rotated during each averaging period by applying a double rotation, aligning the longitudinal wind component into the main wind direction, and forcing the mean vertical wind speed to zero (Kaimal and Finnigan, 1994; Wohlfahrt et al., 2008). Frequency response corrections were applied to raw eddy fluxes

accounting for low-pass (lateral and longitudinal sensor separation, sensor time response, scalar and vector path averaging) and high-pass (block averaging) filtering (Massman, 2000, 2001) using a site-specific, co-spectral reference model (Massman and Clement, 2004; Wohlfahrt *et al.*, 2005). Experimentally-derived frequency response correction factors (Aubinet *et al.*, 2000, 2001) were used to assess the validity of the theoretical low-pass filtering correction method as detailed in Wohlfahrt *et al.* (2005). Finally, fluxes were corrected for the effect of air density fluctuations following Webb *et al.* (1980).

Half-hourly flux data were quality controlled in a five-step filtering procedure. First, periods were identified when the EC system was not working properly because of adverse environmental conditions (usually rain or snow) or instrument malfunction. Second, half-hourly values that were comprised of less than the full complement of measured values (i.e., less than 18,000) were removed. Third, data were subjected to the integral turbulence test (Foken and Wichura, 1996) and accepted only on the condition that they did not exceed the target value (Foken *et al.*, 2004) by more than 60 percent (Wohlfahrt *et al.*, 2008). Fourth, data were subjected to the angle of attack test (β - beta; the angle between the wind vector and horizontal), which identifies errors in data resulting from the imperfect cosine response of sonic anemometers. Data were excluded when the angle of attack was greater than 20º (Geissbühler *et al.*, 2000; Gash and Dolman, 2003). Finally, data were excluded when the automatic gain control (AGC) of the IRGA was greater than 10% of the specific baseline value for each instrument. Increases from baseline AGC typically result from rain, snow, or ice accumulation on the surface of the lens of the IRGA and result in errors in water vapor density values.

GAP FILLING AND UNCERTAINTY ANALYSIS

Data gaps (30-min time steps; both daytime and nighttime values) for each site, resulting from filtering or missing data, were filled using a site-specific regression equation of ET vs. photon flux density (PFD) of photosynthetically active radiation (PAR) (Figure 3 and Figure 4). Seventeen percent of the 30-min values for the sagebrush site were gap filled using the site-specific regression equation of ET vs. PAR; nine percent of the 30-min values were gap filled for the pinyon pine/juniper site. Photosynthetically active radiation was used because of its relationship to plant physiological processes (e.g., transpiration and stomatal conductance). This method resulted in gap-filled nighttime ET values being zero. Gap filling nighttime values with a site-specific regression using PAR is a conservative approach when compared to other gap filling methods such as linear interpolation or the mean diurnal variation method with a time window of one month (Falge *et al.*, 2001). These methods tend to result in overestimation of nighttime ET. Gap filling 30-min data using net radiation is also a viable gap filling method and site-specific regression equations of ET vs. net radiation measured during this study resulted in similar regressions (sagebrush site: $r^2 = 0.53$, *P*<0.0001, slope = 0.0001, y-int. = 0.0089; pinyon pine/juniper site: $r^2 = 0.59$, *P*<0.0001, slope = 0.0001, y-int. = 0.011) to those using PAR.

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Figure 3.   Site-specific regression of ET vs. PFD of PAR for the sagebrush site located at Pahute Mesa (elevation 1915 m). Each point represents a 30-min time period between March 26, 2011 and March 26, 2012, and includes both daytime and nighttime values. The resulting regression equation was used to fill gaps in ET data resulting from filtering or missing data.
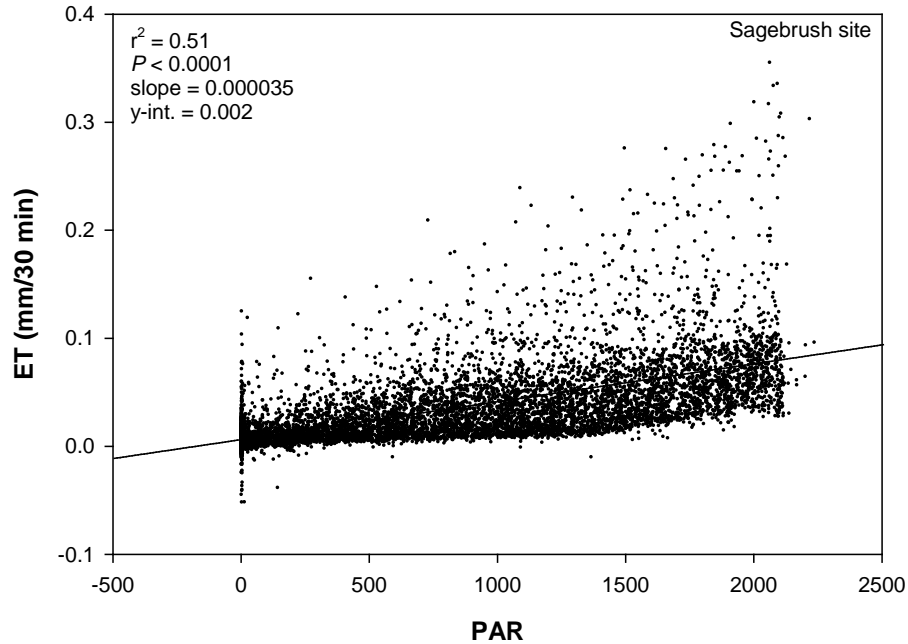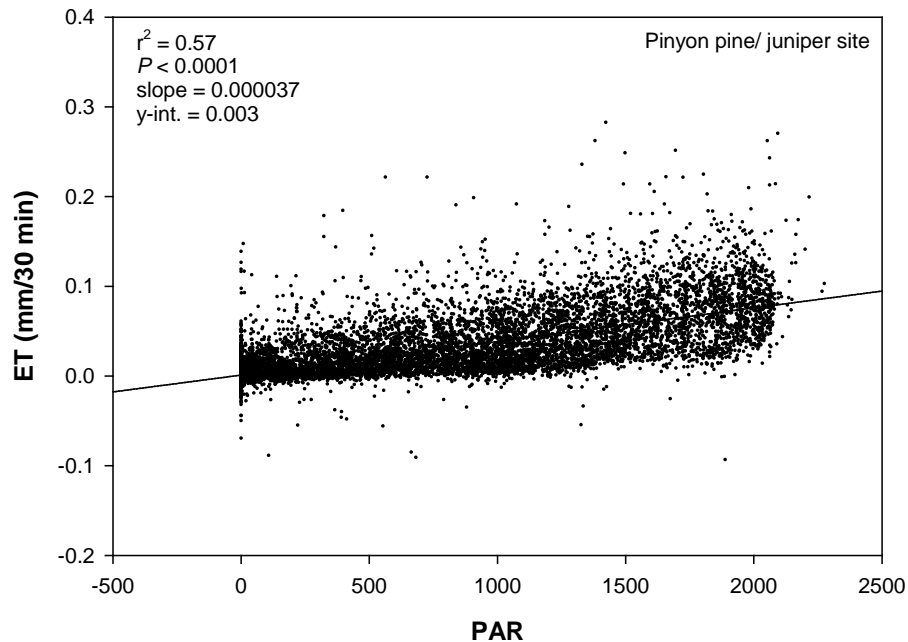

Figure 4.   Site-specific regression of ET vs. PFD of PAR for the pinyon/juniper site located at Pahute Mesa (elevation 2223 m). Each point represents a 30-min time period between March 26, 2011 and March 26, 2012, and includes both daytime and nighttime values. The resulting regression equation was used to fill gaps in ET data resulting from filtering or missing data.

Systematic uncertainty of ET estimates derives primarily from the collective effects of inherent instrument measurement errors on density corrections (Webb *et al.*, 1980; Webb, Pearman and Leuning Correction [WPL]). Uncertainty introduced by applying the WPL correction under the range of inherent measurement errors for each instrument (sensor) was estimated by defining a likely relative uncertainty for each independent parameter (instrument measurement) and by applying this, in turn, to calculate annual ET. Assuming that the various component uncertainties are independent, the combined uncertainty from the WPL correction was calculated by taking the square root of the sum of the squared individual uncertainties. Based on manufacturers' specifications, and on past experience with long-term sensor stability, the water vapor density, and static air pressure were assigned uncertainties of 10 percent (Wohlfahrt *et al*., 2008) while air temperature was assigned an uncertainty of 2 percent (Table 1). Uncertainty in the sensible heat flux may arise from the fact that the sensible heat flux was measured based on speed of sound measurements, which has been shown by Loescher *et al*. (2005) to deviate from sensible heat flux derived from measurements of air temperature with a fast-response platinum resistance thermometer by up to 10 percent for this specific sonic anemometer model. Alternatively, Ham and Heilman (2003) – again for the same anemometer model used in this study – found extremely close correspondence between sonic- and thermocouple-derived sensible heat flux measurements. Additional uncertainty of the sensible heat flux arises from the choice of coordinate system (Lee *et al*., 2004) and from the necessary (small) frequency response corrections (Massman, 2001). Based on the research findings

Table 1.   Total systematic uncertainty of annual evapotranspiration (mm) calculated as the square root of the sum of squared individual sources of uncertainty. T_{air} – air temperature; ρv – H_2O density; P – air pressure; F_H – sensible heat before accounting for density effect and storage flux; F_{LE} – latent energy before accounting for density effects and storage flux.

Source of uncertainty	Sagebrush	Pinyon Pine/Juniper
T_{air} (2%)	0.13	0.12
ρ_v (10%)	2.28	2.66
P (10%)	0.19	0.20
F_H (5%)	1.03	1.19
F_{LE} (5%)	13.66	15.70
Total systematic uncertainty (mm):	± 13.89	± 15.97

presented above and some preliminary sensitivity tests with different coordinate systems (data not shown), a 5 percent uncertainty for the sensible heat flux was assumed. Similar to the sensible heat flux, a 5 percent uncertainty for latent heat flux was assumed, intended to reflect uncertainties because of choice of the coordinate system and frequency response corrections, which are based on a site-specific co-spectral reference model (cf. Massman and Clement, 2004; Wohlfahrt *et al*., 2005) and have been validated against experimentally derived frequency response correction factors following Aubinet *et al*. (2000) and Aubinet *et al*. (2001) as described in Wohlfahrt *et al*. (2005) and Wohlfahrt *et al*. (2008). Based on this information, 5 percent uncertainty is justified and not nearly as large as the upper range of potential errors in frequency response correction factors (30 percent) reported by Massman and Clement (2004) (Table 1).

AREA OF INTEREST FOOTPRINT ANALYSIS

The area of interest footprint for each site (sagebrush [Figure 5] or pinyon pine/juniper [Figure 6] communities) was calculated using the footprint model of Hsieh *et al.* (2000) to estimate the upwind distance and compass direction that represented 90 percent of the surface flux for each half-hour period ($X_{90\%}$). Close agreement between modeled and measured data from arid and agricultural areas has shown the model to be valid and provides reliable footprint data (Hsieh *et al*. 2000).

$$\text{Error! Bookmark not defined. } X_{90\%} = \frac{-D \, | \, L \, |^{(1-P)} \, Z_u^P}{k^2 \, \ln(0.90)}$$

Eq. 1

where k is the von Karman constant (0.4), L is the Obukhov length, and Z_u is the length scale calculated as:

$$Z_u = \frac{Z_m \, u \, k}{u_*}$$

Eq. 2

where Z_m is the measurement height, u is the mean wind speed, and D and P are stability-dependent coefficients:

$D = 0.28$; $P = 0.59$ for unstable conditions ($Z_u / L < $ -0.04)

$D = 0.97$; $P = 1.00$ for near-neutral conditions (-0.04 $< Z_u / L < 0.04$)

$D = 2.44$; $P = 1.33$ for stable conditions ($Z_u/L > 0.04$).

Each calculated point, or footprint distance and direction (that corresponds to an individual 30-min ET value), was then plotted in ArcGIS and a polygon circumscribed on the outside of the collective set of points that represented an area of interest (sagebrush or pinyon pine/juniper communities). Evapotranspiration for each area of interest was then calculated using ET values that were within the polygon and, therefore, representing ET from only the sagebrush or pinyon pine/juniper communities. Evapotranspiration values that were removed during this process were gap filled using the gap filling method previously described.
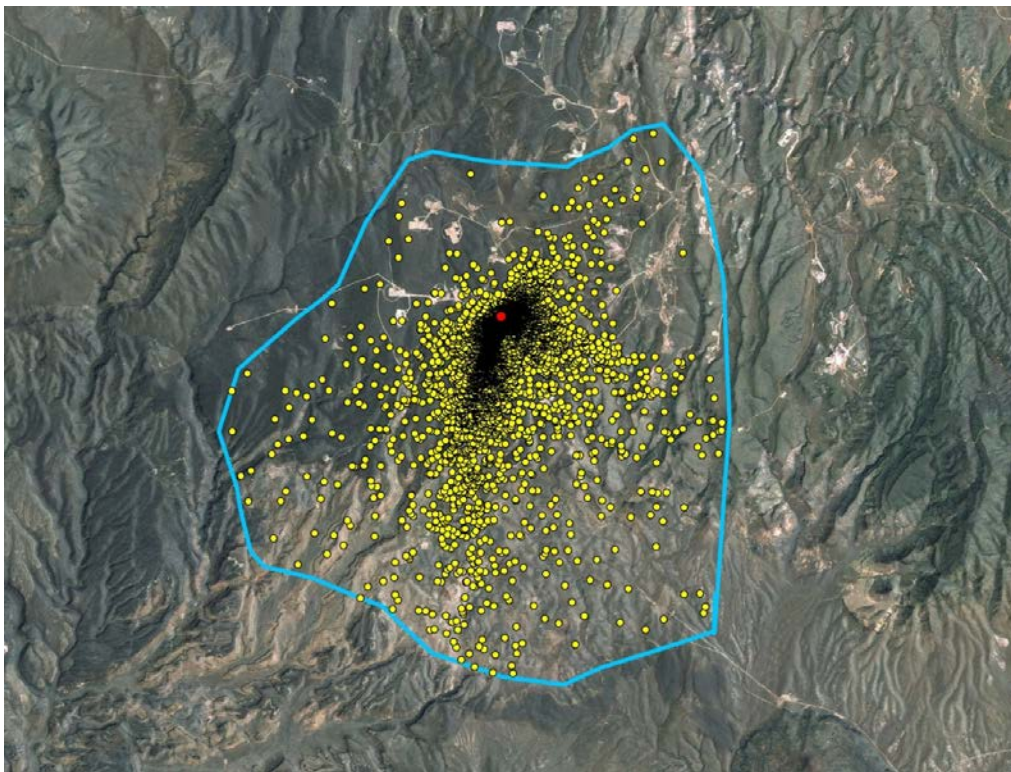

Figure 5.   Area of interest footprint for the sagebrush site located at Pahute Mesa. The red dot indicates the location (elevation 1915 m) of the eddy covariance tower. Yellow points represent individual 30-min flux values measured by the eddy covariance instrumentation between March 26, 2011 and March 26, 2012. The light blue line represents the area of interest footprint.
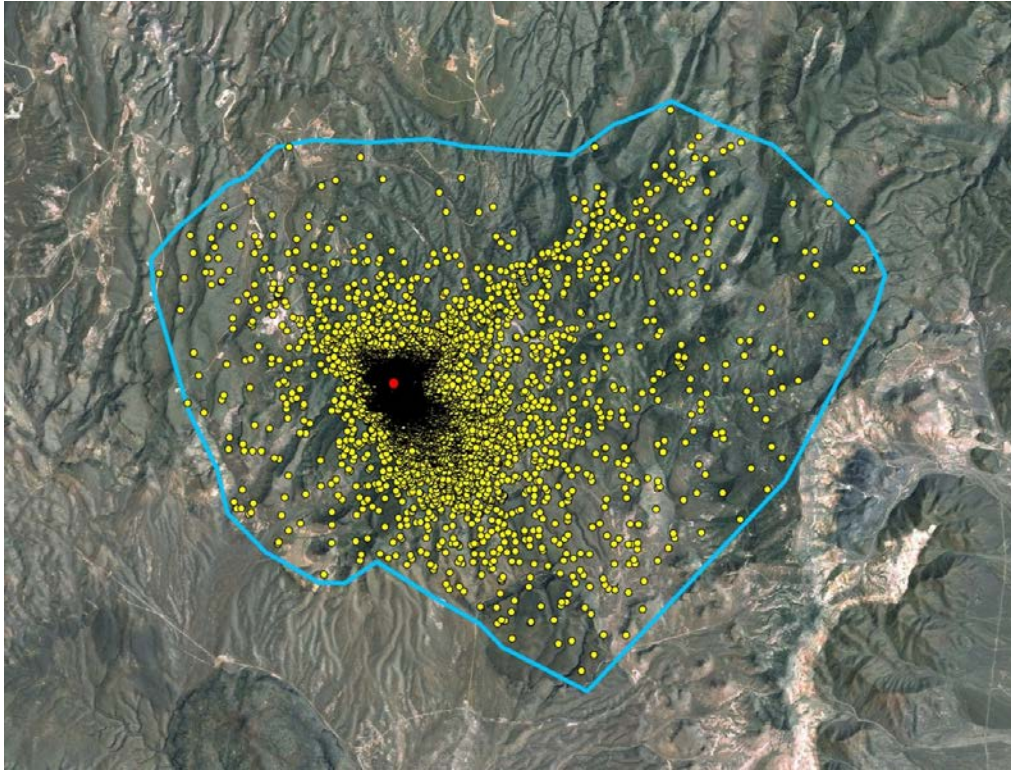
Figure 6.   Area of interest footprint for the pinyon pine/juniper site located at Pahute Mesa. The red dot indicates the location (elevation 2223 m) of the eddy covariance tower. Yellow points represent individual 30-min flux values measured by the eddy covariance instrumentation between March 26, 2011 and March 26, 2012. The light blue line represents the area of interest footprint.

AIR TEMPERATURE, SOIL TEMPERATURE AND MOISTURE, NET RADIATION, AND PRECIPITATION DATA

Mean daily air temperature, soil temperature, soil moisture, and net radiation were calculated by averaging all forty-eight half-hourly values for each day between March 26, 2011 and March 26, 2012 (Figure 7). At the sagebrush site, mean daily air temperature ranged from -6.4 to 25.9 °C; mean daily soil temperature ranged from -2.4 to 28.7 °C; mean daily soil moisture ranged from 7.3 to 28 percent; and net radiation ranged from -23.5 to 215.7 W m^{-2}. At the pinyon pine/juniper site, daily air temperature ranged from -7.7 to 24.1 °C; mean daily soil temperature ranged from -5.6 to 28.9 °C; mean daily soil moisture ranged from 7.9 to 43 percent; and net radiation ranged from -48.7 to 174 W m^{-2}. Precipitation was measured at these sites with an unheated tipping bucket gauge for one year between March 26, 2011 and March 26, 2012; precipitation was 179 mm at the sagebrush site and 159 mm at the pinyon pine/juniper site (Table 2). Precipitation also was measured with bulk gauges between March 21, 2011 and March

28, 2012; precipitation from the bulk gauges was 222 mm at the sagebrush site and 227 mm at the pinyon pine/juniper site. Average annual air temperature, vapor pressure, vapor pressure deficit, and soil temperature (average depth was 4 cm) are listed in Table 2.

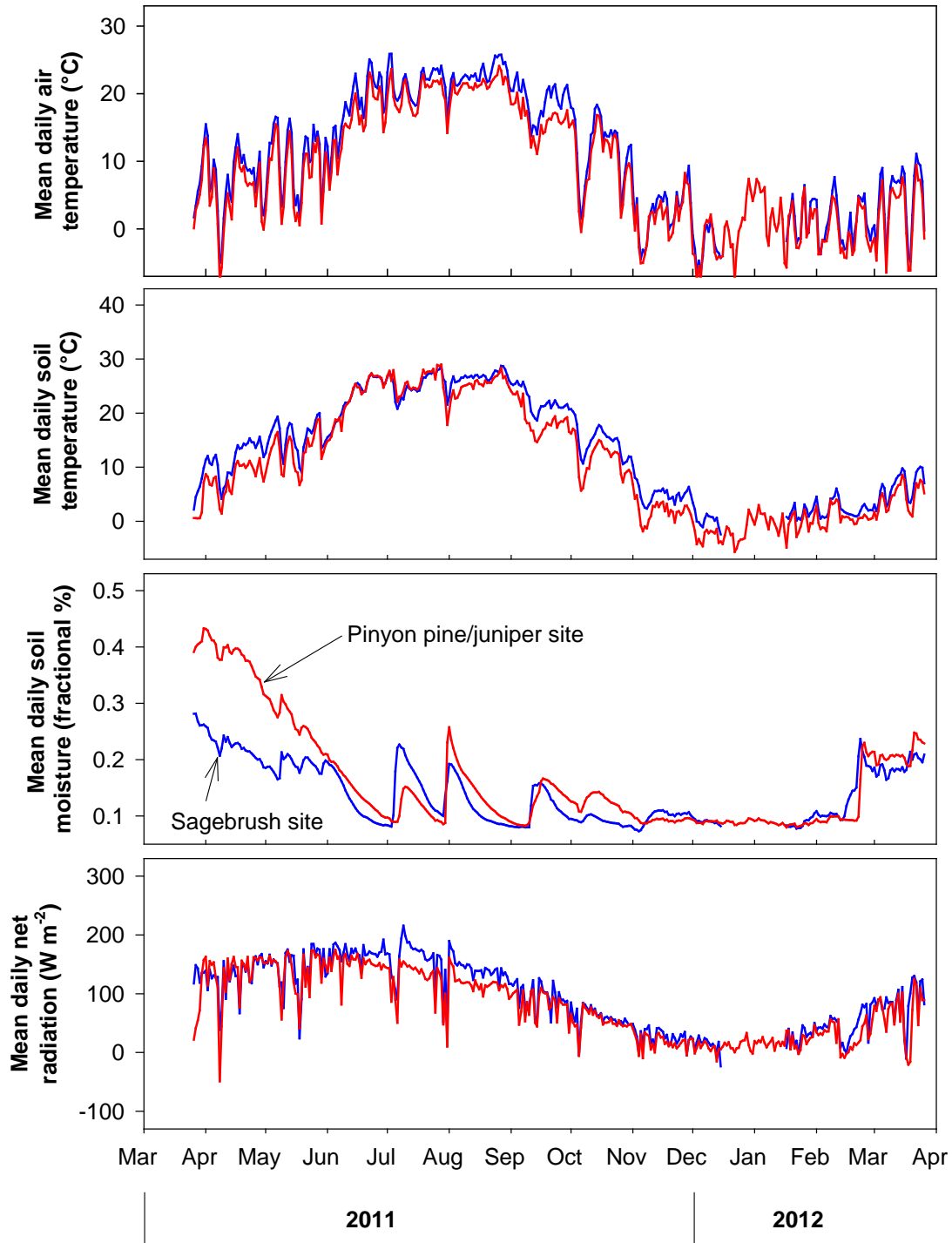Figure 7.   Mean daily air temperature, soil temperature, soil moisture, and net radiation measured at the sagebrush (blue line) and pinyon pine juniper (red line) sites located at Pahute Mesa between March 26, 2011 and March 26, 2012.

Table 2. Study-year: average air temperature, air vapor pressure, air vapor pressure deficit, soil temperature, and total precipitation for the sagebrush and pinyon pine/juniper sites.

Characteristic	Sagebrush	Pinyon Pine/Juniper
Air temperature (°C)	10.9	8.5
Vapor pressure (kPa)	0.11	0.15
Air vapor pressure deficit (kPa)	1.20	0.96
Soil temperature (°C)	14.0	10.8
Tipping bucket precipitation (mm)†	179‡	159
Bulk gauge precipitation (mm)	222*	227**

† Precipitation was measured using an unheated tipping bucket rain gauge; therefore, the total amount of precipitation may be underestimated, especially during periods of frozen precipitation

‡ Data range: March 26, 2011 to March 26, 2012; missing data between December 15, 2011 and January 17, 2012

* Data range: March 21, 2011 to March 27, 2012

** Data range: March 21, 2011 to March 28, 2012

EVAPOTRANSPIRATION DATA

Daily ET was calculated for each site by summing the individual 30-min values for each day (48 30-min values per day). Maximum daily ET at the sagebrush site was 6.0 mm/day and 3.3 mm/day at the pinyon pine/juniper site (Figure 8). Daily ET increased immediately after precipitation events (Figure 8). An example of the response of energy fluxes to these precipitation events at the sagebrush site during July, 2011 is presented in Figure 9. Before precipitation occurred, latent energy (LE) was 87 percent lower than sensible heat (H) (Figure 9) indicating that most of the energy was going toward H flux and that soils were relatively dry with limited water available for evaporation and plant transpiration. After precipitation occurred, LE became greater than H (a maximum difference of 42 percent between these two energy fluxes occurred during the time period presented in Figure 9) indicating LE was the major energy flux during this time (Figure 9). Latent energy started to decrease as the amount of available soil moisture began to decrease and by the last three days of the July time period, H flux was again greater than LE flux as it had been prior to the precipitation events. Monthly ET was calculated by summing all daily values for each month (Table 3). The highest monthly ET occurred in July for the sagebrush site and May for the pinyon pine/juniper site. The lowest monthly ET occurred in December for both study sites. Annual ET was calculated by summing all monthly values (Table 3). Annual ET was 310 ± 13.9 and 347 ± 15.9 mm for the sagebrush and pinyon pine/juniper sites, respectively (Table 3).

Annual ET at both sites exceeded tipping bucket precipitation gauge (179 mm for the sagebrush site and 159 mm for the pinyon pine/juniper site) and bulk precipitation gauge (222 mm for the sagebrush site and 227 mm for the pinyon pine/juniper site) annual precipitation (Table 1). Annual ET exceeded annual precipitation at both sites because the precipitation gauges and EC instrumentation did not start collecting data until March 26, 2011. By this date, significant amounts of precipitation had already fallen at both sites between October 1, 2010 (the start of the hydrologic year) and March 26, 2011 (the first day of data collection at the sites); therefore, estimates of ET presented here include precipitation that fell prior to, and during, EC data collection. Precipitation data for Pahute Mesa for this time period are incomplete (http://www.sord.nv.doe.gov/raingage/Monthly/Pahute_Mesa_Monthly_Data.txt) so the actual amount of precipitation that fell prior to installation of instrumentation at the EC sites could not be quantified. However, other precipitation stations at the NNSS show significant amounts of precipitation likely had fallen at the EC sites from October 2010 through March 2011 (Table 4), particularly in October and again in December.
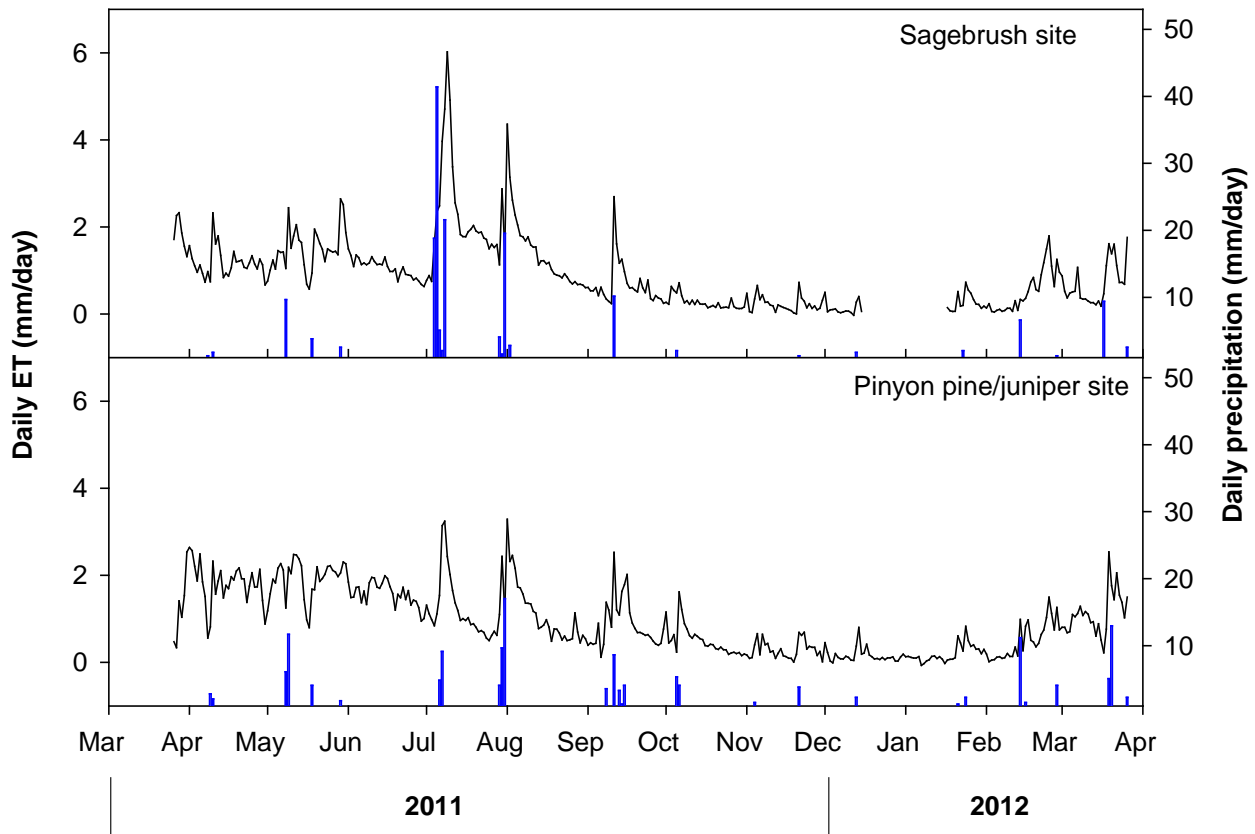
Figure 8.   Daily evapotranspiration (ET) (black line) and daily precipitation (blue bars) for the sagebrush and pinyon pine/juniper sites located at Pahute Mesa during the one-year study (March 26, 2011 and March 26, 2012). Daily precipitation, measured by an unheated tipping bucket rain gauge, was calculated by summing all forty-eight half-hourly values for each day. It should be noted that unheated tipping bucket rain gauges can underestimate frozen precipitation, and, therefore,

the data from these gauges should be used with caution; however, tipping bucket precipitation data are presented in this figure to show the response of daily ET to precipitation events and not necessarily for absolute precipitation amounts.
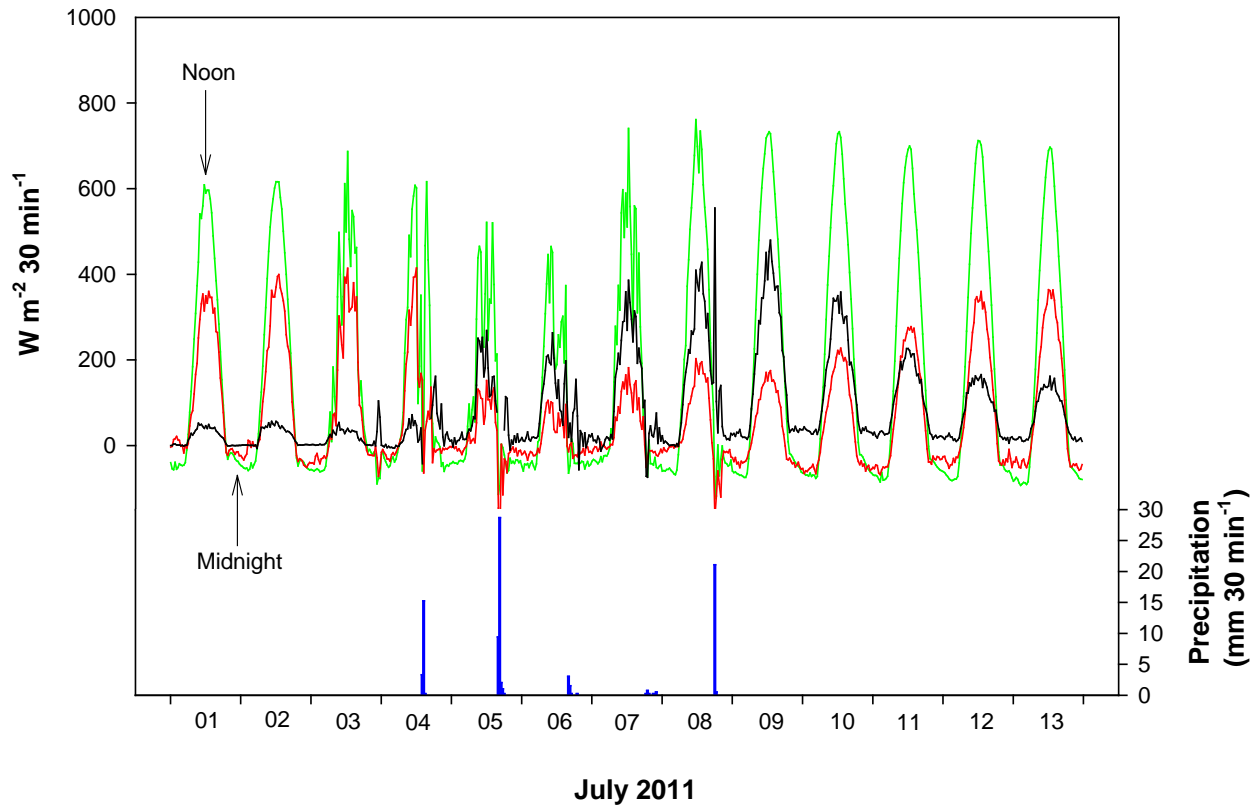
Figure 9.   Response of available energy (green line), latent energy (LE; black line), and sensible heat (H; red line) fluxes to precipitation events (blue bars) between the dates of July 1 and July 13, 2011 at the sagebrush site located on Pahute Mesa.

COMPARISON OF TIPPING BUCKET AND BULK GAUGE PRECIPITATION DATA

Both the sagebrush and pinyon pine/juniper sites contained a bulk precipitation gauge and an unheated tipping bucket precipitation gauge. Bulk precipitation measurements were taken manually approximately once per month during the one-year study while the tipping bucket precipitation gauges automatically logged individual 30-min sums of precipitation throughout the year-long study to the CR5000 data logger and compact flash card at each site. Total precipitation measured by the unheated tipping bucket precipitation gauge was 17 and 20 percent lower than precipitation measured with the bulk precipitation gauge for the sagebrush and pinyon pine/juniper sites, respectively (Table 5). The lower amounts of precipitation measured at both study sites by the unheated tipping bucket precipitation gauge is most likely because the unheated tipping bucket precipitation gauge did not measure frozen precipitation as accurately as the bulk precipitation gauge.

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Table 3. Monthly evapotranspiration (ET) values (mm/month) for the sagebrush and pinyon pine/juniper sites located at Pahute Mesa between March 26, 2011 and March 26, 2012.

	Monthly Evapotranspiration (mm/month)	
	Site	
Month	Sagebrush	Pinyon pine/juniper
2011		
March†	11.0	7.3
April	35.2	54.4
May	46.1	59.9
June	31.7	47.2
July	68.8	38.3
August	43.2	34.7
September	20.1	26.0
October	8.2	15.5
November	6.8	8.7
December	1.9*	5.0
2012		
January	4.1‡	6.1
February	15.1	14.4
March**	18.1	29.0
Annual ET (mm)	**310.3**	**346.5**

† Data collection did not start until March 26, 2011

* Missing data because of flash card reader error (data range, December 1 - 14)

‡ Missing data because of flash card reader error (data range, January 17 - 31)

** March 26, 2012 - last day of data collection

Table 4.   Precipitation data for select gauges at the NNSS from October 2010 through March 2011 (http://www.sord.nv.doe.gov/home_climate_rain.htm).

	Oct (mm)	Nov (mm)	Dec (mm)	Jan (mm)	Feb (mm)	Mar (mm)	6-month total (mm)
Precipitation Gauge	Latitude (deg min sec)	Longitude (deg min sec)	Elevation (m)				
RAINIER MESA	37 11 28.6 N	116 12 58.7 W	2298				
2010	49	24	153	-	-	-	-
2011	-	-	-	6	33	47	312
Average	14	26	27	41	43	49	201
Percent of Average	345	91	556	16	76	97	156
E TUNNEL	37 11 18.0 N	116 11 38.9 W	1856				
2010	61	25	148	-	-	-	-
2011	-	-	-	8	35	49	325
Average	20	16	37	33	62	26	195
Percent	301	156	401	24	56	184	167
TIPPIPAH SPRING	37 02 30 N	116 14 07 W	1667	(until 09/28/1964)			
	37 03 07.8 N	116 11 39.7 W	1506	(as of 09/28/1964)			
2010	39	8	92	-	-	-	-
2011	-	-	-	5	19	23	186
Average	12	16	22	28	36	26	140
Percent	317	50	414	17	53	88	132
YUCCA DRY LAKE	36 57 22.2 N	116 03 00.0 W	1178				
2010	27	1	115	-	-	-	
2011	-	-	-	4	12	18	177
Average	9	13	18	24	25	18	107
Percent	309	4	628	17	48	99	165

Table 5. Comparison of unheated tipping bucket and bulk precipitation gauges located at both the sagebrush and pinyon pine/juniper sites at Pahute Mesa, Nevada. Because of a slight difference in the start (5 days) and end date (1 day) of data collection from the two types of gauges, and to make a fair comparison, data were only used from dates that were in common for the two types of measurement methods.

Date range	Sagebrush Site		Pinyon Pine/Juniper Site	
	Bulk gauge (mm)	Unheated tipping bucket gauge (mm)	Bulk gauge (mm)	Unheated tipping bucket gauge (mm)
2011				
April 25 - May 31	25.4	16.3	34.9	23.9
June 1 - June 29	0.0	0.0	0.0	0.3
June 30 - August 2	104.8	116.8	44.5	45.5
August 3 - September 8	15.9	0.0	4.8	4.3
September 9 - October 17	6.4	14.7	27.0	29.0
October 18 - November 15	3.2	0.8	0.0	2.3
November 16 - December 15	4.8	3.0	6.4	6.4
2012				
January 18 - February 23	33.3	9.9	42.9	16.8
Total precipitation	**193.8**	**161.5**	**160.5**	**128.5**

SUMMARY

To provide data for the Pahute Mesa INFIL3.0 recharge model, two EC stations, along with meteorological and energy balance instrumentation, were installed on Pahute Mesa to estimate ET. The EC method was used to estimate ET for one year at two predominant plant communities (sagebrush and pinyon pine/juniper) on Pahute Mesa. Estimated annual ET at the sagebrush site during the one-year study was 310 ± 13.9 mm while at the pinyon pine/juniper site annual ET was 347 ± 15.9 mm. Precipitation was measured at each site using an unheated tipping bucket precipitation gauge and a bulk precipitation gauge. Annual precipitation from the sagebrush site was 222 and 179 mm from the bulk and tipping bucket gauges, respectively. Annual precipitation from the pinyon pine/juniper site was 227 and 159 mm from the bulk and tipping bucket precipitation gauges, respectively. Precipitation measured with the tipping bucket precipitation gauge was 17 percent lower than the bulk precipitation gauge at the sagebrush site and 20 percent lower at the pinyon pine/juniper site. Differences in precipitation measured using the two gauges were most likely caused by the tipping bucket precipitation gauge not measuring frozen precipitation as accurately as the bulk precipitation gauge and inherent tipping bucket measurement errors (e.g., evaporation from the tipping bucket spoon). In this one-year study, evapotranspiration exceeded precipitation at both study sites because estimates of evapotranspiration included precipitation that fell during the winter of 2010-2011 prior to installation of EC instrumentation in late March 2011.

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