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SOUTHERN NEVADA
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Groundwater Resources Department
Water Resources Division

2006-2010 Evapotranspiration Data Report

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2006-2010 Evapotranspiration Data Report

By: Rebecca D. Shanahan, Casey A. Collins, and Andrew G. Burns

June 2011

SOUTHERN NEVADA WATER AUTHORITY
Groundwater Resources Department
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ACRONYMS

3D	three-dimensional
AGC	automatic gain control
DRI	Desert Research Institute
DTW	depth to water
EBR	energy balance ratio
EC	eddy covariance
ET	evapotranspiration
ET_{ref}	reference ET
IRGA	infrared gas analyzer
ITT	integral turbulence test
NDVI	Normalized Difference Vegetation Index
PVC	polyvinyl chloride
QA	Quality Assurance
QC	Quality Control
SNWA	Southern Nevada Water Authority
TDR	time domain reflectometer
TDT	time-domain transmissivity
UNLV	University of Nevada, Las Vegas
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
WRCC	Western Regional Climate Center

ABBREVIATIONS

°C	degrees Celsius
ags	above ground surface
amsl	above mean sea level
bgs	below ground surface
cm	centimeter
ft	foot
in.	inch
Hz	hertz
kg	kilogram
m	meter
min	minute

ABBREVIATIONS (CONTINUED)

MJ	megajoules
mL	milliliter
mm	millimeter
nm	nanometer
W	watt

1.0 INTRODUCTION

This report describes evapotranspiration (ET) data collection in White River, Spring and Snake valleys performed by the Southern Nevada Water Authority (SNWA), the University of Nevada, Las Vegas (UNLV), and the Desert Research Institute (DRI) during 2006 through 2010. This report describes the technical approach used to measure ET, the locations and data collected at the ET-measurement sites, and the methods used to calculate ET from the Eddy Covariance (EC) data measured at each site.

1.1 Background

ET is the process whereby water is lost to the atmosphere through evaporation from soil, open water bodies, and transpiration from plants. Different plant species use available water at different rates. There are several conditions that influence ET rates, such as water availability (soil moisture, groundwater occurrence), vegetation type, density, soil characteristics, depth to water (DTW), and climatic conditions.

The U.S. Geological Survey (USGS) began estimating water-use rates for phreatophytes in eastern and southern Nevada nearly 50 years ago. The estimates resulting from these early studies were based on research relating vegetation type, density, and DTW by numerous scientists in the USGS, notably Lee (1912), Blaney et al. (1930, 1938), White (1932), Young and Blaney (1942), Gatewood et al. (1950), and Robinson (1970). Methodologies for estimating ET have evolved over time and researchers are now employing an energy balance approach that takes into account micrometerological parameters that directly influence the ability of a plant to use the available water. Studies such as Nichols et al. (1997), DeMeo et al. (2003), Laczniak et al. (2006), Moreo et al. (2007), Arnone et al. (2008) and Devitt et al. (2008) have used energy balance approaches to update water-use rates among various vegetation types in central Nevada.

In 2004, SNWA initiated a study with the UNLV to estimate ET within Spring and White River valleys. The study was expanded to include Snake Valley in 2007 (Devitt et al., 2008). Spring and Snake valleys were selected for the study because of their large discharge areas and because of the potential for water-resource development in these basins by SNWA. SNWA also holds applications in hydrographic basins of the White River Flow System (WRFS). White River Valley, therefore, was selected for the study because it contains the largest groundwater discharge area in the WRFS.

SNWA's primary objective for initiating the study was to refine previous ET estimates using newer methodologies to support the development of groundwater-resource budgets. Although the primary objective has remained the same, several objectives have been added as the study has progressed. These include (1) measuring the variability of ET rates among different vegetation communities; (2) gaining an understanding of plant water uptake; and (3) developing relationships between ET and vegetation indices that represent plant community health using remote sensing applications. Analyses and results associated with the third objective are not included in this report.

1.2 Purpose and Scope

This report presents ET data collected by SNWA, UNLV, and DRI at measurement sites located in White River, Spring and Snake valleys during 2006 through 2010 (January through December). Annual totals for ET, ET_{ref}, and precipitation are reported and time-series plots of DTW are provided. These data are important for characterizing hydrologic conditions and are critical for understanding the relationship and variability of groundwater use by plant communities in basins of water-resource interest. Such data are used to estimate ET distributions within areas of groundwater discharge and develop groundwater resource budgets.

1.3 Document Contents

This document provides a brief overview of the EC method for measuring ET in Section 2.0 and then provides information as to how the measurement sites were selected and instrumented in Section 3.0. The methods for data collection and reduction and data results are presented in Section 4.0. Section 5.0 provides a list of cited references. Appendices A through D presents tipping bucket precipitation data, bulk gage precipitation data, and daily total ET data plotted with daily total ET_{ref} data and daily water-level data for each site and year of data collection.

2.0 TECHNICAL APPROACH

Five methods for ground-based ET measurements considered for this study were the open-path EC method (Section 2.1), weighing lysimeters, bowen ratio towers, large aperture scintillometers, and hemispherical measurement chambers. The EC method is one of the most direct and defensible ways to measure fluxes of carbon dioxide, water vapor, sensible heat (H), latent heat (*LE*) and momentum (UW) between the atmosphere and biosphere (Burba and Anderson, 2010). For this study, the EC method was chosen for measuring half-hourly ET rates based on (1) sufficient area contributing to measurement flux (e.g., footprint), (2) high temporal resolution, (3) high instrument dependability and reliability as recommended by ET research scientists, and (4) extensive publications of acceptance and use in measuring atmospheric fluxes of ET.

2.1 Energy Budget and EC Method to Measure ET

The sun provides radiant energy to the earth's surface and drives processes of energy exchange between the earth's surface and the atmosphere, including the process of ET. The incoming radiant energy from the sun is commonly referred to as net radiation which is the difference between incoming and outgoing long- and short-wave radiation. Net radiation represents available radiant energy at the earth's surface and therefore is balanced by three key flux terms: latent heat flux which is the energy absorbed or released when water is converted between liquid and gas phases; sensible heat flux which is the heat energy that can be sensed as a positive or negative temperature change; and soil heat flux which is the vertical conductance of heat into or out of the ground. The transfer of this energy is illustrated by the schematic presented in Figure 2-1, and is expressed by the energy budget equation as defined by Brustaert (1982):

$$R_n = L_e E + H + G \qquad \text{(Eq. 2-1)}$$

where,

R_n = Net Radiation [watts per square meter]
G = Soil heat flux [watts per square meter]
H = Sensible heat flux [watts per square meter]
L_eE = Latent heat flux [watts per square meter]

The latent heat flux is the energy used to drive the ET process by changing solid or liquid phases of water into vapor, where L_e is the latent heat of evaporation and E is the rate of evaporation. The latent heat flux can be computed using Equation 2-1 and known values of the remaining parameters, or can be measured directly using the EC method.

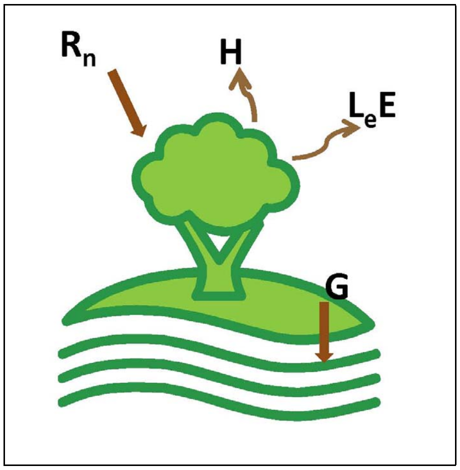

Figure 2-1
Simplified Schematic of the Energy Budget

The EC method has been widely used to measure latent heat fluxes because of its ability to resolve vertical flux densities of water vapor between the atmosphere and biosphere that are directly proportional to the average covariance between the vertical wind velocity (Ux) and scalar water concentrations (Baldocchi et al., 1996; Massman, 2000; Lee et al., 2004; Wohlfahrt et al., 2008). The method is a sophisticated approach that uses state-of-the-art sensors to measure turbulent fluxes, or eddies, that transport parcels of air upward and downward at certain speeds while moving across the landscape (atmospheric eddy transport). Each eddy has specific heat, water vapor and gas concentration properties. By measuring these properties and the speed of vertical air movement, the amount of upward and downward fluxes of heat, water vapor and gas concentration can be determined (Burba and Anderson, 2010).

The latent heat flux measured by the EC sensors can be converted to a rate of evaporation by dividing the measured values by the latent heat of evaporation (L_e), described as L_v in Oke (1987), times the density of water (ρ_w) using Equation 2-2 (based on Oke, 1987) The rate of evaporation is expressed in units of millimeters per 30-minute measurement interval.

$$E = 0.0018LE/(L_e \times \rho_w) \times 1000 \qquad \text{(Eq. 2-2)}$$

where,

E = Rate of evaporation [millimeters per 30-minute measurement interval]
LE = Measured latent heat flux [watts per square meter]
ρ_w = Density of water [kilogram per cubic meter] (Equation 2-3) (based on data in Oke, 1987)
L_e = Latent heat of evaporation [MegaJoules per kilogram] (Equation 2-4) (List, 1951)

and 0.0018 is a unit conversion factor used to convert average 30-minute LE values from [W/m^2] to [MJ/m^2 per 30-minute period]. Values for ρ_w and L_e were are computed as a function of the sonic temperature, T_s, measured by the EC three-dimensional (3D) sonic anemometer sensor.

$$\rho_w = 999.168 - 1.474 \times 10^{-1} T_s - 6.4844 \times 10^{-3} T_s^2 + 5.0868 \times 10^{-5} T_s^3 \quad [\text{kg m}^{-3}] \qquad \text{(Eq. 2-3)}$$

$$L_v = ((2.501) - (0.002361) T_s)(1000) \quad [\text{MJ kg}^{-1}, °\text{C}] \qquad \text{(Eq. 2-4)}$$

where,

T_s = Air temperature [°C]

2.2 Requirements for the EC Method

The EC method is a mathematically complex method and requires ideal terrain and very sophisticated instrumentation to be able to capture turbulent fluctuations. Details regarding site selection and instrumentation are presented in Section 3.0. Section 4.0 discusses the data collection and data processing methods used to generate the final 30-min results.

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3.0 DESCRIPTION OF MEASUREMENT SITES

The objectives for selecting ET measurement sites were to (1) represent a range in phreatophytic vegetation composition on the valley floor, (2) have sufficient fetch to measure atmospheric fluxes, (3) be located within the groundwater discharge areas in basins, or adjacent basins, where SNWA has water-right application points of diversion, and (4) be easily accessible by vehicle. The following sections describe how the phreatophytic areas were delineated and provide a description of each site (location, vegetation composition) and the types of sensors measuring ET at each site.

3.1 ET-Unit Mapping

The distribution of ET units, or areas of groundwater discharge, under current conditions for each valley is based on a compilation of earlier work performed by the USGS in the Reconnaissance Series Reports, Woodward-Clyde Consultants et al. (1994), Nichols (2000), and LVVWD (2001). In some instances, the Southwest Regional Gap Analysis Project data (USGS, 2004) and the National Land Cover Data (NLCD, 1992) were used if there was great uncertainty over the location of a boundary. Refinements were also focused on the edges of the valley floors where the extent boundaries would be expected. These areas were defined as land expanses in the valley where the land-surface slope is less than or equal to 2 percent, and were delineated by performing a slope analysis in ArcGIS using USGS 30-m National Elevation Dataset (NED) seamless digital elevation models. The extent boundaries were refined in these areas to exclude land-cover features that fell on slopes greater than 2 percent. The ET boundaries of White River, Spring, and Snake valleys were field-checked during the summer of 2004 by SNWA and modified, as needed, using highly accurate Global Positioning System equipment.

To further define current conditions, the ET areas in White River, Spring, and Snake Valleys were classified into six units and delineated using the normalized difference vegetation index (NDVI) (Rouse et al., 1974) and Landsat 7 Thematic Mapper 2002 satellite imagery. Imagery from 2002 was selected because during this year precipitation was significantly below normal according to the Palmer Drought Severity Index (NCDC, 2011), and it was assumed that the extent of the groundwater ET areas would be more apparent in the imagery under conditions in which the vegetation is primarily relying on groundwater rather than precipitation. The units are: open water, bare soil/low density vegetation, medium density vegetation, wetland/meadow, agriculture, and playa (Figure 3-1 and Table 3-1).

Vegetation indices, such as NDVI, are a type of remote sensing algorithm used to predict green vegetation cover. These tools, or technologies, are particularly helpful in regional geographic studies because of the large spatial distribution of targeted plants in the landscape. Remotely sensed data images provide a mechanism for measuring the relationships between cover type and spectral

Table 3-1
Land-Cover Classification

ET Class	Classification	Description	DTW Range[a] (ft bgs)
1	Open Water	Bodies of open water fed by groundwater sources (direct hydraulic connection, springs, seeps, etc.)	Above ground surface
2	Bare Soil/Low Vegetation	Shrubland less than or equal to 20% plant cover - Areas dominated by bare soil and low- to moderate-density desert shrubland, including greasewood, rabbit brush, and other phreatophytic species	Mostly 10 to <60 ft bgs
3	Phreatophyte/ Medium Vegetation	Shrubland with plant cover greater than 20% - Areas dominated by desert shrubland, including mixed stands of medium-density greasewood, rabbit brush, and other phreatophytic species	2 to 60
4	Wetland/Meadow	Area of shallow groundwater near bodies of open water consisting of wetland vegetation, marshland, woodland, and dense meadows - additionally includes riparian corridors in the southern part of study area, consisting of saltcedar, desert willows, cottonwood, and mesquite trees with underlying shrubs and grasses	0 to 20
5	Agriculture	Agricultural crop lands identified from 2002 satellite image and field observations	NA
6	Playa	Bare-soil flat areas located in the bottoms of some basins. Classified as potential groundwater ET areas in basins where the water table is within 10 ft of the land surface	0 to 10

[a]DTW ranges from SNWA (2009; Table 7-1, page 7-9)
NA = Not applicable

reflectance. The NDVI is one of the most common vegetation indices used to estimate plant cover and is based on the red and near-infrared bands of the electromagnetic spectrum.

A number of transects were generated to validate the remote-sensing techniques used to delineate the extent boundaries and define the land-cover classes within them. Along each transect the percent cover and density of the vegetation community was observed and recorded. Percent cover was estimated as the fraction of the transect covered by each species, and density estimates were calculated as described in Barbour et al. (1987).

Many of the boundaries delineating the groundwater-ET extents and land-cover classes were checked in the field during the summer of 2004, and modified as appropriate using high-resolution global positioning system equipment. An assessment was completed to evaluate the accuracy of the land classification using accepted protocols as outlined in Congalton and Green (1999). A total of 249 randomly selected points representing each classification were field checked. This assessment returned an overall accuracy of 88 percent, the results of which are presented by land-cover class in Table 3-2. This value is above the generally accepted value of 85 percent as established by Anderson et al. (1976).

There are discrepancies regarding the phreatophytic boundaries between this study and previous studies. Discrepancies between this study and the Reconnaissance Series and Nichols (2000) are largely attributed to the lack of high-accuracy technologies and the use of large-scale maps in the

Table 3-2
Accuracy of ET Classification

ET Class	Accuracy
Open Water	0.92
Bare Soil/Low Vegetation	0.78
Phreatophyte/Medium Vegetation	0.89
Wetland/Meadow	0.90
Agriculture	0.88

previous studies. Also, there have been historical land-use changes in some areas since these earlier studies.

Discrepancies in the phreatophytic boundaries also exist between this study and the Basin and Range Carbonate Aquifer System Study (Smith et al., 2007). These discrepancies can be attributed to the difference in the years that the areas were field-checked as well as differences in the years of imagery used and the remote sensing applications applied.

3.2 Site Descriptions

ET, meteorological variables, and depth-to-water were measured at 10 sites during 2006 through 2010. Figure 3-1 illustrates the site locations within each valley. Table 3-3 describes each site, including site coordinates and installation date.

During the 2004-2005 data collection period, the EC towers were rotated among 3 sites in each valley (Figure 3-1, WRV1, WRV2, WRV3, SV1, SV2a, SV3). Rotating the towers revealed the variability within the valley but did not provide a continuous data set for a specific site.

The towers remained stationary at a single location (SV1 and WRV2) in each valley during the 2005-2006 data collection period. Keeping the towers in one location allowed for a better temporal assessment of the data providing additional, although still limited, insight into the interannual and interbasin variability in ET. Data filtering and corrections were also revisited from the onset of the study to reflect recommendations of Campbell Scientific, Inc., the manufacturers of the towers and associated equipment.

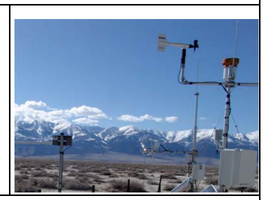
In 2007, SNWA purchased additional ET towers and weather stations thereby establishing two additional sites in Spring Valley (for a total of three sites), two in Snake Valley, and maintained the WRV2 site in White River Valley (Figure 3-1, WRV2, SV1, SV2b, SV3, SNV1, SNV2).

Also in 2007, SNWA initiated a study with DRI for additional ET measuring sites in Spring Valley (Arnone et al., 2008) (Figure 3-1, SV4, SV5, SV6, SV7). Data collection and analyses were performed in conjunction with the UNLV study through close collaboration and adoption of uniform methods, including, set-up, instrumentation configuration, and data capture and analysis protocols for all towers.

Table 3-3
ET Measurement Site Descriptions
(Page 1 of 2)

Site Name	Location[a] UTM Northing	Location[a] UTM Easting	Altitude (ft amsl)	Installation Date	Site Description[b]	Photograph
WRV2						
Met Station	4,277,368	664,984	5,311	Aug 2004	55% cover; predominantly sagebrush and greasewood with minor amounts of shadscale	
EC Station	4,277,445	665,017	5,308	Aug 2004		
Well	4,277,374	665,077	5,314	May 2006		
SV1						
Met Station	4,294,921	720,012	5,780	Sept 2004	27% cover; predominantly sagebrush with rabbitbrush and greasewood; shadscale and buckwheat also present	
EC Station	4,294,919	719,920	5,780	Sept 2004		
Well	4,294,854	720,049	5,783	May 2006		
SV2b						
Met Station	4,360,824	716,789	5,594	March 2007	irrigated pasture/grassland; 100% cover of perennial grasses	
EC Station	4,360,829	716,743	5,595	March 2007		
Well	4,360,825	716,792	5595	October 2008		
SV3						
Met Station	4,375,833	715,822	5,614	May 2005	32% cover; predominantly greasewood and rabbitbrush; shadscale and pickleweed also present	
EC Station	4,375,912	715,857	5,615	May 2005		
Well	4,375,797	715,452	5,628	May 2007		
SV4						
Met Station	4,303,124	725,313	5,816	April 2007	Irrigated pasture/grassland; 100% cover of perennial grasses	
EC Station	4,303,125	725,311	5,816	April 2007		
Well	4,303,127	725,316	5,817	May 2007		
SV5						
Met Station	4,323,394	717,655	5,774	April 2007	87% cover; mixed stand of greasewood, sagebrush, and rabbitbrush	
EC Station	4,323,395	717,653	5,774	April 2007		
Well	4,323,360	717,660	5,775	May 2007		

Table 3-3
ET Measurement Site Descriptions
(Page 2 of 2)

Site Name	Location[a] UTM Northing	UTM Easting	Altitude (ft amsl)	Installation Date	Site Description[b]	Photograph
SV6						
Met Station	4,324,556	717,827	5,760	April 2007	76% cover; mixed stand of greasewood, sagebrush, and rabbitbrush	
EC Station	4,324,555	717,824	5,760	April 2007		
Well	4,324,577	717,853	5,759	May 2007		
SV7						
Met Station	4,357,985	726,577	5,555	April 2007	19% cover; homogenous stand of greasewood	
EC Station	4,357,985	726,575	5,555	April 2007		
Well	4,357,989	726,577	5,555	May 2007		
SNV1						
Met Station	4,287,287	753,159	5,528	April 2007	62% cover; predominantly greasewood with minor amounts of shadscale and sagebrush	
EC Station	4,287,266	753,182	5,528	April 2007		
Well	4,287,317	753,331	5,531	May 2007		
SNV2						
Met Station	4,325,082	754,576	5,133	April 2007	13% cover; mixed community of rabbitbrush, greasewood, sagebrush, and shadscale	
EC Station	4,325,090	754,601	5,132	April 2007		
Well	4,325,458	754,502	5,138	May 2007		

[a]Universal Transverse Mercator, North American Datum of 1983, Zone 11.
[b]Percent cover estimates from Devitt et al. (2008) and Arnone et al. (2008)

ET measuring by UNLV ended in the fall of 2007; therefore, 2008 marked the first year in which SNWA assumed all responsibilities for the ongoing ET study including tower and sensor operation and maintenance, data collection, data management and analysis, and reporting. DRI remained responsible for tower maintenance and data collection at four of the Spring Valley locations through the 2009 measurement year, however, SNWA assumed responsibility for the management, analysis, and reporting of the collected data.

3.3 Site Instrumentation

The ET sites were equipped with high frequency sensors required for the EC method and additional meteorological and ancillary sensors for measuring energy budget and reference ET parameters, physical properties of the soil, and precipitation. The sensors are mounted at heights and depths as required for the EC method and recommended by manufacturer guidelines. The aboveground surface

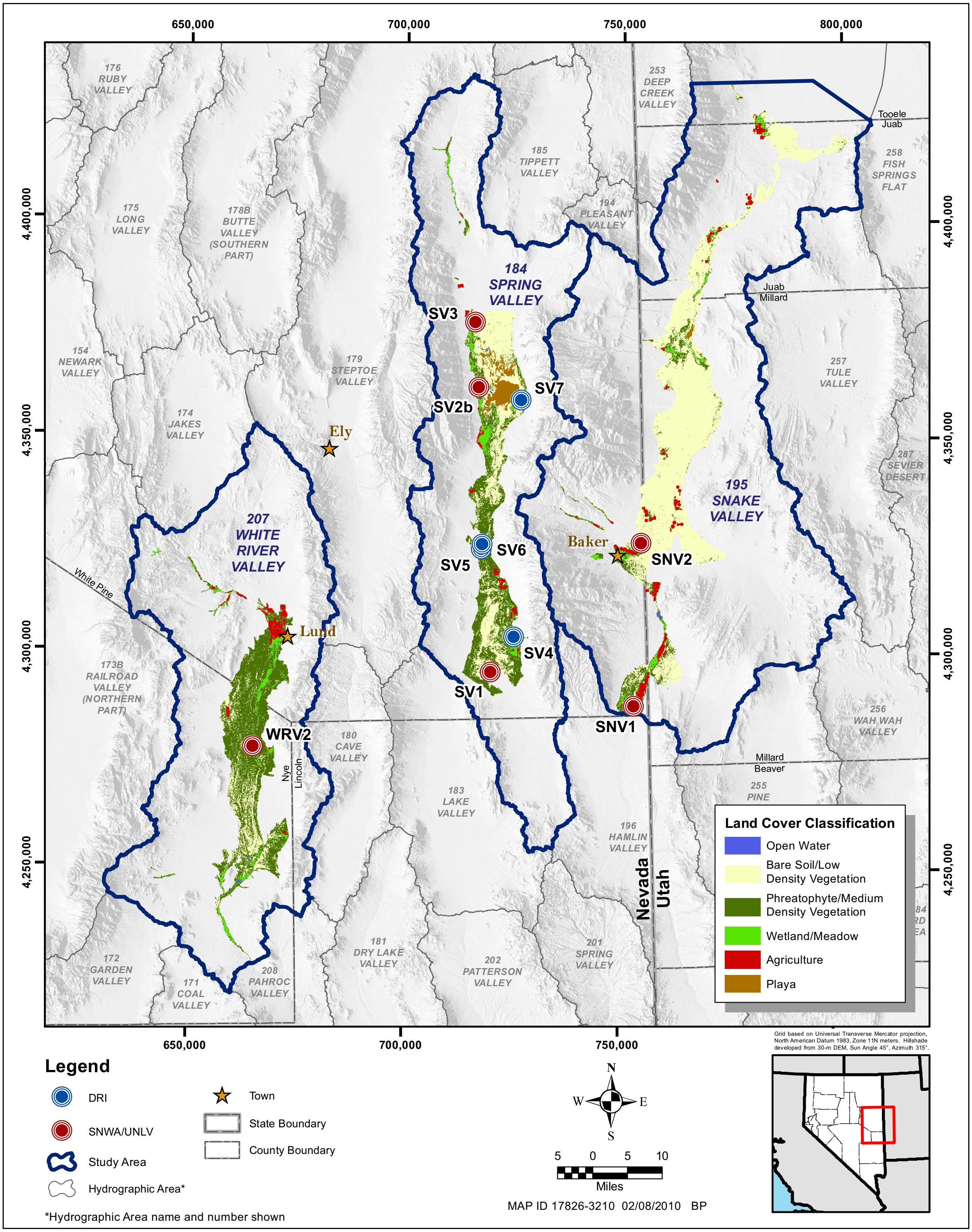


Figure 3-1
Locations of ET-Measurement Sites

sensors are situated within a measurement footprint of relatively homogeneous vegetation and flat topography in order to capture the areas that contribute to the measured fluxes. The measurement protocols, sensor installation, maintenance, and calibrations are based on the sensor manufacturer, Ameriflux (Munger and Loescher, 2006), and Fluxnet-Canada (2003) guidelines. Table 3-4 lists the make and model, output units, and sensor placement for the instrumentation. Figure 3-2a and Figure 3-2b illustrate the sensor locations on the EC station and meteorological station, respectively.

3.3.1 Precipitation Equipment

The SNWA/UNLV ET sites (WRV2, SV1, SV2b, SV3, SNV1, and SNV2) were equipped with two precipitation gages: (1) a NovaLynx, Corp. 8-in. diameter aluminum standard bulk storage rain and snow gage, and (2) a Texas Electronics 8-in. funnel orifice tipping bucket. A standard bulk storage gage was installed at the meteorological station, and a tipping bucket at both the meteorological and EC stations. The DRI ET sites (SV4, SV5, SV6, and SV7) were equipped with a single tipping bucket.

3.3.2 Depth-to-Water Equipment

Shallow monitor wells were installed near the ET stations to measure DTW and to assess how fluctuations in DTW affect the ET rates (Table 3-5). The wells were completed with schedule 40-flush threaded 2-in.diameter polyvinyl chloride (PVC) pipe to depths ranging from 5 to 80 ft bgs. Wells were drilled to depths reflective of vegetation density and composition. The wells were screened with 0.02-in. slotted openings. A gravel pack was placed around the outside of the screen to prevent soil materials from entering the well or clogging the screen. Bentonite was placed above the gravel pack to near the surface and topped with a protected metal casing to secure the well instrumentation and to protect the well against surface contaminant intrusion. Well drillers reports and/or well installation documentation are included in Appendix A.

Each SNWA/UNLV well was originally equipped with a nonvented HOBO water-level data logger for recording water levels. These were replaced with vented Design Analysis DH-21 data loggers in 2009. A USB-based optical interface was used to connect a field computer with the water-level data logger. Onset HOBOware Pro software and Win DH-21 was used to download, analyze, and plot data from the HOBO and DH-21 water-level data loggers, respectively. The DRI wells were equipped with a vented pressure transducer (Pressure Systems, Inc., Hampton, VA, USA) and connected to a CR5000 data logger.

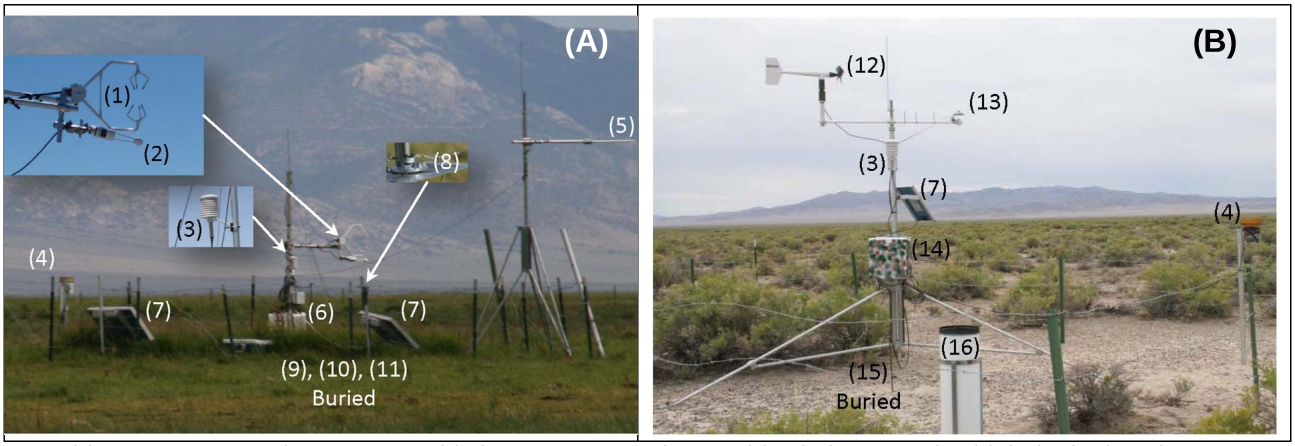
3.3.3 EC System and Associated Micrometerological Measurement Equipment

High frequency EC sensors and meteorological sensors were used to measure L_eE and ET_{ref} data, respectively. The EC system was equipped with a 3-axis symmetrical sonic anemometer (CSAT3) for measuring 3D wind speed, wind direction, and sonic temperature; an infrared gas analyzer (IRGA) (LI-7500) sensor for measuring CO_2 and H_2O concentration; and a relative humidity and temperature probe (HMP45C) for obtaining ambient temperature, relative humidity, and saturated vapor pressure, and a net radiometer (NR-Lite) for measuring incoming and outgoing solar radiation. To store the high frequency (10 Hz) EC data, the EC system was also equipped with a Campbell Scientific, Inc.

Table 3-4
ET-Measurement Site Instrumentation for EC Station, Meteorological Station, and Monitor Well

Measured Parameter	Instrument Type	Sensor Placement
EC Station		
Wind speed and air temperature	Campbell Scientific, Inc. CSAT3 3D sonic anemometer	1 m (3.28 ft) above canopy cover for all sites except SV2b, which was placed 1.55 m (5.09 ft) above canopy[a]
CO_2 and H_2O vapor mass density and air pressure	LiCor, Inc. LI-7500 open-path IRGA	1 m (3.28 ft) above canopy cover for all sites except SV2b, which was placed 1.55 m (5.09 ft) above canopy[a]
Relative humidity and air temperature	Vaisala HMP45C capacitive relative humidity sensor	~ 1.5 to 2 m (4.92 to 6.56 ft) ags
Net radiation	Kipp & Zonen NR-Lite net radiometer	~ 1.5 to 2.5 m (4.92 to 8.20 ft) ags
Photosynthetically active radiation (PAR)	LiCor 190SA quantum sensor (400 to 700 nm)	1.0 to 2.5 m (3.28 to 8.20 ft) ags
Soil Moisture	Campbell Scientific, Inc. CS616 water-content reflectometer	2.5 cm (0.98 in.) bgs
Soil Temperature	Campbell Scientific, Inc. TCAV-Averaging soil thermocouple probe	2.5 to 5.0 cm (0.98 to 1.97 in.) bgs
Soil Heat Flux	Hukseflux HFP01SC-L thermopile gradient	8.0 cm (3.15 in.) bgs
Precipitation	Texas Electronics TE525 tipping bucket	1.37 to 2.50 m (4.50 to 8.17 ft) ags
Data collection and storage	Campbell Scientific, Inc. CR5000 data logger	---
Meteorological Station		
Air Pressure	Setra 278 barometric pressure sensor (600-1,100 millibars); Druck CS115	~ 0.5 to 1.0 m (1.64 to 3.28 ft) ags
Wind speed and direction	R.M. Young Wind Monitor (05103) propeller anemometer and wind vane	~ 2 m (6.56 ft) above canopy
Relative humidity and air temperature	Vaisala HMP45C capacitive relative humidity sensor	~ 1.5 to 2 m (4.92 to 6.56 ft) ags
Sun plus sky radiation	LI-COR, Inc. LI-200SZ pyranometer sensor (400 to 1,100 nm)	1 to 2 m (3.28 to 6.56 ft) ags
Soil Moisture	Acclima Digital TDT® Moisture sensor Time-Domain Transmissivity (TDT)	10 to 105 cm (3.94 to 41.34 in.) bgs
Precipitation	NOVALYNX 260-2510 8-in. diameter standard rain and snow gage Texas Electronics TE525 tipping bucket	80 to 100 cm (31.50 to 39.37 in.) ags 1.37 to 2.50 m (4.50 to 8.17 ft) ags
Data collection and storage	Campbell Scientific, Inc. CR10X data logger	---
Monitor Well		
Groundwater Level	Design Analysis DH-21 submersible pressure transducer and data logger	~<1.5 to 9.5 m (<5 to 31) ft bgs

[a]Placed at 1.55 m (5.09 ft) above canopy to minimize impact from a high enclosure of barb wire fencing around the site installed to deter cattle.



Note: (1) CSI CSAT3 3D sonic anemometer; (2) LiCor 7500 open-path IRGA; (3) Vaisala HMP probe; (4) tipping bucket rain gage; (5) Kipp & Zonen NR-Lite net radiometer; (6) CSI CR5000 data logger; (7) solar panel; (8) LiCor 190SA quantum sensor; (9) CSI CS 616 water-content reflectometer; (10) CSI TCAV-Averaging soil thermocouple probe; (11) Hukseflux HFP01SC-L soil heat flux plates. (12) RM Young wind monitor; (13) LiCor 200SZ pyranometer sensor; (14) CSI CR10X data logger; (15) Acclima Digital TDT sensors; (16) bulk storage rain and snow gage.

Figure 3-2
Typical Deployment of EC (A) and Meteorological (B) Stations

Table 3-5
Monitor-Well Locations and Information

Site Name	Location[a]		Altitude (ft amsl)	Well Installation Date	Open Interval (ft bgs)	
	UTM Northing	UTM Easting			Top	Bottom
WRV2-Well	4,277,374	665,077	5,314	5/16/2006	15	80
SV1-Well	4,294,854	720,049	5,783	5/19/2007	10	75
SV2b-Well	4,360,825	716,792	5,595	10/23/2008	2.5	5.0
SV3-Well	4,375,797	715,452	5,628	5/7/2007	10	35
SV4-Well	4,303,127	725,316	5,817	5/14/2007	9.5	24
SV5-Well	4,323,360	717,660	5,775	5/13/2007	25	39
SV6-Well	4,324,577	717,853	5,759	5/12/2007	15	29
SV7-Well	4,357,989	726,577	5,555	5/12/2007	18	32
SNV1-Well	4,287,317	753,331	5,531	5/8/2007	8.0	38
SNV2-Well	4,325,458	754,502	5,138	5/9/2007	10	50

[a]Universal Transverse Mercator, North American Datum of 1983, Zone 11.

CR5000 data logger and data acquisition device. The EC system, with its energy balance sensors, also measures sensible heat flux, net radiation, and soil characteristics, such as soil heat flux, volumetric water content and temperature, (Section 3.3.4).

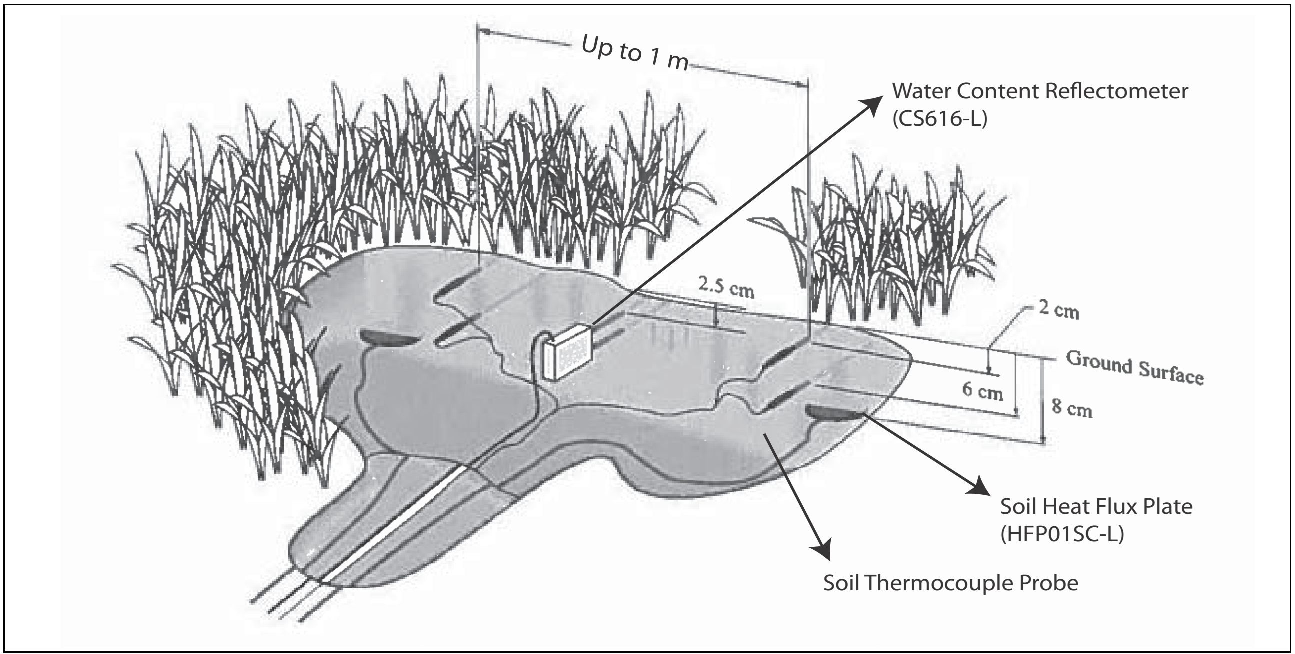
The meteorological station was equipped with sensors for measuring wind speed and direction (RM-Young), relative humidity and temperature (HMP45C), a pyranometer (LI200X-L) for measuring incoming solar radiation (the DRI sites were not equipped with a pyranometer), and barometric pressure sensors. Raw data were collected hourly from the sensors and stored in a Campbell Scientific, Inc. CR10X data logger and later used to compute ET_{ref} using the Penman-Monteith equation. Further, the data collected from these sensors were used to compare and/or validate the data collected from the same or similar sensors in the EC system.

3.3.4 Soil Parameter Equipment

Soil conditions were measured using soil-heat flux plates (HFP01SC-L), soil-water-content reflectometers (CS616-L), time domain reflectometers (TDR), TDT, and soil thermocouple (TCAV-L) sensors.

Soil-heat flux plates measure incoming and outgoing thermal energy in the soil. On each ET station, two soil-heat flux plates were buried at a depth of 3.15 in. (8 cm) (Figure 3-3), one near shade or plant root and the other in bare soil.

Soil-water-content reflectometers measure the percentage (0 to 100 percent) of volumetric water content of the soil. The reflectometers were buried at a depth of 0.98 in. (2.5 cm) (Figure 3-3) to detect the passing of wetting fronts.



Source: Modified from Campbell Scientific, Inc. (2007)

Figure 3-3
Typical Placement of Water Reflectometer,
Soil Heat Flux Plate, and Soil Thermocouple in the Soil

Soil thermocouples also were used to collect the average temperature of a soil layer for use in calculating stored energy. Two pairs of thermocouples were installed between 0.98 and 1.97 in. (2.5 and 5 cm) deep and were separated at a distance of up to 3.28 ft (1 m) (Figure 3-3).

Volumetric soil-water-content sensors, such as TDR and TDT sensors, were installed at different depths at each SNWA ET station to monitor the wetting front (soil water) along the vertical soil profile (refer to Table 3-4 for each sensor depth). The data from these sensors were also used in conjunction with EC data as a source of data verification for the flux measurement data. The DRI ET sites were not equipped with TDR and TDT sensors.

Data were initially collected from the TDR sensors using a Trase system. According to the manufacturer, the TDR sensors generates short electromagnetic pulses that respond to the presence of soil water and can accurately measure the volumetric soil-water-content. These pulses are processed by the onboard time domain signal generator and signal processors of the Trase system. The pulses are observed after reflection from some impedance or discontinuity in the transmission line. The time measured is a two-way, or round-trip, propagation time.

The TDT sensors, which were installed in September 2008 to replace any further collection of TDR data, store continuous hourly data in the CR10X data logger. The sensors were used to measure the permittivity, volumetric soil-water-content, electrical conductivity, and temperature of the soil media. The concept of TDR electromagnetic pulses also applies to the TDT sensors with the exception of the TDT sensors' ability to transmit electromagnetic pulses from the emitter on one end directly to a receiver at the other end of the transmission line. Therefore, the time measured is a one-way propagation time.

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4.0 DATA COLLECTION, PROCESSING, AND RESULTS

Precipitation, groundwater, soil, and EC data were collected from each of the ET-measurement sites during 2006 through 2010. Individual data parameters were collected and processed according to the manufacturer, Ameriflux (Munger and Loescher, 2006), and Fluxnet-Canada (2003) guidelines. Field collected data follows internal quality control and verification procedures. All raw, preprocessed EC data were stored on a secure network.

4.1 Precipitation

SNWA/UNLV ET-measurement sites were equipped with a standard rain gage and two tipping buckets to primarily monitor precipitation event frequency, magnitude and accumulation and derive a comprehensive annual precipitation record for each site. The tipping-bucket data were also used in conjunction with EC data as a source of data verification for the flux-measurement data. Hourly tipping-bucket data were recorded during the period 2006 through 2010 by the meteorological station CR10X data logger. Concurrently, half-hourly tipping bucket data were recorded by the EC station CR5000 data logger. Data from the standard rain gage and tipping buckets were collected by UNLV and/or SNWA staff during each site visit. The contents of the standard rain gage were measured, discarded and replaced with 100 to 200 mL of mineral oil. The lighter mineral oil covers the water surface in order to eliminate water evaporation between site visits. The tipping buckets were checked for levelness during site visits and calibrated annually by SNWA personnel following the calibration specifications of the manufacturer. (Campbell Scientific, Inc., 2008).

Half-hourly precipitation data at four DRI sites in Spring Valley were collected using tipping buckets from April, 2007 through October 2009 (SV4, SV5, SV6 and SV7). The DRI ET-measurement sites were not equipped with an accompanying bulk storage gage, so only tipping bucket data were available at those measurement sites during the 2007 through 2009 measurement years.

The 8-in. standard rain and snow gage used by SNWA/UNLV to collect accumulated precipitation complies with the National Weather Service bulk storage gage design standards, and is considered the most accurate means of measuring precipitation data (NWS, 2010). Though the continuous record of the tipping bucket is beneficial, it is limited by instrumentation and data-logger malfunctions, and naturally occurring climate and physical disruptions in the data-collection process. Bulk storage gages were generally considered higher quality data and used first in deriving the precipitation record. Tipping-bucket data were used when the bulk-storage gage record was incomplete and the tipping bucket monthly record had no more than 5 days of missing data. Table 4-1 describes the site instrumentation used to calculate the annual precipitation for individual ET-measurement sites.

The meteorological station tipping bucket data were the primary sources for calculating daily precipitation values, and the EC-Station tipping bucket data were used as a surrogate to fill missing

Table 4-1
Site Instrumentation Used for Annual Precipitation Record

Site Name	2006	2007	2008	2009	2010
WRV2	Tipping Bucket	Tipping Bucket	Standard Rain Gage	Standard Rain Gage	Standard Rain Gage
SV1	Tipping Bucket	Tipping Bucket	Standard Rain Gage	Standard Rain Gage	Standard Rain Gage
SV2b	---	Tipping Bucket	Standard Rain Gage	Standard Rain Gage	Standard Rain Gage
SV3	---	Tipping Bucket	Standard Rain Gage	Standard Rain Gage	Standard Rain Gage
SV4	---	Tipping Bucket	Tipping Bucket	Tipping Bucket	---
SV5	---	Tipping Bucket	Tipping Bucket	Tipping Bucket	---
SV6	---	Tipping Bucket	Tipping Bucket	Tipping Bucket	---
SV7	---	Tipping Bucket	Tipping Bucket	Tipping Bucket	---
SNV1	---	Tipping Bucket	Standard Rain Gage	Standard Rain Gage	Standard Rain Gage
SNV2	---	Tipping Bucket	Standard Rain Gage	Standard Rain Gage	Standard Rain Gage

daily records as needed. Missing daily records were not estimated for sites containing only one tipping bucket. These sites include, SV4, SV5, SV6 and SV7.

Individual months with more than five (5) days of missing data were not used in the derivation of the annual statistics. The 5-day criterion is consistent with quality-control specifications defined by the Western Regional Climate Center's (WRCC) online climatological database. A nearby index station with a complete record was used to estimate missing, or disqualified monthly records. This was done by correlating the two records and applying the regression model to complete/estimate the missing record. Table B-1 shows which index stations were used in estimating monthly precipitation values. Figure B-1 through B-5 show the monthly tipping-bucket accumulations for the 2007 through 2010 measurement years.

Annual and monthly statistics were calculated for each site using measured or recorded data first, except for the few instances where missing records were estimated. Table 4-2 lists the annual precipitation at each site for the period of data collection. Monthly precipitation data from the tipping buckets and standard rain gages are summarized in Appendices B and C, respectively. The annual precipitation was calculated by totaling the monthly precipitation values for each precipitation station.

The precipitation measured at WRV2 in White River Valley increased in each successive year from the minimum of 6.23 in. measure in 2007, to the maximum of 14.13 in. measured in 2010. 2007 was the driest year of the 5-year record, and followed one of the more wet years recorded at WRV2 during the period of record. The wet and dry years measured at WRV2 follow similar wet and dry patterns to those reported by the WRCC for the Lund precipitation station also located in White River Valley approximately 17 miles northeast of the WRV2 station. Precipitation measured in Spring Valley from 2006 through 2010 ranged from 2.59-in. at SV7 in 2008 to 12.60-in. measured at SV1 in 2010. In Snake Valley, the minimum precipitation (3.56-in.) was measured at SNV2 in 2007 and the maximum was measured (11.00-in.) at SNV1 in 2010. There were no WRCC records for precipitation stations

Table 4-2
Annual Precipitation at ET Measurement Sites (in.) for the 2006-2010 Measurement Years

Site Name	2006	2007	2008	2009	2010
WRV2	10.45	6.23	6.44	9.02	14.13
SV1	6.11	5.00	6.00	8.17	12.60
SV2b	---	5.27	2.79	7.51	8.42
SV3	---	4.21	3.17	7.78	10.17
SV4	---	5.79	5.12	6.96	---
SV5	---	5.44	3.50	8.70	---
SV6	---	5.24	3.37	8.18	---
SV7	---	3.95	2.59	6.19	---
SNV1	---	7.09	5.13	6.30	11.00
SNV2	---	3.56	4.08	5.74	7.35

in Spring Valley to use as comparison with the 7 Spring Valley, or the 2 Snake Valley stations from 2006 through 2010. However, two sites in Steptoe Valley (Ely WBO) and Snake Valley (Callao) had well-established records and were used as a regional comparison. Like the SNWA/UNLV and DRI precipitation stations in Spring and Snake Valleys, the WRCC reported 2008 as the driest year and 2010 as the wettest year for the Ely and Callao precipitation stations during the period of record. The SNWA and WRCC station records all show below average precipitation for 2006 through 2008 and above average precipitation for 2009 and 2010 (WRCC, 2010).

4.2 Groundwater-Level Monitoring

Periodic and continuous DTW measurements were made at the SNWA/UNLV monitor wells using an electronic measuring tape (E-tape) and a HOBO or Design Analysis pressure transducer, respectively. Continuous measurements were recorded hourly by the integrated data logger. Data were processed using Onset HOBOware Pro software or Win DH-21 software, and statistical analysis tools (Excel and SigmaStat software) to produce the continuous record.

Prior to 2009, the water-level data loggers at WRV2, SV1, SV2b, SV3, SNV1 and SNV2 measured absolute pressure, which incorporates the total head of water plus the barometric pressure. The barometric pressure data obtained from the nearby weather station were then used, along with HOBOware Pro software, to correct the measured water-level data to provide true net water-level readings. After 2009, when the nonvented HOBO data loggers were replaced with the vented Design Analysis data loggers this correction was no longer required because they automatically compensate for barometric pressure changes. SV4, SV5, SV6 and SV7 wells were always equipped with vented transducers so this correction was not necessary. Daily continuous groundwater-level data are reported in Appendix D.

4.3 Soil Parameters

Soil-parameter data are not reported in this document but can be provided upon request. These data are primarily used for estimating energy-balance closures as discussed in Section 4.5.5.

4.4 ET_{ref}

ET_{ref} represents ET demand rather than actual ET. Actual ET is dependent on the availability of water in the soil; whereas, ET_{ref} is the amount of potential ET if soil water were not limited.

The Penman-Monteith equation was used to compute ET_{ref} for this study. The use of this equation to estimate ET_{ref} has been evaluated and recommended by the American Society of Civil Engineers (Smith et al., 1992). This is a standardized equation used to closely approximate ET_{ref} using site-specific meteorological parameters, such as solar radiation, air temperature, humidity and wind speed in relation to physiological and aerodynamic parameters of a reference grass that is not water limited.

At the SNWA/UNLV ET sites, the ET_{ref} data were automatically calculated from the meteorological measurements and stored in a Campbell Scientific, Inc. CR10X data logger (Campbell Scientific, Inc. 1999). The CR10X data logger was pre-programmed by the manufacturer to automatically output ET_{ref} data in hourly and daily time intervals. The data loggers at the DRI sites were not programmed to automatically output ET_{ref}, therefore, the independently written REF-ET program (Allen, 2001) was used at these locations to calculate ET_{ref}. This program utilizes a standardized calculation of ET_{ref} using the FAO 56 Penman-Monteith equation (Allen et al., 1998).

Daily total ET_{ref} values are plotted in Appendix D. Missing data occurs at times of sensor calibration or sensor malfunction. Because ET_{ref} is used to assess environmental demand and not used to represent actual ET, gap-filling was not performed for these calculations. Based on visual inspection of the available records, certain stations and years were selected to compute the annual ET_{ref} (Table 4-3).

4.5 EC Data and Derivation of Total ET Rates

During the period of record, high-resolution 10Hz measurement data were collected and processed from the network of EC stations every four to six weeks. Data for individual parameters were collected and processed according to the manufacturer, Fluxnet-Canada (2003) and Ameriflux guidelines (Munger and Loescher, 2006). All collected data were post-processed using the EdiRe software package (EdiRe, 1999). Post-processing of high-resolution data resulted in corrected half-hourly fluxes. Corrected fluxes were checked using eleven quality assurance (QA)/quality control (QC) tests to verify optimal sensor and data logger performance, adequately developed turbulence, and statistically stable fluxes. Furthermore, ancillary data collected from the onsite meteorological station, monitor well, and TDT and TDR ground sensors were used to validate the timing and magnitude of corrected flux measurements. Flux calculations, corrections, applied QA/QC tests were collaboratively derived among UNLV, DRI, and SNWA and are consistent with

Table 4-3
Annual ET_{ref} (ft)

Site Name	2006	2007	2008	2009	2010
WRV2	4.47	4.84	4.53	3.98	---[a]
SV1	4.17	4.70	3.95	---[a]	4.14
SV2b	---	---[a]	4.14	3.81	3.75
SV3	---	---[a]	4.23	3.95	---[a]
SV4	---	---[a]	4.13	---[a]	---
SV5	---	---[a]	4.26	---[a]	---
SV6	---	---[a]	4.36	---[a]	---
SV7	---	---[a]	3.88	---[a]	---
SNV1	---	---[a]	4.61	4.32	4.33
SNV2	---	---[a]	4.58	4.41	4.40

[a]Gap-filling was not performed for these data during times of calibration or sensor malfunction. Therefore, annual ET_{ref} is only reported for annual records with sufficient data based on visual inspection of the record (Appendix D).

Lee et al. (2004), and Xu (2004), AmeriFlux guidelines (Munger and Loescher, 2006) and Burba and Anderson (2010). The data-processing steps and routines are depicted in Figure 4-1.

4.5.1 EC Data Post-Processing

An important requirement for EC post-processing is a zero mean vertical velocity from the sonic anemometer (CSAT3) data stream. To achieve a zero mean vertical velocity, all CSAT3 sensors were installed level to the ground surface using an inclinometer and planar fit coordinate rotations were applied to 10 Hz data following the methods of Wilczak et al. (2001). Planar fit coordinate coefficients are coefficients computed for a two dimensional regression plane (x and y axis). The regression plane maps the raw 3D (x, y, and z-axis) sonic anemometer measurements by setting the mean vertical velocity to zero and adjusting the x and y velocity. New planar fit coordinate coefficients b_0, b_1 and b_2 were calculated from at least two weeks of site-measurement data and applied in EdiRe to all measurement data collected after a CSAT3 sensor movement or adjustment event. The CSAT3 was rotated twice per year to adjust for the change in prevailing wind patterns (south facing from June through November, north facing from December to May).

Corrections to measured water fluxes for fluctuations in water vapor density and temperature were applied in EdiRe using the Webb, Pearman, Leuning (WPL) (Webb et al., 1980) equations. These equations assume horizontal homogenous flow and have been shown to be correct for both steady and non-steady state turbulence (Leuning, 2007). The overwhelming majority of on-site turbulence fell into these two major categories of turbulence structure, especially during day light hours. An integral turbulence test (ITT) developed by Thomas and Foken (2002) was implemented to assure flux measurement data had well-defined turbulence and that on-site turbulence stability ranges were

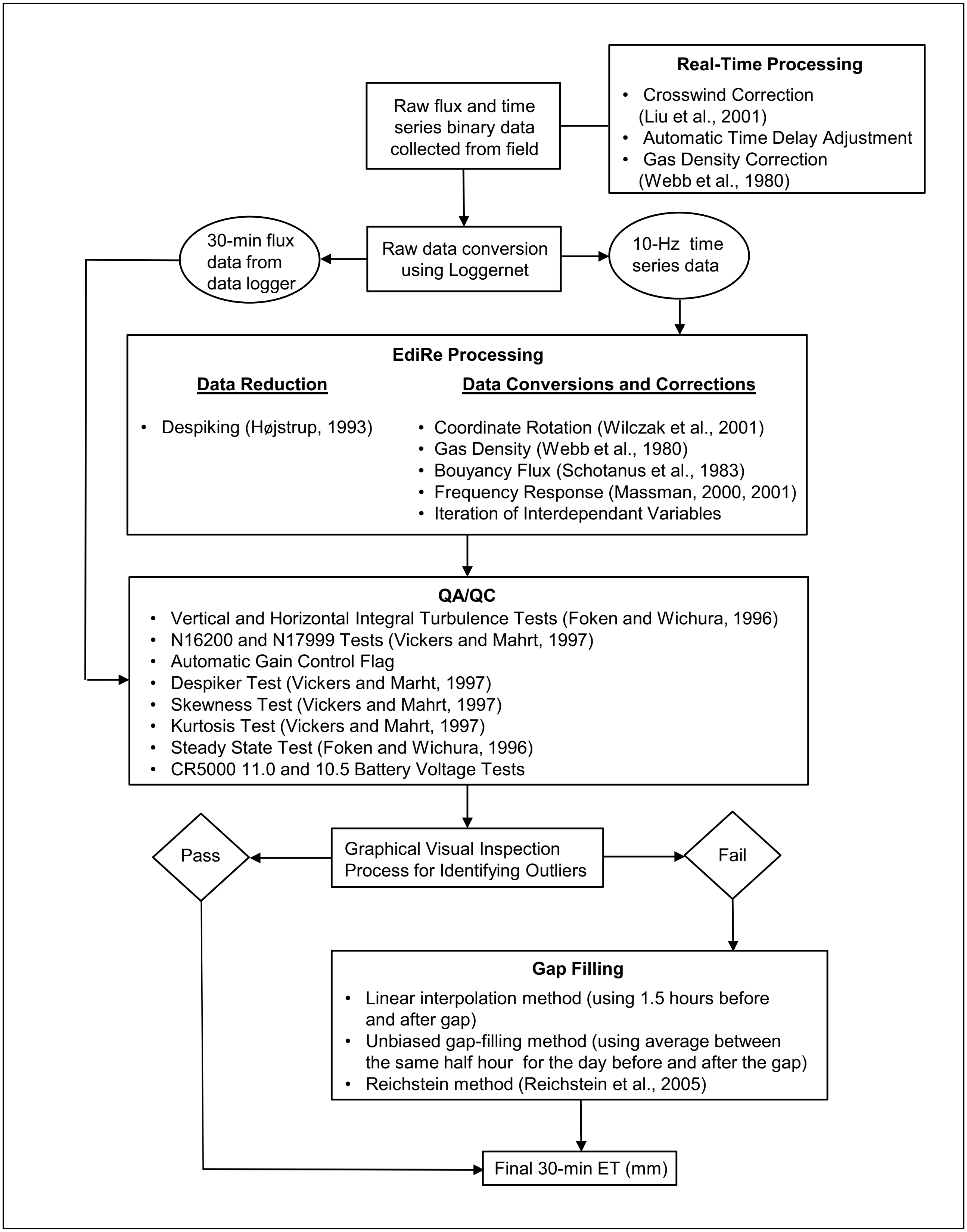

Figure 4-1
Data Processing and Reduction Flowchart

steady or non-steady state. Additionally, frequency response corrections were calculated and applied in EdiRe via methods of Massman (2000, 2001) to adjust measured fluxes for attenuation of the high and low frequency limits. Furthermore, two-step iterations were used to compensate for the interdependence of momentum and the frequency response corrections in EdiRe (Wohlfahrt, 2007).

Buoyance flux measured from the CSAT3 sonic temperature were converted into sensible heat flux using methods developed by Schotanus et al. (1983). The time delay between the CSAT3 and LI-7500 sensors were corrected using the autodetection routine on the CR5000 data logger. Also, an on-board routine was used for a cross wind correction for sonic temperature (Liu et al., 2001).

4.5.2 QA/QC of EC Data

Automated quality control of high resolution measurement data, from the IRGA and CSAT3, was implemented early in the post-processing steps using Despiking. The statistical data screening method known as Despiking was developed by Jørgen Højstrup (1993) and was implemented in EdiRe. The Despiking routine calculates predicted values based on the mean, variance, and point-to-point correlations determined from high-resolution data to compare with the actual measurement. The threshold used for comparison in outlier detection was set at six standard deviations from the predicted estimates. This threshold is consistent with the processing notes for the open-path “Gold” file by Xu (2004) found on the AmeriFlux website and as recommended by Clement (pers. comm., 2007). Detected outliers were counted, removed, and replaced with predicted values.

Skewness and kurtosis tests were used concurrently with EC time-series data to identify flux values associated with instrument error, flux-sampling errors, and data that is physically plausible but prone to error due to inclement weather conditions. Fluxes were flagged when the skewness and kurtosis were outside acceptable limits as defined by Vickers and Mahrt (1997) and were later reviewed during a manual graphical inspection process.

Vertical and horizontal integral turbulence test (ITT) detailed by Kaimal and Finnigan (1994), Foken et al. (2004) and Lee et al. (2004) were used to verify that all fluxes were within a limited range of acceptable flow. If ITT was higher than 30 percent, the corresponding fluxes were flagged for manual graphical inspection.

The stationarity test implemented by Foken and Wichura (1996) was used to verify that all time series has less than 30 percent separation of covariances. Otherwise, measured fluxes were flagged for manual graphical inspection as part of the data quality measure to ensure fluxes met the steady-state criteria. The 30 percent cutoff for stationarity, which is used in this report, is based on the progress made by the Russian scientists Gurjanov et al. (1984) and was then adopted by Foken and Wichura (1996). Gurjanov et al. (1984) is a notable document and method among EC scientists because it compares statistical parameters determined for an averaging period and proposed that a time series is steady-state if the difference in covariances is less than 30 percent.

An automatic gain control (AGC, percent blockage of IRGA viewing window) value of 70 or higher was used to flag data for manual graphical inspection. Blockage of the window is usually associated with precipitation events but could also be associated with dust storms, spiderwebs, or perched birds.

The AGC parameter ranges from a sensor-specific baseline value (40 or higher) to 100 for full blockage. The manufacturer states the IRGA can operate up to an AGC value of 99; however, a maximum value of 70 has been adopted by the SNWA. Other researchers like the DRI and the Biometeorology Research group of the University of Innsbruck have also adopted an AGC value of 70 for their EC research projects. Additionally, if a single value or 1 percent of a 30-min measurement block was missing or replaced by the Despiker routine, the associated fluxes were flagged as defined by Vickers and Mahrt (1997).

Quality-assurance tests were implemented to verify that the data logger and EC measurement sensors had proper battery voltages and were in accordance with manufacturer guidelines. Failure of these battery tests resulted in a flag of the associated 10 Hz and/or 30-min measurement fluxes. Data flagged for improper data logger or sensor battery voltage were graphically inspected.

4.5.3 Data Gap-Filling

Two forms of data gaps were identified in EC data sets: (1) data gaps removed for QA/QC and (2) missing data due to sensor calibration, inclement weather or sensor malfunction. Estimated values used to fill data gaps were derived in a consistent manner. All six SNWA/UNLV sites had inactive time periods during calibration activities, and estimated values for these gaps were not derived.

Data that were flagged for falling below the QA/QC standards detailed in Section 4.5.2, were later removed during the graphical inspection process and the recorded gaps were estimated. These gap-filled data sets were assigned a general flag for data quality. Due to the diurnal nature of measured fluxes, only short gaps, up to four hours, in length were filled through linear interpolation (using 1.5 hours before and after the gap) and assigned a data quality flag of 1. Gaps longer than 4 hours were filled using the average between the same half hour for the day before and day after the gap and assigned a data quality flag of 2. Gaps were typically of short duration but on rare occasions, due to sensor malfunction, data gaps longer than 10 days occurred. These types of gaps were filled using the Reichstein method (Reichstein, pers. comm., 2008). The Reichstein method is an automated algorithm (which can be found at http://www.bgc-jena.mpg.de/bgc-mdi/html/eddyproc/) that replaces the missing value by the average value under similar meteorological conditions within a designated time window. The time window is based on the availability of the similar meteorological data used to fill the gap, such as temperature or relative humidity (Reichstein et al., 2005; Reichstein, pers. comm., 2008). These methods are commonly applied in ET studies and are consistent with Fluxnet-Canada (2003) and Ameriflux (Munger and Loescher, 2006) guidelines as standard techniques as described by Falge et al. (2001) and Reichstein et al. (2005). Figure 4-2 illustrates an example of 30-min gap-filled ET data in the 2008 data set for WRV2.

4.5.4 Total-ET Rates

Annual total ET rates for each site are presented in Table 4-4. Daily ET is presented in Appendix D as it relates to daily ET_{ref} and daily DTW levels.

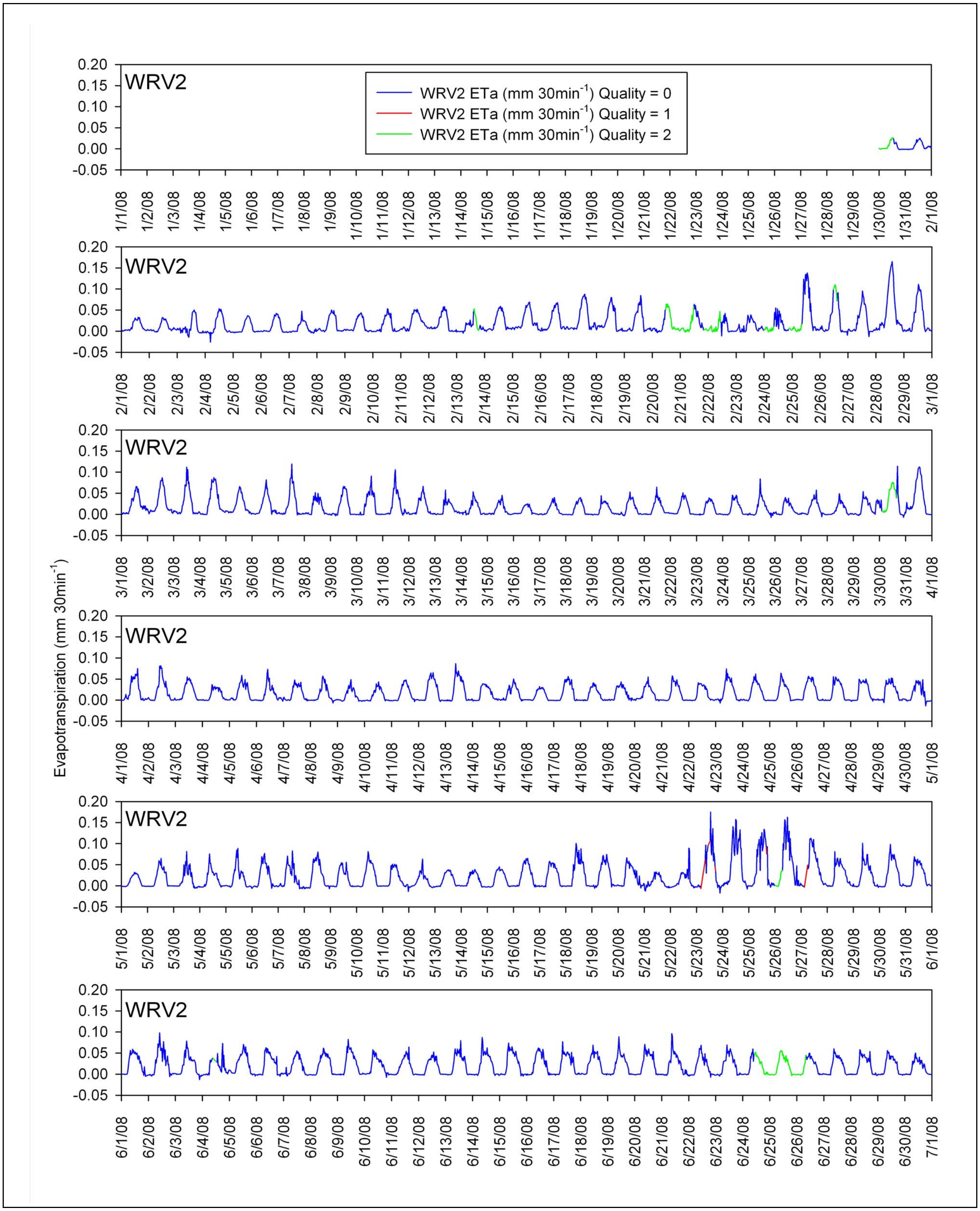

Figure 4-2
Example of 30-min Gap-Filled ET Data

Table 4-4
Annual ET (ft)

Site Name	2006	2007	2008	2009	2010	Period of Record[d]
WRV2	1.39[a]	0.72[b]	0.74	0.86	1.08	Jan. 2006 - Nov. 2010
SV1	0.79[a]	0.61[b]	0.63	0.77	0.96	Jan. 2006 - Nov. 2010
SV2b	---	3.57[b]	3.63	3.52	3.62	March 2007 - Nov. 2010
SV3	---	0.79[b]	0.78	0.99	1.16	March 2007 - Nov. 2010
SV4	---	2.46[c]	3.43[c]	4.19[c]	--	April 2007 - Nov. 2009
SV5	---	0.80[c]	1.09[c]	1.61[c]	--	April 2007 - Dec. 2009
SV6	---	0.68[c]	0.87[c]	1.28[c]	--	April 2007 - Nov. 2009
SV7	---	0.43[c]	0.61[c]	0.80[c]	--	April 2007 - Oct. 2009
SNV1	---	1.60[b]	1.04	0.85	1.02	May 2007 - Nov. 2010
SNV2	---	0.65[b]	0.65	0.73	0.74	May 2007 - Nov. 2010

Note: All annuals are January through December.
[a]Devitt et al. (2008).
[b]These include additional data not reported in Devitt et al. (2008).
[c]Data collected by DRI personnel and processed by SNWA.
[d]Sites are not operational during periods of sensor calibration; typically late December through middle of February.

ET rates measured at WRV2 (located within the medium vegetation classification) between 2006 through 2010 range from 0.72 ft to 1.39 ft. In Spring Valley, ET rates between 2006 through 2010 ranged from 0.43 ft to 0.80 ft within the bare soil/low vegetation classification and 0.61 ft to 1.61 ft in the medium vegetation classification. ET rates among the two wetland/meadow sites in Spring Valley ranged from 2.46 ft to 4.19 ft. In Snake Valley, ET rates within the bare soil/low vegetation classification ranged from 0.65 ft to 0.74 ft and 0.85 ft to 1.60 ft for the medium vegetation classification. All sites show an increase in ET rates from 2007 to 2010 with the exception of SNV1 which decreased over the period of record. This increase coincides with an increase in precipitation over the same period of record.

4.5.5 EC Data Assessment

The limitations associated with this data inherently relate to the overall accuracy and uncertainties associated with the EC method for measuring ET and the gap-filling approaches applied to periods of missing data.

The performance of the EC stations can be assessed by the energy balance closure (Section 2.1). Using the data collected at each site, the energy budget can be used to evaluate the instruments efficiency in measuring the available energy at each site. The performance was assessed by rearranging the energy budget equation (Equation 2-1) in a form to compute the energy balance ratio (*EBR*) expressed by:

$$EBR = (H + L_e E)/(R_n - G) \quad \text{(Eq. 4-1)}$$

The uncertainty in the energy budget can be inferred from the EBR. A ratio of 1.00 implies that all the available energy was accounted for in the measurements of the fluxes. Values larger or smaller than the optimum value of 1.00 imply that not all of the available energy was accounted for in one or more of the measured parameters. However, the *EBR* can be misleading because it is possible that the measurement error of one or more of the parameters can either: (1) offset the measurement error of the others, yielding an apparent *EBR* of 1.00; or (2) cause the *EBR* to diverge from 1.00. These errors can not be reconciled and attributed to a specific parameter; therefore, the *EBR* can only be used to provide a general sense of the EC station performance and the energy balance closure. Forcing energy balance closure by attributing the error to a particular parameter could lead to an overestimation/underestimation of that parameter. Instead, higher energy balance closure can be obtained, as this study has strived to do, by using up-to-date sensor technology, instituting calibration and maintenance protocols, and implementing recent advancements in EC correction methods as recommended by Webb et al. (1980), Massman and Lee (2002), and Lee et al. (2004), and applying more stringent tests for data quality as recommended by Foken et al. (2004).

The *EBR* for the ET-measurement sites were computed using the half-hourly flux data. The average annual values for each station and corresponding years are listed in (Table 4-5). Closing the energy balance is a common problem in energy budget methods. Several papers discuss the energy balance closure problem (Wilson et al., 2002; Foken et al., 2006; Kohsiek, 2007; Mauder et al., 2007; Oncley et al., 2007; Foken, 2008). At some sites the EBR exceeded 1.00 and, according to Hong (2008), this could be explained, in part, by an energy detection difference between the net radiation and sensible heat. That is, the high frequency measurement data may not reconcile the delayed effect that an abrupt drop in net radiation might have on the sensible heat flux (i.e., apparent *EBR* is larger).

Table 4-5
Energy Balance Ratios

Site Name	2006	2007	2008	2009	2010	Average
WRV2	0.98[a]	0.91	0.89	1.02	0.97	**0.95**
SV1	0.89[a]	0.85	0.94	0.92	1.07	**0.93**
SV2b	---	0.94	1.13	1.08	1.25	**1.10**
SV3	---	0.97	0.99	0.99	1.04	**1.00**
SV4	---	1.37	1.68	1.69	---	**1.58**
SV5	---	1.03	1.05	1.10	---	**1.06**
SV6	---	1.01	1.02	1.12	---	**1.05**
SV7	---	0.93	0.94	1.09	---	**0.99**
SNV1	---	1.07	0.94	0.93	0.93	**0.97**
SNV2	---	0.94	0.96	0.90	0.96	**0.94**

[a]Devitt et al. (2008)

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Appendix A

Monitor-Well Construction Documentation

203501

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY
WEV 2

PRINT OR TYPE ONLY
DO NOT WRITE ON BACK

1 Well

STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 99960
Permit No.
Basin 207

NOTICE OF INTENT NO. 57615

1. OWNER Dr. Devin
MAILING ADDRESS 4505 Maryland Parkway
Las Vegas NV

ADDRESS AT WELL LOCATION

2. LOCATION NW 1/4 NE 1/4 Sec. 22 T 9 N/S R 61 E Nye County
PERMIT NO. M/O 1363
Issued by Water Resources | Parcel No. | Subdivision Name

3. WORK PERFORMED
☒ New Well ☐ Replace ☐ Recondition
☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test
☐ Municipal/Industrial ☒ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☐ Rotary ☐ RVC
☐ Air ☒ Other HSA

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thick-ness
Silty Sand		0.0	23.0	23.0
Silty Clay		23.0	28.0	5.0
Sand		28.0	51.0	23.0
Clay		51.0	58.0	7.0
Sand		58.0	71.0	13.0
Clay		71.0	80.0	9.0

Date started 5/15, 2006
Date complated 5/16, 2006

7. WELL TEST DATA

TEST METHOD: ☐ Bailer ☐ Pump ☐ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)

8. WELL CONSTRUCTION

Depth Drilled 80.0 Feet Depth Cased 80.0 Feet

HOLE DIAMETER (BIT SIZE)

8 1/2 Inches From 0.0 Feet To 80.0 Feet
Inches Feet Feet
Inches Feet Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
2.0		Sch 40 PVC	0.0	80.0

Perforations:
Type perforation Machine Slot
Size perforation .020
From 80.0 feet to 15.0 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

Surface Seal: ☒ Yes ☐ No
Depth of Seal 1'
Placement Method: ☐ Pumped ☒ Poured
Seal Type: ☐ Neat Cement ☐ Cement Grout ☒ Concrete Grout

Gravel Packed: ☒ Yes ☐ No
From 80.0 feet to 13.0 feet

9. WATER LEVEL
Static water level 25.0 feet below land surface
Artesian flow G.P.M. P.S.I.
Water temperature °F Quality

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.

Name Eagle Drilling Services LLC
Contractor
Address 7150 Pollock St.
Contractor
Las Vegas NV. 891?

Nevada contractor's license number issued by the State Contractor's Board 51266

Nevada driller's license number issued by the Division of Water Resources, the on-site driller M-2272

Signed [signature]
By driller performing actual drilling on site or contractor

Date 5/22/06

(Rev. 12-01) USE ADDITIONAL SHEETS IF NECESSARY (0)-627

203501

WHITE—DIVISION OF WATER RESOURCES
CANARY—CLIENT'S COPY
PINK—WELL DRILLER'S COPY
SUI

PRINT OR TYPE ONLY
DO NOT WRITE ON BACK

STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 99959
Permit No.
Basin 184

NOTICE OF INTENT NO. 50960

1. OWNER Dr Devitt
MAILING ADDRESS 4505 Maryland Prkwy
Las Vegas NV

ADDRESS AT WELL LOCATION

2. LOCATION NE/4 SE 1/4 NE 1/4 Sec. 32 T. 11 N/S R. 67 E White Pine County

PERMIT NO. m/o 1363
Issued by Water Resources | Parcel No. | Subdivision Name

3. WORK PERFORMED
☒ New Well ☐ Replace ☐ Recondition ☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test ☐ Municipal/Industrial ☒ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☐ Rotary ☐ RVC ☐ Air ☒ Other HSA

6. LITHOLOGIC LOG

Material	Water Strata	From	To	Thickness
Sand & Gravel		0.0	2.5	2.5
Sand		2.5	12.5	10.0
Sand & Gravel		12.5	19.0	6.5
Sand		19.0	43.0	24.0
Silty Sand		43.0	45.0	2.0
Sand		45.0	51.0	6.0
Silty Sand		51.0	62.0	11.0
Sand		62.0	68.0	6.0
Silty Sand		68.0	75.0	7.0

Date started 5/18, 2006
Date complated 5/19, 2006

7. WELL TEST DATA

TEST METHOD: ☐ Bailer ☐ Pump ☐ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)

8. WELL CONSTRUCTION

Depth Drilled 75.0 Feet Depth Cased 75.0 Feet

HOLE DIAMETER (BIT SIZE)

	From	To
8 1/2 Inches	0.0 Feet	75.0 Feet
Inches	Feet	Feet
Inches	Feet	Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
2.0	Sch 4	Sch 40 PVC	0.0	75.0

Perforations:
Type perforation Machine Slot
Size perforation .020
From 75.0 feet to 10.0 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

Surface Seal: ☒ Yes ☐ No
Depth of Seal 1'
Placement Method: ☐ Pumped ☒ Poured

Seal Type: ☐ Neat Cement ☐ Cement Grout ☒ Concrete Grout

Gravel Packed: ☒ Yes ☐ No
From 75.0 feet to 8.0 feet

9. WATER LEVEL
Static water level 15 feet below land surface
Artesian flow G.P.M. P.S.I.
Water temperature °F Quality

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.

Name Eagle Drilling Services LLC
Contractor
Address 7150 Placid St
Las Vegas Nv. 89119
Contractor

Nevada contractor's license number issued by the State Contractor's Board 52066

Nevada driller's license number issued by the Division of Water Resources, the on-site driller M-2272

Signed [signature]
By driller performing actual drilling on site or contractor

Date 5/22/06

(Rev. 12-01) USE ADDITIONAL SHEETS IF NECESSARY (0)-627

STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT

OFFICE USE ONLY
Log No. ....
Permit No. ....
Basin

PRINT OR TYPE ONLY
DO NOT WRITE ON BACK

Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

NOTICE OF INTENT NO. 34201

1. OWNER Southern Nevada Water Authority
MAILING ADDRESS P.O. Box 99956
Las Vegas, NV 89193-9956

ADDRESS AT WELL LOCATION Hwy 893, Robinson Ranch
Subdivision Name: County: White Pine

2. LOCATION SE ¼ NW ¼ Sec 6 T 17N N/S R 63 E
PERMIT/WAIVER No. ....
Issued by Water Resources
Parcel No.

Latitude .... UTM E 716789.3 ☐ NAD 27
Longitude .... N 4360824.3 ☐ NAD 83/WGS 84

3. WORKED PERFORMED
☒ New Well ☐ Replace ☐ Recondition
☐ Deepen ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test
☐ Municipal/Industrial ☒ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☐ Rotary ☐ RVC
☐ Air ☒ Other

6. LITHOLOGIC LOG

Material	*Water Strata*	From	To	Thick-ness
Clayey Silt with Sand		0	2	2
Clayey Silty Sand		2	4	2
Silty Sand		4	6	2

Date started: 23-Oct, 20 08
Date completed: 23-Oct, 20 08

9. *WELL CONSTRUCTION*
Depth Drilled 6 Feet Depth Cased 5.5 Feet

HOLE DIAMETER (BIT SIZE)

Inches	From (Feet)	To (Feet)
6	0	6

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
2		SCH 40 PVC	0	3.0

Perforations:
Type of perforation Mill Slot
Size of perforation 0.020 Inch
From 2.8 feet to 5.3 feet
From .... feet to .... feet
From .... feet to .... feet
From .... feet to .... feet
From .... feet to .... feet

Annular Seal: ☒ Yes ☐ No
☐ Neat Cement .... to .... ☐ Pumped ☐ Poured
☐ Cement Grout .... to .... ☐ Pumped ☐ Poured
☒ Concrete Grout 0 to 0.75 ☐ Pumped ☒ Poured
☐ ≥30% Bentonite Grout to ☐ Pumped ☐ Poured
Gravel Pack: ☒ Yes ☐ No 2.0 to 6.0 ☐ Pumped ☒ Poured
Type: # 3 Silica Sand
Bentonite Chips: ☒ Yes ☐ No 0.75 to 2 ☐ Pumped ☒ Poured
Type: Benseal - Baroid

7. *Water Level*
Static water level: 0.5 feet below land surface
Artesian Flow: .... G.P.M. .... P.S.I.
Water Temperature: .... °F
Quality:

8. WELL TEST DATA
TEST METHOD: ☒ Bailer ☐ Pump ☐ Air Lift

	G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
Bailer	.25	0.2	0.5

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name ....
Contractor
Address ....
Contractor
....
Nevada contractor's license number issued by the *State Contractor's Board* ....
Nevada driller's license number issued by the Division of Water Resources, the *on-site driller* ....
Signed ....
By driller performing actual drilling on site or contractor
Date

(Rev 05-06)

USE ADDITIONAL SHEETS IF NECESSARY

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STATE OF NEVADA
DIVISION OF WATER RESOURCES

WELL DRILLER'S REPORT

Please complete this form in its entirety in accordance with NRS 534.170 and NAC 534.340

OFFICE USE ONLY
Log No. 103828
Permit No.
Basin 184

NOTICE OF INTENT NO. 29276

1. OWNER UNLV
MAILING ADDRESS 4505 maryland parkway Las Vegas, NV 89154
ADDRESS AT WELL LOCATION N. Spring valley

2. LOCATION SE 1/4 SE SW 1/4 Sec. 13 T 19 N/S R 66 E White Pine County
PERMIT NO. MO 1440 (Issued by Water Resources) | SV 3A (Parcel No.) | 39°30.29 N 114°29.65 W el. 5582 wgs 84 (Subdivision Name)

3. WORK PERFORMED
☒ New Well ☐ Replace ☐ Recondition ☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
☐ Domestic ☐ Irrigation ☐ Test ☐ Municipal/Industrial ☒ Monitor ☐ Stock

5. WELL TYPE
☐ Cable ☐ Rotary ☐ RVC ☐ Air ☒ Other auger

6. LITHOLOGIC LOG SV 3A

Material	Water Strata	From	To	Thickness
Silty sand		0	15	
Silty clay	21	15	25	
Silty sand.		25	35	

N 39.508122
W 114.500533 NAD27

Date started 5/7, 2007
Date completed 5/7, 2007

7. WELL TEST DATA

TEST METHOD: ☐ Bailer ☐ Pump ☐ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
N/A		

2007 JUN -5 AM 10:45

8. WELL CONSTRUCTION
Depth Drilled 35 Feet Depth Cased 35 Feet

HOLE DIAMETER (BIT SIZE)
8 Inches From 0 Feet To 35 Feet
Inches Feet Feet
Inches Feet Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
2	PVC	sch 40	0	35

Perforations:
Type perforation Fac
Size perforation .020
From 10 feet to 35 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

Surface Seal: ☒ Yes ☐ No
Depth of Seal 8
Placement Method: ☐ Pumped ☒ Poured
Seal Type: ☒ Neat Cement ☐ Cement Grout ☐ Concrete Grout

Gravel Packed: ☒ Yes ☐ No
From 8 feet to 35 feet

9. WATER LEVEL
Static water level 21 feet below land surface
Artesian flow N/A G.P.M. N/A P.S.I.
Water temperature N/A °F Quality N/A

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name Andresen Drilling (Contractor)
Address 1635 Belford Rd. Reno, NV 89509 (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 34525
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1028
Signed [signature]
By driller performing actual drilling on site or contractor
Date 5/31/07

(Rev. 12-01) USE ADDITIONAL SHEETS IF NECESSARY (O)-627

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STATE OF NEVADA
DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
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Permit No.
Basin 195

NOTICE OF INTENT NO. 29274

1. OWNER UNLV
MAILING ADDRESS 4505 Maryland Parkway Las Vegas, NV 89154
ADDRESS AT WELL LOCATION S end Snake valley

2. LOCATION SE 1/4 NE 1/4 Sec. 35 T 10 N/S R 70 E White Pine County
PERMIT NO. M/O 1440 (Issued by Water Resources) | Parcel No. | 39° 41.93N 114° 05.13W 4852' wgs 84 | Subdivision Name

3. WORK PERFORMED	4. PROPOSED USE	5. WELL TYPE
☒ New Well ☐ Replace ☐ Recondition ☐ Deepen ☐ Abandon ☐ Other	☐ Domestic ☐ Irrigation ☐ Test ☐ Municipal/Industrial ☒ Monitor ☐ Stock	☐ Cable ☐ Rotary ☐ RVC ☐ Air ☒ Other auger

6. LITHOLOGIC LOG SNV-1

Material	Water Strata	From	To	Thickness
sandy silt		0	10	
silty sand	18	10	38	

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N 38.697858
W 114.087932 NAD27

Date started 5/8, 2007
Date completed 5/8, 2007

8. WELL CONSTRUCTION
Depth Drilled 38 Feet Depth Cased 38 Feet

HOLE DIAMETER (BIT SIZE)
8 Inches From 0 Feet To 38 Feet
Inches Feet Feet
Inches Feet Feet

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
2	PVC	sch 40	0	38

Perforations:
Type perforation Fac
Size perforation .020
From 8 feet to 38 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

Surface Seal: ☒ Yes ☐ No
Depth of Seal 7
Placement Method: ☐ Pumped ☒ Poured
Seal Type: ☒ Neat Cement ☐ Cement Grout ☐ Concrete Grout

Gravel Packed: ☒ Yes ☐ No
From 7 feet to 38 feet

9. WATER LEVEL
Static water level 18' feet below land surface
Artesian flow N/A G.P.M. N/A P.S.I.
Water temperature Cold °F Quality N/A

7. WELL TEST DATA
TEST METHOD: ☐ Bailer ☐ Pump ☐ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
N/A		

STATE ENGINEER'S OFFICE 2007 JUN -5 AM 10:45 RECEIVED

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name Andresen Drilling (Contractor)
Address 1635 Bedford rd. Reno, NV 89509 (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 34525
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1028
Signed [signature] By driller performing actual drilling on site or contractor
Date 5/31/07

(Rev. 12-01) USE ADDITIONAL SHEETS IF NECESSARY (O)-627

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DIVISION OF WATER RESOURCES
WELL DRILLER'S REPORT
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Permit No.
Basin 195

NOTICE OF INTENT NO. 29273

1. OWNER UNLV
MAILING ADDRESS 4505 Maryland Parkway Las Vegas NV 89154

ADDRESS AT WELL LOCATION N end Snake Valley

2. LOCATION ~~SE~~ NW 1/4 ~~SE~~ NE 1/4 Sec. 36 T 14 N/S R 70 E White Pine County
PERMIT NO. MO 1440 (Issued by Water Resources) Parcel No. 39° 02.47N 114° 03.56W el. 5098 wgs84 (Subdivision Name)

3. WORK PERFORMED
- [x] New Well ☐ Replace ☐ Recondition
- ☐ Deepen ☐ Abandon ☐ Other

4. PROPOSED USE
- ☐ Domestic ☐ Irrigation ☐ Test
- ☐ Municipal/Industrial [x] Monitor ☐ Stock

5. WELL TYPE
- ☐ Cable ☐ Rotary ☐ RVC
- ☐ Air [x] Other auger

6. LITHOLOGIC LOG SNV-2

Material	Water Strata	From	To	Thickness
sandy silt		0	20	
Clay silt		20	30	
Silty gravel	30.6	30	50	

N 39.046445
W 114.064718 NAD27

Date started 5/9, 2007
Date completed 5/9, 2007

7. WELL TEST DATA

TEST METHOD: ☐ Bailer ☐ Pump ☐ Air Lift

G.P.M.	Draw Down (Feet Below Static)	Time (Hours)
N/A		

2007 JUN -5 AM 10:45

8. WELL CONSTRUCTION
Depth Drilled 50 Feet Depth Cased 50 Feet

HOLE DIAMETER (BIT SIZE)

Inches	From (Feet)	To (Feet)
8	0	50

CASING SCHEDULE

Size O.D. (Inches)	Weight/Ft. (Pounds)	Wall Thickness (Inches)	From (Feet)	To (Feet)
2	PVC	Sch 40	0	50

Perforations:
Type perforation Fac
Size perforation .020
From 10 feet to 50 feet
From feet to feet
From feet to feet
From feet to feet
From feet to feet

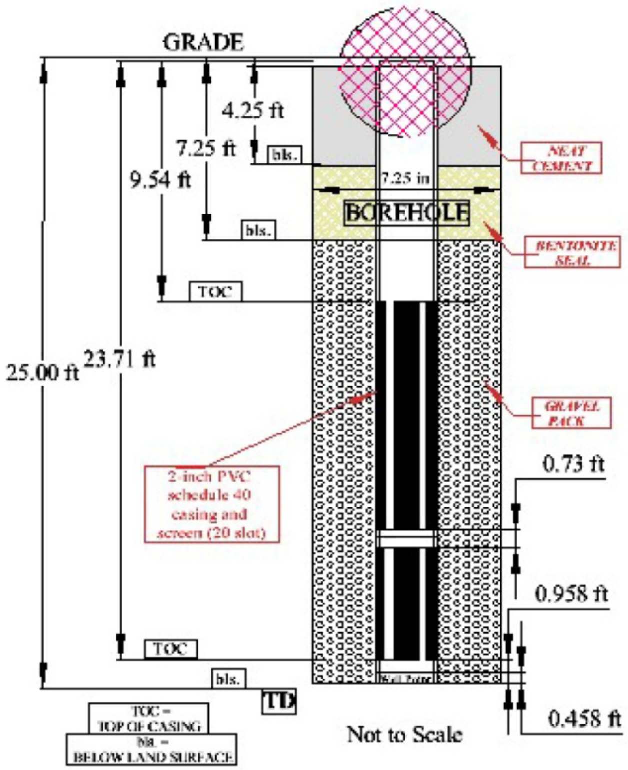
Surface Seal: [x] Yes ☐ No
Depth of Seal 9
Placement Method: ☐ Pumped [x] Poured
Seal Type: [x] Neat Cement ☐ Cement Grout ☐ Concrete Grout

Gravel Packed: [x] Yes ☐ No
From 9 feet to 50 feet

9. WATER LEVEL
Static water level 30.6 feet below land surface
Artesian flow N/A G.P.M. N/A P.S.I.
Water temperature cold °F Quality N/A

10. DRILLER'S CERTIFICATION
This well was drilled under my supervision and the report is true to the best of my knowledge.
Name Andresen Drilling (Contractor)
Address 11035 Belford rd Reno NV 89509 (Contractor)
Nevada contractor's license number issued by the State Contractor's Board 34525
Nevada driller's license number issued by the Division of Water Resources, the on-site driller 1028
Signed [signature] By driller performing actual drilling on site or contractor
Date 5/31/07

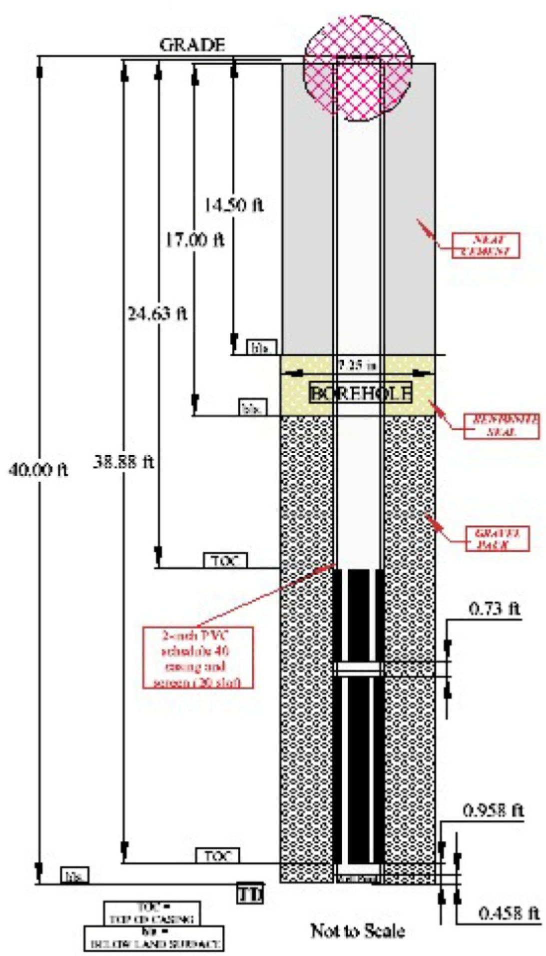
(Rev. 12-01) USE ADDITIONAL SHEETS IF NECESSARY (O)-627



Depth (ft)	Lithological Description (from cores)
0-2	Brown silt, roots, few large clasts, moist at 2 ft.
5-7	Grey clayey silt, few clasts, roots, dark brown mottling transition to moist soft grey clay. minor clasts, rootS, Fe stainings
10-12	Sand and coarse gravel mixed with fine sand; 11.5 ft. gravel, core loss due to gravel - W.L. - 11.4 ft. bls.
12-13	Large black cobbles (hard) with brown clay matrix
15-17	Brown silty clay, Fe stained mottles, dark brown to black mottling grades into coarse gravel at 16.5 ft., gravel mixed with clay
20-22	Minimal recovery; grey silt to fine sand, Fe staining (sand and gravel - 20.3 to 22ft.)
23-25	Light grey uniform fine sand, well sorted, wet, higher clay content in upper part of core with light colored mottles - W.L. - 19.2 ft. bls.
25	Total Depth - TD

Source: Healey, J.M. and Young, M.H., 2007, Well installations for Spring Valley Project, White Pine County, Nevada: submitted to the Southern Nevada Water Authority: Desert Research Institute, Las Vegas, NV.

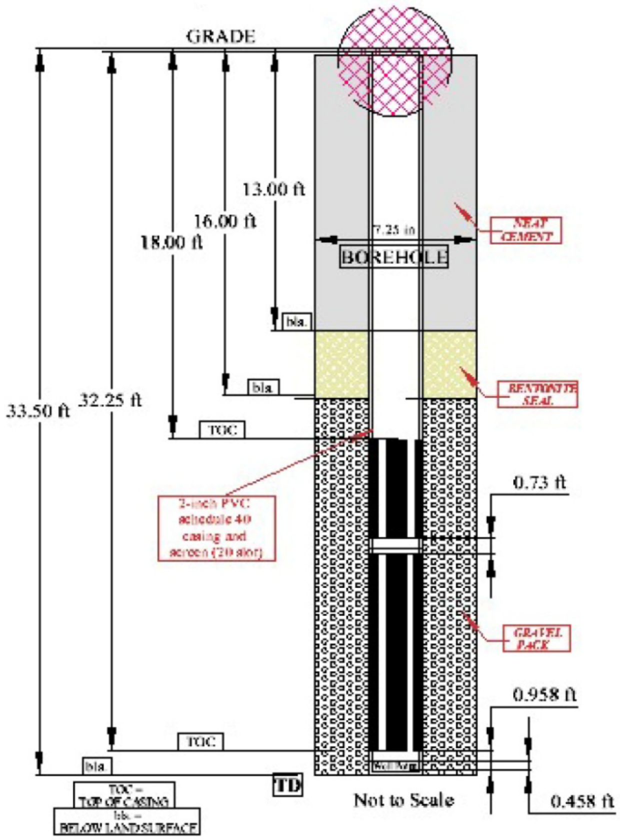
Well Schematic for SV4



Depth(ft)	Lithological Description (from cores)
0-2	Dry yellow rown silt, roots, uniform grain size
3-5	Coarse sand and gravel, sand at 3.5 ft.
5-7	Light brown silt mixed with gravel, gravel lense visable in core at 6 ft.
7-8	Sand and coarse gravel, well rounded, well sorted, dry
10-12	Hard silt and clay, some caliche, light brown in color, some pores blocky texture, dry and friable
15-17	Light brown silt, few roots, dark and light linings, pores: grades into light brown silt sand and gravel grading further into hard silt with white linings
20-22	Yellow brown fine sand uniform size and well sorted, minor clay fraction grading to yellow borwn fine sand, well sorted grades into dry gravel lense
25-27	Hard drilling, 25 to 25.3 ft. - coarse gravel grading into tight light brown clay with mottles - stiff, no water, uniform density
30-32	Soft light brown clay, very moist followed by soft light brown silty clay with minor sand and gravel lenses, Fe stains mottles
35-37	Light brown fine sand, wet, high clay content: gravel at 35.5 ft. followed by light grey fine sand with light grey mottles - water
38-40	Brown fine sand (sediment from drilling). Core mixed coarse sand and gravel at 39 ft., high clay content
40	Total Depth - TD

Source: Healey, J.M. and Young, M.H., 2007, Well installations for Spring Valley Project, White Pine County, Nevada: submitted to the Southern Nevada Water Authority: Desert Research Institute, Las Vegas, NV.

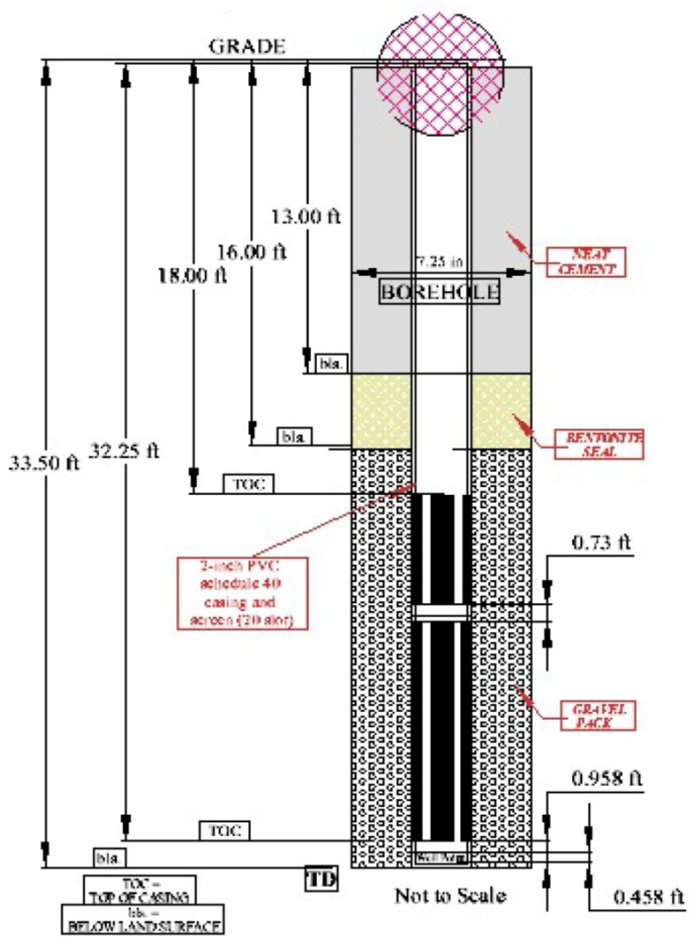
Well Schematic for SV5



Depth(ft)	Lithological Description (from cores)
0-2	Light brown sand and silt, uniform size, roots: at 3 ft. light greenish grey clay
5-7	Light greenish grey clay, massive, no structures
10-12	Light brown silt changing to grey green silt with minor amount of clay, Fe stains, massive, no strucures
15-17	Light green grey clay, some roots, good silt fraction, very moist at 15.6 ft. , minor rock fragements
20-22	Light grey clay, very moist, blocky structure, minor amount of silt
23-25	Grey silty clay, roots, no structure grades to silt rich zone in lower part of core
28-29	Smooth and rapid drilling, cutting turning up soupy clay
30-32	Grey silty clay, roots, no structure grades to silt rich zone in lower part of core
33.5	Total Depth - TD

Source: Healey, J.M. and Young, M.H., 2007, Well installations for Spring Valley Project, White Pine County, Nevada: submitted to the Southern Nevada Water Authority: Desert Research Institute, Las Vegas, NV.

Well Schematic for SV6



Depth(ft)	Lithological Description (from cores)
0-2	Light brown sand and silt, uniform size, roots: at 3 ft. light greenish grey clay
5-7	Light greenish grey clay, massive, no structures
10-12	Light brown silt changing to grey green silt with minor amount of clay, Fe stains, massive, no strucures
15-17	Light green grey clay, some roots, good silt fraction, very moist at 15.6 ft. , minor rock fragements
20-22	Light grey clay, very moist, blocky structure, minor amount of silt
23-25	Grey silty clay, roots, no structure grades to silt rich zone in lower part of core
28-29	Smooth and rapid drilling, cutting turning up soupy clay
30-32	Grey silty clay, roots, no structure grades to silt rich zone in lower part of core
33.5	Total Depth - TD

Source: Healey, J.M. and Young, M.H., 2007, Well installations for Spring Valley Project, White Pine County, Nevada: submitted to the Southern Nevada Water Authority: Desert Research Institute, Las Vegas, NV.

Well Schematic for SV7

Appendix B

Tipping Bucket Data

Table B-1
Index Precipitation Stations
Used to Estimate Monthly Precipitation Value for
ET Measurement Site Tipping Bucket Records

Year	Estimated Months	Estimated Precipitation Station	Index Precipitation Station	R^2
2007	Dec	WRV2	Lund[a]	0.71
	Jan - Mar, Dec	SV2b	SV1	0.43
	Jan - Mar	SV3	SV1	0.56
	Jan - Apr	SV4	SV1	0.90
	Jan - Apr, Jun	SV5	SV1	0.95
	Jan - Apr	SV6	SV1	0.89
	Jan - Apr	SV7	SV1	0.74
	Jan - Apr	SNV1	Eskdale[a]	0.81
	Jan - Apr	SNV2	Eskdale[a]	0.92
2009	Oct - Dec	SV4	SV3	0.94
	Oct - Dec	SV5	Bastian	0.89
	Oct - Dec	SV6	Bastian	0.89
	Oct - Dec	SV7	Bastian	0.88

[a]Monthly precipitation data source: WRCC online database accessed on September 1, 2010

Table B-2
ET-Measurement Site Monthly Tipping Bucket Precipitation Record (in.) for the Period 2006 through 2010

Site Name	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
WRV2	2006	0.82	0.97	1.74	1.33	0.05	0.52	2.28	0.02	1.54	0.97	0.03	0.18	**10.45**
	2007	0.10	0.45	0.42	0.75	0.01	0.28	0.31	1.64	1.15	0.13	0.00	0.99e	**6.23**
	2008	1.28	1.23	0.14	0.01	0.50	0.03	0.01	0.23	0.21	0.28	0.62	---	**4.54**
	2009	--	1.30	0.36	0.58	0.34	0.85	0.73	0.63	0.40	1.21	0.06	0.67	**7.13**
	2010	1.48	0.76	0.62	0.96	1.15	0.03	2.41	1.40	0.00	1.49	0.68	2.93	**13.91**
SV1	2006	0.41	0.55	1.11	0.84	0.06	0.18	1.64	0.06	0.29	0.87	0.02	0.08	**6.11**
	2007	0.00	0.89	0.67	0.49	0.02	0.02	0.31	1.00	1.08	0.03	0.06	0.43	**5.00**
	2008	0.99	0.98	0.53	0.00	0.06	0.13	0.67	0.21	0.23	0.49	0.45	---	**4.74**
	2009	0.00	1.00	0.08	0.58	0.72	0.87	0.56	0.35	0.21	0.80	0.13	0.54	**5.84**
	2010	1.03	0.49	0.74	1.22	1.02	0.04	1.23	0.79	0.02	1.94	0.72	2.01	**11.25**
SV2b	2007	0.31e	0.59e	0.52e	0.23	0.25	0.02	0.85	0.61	0.64	0.74	0.07	0.44e	**5.27**
	2008	1.94	0.27	0.71	0.02	2.28	0.02	0.18	1.91	---	---	---	---	**7.33**
	2009	0.99	0.74	---	---	---	---	---	---	---	1.08	0.00	0.30	**3.11**
	2010	0.43	0.14	0.40	0.90	0.76	0.23	0.55	0.08	0.00	1.26	0.68	1.94	**7.37**
SV3	2007	0.20e	0.52e	0.44e	0.14	0.25	0.00	0.53	0.69	0.39	0.35	0.02	0.68	**4.21**
	2008	0.37	0.31	0.14	0.00	0.06	0.33	0.23	0.22	0.04	0.17	0.80	0.05	**2.72**
	2009	0.53	0.39	0.12	0.54	0.30	1.33	1.44	0.06	0.09	1.30	0.00	0.46	**6.56**
	2010	0.52	0.31	0.51	0.85	0.88	0.60	0.84	0.07	0.00	1.13	0.89	1.36	**7.96**
SV4	2007	0.16e	0.85e	0.68e	0.54e	0.16	0.15	0.59	0.82	0.93	0.09	0.02	0.80	**5.79**
	2008	0.70	0.68	0.45	0.00	0.50	0.37	1.08	0.36	0.06	0.17	0.58	0.17	**5.12**
	2009	0.33	0.65	0.10	0.77	0.41	1.16	1.23	0.27	0.21	1.14e	0.17e	0.52e	**6.96**
SV5	2007	0.14e	0.81e	0.65e	0.51e	0.11	0.15e	0.31	0.91	0.92	0.33	0.02	0.58	**5.44**
	2008	0.42	0.61	0.32	0.00	0.11	0.24	0.22	0.51	0.06	0.11	0.49	0.41	**3.50**
	2009	1.42	0.82	0.11	0.89	0.34	1.99	0.79	0.31	0.18	1.04e	0.00e	0.81e	**8.70**
SV6	2007	0.08e	0.84e	0.65e	0.50e	0.11	0.00	0.19	1.20	0.75	0.33	0.01	0.58	**5.24**
	2008	0.50	0.57	0.28	0.01	0.06	0.24	0.21	0.51	0.06	0.10	0.40	0.43	**3.37**
	2009	1.33	0.80	0.12	0.95	0.25	1.88	0.71	0.22	0.17	0.99e	0.00e	0.76e	**8.18**
SV7	2007	0.17e	0.51e	0.43e	0.36e	0.13	0.15	0.20	0.42	0.63	0.32	0.00	0.63	**3.95**
	2008	0.33	0.37	0.23	0.01	0.22	0.22	0.13	0.56	0.00	0.05	0.42	0.05	**2.59**
	2009	1.19	0.50	0.21	0.79	0.31	1.19	0.44	0.06	0.20	0.73e	0.00e	0.57e	**6.19**
SNV1	2007	0.37e	1.18e	1.10e	0.70e	0.09	0.06	0.48	0.90	0.91	0.01	0.16	1.13	**7.09**
	2008	0.32	0.91	0.50	0.00	0.50	0.14	0.31	0.27	0.18	0.81	0.16	0.11	**4.21**
	2009	0.06	0.88	0.13	1.40	0.29	0.60	0.69	0.05	0.02	0.21	0.15	0.44	**4.92**
	2010	0.80	0.70	0.76	1.00	0.41	0.66	0.78	0.31	0.00	1.54	0.72	---	**7.68**
SNV2	2007	0.16e	0.66e	0.61e	0.37e	0.11	0.01	0.30	0.16	0.52	0.01	0.01	0.64	**3.56**
	2008	0.08	0.30	0.47	0.00	0.16	0.32	0.02	0.82	0.08	0.41	0.15	0.20	**3.01**
	2009	0.38	0.78	0.12	0.88	0.27	0.70	0.53	0.02	0.42	0.40	0.00	0.20	**4.70**
	2010	0.89	0.50	0.46	0.98	0.29	0.44	0.66	0.34	0.01	0.74	0.68	1.40	**7.39**

e = estimated

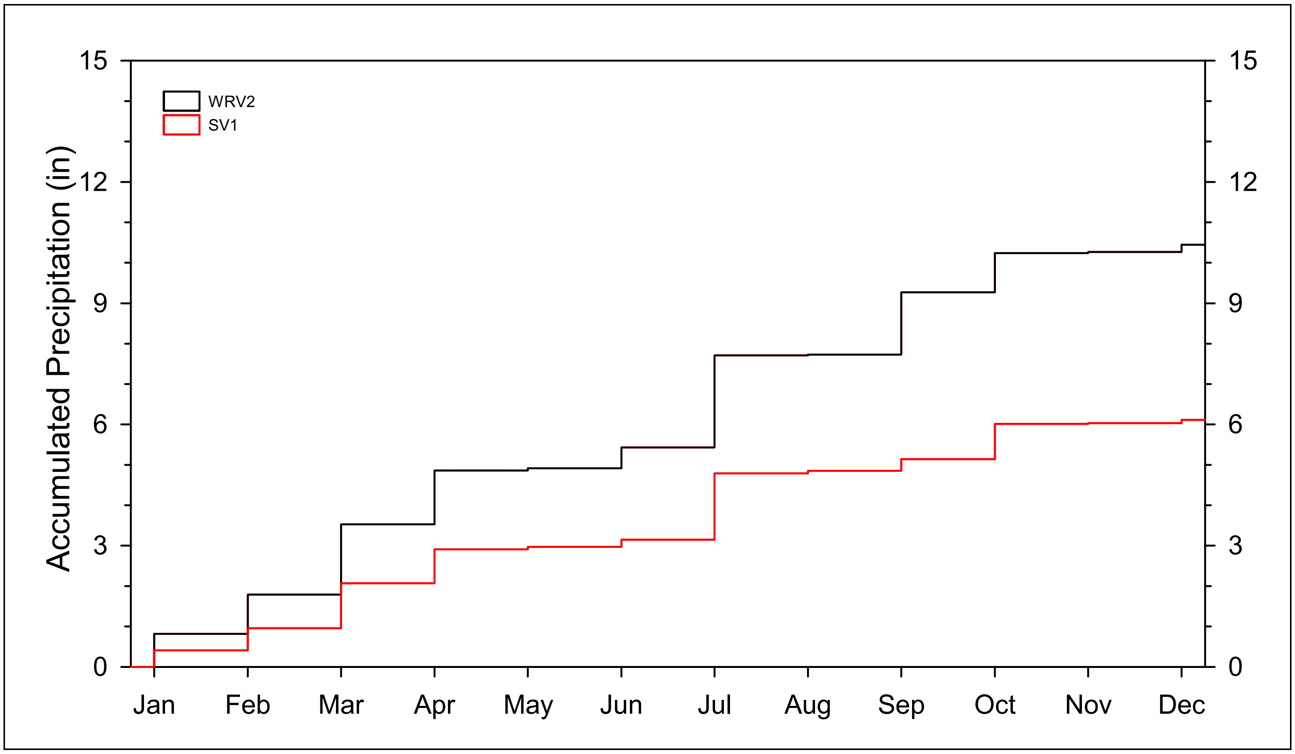


Figure B-1
2006 Daily Accumulated Tipping Bucket Precipitation

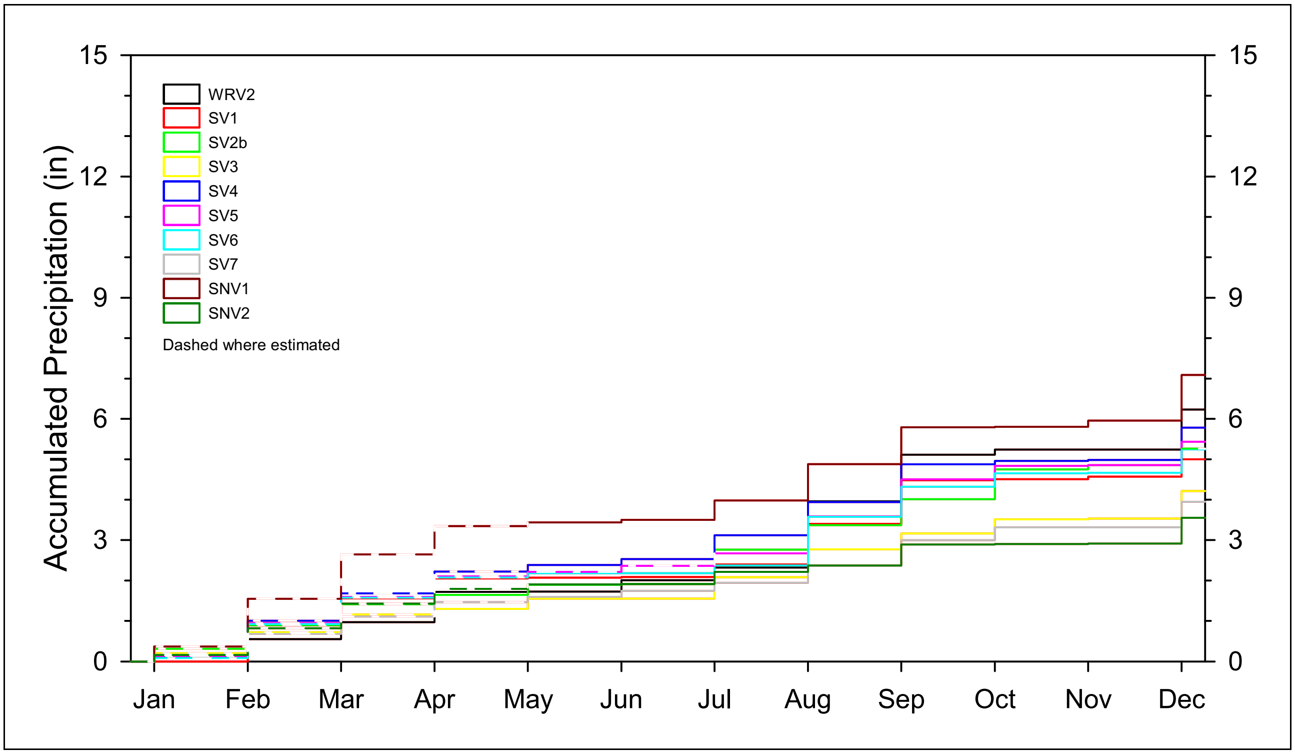


Figure B-2
2007 Daily Accumulated Tipping Bucket Precipitation

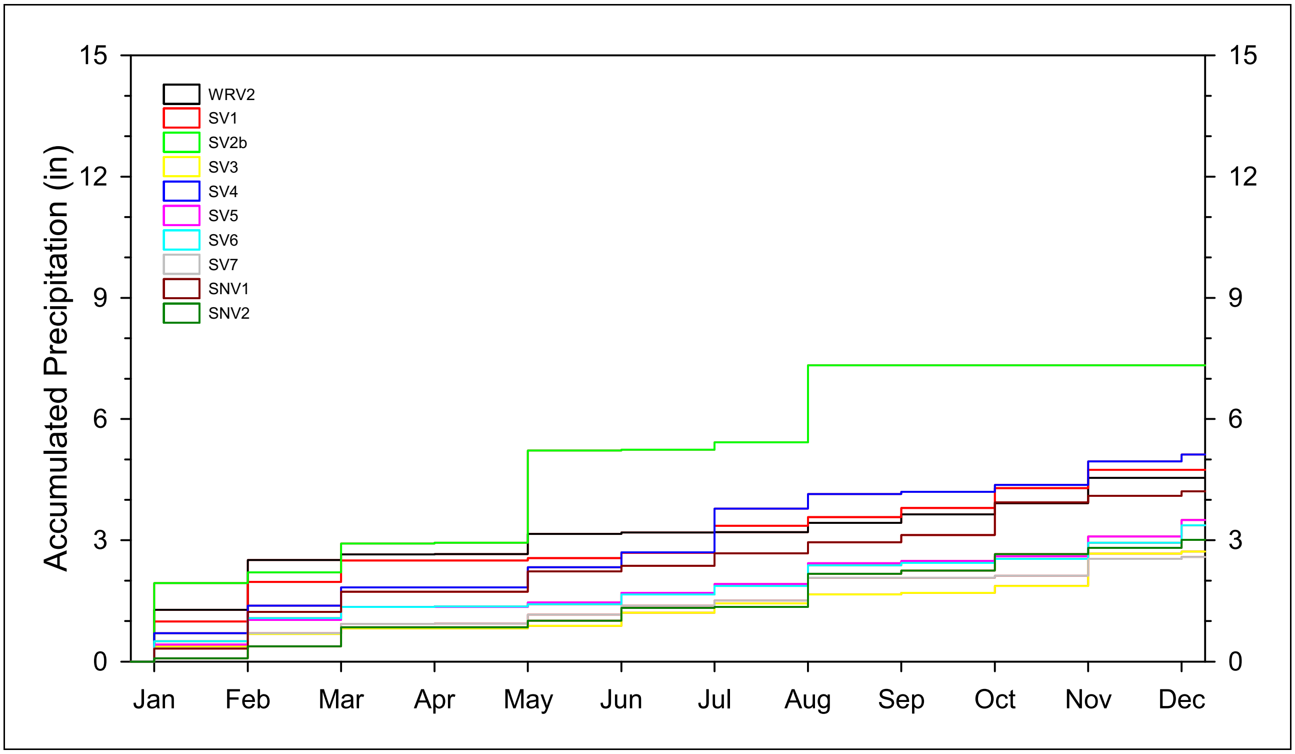


Figure B-3
2008 Daily Accumulated Tipping Bucket Precipitation

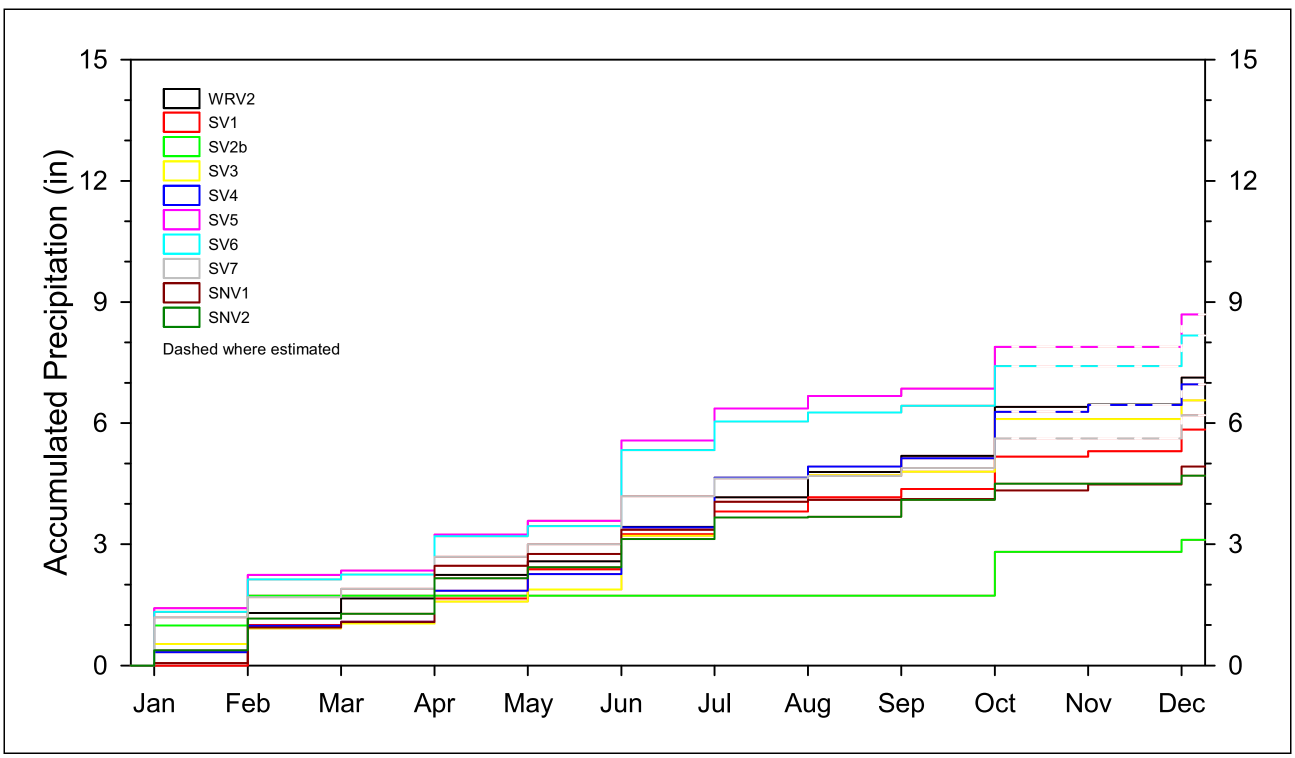


Figure B-4
2009 Daily Accumulated Tipping Bucket Precipitation

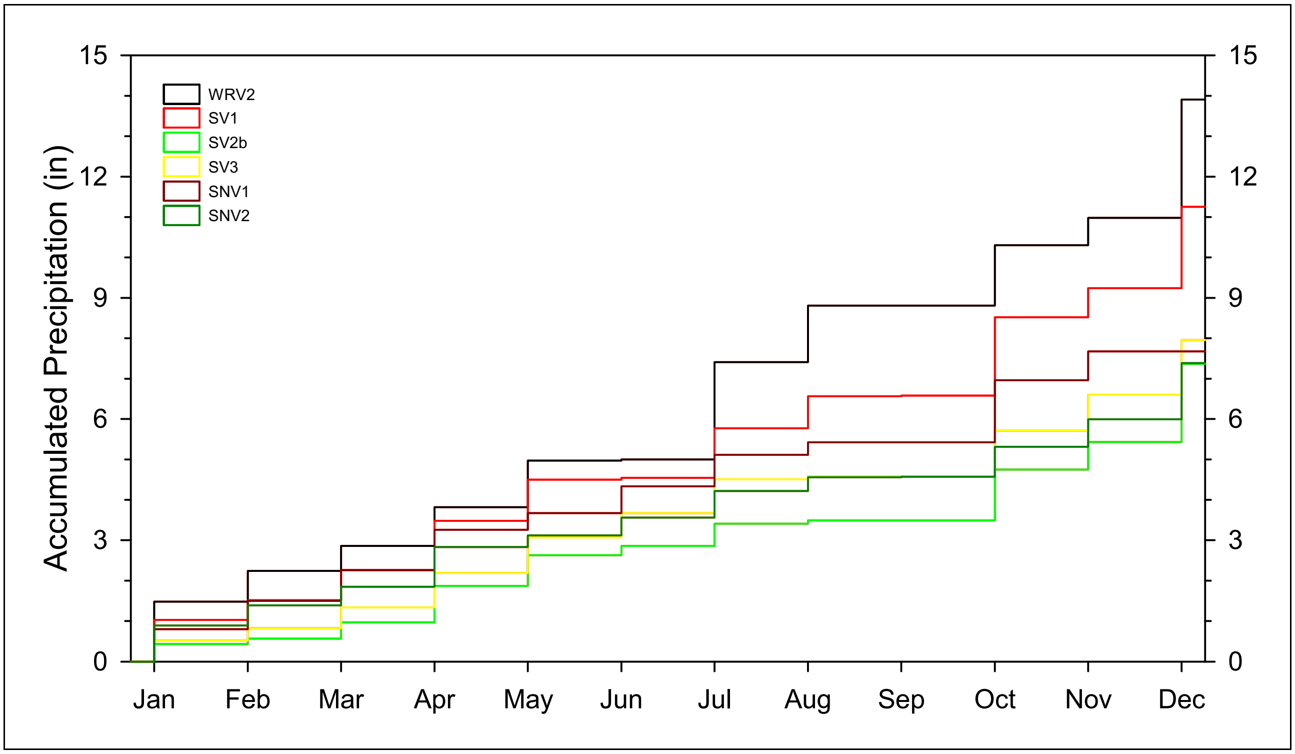


Figure B-5
2010 Daily Accumulated Tipping Bucket Precipitation

References

WRCC, see Western Regional Climate Center.

Western Regional Climate Center, 2010, Western US COOP Station Map [Internet], [accessed September 1, 2010], available from http://www.wrcc.dri.edu/coopmap/.

Appendix C

Bulk Storage Precipitation Gage Data

Table C-1
Date of Site Visits and Measured Precipitation at the Bulk Storage Precipitation Gages for the 2008 Measurement Year

Accumulation Time	WRV2	SV1	SV2b	SV3	SNV1	SNV2
1/1/2008 - 2/21/2008	2.74e	1.61e	0.72e	0.73e	1.13e	0.98e
2/22/2008 - 3/18/2008	0.00	0.74	0.12	0.18	0.19	0.38
3/19/2008 - 4/15/2008	0.18	0.57	0.11	0.10	0.57	0.39
4/16/2008 - 5/8/2008	0.00	0.00	0.06	0.06	0.01	0.16
5/9/2008 - 5/28/2008	0.59	0.13	0.00	0.00	0.56	0.00
5/29/2008 - 6/24/2008	0.08	0.15	0.10	0.34	0.15	0.00
6/25/2008 - 7/17/2008	0.02	0.57	0.18	0.08	0.13	0.40
7/18/2008 - 8/6/2008	0.02	0.39	0.31	0.27	0.53	0.00
8/7/2008 - 8/28/2008	0.19	0.02	0.13	0.15	0.04	0.15
8/29/2008 - 9/17/2008	0.35	0.12	0.41	0.19	0.13	0.17
9/18/2008 - 10/23/2008	0.36	0.74	0.17	0.26	1.08	0.80
10/24/2008 - 11/20/2008	1.09	0.44	0.44	0.75	0.13	0.42
11/21/2008 - 12/17/2008	0.43	0.25	0.00	0.00e	---	0.00
12/18/2009 - 12/31/2008	0.39e	0.27e	0.04e	0.06e	0.48e,a	0.23e
Total	**6.44**	**6.00**	**2.79**	**3.17**	**5.13**	**4.08**

e = Estimated
a = Accumulation Time: 11/21/2008 - 12/31/2010

Table C-2
Date of Site Visits and Measured Precipitation at the Bulk Storage Precipitation Gages for the 2009 Measurement Year

Accumulation Time	WRV2	SV1	SV2b	SV3	SNV1	SNV2
1/1/2009 - 1/30/2009	0.90e	0.48e	0.86e	0.81e	0.23e	0.37e
1/31/2009 - 2/19/2009	1.77	0.91	0.95e	0.60	1.13	0.91
2/20/2009 - 3/12/2009	0.46	0.10	0.10	0.05	0.05	0.13
3/13/2009 - 4/7/2009	0.06	0.12	0.18	0.27	0.44	0.17
4/8/2009 - 4/28/2009	0.80	0.80	0.57	0.57	1.29	0.81
4/29/2009 - 6/10/2009	0.45	1.08	1.02	0.68	0.60	0.62
6/11/2009 - 7/22/2009	2.14	1.65	1.78	2.32	1.26	1.40
7/23/2009 - 8/18/2009	0.07	0.83	0.05	0.19	0.24	0.00
8/19/2009 - 9/23/2009	0.85	0.57	0.38	0.19	0.06	0.54
9/24/2009 - 11/18/2009	0.50	0.96	1.21	1.42	0.48	0.50
11/19/2009 - 12/22/2009	0.79	0.58	0.39	0.53	0.48	0.29
12/23/2009 - 12/31/2009	0.23e	0.09e	0.02e	0.15e	0.04e	0.00e
Total	**9.02**	**8.17**	**7.51**	**7.78**	**6.30**	**5.74**

e = Estimated

Table C-3
Date of Site Visits and Measured Precipitation at the Bulk Storage Precipitation Gages for the 2010 Measurement Year

Accumulation Time	WRV2	SV1	SV2b	SV3	SNV1	SNV2
1/1/2010 - 2/2/2010	1.86e	1.80e	0.44e	---	1.79e	0.98e
2/3/2010 - 3/16/2010	1.62	0.59	0.44	1.61e,a	0.59	0.70
3/17/2010 - 4/27/2010	0.98	1.57	1.31	1.58	---	---
3/17/2010 - 5/5/2010	---	---	---	---	1.60	0.91
4/28/2010 - 6/15/2010	1.36	1.27	1.19	1.66	---	---
5/6/2010 - 6/15/2010	---	---	---	---	1.14	0.68
6/16/2010 - 7/20/2010	0.02	0.22	0.02	0.01	0.06	0.16
7/21/2010 - 9/1/2010	3.28	1.81	0.76	1.05	1.21	0.87
9/2/2010 - 10/12/2010	0.38	1.22	0.41	0.63	0.81	0.48
10/13/2010 -11/15/2010	1.54	0.99	1.17	0.99	1.54	0.62
11/16/2010 - 12/31/2010	3.09e	3.13e	2.68e	2.64e	2.26e	1.95e
Total	**14.13**	**12.60**	**8.42**	**10.17**	**11.00**	**7.35**

e = Estimated
a = Accumulation time: 1/1/2010 - 3/16/2010

Appendix D

Daily ET, ET Reference, and Depth-to-Water Data

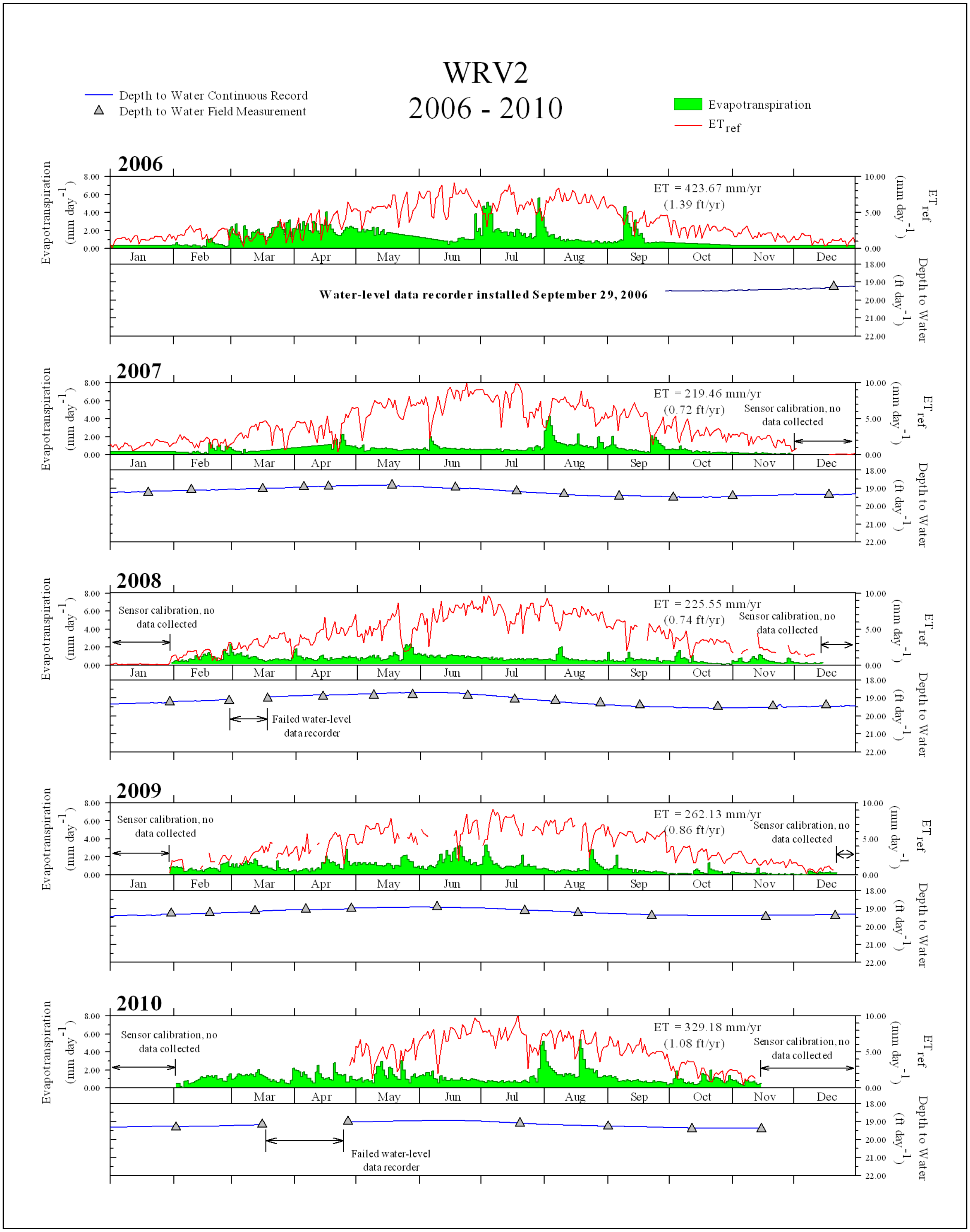


Figure D-1
Daily ET, ET_{ref} and Depth-to-Water at WRV2 2006-2010

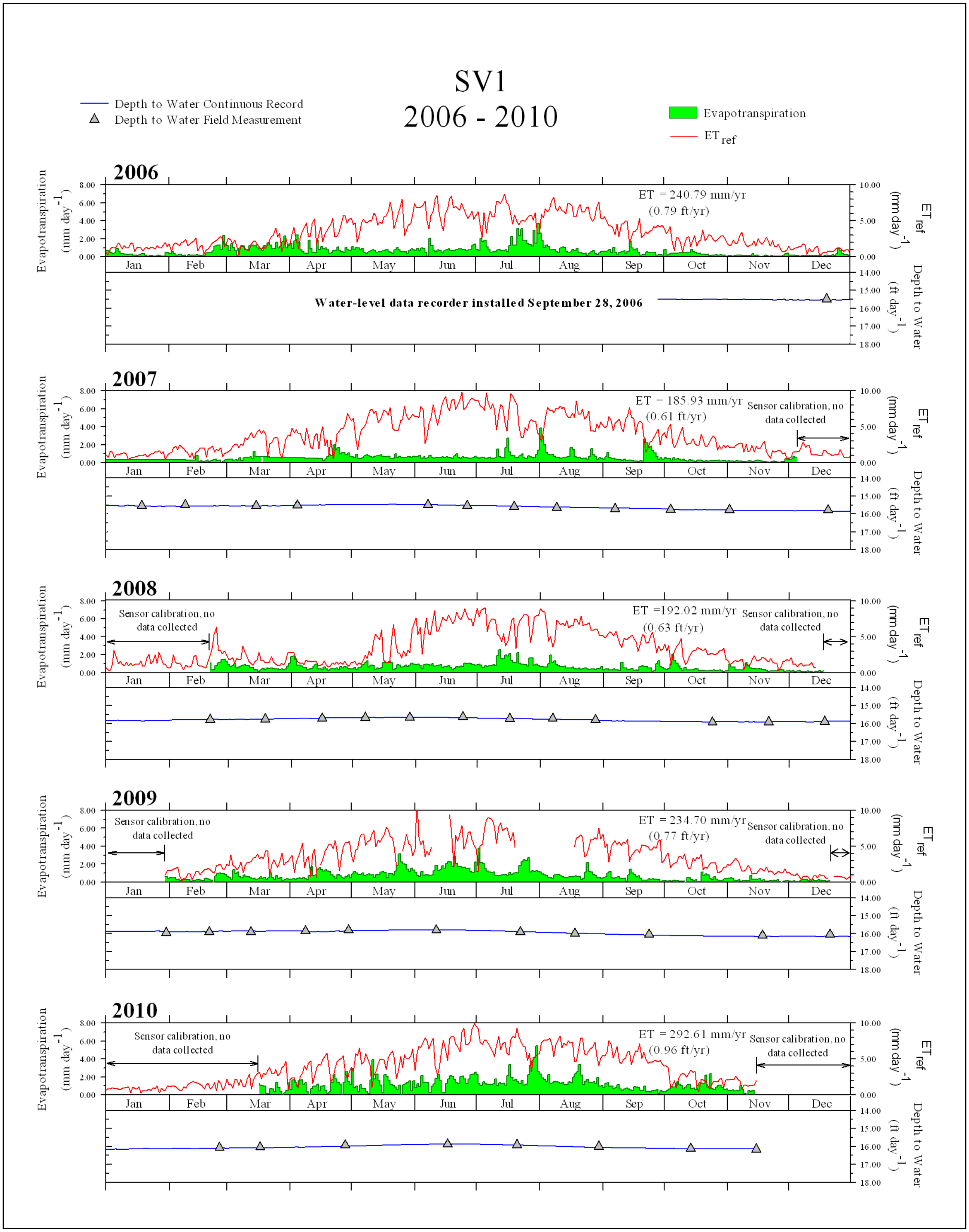


Figure D-2
Daily ET, ET_{ref} and Depth-to-Water at SV1 2006-2010

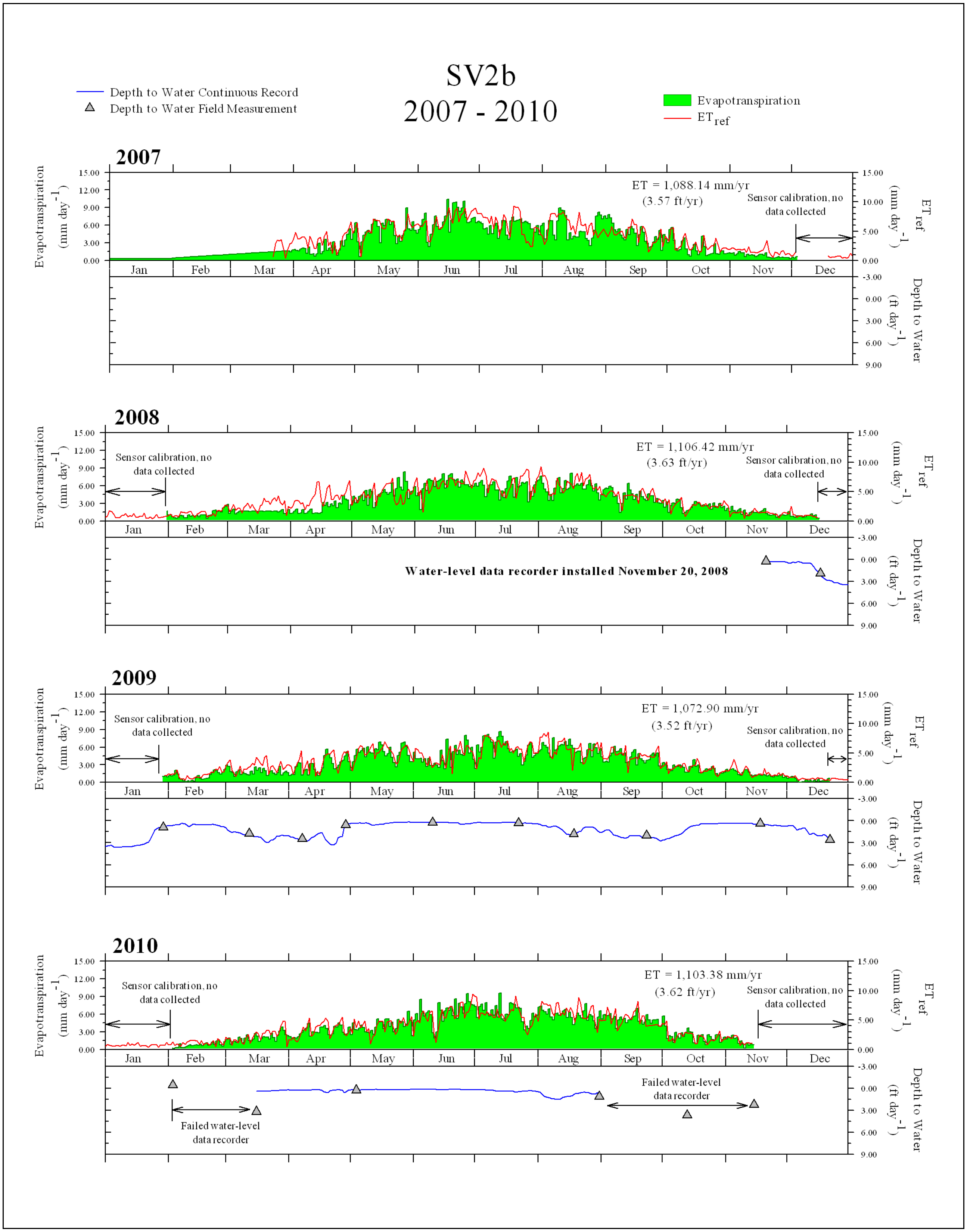


Figure D-3
Daily ET, ET_{ref} and Depth-to-Water at SV2b 2007-2010

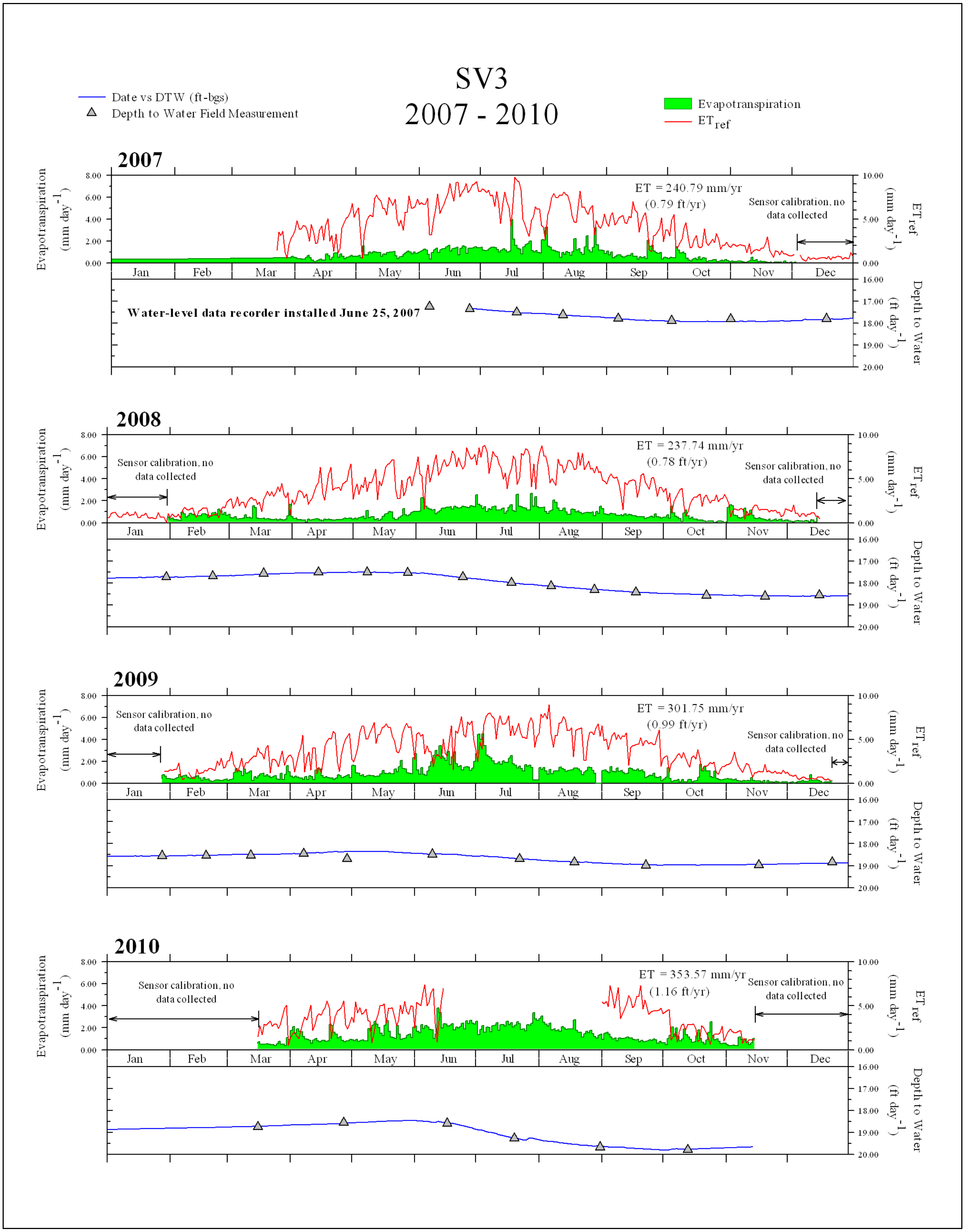


Figure D-4
Daily ET, ET_{ref} and Depth-to-Water at SV3 2007-2010

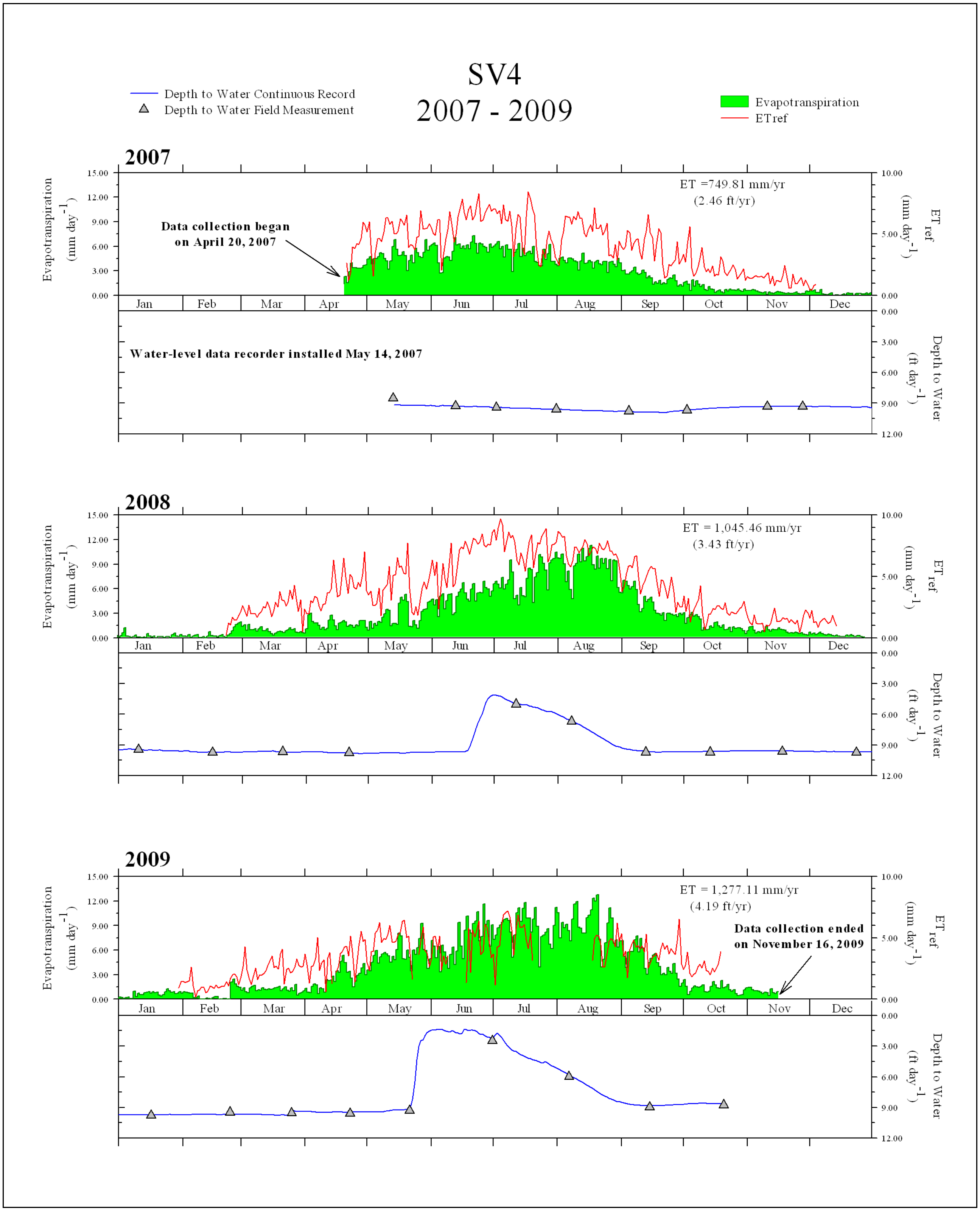


Figure D-5
Daily ET, ET_{ref} and Depth-to-Water at SV4 2007-2009

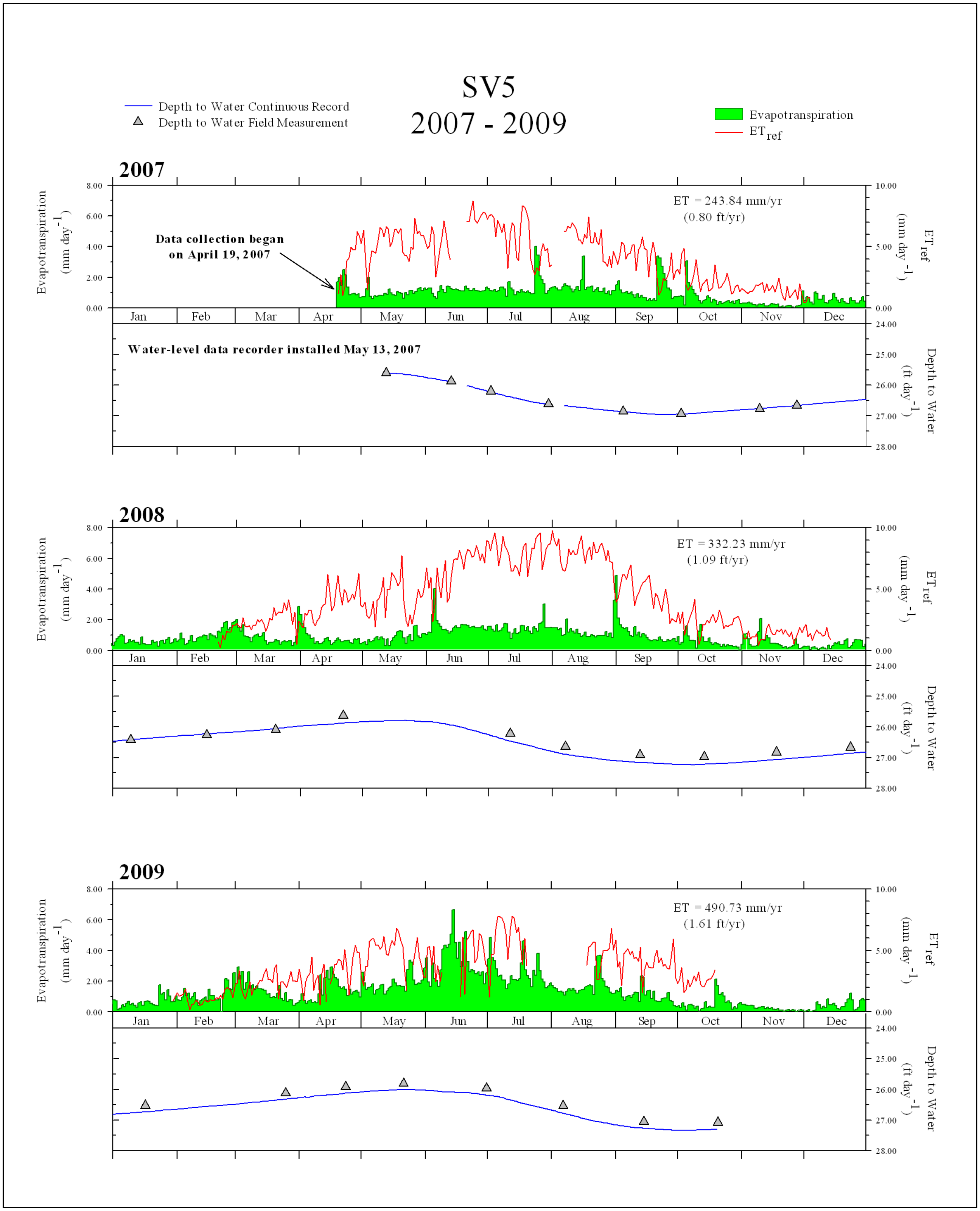


Figure D-6
Daily ET, ET_{ref} and Depth-to-Water at SV5 2007-2009

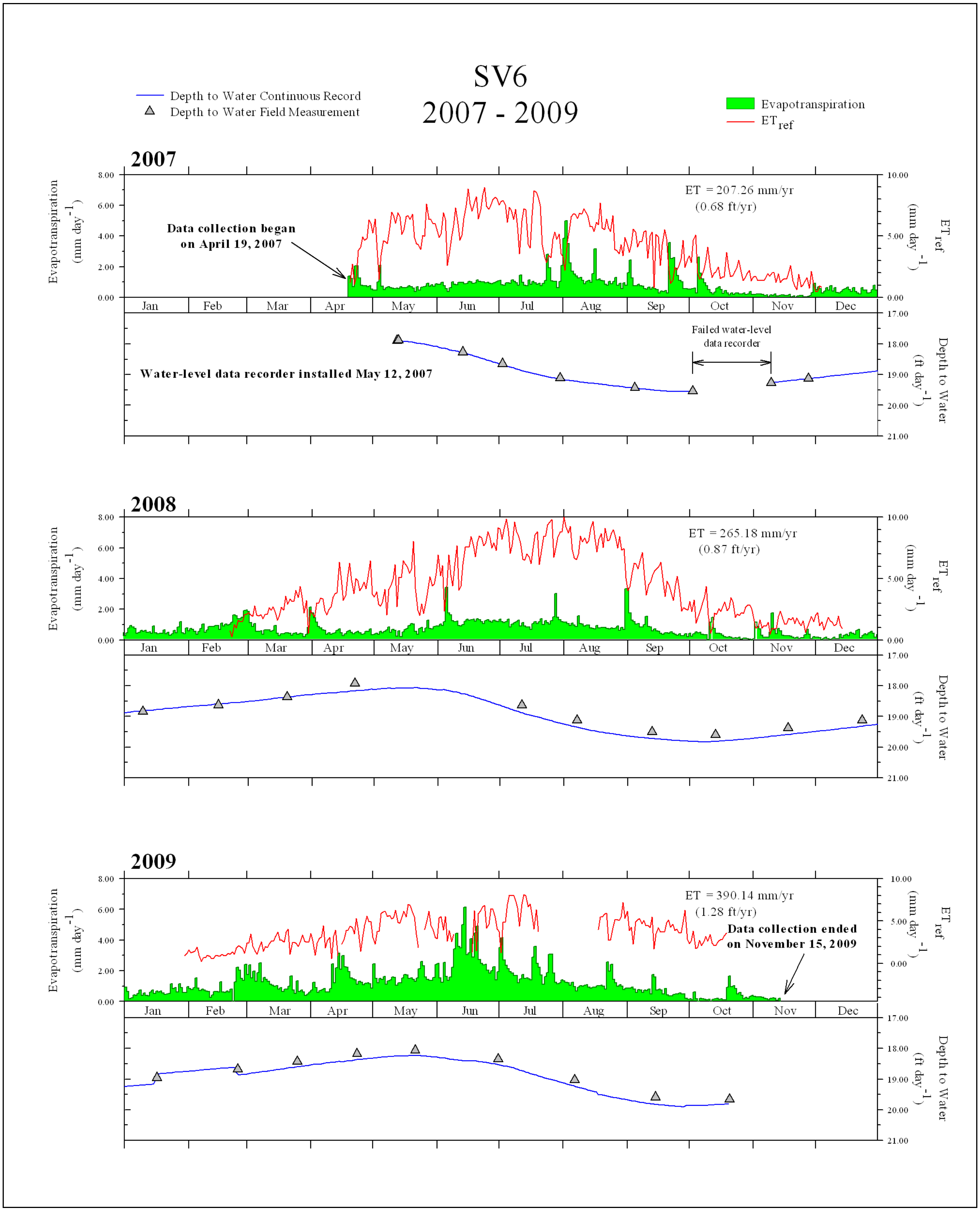


Figure D-7
Daily ET, ET_{ref} and Depth-to-Water at SV6 2007-2009

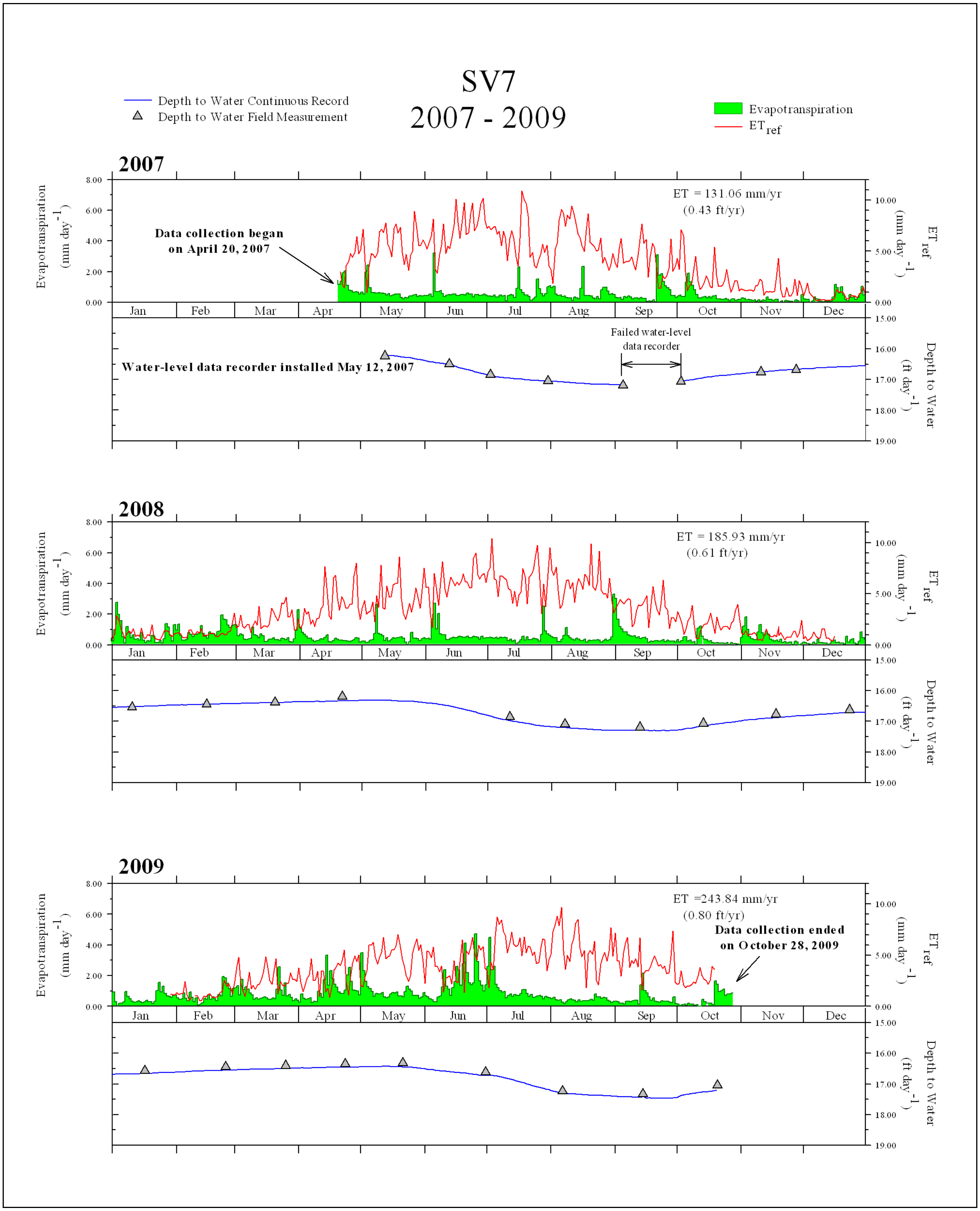


Figure D-8
Daily ET, ET_{ref} and Depth-to-Water at SV7 2007-2009

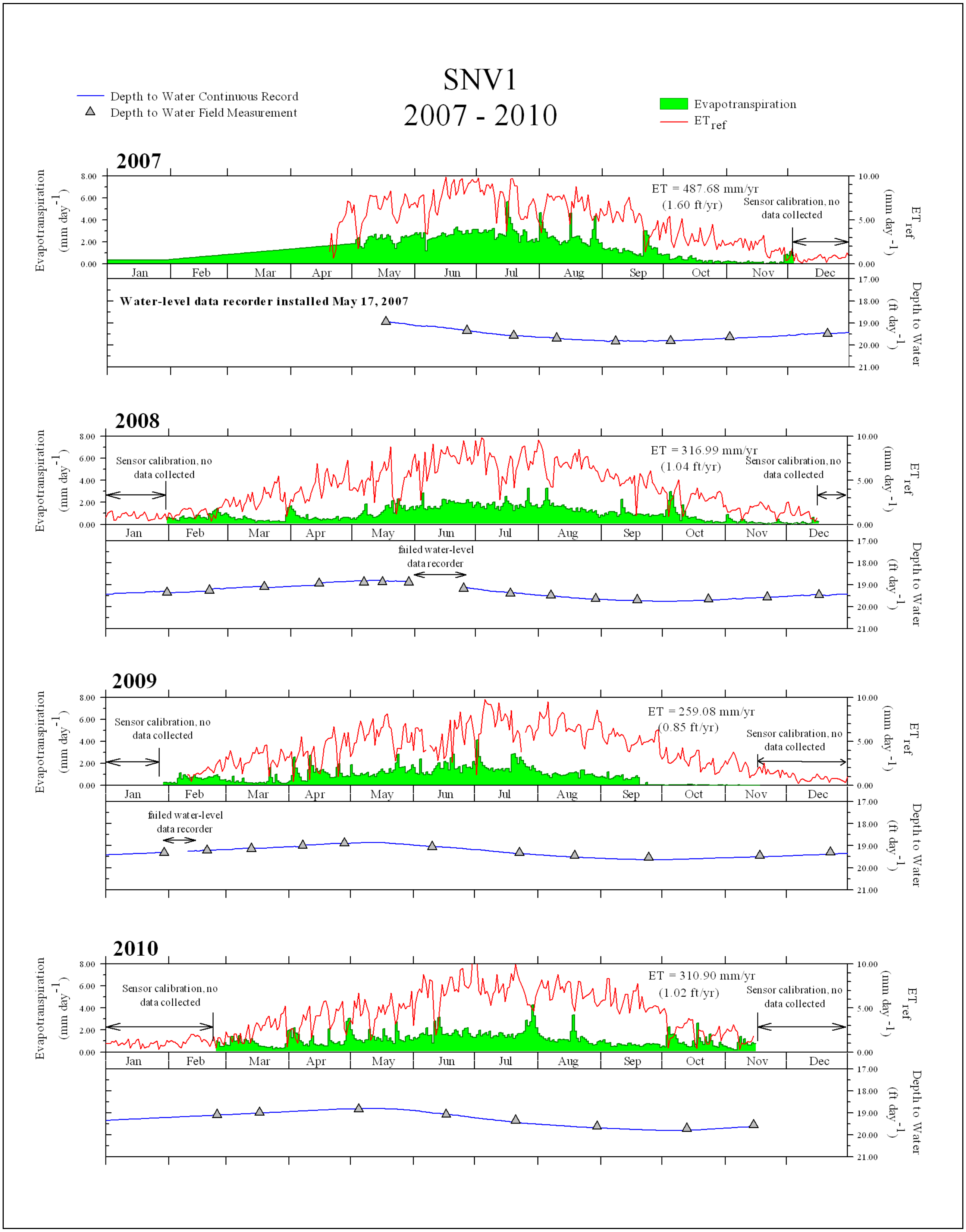


Figure D-9
Daily ET, ET_{ref} and Depth-to-Water at SNV1 2007-2010

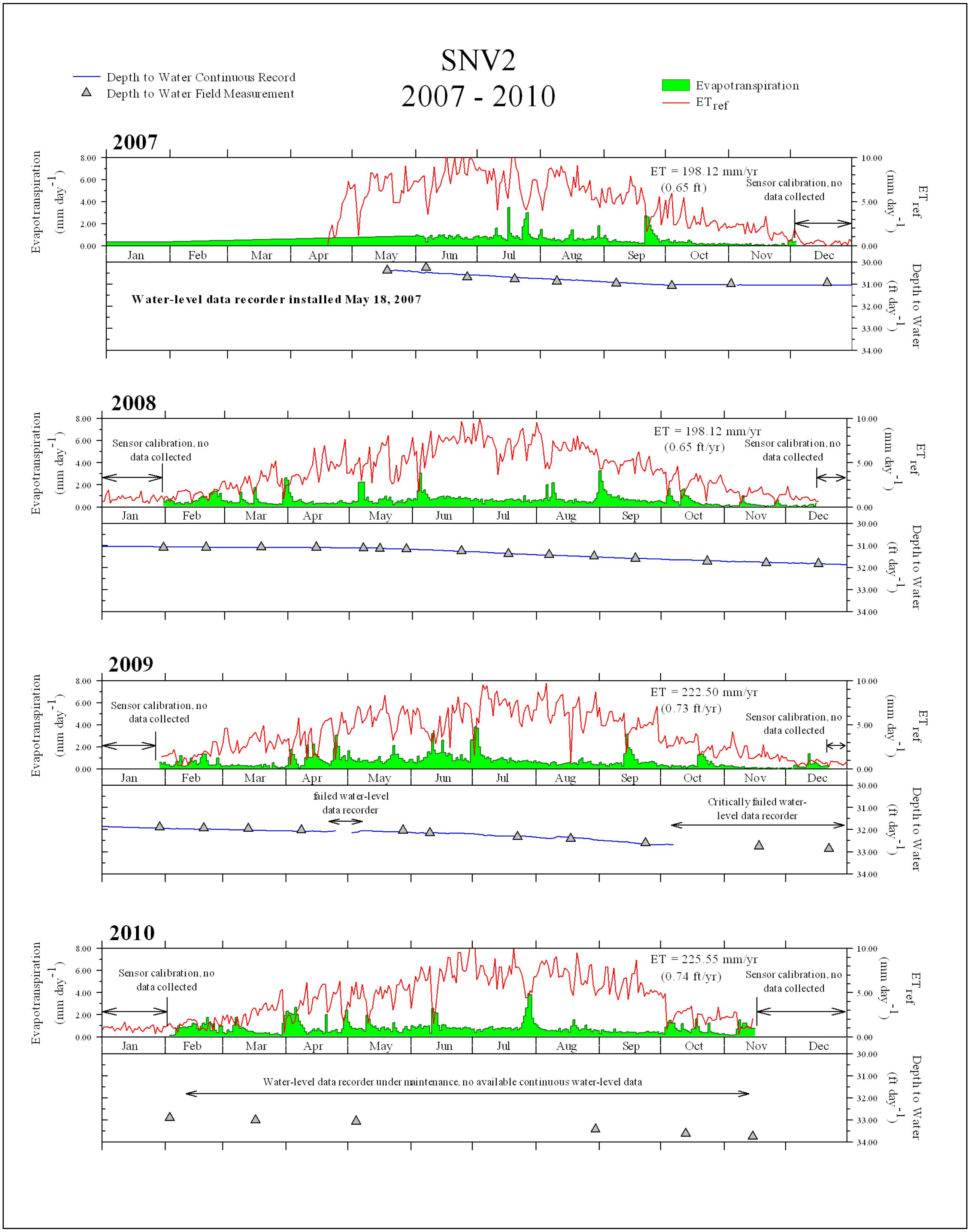


Figure D-10
Daily ET, ET_{ref} and Depth-to-Water at SNV2 2007-2010