# Evapotranspiration Estimates in North Eastern Nevada Basins

**Final Report**

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**List of Acronyms**

$\%Area_{na}$...Percent of area that was not available
ADC... ..Agricultural Digital Camera
Ag...... ..Agricultural acres
AGC... ..Automatic Gain Control
ARVI... .Atmospherically Resistant Vegetation Index
ASCE... .American Society of Civil Engineers
$b_o$, $b_1$, $b_2$ Wilczaks et al. (2001) coordinate rotation coefficients
EC............Eddy Covariance
$EC_e$... .... Electrical conductivity of Saturation Extract ($dSm^{-1}$)
$EC_w$......... Electrical conductivity of Water ($dSm^{-1}$)
$ET_C$ ....... The sum of ET values calculated for cloud covered pixels
$ET_{neg}$....... The sum of ET values calculated for all pixels with negative ET values
EM.......... Electromagnetic mapping
ENVI..... ENvironment for Visualizing Images
EROS....... Earth Resources Observation and Science
ET........... Evapotranspirationion
ETa.......... Actual Evapotranspiration (mm)
$ET_{all}$......... The sum of ET values calculated for every pixel within the phreatophyte area of a particular valley
$ET_{ref}$.........Penman Monteith reference evapotranspiration (mm)
$ET_{tadj}$.......Total adjusted ET
$ET_{ta-na}$...... ET for the total phreatophyte area excluding any missing, cloud covered or cloud shadow pixels
EVI......... Enhanced vegetation index
FWHM.... Full-width at half maximum
G........... Soil heat flux ($W\ m^{-2}$)
GARI...... Green Atmospherically Resistant Index
GEMI...... Global Environment Monitoring Index
GNDVI... Green Normalized Difference Vegetation Index
GPS........ Global Positioning Satellite
H........... Sensible heat ($W\ m^{-2}$)
IDL......... Interactive Data Language
IRGA....... Infrared Gas Analyzer
ITT.......... Integral Turbulence Test
ITT™...... Visual Information Solutions the vendor for ENVI. ITT is the trademark name.
LAI..........Leaf Area Index
LE............Latent heat of evaporation ($W\ m^{-2}$)
LXWP.......Leaf xylem water potential (MPa)
MOST.......Monin-Obukhov Similarity Theory
MSAVI-2.. Modified soil adjusted vegetation index 2
NDVI....... Normalized Difference Vegetation Index
$R_{BLUE}$....... Reflectance within the blue band

$R_{GREEN}$...... Reflectance within the green band
Rn.......... Net radiation (W $m^{-2}$)
$R_{NIR}$......... Reflectance within the Near InfraRed (NIR) band
$R_{RED}$......... Reflectance within the red band
ROI......... Region-Of-Interest
SAVI-A..... Soil adjusted vegetation index version a
SNK1....... Snake Valley site 1
SNK2....... Snake Valley site 2
SNWA...... Southern Nevada Water Authority
Sqrt.......... Square root
SR........... Simple Ratio
ST........... Stationarity Test
SV1......... Spring Valley site 1
SV2a........ Spring Valley site 2a
SV2b........ Spring Valley site 2b
SV3......... Spring Valley site 3
SVAT....... Soil-vegetation-atmosphere transfer
WRV1...... White River Valley site 1
WRV2...... White River Valley site 2
WRV3...... White River Valley site 3
Tc-Ta....... Temperature differential between canopy and atmosphere ($^{o}$C)
TDR......... Time domain reflectometry ($cm^3$ water per $cm^3$ soil)
TM.......... Thematic Mapper
USGS....... United States Geological Survey
VI........... Vegetation indices
VIF......... Variance inflation factor
VPD......... Vapor pressure deficit (kPa)
WPL......... Webb, Pearman and Leuning (1980) density correction

## Executive Summary

Evapotranspiration (ET) was estimated for Spring Valley and White River Valley in 2005, 2006 and 2007 and in Snake Valley in 2007. Evapotranspiration estimates were made based on an energy balance approach using the eddy covariance method. ET estimates in this report are different from previously reported values, reflecting changes based on using the 10Hz data and incorporating a series of post processing adjustments. Changes also occurred with the remote sensing data, as a more refined atmospheric correction process was utilized. ET estimates at the basin scale were made by developing empirical relationships between ET and remotely sensed spectral data (Landsat). Groundwater, soil moisture, rainfall and leaf level measurements were used to validate the differences in ET estimates based on site, year and basin.

ET estimates were based on operating one to three eddy covariance systems per valley over a three-year period. This research represented a major undertaking by the University and required a significant level of funding by SNWA. Different approaches for collecting and analyzing data were taken; however, all were subject to some limitations. As such, we report a range in the ET estimates. Testing the suitability of these estimates is left to modeling and water management personnel as they move forward with closing hydrologic balances for the individual basins.

The findings were quite clear in depicting a significant downward trend in winter rainfall over the three year period. Whereas, environmental demand during the most active growing period of April-June, increased over the three-year period. In particular, reference ET increased significantly during this April to June active growing period, increasing by 11-13 cm in both Spring Valley and White River Valley when 2005 was

contrasted with 2007. When the rainfall was compared between growing and non growing periods based on the ratio of rainfall to reference evapotranspiration, a dramatic decline during the non growing period was revealed, dropping from 79% to 40% to 11% over the three-year period in White River Valley.

The 2005 year provided a more optimum condition for growth and elevated ET compared to the other two years. Leaf xylem water potentials were less negative going into the spring growing period of 2005 compared to the more negative values recorded in 2006 and 2007. In 2007 at sites SV1, SNK1 and SNK2, tissue moisture contents of rabbitbrush and big sage declined rapidly from May to mid June, whereas greasewood was able to maintain tighter control of internal plant water status. In 2005, halophytes were able to maintain higher tissue moisture contents associated with more positive leaf xylem water potentials compared to glycophytes. Although both valleys showed similar trends, lower plant water status was measured in White River Valley.

Groundwater depth varied from site to site, with the shallowest average depth recorded at a shrub-grassland site in Spring Valley (SV2a, 1.1 m) and the deepest average depth recorded at a mixed shrubland site in White River Valley (WRV3, 12.6 m). In 2007, groundwater depths at the continuously monitored sites declined slowly over time, revealing well defined daily oscillations at a few sites. However, depth to groundwater was rejected as a significant variable in all multiple regression analyses conducted to assess ET, percent plant cover or plant water status.

Other than the irrigated pasture grassland site monitored in 2007, the highest daily ET values were recorded at sites in both Spring Valley and White River Valley during 2005. A tighter relationship existed between cumulative ET, $ET_{ref}$, and rainfall in 2005.

Although $ET_{ref}$ was highly correlated with ET at the irrigated grassland site in 2007 and during a few wetter periods at sites in 2005, poor correlations existed at most sites. Such a result clearly indicated that limitations exist with using a crop coefficient approach with grassland and shrubland sites under the limited water resources observed in these valleys.

ET and surface soil moisture were highly responsive to precipitation events, especially during the summer months. No indication of any deep movement of water was associated with rainfall events (as monitored using TDR sensors and soil sampling for salinity) during summer months. The results would suggest that the majority of rainfall during the summer months was lost through the process of soil evaporation. When soil moisture was available, a strong coupling between net radiation and evapotranspiration occurred. However at most shrubland sites, where soil moisture was a limitation, poor correlations existed between Rn and ET. At most sites a decoupling between ET and $ET_{ref}$ occurred by mid to late June suggesting that, if groundwater was being utilized, it was not adequate at most sites in most years to offset plant stress.

In 2005, ET data were collected over different time periods at the different sites in each valley as the single eddy covariance system was moved throughout each valley. In 2006, complete ET estimates were obtained for the full year, at two sites, one in Spring Valley (SV1) and one in White River Valley (WRV2), where the eddy covariance system was maintained for continuous monitoring. In 2007, ET was measured for the May 10 through September 5 time period at six sites (WRV2, SV1, SV2b, SV3, SNK1 and SNK2). Yearly ET estimates were generated by utilizing a gap filling approach based on assuming a winter baseline value of 0.35 mm per day and then establishing a linear fit to the May 10 through September 5 time period. Testing on actual data sets (site SV1 in

2006) and published USGS data for the same valleys (Moreo et al., 2007), indicated that such an approach would lead to an 8% underestimation at SV1 and an average 6.3% under estimation at the USGS mixed shrubland sites.

ET in 2006 at SV1 was estimated at 24 cm and at WRV2 the estimate was 42.4 cm. In 2007, four of the six sites had yearly ET estimates between 20 and 30 cm. However, at the SNK1 site with a dense greasewood canopy, the estimated ET was 49.9 cm, as compared to site SV2b (the irrigated pasture grassland site) where the estimated ET was 124.97 cm. Empirical relationships were developed between the daily ET and NDVI values at all sites in 2005, 2006 and 2007 (approach 1). Whereas total ET for the May 10 through September 5 time period and yearly ET estimates in 2006 and 2007 were correlated with average NDVI growing period values (approach 2).

It is important that the two approaches are clearly understood. The two approaches selected were based on different data sets being available in 2005 vs. 2006 and 2007. Because we moved a single EC tower throughout White River Valley and an additional single tower throughout Spring Valley in 2005, a complete yearly ET estimate was not collected at any site. A relationship was thus developed between daily ET and the corresponding NDVI at the particular site on days in which data were available. Such an approach was limited by how well the data reflected the entire growing period. Although satellite imagery was available every 16 days, restrictions based on cloud cover, rainfall and equipment failure limited the paired data sets. However, in 2006 and 2007 we increased the number of EC towers and were able to acquire larger data sets (either yearly ET or May 10-September 5 time period ET totals that could be gap filled to obtain yearly ET estimates). We selected the average NDVI during the growing period to correlate with both the May 10- September 5 ET total and the yearly estimates. Although greater uncertainty existed with the yearly totals (gap filling technique), basin wide ET estimates needed to be generated based on a yearly ET approach. How well the USGS data merged with our data using this approach was used as an assessment tool.

In 2005, regression equations in both Spring Valley and White River Valley were based on ET values that ranged from approximately 1 to 5 mm. Both regression equations were highly significant ($R^2$=0.79*** at Spring Valley and $R^2$=0.68** at White River Valley). In 2006 and 2007, regression equations were generated based on adding additional NDVI-ET data to the 2005 data set. The equations for 2006 and 2007 were heavily influenced by the 2005 data set associated with a significantly wetter winter period and less stressful spring growing period. All 2006 and 2007 NDVI-ET data were clustered in the lowest NDVI-ET region, which would have generated non significant correlations based solely on the drier 2006 and 2007 years. The highest NDVI-ET correlation was generated in Snake Valley ($R^2$=0.81***); however, the slope of the equation was significantly lower than in Spring Valley or White River Valley. When all sites, basins and years were merged, a lower $R^2$ value was obtained for the daily NDVI-ET equation, indicating that basins should not be merged when developing such relationships based on the integrated approach with daily NDVI-ET data as outlined in this study.

In 2007, NDVI-ET correlations were generated based on the total ET for the May 10 through September 5 growing period. A highly significant curvilinear correlation was obtained between the average growing period NDVI and ET ($R^2$=0.99). When ET estimates for the same time period were taken from the published USGS data set and merged with the UNLV data set for the same valley's (Moreo et al 2007), the data was best approximated by a linear fit ($R^2$=0.97***). However, when this approach was tested on the 2005 data sets obtained at the various sites, the 2006 and 2007 regression equations under predicted the 2005 ET value by an average of 44% at five of six sites (25% under estimation based on all six sites).

In 2007, 96% of the variation in total ET for the May 10 through September 5 time period (all sites except the irrigated pasture grassland site) could be accounted for based on the percent greasewood cover, suggesting a clear and distinct relationship between the presence of phreatophytes and plant community level ET.

Basin wide ET estimates were highest in 2005, decreasing in 2006 and 2007, reflecting the annual variability in ET that can occur in such large basins and the need to continue to make such assessments over longer periods of time. We report basin wide ET estimates based on the daily NDVI-ET approach and based on the average NDVI yearly ET approach. Based on the average NDVI approach, we predict similar ET values in 2005 for both Spring Valley and White River Valley (233,176 acre feet and 225,371 acre feet). Both valleys showed a similar decline in 2006 (Spring Valley with 185,584 acre feet and White River Valley with 181,440 acre feet) but a larger decline occurred in White River Valley in 2007 (Spring Valley with 164,496 acre feet and White River Valley with 152,496 acre feet). In Snake Valley in 2007, the basin wide ET estimate was significantly higher (239, 513 acre feet) than in Spring Valley or White River Valley. However, Snake Valley had more than 114,000 additional acres assigned to the phreatophytic zone compared to White River Valley. Based on the conditions outlined in this report, it is the belief of the investigators of this study that the approach taken accurately reflects ET estimates for these basins. With continued monitoring, more robust data sets can be obtained for NDVI and ET over greater spatial and temporal scales that will further refine these estimates.

## 1.0 INTRODUCTION

Situated in the Basin and Range Physiographic Province, the majority of Nevada's landscape is covered by a series of basins separated by mountain ranges. These basins are sparsely populated with relatively low amounts of acreage in agricultural production. Groundwater availability in these basins continues to be a subject of much investigation. The Southern Nevada Water Authority (SNWA) has filed for water rights in several of these northern basins for water transport to southern Nevada. The basins of interest for this study are Spring Valley, White River Valley and Snake Valley. These basins are all large basins, each estimated at more than one million acres in size (similar to the Las Vegas Valley). Although Basin and Range systems often restrict water flow from one basin to another, they are rarely hydrologically closed. As such, hydrologists must account for surface and subsurface flows. In arid environments, basin wide evapotranspiration (ET) typically dominates the discharge component of the water balance. In basins with limited water resources, vegetation often reveals a close link between precipitation and evapotranspiration (i.e., water loss through ET approaching precipitation rates). However, in basins that have a shallow and reliable groundwater source, ET and plant growth will not be constrained by limitations associated with low precipitation; here, ET rates may exceed precipitation rates because plants are able to access the groundwater (facultative and obligate phreatophytes).

Each basin is unique with regard to soil type, groundwater depth, water availability, climate, and plant communities. Generalizations often cannot be made, so detailed field studies are needed to understand these relationships. Plant density and ET rates will vary with growing conditions, leading to a spatio-temporal mosaic of discrete zones where ET processes are uniquely different. Although several species found in the dominant plant communities in Spring Valley, White River Valley and Snake Valley are known to be phreatophytes, the extent to which these species meet plant water requirements from groundwater sources is unknown. Nonetheless, the extent to which plants either remain closely coupled to, or become decoupled from, groundwater sources is clearly revealed during peak environmental demand periods.

In 2004, a study funded by the SNWA was initiated to estimate ET on a basin-wide scale in both Spring Valley and White River Valley. This study was later expanded to include Snake Valley. An energy balance approach, in combination with leaf level measurements, was selected to assess ET. Remote sensing analyses were used to scale ET estimates at the plant community level to the basin level. During the first year, the instrumentation was rotated between three sites in each valley. In 2006, the instrumentation was maintained at one site in each valley for continuous data collection. In 2007, four additional sites were added. The final site locations included one site in White River Valley, three sites in Spring Valley and two sites in Snake Valley. This report presents the methodology, data analysis, and scaling approaches taken to generate basin-wide ET estimates during this three year study.

## 2.0 MATERIALS AND METHODS

### 2.1 Site Selection

In July 2004, three monitoring sites in Spring Valley (SV1, SV2a, and SV3) and three sites in White River Valley (WRV1, WRV2, and WRV3) were selected. All sites in each basin were located on the valley floor with extensive fetch (measured in km) in all directions and at a distance far enough from nearby mountains to minimize the impact of topographically induced cold air movement. The sites were selected to be representative of plant communities that depend (or have the potential to depend) upon groundwater and are associated with phreatophytic zones in each valley (Table 1, Table 2, note that all Tables not embedded are found in the Appendix). Selection was based on achieving a range in percent canopy cover and percent cover of greasewood (*Sarcobatus vermiculatus*), a known phreatophyte. Species composition (Pictures 1-6, Appendix) and percent cover (Table 2) at each site were evaluated by counting species and estimating canopy surface area of each plant in a 25m by 25m plot (aerial validation was done in 2007 with a Tetracam Inc ADC multispectral camera mounted on a radio control helicopter). Site descriptions also included soil textural classification and an assessment of soil salinity (saturation extracts, Electrical Conductivity Bridge) and major cations and anions (atomic absorption spectrophotometer, ion chromatograph) in the soil, to site specific depths (Tables 3, 4 and 5).

In the fall of 2005, the active sites were reduced to one in Spring Valley (SV1) and one in White River Valley (WRV2), and in 2006, these two sites were maintained as continuous monitoring sites. In late 2006, SV3 was reactivated and a new site referred to as SV2b was added and instrumented in March 2007 (meeting the same site requirements as noted in 2004, Map 1, note that all Maps not embedded are found in the Appendix, Table 1). The SV2b site was an irrigated pasture grassland site. In 2006, two sites were selected in Snake Valley (SNK1 and SNK2, it should be noted that SNWA refers to these sites as SNV1 and SNV2) both dominated by greasewood plant communities. Site location coordinates, elevation and vegetation classification are reported in Table 1 for all sites maintained during the three-year study.

### 2.2 Reference Evapotranspiration

An automated weather station (Table 6) was initially located at the central location in Spring Valley (site SV2a) and White River Valley (site WRV 2). The weather stations were equipped with an anemometer to measure wind speed (3m height), and sensors to measure temperature, relative humidity, solar radiation, and rainfall (2 m height). Hourly averaged data were incorporated into the Penman-Monteith equation to predict reference evapotranspiration ($ET_{ref}$), where the Penman-Monteith equation is an empirically based equation that is used to assess environmental demand (the Penman-Monteith equation as opposed to the Penman equation includes surface and aerodynamic resistances). This approach has been recommended by the American Society of Civil Engineers (ASCE) Task Committee on Standardization of Reference Evapotranspiration (Allen et al. 2005). All weather stations used surface and aerodynamic resistance values for grass. Future research should determine specific resistance values for each site. The data were stored in a data logger and downloaded to a lap top computer every two to three weeks. In November 2005, the weather station and the eddy covariance tower in Spring Valley was relocated to the southern most site (site SV1), whereas in White River

Valley, the weather station remained at WRV2 and the eddy covariance tower was relocated also to WRV2, allowing a continuous stream of data to be collected at two separate sites. In 2007, additional weather stations were added, such that each eddy covariance tower location (six total sites in three basins) also had automated weather stations.

### 2.3 Ground Water Depth

In arid basins of the West, some plants (phreatophytes) have the ability to access groundwater to supplement water needs that are unmet by rainfall. Accessing groundwater can allow such plants the ability to decouple totally or partially from the environmental constraints of high evaporative demand and low soil moisture content. Knowing the depth to groundwater can help explain species composition and density. Monitoring groundwater depth, soil moisture and rainfall over time can provide greater insight into which water resources are being accessed by the plant communities. As such, depth to ground water was monitored in 2005 at WRV3 (using a non pumping irrigation well) and SV2a (using a piezometer). A Solinst water level probe was lowered into the well/piezometer during each site visit to measure depth to ground water. In May of 2006, three monitoring wells were installed to a depth of 22.9-24.4 m (75-80 feet), one each at WRV2, SV1 and SV3. In early spring of 2007, three additional wells were installed to a depth of 11.0-15.8 m (36-52 feet), one each at SV3, SNK1 and SNK2. A second well was installed at site SV3 because the first well was deemed artesian. All monitoring wells were equipped with HOBO ground water level sensor/data loggers. The HOBO water level transducer records absolute pressure, which is then converted to sensor depth below water level by the software (HOBOware Pro VS 2.3.1, 2007). However, the absolute pressure was compensated for changes in weather and altitude using barometric pressure readings, obtained from the barometric pressure sensor mounted on the nearby weather station. The barometric sensors recorded data hourly and were corrected for elevation relative to sea level. A linear regression equation was developed to convert the sensor depth to water level below land surface, using physical depth water level measurements as the dependent variable and sensor depth from the transducer as the independent variable.

### 2.4 Plant and Soil Measurements

To assess plant water status and the effective growing period, all major plant species were monitored during each site visit during 2005 for canopy temperature (infrared thermometer), leaf xylem water potential (pressure bomb), stomatal conductance (steady state porometer), chlorophyll content (chlorophyll index meter) and leaf area index (LAI wand). All measurements were taken only on plants with leaves. Digital photos were taken to document the growth status of all major plant species throughout the year. Tissue moisture content (fresh and dry weights) and tissue ion analysis (ion chromatograph / atomic absorption spectrophotometer) were assessed on a yearly basis (Table 7).

Volumetric soil water content was monitored with a theta probe in surface soil in the 0-5 cm depth interval and with Time Domain Reflectometry at 15, 45, 75 and 105 cm (not all sites had the 105 cm probes) during site visits. Soil volumetric water contents below the canopy and in the open space between plants were continuously monitored with soil water content sensors at the 5 cm depth associated with the EC systems. Soil surface temperatures were monitored with an infrared thermometer. In 2006, the same parameters were monitored but only at sites SV1 and WRV2. In 2007, plant and soil measurements were taken on a regular basis only at sites SV1, SNK1 and SNK2 associated with graduate student research projects.

### 2.5 Energy Balance Measurements

Energy from the sun drives water movement in the soil-plant-atmospheric continuum. How this energy is partitioned is critical in assessing evapotranspiration at the canopy level. To assess water fluxes moving up from the canopy, latent heat was monitored with eddy covariance flux systems (Table 8). The EC systems were set up in selected areas that met fetch requirements, where fetch is defined as distance measured in the upwind direction (Oke, 1987). All sites safely exceeded the first approximation of fetch as 100 times the sensor height. All sites also had minimal obstructions such as hills, stream beds or depressions in all directions as delineated by field surveys and satellite observations. The systems were initially setup at the central location in Spring Valley (SV2a) and White River Valley (WRV2), but during early spring 2005, the systems were rotated from one site to another approximately every three weeks. The rotations were undertaken so spatial and temporal variability in ET could be assessed, assuring a wider range in flux estimates for regression analysis. However, in 2006 only sites SV1 and WRV2 were selected to collect continuous data and in 2007 additional sites (SV2b, SV3, SNK1 and SNK2) were added for continuous measurements between May 10 and September 5 (SV1, SV2b, SV3, SNK1, SNK2 and WRV2). Energy, $H_2O$, and $CO_2$ fluxes were measured with the EC systems as described by Goulden et al. (1996). Briefly, fluxes of $H_2O$ and $CO_2$ were measured using a 3-D sonic anemometer (CSAT-3, Campbell Scientific Inc., Logan, UT, USA) and an open-path infrared gas analyzer (IRGA, Li-Cor 7500, Li-Cor Inc, Lincoln NE, USA). Both instantaneous and time-averaged data were collected and stored at the tower using a CR 5000 data logger with external memory cards (Campbell Scientific, Logan, UT, USA). Sensors on the eddy covariance tower were placed 1 m above the plant canopy, except for the irrigated pasture/grassland site, where sensors were placed 1.55 m above canopy (to minimize the impact of the enclosure which kept cattle out while still keeping sensors within the turbulent layer above the mixed grass stand). The total horizontal sensor separation for 2004 until the last data retrieval of 2006 was set at 0.18 m (0.10 m longitudinal and 0.15 m lateral) with no vertical sensor separation. Horizontal sensor separation beginning in 2007 was kept as close to zero as possible by placing the IRGA sensor head directly below the sonic anemometer sensor path (Ivaans 2007; Lee et al., 2004; Kristensen et al. 1997). Establishing a zero horizontal separation had the added effect of reducing flux loss and reliance on sensor separation correction routines (Kristensen et al. 1997, Wohlfahrt 2007, Ivans, 2007, Clement 2007 and Massman 2007). In 2007, vertical sensor separation was set at 0.26 m (+/-2 cm) for all sites with the exception of 0.19 m for the irrigated pasture/grassland site.

### 2.5.1 Data Sampling

Raw 10Hz binary data and online 30-minute computed fluxes with a correction for density effects (Webb et al. 1980) were collected from the Campbell data loggers every three weeks and were later post-processed using the EdiRe Program (Clement and Moncreif 1999).

### 2.5.2 Data Preparation

Despiking of raw 10Hz data for all sensors followed the methods of Højstrup (1993). Spike detection levels were set to six standard deviations or larger (Xu 2004, Clement 2007), with 30% spike consistency and spike widths of at least four 10hz intervals. An auto time delay adjustment aligned all fast response sensor time series data before final storage and computed online fluxes. The CSAT3 had a fixed two scan delay and the LI-7500 was programmed for a 300 millisecond delay (Campbell Scientific, Inc. 2008).

### 2.5.3 Conversions and Corrections

To achieve a zero mean vertical velocity from the sonic anemometer, coordinate rotations were applied to the raw 10Hz data following the planar fit method (Wilczaks et al. 2001). New coordinate coefficients $b_0$, $b_1$ and $b_2$ were calculated whenever the sonic anemometer was moved, which occurred twice per year to adjust for the change in prevailing wind patterns (early spring – south facing, early fall – north facing). Although wind direction was constantly changing, wind directional data verified this general north south shift. This seasonal change in the sensor locations was performed to minimize the impact of the tower and data loggers on the parcels of air striking the sensors.

Density corrections were applied for computed eddy fluxes of trace gases of $CO_2$ and $H_2O$ using the WPL equations (Webb et al. 1980). These equations assume horizontal homogeneous flow and have been shown to be correct for both steady and non-steady state turbulence (Leuning 2007). High frequency response corrections were calculated for flux attenuation via methods of Massman (2000) and Massman (2001). Other corrections were applied to adjust for high frequency attenuation caused by sonic anemometer line averaging (Kaimal et al. 1968; Kristensen and Fitjarrald 1984), line averaging for scalar sensors (Gurvich 1962; Silverman 1968), lateral sensor separation (Kristensen and Jensen 1979) and longitudinal sensor separation (Massman 2001). Low frequency response corrections were also incorporated for block averaging (Kaimal et al. 1989) and linear detrending (Kristensen 1998; Rannik and Vesala 1999). A sensor timing lag of 0.032 seconds for the IRGA was also included in the adjustments (Wohlfahrt 2007). All interdependent variables for these corrections were iterated twice in EdiRe. A cross wind correction of sonic temperature data (Liu et al. 2001) and a conversion for buoyancy flux using sonic temperature (Ts) data following Schotanus et al. (1983) was implemented in real time on the Campbell Scientific data logger.

### 2.5.4 Quality Control and Quality Assurance

Additional quality assurance/quality control (QA/QC) methods were applied following the methods of Foken and Wichura (1996). The Integral Turbulence Test - ITT - (Kaimal and Finnigan 1994; Arya 2001) was used to verify that all fluxes were within a limited range of acceptable flow. If ITT was higher than 30%, the corresponding fluxes were flagged for manual graphical inspection. Under nearly neutral conditions (no turbulence) the ITT test of the fast response parameters tested were high and failed the test. A well developed turbulence can be assumed if the ITT test result is <30%, otherwise the 30 minute block average is flagged for graphical inspection and removal. A Stationarity Test (ST) developed by Foken and Wichura (1996) was used to verify that all time series had less than 30% separation of covariances; otherwise these fluxes were flagged for manual graphical inspection. Data were flagged when the number of spikes replaced was greater than 1% of the 30-minute block (Vikers and Mahrt 1997). Sensor performance flags such as the automatic gain control (AGC, % blockage of viewing window > 70) were used to flag data for manual graphical inspection. These QA/QC tests removed between 1.7 and 10.3%of the 2005, 2006, and 2007 flux data, respectively (Table 9).

### 2.5.5 Gap Filling Strategies

Missing data associated with loss of power, sensor malfunction or inclement weather were gap filled. The method of substitution for flux data was based upon the number of missing values. When the number of missing values was small (< 4 hours), a polynomial fit was used to estimate values through interpolation. For longer gaps (> 4 hours), daily averages for the time period preceding and following the gap were used. This protocol was consistent with that identified by AMERIFLUX as a standard data filling scheme (Falge et al. 2001a and 2001b).

### 2.5.6 Eddy Covariance Flux

Eddy covariance fluxes were calculated as $F = p<w'C'>$, where F represents flux of sensible heat, latent heat or $CO_2$, p is air density, w is the vertical wind velocity, C is the $CO_2$ mixing ratio (or temperature or water vapor), $<>$ represents Reynolds averaging, and the primes represent deviations from the Reynolds average. Energy balance closure was estimated during the growing period by dividing latent heat (LE) plus sensible heat (H) by the available energy (net radiation ($R_n$) minus soil heat flux (G)); thus ((LE+H)/($R_n$-G) =1.00 (100%) for perfect energy balance closure.

### 2.5.7 ET Totals

Due to calibration activities and equipment failures in 2006 and the addition of new sites in early Spring of 2007, neither year reflected a full year of measurements, leading to the need for gap filling and/or developing an approach to project ET annual totals. ET annuals for 2005 using this approach were not possible due to monthly spot measurements made from rotating two towers across six sites. The procedure to predict 12-month totals in 2007 was to first apply a baseline value of 0.35 mm/day for the winter period from January 1-31 and November 2 through December 31. Secondly, a simple linear fit was developed and applied between February 1 to May 10 and from September 5 to November 1. The linear fit was anchored on both sides using a five day average of May 10-14 and September 1-5. For SV1 and WRV2 in 2006, gap filling was based on using the same winter baseline value and then using linear regression to gap fill missing data that occurred during random time intervals (for WRV2 missing data occurred between January 1 through February 2, May 17 through June 15 and September 30 to December 1, 2006).

In order to corroborate the above approach, this same approach was used on the ET data acquired for six sites in the same valleys published by the USGS (Moreo et. al, 2007). Although a 12 month data set existed for these USGS sites and the SV1 2006 data set (but not WRV2 because of missing data that required significant gap filling), the previous gap filling technique based solely on May 10-September 5 data (coinciding with the 2007 data sets) was applied and then compared the gap filling estimates with the actual 12 month totals. The analysis for this approach also assumed a baseline value of 0.35 mm/day for the winter months of November, December and January in 2006 (visual inspection), which happened to fall within the range generated from the six USGS sites ($0.29 \pm 0.20$), and applied the same linear regressions as stated above in the original approach. The error in the estimate was determined based on using this approach on existing 12-month data sets. Results of this analysis are presented in Section 3.7.6.

### 2.5.8 Scaling

The scaling of latent heat estimates (representative of an area measured in hundreds of meters, footprint of eddy covariance tower) to basin-scale estimates (measured in km) is a significant technical issue in the hydrologic sciences, and one that is the subject of considerable research. Some up-scaling methods involve the use of soil-vegetation-atmosphere transfer (SVAT) models, which are designed to simulate loss of water vapor and $CO_2$ from the soil/plant environment to the atmosphere. Other approaches look toward quantifying soil moisture, where the variability is used in larger mesoscale models (cf. Yu et al. 2001) for estimating surface runoff and infiltration. Both approaches are extremely complex and subject to compounded errors. Based on the data obtained during different time periods at different sites over a three year period it was decided that an empirical relationship between evapotranspiration (LE converted to mm evaporation) and vegetation indices (VI's) obtained from Landsat data would provide a reliable estimate of total ET, as was demonstrated by Nagler et al. (2005). ET-vegetation index correlations were assessed between six indices and ET measured at different time periods. Empirical relationships were also assessed with total growing period ET estimates. Merging of data sets from different years and basins was also evaluated. To further test the reliability of scaling eddy covariance data to larger transects (similar in scale to Landsat), a number of controlled studies evaluating sensible heat were conducted. Sensible heat was measured over 1.5 km transects using a boundary layer scintillometer (model BLS900, Scintec AG, Tubingen, Germany) at the three White River Valley eddy covariance tower sites. The scintillometer uses displaced–beam laser technology, providing extensive turbulence information, including the fluxes of heat and momentum. Scintillometer measurements of sensible heat flux were made over the same basin subunits containing the eddy covariance towers. In each case, efforts were made to ensure that the fetch of the eddy covariance tower was along the path length between the scintillometer source and detector, similar to the method described by Chebouni et al (1999). In this way, the techniques evaluated differences in sensible heat over the same footprint but over different scales. The scintillometer was used to estimate sensible heat (abiding to Monin-Obukov Similarity Theory - MOST) over longer transects containing a range in plant density and species composition. Additional estimates of net radiation and soil heat flux were made at locations along this transect, generally 25% and 75% of the path length of the scintillometer, enabling latent heat to be estimated by energy balance closure (LE = Rn-G-H). Correlations between sensible heat estimated via the scintillometer (1.5 km) and the eddy covariance tower (100's meters) provided validation to the scaling process ($R^2 = 0.94$, $p<0.001$).

### 2.6 Remote Sensing Materials and Methods

Remote sensing analysis for this phase of the project included both satellite image analysis as well as field spectra analysis. Landsat 5 Thematic Mapper (TM) images were purchased from the U.S. Geological Survey's National Center for Earth Resources and Observation Science (EROS) Data Center. The TM data are comprised of six visible and near infrared bands plus a thermal band. The data were georectified with terrain correction (the highest level of geometric correction) by EROS to a 25 m spatial resolution. Terrain correction included "*radiometric, geometric and precision correction, as well as the use of a digital elevation model (DEM) to correct parallax error due to local topographic relief*" (EROS, 2006). Scenes with little or no cloud cover were acquired for Landsat Path/Row 40/33, which contains all of the White River Valley and most of Spring Valley, and Landsat Path/Row 39/33, which contains all of Spring Valley and most of Snake Valley and approximately 2/3 or more of White River Valley. In 2007, Path/Row 39/32-33 multi-scenes (two adjacent scenes within the same Landsat path) were acquired to ensure complete coverage of Snake Valley. Landsat data acquisition occurred every 16 days for the same path. The dates of all Landsat images acquired for this project are listed in Table 10. The primary reason that multiple Landsat images were acquired over the growing season was to assess correlations between changes in green vegetation cover and changes in ET. While all of the images were examined in the development of an empirical relationship between ET and VI's, a few were excluded from the calculation of basin-wide ET because of significant cloud cover (as indicated in the table).

Ground-based spectral measurements were acquired with a field spectrometer during the June 20, 2006 Landsat overpass to enable atmospheric correction and normalization of all Landsat images. The FieldSpec Pro (Analytical Spectral Devices, Inc., Boulder, CO) has an effective spectral range of 350 to 2500 nm with 1 nm waveband increments, which encompasses all of the Landsat TM 5 bands except the thermal band. Field spectra were acquired for easily identified light through dark ground targets within White River Valley in accordance with recommendations from previous research (Smith and Milton 1999). The targets included an igneous outcrop (low/dark spectral area with low density of vegetation), gravel pit (medium spectral area with virtually no vegetation and uniform soil color/texture) and two white soil areas (high relatively flat spectral area with minimal vegetation cover). These sites were selected because: 1) they encompass at least four TM pixels; 2) have minimal vegetative cover; 3) are spectrally fairly uniform and cover a gradation of dark to light ground targets; 4) are easily accessible and located within or near the Kirch Wildlife Management Area (Map 2) which enabled data acquisition within a 2-hour time period; and 5) because this area was included within both the 40/33 and 39/33 Landsat images.

The image processing steps performed to empirically estimate ET included: 1) calibration, atmospheric correction and normalization; 2) calculating vegetation indices; 3) analysis and application of empirical relationships between VIs and eddy covariance-based ET for individual image dates; 4) defining areas that have clouds/cloud shadows, open water, high VI (ag and meadow with an NDVI > 0.2500) and any negative ET pixels; 5) summing ET values of all pixels within the phreatophyte zone of each valley excluding cloud/cloud shadows, open water and any negative ET pixels; 6) examining complete, cloud-free images to provide an ET estimate for missing and cloudy areas, which was then used to provide an adjusted ET for images that did not encompass an entire basin or had clouds; 7) calculating average VI images to develop an empirical relationship between the average VI and both growing season and annual ET, and summing pixel values within the resulting ET image phreatophyte areas . The ENvironment for Visualizing Images (ENVI) software package (ITT™ Visual Information Solutions, Boulder, CO) and SigmaStat (Systat Software Inc., CA) were used for all image and data analysis.

### 2.6.1 Calibration, Atmospheric Correction and Normalization

The first step in processing the images was a calibration to top-of-atmosphere radiance performed by the ENVI Landsat TM 5 calibration subroutine. Top-of-atmosphere radiance is the spectral radiance measured at the Landsat sensor's aperture in units of W $m^{-2}$ $sr^{-1}$ $\mu m^{-1}$, which is the radiance of the land surface plus any atmospheric affects between the land surface and the satellite. The equations, gains and offsets published by Chander and Markham (2003) were used in the ENVI calibration algorithm. The second step was atmospheric correction, image normalization and conversion to ground reflectance values. Several atmospheric correction techniques were previously examined to determine the best atmospheric correction technique(s) and the empirical line method was selected for this project (Devitt et al. 2006, Farrand et al. 1994 and Smith and Milton 1999). This approach was based on the regression of dark and light ground target spectra to image radiance values for the same areas. For each image date, the coordinates for the ground target locations were used to collect the image radiance values for the 2-4 corresponding pixels (Table 11). The field spectra (with 1 nm spectral resolution) were converted to Landsat TM bandwidths with the ENVI Spectral Library Resampling tool, which employs a Gaussian model based on the TM band wavelength and full-width at half maximum (FWHM) sensitivity of the Landsat TM detector for the conversion. The resulting converted field reflectance spectra and corresponding average Landsat TM pixel radiances were used to develop regression equations. The regression equations were entered one band at a time into the ENVI Band Math subroutine to atmospherically correct all pixels within the images to ground reflectance values. To ensure that differences in sun angle throughout the year did not impact further image analysis, all images were corrected with regression equations based on the field spectra from June 20, 2006, which provided simultaneous normalization of all images.

### 2.6.2 Calculation of Vegetation Indices

Numerous VI's have been demonstrated to be highly correlated with such plant characteristics as chlorophyll content, biomass, leaf area and general health and density of surface vegetation (Duncan et al. 1993; Gao et al. 2000, Gitelson et al. 2002; Nagler et al. 2004; and North 2002). A primary remote sensing effort for this study focused on the calculation of several VI's (appropriate for this semi-arid region) to regress with daily growing season and yearly eddy covariance data (latent heat (LE) converted to ET). Six VI's were computed for each atmospherically corrected and normalized image date. The indices included the following.

1) Normalized difference vegetation index: $NDVI = (R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED})$ (Rouse et al. 1974).

2) Simple ratio: $SR = R_{NIR} / R_{RED}$, (Tucker 1979).

3) Soil adjusted vegetation index version a: $SAVI\text{-}A = ((R_{NIR} - R_{RED}) / (R_{NIR} + R_{RED} + 0.25))\ 1.25$ (Huete 1988).

4) Modified soil adjusted vegetation index 2: $MSAVI\text{-}2 = 0.5 * (2 (R_{NIR} + 1) - \mathrm{sqrt}((2 (R_{NIR} + 1)^2 - 8(R_{NIR} - R_{RED})$, (Qi et al. 1994).

5) Green normalized difference vegetation index: $GNDVI = (R_{NIR} - R_{GREEN}) / (R_{NIR} + R_{GREEN})$ (an NDVI variant that is more sensitive to chlorophyll content; Moges et al. 2004).

6) Enhanced vegetation index: $EVI = 2.5 * (R_{NIR} - R_{RED}) / (R_{NIR} + (6 * R_{RED}) + (7.5 * R_{BLUE}) + 1.0)$, where R is the reflectance for the waveband indicated via subscript (Nagler et al. 2005).

Numerous VI's have been developed and published since the deployment of satellite remote sensing systems. Four of the VI's selected for this project are permutations of the red to near infrared waveband relationship; the NDVI is the most published VI. Because most red:near infrared VI's tend to saturate with high vegetation cover (>60% cover according to Gitelson et al. 2002), a green NDVI (GNDVI) and two soil adjusted VI's were also examined. The GNDVI uses a green band instead of the red band and the soil adjusted VI's incorporate coefficients to minimize the effect of soil on the VI. The EVI which includes a blue band and two coefficients in addition to the red and near infrared bands has been reported to have a strong empirical relationship with ET (Nagler et al. 2005) and hence was included in the examination of VI:ET empirical relationships for this study. The EVI is similar to some of the atmospherically insensitive VI's that have been reported such as the ARVI (Atmospherically Resistant VI), GARI

(Green Atmospherically Resistant Index) and GEMI (Global Environment Monitoring Index) (Gitelson et al. 2002; Leprieur et al. 2000). In preliminary studies, atmospherically insensitive indices did not yield meaningful VI ranges and hence most of the atmospherically insensitive Vis were eliminated from further consideration.

### 2.6.3 Analysis and Application of Empirical VI:ET Relationship

A survey grade GPS was used to acquire the coordinates for each eddy covariance (EC) tower location. These coordinates were then used to extract three sets of VI values for each tower site (Map3) from the image data. The three sets of VI values included the single pixel value for the EC tower location, the average for a 5 by 5 pixel square centered on the EC tower and the average for a 5 by 5 pixel square with the EC tower location centered along the northern perimeter of the square (roughly the expected EC tower footprint based on growing season wind patterns; a footprint analysis was not performed). These three sets of numbers for all six VI's were regressed against the EC calculated ET data to develop an empirical relationship that would provide an equation to calculate individual pixel ET values from the VI pixel values.

The results from the preliminary regression analysis revealed that the NDVI, SR and EVI had very similar $R^2$ values (see section 3.8.2 for more details). Because the NDVI has a more extensive publication record, a decision was made to use this index for the calculation of ET within the valley phreatophyte areas. Individual regression equations were developed for each valley and applied appropriately to each NDVI image, resulting in unique ET images for each valley and date. Within Spring Valley, theYelland playa (as mapped by the Southern Nevada Water Authority), was excluded because it was spectrally difficult to differentiate distinct boundaries with any certainty among dry playa, moist playa and playa with a thin layer of standing water. Final regression equations were calculated and then used in combination with the NDVI images to produce an ET image for each valley (see Section 3.8.2).

### 2.6.4 Identification of Clouds, Cloud Shadows and Open Water Bodies

Clouds, cloud shadows, and open water pixels were identified for each image date by a series of band thresholds using the ENVI Region-of-Interest (ROI) tool set. These areas were identified to ensure that cloud, shadow and open water pixels were excluded from the calculation of total phreatophyte area ET as well as providing an assessment of the acres impacted by cloud cover. Clouds were best identified by setting a threshold of greater than approximately 0.35 for all pixels in the atmospherically corrected blue band (Landsat TM band 1). The specific threshold value was determined via an iterative process for each image where a color composite image (bands 4, 3 and 1 as red, green and blue) was carefully examined to ensure that the maximum amount of cloud pixels were identified with either none or a very minimal amount of bright soil pixels included with the cloud pixels. In one instance, subsetting was required to ensure that bright soil areas in southern White River Valley were not included in the resulting cloud ROI. Cloud shadows, particularly cumulus cloud shadows, were easily identified by thresholding all negative ET band pixels. However, in a few cases the presence of thin cirrus clouds made it difficult to spectrally distinguish cloud shadow from surface pixels, so these images were excluded from basin-wide ET estimations. Specifically, the 5/3/06 image was excluded for White River Valley, the 5/3/06, 5/19/06 and 8/3/07 images were excluded for Spring Valley and the 8/3/07 image was excluded for Snake Valley (as noted in Table 10). Open water bodies were determined either using a negative VI band threshold (<-0.000001) or a negative ET band threshold (< -1.00000). For estimation of water body acreage, cloud shadows and water bodies that were identified by thresholding negative ET pixels were separated by subsetting the water body areas. In a few cases, very high NDVI values were calculated for portions of the Kirch Wildlife Management Area lakes in White River Valley. From visual observations during field trips, it was highly probable that these high NDVI pixels were the result of aquatic vegetation, e.g., dense, healthy vegetation with a water substrate instead of a soil substrate. In these cases, the high NDVI lake areas were merged with the negative pixel lake areas to more accurately define all open water pixels. This is a reasonable approach as ET from vegetation with a water substrate would be most similar to ET from an open water body than to ET from dense vegetation with a soil substrate.

Map 4 provides an example of an image with cloud/cloud shadow regions demarcated with different color ROI's as well as an ROI defining a portion of the basin that was off the edge of the Landsat image. Every attempt was made to account for the total acreage within each basin's phreatophyte area to provide the best possible estimate of total ET.

### 2.6.5 Summing of ET Pixel Values within the Basin Phreatophyte Areas

The next step in the remote sensing data analysis was to sum the pixel ET values for all defined ROIs. The defined ROIs included the entire phreatophyte polygon, a negative ET ROI (which generally included water and cloud shadow as well as very low

NDVI pixels that yielded very small negative ET values as a result of the regression equation negative intercept) and an agriculture/meadow ROI that was defined to provide a means to separately assess high NDVI areas if desired. To perform the pixel summing, an IDL (Interactive Data Language) macro that operates within the ENVI ROI subroutines was prepared by an ITT™ Visual Information Solutions technician specifically for this project. To function within ENVI, the file "sum_roi_data.pro" must be manually placed in the ENVI program directory entitled "C:\RSI\IDL64\products\envi43\save_add". Additionally, only one ROI can be opened within the ROI Tool window when summing pixel values. The ITT Visual Information Solutions technician stated that further effort to make the macro more user-friendly would not occur until other users requested this macro tool.

To reduce processing time the method used to sum pixel ET values was carried out using the following equation:

$$ET_{ta} = ET_{all} - ET_C - ET_{neg},$$

where $ET_{ta}$ = total actual ET within the phreatophyte area,

$ET_{all}$ = the sum of ET values calculated for every pixel within the phreatophyte polygon, $ET_C$ is the sum of ET pixel values that were calculated for areas covered by clouds, and

$ET_{neg}$ = any negative ET pixels including water, cloud shadow and some very small negative pixels associated with very low NDVI values.

If separate ROIs had been generated first to define the water areas, clouds, etc., these ROIs were merged prior to summing to ensure that pixels were not counted/summed twice. The values for this equation were assessed by summing all pixels within the phreatophyte polygon and then subtracting the sum of the ET values calculated for pixels falling within each ROI category. A ROI was produced for all agricultural and meadow (ag/meadow) areas, so that the acreage and ET for these areas could be assessed and provide a means to employ multiple approaches for assessing ET from these areas (data not reported). All pixels within an NDVI image with a value greater than 0.2500 (e.g., above the highest shrubland NDVI value calculated for any of the eddy covariance tower sites, with the exception of the irrigated pasture grassland site) were assigned to an ag/meadow ROI for each image. The total number of acres for this ROI (as well as all other ROI's) and the sum of the ROI pixel ET values were recorded.

### 2.6.6 Calculating an Adjusted Total ET

As depicted in Map 4, areas that were outside of the Landsat scene boundary and areas with cloud cover could not be included in the summing of the total phreatophyte area ET for some image dates. Thus, a method was developed to calculate an "adjusted" total phreatophyte area ET value for each date. The method was based on the percent of ET that would likely have come from the area that was unavailable for ET summing. The ET for these areas from other image dates that were cloud free and contained the entire phreatophyte area was examined. To do this, the ROI's that had been defined for cloud, cloud shadow and outside-the-scene areas were placed over the cloud-free, complete ET images. The sum of the ET for these ROI's was divided by the total ET for that image date to calculate the percent ET occurring from the "not-available" or cloud areas for the bad image date. This percentage value, or an average percent if multiple cloud-free, complete images were assessed, was then used to calculate an adjusted total ET for the particular image date where portions of the phreatophyte area were "not available" for summing. The following equation was used to calculate the adjusted total ET:

$$ET_{tadj} = ET_{ta\text{-}na} / (1 - \%ET_{na}),$$

where $ET_{tadj}$ = total adjusted ET,

$ET_{ta\text{-}na}$ = ET for the total phreatophyte area excluding any missing, cloud covered or cloud shadow pixels and

$\%ET_{na}$ = the percentage of ET coming from the "not available" area for other image dates when the phreatophyte area was complete and there were no clouds.

### 2.6.7 Calculating an Average NDVI Image

Average NDVI images were prepared for 2006 and 2007 to provide an alternate means of calculating total growing period and annual ET for the White River Valley and Spring Valley and 2007 Snake Valley phreatophyte areas. To calculate an average NDVI image, each pixel within the phreatophyte areas had to be present (not off the edge of the scene) and not cloud covered or cloud shadowed. For image dates where phreatophyte areas were missing or clouds were present, the corresponding pixels had to be replaced with an appropriate value that would result in an accurate as possible average image. A subset of complete (e.g., all of phreatophyte polygon was within the image); cloud-free images from across the growing period of each year were used to calculate a preliminary average NDVI image. The ROI's that had been previously defined for missing or cloud covered areas were then used, via the ENVI masking subroutine, to create images that contained only the preliminary average pixel values for the cloud, shadow or missing ROI's. The same ROI's were also used to mask and convert all pixels within the "bad" image where clouds or missing areas were present to a zero value. The resulting masked average image and the image minus clouds or missing areas were then added together. All merged images as well as complete, cloud-free images from the growing period of each year were then averaged using the ENVI layer stacking and band math subroutines. The layer stacking subroutine allows the user to transform georeferenced images that may have different pixel resolutions, extents or projections into one multiband image file. After layer stacking, the band math subroutine was used to add all image bands together and then divide by the number of bands. The average NDVI images were converted to yearly ET images using an empirical regression equation that was determined in the same manner as the individual ET images. The total yearly ET was then summed from the resulting yearly ET images in the same manner as the individual image dates.

**2.7 Technique Used to Scale up to Basin Wide Yearly ET Estimates**

Yearly basin wide ET estimates for each valley were made based on two different approaches.

Approach 1: In the first approach, empirical relationships were developed between daily NDVI Landsat values (based on center pixel) and daily ET for the pixel containing the EC system (here after referred to as the daily NDVI approach). All NDVI pixel values were then converted to ET for each Landsat data set. ET totals for the Landsat dates were then plotted as a function of time. Basin wide estimates were obtained by quantifying the area under the daily basin wide ET NDVI response curves. Areas under the response curves were estimated using SigmaPlot software (version 9.0, 2004). In 2005, NDVI-ET relationships were generated individually for Spring Valley and White River Valley. In 2006 and 2007, the basin wide empirical relationships were based on the merger of the 2005, 2006 and 2007 data. In addition, the validity of applying the merged ET relationship to the 2005 data set was tested. ET for agricultural land and grasslands (NDVI> 0.25) were not incorporated directly into this approach.

Approach 2: In the second approach (2006 and 2007), basin estimates were generated based on data sets collected from May 10 – September 5 time periods which were then used to estimate 12 month totals (in the case of 2006, 12 month totals were available), using the technique outlined in the earlier ET section. Empirical relationships were developed between the ET totals for all sites (based on the center pixel) and the average NDVI for the entire growing period at each site (here after referred to as the average NDVI approach). Pixels with average NDVI values (calculated separately for each year) for the growing period were converted to yearly ET values and summed for a total basin wide ET estimate based on the empirical relationship between average NDVI and yearly ET totals (data from this study and the USGS study, Moreo et al. 2007). ET from agricultural land and grasslands were incorporated directly into this approach.

### 2.8 Data Analysis

Data were analyzed using descriptive analyses, analysis of variance, and/or linear and multiple regression analyses. Multiple regressions were performed in a backward stepwise manner, with deletion of terms occurring when p values for the t test exceeded 0.05. To eliminate the possibility of co-correlation, parameters were included only if variance inflation factors (VIF) were less than three and the sum total was less than 10. If the accepted VIF was exceeded, parameters were eliminated and regression analyses were rerun. All statistical analyses were performed using SigmaStat Software (Systat Software Inc., Point Richmond, CA).

## 3.0 RESULTS

### 3.1 Reference Evapotranspiration ($ET_{ref}$)

$ET_{ref}$ followed a sinusoidal pattern in all basins, peaking during the month of July (Figure 1, note that all Figures not embedded are found in the Appendix). In Spring Valley and White River Valley, $ET_{ref}$ ranged from values greater than 9 mm to values less than 0.10 mm per day. The highest $ET_{ref}$ values were estimated in Snake Valley during 2007. At SNK1 the maximum daily $ET_{ref}$ value was 9.9 mm and at SNK2, the maximum daily $ET_{ref}$ value was 10.5 mm. Table 12 reports the annual $ET_{ref}$, rainfall and ET totals for each basin based on continuous data collected at SV1 and WRV2, while Table 13 reports the exact same parameters for the May 10 – September 5, 2007 monitoring period. Results show that cumulative $ET_{ref}$ totals in White River Valley and Spring Valley increased each year from 2005 to 2007 (Figure 2a, 2b, note that 2007 was not a complete monitoring year).

**Table 13: $ET_{ref}$, ET, Rain and ET-Rain for the period 5/10-9/5 2006 and 2007 along with projected yearly ET totals in 2007**

| | $ET_{ref}$ (cm) | ET (cm) | Rain (cm) | ET-Rain (cm) | ET (year-cm) |
|---|---|---|---|---|---|
| SV1-2006 | 71.43 | 11.18 | 4.85 | 6.33 | 24.04* |
| WRV2-2006 | 76.60 | 18.60 | 7.39 | 11.21 | 42.43* |
| SV1-2007 | 79.53 | 9.04 | 3.48 | 5.56 | 20.24 |
| SV2b-2007 | 73.60 | 71.56 | 3.79 | 67.77 | 124.97 |
| SV3-2007 | 77.85 | 14.52 | 3.10 | 11.42 | 27.24 |
| WRV2-2007 | 83.53 | 10.60 | 6.13 | 4.47 | 27.48 |
| SNK1-2007 | 84.82 | 30.57 | 3.66 | 26.91 | 49.88 |
| SNK2-2007 | 85.62 | 9.94 | 1.19 | 8.75 | 21.37 |

* Actual ET Totals - not projected

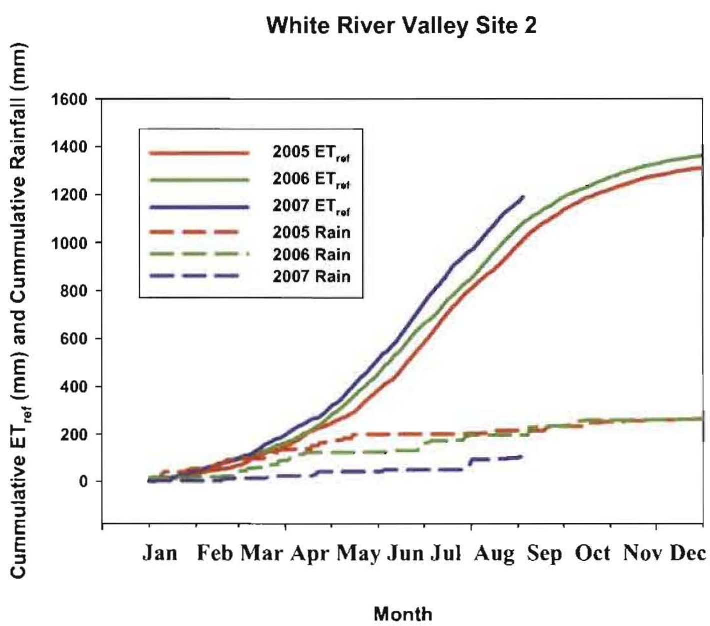


**Figure 2a. Cumulative reference evapotranspiration and rainfall for WRV2 in 2005, 2006 and 2007.**

Although a complete data set for 2007 was not obtained, when $ET_{ref}$ for all six sites were plotted on the same graph (Figure 3), a general trend existed in which $ET_{ref}$ at all sites increased or decreased in a similar fashion, suggesting that the plant communities in these basins were all growing under a similar environmental demand. However, the demand clearly increased each year during the most active growing period (April-June) in both Spring Valley and White River Valley (Figure 4a, 4b).

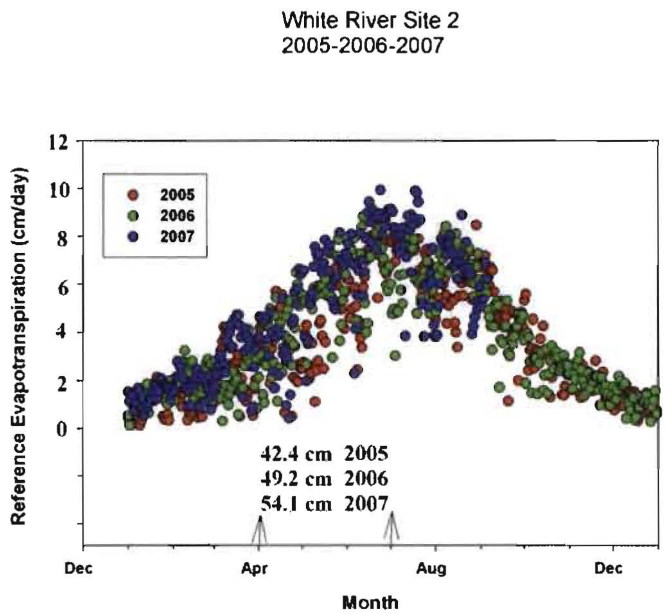


**Figure 4a. Reference evapotranspiration for WRV2 in 2005, 2006 and 2007. Reference evapotranspiration totals are included for the April, May and June period in each year.**

Spring Valley Sites 1 and 2
2005-2006-2007

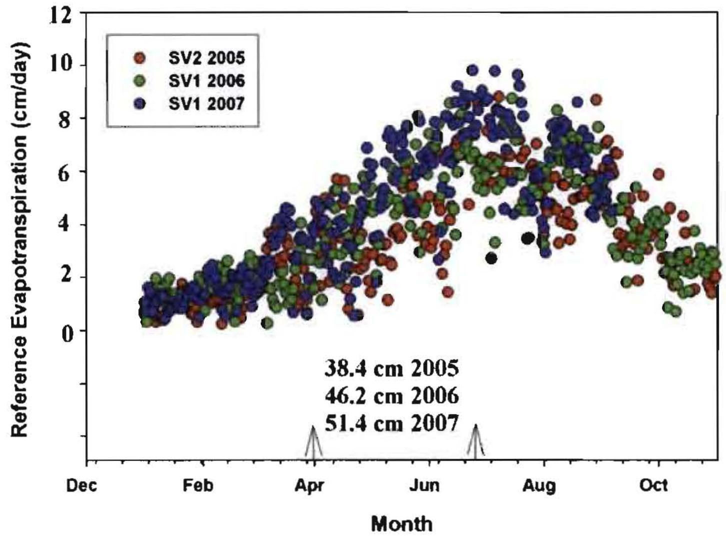


**Figure 4b. Reference evapotranspiration for SV2/SV1 in 2005, 2006 and 2007. Reference evapotranspiration totals are included for the April, May and June period in each year.**

In White River Valley, $ET_{ref}$ increased 11.7 cm during this 3-month period and in Spring Valley it increased 13.0 cm between the 2005 year and the 2007 year. Highly significant linear correlations existed between $ET_{ref}$ estimates generated at the six sites during 2007 (Figure 5a, 5b). Slopes for the regression equations ranged from 0.9 to 1.0 for all site comparisons, suggesting that $ET_{ref}$ data from one site could be used at another site with only a small predictable adjustment. However, only in the case of the irrigated pasture grassland site (SV2b) did the surface and aerodynamic resistances reflect the true vegetation cover. Changes in species composition and density will affect the selection of resistance values. However, the same standard approach was used at all sites, such that $ET_{ref}$ was based only on changes in measured meteorological parameters, thus a consistent approach was used in assessing environmental demand.

## 3.2 Rainfall

Rainfall totals for each year are reported in Table 12, which indicated similar values for 2005 and 2006 in White River Valley but a significantly lower value in Spring Valley in 2006. Although 2007 data were incomplete, rainfall totals from January 1 through September 5 were significantly lower in 2007 when compared to the other years. Rainfall totals for the 2007 monitoring period are reported in Table 13. Totals for this spring/summer period were low at all sites, varying from 1.19 cm at SNK2 to 6.13 cm at WRV2. Total winter rainfall (i.e., from November 1 through March 31) revealed a decreasing trend over the three-year period (Table 14). In White River Valley, the winter rainfall total decreased 14.5 cm, and in Spring Valley, rainfall decreased 10.0 cm when data from 2005 was compared to 2007 (Figures 6 and 7). It should be noted that the totals in Spring Valley are somewhat complicated by the fact that the station was moved to a new location in 2005.

When rainfall and soil moisture were plotted over time at each site in 2007 (Figure 8a, 8b), soil moisture at the 5-cm depth was highly responsive to precipitation events, with soil moisture rising as much as ten fold at some sites. However, at the deeper depths, TDR probes did not respond to precipitation events and in fact changed very little over time, suggesting that deep percolation (May 10-September 5 time period) was either very low or not occurring and that rainfall was either being taken up by shallow roots or was being lost through the process of evaporation. In all basins during the early spring period, annual plants were active and near-surface shrub roots were probably also active. However, by early summer, soil surface temperatures in excess of 70°C were measured, which would indicate that the near surface soil could not support root activity. Rainfall totals for the growing and non growing periods are reported in Figure 9. A clear decline in the percentage of rainfall occurring during the non-growing period compared to the growing period occurred in both valleys (2005, 2006, 2007), with White River Valley decreasing from 60% to 22% (Figure 9). The effectiveness of precipitation was evaluated by assessing the ratio of rainfall to $ET_{ref}$ for these same time periods (Figure 10). Clearly higher rainfall associated with lower $ET_{ref}$ would have a higher probability of recharging the active root zones. In the case of monitoring sites in White River Valley, the ratio declined from 79% to 40% to 11% when the 2005, 2006 and 2007 data sets were compared. In Spring Valley the ratio also declined from 68% to 28% to 16% during this same three-year period. Such a response would indicate that the plant communities in each successive year would enter the growing period with less available soil moisture. The results show that the 2005 year was not only wetter but the timing of the precipitation was ideal for initiating new spring growth and supporting higher evapotranspiration rates.

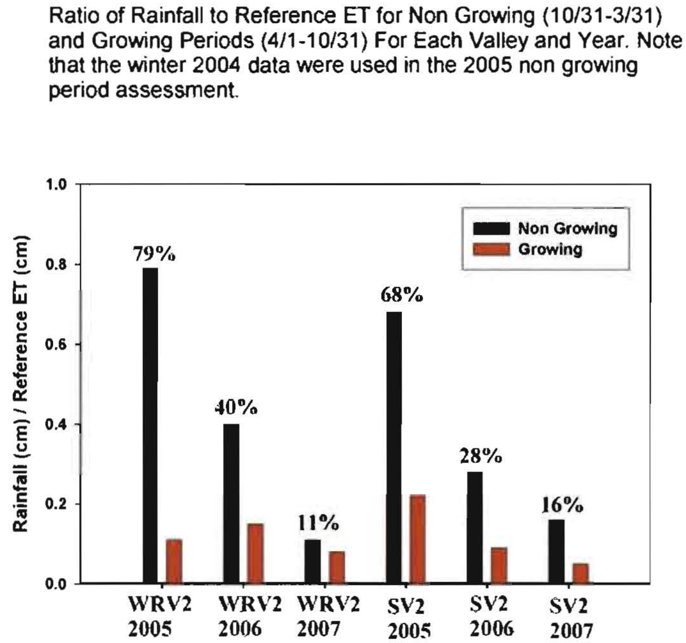


**Figure 10. Ratio of rainfall to reference evapotranspiration during the growing and non growing periods at WRV2, and SV2/SV1 during 2005, 2006 and 2007.**

Rainfall at each site was cross-correlated with all other sites in 2007 (Figure 11a, 11b). Rainfall (amount of each rainfall event) at one site could not account for more than 41% of the variation in rainfall (amount of each rainfall event) at another site, indicating that although rainfall totals were low, spatial variability was significant. Because many of these plant communities are highly dependent on rainfall to meet plant water requirements, a greater effort in the future should be made to assess variation in rainfall on both spatial and temporal scales.

### 3.3 Groundwater

Depth to groundwater was physically measured at SV2a and WRV3 during the three-year period on a three to four week basis (Figure 12). Depth to water at SV2a was typically within 1.2 m (4 feet) of the surface and on several occasions was within 0.31 m

(1 foot) of the surface (shallowest depths of all monitoring sites). Depth to groundwater at site WRV3 (the deepest of all monitoring sites) declined from a depth of 8.8 m (29 feet) in 2005 to a depth of about 13.7 m (45 feet) in 2006, but changed very little over the last 400 days of monitoring. Depths to groundwater for all sites are reported in Table 15. All of the 2007 ET monitoring sites which possessed monitoring wells (i.e., site SV2b did not have a well) revealed water table depths that varied little over the nine-month period, with the majority of these sites revealing water table depths between 4.5 and 5.8 m (15 and 19 feet). The one exception occurred at site SNK2, where average groundwater depth was just over 9.1 m (30 feet). Continuous depth readings for the five sites monitored in 2007 are plotted in Figure 13, revealing a gentle linear decline over time. All sites had a highly linear correlation between day of year and the depth to groundwater ($R^2 = 0.92^{***}$ to $0.98^{***}$). Although depth to groundwater appeared to change very little, daily oscillations were observed at several sites (Figure 14a, 14b). When individual weeks were evaluated more closely over the summer period at site SNK1, a decline of about 6 cm (0.2 feet) occurred each month with daily oscillations of about +/- 3 cm (0.1 feet) occurring by late August. Such daily oscillations suggest a direct coupling between groundwater extraction and plant community level ET. At SV1, the groundwater depth also declined, but only on the order of 3 cm (0.1 feet) per month, with minor daily oscillations. Although it is believed that groundwater extraction was also occurring at SV1, the sediments at SV1 were higher in sand content (Table 3), and probably possessed a higher transmissivity, which enabled recovery to occur more rapidly masking daily groundwater extraction.

In 2007, depth to groundwater at all sites within the same basin were highly correlated (Figure 15a, 15b). These correlations were typically curvilinear in nature, depicting slightly different rates of decline at each site. In the case of the comparison between SV1 and SV3, the decline was greater at SV3 than SV1 in May, but by late August little change occurred at SV3. In the case of the two Snake Valley sites, the decline was greater at the SNK1 site than at the SNK2 site in May, but by early summer the declines were approximately equal. The total decline was approximately 15 cm (0.5 feet) at both sites; however, the percent cover at SNK2 was approximately five times lower than that observed at SNK1. Inferring groundwater extraction by plants based on these groundwater changes will require information not only on daily changes in groundwater depth and ET rates, but also information on the rates that specific water-bearing sediments will release water. It was interesting to note that at site SNK1 (Figure 16), the greatest daily oscillations occurred late in the summer associated with declining ET rates, suggesting that the response was most likely being magnified because of a slower recharge rate and not an increased extraction rate.

At the two sites with the longest continuous daily monitoring (sites WRV2 and SV1), groundwater depths were shallowest in late May, reflecting the greater groundwater recharge to extraction rate during the winter and early spring period (Figure 17a, 17b). Once $ET_{ref}$ began to increase and ET rates subsequently rose, groundwater depths began to decline, typically just prior to the maximum $ET_{ref}$ period in July.

Groundwater quality was assessed at various times over the course of the study and is reported in Table 16. The salinity measured in the ground water at all sites was below 1.0 $dSm^{-1}$. At most sites, groundwater chemistry was dominated by calcium and bicarbonate; however, at a few sites both magnesium and sodium were also significant cations. The pH typically ranged from 7.5 to 8.1.

### 3.4 Isotopic Signature in Groundwater and Soil Solution

Isotopic signatures in water can be used to distinguish which sources of water plant communities are utilizing. Soil water was sampled from the 0-30 cm depth and compared it to groundwater samples and transpirational capture and stem extraction taken at the same time (Figure 18a, 18b). The clear separation in the isotopic signature between these two water sources indicated that this technique can be used along with xylem isotopic analysis to assess groundwater dependency. This technique is currently underway.

Natural isotopes of oxygen and hydrogen ($^{18}O$ and $^{2}H$) were analyzed in groundwater samples taken from monitoring wells and from soil solution cryogenically trapped from near surface soil samples in 2007. Deviations in per thousand parts (‰) of both $^{18}O$ and $^{2}H$ in groundwater samples are plotted in Figure 19 along with the Meteoric Water Line. A parallel shift from the Meteoric Water Line is associated with geographic dependencies (elevation, latitude, groundwater depth/evaporation). Comparing the isotopic signatures of samples collected in all of the monitoring wells indicated that the most enriched isotopic signature (less negative) occurred at SV2a which had the shallowest groundwater and would have been under the greatest influence of surface evaporation. Although $^{18}O$ and $^{2}H$ was highly correlated ($R^2$=0.81***), the isotopic signature at site WRV3 deviated significantly from this regression line. Site WRV3 had the deepest measured groundwater, and soil moisture data at this site would suggest that little precipitation at the surface would reach the groundwater under current climatic conditions. The isotopic signature from samples collected at the old SV3 site (abandoned) was the most negative, associated with artesian conditions and would suggest a moisture source different from the other sites, perhaps a much older water source formed under different climatic conditions.

### 3.5 Soil

Soil samples were taken in the near surface 0-2 m (0-6.6 feet) depth with a hand auger and at deeper depths associated with the monitoring well installation. Textural analysis and classification are reported in Tables 3, 4, and 5. Soil texture was highly variable, with samples collected from site SV1 containing 70 to 90% sand in the 0-140 cm (0-4.6 feet) depth compared to samples collected from site SV2a, which contained 45 to 63% clay. Soil salinity, measured with the saturation extraction technique, varied significantly not only from site to site, but also with depth. Well defined peaks in soil salinity were observed at sites WRV2, SV2a, SNK1, and SNK2 (Figure 20a, 20b), with maximum ECe values typically found at a depth near 2 m (6.6 feet), suggesting that deep leaching associated with precipitation exceeding evapotranspiration had not occurred in recent times at these sites. Soil salinity was lower at the Spring Valley sites, with the exception of high near surface soil salinity values at site SV2a associated with capillary rise from the shallow groundwater system. All sites had ECe values greater than 4.0 $dSm^{-1}$ at some depth indicating a saline soil classification. Higher soil salinity values at sites WRV2, SNK1, and SNK2 suggest a more suitable growing condition for halophytes. Low salinity levels in association with high sand content at site SV1 appeared to limit greasewood establishment, although greasewood plants growing at this location were assessed to be very healthy.

Gravimetric water contents obtained at a few sites revealed increasing water content in the capillary region above the water tables. However, decreased water contents at or above the water table were also observed, often associated with gravel layers. These lower water contents might be an artifact associated with macro pore drainage during the well drilling process. Such macro pores are, however, ideal for phreatophytic root development in the capillary region.

### 3.6 Plant Response

### 3.6.1 Tissue Ion Concentrations

Tissue samples (leaves from the upper- and outer-most part of the canopy exposed to direct sunlight) were taken during the growing season to assess ion accumulation. Tissue analysis was conducted for $Na^{+1}$, $K^{+1}$ $Ca^{+2}$, $Mg^{+2}$, $Cl^{-1}$ and $SO_4^{-2}$ (Table 7). A consistent pattern of elevated tissue ion concentrations was observed in the two halophytes (greasewood and shadscale) compared to those measured in the two glycophytes (rabbitbrush and big sage). Average tissue $Na^{+1}$ concentration in the leaves of greasewood approached 8% in Snake Valley and White River Valley compared to 6% in Spring Valley (Figure 21a, 21b). An even greater difference in $Na^{+1}$ concentration was observed for shadscale sampled in these same basins (8% vs. 3%). However, the glycophytes consistently accumulated $Na^{+1}$at concentrations less than 0.3% or as much as 25 times lower than that observed in the halophytes. Tissue $K^{+1}$ concentrations were also elevated in the halophytes, with significantly higher concentrations in the plants sampled from Snake Valley. Although the $K^{+1}$ concentration in the glycophytes were lower than in the halophytes (Figure 22a, 22b), measured $K^{+1}$ concentrations were greater than 1.5% in all of the glycophytes. Potassium is an essential element critical in long distance transport of anions within plants and in the regulation of stomata. Sodium is not known to be an essential element for higher plants; however it can be effectively used by halophytes in osmoregulation to maintain favorable plant water status. It has been documented in many plant species that $Na^{+1}$ can interfere with $K^{+1}$ uptake and utilization (Devitt 1981, 1984a, 1984b). Glycophytes in particular attempt to regulate and maintain favorable $Na^{+1}/K^{+1}$ ratios. In this study $Na^{+1}/K^{+1}$ ratios were found to be higher for the halophytes than the glycophytes, but the separation also occurred based on a valley comparison, with higher ratios in White River Valley and Snake Valley compared to Spring Valley (Figure 23a, 23b).

Plants must balance cation uptake with anion uptake or anionic compounds must be synthesized to maintain proper ion balance. Chloride can be extremely damaging to woody plants, especially glycophytes. Chloride concentrations were significantly lower in the glycophytes than in the halophytes (Figure 24a, Figure 24b, Table 7), with concentrations greater than 8% measured in shadscale in both Snake Valley and White River Valley. However, significantly lower concentrations (~3%) were measured in greasewood, suggesting that ion balance must be occurring via internal synthesis of anionic organic compounds.

A curvilinear correlation between elevated soil salinity in the 0-2 m (0-6.6 feet) depth and elevated leaf tissue $Na^{+1}$ concentration was observed for greasewood (Figure 25). Distribution of halophytes should be linked to elevated soil salinity, suggesting that salinity mapping may be a useful approach for delineating halophyte distribution. However, care would need to be taken to account for the ability of some halophytes to operate in a facultative halophytic mode.

### 3.6.2 Plant Water Status

Mid day leaf xylem water potential (LXWP, MPa), tissue moisture content and canopy to air temperature differences (Tc-Ta, °C) were assessed on a monthly basis during the growing season in both Spring Valley and White River Valley during 2005 and 2006. In 2007, plant water status was only assessed at sites SV1, SNK1 and SNK2. Greasewood LXWP declined during the growing season in each year in all three valleys (Figure 26a, 26b, average values with standard error bars).

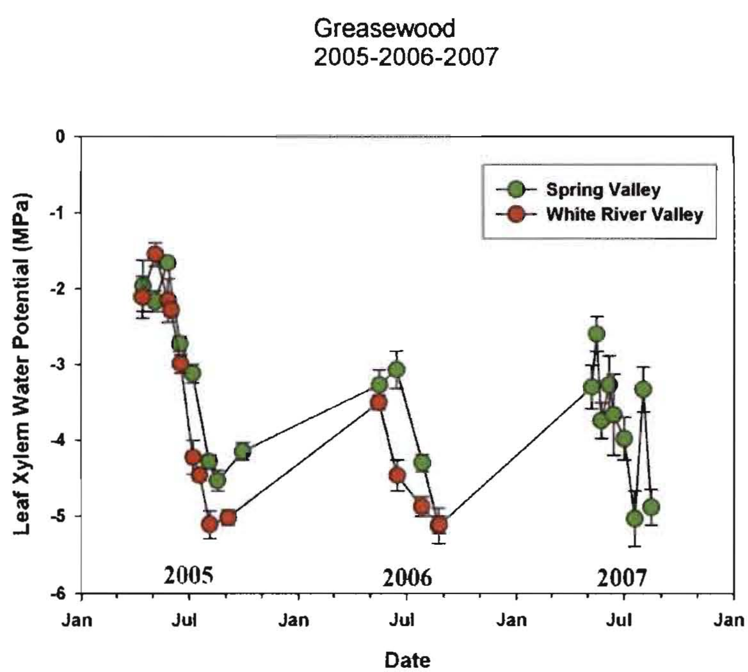


**Figure 26a. Leaf xylem water potential (MPa) for greasewood in Spring Valley and White River Valley in 2005, 2006 and 2007.**

Water potentials were above -2.0 MPa at the start of the growing season in 2005, whereas in 2006 and 2007, LXWP at the beginning of the growing season were lower than -3.0 MPa. Such a response was clearly linked to the significant difference in winter rainfall in 2005 compared to 2006 and 2007. When significant differences in greasewood LXWP occurred in 2005 and 2006 between Spring Valley and White River Valley, greasewood LXWP in White River Valley was always the more negative. A similar response was also noted for big sage.

Tissue moisture contents were high in all species during April and May. However, rabbitbrush and big sage revealed a significant decline by June/July compared to greasewood, which revealed only a subtle decline over the entire growing period (Figure 27a, 27b). Part of this difference was also related to the ability of greasewood to maintain succulence via salt accumulation. Nevertheless, the fact that the two glycophytes could not maintain tissue moisture contents at a site where the water table was at approximately 4.6 m (15 feet) would suggest that this source of water was not accessible at rates to offset early summer stress.

2007

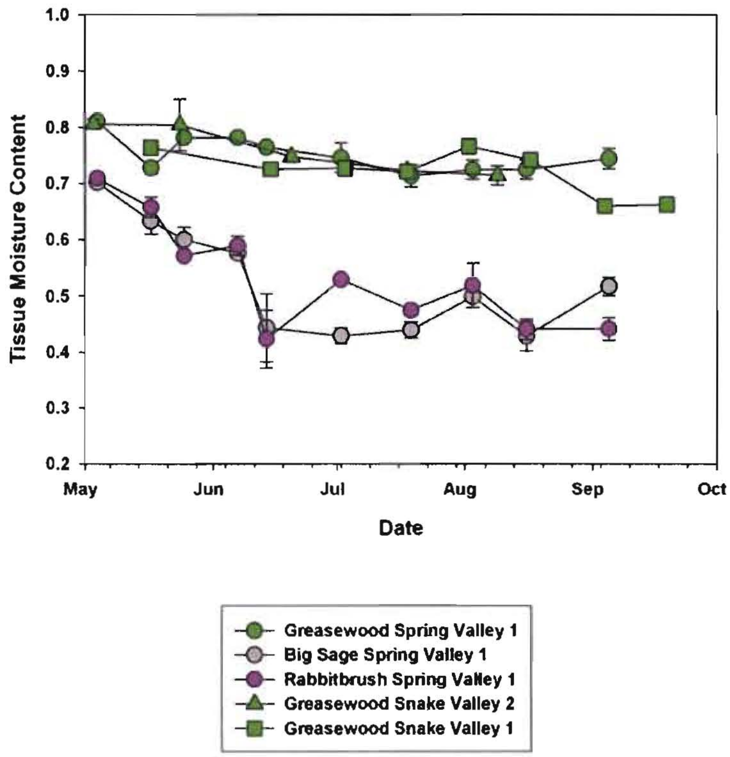


**Figure 27a. Tissue moisture content for greasewood, big sage and rabbitbrush in Spring Valley and greasewood in Snake Valley during 2007.**

The chlorophyll index, which can be used to assess overall greenness, revealed a cyclic response in most species. Chlorophyll index values for greasewood were low during winter dormancy but then increased rapidly during the spring green-up period (Figure 28a, 28b). Maximum values were typically attained by late May or early June, followed by a decline that occurred during the latter part of June, with values subsequently returning toward baseline values by early fall.

Significant differences in Tc-Ta values for greasewood and big sage in Spring Valley versus White River Valley occurred in 2006, with higher values associated with

White River Valley (Figure 29a, 29b). Higher canopy to air temperature differences signal greater plant water stress and are often associated with closure of stomata.

Tissue moisture-leaf xylem water potential correlations were established in each valley for each species (Figure 30a, 30b). Such relationships depict how the plants respond to stress and their ability to control water deficit conditions at the leaf level. Significant correlations existed for the different species in each valley; however, higher $R^2$ values were typically associated with Snake Valley and Whiter River Valley which had a wider range in both tissue moisture content and LXWP. When all species were contrasted on the same graph (Figure 31a) for sites in White River Valley and Spring Valley (Figure 31b), a separation based on species was observed. A significant difference in the data between the two valleys was apparent, with all species in Spring Valley maintaining a tighter, narrower separation of both tissue moisture content and LXWP. Such results, based on the sites monitored in this study, support the conclusion that general growing conditions were less stressful in Spring Valley than in White River Valley.

Groundwater depth slowly declined at all sites during the spring and summer periods. Plant water status also typically declined as the summer period was entered, with the exception of the tissue moisture content of the halophytes (Figure 32a, 32b). Results showed that LXWP was highly correlated with groundwater decline at some sites (Figure 33a, 33b). Such correlations by themselves do not define the level of dependency that plant communities have on groundwater; it does however, add to a growing base of information suggesting that rainfall and groundwater extraction were not adequate to avoid elevated stress during the summer months. The fact that even greasewood, growing at the site with the shallowest groundwater, revealed a decline in LXWP would suggest that groundwater extraction is not able to reverse this trend. This result indicates that all plant communities monitored in this study were operating under some level of stress (with the exception of the irrigated pasture grassland).

Groundwater depth was not highly correlated with percent cover or percent greasewood cover (Figure 34a, 34b) and combinations of groundwater depth and soil salinity could not adequately describe percent greasewood cover (Figure 35), indicating that plant cover was controlled in a complex fashion by many soil-plant-atmospheric conditions. In 2007, percent cover was highly correlated with average daily net radiation (Rn) during summer months (Figure 36a, $R^2$=0.95***, with standard error bars, Figure 36b). An 87% reduction in cover was associated with a 33% reduction in Rn. Such a response was linked to the higher reflectance from bare soil compared to vegetative cover, thus as the percent cover increased, soil reflectance decreased. Higher daily Rn associated with higher percent cover should drive higher ET rates if water is readily available, as was the case for the 100% covered irrigated pasture grassland site. However, higher percent cover under declining water availability (extended drought conditions) would be expected to establish a strong negative feedback on plant water status.

### 3.7 Measured Evapotranspiration (Eddy Covariance)

Evapotranspiration estimated on a daily basis in 2005 is plotted as a function of time in Figures 37a,b and 38a,b and is plotted with Rn and rainfall for comparative purposes in Figures 39a-h. In 2005, ET values in excess of 3 mm per day occurred at all sites during some period of monitoring, with values approaching 6 mm on certain days at sites WRV1 (dense greasewood) and SV2a (shallow groundwater).

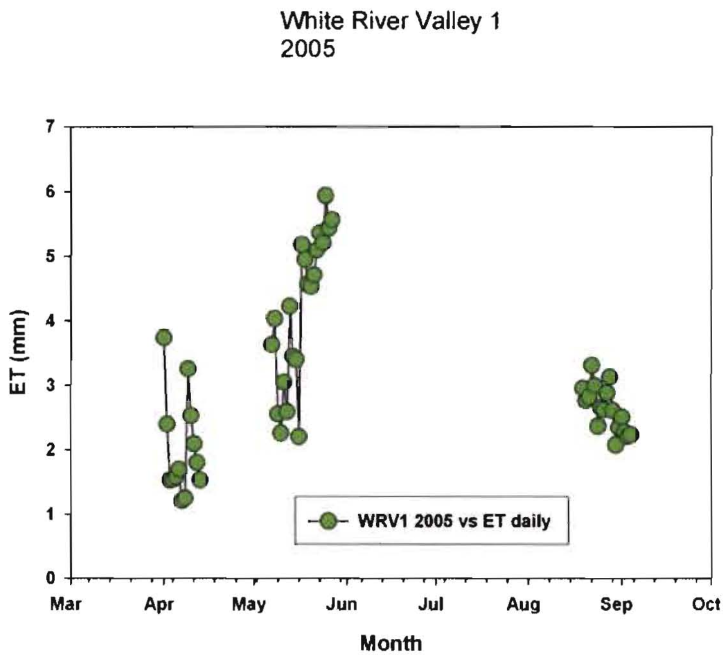


**Figure 37a. Daily evapotranspiration for White River Valley 1 in 2005.**

When ET was compared at site SV1 over the same time periods each year, the 2005 year revealed higher values and significant separation during the May and October/November periods (Figure 40a) however such separation was not as clear at WRV2 (Figure 40b). Unfortunately, sites SV1 and WRV1 were not monitored during the June, July and August period in 2005. In 2006 and 2007, little difference in ET was noted during the summer months at site SV1. At site WRV2, ET rose steadily from January to April in both 2005 and 2006, with a significant decline in ET during the summer months of 2007. ET estimates for sites SV1 and WRV2 on a daily basis for the entire 2006 year are plotted in Figures 41a and 41b. The majority of ET occurred during the period between March and October, with yearly totals of 24.04 cm at site SV1 compared to 42.43 cm at site WRV2. ET measured at site WRV2 during 2006 did require some gap filling due to equipment failure during the mid May to mid June period and during the winter period of October to January, due to the instruments being sent back to the manufacturer for recalibration checks.

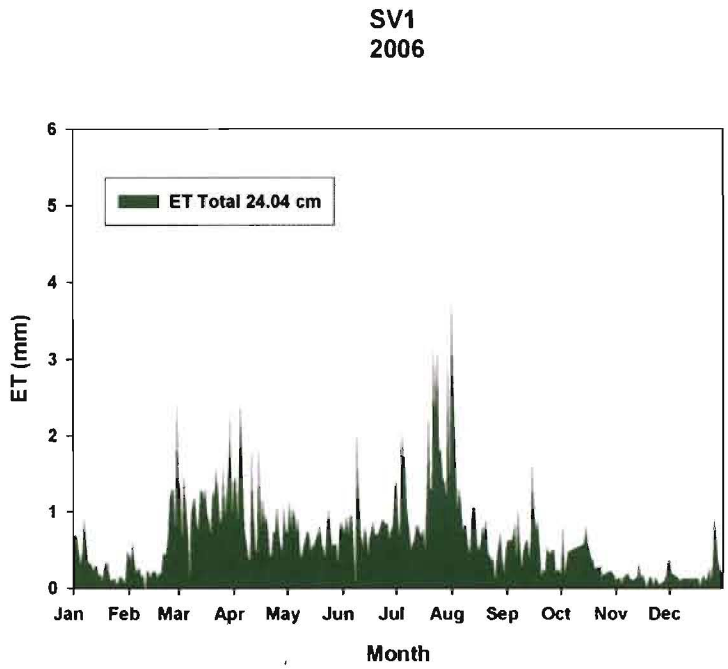


**Figure 41a. Evapotranspiration for Spring Valley 1 in 2006 with yearly total.**

Energy balance closure was estimated during the growing period by dividing latent heat (LE) plus sensible heat (H) by the available energy (net radiation ($R_n$) minus soil heat flux (G)); thus $((LE+H)/(R_n\text{-}G) = 1.00$ (100%) for perfect energy balance closure. Energy closures ranged from a low of 84% to a high of 104%, with 11 of the 14 site by year closures in the range of 84-99% (Table 17). These closures were similar to those reported by Moreo et al. (2007) for the same three valleys.

**Table 17: Energy Balance Closure Estimates**

| Site | Year | Energy Balance Closure Estimate | Date of Closure Estimate |
|---|---|---|---|
| SV1 | 2007 | 97% | 2/15-9/7/2007 |
| SV2b | 2007 | 90% | 3/29-9/7/2007 |
| SV3 | 2007 | 104% | 3/30-9/6/2007[b] |

| | | | |
|---|---|---|---|
| WRV2 | 2007 | 101% | 4/23-9/6/2007 |
| SNK1 | 2007 | 104% | 5/31-9/7/2007 [b] |
| SNK2 | 2007 | 99% | 6/1-9/7/2007 [b] |
| SV1 | 2006 | 89% | 1/1-2/3 & 3/7-9/28/2006 [b] |
| WRV2 | 2006 | 98% | 1/1-4/12 & 5/6-8/17/2006 [b] |
| SV1 | 2005 | 87% | 3/31-5/26 & 8/18-12/22/2005 [a] |
| SV2a | 2005 | 93% | 7/7-8/18 [a, b] |
| SV3 | 2005 | 84% | 5/26-7/7/2005 [a] |
| WRV1 | 2005 | 96% | 5/16-5/27 [a, b] |
| WRV2 | 2005 | 89% | 1/1-4/1 & 7/18-12/24/2005 [a] |
| WRV3 | 2005 | 88% | 5/27-6/17 & 7/8-7/17/2005* [a] |

[a] Eddy Covariance Tower was moved to another location.
[b] Missing days due to malfunction associated with soil heat flux sensors.

*NOTE, Energy Balances were calculated on all available data.

### 3.7.1 Cumulative ET – $ET_{ref}$ – Rainfall Relationships

Cumulative values for ET, $ET_{ref}$ and rainfall are shown for all sites and years in Figures 42a-f. Higher rainfall in 2005 led to cumulative ET values that were elevated and tracked rainfall in a more parallel fashion (note in particular the responses from sites SV2a, WRV2). Although cumulative ET rose with increasing cumulative $ET_{ref}$, only in the case of the wetter site SV2a (water table < 3 feet) in 2005, and the irrigated pasture grassland site (SV2b) in 2007 did cumulative ET move in a tight relationship with cumulative $ET_{ref}$.

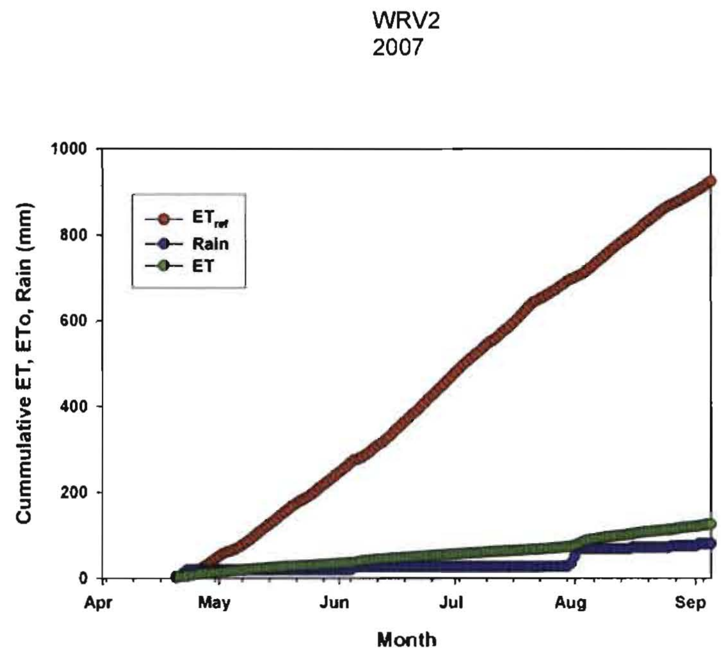


**Figure 42d. Cumulative evapotranspiration, reference evapotranspiration and rain for White River Valley in 2007.**

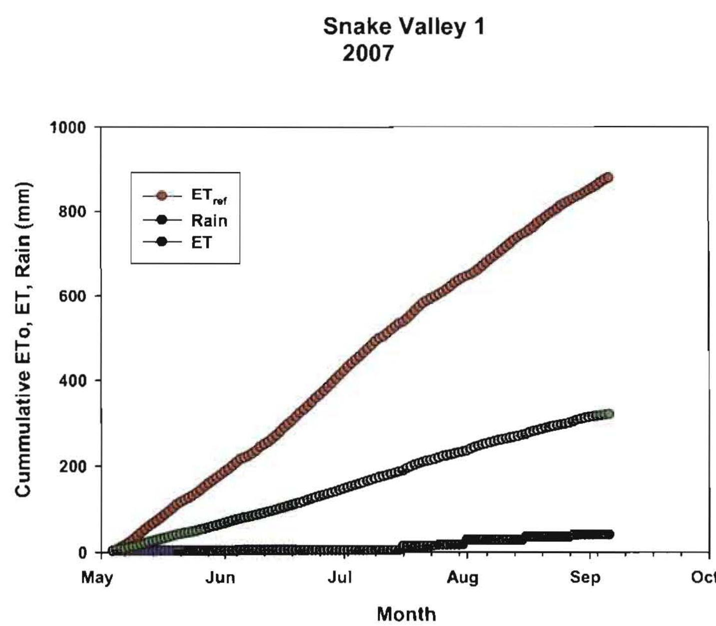


**Figure 42e. Comparison of cumulative reference evapotranspiration, evapotranspiration and rain for Snake Valley 1 in 2007.**

In arid environments, the difference between cumulative ET and cumulative rainfall can be used to assess possible linkages between plant community ET and groundwater extraction. In Tables 12 and 13, yearly cumulative ET, $ET_{ref}$, rainfall and ET minus rainfall are reported for all sites and years where such data were available. In 2005, the EC systems were moved every three to four weeks, but the weather station always remained at the same location; thus, not allowing an evaluation of ET minus rainfall on a consistent basis. In 2006, only sites SV1 and WRV2 were continuously maintained. Nonetheless, higher ET minus rainfall estimates for site WRV2 compared to site SV1 were observed, even though the water table was shallower at site SV1. It is believed that this difference was directly linked to the significantly lower percent greasewood in the plant community at site SV1, thus representing a weaker coupling of the plant community to the groundwater source. In 2007 for the May 10 to September 5 period, the ET minus rainfall total ranged from 4 to12 cm at most sites. These totals of course did not include winter rainfall. At site SV2b, ET minus rainfall was high, reflecting the irrigation applied to the pasture grassland site and not groundwater extraction. However at the SNK1 site, ET minus rainfall was almost 27 cm or three times the amount measured at SNK2. In this case, a dense mono specific stand of greasewood was found at the SNK1 site, with groundwater at approximately 4.9 m (16 feet) compared to a very sparsely vegetated plant community at the SNK2 site where groundwater was measured at approximately 9.1 m (30 feet).

### 3.7.2 Daily Evapotranspiration Rainfall Relationship

Major peaks in ET during the growing period at the shrubland sites were explicitly linked to rainfall events (Figures 43a, 43b). Continuous measurements of soil moisture content at the 5 cm depth were measured both under the canopy and in the open space between plants. Lower soil moisture contents were typically associated with the sensors located beneath the plant canopies. In 2007, soil moisture at the 5-cm (2-inch) depth at SNK1 declined during the spring and early summer periods as $ET_{ref}$ increased and few major rainfall events occurred. However, in July and August multiple rainfall events in excess of 2 mm per day occurred, leading to an immediate rise in the soil moisture content and ET. These peaks in soil moisture declined during the period between rainfall events, approaching base line values within a two-week period. However, ET peaks associated with these rainfall events typically lasted for no more than 2 to 4 days. The fact that ET returned to base line values very quickly, while surface soil moisture remained elevated for a longer period, would suggest that greater transpiration was not occurring but was rate limited, and that the majority of this water (rainfall/elevated surface soil moisture in July-August) was probably lost through evaporation and not transpiration. However, this response was site dependent.

### 3.7.3 Evapotranspiration-Rn Relationships

When water is readily available and the amount of net energy (Rn) at a site declines, ET also declines in a systematic fashion (Figure 44). At site SV2b in mid July, when Rn decreased by approximately 50%, ET declined by 42%, and when Rn returned to similar values three days later, ET also returned to higher values. However, this was not the case at other sites that all operated under water limiting conditions. ET and Rn was significantly correlated when based on 30-minute totals (Figures 45a, 45b), as would be expected based on the typical bell shaped curve established for both parameters between sunrise and sunset. Daily total Rn and ET, however, were typically poorly correlated (Figures 46a, 46b), with the exception of some data sets during the wetter 2005 year.

### 3.7.4 Evapotranspiration-VPD Relationships

Vapor pressure deficit (VPD), defined as the difference between saturated vapor pressure and actual vapor pressure (maximum daytime value) was plotted as a function of time in Figures 47a and 47b. Maximum VPD values were greatest during summer months and were highest at SNK2 which had the deepest groundwater and smallest percent plant cover. Data from the SNK2 site was contrasted with data from the SV2b site (the irrigated pasture grassland site) that had VPD values as much as 2 kPa lower. However, VPD was only found to be significantly correlated to ET at one of the six sites in 2007 (Figures 48a, 48b).

### 3.7.5 Evapotranspiration-$ET_{ref}$ Relationships

As reference ET goes up, signaling increased environmental demand, actual ET will change based on water availability. However, in this study, $ET_{ref}$ did not account for a significant amount of variation in ET (Figures 49a, 49b, <25%), except at site SV2a in 2005, where groundwater was shallowest of all sites and in which only limited data was collected during two contrasting time periods and also at the irrigated pasture grassland site (SV2b) in 2007. In 2005 at the wetter sites, ET declined with increasing $ET_{ref}$ (Figures 50a, 50b), revealing a decoupling from environmental control. Such decoupling also infers that groundwater extraction was unable to meet higher plant water needs to maintain elevated ET rates during this period. The poor correlation between ET and $ET_{ref}$ indicated that $ET_{ref}$ does not dictate ET under water limiting conditions and the application of crop coefficients would be problematic at most sites in most years. Use of crop coefficients during stress periods would require that ETa to $ET_{ref}$ ratios be generated under similar conditions for each specific site (stress duration, stress intensity and type of stress). However, $ET_{ref}$ was estimated only as a grass cover and future research should be done to assess $ET_{ref}$ at each site based on true vegetative cover.

### 3.7.6 Growing Period Evapotranspiration Estimates

In 2007, ET values (mm per day) were estimated for the May 10 to September 5 time period at most sites (Table 13). In order to estimate 12-month totals, missing daily estimates were gap filled during the November-January period with 0.35 mm per day and linear fit between February 1 and May 10 and between September 6 and November 1 (see methodology section). The 0.35 mm per day value was selected based on limited existing winter values but was corroborated with the USGS 2006 data (0.29 $\pm$0.20 mm per day). The linear fit was based on anchoring the ET with an average ET value for the May 10 to 14 and the September 1 to 5 time periods. In Figure 51 this approach was demonstrated for the complete 2006 ET data set at site SV1, which resulted in an 8% under estimation of the actual ET total. In Figures 52a-f, ET yearly estimates are reported for all 2007 sites.

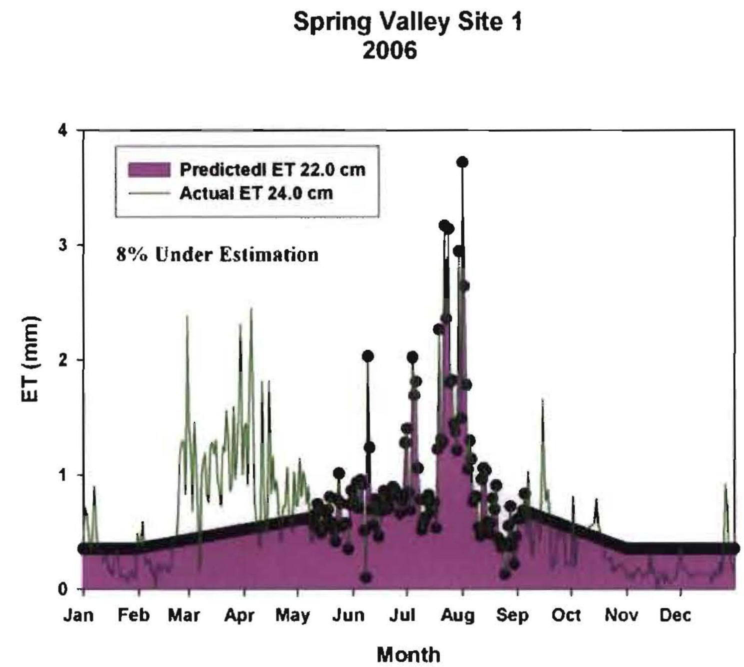


Figure 51. Predicted and actual evapotranspiration in 2006 for Spring Valley Site 1 with yearly totals.

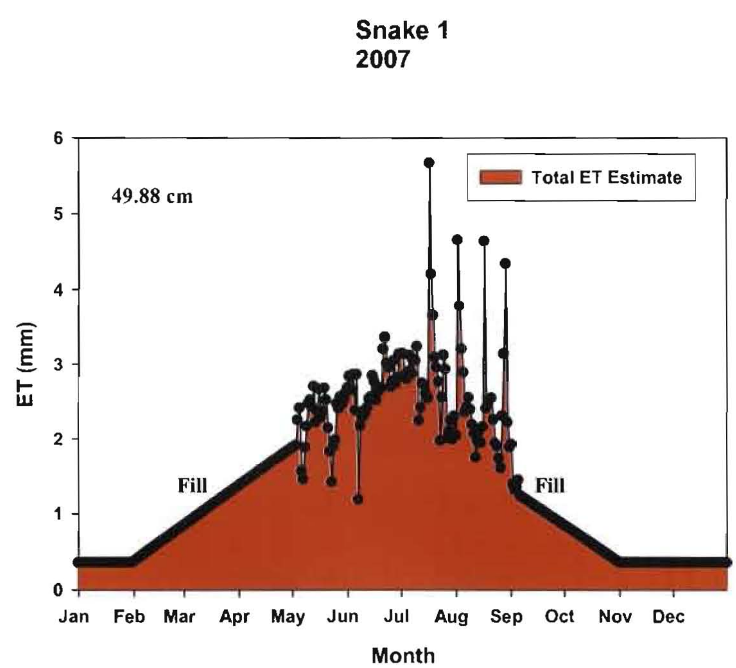


Figure 52e. Estimated evapotranspiration in 2007 for Snake Valley Site 1 with yearly total.

In Table 18 this approach was further demonstrated with published data by the USGS (Moreo et al. 2007) for the same valleys in 2006. At the USGS shrubland sites, the May 10 to September 5 time period represented, on average, 49% of the total ET estimate. The gap filling approach used in this study for the 2007 year also led to the same percentage. At the USGS grassland site, this same time period represented 64% of the total ET estimate, whereas the $ET_{ref}$ estimate at site SV2b was approximately 57% of the yearly total.

Next, the published USGS data for the May 10 to September 5 time period were assessed, gap filling the November, December and January months with base line ET values of 0.35 mm per day and gap filling the remaining time periods as previously described. The error associated with estimating ET using this approach amounted to a 6.34% ($\pm$ 3.9) under estimation. Only in the case of the grassland site did an over prediction occur (12.5%). Whether a similar over prediction was occurring at site SV2b is difficult to assess. However, it should be noted that the ratio of ET to $ET_{ref}$ at the USGS site was estimated at 0.62 for the May 10 to September 5 time period compared to a ratio of 1.00 for site SV2b, suggesting that under non water limiting conditions, gap filling based on $ET_{ref}$ might be superior. Such an $ET_{ref}$ gap filling approach estimated ET for site SV2b at 126.43 cm compared to the baseline linear gap filling technique which estimated ET at 124.97 cm which represented a 1.2% difference (Figure 53). However, this technique still over estimated the USGS grassland site by 14.8% suggesting that the USGS grassland site did not respond in a similar fashion to shrubland sites or irrigated sites. Further evaluation will be needed to explain these differences.

### 3.8 Remote Sensing

### 3.8.1 Calibration, Atmospheric Correction and Normalization

The $R^2$ values for the regression equations used to perform the atmospheric correction and normalization ranged from 0.90 to 0.99 for the blue, green, red and near infrared bands that were corrected (Landsat TM bands 1, 2, 3, and 4). The red and near infrared bands generally had the highest $R^2$ values for each date, except for one anomalous date, August 3, 2007, where the $R^2$ values were as low as 0.79 for the blue band, 0.86 and 0.87 for the green and red bands, and 0.93 for the near infrared band. Despite the lower $R^2$ values for the 8/3/07 regression equations, the resulting image values did not impact the overall summary statistics. Based on a qualitative assessment of this image, it appeared that the satellite sensor was saturated by a large band of clouds across the eastern edge of the image, which produced pixels in the western and central portions of the image with very low radiance values and minimal spectral separation. Both an analysis of variance and descriptive statistics were prepared for all calibration targets within each image band and date. Because all images were corrected with the same field data, the target pixels should, in theory, have statistically similar values. No statistically significant differences existed for the two bright soil targets. However, the igneous rock and gravel pit targets did have statistically significant differences among the image dates within each band, except band 4 (the near infrared band) for the igneous rock target. When compared to the field data, no significant differences were observed between image and field values for the Bright Soil 1 and Igneous Rock. A significant difference between image and field values was observed for the Gravel Pit and Bright

Soil 2. Overall, the atmospherically corrected and normalized images were considered suitable to meet the project goals.

### 3.8.2 Vegetation Indices

Canopy transpiration is typically the largest component of water flux from the earth's surface, approximately 80 percent or more (Glenn et al. 2007). Therefore numerous studies have examined the use of VI's calculated from remotely sensed data as inputs into either empirical models or energy balance equations to estimate ET over large areas (Glenn et al. 2007, ). In this study six different VI's (NDVI, SR, SAVI, MSAVI, GNDVI and EVI) were tested as single and multiple pixel values for correlation with daily or yearly ET estimates. A preliminary analysis was performed to select an appropriate VI for the more in-depth empirical analysis. All data point combinations were used for the preliminary analysis with no filtering to remove any problematic image dates (large areas of cloud cover) or image dates immediately after precipitation. (Note: the next section discusses the results for the final filtered NDVI:ET relationship.) Several indices performed well ($R^2$ ranged from 0.44 to 0.89 for all six VI's and basin combinations for each of the three years) and a case could be made for selecting any one of the following three VI's: 1) NDVI ($R^2 = 0.58$ for WRV, 0.70 for SV and 0.86 for SNV); 2) SR ($R^2 = 0.61$ for WRV, 0.70 for SV, 0.89 for SNV); or 3) EVI ($R^2 = 0.60$ for WRV, 0.78 for SV and 0.84 for SNV). The SAVI had the poorest overall correlation with ET for all three basins. NDVI was selected based on the overall good $R^2$ values, and prior historical use in Nevada and other arid and semi-arid regions as well as the large number of NDVI publications demonstrating its use (Malo and Nicholson 1990, Peters and Eve 1995, Peters et al. 1997, Weiss et al. 2004). After a preliminary examination of the 2005 images, which originally included fall and winter dates, it was found that images restricted to the growing season (April – September) provided the best correlation with ET as measured by the eddy covariance method. This corresponds to research performed by Ramsey et al. (1995) who found a lack of clear phenological separation among different vegetation in Utah during the fall and winter time period.

In this study not only were the expected seasonal changes in NDVI found, there were annual changes in NDVI for both White River and Spring Valleys as well. To more closely examine these changes over time, arbitrary ranges of NDVI values were selected that approximately corresponded to the low (0.01-0.05), medium (0.05-0.10) and high (0.10-0.25) canopy cover shrub sites as well as ranges that corresponded to water (<0) and agricultural fields and meadows (>0.25). Changes in acreage for each NDVI range for each image date as well as each annual average NDVI image were assessed. Figures 54-57 provide summaries of changes in NDVI values at each EC tower site and changes in 2005, 2006 and 2007 NDVI acreage for White River and Spring Valleys, respectively.

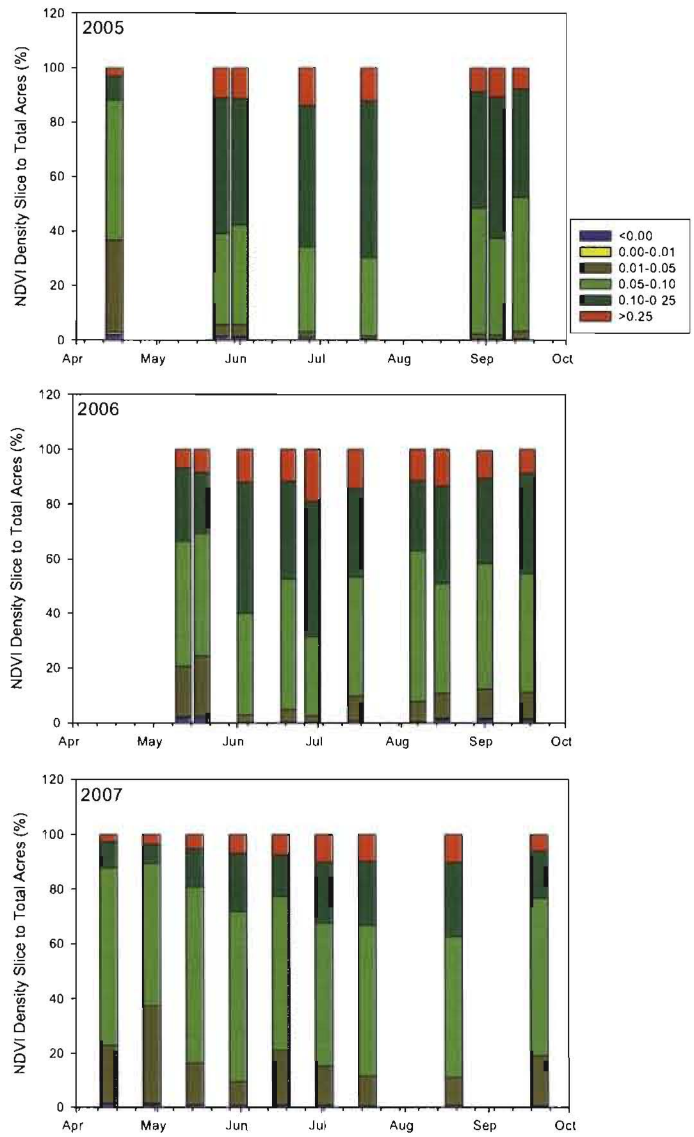


**Figure 55. The above graphs depict the changes in percent acreage of several NDVI ranges respective to the entire White River Valley phreatophyte polygon acres (minus any clouds, cloud shadows or missing acres) during 2005, 2006 and 2007. The arbitrary NDVI ranges presented roughly correspond to: water (<0); bare soil (0.00-0.01); low shrub cover (0.01-0.05); moderate shrub cover (0.05-0.10), high shrub cover or moderate herbaceous cover (0.10-0.25); and agricultural fields and meadows (>0.25). An overall decline in the more dense canopy cover ranges is observable as well as a corresponding increase in the moderate and low shrub cover ranges.**

In the growing season, NDVI values generally increase from April through June/July and then decline in August and September for all sites and all years. However, only in 2005 was there a similar growing season pattern between NDVI values and NDVI acreage data. In 2006 and 2007 (lower precipitation years), the seasonal changes in NDVI did not have as strong of a growing season pattern as 2005 and exhibited somewhat erratic changes in acreage values over time. Figure 58 depicts the 2007 growing season changes in NDVI values at the EC tower site and changes in NDVI acreage for Snake Valley. These data were quite similar to the 2007 WRV and SV data and show why it was important to examine seasonal changes in VI's rather than relying on a single date for the development of a VI:ET empirical relationship. Annual changes in NDVI patterns were apparent for WRV and SV in 2005, 2006 and 2007 as depicted in Figures 59 and 60.

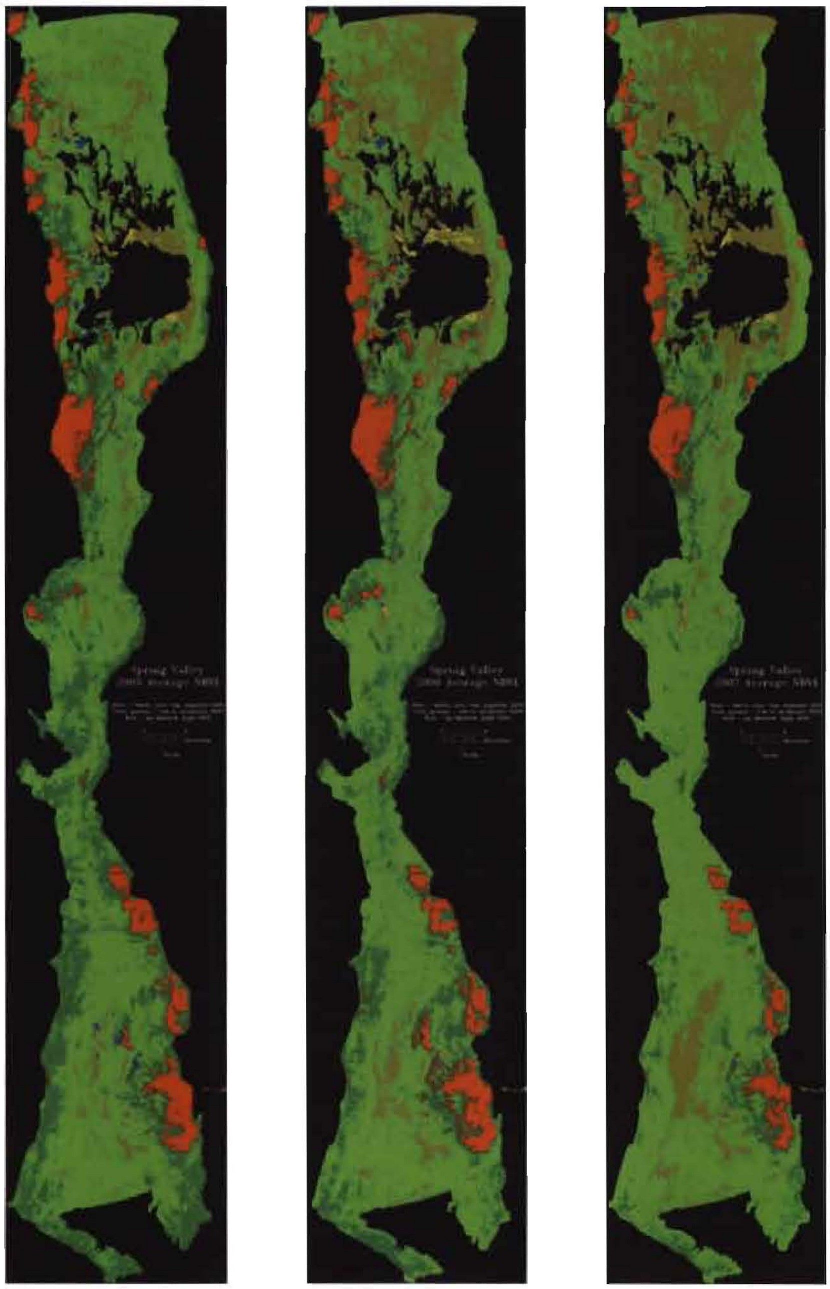

**Figure 60. The above figures are average NDVI images for Spring Valley during the growing seasons of 2005, 2006 and 2007. Similar to the average NDVI images for the White River Valley there is a decline in NDVI values during the period of 2005 through 2007.**

The 2005 images demonstrate the impact of above average annual precipitation on vegetation cover. The following two years were successively drier and an apparent decrease in NDVI values were accompanied by quantitative decreases in acreage of the higher vegetation cover NDVI ranges, as shown in the graphs of Figure 61. Figure 62 includes the 2007 average NDVI image for Snake Valley and a graph summarizing the acreage within each NDVI range. Although the phreatophytic zone was significantly larger in Snake Valley than in the other basins, greater than 50% of the area in 2007 was assigned an NDVI classification of 0.01-0.05, significantly higher than estimated for either Spring Valley or White River Valley.

### 3.8.3 Development of the NDVI:ET Empirical Relationships

Vegetation indices were evaluated for three different pixel size groups consisting of: 1) the single pixel containing the EC system; 2) 5x5 pixel square containing the EC tower in the center pixel; or 3) 5x5 pixel square located due south of the EC system. Based on a consistent higher $R^2$ value for the single pixel at all sites in two of the three basins, the single pixel was selected for developing ET-NDVI correlations . Finally, different ET periods were evaluated (day of Landsat pass versus day before Landsat pass) to develop the ET-NDVI correlations. Based on an improved correlation in White River Valley, the 24-hour ET estimate for the day before the Landsat pass was selected. Because the Landsat pass occurred around 11 AM and the spectral image acquired represented an assessment of the health/stress status of the plant communities for the morning hours, selecting the day before the Landsat pass proved to be a suitable choice. Finally, dates that occurred within a day of major rainfall events were not included.

The approach outlined led to correlations in 2005 based on seven Landsat dates in Spring Valley and five Landsat dates in White River Valley (daily NDVI approach). The $R^2$ value was higher for the Spring Valley data set than for the White River Valley data set (Figure 63, $R^2$=0.79** versus 0.68**), with a slightly greater slope for Spring Valley (22.9 versus 21.1).

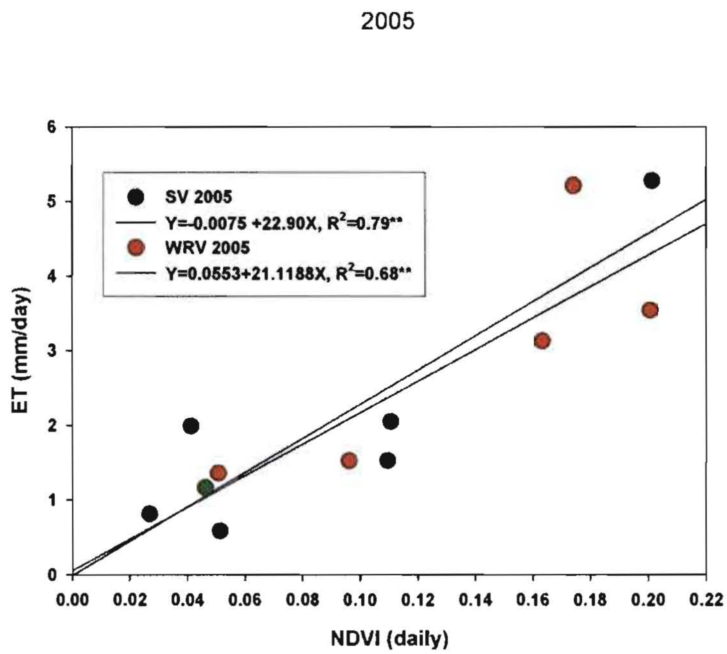


**Figure 63. Relationship between evapotranspiration (ET) and daily normalized difference vegetation index (NDVI) for Spring Valley and White River Valley in 2005.**

Both data sets contained ET that ranged from values slightly over 5 mm per day to ET values at or near 1 mm per day. In 2006, the 2005 data was merged with the 2006 data in both valleys (Figures 64a, 64b) and in 2007, all three years of data were merged (Figure 65a, 65b). In assessing the equations for the 2005 + 2006 data and the 2005 + 2006 + 2007 data, the correlations were strongly linked to the 2005 data set that anchored the equations. With the larger data sets, the $R^2$ values were slightly less than that obtained for the regression generated for the 2005 data set in each valley. Although the slopes were similar for all regression equations generated for Spring Valley, the slope increased significantly for the 2007 equation compared to the 2005 equation in White River Valley (21.1 versus 26.6). For basin ET estimates using the daily ET-NDVI approach, the 2005 equation was used for Spring Valley and White River Valley in 2005, however in 2006 and 2007, it was the 2005-06-07 equation that was selected. In Snake Valley, the regression equation was based solely on the 2007 data (Figure 66), and the $R^2$ value was slightly higher ($R^2$=0.81***) with a significantly lower slope (14.9) than generated for other valleys and years. When all basins and years were merged, a lower $R^2$ value was obtained (Figure 67), supporting the decision to evaluate the daily ET-NDVI data separately in each valley.

In 2006 and 2007, the opportunity arose to generate equations based not just on single days, but also on larger ET periods (May 10 to September 5, and 12 month actual or predicted totals). For the ET – NDVI equations generated for the May 10 to September 5 period, all six sites in 2007 and the same time periods in 2006 at SV1 and WRV2 were included. The NDVI selected was the average value based on multiple Landsat passes during the same time period. The data was fit to a curvilinear equation, anchored at the high end with data from site SV2b (Figure 68). However, when data for the same time periods from the USGS sites were added, the regression became linear with a coefficient of determination of 0.97*** (Figure 69).

NDVI vs Total ET
White River Valley, Spring Valley and Snake Valley
Periods 5/10-9/5 2006 (WRV and SV)
Periods 5/10-9/5 2007 (WRV, SV and Snake)

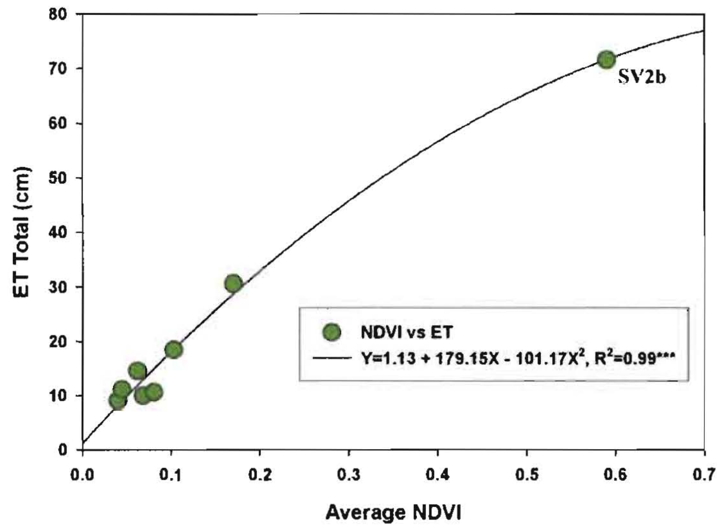


**Figure 68. Comparison between normalized difference vegetation index (NDVI) and total evapotranspiration (ET) for White River Valley, Spring Valley and Snake Valley for periods 5/10-9/5 2006 for White River Valley and Spring Valley and periods 5/10-9/5 2007 for White River Valley, Spring Valley and Snake Valley.**

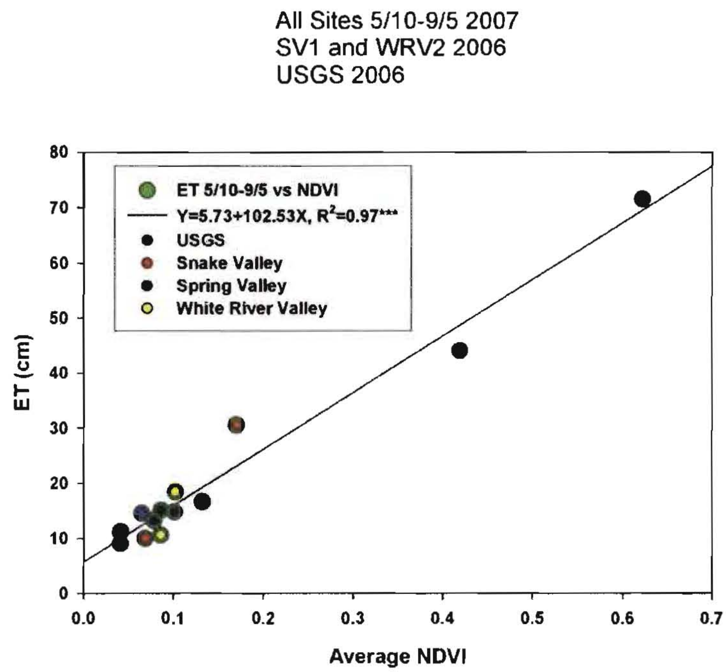


**Figure 69. Relationship between ET and NDVI for all sites for the period 5/10-9/5 2007 and SV1, WRV2 and USGS 2006 with USGS in black, Snake Valley in red, Spring Valley in blue and White River Valley in yellow.**

The 2005 year was significantly wetter and less stressful for the plant communities in both Spring and White River Valleys compared to 2006 and 2007. This led to the question: could the average NDVI-ET approach for larger data sets also work for the 2005 data? In order to test this approach, ET data at each site in 2005 for the various time periods was summed, and then the same time periods in 2006 and 2007 were also summed. The regression equations generated for the 2006 and 2007 data were always highly correlated ($R^2$>0.90***). However, when tested to determine if the 2005 data points were adequately described by the 2006/2007 regression equation (Figures 70a-f), the regression equation under predicted the actual value at five out of the six sites (36%, 52%, 52%, 37% and 43%). Only at site WRV2 for the summer period (July 19 through August 18) did the equation over predict the 2005 data. Such results confirm that during 2005, conditions were more conducive for higher plant water use rates and that basin wide ET estimates should also be significantly higher compared to either 2006 or 2007. Regression equations based on the relationship between average NDVI values for the growing period versus the 12-month ET estimate, which was either measured (e.g., sites SV1 and WRV2 during 2006) or predicted based on the gap filling approach previously described, were also developed. The correlation was highly significant (Figure 71, $R^2$=0.99***) and also fit the USGS data ($R^2$=0.98***, Figure 72).

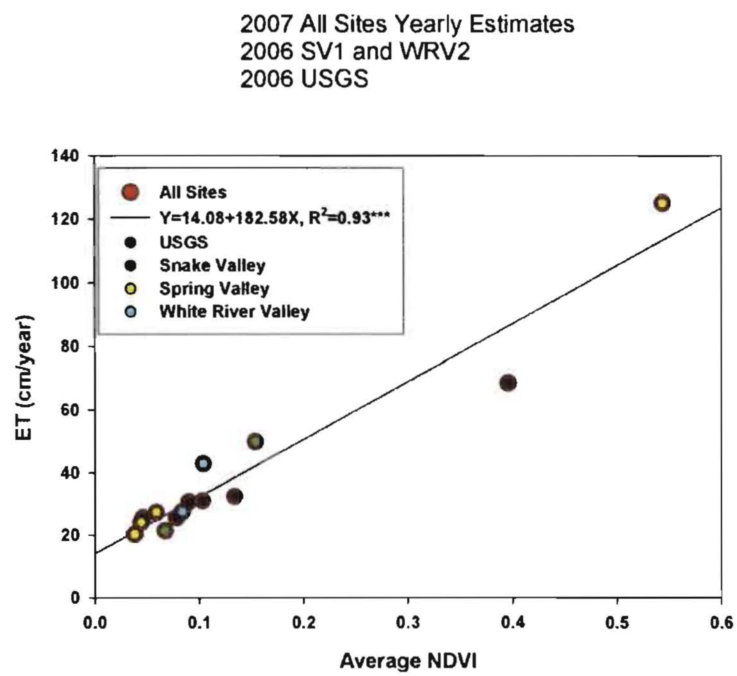


**Figure 72. Relationship of yearly ET estimates and NDVI for all sites in 2007 with Spring Valley 1, White River Valley 2 and USGS for 2006 with USGS in black, Snake Valley in green, Spring Valley in yellow and White River Valley in blue.**

All basin wide ET estimates were based on the equations previously described; however, in Spring Valley it was determined that a multiplicative term based on NDVI and Rn, improved the $R^2$ value (Figures 73a,b, 2005, $R^2$=0.79 increasing to 0.85, 2007,

$R^2$=0.75 increasing to 0.82). However, no significant correlations with a multiplicative term existed in White River Valley. Such an approach of using multiplicative terms may have value and should be further tested.

### 3.8.4 Percent Cover ET Correlations

In 2007, 82% of the variation in the ET total for the May 10 to September 5 time period was accounted for based on the percent cover (Figure 74). However, an even higher coefficient of determination ($R^2$=0.96***) was obtained for the regression between percent greasewood cover and ET totals in 2007 (Figure 75, not including the pasture grassland site).

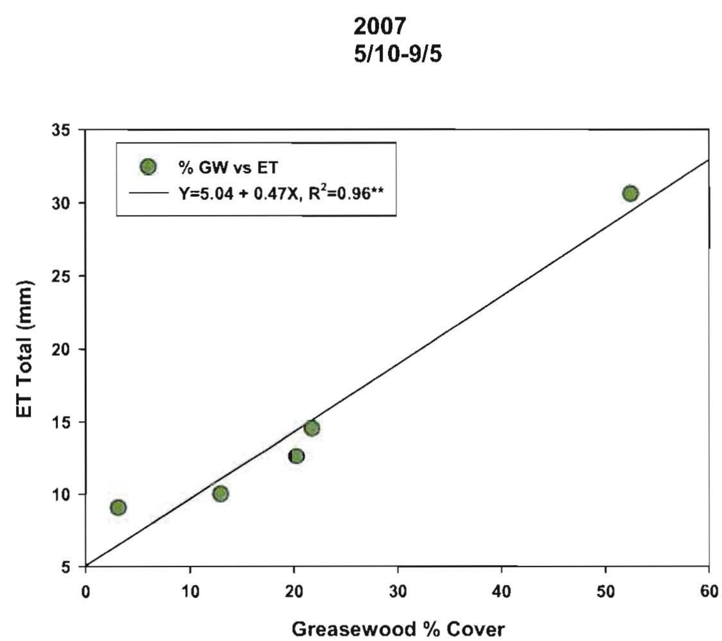


**Figure 75. Relationship between ET total and greasewood percent cover in 2007 for the period 5/10-9/5.**

Such a response suggests a strong connection between higher ET totals and the presence of phreatophytes such as greasewood, which can access groundwater. A curvilinear correlation between percent greasewood cover and ET minus rainfall was obtained for the five sites assessed in 2007 (Figures 76a, 76b). However, this correlation was highly dependent on the higher ET total for the SNK1 site. Finally, various parameter combinations that included percent cover to assess not only ET but also NDVI were evaluated. Highly linear correlations between NDVI and ET should be described by similar parameters that assess growing conditions. In this study Rn/VPD and percent cover were found to be highly correlated in a linear fashion to both NDVI (Figure 77, $R^2$=0.90) and ET ($R^2$=0.93). Higher energy loading associated with lower VPD reflected conditions optimum for higher ET, and when this was weighted with higher percent cover, a higher $R^2$ was obtained compared to the correlation with percent cover alone ($R^2$=0.82). All of the percent cover correlations reported in this study, however, will need to be tested further by adding more data based on sites, years and basins.

### 3.8.5 Limitations Associated With Cloud Free Day NDVI –ET Assessments

In 2005, the approach used to estimate total basin wide ET was based solely on the empirical relationship between NDVI and ET on individual cloud free days. Clearly, cloud cover will reduce Rn, and even if soil moisture is readily available, ET would be expected to decline as was demonstrated for site SV2b. However, under water limiting conditions, which represented the majority of the growing period in all three basins (with the exception of the early spring period), such a relationship was not well established. Although 30-minute Rn-ET values were highly correlated, daily Rn-ET values were often poorly correlated. To investigate this relationship further, the Rn-ET-rainfall data at site SV3 in 2007 was assessed in greater detail. In Figure 78, both Rn and ET were plotted over the 2007 monitoring period. Rn revealed far greater variability than did ET. In fact, when daily ET and Rn values minus their corresponding monthly averaged values were plotted, as shown in Figure 79, larger deviations in Rn were clearly not associated with larger deviations in ET. Lower Rn values were often associated with rainfall events (Figure 80), which were the major driving force behind higher ET/Rn ratios (Figure 81). Only 12% of the ET data for this time period was greater than 1 standard deviation below the monthly ET average. Many low Rn days were rainfall days, which were associated with elevated ET (typically a day or two later). To assess the impact of significant reductions in Rn on ET, all days which had Rn values greater than 1 standard deviation below the monthly average were assessed. In this calculation, rainfall events were avoided and the ratio of Rn for the particular day to the average Rn $\pm$ 2 days around the low Rn value (not including the low Rn value) were calculated, and plotted against the corresponding ET values divided by the average ET $\pm$ 2 days (not including the low ET value). Such a data set represents a worse case scenario with regard to large changes in Rn. No relationship existed between the Rn ratio and the ET ratio (Figure 82), suggesting that many factors outside of a declining Rn must be affecting ET. Based on this limited data set presented, fourteen of the twenty selected dates had ET declines of less than 25% associated with Rn declines as great as 75%. Of course, limitations do exist with NDVI-ET correlations, but our results show that cloud days associated with shrublands operating under limited water resources do not translate into predictable decreases in ET. Perhaps the greatest limitation in the NDVI-ET approach relates to the number of NDVI days to adequately represent the growing period. However, if ET relationships are based on larger growing periods such as the May 10 to September 5 time period or the yearly total estimates, this limitation can be avoided. In 2007, basin wide ET based on daily NDVI-ET correlations, but also on an average NDVI growing period ET basis (which was used to develop 12-month adjusted ET NDVI correlations) were estimated.

### 3.8.6 Basin-Wide Evapotranspiration Estimates

Basin wide ET was estimated using two different techniques. The first technique estimated ET based on developing an empirical relationship between daily NDVI and ET data (5-7 NDVI dates in 2005, 6 dates in 2006 and 4-7 dates in 2007), converting all NDVI pixels to ET and summing them for each basin on Landsat dates. The daily basin ET estimates were then plotted as a function of time and the area under the response curve was estimated using integration. The second technique was based on developing a relationship between the average NDVI for the growing period and the yearly ET estimates at multiple sites. Daily NDVI-ET correlations were limited to individual basins; however, the average NDVI approach was demonstrated to be applicable for all basins in 2006 and 2007, but not in 2005.

Basin wide ET estimates generated from the daily NDVI-ET correlations are plotted in Figure 83 for Spring Valley and Figure 84 for White River Valley in 2005, 2006 and 2007.

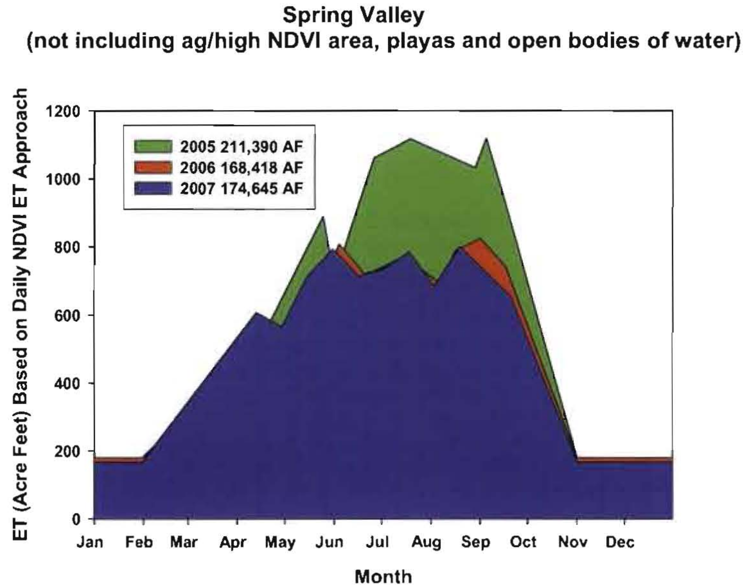


**Figure 83. Evapotranspiration based on daily NDVI-ET approach in Spring Valley for 2005, 2006 and 2007 with yearly totals not including Ag/high NDVI area, playas and open bodies of water.**

Basin wide ET estimates (daily NDVI) were made in Snake Valley only in 2007 and are shown in Figure 85. Daily NDVI correlations did not include playas, open water or high NDVI acreage . ET estimates in 2005 were similar for both Spring Valley and White River valley, with values estimated for Spring Valley at 211,000 acre feet versus White River Valley at 216,000 acre feet. However, a greater decline in yearly ET was estimated for White River Valley compared to Spring Valley when 2005 was contrasted with 2006 and 2007. In Snake Valley the ET estimate for 2007 was 146,000 acre feet (Figure 85). All of the ET estimates based on the daily NDVI approach (Figures 83,84,85) did not include high NDVI (>0.25) areas typically associated with agricultural lands and grasslands. Based on the yearly estimate of ET associated with an NDVI value of 0.25 (conservative approach, Figure 72) and an average high NDVI acreage estimate from all

Landsat dates, additional ET amounts were added to the estimates reported in Figure 83, 84 and 85 (60 cm associated with high NDVI acreage), as reported in Table 19.

**Table 19. Basin wide ET estimates for Spring Valley and White River Valley in 2005, 2006, 2007 and Snake Valley 2007 based on daily NDVI-ET estimates and average NDVI-yearly ET estimates. Pheatophytic zone for Spring Valley and White River Valley 2005, 2006, 2007 and Snake Valley 2007.**

| | Spring Valley | | White River Valley | | Snake Valley | | Spring Valley | White River Valley | Snake Valley |
|---|---|---|---|---|---|---|---|---|---|
| | Daily NDVI | Avg. NDVI | Daily NDVI | Avg. NDVI | Daily NDVI | Avg. NDVI | | Pheatophytic Zone | |
| | Acre feet | | | | | | Acres | | |
| 2005 | 233,864 | 233,176* | 241,172 | 225,371* | | | 156,232 | 142,557 | |
| 2006 | 195,980 | 185,584 | 145,052 | 181,440 | | | 156,409 | 142,761 | |
| 2007 | 195,399 | 164,496 | 127,014 | 152,496 | 176,670 | 239,513 | 156,497 | 141,743 | 256,016 |

*Estimate adjusted by 25% based on assessing the underestimate of 2005 data based on 2006 and 2007 regression equation.

The average NDVI approach incorporated all NDVI areas but was demonstrated to under estimate the wetter 2005 data by approximately 25% based on the linear relationship established for the same time periods in 2006 and 2007 (not including water bodies and playas). As such, the 2005 yearly estimate was based on a 25% adjustment. Future wet years will be needed to further validate this adjustment. Estimates for total ET using both techniques are reported in Table 19. In 2007, a significantly higher basin ET estimate occurred in Snake Valley compared to White River Valley or Spring Valley based on the average NDVI approach. However, it should be noted that Snake Valley had significantly more acreage assigned to the phreatophytic zone (Table 19). Although both techniques (daily NDVI-ET vs. average yearly NDVI-ET) did not give the same ET estimate, they were in general agreement for Spring Valley and White River Valley, which provided a possible range in ET for each basin on a year-to-year basis (larger difference noted in Snake Valley). However, based on greater limitations associated with the single day NDVI approach (5 to 7 Landsat passes representing the entire growing period in 2005), it is believed the estimates associated with the average NDVI and yearly ET estimates should be used for modeling purposes.

Finally, the impact of the decline in winter rainfall on basin wide ET estimates was assessed in Figure 86 (Spring Valley and White River Valley based on an average NDVI approach). Although additional rainfall data at multiple sites over multiple years is needed to fine tune such a relationship, Figure 86 indicates that winter rainfall clearly was a major driving force in dictating basin wide ET on a year-to-year basis, with a significantly higher coefficient of determination associated with the average NDVI approach compared to the daily NDVI approach ($R^2$ =0.93** vs. 0.57*).

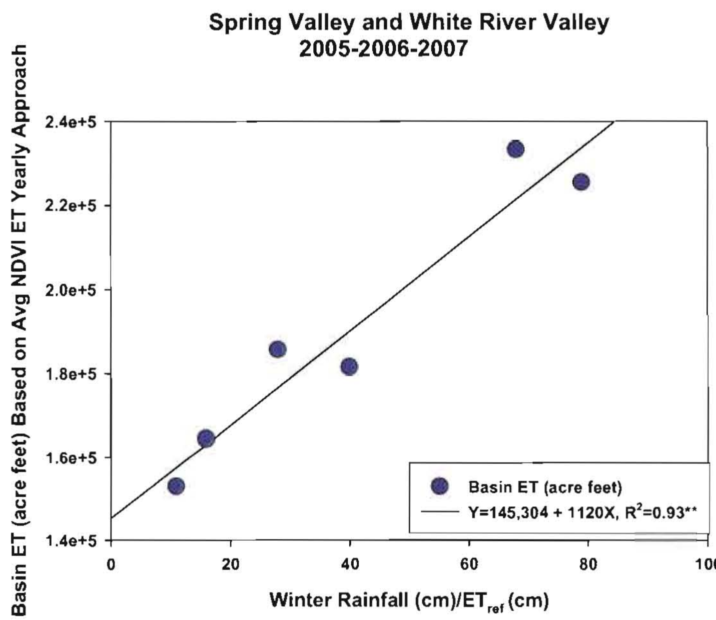


**Figure 86. Basin ET yearly estimates based on the average NDVI-ET yearly approach as a function of the ratio of winter rainfall to ET reference for SV and WRV in 2005, 2006, and 2007.**

### 3.9 Limitations

1) Uncertainty in eddy covariance measurements occur during non-turbulent conditions (generally early morning hours) and during rainfall periods. Gap filling techniques were employed to replace missing data. ET results reported in this report were based on 10 Hz data with post data processing using EdiRe, and corrections were made based on sensor separation, coordinate rotation, despiking, density and frequency attenuation. The data were also assessed using the Integral Turbulence Test, a Stationarity Test, along with kurtosis and skewness statistics to identify and remove outlier latent heat used in the final ET calculation. Additional ET validation work should be conducted at these sites in the future employing multiple techniques over varying time periods. The results will provide a stronger basis for determining which corrections are needed and the errors introduced into ET estimates if specific corrections are not done.

2) Complete (100%) energy balance closure did not occur at the sites, however closure obtained in this study was +/- 7% from 100% closure (excellent when compared to results reported in the literature).Uncertainty exists as to where to assign the unaccounted energy. Forcing energy closure based on maintaining Bowen ratios is sometimes used by scientist but it is not widely accepted by the scientific community. The Bowen ratio technique forces closure to estimate latent heat, whereas the Eddy covariance technique assesses each parameter individually. Thus, in this study the energy balance components were left alone, recognizing that adjustments to either Rn-G or latent heat and/or sensible heat would need to occur for energy balance closure to occur (7% average adjustment in the (LE+H)/(Rn-G) ratio).

3) Cloud cover was a constraint to establishing empirical relationships between NDVI and actual ET ($ET_a$) on a daily basis. Landsat images within the same path were available every 16 days and although the sites were generally clear on many selected days, they were not 100% clear. Such a limitation resulted in a reduced number of data points used for the scaling operation. The average NDVI approach was correlated with growing season and yearly ET estimates, so changes in ET associated with changes in cloud cover were incorporated in the total ET estimate. Greater uncertainty existed in assessing ET on a basin scale using the daily NDVI ET approach compared to the average NDVI growing period ET or yearly ET estimates. This uncertainty was associated with how well 5-7 Landsat passes could assess the active growing period. Although the daily NDVI ET estimates were in the same general range as the average NDVI yearly ET estimates, it is recommended that the yearly approach be used for modeling purposes. Future assessments should also look at partitioning the yearly ET into subunits (15-30 days) associated with individual NDVI assessments and determining the relative change compared to the average approach.

4) A significant linear relationship between $ET_a$ and NDVI only existed for the growing period. The active growing period was on the order of 145 days based on visual observations. However, NDVI sensors would suggest that the time between the beginning and end of physiological activity of greasewood was more on the order of 200 days.

5) The foot print of the EC tower continually varies depending on atmospheric conditions, and improved NDVI:ET correlations may occur if these shifting footprints

(pixels) are properly weighted. In this report, the NDVI:ET data based on the single pixel containing the EC tower was evaluated, the square 25-pixel area centered on the EC tower, and on 25 pixels to the south (or upwind) of the tower. Selection of the single pixel was based on the higher $R^2$ values. The actual footprints may extend up to 5 km from the EC tower but the area closest to EC towers are known to have the largest impact on EC measurements. Future estimates should evaluate footprints more closely, even given the $R^2$ value of 0.93*** associated with the correlation between the average NDVI and the yearly ET estimate (Figure 72).

6) The remote sensing analytical procedures used in this project were selected to provide standardized methods yielding consistent and comparable results, which are critical for monitoring changes in ET over time. Therefore, any future changes made to the imagery source, atmospheric correction calculations, choice of vegetation index, or type of empirical relationship (e.g., linear vs. non-linear) will likely result in a different ET estimate (may be significant or non-significant) than would otherwise be attained following the steps described in this report.

7) Numerous studies have examined the pros and cons of vegetation indices to estimate various plant physiological and ecological properties. NDVI is well known for saturating at higher vegetation densities. For this study, the NDVI did not saturate, even for irrigated agricultural fields and hence provided a reasonable substitute for monitoring changes in green leaf (transpirational) area.

8) Various thresholds were established to define water, Ag/meadow and cloud/shadow pixels. If these thresholds are altered, a concurrent modification will occur in the aerial extent of the land cover types categorized for this project (e.g., water, Ag/meadow and cloud/shadow) and hence the total ET result may be slightly different after summing pixels that might otherwise have been included (or excluded) in the total ET number. In addition, a threshold of 30% missing or cloud covered areas was set as a cut-off for including a specific image date in the calculation of the average NDVI image. The threshold selection was based on a cursory examination on the impact of large cloud covered (or missing) acreages for the White River Valley ET estimation. Simulations could be performed in the future to address the actual impact of threshold values on the final total ET value/range.

9) The results discussed in this report represented three growing periods over three years of data collection. Variability in yearly estimates did occur and need to be assessed in light of the decreasing trend in rainfall and increasing trend in $ET_{ref}$ during the measurement period. A longer period of time (years) is needed to adequately describe the range in rainfall, groundwater, environmental demand and overall plant community vigor and how evapotranspiration is subsequently altered as atmospheric drivers change from year to year. The Penman-Monteith reference ET (ETref) used in this study utilized standard surface and aerodynamic resistances for grass. Since only one site had 100% grass cover, individual resistance values should be calculated for each site in the future. Once these resistance values are estimated, ratios of ETref mixed/ ETref grass cover can be used to adjust historical data sets.

10) Rainfall was measured at all 6 research sites during 2007. However, due to the variability from site to site and the relatively poor correlation between rainfall event amounts at the sites, an extensive network of rain gauges should be employed to more accurately describe rainfall distribution on a basin wide scale.

11) The phreatophytic zone boundaries were estimated based on aerial photos, spectral imagery and field validation by the Southern Nevada Water Authority. Scaling ET estimates to the basin scale depend on the location of these boundary lines. Although the approach taken is satisfactory, additional future effort should be directed toward fine tuning these estimates with more extensive field validation.

## 4.0 CONCLUSIONS

Evapotranspiration was estimated for Spring Valley and White River Valley in 2005, 2006 and 2007 and in Snake Valley in 2007. Evapotranspiration estimates were made based on an energy balance approach using the eddy covariance method. ET estimates in this report are different from previously reported values, reflecting changes based on using the 10Hz data and incorporating a series of data post processing adjustments recommended by Ameriflux(as outlined in Lee et al.2004). Changes also occurred with the remote sensing data, as a more refined atmospheric correction process (i.e., better ground calibration targets) changed NDVI values and altered the area associated with NDVI classes. ET estimates at the basin scale were made by developing empirical relationships between ET and remotely sensed spectral data (Landsat).

Groundwater, soil moisture, rainfall and leaf level measurements were used to validate the differences in ET estimates based on site, year and basin.

All three of the valleys were large and contained plant communities with a range in density and species composition. As such, estimating ET at the basin level represented a formidable challenge. ET estimates were based on operating one to three eddy covariance systems per valley over a three-year period. This research represented a major undertaking by the University and required a significant level of funding by SNWA. Different approaches for collecting and analyzing data were taken; however, all were subject to some limitations. As such, a range in the ET estimates are reported. Testing the suitability of these estimates is left to modeling and water management personnel as they move forward with closing hydrologic balances for the individual basins.

The findings were quite clear in depicting a significant downward trend in winter rainfall associated with increasing environmental demand (Figure 10). Whereas, reference ET increased significantly during the most active growing period April to June, increasing by 11-13 cm in both Spring and White River Valleys when 2005 was contrasted with 2007 (Figure 4a, 4b). When rainfall was compared between growing and non growing periods based on the ratio of rainfall to reference evapotranspiration, a dramatic decline during the non growing period was revealed, dropping from 79% to 40% to 11% over the three-year period in White River Valley.

The 2005 year provided a more optimum condition for growth and elevated ET compared to the other two years. Leaf xylem water potentials were less negative going into the spring growing period of 2005 compared to the more negative values recorded in 2006 and 2007. In 2007 at sites SV1, SNK1 and SNK2, tissue moisture contents of rabbitbrush and big sage declined rapidly from May to mid June, whereas greasewood was able to maintain tighter control of internal plant water status. In 2005, halophytes were able to maintain higher tissue moisture contents associated with more positive leaf xylem water potentials compared to glycophytes. Although both valleys showed similar trends, lower plant water status was measured in White River Valley.

Groundwater depth varied from site to site, with the shallowest depth recorded at a shrub-grassland site in Spring Valley (SV2a) and the deepest depth recorded at a mixed shrubland site in White River Valley (WRV3). In 2007, groundwater depths at the continuously monitored sites declined slowly over time, revealing well defined daily oscillations at a few sites. However, depth to groundwater was rejected as a significant variable in all multiple regression analyses conducted to assess ET, percent plant cover or plant water status.

Other than the irrigated pasture grassland site monitored in 2007, the highest daily ET values were recorded at sites in both Spring Valley and White River Valley during 2005. A tighter relationship between cumulative ET, $ET_{ref}$, and rainfall occurred in 2005. Although $ET_{ref}$ was highly correlated with ET at the irrigated grassland site in 2007 and during a few wetter periods at sites in 2005, poor correlations existed at most sites. Such a result clearly indicated that limitations exist with using a crop coefficient approach with grassland and shrubland sites under the limited water resources observed in these valleys.

ET and surface soil moisture were highly responsive to precipitation events, especially during the summer months. No indication of any deep movement of water was associated with rainfall events (as monitored using TDR sensors and soil sampling for salinity) during summer months. The results would suggest that the majority of rainfall during the summer months was lost through the process of soil evaporation. When soil moisture was available, a strong coupling between net radiation and evapotranspiration occurred. However at most shrubland sites, poor correlations existed between Rn and ET. At most sites a decoupling between ET and $ET_{ref}$ occurred by mid to late June suggesting that, if groundwater was being utilized, it was not adequate at most sites in most years to offset plant stress.

In 2005, ET data were collected over different time periods at the different sites in each valley as the single eddy covariance system was moved throughout each valley. In 2006, complete ET estimates were obtained for the full year, at two sites, one in Spring Valley (SV1) and one in White River Valley (WRV2), where the eddy covariance system was maintained. In 2007, ET was estimated for the May 10 through September 5 time period at six sites. Yearly ET estimates were generated by utilizing a gap filling approach based on assuming a winter baseline value of 0.35 mm per day and then establishing a linear fit to the May 10 through September 5 time period (anchoring the regression on average values for the May 10-14 and September 1-5 time periods). Testing on actual data sets (site SV1 in 2006) and published USGS data for the same valleys, indicated that such an approach would lead to an 8% underestimation at SV1 and an average 6.3% under estimation at the USGS mixed shrubland sites.

ET in 2006 at site SV1 was estimated at 24 cm and at site WRV2 the estimate was 42.4 cm. In 2007, four of the six sites had yearly ET estimates between 20 and 30 cm. However, at the SNK1 site with a dense greasewood canopy, the estimated ET was 49.9 cm, as compared to site SV2b (the irrigated pasture grassland site) where the estimated ET was 124.97 cm. Empirical relationships were developed between the daily ET and

NDVI values at all sites in 2005, 2006 and 2007. Whereas total ET for the May 10 through September 5 time period and yearly ET estimates in 2006 and 2007 were correlated with average NDVI growing period values.

In 2005, regression equations in both Spring Valley and White River Valley were based on ET values that ranged from approximately 1 to 5 mm. Both regression equations were highly significant ($R^2$=0.79*** at Spring Valley and $R^2$=0.68** at White River Valley). In 2006 and 2007, regression equations were generated based on adding additional NDVI-ET data to the 2005 data set. The equations for 2006 and 2007 were heavily influenced by the 2005 data set associated with a significantly wetter winter period and less stressful spring growing period. All 2006 and 2007 NDVI-ET data were clustered in the lowest NDVI-ET region, which would have generated non significant correlations based solely on the drier 2006 and 2007 years. The highest NDVI-ET correlation was generated in Snake Valley ($R^2$=0.81***); however, the slope of the equation was significantly lower than in Spring Valley or Whiter River Valley. When all sites, basins and years were merged, a lower $R^2$ value was obtained for the daily NDVI-ET equation, indicating that basins should not be merged when developing such relationships based on the integrated approach with daily NDVI-ET data as outlined in this study.

In 2007, NDVI-ET correlations were generated based on the total ET from the May 10 through September 5 growing period. A highly significant curvilinear correlation was obtained between the average growing period NDVI and ET ($R^2$=0.99). When ET estimates from the same time period were taken from the published USGS data set for the same valleys (Moreo et al 2007), the new data set was best approximated by a linear fit ($R^2$=0.97***). However, when this approach was tested on the 2005 data sets obtained at the various sites, the 2006 and 2007 regression equations under predicted the 2005 ET value by an average of 44% at five of six sites (25% under estimation based on all six sites).

In 2007, 96% of the variation in total ET for the May 10 through September 5 time period (all sites except the irrigated pasture grassland site) could be accounted for based on the percent greasewood cover, suggesting a clear and distinct relationship between the presence of phreatophytes and plant community level ET.

Basin wide ET estimates were highest in 2005, decreasing in 2006 and 2007, reflecting the annual variability in ET that can occur in such large basins and the need to continue to make such assessments over longer periods of time. Basin wide ET estimates based on the daily NDVI-ET approach and based on the yearly ET-average NDVI approach are reported. Based on the yearly ET approach, similar ET values in 2005 for both Spring Valley and White River Valley (233,176 acre feet and 225,371acre feet) are predicted. Both valleys showed a similar decline in 2006 (Spring Valley with 185,584 acre feet and White River Valley with 181,440 acre feet) but a larger decline occurred in White River Valley in 2007 (Spring Valley with 164,496 acre feet and White River Valley with 152,496 acre feet). In Snake Valley in 2007, the basin wide ET estimate was significantly higher (239, 513 acre feet) than in Spring Valley or White River Valley. However, Snake Valley had more than 114,000 additional acres assigned to the phreatophytic zone compared to White River Valley (Table 19). Based on the conditions outlined in this report, it is the belief of the investigators of this study that the approach taken accurately reflects ET estimates for these basins. With continued monitoring, more robust data sets can be obtained for NDVI and ET over greater spatial and temporal scales that will further refine these estimates.

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APPENDIX (Tables)

**Table 1: Sping Valley, White River Valley and Snake Valley Site Locations**

| Site | Vegetation Classification | GPS Location Northing (Y) | Easting (X) | Basin | Elevation (m) | Lat | Lon | f (Coriolis parameter) |
|---|---|---|---|---|---|---|---|---|
| SV1 | low density mixed shrubland | 4294918.624 | 719919.557 | Spring Valley 184 | 1761.64 | 38.776 | -114.468 | 0.000127995 |
| SV2a | high density grass shrubland | 4351204.381 | 720176.620 | Spring Valley 184 | 1679.00 | 39.282 | -114.447 | 0.000145389 |
| SV2b | irrigated pasture/grassland | 4360828.725 | 716742.825 | Spring Valley 184 | 1705.47 | 39.370 | -114.484 | 0.000144677 |
| SV3 | moderate density mixed shrubland | 4375911.750 | 715856.657 | Spring Valley 184 | 1711.36 | 39.506 | -114.489 | 0.000141375 |
| WRV1 | high density mixed shrubland | 4253556.677 | 670229.512 | White River Valley 207 | 1576.30 | 38.414 | -115.050 | 0.000095314 |
| WRV2 | moderate density mixed shrubland | 4277444.669 | 665016.698 | White River Valley 207 | 1617.84 | 38.630 | -115.104 | 0.000116650 |
| WRV3 | moderate density mixed shrubland | 4301044.414 | 668299.941 | White River Valley 207 | 1661.35 | 38.842 | -115.061 | 0.000132290 |
| SNK1 | high density monotypic stand of greasewood | 4287266.191 | 753181.613 | Snake Valley 195 | 1684.87 | 38.698 | -114.089 | 0.000122247 |
| SNK2 | moderate density monotypic stand of greasewood | 4325089.731 | 754600.619 | Snake Valley 195 | 1564.32 | 39.038 | -114.058 | 0.000141501 |

**Table 2: Percent Cover and Species Count for Spring Valley, White River Valley and Snake Valley EC Tower Site Locations.**

| Site | Species | Scientific Name | Percent Cover | Plant Count | Total Percent Cover |
|---|---|---|---|---|---|
| SV1 | Greasewood | *Sarcobatus vermiculatus* | 3.164 | 18 | 27 |
| SV1 | Sagebrush | *Artemisia tridentata* | 17.534 | 376 | |
| SV1 | Rabbitbrush | *Chrysothamnus nauseosus* | 5.361 | 188 | |
| SV1 | Shadscale | *Atriplex confertifolia* | 0.475 | 35 | |
| SV1 | Buckwheat | | 0.434 | 34 | |
| SV1 | Grass | | 0.032 | 9 | |
| SV2a | Greasewood | *Sarcobatus vermiculatus* | 13.011 | 119 | 62.1 |
| SV2a | Rabbitbrush | *Chrysothamnus nauseosus* | 11.957 | 207 | |
| SV2a | Mixed Grass | | 37.100 | | |
| SV2b | Pasture/Grassland | | 100.000 | | 100 |
| SV3 | Greasewood | *Sarcobatus vermiculatus* | 21.800 | 242 | 32 |
| SV3 | Rabbitbrush | *Chrysothamnus nauseosus* | 8.800 | 90 | |
| SV3 | Shadscale | *Atriplex confertifolia* | 1.200 | 61 | |
| SV3 | Pickleweed | *Salicornia europeae* | 0.060 | 3 | |
| WRV1 | Greasewood | *Sarcobatus vermiculatus* | 50.096 | 286 | 62 |
| WRV1 | Sagebrush | *Artemisia tridentata* | 11.836 | 255 | |
| WRV1 | Buckwheat | | 0.037 | 2 | |
| WRV2 | Greasewood | *Sarcobatus vermiculatus* | 20.257 | 186 | 55 |
| WRV2 | Sagebrush | *Artemisia tridentata* | 32.153 | 1469 | |
| WRV2 | Rabbitbrush | *Chrysothamnus nauseosus* | 0.001 | 246 | |
| WRV2 | Shadscale | *Atriplex confertifolia* | 2.664 | 1 | |
| WRV3 | Greasewood | *Sarcobatus vermiculatus* | 28.062 | 237 | 42 |
| WRV3 | Sagebrush | *Artemisia tridentata* | 1.759 | 149 | |
| WRV3 | Rabbitbrush | *Chrysothamnus nauseosus* | 7.585 | 558 | |
| WRV3 | Shadscale | *Atriplex confertifolia* | 4.101 | 198 | |
| WRV3 | Cactus | | 0.102 | 5 | |
| WRV3 | Grass | | 0.001 | 1 | |
| SNK1 | Greasewood | *Sarcobatus vermiculatus* | 52.498 | 692 | 62.4 |
| SNK1 | Sagebrush | *Artemisia tridentata* | 0.003 | 1 | |
| SNK1 | Shadscale | *Atriplex confertifolia* | 2.208 | 125 | |
| SNK1 | Annuals | | 0.217 | 102 | |
| SNK2 | Greasewood | *Sarcobatus vermiculatus* | | 145 | 13 |
| SNK2 | Sagebrush | *Artemisia tridentata* | | 62 | |
| SNK2 | Rabbitbrush | *Chrysothamnus nauseosus* | | 277 | |
| SNK2 | Shadscale | *Atriplex confertifolia* | | 264 | |
| SNK2 | Saltlover | *Halogeton glomeratus* | | 519 | |
| SNK2 | Annuals | | | 12 | |

Table 3: Soil Textural Analysis

| Site | Depth (cm) | Moisture (g/g) | Gravel >2 mm | Sand >62.5 um | Silt 15-62.5 um | Silt 3-15 um | Clay <3 um | sum of fraction <2mm % |
|---|---|---|---|---|---|---|---|---|
| WRV1 | 0.0-21.6 | 0.070 | 0 | 21.2 | 27.4 | 21.7 | 29.6 | 99.9 |
| WRV1 | 21.6-43.1 | 0.062 | 0 | 30.2 | 29.3 | 19.4 | 21.1 | 100.0 |
| WRV1 | 43.1-64.8 | 0.073 | 0 | 30.4 | 25.5 | 20.9 | 23.1 | 99.9 |
| WRV1 | 64.8-86.4 | 0.078 | 0 | 39.8 | 20.7 | 18.8 | 20.6 | 99.9 |
| WRV1 | 86.4-108.0 | 0.086 | 0.4 | 38.4 | 18.5 | 20.1 | 23.1 | 100.1 |
| WRV1 | 108.0-129.5 | 0.120 | 0 | 19.5 | 16.8 | 31.8 | 32 | 100.1 |
| WRV1 | 129.5-151.1 | 0.133 | 0.7 | 15.5 | 17 | 34.8 | 32.7 | 100.0 |
| WRV2 | 0-21.6 | 0.052 | 1.9 | 29 | 17.3 | 28.7 | 25.1 | 100.1 |
| WRV2 | 21.6-43.2 | 0.093 | 2.6 | 34.8 | 16.6 | 25.9 | 22.7 | 100.0 |
| WRV2 | 43.2-64.8 | 0.183 | 9.8 | 19.4 | 13.1 | 29.2 | 38.4 | 100.1 |
| WRV2 | 64.8-86.3 | 0.145 | 2 | 57.3 | 11.4 | 14.6 | 16.7 | 100.0 |
| WRV2 | 86.3-108.0 | 0.163 | 12.3 | 46.7 | 12.4 | 15.8 | 25 | 99.9 |
| WRV2 | 108.0-129.5 | 0.196 | 0.5 | 41.2 | 14.6 | 16.9 | 27.4 | 100.1 |
| WRV2 | 129.5-151.1 | 0.212 | 0.3 | 44 | 14.5 | 18.8 | 22.7 | 100.0 |
| WRV2 | 129.5-139.7 | 0.199 | 0.7 | 56.2 | 12.3 | 14 | 17.6 | 100.1 |
| WRV3 | 0.0-28.0 | 0.014 | 13.3 | 33.9 | 44.4 | | 21.7 | 100.0 |
| WRV3 | 28.0-56.0 | 0.017 | 13.7 | 37.5 | 42.7 | | 19.8 | 100.0 |
| WRV3 | 56.0-84.0 | 0.016 | 3.0 | 39.9 | 40.6 | | 19.5 | 100.0 |
| WRV3 | 84.0-112.0 | 0.020 | 3.7 | 29.1 | 48.4 | | 22.5 | 99.9 |
| WRV3 | 112.0-140.0 | 0.023 | 7.5 | 45.5 | 44.2 | | 10.3 | 100.0 |
| WRV3 | 140.0-168.0 | 0.026 | 4.9 | 38.9 | 51.7 | | 9.4 | 100.0 |
| WRV3 | 168.0-196.0 | 0.017 | 2.9 | 27.5 | 59.0 | | 13.6 | 100.1 |
| SV1 | 0-28.0 | 0.093 | 11.4 | 85.2 | 4.3 | 4.7 | 5.9 | 100.1 |
| SV1 | 28.0-56.0 | 0.104 | 13.6 | 81.7 | 4.3 | 4.7 | 9.4 | 100.1 |
| SV1 | 56.0-84.0 | 0.132 | 14.3 | 72.3 | 4.1 | 4.7 | 19 | 100.1 |
| SV1 | 84.0-112.0 | 0.071 | 27.2 | 86.2 | 2.7 | 3.3 | 7.8 | 100.0 |
| SV1 | 112.0-140.0 | 0.053 | 18.4 | 90.4 | 2.3 | 2.5 | 4.8 | 100.0 |
| SV2a | 0.0-28.0 | 0.226 | 0.1 | 11.3 | 16 | 34.4 | 38.3 | 100.0 |
| SV2a | 28.0-56.0 | 0.234 | 8.1 | 10.4 | 13.5 | 31.1 | 45 | 100.0 |
| SV2a | 56.0-84.0 | 0.302 | 11 | 4.2 | 12.5 | 33.2 | 50.1 | 100.0 |
| SV2a | 84.0-112.0 | 0.330 | 1.4 | 4.3 | 12.2 | 35.3 | 48.2 | 100.0 |
| SV2a | 112.0-140.0 | 0.287 | 0 | 5.2 | 10.6 | 34.8 | 49.5 | 100.1 |
| SV2a | 140.0-168.0 | 0.241 | 10.8 | 4.8 | 7 | 25 | 63.2 | 100.0 |
| SV2a | 168.0-196.0 | 0.257 | 0.3 | 2.8 | 9.6 | 33.2 | 54.4 | 100.0 |
| SV3* | 0.0-28.0 | 0.103 | 0.4 | 12.1 | 13.1 | 27.2 | 47.6 | 100.0 |
| SV3* | 28.0-56.0 | 0.127 | 0.2 | 16 | 15.4 | 25.9 | 42.7 | 100.0 |
| SV3* | 56.0-84.0 | 0.165 | 0.3 | 31.7 | 18.6 | 21.5 | 28.2 | 100.0 |
| SV3* | 84.0-112.0 | 0.182 | 0.7 | 34.9 | 20.7 | 19.3 | 25 | 99.9 |
| SV3* | 112.0-140.0 | 0.150 | 3.1 | 27.8 | 12 | 16.8 | 43.4 | 100.0 |
| SV3* | 140.0-168.0 | 0.043 | 5.5 | 57 | 16.2 | 14.1 | 12.6 | 99.9 |
| SV3* | 168.0-196.0 | 0.076 | 3.6 | 47.3 | 21.3 | 18 | 13.4 | 100.0 |

Table 3 continued: Soil Textural Analysis

| Site | Depth (cm) | Moisture (g/g) | Gravel >2 mm | Sand >62.5 um | Silt 15-62.5 um | Silt 3-15 um | Clay <3 um | sum of fraction <2mm % |
|---|---|---|---|---|---|---|---|---|
| SV3 | Surface | 0.002 | 19.1 | 74.1 | 14.9 | | 11.0 | 100.0 |
| SV3 | 0-45.72 | 0.003 | 8.8 | 75.1 | 12.5 | | 12.4 | 100.0 |
| SV3 | 304.8-350.5 | 0.000 | 65.4 | 87.9 | 8.8 | | 3.3 | 100.0 |
| SV3 | 457.2-502.9 | 0.007 | 0.8 | 18.6 | 66.3 | | 15.0 | 99.9 |
| SV3 | 914.4-960.12 | 0.002 | 4.5 | 96.3 | 2.6 | | 1.1 | 100.0 |
| SV3 | 1066.8-1112.5 | 0.003 | 24.2 | 92.3 | 5.3 | | 2.4 | 100.0 |
| SNK1 | Surface | 0.005 | 6.8 | 42.6 | 34.4 | | 23.1 | 100.1 |
| SNK1 | 152.4-198.1 | 0.008 | 2.1 | 38.8 | 36.2 | | 24.9 | 99.9 |
| SNK1 | 304.8-350.5 | 0.016 | 8.3 | 13.5 | 45.7 | | 40.9 | 100.1 |
| SNK1 | 457.2-502.9 | 0.003 | 58.4 | 90.7 | 5.4 | | 3.9 | 100.0 |
| SNK1 | 609.6-655.3 | 0.002 | 61.9 | 96.4 | 1.9 | | 1.7 | 100.0 |
| SNK1 | 762-807.7 | 0.004 | 61.5 | 93.0 | 4.3 | | 2.7 | 100.0 |
| SNK1 | 914.4-960.12 | 0.004 | 35.3 | 97.0 | 1.6 | | 1.4 | 100.0 |
| SNK1 | 1066.8-1112.5 | 0.002 | 53.9 | 94.2 | 3.3 | | 2.5 | 100.0 |
| SNK1 | 1112.52-1158.24 | 0.012 | 0.6 | 94.8 | 3.0 | | 2.2 | 100.0 |
| SNK2 | Surface | 0.002 | 1.9 | 26.4 | 30.4 | | 43.2 | 100.0 |
| SNK2 | 152.4-198.1 | 0.004 | 23.9 | 51.6 | 35.4 | | 13.0 | 100.0 |
| SNK2 | 304.8-350.5 | 0.003 | 5.6 | 54.6 | 34.3 | | 11.1 | 100.0 |
| SNK2 | 457.2-502.9 | 0.006 | 1.4 | 23.7 | 55.3 | | 21.1 | 100.1 |
| SNK2 | 609.6-655.3 | 0.007 | 0.5 | 13.5 | 48.3 | | 38.2 | 100.0 |
| SNK2 | 762-807.7 | no sample | | | | | | |
| SNK2 | 914.4-960.12 | 0.001 | 54.1 | 88.6 | 8.3 | | 3.2 | 100.0 |
| SNK2 | 1066.8-1112.5 | 0.020 | 1.3 | 8.2 | 71.7 | | 20.1 | 100.0 |
| SNK2 | 1219.2-1264.9 | 0.019 | 3.4 | 21.5 | 59.6 | | 18.9 | 100.0 |
| SNK2 | 1371.6-1417.3 | 0.023 | 8.9 | 40.0 | 40.1 | | 19.9 | 99.9 |
| SNK2 | 1524-1569.7 | 0.024 | 2.7 | 35.1 | 46.5 | | 18.4 | 100.0 |

*abandoned artesian site

**Table 4: Soil gravimetric water content, volumetric water content and bulk density of Spring Valley, White River Valley and Snake Valley sites**

| Site Location | Gravimetric Water Content | Volumetric Water Content | Bulk Density |
|---|---|---|---|
| | (g/g) | ($m^3/m^3$) | ($kg/m^3$) |
| SV 1_C1 | | | |
| SV 1_C2 | 0.060 | 0.102 | 1720.02 |
| SV 1b_C1 | 0.046 | 0.066 | 1443.08 |
| | | | |
| SV 2b_C1 | | | |
| SV2b_C1 | 0.500 | 0.759 | 1516.51 |
| SV 2_C1 | 0.064 | 0.062 | 960.42 |
| | | | |
| SV 3_C1 | 0.028 | 0.036 | 1302.40 |
| SV 3b_C1 | 0.218 | 0.274 | 1255.68 |
| | | | |
| Snake 1_C1 | | | |
| Snake 1_C2 | 0.051 | 0.078 | 1518.72 |
| Snake 1b_C1 | | | |
| Snake 1b_C2 | 0.157 | 0.255 | 1623.40 |
| | | | |
| Snake 2_C1 | | | |
| Snake 2_C2 | 0.023 | 0.041 | 1805.84 |
| Snake 2b_C1 | | | |
| Snake 2b_C2 | 0.018 | 0.037 | 2021.86 |
| | | | |
| WRV 2_C1 | | | |
| WRV 2_C2 | 0.019 | 0.031 | 1665.00 |

Table 5: Ion Analysis of Soil Saturation Extracts from Spring Valley, White River Valley and Snake Valley Sites

| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/8/2007 | SNK1 | Surface | 1.097 | 10.58 | 0.98 | | 0.37 | 0.70 | 2.63 | 0.17 | 0.50 | 0 | 5.6 | 8.90 | 12.63 |
| 5/8/2007 | SNK1 | 1.52-1.98 | 18.24 | 108.72 | 1.85 | | 58.10 | 43.67 | 154.83 | 1.45 | 116.28 | 0 | 1.9 | 274.47 | 212.34 |
| 5/8/2007 | SNK1 | 3.05-3.51 | 14.07 | 140.35 | 1.37 | | 61.88 | 32.93 | 137.11 | 1.36 | 54.86 | 0 | 1.2 | 194.54 | 236.53 |
| 5/8/2007 | SNK1 | 4.57-5.03 | 1.0322 | 6.77 | 0.05 | | 3.33 | 2.39 | 2.48 | 0.13 | 6.24 | 0 | 1.8 | 10.65 | 12.54 |
| 5/8/2007 | SNK1 | 6.10-6.55 | 0.9527 | 1.02 | 0.08 | | 3.07 | 5.14 | 0.70 | 0.05 | 8.69 | 0 | 1.3 | 10.73 | 9.30 |
| 5/8/2007 | SNK1 | 7.62-8.08 | 2.247 | 2.96 | 0.17 | | 8.03 | 16.23 | 0.99 | 0.05 | 24.97 | 0 | 1.1 | 27.11 | 27.39 |
| 5/8/2007 | SNK1 | 9.14-9.60 | 0.3514 | 0.61 | 0.04 | | 0.91 | 1.62 | 0.29 | 0.03 | 1.74 | 0 | 1.4 | 3.46 | 3.19 |
| 5/8/2007 | SNK1 | 10.67-11.13 | 0.3206 | 1.07 | 0.05 | | 0.62 | 1.13 | 0.64 | 0.03 | 0.61 | 0 | 1.6 | 2.88 | 2.87 |
| 5/8/2007 | SNK1 | 11.13-11.58 | 0.2884 | 0.99 | 0.11 | | 0.64 | 1.04 | 0.46 | 0.09 | 0.62 | 0 | 0.5 | 1.67 | 2.77 |
| **Sample Date** | **Sample Name** | **Depth (m)** | **$EC_e$ (dS/m)** | **NA (mEq/L)** | **K (mEq/L)** | **NH4 (mEq/L)** | **CA (mEq/L)** | **MG (mEq/L)** | **CL (mEq/L)** | **NO3 (mEq/L)** | **SO4 (mEq/L)** | **CO3 (mEq/L)** | **HCO3 (mEq/L)** | **Cations** | **Anions** |
| 5/11/2007 | SNK2 | Surface | 8.262 | 102.64 | 1.37 | | 1.75 | 5.69 | 75.36 | 0.72 | 14.41 | 0 | 5.3 | 95.79 | 111.45 |
| 5/11/2007 | SNK2 | 1.52-1.98 | 22.16 | 245.75 | 0.48 | | 22.56 | 63.45 | 349.80 | 3.13 | 35.92 | 0 | 2 | 390.85 | 332.25 |
| 5/11/2007 | SNK2 | 3.05-3.51 | 19.23 | 153.06 | 0.47 | | 36.93 | 82.83 | 233.87 | 2.19 | 24.01 | 0 | 1.4 | 261.47 | 273.29 |
| 5/11/2007 | SNK2 | 4.57-5.03 | 2.001 | 7.50 | 0.06 | | 2.46 | 10.34 | 13.44 | 0.23 | 2.14 | 0 | 1.4 | 17.22 | 20.36 |
| 5/11/2007 | SNK2 | 6.10-6.55 | 0.6847 | 4.16 | 0.03 | | 0.59 | 3.36 | 2.25 | 0.07 | 0.77 | 0 | 3.4 | 6.48 | 8.13 |
| 5/11/2007 | SNK2 | 7.62-8.08 | 0.72 | 2.05 | 0.04 | | 0.67 | 4.03 | 3.05 | 0.08 | 1.05 | 0 | 1.6 | 5.78 | 6.79 |
| 5/11/2007 | SNK2 | 9.14-9.60 | 0.5692 | 2.78 | 0.03 | | 0.43 | 2.51 | 1.59 | 0.05 | 1.36 | 0 | 2 | 5.00 | 5.75 |
| 5/11/2007 | SNK2 | 10.67-11.13 | 0.341 | 1.12 | 0.02 | | 0.33 | 1.92 | 0.95 | 0.05 | 0.56 | 0 | 1.6 | 3.15 | 3.39 |
| 5/11/2007 | SNK2 | 12.19-12.65 | 0.4958 | 1.28 | 0.02 | | 0.40 | 2.05 | 1.56 | 0.06 | 0.58 | 0 | 1.6 | 3.80 | 3.75 |
| 5/11/2007 | SNK2 | 13.72-14.17 | 0.48 | 1.65 | 0.04 | | 0.55 | 2.20 | 1.35 | 0.08 | 0.82 | 0 | 1.7 | 3.95 | 4.45 |
| 5/11/2007 | SNK2 | 15.24-15.70 | 0.4084 | 1.14 | 0.04 | | 0.45 | 2.16 | 1.04 | 0.07 | 0.62 | 0 | 1.8 | 3.53 | 3.80 |
| **Sample Date** | **Sample Name** | **Depth (m)** | **$EC_e$ (dS/m)** | **NA (mEq/L)** | **K (mEq/L)** | **NH4 (mEq/L)** | **CA (mEq/L)** | **MG (mEq/L)** | **CL (mEq/L)** | **NO3 (mEq/L)** | **SO4 (mEq/L)** | **CO3 (mEq/L)** | **HCO3 (mEq/L)** | **Cations** | **Anions** |
| 5/16/2006 | SV 1 | 0.0-1.98 | 4.493 | 43.79 | 0.00 | 0.71 | 0.69 | 3.93 | 30.78 | 0.22 | 23.00 | 0.8 | 7.9 | 62.69 | 49.11 |
| 5/16/2006 | SV 1 | 3.05-3.51 | 6.484 | 41.25 | 0.00 | 0.00 | 10.85 | 27.73 | 81.65 | 0.00 | 16.73 | 0 | 3 | 101.38 | 79.84 |
| 5/16/2006 | SV 1 | 4.57-5.03 | 1.905 | 7.92 | 0.00 | 0.46 | 2.24 | 8.24 | 13.70 | 0.00 | 3.70 | 0 | 2.1 | 19.50 | 18.85 |
| 5/16/2006 | SV 1 | 6.10-6.55 | 0.8207 | 2.04 | 0.00 | 0.27 | 0.91 | 4.03 | 2.86 | 0.02 | 1.92 | 0 | 3.3 | 8.09 | 7.25 |
| 5/16/2006 | SV 1 | 7.62-7.92 | 0.8182 | 2.00 | 0.00 | 0.31 | 0.97 | 3.97 | 3.52 | 0.02 | 1.98 | 0 | 2 | 7.52 | 7.25 |

Table 5 continued: Ion Analysis of Soil Saturation Extracts from Spring Valley, White River Valley and Snake Valley Sites

| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/15/2006 | SV 1 | 0.0-0.30 | 0.4323 | 1.18 | 0.00 | 0.40 | 0.38 | 1.89 | 0.28 | 0.06 | 0.28 | 0 | 4.1 | 4.73 | 3.85 |
| 6/15/2006 | SV 1 | 0.30-0.60 | 0.2417 | 1.00 | 0.00 | 0.25 | 0.27 | 1.73 | 0.18 | 0.04 | 0.16 | 0 | 2.4 | 2.78 | 3.25 |
| 6/15/2006 | SV 1 | 0.60-0.75 | 0.3874 | 1.15 | 0.00 | 0.63 | 0.52 | 3.42 | 0.21 | 0.03 | 0.27 | 0 | 4.1 | 4.61 | 5.72 |
| **Sample Date** | **Sample Name** | **Depth (m)** | **$EC_e$ (dS/m)** | **NA (mEq/L)** | **K (mEq/L)** | **NH4 (mEq/L)** | **CA (mEq/L)** | **MG (mEq/L)** | **CL (mEq/L)** | **NO3 (mEq/L)** | **SO4 (mEq/L)** | **CO3 (mEq/L)** | **HCO3 (mEq/L)** | **Cations** | **Anions** |
| 6/15/2006 | SV2a | 0.0-0.30 | 12.4 | 69.98 | 0.00 | 7.75 | 21.59 | 15.86 | 31.37 | 0.61 | 109.61 | 0 | 5.1 | 146.70 | 115.17 |
| 6/15/2006 | SV2a | 0.30-0.60 | 3.247 | 14.01 | 0.00 | 1.70 | 2.91 | 0.00 | 6.54 | 0.00 | 17.80 | 0 | 13.4 | 37.74 | 18.62 |
| 6/15/2006 | SV2a | 0.60-0.90 | 1.252 | 4.06 | 0.00 | 0.47 | 2.72 | 7.96 | 2.87 | 0.00 | 8.29 | 0 | 11.8 | 22.96 | 15.22 |
| **Sample Date** | **Sample Name** | **Depth (m)** | **$EC_e$ (dS/m)** | **NA (mEq/L)** | **K (mEq/L)** | **NH4 (mEq/L)** | **CA (mEq/L)** | **MG (mEq/L)** | **CL (mEq/L)** | **NO3 (mEq/L)** | **SO4 (mEq/L)** | **CO3 (mEq/L)** | **HCO3 (mEq/L)** | **Cations** | **Anions** |
| 5/16/2006 | SV 3 | 1.52-1.98 | 0.7134 | 5.04 | 0.00 | 0.39 | 1.14 | 2.92 | 0.88 | 0.02 | 1.29 | 0.5 | 5.2 | 7.89 | 9.49 |
| 5/16/2006 | SV 3 | 3.05-3.51 | 0.05922 | 2.53 | 0.00 | 0.10 | 0.17 | 2.68 | 0.66 | 0.01 | 1.80 | 0 | 3.5 | 5.97 | 5.47 |
| 5/16/2006 | SV 3 | 4.57-5.03 | 0.499 | 1.83 | 0.00 | 0.05 | 0.37 | 2.45 | 0.65 | 0.02 | 1.39 | 0 | 3.3 | 5.36 | 4.70 |
| 5/16/2006 | SV 3 | 6.10-6.55 | 0.5064 | 1.99 | 0.00 | 0.00 | 0.36 | 3.02 | 0.55 | 0.02 | 1.12 | 0 | 3.7 | 5.40 | 5.36 |
| **Sample Date** | **Sample Name** | **Depth (m)** | **$EC_e$ (dS/m)** | **NA (mEq/L)** | **K (mEq/L)** | **NH4 (mEq/L)** | **CA (mEq/L)** | **MG (mEq/L)** | **CL (mEq/L)** | **NO3 (mEq/L)** | **SO4 (mEq/L)** | **CO3 (mEq/L)** | **HCO3 (mEq/L)** | **Cations** | **Anions** |
| 6/15/2006 | SV 3 | 0.0-0.30 | 5.162 | 77.17 | 0.00 | 7.68 | 0.00 | 20.18 | 13.66 | 0.00 | 45.11 | 3 | 14.5 | 76.27 | 105.04 |
| 6/15/2006 | SV 3 | 0.30-0.60 | 9.908 | 127.89 | 0.00 | 10.84 | 0.00 | 4.54 | 33.31 | 0.28 | 132.08 | 0 | 4.2 | 169.87 | 143.27 |
| 6/15/2006 | SV 3 | 0.60-0.90 | 8.087 | 116.20 | 0.00 | 5.47 | 2.54 | 13.36 | 47.90 | 0.49 | 79.02 | 1.4 | 27.6 | 156.41 | 137.57 |
| **Sample Date** | **Sample Name** | **Depth (m)** | **$EC_e$ (dS/m)** | **NA (mEq/L)** | **K (mEq/L)** | **NH4 (mEq/L)** | **CA (mEq/L)** | **MG (mEq/L)** | **CL (mEq/L)** | **NO3 (mEq/L)** | **SO4 (mEq/L)** | **CO3 (mEq/L)** | **HCO3 (mEq/L)** | **Cations** | **Anions** |
| 06/18/04 | SV1 | 0.0-0.28 | 0.399 | 0.37 | 0.41 | | 4.15 | 2.07 | 0.43 | | 2.17 | | | 7.00 | 2.61 |
| 06/18/04 | SV1 | 0.28-0.56 | 0.3331 | 0.15 | 0.21 | | 4.15 | 2.08 | 0.18 | | 2.17 | | | 6.59 | 2.35 |
| 06/18/04 | SV1 | 0.56-0.84 | 0.3052 | 0.28 | 0.38 | | 2.07 | 2.08 | 0.14 | | 4.24 | | | 4.80 | 4.38 |
| 06/18/04 | SV1 | 0.84-1.12 | 0.3 | 0.40 | 0.39 | | 2.07 | 1.04 | 0.18 | | 2.17 | | | 3.91 | 2.36 |
| 06/18/04 | SV1 | 1.12-1.40 | 0.3551 | 0.63 | 0.68 | | 2.07 | 2.08 | 0.87 | | 2.17 | | | 5.45 | 3.04 |

Table 5 continued: Ion Analysis of Soil Saturation Extracts from Spring Valley, White River Valley and Snake Valley Sites

| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 06/18/04 | SV2a | 0.0-0.28 | 17.43 | 138.54 | 13.43 | | 37.35 | 128.65 | 87.10 | | 232.46 | | | 317.97 | 319.56 |
| 06/18/04 | SV2a | 0.28-0.56 | 18.42 | 134.75 | 9.49 | | 25.94 | 147.33 | 69.51 | | 175.18 | | | 317.50 | 244.69 |
| 06/18/04 | SV2a | 0.56-0.84 | 7.993 | 8.02 | 5.62 | | 10.38 | 41.50 | 36.75 | | 50.30 | | | 65.52 | 87.05 |
| 06/18/04 | SV2a | 0.84-1.12 | 3.324 | 11.01 | 1.97 | | 6.23 | 14.53 | 11.52 | | 22.45 | | | 33.73 | 33.98 |
| 06/18/04 | SV2a | 1.12-1.40 | 2.541 | 6.43 | 1.49 | | 6.23 | 16.60 | 5.69 | | 14.94 | | | 30.74 | 20.64 |
| 06/18/04 | SV2a | 1.40-1.68 | 1.14 | 2.72 | 0.47 | | 6.23 | 4.15 | 1.77 | | 5.93 | | | 13.57 | 7.70 |
| 06/18/04 | SV2a | 1.68-1.96 | 0.9548 | 1.47 | 0.23 | | 6.23 | 4.15 | 0.97 | | 6.49 | | | 12.08 | 7.46 |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 09/10/04 | SV2a | 2.57-2.85 | 1.992 | 5.26 | 0.70 | | 10.38 | 19.71 | 2.88 | | 15.01 | | | 36.05 | 17.89 |
| 09/10/04 | SV2a | 2.90-3.07 | 1.0102 | 3.28 | 0.32 | | 7.26 | 6.23 | 1.27 | | 5.39 | | | 17.09 | 6.66 |
| 09/10/04 | SV2a | 3.10-3.25 | 1.0091 | 2.59 | 0.38 | | 6.23 | 5.19 | 1.07 | | 5.55 | | | 14.39 | 6.62 |
| 09/10/04 | SV2a | 3.28-3.43 | 1.22 | 0.56 | 2.49 | | 3.11 | 10.38 | 1.65 | | 7.15 | | | 16.55 | 8.80 |
| 09/10/04 | SV2a | 3.45-3.61 | | | | | 3.11 | 10.38 | | | | | | 13.49 | 0.00 |
| 09/10/04 | SV2a | 3.63-3.79 | 0.8087 | 1.67 | 0.49 | | 4.15 | 6.23 | 0.65 | | 3.80 | | | 12.54 | 4.46 |
| 09/10/04 | SV2a | 3.81-3.94 | 1.418 | 3.32 | 0.76 | | 4.15 | 13.49 | 1.90 | | 8.97 | | | 21.72 | 10.87 |
| 09/10/04 | SV2a | 3.96-4.12 | 8.293 | 57.11 | 0.59 | | 3.11 | 85.08 | 20.74 | | 42.18 | | | 145.89 | 62.92 |
| 09/10/04 | SV2a | 4.14-4.29 | 0.8712 | | | | | | | | | | | | |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 06/18/04 | SV3 | 0.0-0.28 | NES | | | | | | | | | | | 0.00 | 0.00 |
| 06/18/04 | SV3 | 0.28-0.56 | 13.56 | 0.52 | 16.50 | | 1.04 | 1.04 | 27.00 | | 82.84 | | | 19.09 | 109.84 |
| 06/18/04 | SV3 | 0.56-0.84 | 14.23 | 146.83 | 9.74 | | 1.04 | 0.00 | 37.95 | | 85.47 | | | 157.60 | 123.43 |
| 06/18/04 | SV3 | 0.84-1.12 | 9.893 | 99.21 | 11.21 | | 3.11 | 0.00 | 52.33 | | 39.65 | | | 113.53 | 91.98 |
| 06/18/04 | SV3 | 1.12-1.40 | 7.018 | 67.12 | 2.24 | | 3.11 | 4.15 | 43.58 | | 18.99 | | | 76.62 | 62.58 |
| 06/18/04 | SV3 | 1.40-1.68 | 8.741 | 102.66 | 6.35 | | 5.19 | 6.23 | 76.25 | | 51.67 | | | 120.42 | 127.91 |
| 06/18/04 | SV3 | 1.68-1.96 | 1.977 | 8.48 | 0.85 | | 1.04 | 3.11 | 6.50 | | 9.60 | | | 13.48 | 16.10 |

Table 5 continued: Ion Analysis of Soil Saturation Extracts from Spring Valley, White River Valley and Snake Valley Sites

| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10/14/04 | SV3 | 1.34-1.46 | 2.635 | 27.02 | 1.71 | | 4.15 | 1.66 | 3.08 | | 9.30 | | | 34.54 | 12.38 |
| 10/14/04 | SV3 | 1.43-1.64 | 0.8892 | 7.14 | 0.22 | | 0.00 | 0.41 | 0.97 | | 2.14 | | | 7.78 | 3.11 |
| 10/14/04 | SV3 | 1.64-1.76 | 1.562 | 15.17 | 0.41 | | 1.66 | 2.91 | 2.66 | | 6.01 | | | 20.14 | 8.67 |
| 10/14/04 | SV3 | 1.76-1.88 | 1.676 | 16.34 | 0.21 | | 1.04 | 2.08 | 3.30 | | 4.79 | | | 19.67 | 8.09 |
| 10/14/04 | SV3 | 1.85-2.01 | 2.825 | 29.28 | 0.60 | | 4.15 | 4.15 | 5.96 | | 9.81 | | | 38.18 | 15.78 |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 01/20/05 | SV3 | 0.0-0.50 | 1.924 | 21.22 | 0.64 | | 7.26 | 6.23 | 2.43 | | 4.38 | | | 35.35 | 6.82 |
| 01/20/05 | SV3 | 0.50-1.00 | 9.731 | 42.96 | 0.33 | | 52.91 | 70.55 | 105.12 | | 26.07 | | | 166.75 | 131.20 |
| 01/20/05 | SV3 | 1.00-1.50 | 1.027 | | 0.33 | | 2.07 | 2.08 | | | | | | 4.48 | 0.00 |
| 01/20/05 | SV3 | 1.50-2.00 | 11.04 | 61.25 | 0.95 | | 47.72 | 60.18 | 114.95 | | 19.55 | | | 170.10 | 134.49 |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 5/10/2007 | SV3 | Surface | 0.6987 | 2.41 | 0.06 | | 0.80 | 3.49 | 0.19 | 0.02 | 0.38 | 0 | 6.6 | 7.19 | 6.76 |
| 5/10/2007 | SV3 | 0.0-0.46 | 1.031 | 3.40 | 1.17 | | 1.51 | 5.01 | 1.30 | 0.08 | 1.92 | 1.5 | 7.1 | 11.89 | 11.08 |
| 5/10/2007 | SV3 | 1.52-1.98 | 4.874 | 54.14 | 3.02 | | 0.26 | 1.19 | 15.55 | 0.35 | 27.69 | 0.5 | 1.8 | 45.87 | 58.61 |
| 5/10/2007 | SV3 | 3.05-3.51 | 0.8234 | 5.68 | 0.28 | | 0.63 | 2.09 | 1.94 | 0.06 | 3.18 | 0 | 2 | 7.18 | 8.68 |
| 5/10/2007 | SV3 | 4.57-5.03 | 0.5496 | 1.71 | 0.12 | | 0.73 | 2.89 | 1.93 | 0.07 | 3.18 | 0 | 2.4 | 7.58 | 5.45 |
| 5/10/2007 | SV3 | 6.10-6.55 | 0.7564 | 1.84 | 0.27 | | 0.94 | 4.15 | 0.97 | 0.05 | 4.30 | 0 | 2.4 | 7.72 | 7.21 |
| 5/10/2007 | SV3 | 7.62-8.08 | 0.4798 | 1.31 | 0.10 | | 0.58 | 2.51 | 0.41 | 0.04 | 2.29 | 0 | 2.6 | 5.35 | 4.50 |
| 5/10/2007 | SV3 | 9.14-9.60 | 0.4452 | 1.28 | 0.06 | | 0.54 | 2.32 | 0.41 | 0.04 | 2.04 | 0 | 1.7 | 4.20 | 4.20 |
| 5/10/2007 | SV3 | 10.67-11.13 | 0.4508 | 1.48 | 0.08 | | 0.52 | 2.30 | 0.42 | 0.05 | 1.70 | 0 | 2.2 | 4.37 | 4.39 |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 06/17/04 | WRV1 | 0.0-0.22 | NES | | | | | | | | | | | | |
| 06/17/04 | WRV1 | 0.22-0.43 | 5.827 | 15.57 | 0.10 | | 26.98 | 22.83 | 46.90 | | 10.07 | | | 65.47 | 56.97 |
| 06/17/04 | WRV1 | 0.43-0.65 | 1.039 | 4.53 | | | 2.07 | 2.08 | 2.98 | | 1.09 | | | 8.68 | 4.07 |
| 06/17/04 | WRV1 | 0.65-0.86 | 4.272 | 13.56 | 0.02 | | 12.45 | 24.90 | 31.02 | | 11.57 | | | 50.94 | 42.59 |
| 06/17/04 | WRV1 | 0.86-1.08 | 8.004 | 12.62 | 0.07 | | 35.28 | 89.23 | 38.36 | | 34.04 | | | 137.19 | 72.40 |
| 06/17/04 | WRV1 | 1.08-1.30 | 9.704 | 13.23 | 0.10 | | 45.65 | 116.20 | 41.77 | | 53.52 | | | 175.18 | 95.29 |
| 06/17/04 | WRV1 | 1.30-1.51 | 9.474 | 18.36 | 0.41 | | 43.58 | 118.28 | 37.65 | | 49.78 | | | 180.61 | 87.43 |

Table 5 continued: Ion Analysis of Soil Saturation Extracts from Spring Valley, White River Valley and Snake Valley Sites

| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01/21/05 | WRV1 | 0.0-0.50 | 7.31 | 73.94 | 0.21 | | 4.15 | 12.45 | 22.09 | | 13.25 | | | 90.75 | 35.34 |
| 01/21/05 | WRV1 | 0.50-1.00 | 21.87 | 178.58 | 0.09 | | 58.10 | 114.13 | 65.73 | | 69.59 | | | 350.89 | 135.32 |
| 01/21/05 | WRV1 | 1.00-1.50 | 13.97 | 115.21 | 0.52 | | 41.50 | 64.33 | 39.22 | | 78.59 | | | 221.55 | 117.81 |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 6/15/2006 | WRV1 | 0.0-0.30 | 0.8959 | 6.37 | 0.00 | 0.81 | 9.77 | 0.00 | 0.80 | 0.06 | 0.75 | 1.2 | 8.1 | 10.90 | 16.96 |
| 6/15/2006 | WRV1 | 0.30-0.60 | 2.166 | 15.40 | 0.00 | 0.17 | 0.00 | 0.62 | 4.52 | 0.00 | 4.83 | 1 | 9 | 19.35 | 16.19 |
| 6/15/2006 | WRV1 | 0.60-0.90 | 10.707 | 54.11 | 0.00 | 0.40 | 15.47 | 39.50 | 50.76 | 9.06 | 100.72 | 0 | 10.5 | 171.04 | 109.49 |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 01/21/05 | WRV1/RN-G E | 0.0-0.23 | 0.9342 | 2.66 | 3.21 | | 3.11 | 1.04 | 0.79 | | 1.29 | | | 10.02 | 2.08 |
| 01/21/05 | WRV1/RN-G E | 0.23-0.41 | 0.9706 | 4.97 | 3.01 | | 2.07 | 4.15 | 1.00 | | 1.86 | | | 14.21 | 2.86 |
| 01/21/05 | WRV1/RN-G W | 0.18-0.31 | 0.6052 | 2.14 | 0.32 | | 2.07 | 4.15 | 0.65 | | 0.80 | | | 8.68 | 1.45 |
| 01/21/05 | WRV1/RN-G W | 0.31-0.38 | 0.6705 | 3.49 | 0.12 | | 2.08 | 5.19 | 0.72 | | 2.05 | | | 10.87 | 2.78 |
| 01/21/05 | WRV1/RN-G W | 0.38-0.46 | | | | | | | | | | | | | |
| 01/21/05 | WRV1/RN-G W | 0.46-0.61 | 1.48 | 12.41 | 0.11 | | 2.07 | 4.15 | 8.34 | | 2.38 | | | 18.74 | 10.72 |
| 01/21/05 | WRV1RN-G W | 0.0-0.18 | 0.759 | 3.19 | 0.37 | | | | 1.02 | | 1.90 | | | 3.56 | 2.92 |
| Sample Date | Sample Name | Depth (m) | $EC_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 06/17/04 | WRV2 | 0.0-0.22 | 0.7946 | | | | | | 1.37 | | 2.75 | | | 0.00 | 4.12 |
| 06/17/04 | WRV2 | 0.22-0.43 | 1.912 | 8.66 | 0.82 | | 2.07 | 4.15 | 13.73 | | 1.56 | | | 15.70 | 15.29 |
| 06/17/04 | WRV2 | 0.43-0.65 | 10.218 | 115.21 | 1.25 | | 7.26 | 5.19 | 74.34 | | 41.16 | | | 128.90 | 115.50 |
| 06/17/04 | WRV2 | 0.65-0.86 | 21.22 | 173.96 | 1.91 | | 28.01 | 62.25 | 113.03 | | 180.82 | | | 266.14 | 293.85 |
| 06/17/04 | WRV2 | 0.86-1.08 | 21.32 | 218.79 | 1.96 | | 30.09 | 61.21 | 117.45 | | 153.59 | | | 312.05 | 271.04 |
| 06/17/04 | WRV2 | 1.08-1.30 | 24.27 | 197.10 | 1.90 | | 35.28 | 77.81 | 161.27 | | 180.82 | | | 312.08 | 342.09 |
| 06/17/04 | WRV2 | 1.30-1.51 | 25.18 | 240.48 | 1.69 | | 31.13 | 95.45 | 155.84 | | 156.40 | | | 368.74 | 312.25 |
| 06/17/04 | WRV2 | 1.30-1.40 | 39.34 | 405.24 | 3.09 | | 45.65 | 194.64 | 411.99 | | 545.14 | | | 648.62 | 957.12 |

Table 5 continued: Ion Analysis of Soil Saturation Extracts from Spring Valley, White River Valley and Snake Valley Sites

| Sample Date | Sample Name | Depth (m) | EC$_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/16/2006 | WRV2 | 1.52-1.98 | 26.9 | 379.88 | 0.00 | 11.75 | 24.98 | 86.13 | 159.11 | 0.00 | 163.36 | 0 | 7.5 | 329.97 | 502.74 |
| 5/16/2006 | WRV2 | 3.05-3.51 | 14.38 | 129.45 | 0.00 | 0.00 | 23.23 | 19.97 | 126.53 | 0.00 | 189.34 | 0 | 1.6 | 317.47 | 172.64 |
| 5/16/2006 | WRV2 | 4.57-5.03 | 0.9382 | 21.59 | 0.00 | 0.00 | 10.19 | 9.67 | 18.91 | 0.01 | 33.23 | 0 | 3 | 55.15 | 41.45 |
| 5/16/2006 | WRV2 | 6.10-6.55 | 0.6263 | 6.96 | 0.00 | 0.08 | 0.35 | 0.21 | 1.52 | 0.02 | 2.19 | 0 | 2.5 | 6.23 | 7.60 |
| 5/16/2006 | WRV2 | 7.62-8.08 | 0.591 | 2.77 | 0.00 | 0.19 | 1.05 | 1.95 | 0.88 | 0.03 | 2.44 | 0 | 2.5 | 5.85 | 5.96 |
| 5/16/2006 | WRV2 | 9.14-9.60 | 0.5611 | 2.88 | 0.00 | 0.21 | 1.04 | 2.31 | 0.95 | 0.03 | 1.72 | 0 | 2.8 | 5.49 | 6.44 |
| 5/16/2006 | WRV2 | 10.67-11.13 | 0.6812 | 3.48 | 0.00 | 0.23 | 1.74 | 2.45 | 1.66 | 0.03 | 2.39 | 0 | 2.3 | 6.38 | 7.89 |
| 5/16/2006 | WRV2 | 12.19-12.65 | 0.735 | 4.11 | 0.00 | 0.34 | 1.71 | 3.90 | 1.39 | 0.03 | 2.61 | 0 | 3.7 | 7.73 | 10.06 |
| 6/15/2006 | WRV2 | 0.0-0.30 | 1.137 | 6.77 | 0.00 | 0.55 | 0.63 | 4.32 | 0.77 | 0.10 | 0.33 | 0 | 15.2 | 16.40 | 12.28 |
| 6/15/2006 | WRV2 | 0.30-0.60 | 4.72 | 28.54 | 0.00 | 0.63 | 0.00 | 2.34 | 49.06 | 0.53 | 7.40 | 0.9 | 7.2 | 65.09 | 31.51 |
| 6/15/2006 | WRV2 | 0.60-0.90 | 14.27 | 89.53 | 0.00 | 0.95 | 2.58 | 0.00 | 188.14 | 1.66 | 42.34 | 0 | 4.3 | 236.43 | 93.06 |
| Sample Date | Sample Name | Depth (m) | EC$_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 06/25/04 | WRV3 | 0.0-0.28 | 0.6655 | 1.62 | 1.04 | | 2.49 | 5.81 | 0.43 | | 1.09 | | | 10.96 | 1.52 |
| 06/25/04 | WRV3 | 0.28-0.56 | 0.6557 | 10.44 | 0.93 | | 0.00 | 2.70 | 0.46 | | 1.09 | | | 14.07 | 1.54 |
| 06/25/04 | WRV3 | 0.56-0.84 | 4.176 | 68.31 | 1.49 | | 0.00 | 3.53 | 21.87 | | 7.81 | | | 73.33 | 29.68 |
| 06/25/04 | WRV3 | 0.84-1.12 | 7.847 | 94.91 | 2.07 | | 0.00 | 0.21 | 38.36 | | 25.08 | | | 97.19 | 63.44 |
| 06/25/04 | WRV3 | 1.12-1.40 | 11.73 | 142.30 | 2.48 | | 1.87 | 3.32 | 55.04 | | 57.01 | | | 149.97 | 112.05 |
| 06/25/04 | WRV3 | 1.40-1.68 | 17.63 | 196.11 | 3.69 | | 30.09 | 42.54 | 68.00 | | 180.87 | | | 272.43 | 248.88 |
| 06/25/04 | WRV3 | 1.68-1.96 | 14.5 | 149.99 | 2.53 | | 26.98 | 47.73 | 59.06 | | 155.71 | | | 227.22 | 214.77 |
| Sample Date | Sample Name | Depth (m) | EC$_e$ (dS/m) | NA (mEq/L) | K (mEq/L) | NH4 (mEq/L) | CA (mEq/L) | MG (mEq/L) | CL (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Cations | Anions |
| 6/15/2006 | WRV3 | 0.0-0.30 | 0.6339 | 8.83 | 0.00 | 1.23 | 0.52 | 8.84 | 0.78 | 0.04 | 0.91 | 0 | 5.3 | 7.03 | 19.42 |
| 6/15/2006 | WRV3 | 0.30-0.60 | 2.096 | 11.68 | 0.00 | 0.58 | 3.51 | 0.53 | 8.62 | 0.08 | 3.58 | 0.6 | 7.2 | 20.08 | 16.30 |
| 6/15/2006 | WRV3 | 0.60-0.90 | 12.02 | 72.84 | 0.00 | 1.17 | 0.62 | 7.11 | 136.64 | 1.05 | 52.34 | 0 | 5.4 | 195.43 | 81.74 |

**Table 6: MET Station Equipment, Bandwidth and Output Units**

| Measurement | Instrument Type | Make and Model | Bandwidth | Output Units |
|---|---|---|---|---|
| Air pressure | Barometric pressure sensor | Vaisala CS105 | 1 Second | ºC |
| Sun plus sky radiation | Pyranometer sensor (400 to 1100nm) | LI-COR 200SZ | 1 Second | µmol $m^{-2}$ $s^{-1}$ |
| Air temperature | Capacitive RH sensor | Vaisala HMP45C | 1 Second | ºC |
| Relative Humidity | Capacitive RH sensor | Vaisala HMP45C | 1 Second | % |
| Wind speed | Cup/propeller anemometers | RM Young Wind Sentry &Monitor (05103) | 1 Second | m $s^{-1}$ |
| Wind direction | Wind vane | RM Young Wind Monitor | 1 Second | Degrees from north |
| Data logger | CR10X | Campbell Sci. | | |

| Table 7: Tissue Ion Analysis of Predominate Species in Spring Valley, White River Valley and Snake Valley Sites | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | Date | Species | Ave. Ca (%) | SD Ca (%) | Ave. Mg (%) | SD Mg (%) | Ave. Na (%) | SD Na (%) | Ave. K (%) | SD K (%) | Ave. Cl (%) | SD Cl (%) | Ave. $SO_4$ (%) | SD $SO_4$ (%) |
| SNK1 | 5/17/2007 | GW | 0.80 | 0.26 | 0.26 | 0.06 | 6.75 | 0.55 | 4.19 | 0.44 | 3.51 | 0.31 | 0.36 | 0.06 |
| SNK1 | 5/17/2007 | SS | 0.84 | 0.04 | 0.46 | 0.07 | 8.81 | 0.46 | 5.33 | 1.19 | 10.40 | 1.00 | 0.42 | 0.11 |
| SNK2 | 5/3/2007 | IP | 0.64 | 0.12 | 0.21 | 0.03 | 5.95 | 0.19 | 3.53 | 0.36 | 3.07 | 0.92 | 0.60 | 0.28 |
| SNK2 | 5/3/2007 | ST | 0.96 | 0.12 | 0.23 | 0.02 | 6.96 | 0.12 | 3.17 | 0.98 | 3.67 | 0.93 | 0.48 | 0.07 |
| SNK2 | 5/3/2007 | TC | 0.90 | 0.33 | 0.22 | 0.05 | 7.85 | 0.96 | 3.41 | 0.62 | 2.93 | 0.83 | 0.30 | 0.03 |
| SNK2 | 5/24/2007 | IP | 0.63 | 0.11 | 0.15 | 0.02 | 8.85 | 0.58 | 2.43 | 0.58 | 2.50 | 0.79 | 1.42 | 0.02 |
| SNK2 | 5/24/2007 | SC | 0.70 | 0.26 | 0.13 | 0.02 | 9.90 | 0.22 | 2.35 | 0.40 | 2.35 | 0.35 | 1.45 | 0.04 |
| SNK2 | 5/24/2007 | ST | 0.62 | | 0.12 | | 7.00 | | 3.46 | | 3.14 | | 1.45 | |
| SNK2 | 5/24/2007 | TC | 0.76 | 0.09 | 0.20 | 0.03 | 9.91 | 1.58 | 2.45 | 0.60 | 2.36 | 0.73 | 1.41 | 0.02 |
| SV1 | 5/18/2006 | BS | 0.84 | 0.12 | 0.22 | 0.02 | 0.32 | 0.14 | 1.59 | 0.19 | 0.53 | 0.10 | 0.46 | 0.02 |
| SV1 | 5/18/2006 | GW | 0.54 | 0.20 | 0.28 | 0.02 | 4.19 | 0.58 | 2.66 | 0.20 | 1.52 | 0.06 | 0.46 | 0.01 |
| SV1 | 5/18/2006 | RB | 2.23 | 0.20 | 0.23 | 0.01 | 0.15 | 0.03 | 2.00 | 0.33 | 0.55 | 0.03 | 0.50 | 0.02 |
| SV1 | 5/18/2006 | SS | 2.53 | 0.52 | 0.33 | 0.03 | 2.58 | 0.37 | 5.42 | 0.44 | 1.39 | 0.40 | 0.43 | 0.04 |
| SV1 | 5/4/2007 | BS | 0.95 | 0.09 | 0.16 | 0.03 | 0.11 | 0.01 | 2.71 | 0.21 | 0.48 | 0.10 | 0.38 | 0.05 |
| SV1 | 5/4/2007 | GW | 0.70 | 0.07 | 0.23 | 0.01 | 3.17 | 0.37 | 3.94 | 0.54 | 1.31 | 0.54 | 0.35 | 0.03 |
| SV1 | 5/4/2007 | RB | 1.54 | 0.07 | 0.18 | 0.02 | 0.21 | 0.18 | 2.86 | 0.16 | 0.34 | 0.08 | 0.51 | 0.04 |
| SV1 | 5/17/2007 | BS | 0.75 | 0.22 | 0.15 | 0.03 | 0.14 | 0.14 | 3.21 | 0.24 | 0.43 | 0.07 | 0.35 | 0.04 |
| SV1 | 5/17/2007 | GW | 0.74 | 0.15 | 0.23 | 0.03 | 1.69 | 1.69 | 3.45 | 0.51 | 0.98 | 0.24 | 0.30 | 0.01 |
| SV1 | 5/17/2007 | RB | 1.47 | 0.31 | 0.21 | 0.03 | 0.01 | 0.01 | 3.28 | 0.22 | 0.36 | 0.13 | 0.38 | 0.03 |
| SV1 | 5/25/2007 | IP | 1.20 | 0.18 | 0.20 | 0.03 | 9.29 | 1.77 | 5.06 | 0.18 | 2.30 | 0.76 | 1.44 | 0.02 |
| SV1 | 5/25/2007 | SC | 0.70 | 0.26 | 0.13 | 0.02 | 9.94 | 1.04 | 2.42 | 0.44 | 2.25 | 0.38 | 1.44 | 0.03 |
| SV1 | 5/25/2007 | TC | 1.11 | 0.63 | 0.19 | 0.03 | 9.87 | 1.65 | 4.83 | 0.43 | 1.78 | 0.86 | 1.44 | 0.01 |
| SV2a | 5/18/2007 | GRASS | 0.19 | 0.09 | 0.20 | 0.01 | 0.50 | 0.06 | 0.91 | 0.19 | 1.27 | 0.26 | 0.37 | 0.04 |
| SV2a | 5/18/2007 | GW | 0.94 | 0.18 | 0.31 | 0.06 | 2.91 | 0.73 | 3.17 | 0.35 | 2.67 | 0.44 | 0.44 | 0.03 |
| SV2a | 5/18/2007 | RB | 0.42 | 0.10 | 0.26 | 0.02 | 0.35 | 0.12 | 2.42 | 0.09 | 0.89 | 0.09 | 0.47 | 0.04 |
| SV3 | 5/16/2006 | GW | 0.58 | 0.15 | 0.21 | 0.04 | 2.98 | 0.19 | 3.07 | 0.40 | 2.81 | 0.60 | 0.45 | 0.01 |
| SV3 | 5/16/2006 | RB | 0.64 | 0.42 | 0.20 | 0.02 | 0.16 | 0.01 | 1.90 | 0.31 | 0.79 | 0.10 | 0.45 | 0.03 |
| SV3 | 5/16/2006 | SS | 1.44 | 0.47 | 0.25 | 0.07 | 4.45 | 0.45 | 4.04 | 0.08 | 8.93 | 1.38 | 0.43 | 0.04 |
| WRV1 | 4/14/2005 | BS | 0.59 | 0.15 | 0.13 | 0.03 | 0.15 | 0.08 | 1.35 | 0.30 | 0.15 | | 0.36 | 0.07 |
| WRV1 | 4/14/2005 | GW | 0.44 | 0.12 | 0.22 | 0.03 | 4.62 | 0.58 | 2.08 | 0.06 | 0.87 | 0.32 | 0.27 | 0.02 |
| WRV1 | 4/14/2005 | RB | 0.82 | 0.17 | 0.17 | 0.03 | 0.16 | 0.02 | 2.29 | 0.24 | 0.24 | 0.11 | 0.25 | 0.00 |
| WRV1 | 9/5/2005 | BS | 0.59 | 0.18 | 0.20 | 0.04 | 0.06 | 0.04 | 1.11 | 0.19 | 0.11 | 0.10 | 0.27 | 0.05 |
| WRV1 | 9/5/2005 | GW | 0.86 | 0.33 | 0.50 | 0.17 | 9.80 | 1.47 | 1.33 | 0.70 | 2.39 | 0.98 | 0.25 | 0.04 |
| WRV1 | 9/5/2005 | RB | 0.80 | 0.26 | 0.29 | 0.06 | 0.06 | 0.03 | 1.53 | 0.32 | 0.29 | 0.18 | 0.25 | 0.02 |
| WRV1 | 5/16/2006 | BS | 0.64 | 0.15 | 0.24 | 0.02 | 0.34 | 0.06 | 1.53 | 0.14 | 0.64 | 0.11 | 0.51 | 0.03 |
| WRV1 | 5/16/2006 | GW | 0.59 | 0.08 | 0.19 | 0.02 | 2.42 | 0.40 | 2.00 | 0.25 | 1.40 | 0.15 | 0.54 | 0.04 |
| WRV2 | 7/19/2005 | BS | 0.68 | 0.20 | 0.14 | 0.07 | 0.14 | 0.08 | 1.49 | 0.22 | 0.23 | 0.13 | 0.30 | 0.05 |
| WRV2 | 7/19/2005 | GW | 0.74 | 0.16 | 0.26 | 0.06 | 9.20 | 1.52 | 2.22 | 0.72 | 3.76 | 0.91 | 0.35 | 0.18 |
| WRV2 | 7/19/2005 | RB | 1.05 | 0.25 | 0.16 | 0.05 | 0.17 | 0.14 | 1.65 | 0.20 | 0.34 | 0.14 | 0.29 | 0.02 |
| WRV2 | 7/19/2005 | SS | 1.67 | 0.54 | 0.42 | 0.14 | 9.83 | 1.70 | 3.86 | 1.07 | 11.35 | 1.91 | 1.24 | 0.76 |
| WRV2 | 5/16/2006 | BS | 0.83 | 0.16 | 0.30 | 0.07 | 1.88 | 1.36 | 1.74 | 0.30 | 0.84 | 0.25 | 0.47 | 0.06 |
| WRV2 | 5/16/2006 | GW | 0.38 | 0.14 | 0.29 | 0.02 | 4.08 | 1.98 | 2.66 | 0.12 | 3.68 | 0.50 | 0.46 | 0.08 |
| WRV2 | 5/16/2006 | SS | 1.20 | 0.26 | 0.34 | 0.04 | 5.21 | 1.37 | 3.24 | 0.65 | 8.45 | 0.99 | 0.46 | 0.05 |
| WRV3 | 6/1/2005 | BS | 0.73 | 0.15 | 0.17 | 0.04 | 0.14 | 0.02 | 2.10 | 0.24 | 0.19 | 0.14 | 0.29 | 0.05 |
| WRV3 | 6/1/2005 | GW | 0.58 | 0.14 | 0.19 | 0.04 | 5.82 | 1.45 | 2.40 | 0.26 | 1.24 | 0.78 | 0.29 | 0.02 |
| WRV3 | 6/1/2005 | RB | 1.10 | 0.30 | 0.22 | 0.05 | 0.12 | 0.02 | 2.87 | 0.16 | 0.15 | 0.06 | 0.32 | 0.05 |
| WRV3 | 6/1/2005 | SS | 1.68 | 0.64 | 0.30 | 0.07 | 7.16 | 1.32 | 3.04 | 0.77 | 5.15 | 1.90 | 0.25 | 0.02 |
| WRV3 | 5/16/2006 | BS | 0.80 | 0.15 | 0.36 | 0.05 | 0.72 | 0.03 | 1.81 | 0.74 | 1.18 | 0.20 | 0.55 | 0.04 |
| WRV3 | 5/16/2006 | GW | 0.65 | 0.42 | 0.17 | 0.02 | 4.39 | 2.03 | 2.44 | 0.24 | 1.94 | 0.50 | 0.43 | 0.05 |
| WRV3 | 5/16/2006 | RB | 0.35 | 0.09 | 0.18 | 0.02 | 0.08 | 0.03 | 2.69 | 0.09 | 0.64 | 0.07 | 0.42 | 0.05 |
| WRV3 | 5/16/2006 | SS | 1.44 | 0.16 | 0.39 | 0.02 | 2.71 | 0.60 | 3.63 | 0.41 | 7.00 | 0.45 | 0.61 | 0.05 |

**Table 8: Eddy Covariance Tower Equipment Bandwidth and Output Units**

| Measurement | Instrument Type | Make and Model | Bandwidth | Output Units |
|---|---|---|---|---|
| Turbulence (u,v,w) | 3-D Sonic anemometer | Campbell CSAT3 | 10 Hz | m s-1 |
| Sonic Temperature (Ts) | 3-D Sonic anemometer | Campbell CSAT3 | 10 Hz | °C |
| Carbon dioxide mass density ($co_2$) | Open path infrared gas analyzer | LI-COR 7500 | 10 Hz | $mg^{-1}m^3$ |
| Water vapor mass density ($H_2O$) | Open path infrared gas analyzer | LI-COR 7500 | 10 Hz | $g^{-1}m^3$ |
| Air Pressure (press) | Open path infrared gas analyzer | LI-COR 7500 | 10 Hz | kPa |
| Vapor Pressure (e_hmp) | Capacitive RH sensor | Vaisala HMP45C | 10 Hz | kPa |
| Air temperature (t_hmp) | Capacitive RH sensor | Vaisala HMP45C | 10 Hz | °C |
| Incoming/ reflected/ emitted shortwave /longwave radiation | Net radiometer (high-output thermopile) | Kipp & Zonen NR-LITE-L | 1 Second | $W\ m^{-2}$ |
| Photosynthetically active radiation (PAR) | Quantum sensor (400 to 700nm) | LI-COR 190SA | 1 Second | $\mu mol\ m^{-2}\ s^{-1}$ |
| Soil volumetric water content | Water content reflectometer | Campbell CS616 | 1 Second | $m^3\ m^{-3}$ |
| Soil temperature profile | Thermistor | Campbell CS107 | 1 Second | °C |
| Soil heat flux | Thermopile gradient | Huseflux Self Calibrating Soil Heat Flux Plate HFP01SC-L | 1 Second | $W\ m^{-2}$ |
| Precipitation | Tipping bucket | Texas Instruments TE525 | 1 Second | mm |
| Data logger | CR 5000 | Campbell Sci. | | |

**Table 9: Percent ET Removed From QA/QC Post-Processing by site and year**

| Site | Year | Percent ET (mm) Removed |
|---|---|---|
| SV1 | 2007 | 1.95% |
| SV2b | 2007 | 4.37% |
| SV3 | 2007 | 3.59% |
| WRV2 | 2007 | 2.04% |
| SNK1 | 2007 | 1.73% |
| SNK2 | 2007 | 2.73% |
| SV1 | 2006 | 4.17% |
| WRV2 | 2006 | 6.44% |
| SV1 | 2005 | 3.81% |
| SV2a | 2005 | 10.32% |
| SV3 | 2005 | 6.35% |
| WRV1 | 2005 | 2.27% |
| WRV2 | 2005 | 7.28% |
| WRV3 | 2005 | 8.03% |

Table 10. This table lists all Landsat TM 5 image dates used for the empirical ET analysis. The images were acquired from two Landsat path/rows as indicated below. While most of the images were used to estimate basin-wide ET, a few of the images (denoted below) had too much cloud cover to be included in the total ET estimate.

| 2005 | 2006 | 2007 |
|---|---|---|
| April 14* | May 3* # | April 13 |
| May 25 | May 12 | April 29 |
| June 1* | May 19* & | May 15 |
| June 26 | June 4* | May 31 |
| July 19* | June 20* | June 16 |
| Aug 29 | June 29 | July 2 |
| Sept 5* | July 15 | July 18 |
| Sept 14 | Aug 7* | Aug 3 ^ |
| | Aug 16 | Aug 19 |
| | Sept 1 | Sept 20 |
| | Sept 17 | |

* Denotes images from Landsat path/row 40/33; all other images are from path/row 39/33

\# Denotes images that were excluded from total ET calculations for all valleys due to clouds

& Denotes image that was excluded from Spring Valley total ET calculation due to clouds

^ Denotes image that was excluded from Spring and Snake Valley total ET calculation due to clouds

Table 11. The upper left (NW) and lower right (SE) UTM coordinates for the ground calibration targets are listed in this table.

| Site | Upper Left Northing | Upper Left Easting | Lower Right Northing | Lower Right Easting |
|---|---|---|---|---|
| Igneous Rock | 4241412.5 | 667137.5 | 4241362.5 | 667162.5 |
| Gravel Pit | 4244037.5 | 670262.5 | 4243987.5 | 670312.5 |
| Bright Soil 1 | 4247387.5 | 665212.5 | 4247337.5 | 665237.5 |
| Bright Soil 2 | 4254112.5 | 669062.5 | 4254062.5 | 669087.5 |

**Table 12: $ET_{ref}$, ET and Rain by year and site**

| | 2005 | | 2006 | | | | 2007 (1/1-9/5) | |
|---|---|---|---|---|---|---|---|---|
| | $ET_{ref}$ (cm) | Rain (cm) | $ET_{ref}$ (cm) | ET (cm) | Rain (cm) | ET-Rain (cm) | $ET_{ref}$ (cm) | Rain (cm) |
| SV1 | 118.92* | 30.65* | 127.11 | 24.04 | 15.55 | 8.49 | 112.00 | 8.71 |
| WRV2 | 131.05 | 26.62 | 136.16 | 42.43 | 26.54 | 15.89 | 118.89 | 10.51 |

* SV2 and SV1 sites combined

**Table 13: $ET_{ref}$, ET, Rain and ET-Rain for the period 5/10-9/5 2006 and 2007 along with projected yearly ET totals in 2007**

| | $ET_{ref}$ (cm) | ET (cm) | Rain (cm) | ET-Rain (cm) | ET (year-cm) |
|---|---|---|---|---|---|
| SV1-2006 | 71.43 | 11.18 | 4.85 | 6.33 | 24.04* |
| WRV2-2006 | 76.60 | 18.60 | 7.39 | 11.21 | 42.43* |
| SV1-2007 | 79.53 | 9.04 | 3.48 | 5.56 | 20.24 |
| SV2b-2007 | 73.60 | 71.56 | 3.79 | 67.77 | 124.97 |
| SV3-2007 | 77.85 | 14.52 | 3.10 | 11.42 | 27.24 |
| WRV2-2007 | 83.53 | 10.60 | 6.13 | 4.47 | 27.48 |
| SNK1-2007 | 84.82 | 30.57 | 3.66 | 26.91 | 49.88 |
| SNK2-2007 | 85.62 | 9.94 | 1.19 | 8.75 | 21.37 |

* Actual ET Totals - not projected

**Table 14. Rainfall (cm) by growing (4/1-10/31) and non-growing periods (11/1-3/31) for Spring Valley and White River Valley**

| Year | Site | Non-growing (cm) | Growing (cm) |
|---|---|---|---|
| 2005 | | | |
| | WRV | 17.45 | 11.79 |
| | SV | 14.15 | 21.26 |
| 2006 | | | |
| | WRV | 10.26 | 17.04 |
| | SV | 6.63 | 10.08 |
| 2007 | | | |
| | WRV | 2.99 | 13.78 |
| | SV | 4.24 | 7.65 |

**Table 15: Well Depth of Spring Valley, White River Valley and Snake Valley Sites**

| Site | 2007 (~9mo) in feet (meters) | 2006 (~3mo) in feet (meters) |
|---|---|---|
| SV1 | 15.29±0.15 (4.66±0.05) | 15.2 (4.6) |
| SV2 | 3.70±2.36* (1.13±0.72*) | |
| SV3 | 17.33±0.13 (5.28±0.04) | |
| WRV1 | 32.39** | |
| WRV2 | 18.95±0.14 (5.78±0.04) | 19.1 (5.8) |
| WRV3 | 41.23±4.95* (12.57±1.51*) | |
| SNK1 | 16.40±0.14 (5.00±0.04) | |
| SNK2 | 30.54±0.14 (9.31±0.04) | |

*Depth calculated from 2004-2006 data
**Data from USGS

**Table 16: Well Water Ion Analysis of Spring Valley, White River Valley and Snake Valley Sites**

| Sample Date | Site | $EC_w$ (dS/m) | pH | Na (mEq/L) | NH4 (mEq/L) | K (mEq/L) | Mg (mEq/L) | Ca (mEq/L) | Cl (mEq/L) | NO3 (mEq/L) | SO4 (mEq/L) | CO3 (mEq/L) | HCO3 (mEq/L) | Anions | Cations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/16/2006 | SV 1 | 0.9833 | 8.07 | 3.80 | 0.00 | 0.55 | 1.62 | 7.26 | 4.81 | 0.00 | 2.40 | 0.00 | 3.20 | 10.41 | 13.23 |
| 7/29/2006 | SV 1 | 0.7982 | 7.49 | 1.04 | 0.00 | 0.32 | 1.59 | 4.55 | 3.05 | 0.00 | 1.19 | 0.00 | 3.20 | 7.44 | 7.50 |
| 12/19/2006 | SV 1 | 0.3702 | 8.1 | 1.26 | 0.00 | 0.24 | 0.66 | 2.40 | 0.81 | 0.00 | 0.61 | 0.00 | 2.20 | 3.62 | 4.57 |
| 4/4/2007 | SV 1 | 0.3655 | 7.55 | 0.38 | 0.05 | 0.97 | 0.00 | 1.11 | 1.66 | 0.24 | 0.30 | 0.00 | 0.40 | 2.60 | 2.52 |
| 6/16/2006 | SV 2a | 0.6215 | 7.82 | 1.13 | 0.00 | 0.10 | 1.88 | 6.30 | 0.54 | 0.04 | 0.87 | 0.00 | 3.90 | 5.35 | 9.41 |
| 7/28/2006 | SV 2a | 0.6417 | 7.49 | 1.14 | 0.00 | 0.12 | 1.71 | 3.50 | 0.50 | 0.00 | 0.76 | 0.00 | 4.90 | 6.16 | 6.48 |
| 12/19/2006 | SV 2a | 1.4450 | 7.93 | 1.22 | 0.21 | 0.17 | 1.78 | 4.07 | 0.38 | 0.00 | 1.26 | 0.00 | 4.80 | 6.44 | 7.45 |
| 6/16/2006 | SV 3 | 0.2641 | 7.88 | 0.34 | 0.00 | 0.09 | 0.36 | 1.59 | 0.46 | 0.02 | 0.57 | 0.00 | 1.90 | 2.96 | 2.39 |
| 7/28/2006 | SV 3 | 0.2800 | 7.54 | 0.43 | 0.00 | 0.05 | 0.46 | 1.86 | 0.42 | 0.02 | 0.51 | 0.00 | 1.10 | 2.06 | 2.80 |
| 6/16/2006 | WRV 1 | 0.6310 | 7.81 | 1.54 | 0.00 | 0.19 | 2.53 | 1.79 | 0.40 | 0.00 | 1.37 | 0.00 | 4.70 | 6.47 | 6.05 |
| 6/16/2006 | WRV 2 | 0.6637 | 7.73 | 2.46 | 0.00 | 0.20 | 2.01 | 1.72 | 1.19 | 0.00 | 1.49 | 0.00 | 5.10 | 7.78 | 6.39 |
| 7/27/2006 | WRV 2 | 0.6480 | 7.48 | 1.92 | 0.00 | 0.16 | 2.28 | 6.94 | 0.88 | 0.00 | 1.42 | 0.00 | 4.00 | 6.30 | 11.31 |
| 12/20/2006 | WRV 2 | 0.5650 | 7.97 | 2.30 | 0.00 | 0.15 | 1.64 | 2.29 | 0.87 | 0.00 | 1.45 | 0.00 | 3.80 | 6.11 | 6.38 |
| 4/5/2007 | WRV 2 | 0.3532 | | 0.51 | 0.00 | 0.11 | 0.00 | 1.31 | 0.45 | 0.22 | 0.31 | 0.00 | 0.40 | 1.38 | 1.93 |
| 6/16/2006 | WRV 3 | 0.9956 | 7.61 | 2.33 | 0.00 | 0.18 | 2.60 | 5.75 | 1.96 | 0.03 | 3.03 | 0.00 | 5.50 | 10.52 | 10.85 |
| 7/27/2006 | WRV 3 | 0.8261 | 7.79 | 1.98 | 0.00 | 0.15 | 2.54 | 4.08 | 1.75 | 0.00 | 2.92 | 0.00 | 3.60 | 8.28 | 8.75 |
| 10/5/2007 | SNK1 Top | 0.4610 | 7.71 | 0.47 | | 0.15 | 1.87 | 2.76 | 0.33 | 0.02 | 0.18 | 0.00 | 4.38 | 4.92 | 5.25 |
| 10/5/2007 | SNK1 Purge | 0.4465 | 7.72 | 0.46 | | 0.07 | 1.87 | 2.90 | 0.25 | 0.02 | 0.15 | 0.00 | 4.28 | 4.71 | 5.30 |
| 10/5/2007 | SNK2 Top | 0.5470 | 7.74 | 1.44 | | 0.07 | 0.96 | 3.69 | 1.44 | 0.04 | 0.47 | 0.00 | 3.39 | 5.34 | 6.16 |
| 10/5/2007 | SNK2 Purge | 0.5376 | 7.74 | 1.45 | | 0.10 | 0.94 | 3.33 | 1.50 | 0.05 | 0.38 | 0.00 | 3.39 | 5.31 | 5.83 |

**Table 17: Energy Balance Closure Estimates**

| Site | Year | Energy Balance Closure Estimate | Date of Closure Estimate |
|---|---|---|---|
| SV1 | 2007 | 97% | 2/15-9/7/2007 |
| SV2b | 2007 | 90% | 3/29-9/7/2007 |
| SV3 | 2007 | 104% | 3/30-9/6/2007 [b] |
| WRV2 | 2007 | 101% | 4/23-9/6/2007 |
| SNK1 | 2007 | 104% | 5/31-9/7/2007 [b] |
| SNK2 | 2007 | 99% | 6/1-9/7/2007 [b] |
| SV1 | 2006 | 89% | 1/1-2/3 & 3/7-9/28/2006 [b] |
| WRV2 | 2006 | 98% | 1/1-4/12 & 5/6-8/17/2006 [b] |
| SV1 | 2005 | 87% | 3/31-5/26 & 8/18-12/22/2005 [a] |
| SV2a | 2005 | 93% | 7/7-8/18 [a, b] |
| SV3 | 2005 | 84% | 5/26-7/7/2005 [a] |
| WRV1 | 2005 | 96% | 5/16-5/27 [a, b] |
| WRV2 | 2005 | 89% | 1/1-4/1 & 7/18-12/24/2005 [a] |
| WRV3 | 2005 | 88% | 5/27-6/17 & 7/8-7/17/2005* [a] |

[a] Eddy Covariance Tower was moved to another location.
[b] Missing days due to malfunction associated with soil heat flux sensors.

*NOTE, Energy Balances were calculated on all available data.

**Table 18: Ratio of ET or $ET_{ref}$ for the 5/10-9/5 period divided by the one year actual and projected totals.**

| | | |
|---|---|---|
| ET (actual) | USGS* (not including grassland site) | 0.49±0.03 |
| | USGS* (grassland site) | 0.64 |
| | This study | 0.45±0.01 |
| $ET_{ref}$ | This study | 0.56±0.01 |
| ET (projected) | This study (not including pasture/grassland) | 0.49±0.09 |
| | This study (pasture/grassland) | 0.57 |

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**Table 19. Basin wide ET estimates for Spring Valley and White River Valley in 2005, 2006, 2007 and Snake Valley 2007 based on daily NDVI-ET estimates and average NDVI-yearly ET estimates. Pheatophytic zone for Spring Valley and White River Valley 2005, 2006, 2007 and Snake Valley 2007.**

| | Spring Valley | | White River Valley | | Snake Valley | | Spring Valley | White River Valley | Snake Valley |
|---|---|---|---|---|---|---|---|---|---|
| | Daily NDVI | Avg. NDVI | Daily NDVI | Avg. NDVI | Daily NDVI | Avg. NDVI | | Pheatophytic Zone | |
| | Acre feet | | | | | | Acres | | |
| 2005 | 233,864 | 233,176* | 241,172 | 225,371* | | | 156,232 | 142,557 | |
| 2006 | 195,980 | 185,584 | 145,052 | 181,440 | | | 156,409 | 142,761 | |
| 2007 | 195,399 | 164,496 | 127,014 | 152,496 | 176,670 | 239,513 | 156,497 | 141,743 | 256,016 |

*Estimate adjusted by 25% based on assessing the underestimate of 2005 data based on 2006 and 2007 regression equation.

Appendix (Pictures)

Picture 1: *Sarcobatus vermiculatus*

Picture 2: *Artemisia tridentata*

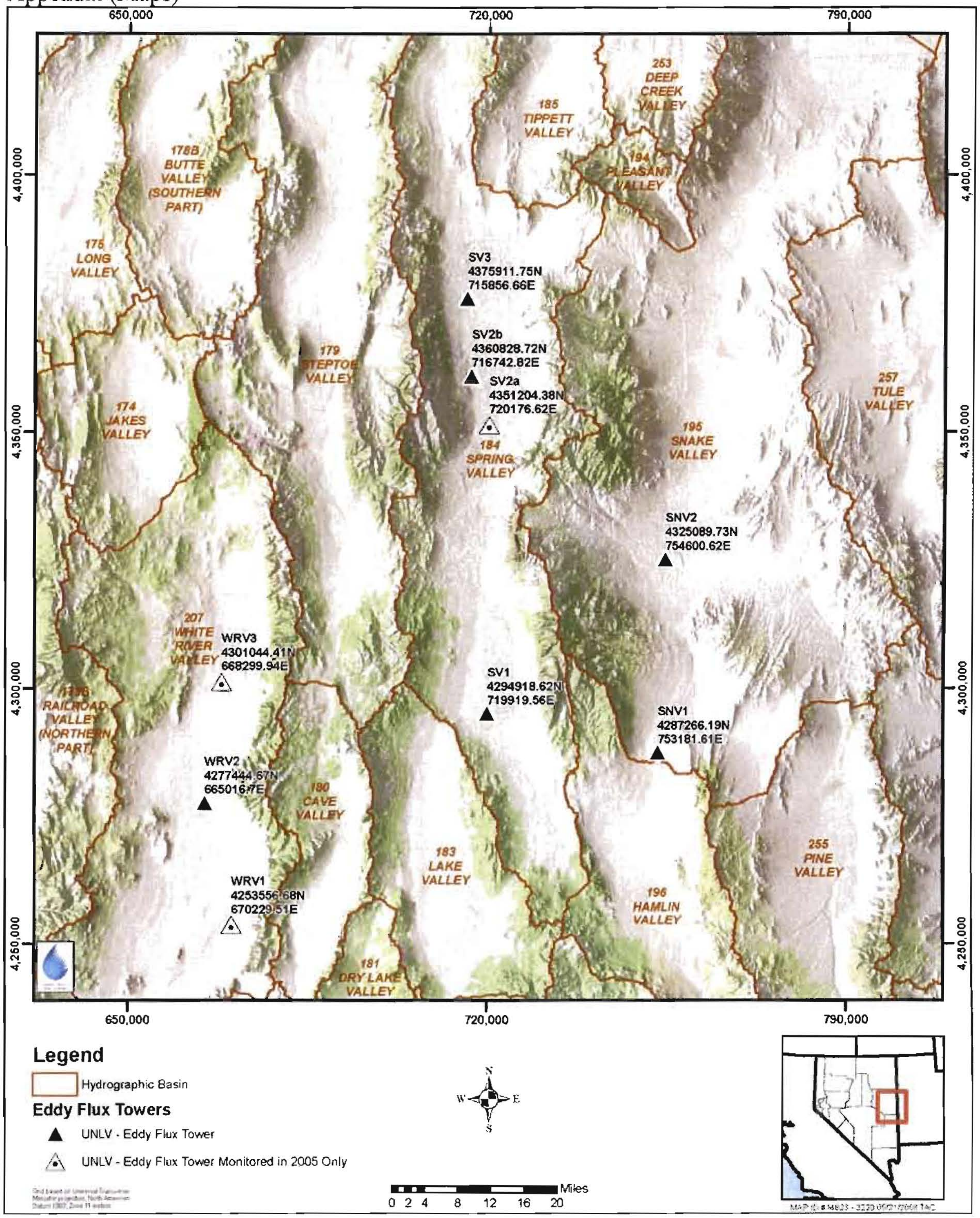
Picture 3: *Chrysothamnus nauseosus*

Picture 4: *Atriplex confertifolia*

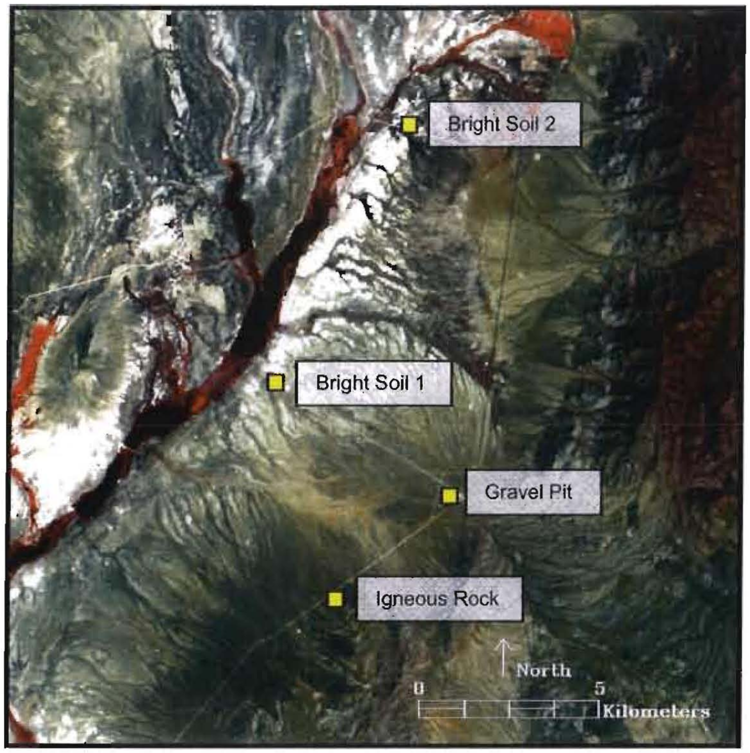

Picture 5: *Artemesia spinescens*


Picture 6: *Tetradymia canescens*

Appendix (Maps)

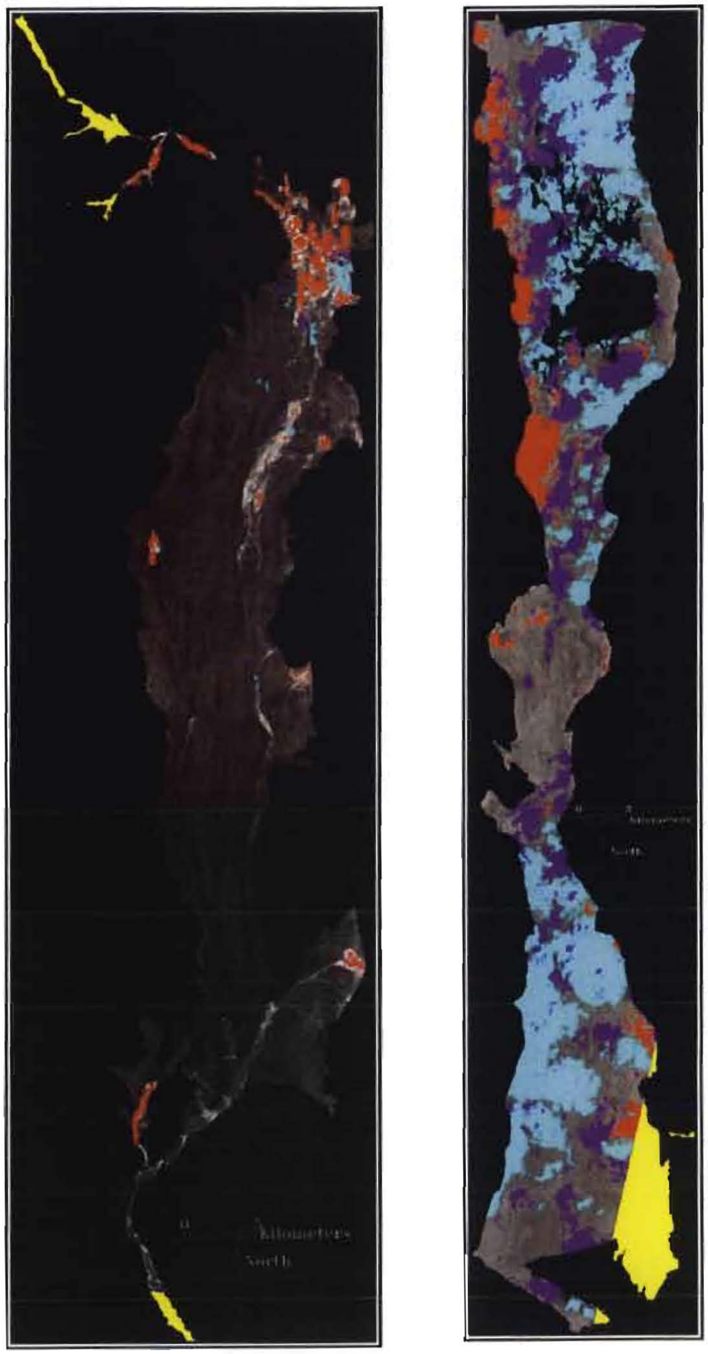



**Map 1. Site locations in White River Valley, Spring Valley and Snake Valley.**




**Map 2. Locations of the southern White River Valley ground targets are depicted above. Field spectra were acquired at these locations during a Landsat overpass for use in the atmospheric correction and image normalization process.**


**Map 3. The location of each UNLV (yellow +) and USGS (green +) Eddy Covariance tower, as well as basin phreatophyte areas (darker regions outlined in blue), are depicted in the above single-scene Landsat color infrared composite image from June 16, 2007. As can be seen above, portions of the basin phreatophyte regions were not always captured within a single date/scene Landsat image.**



**Map 4. The above images of the phreatophyte area for White River Valley (left) and Spring Valley (right) depict the regions-of-interest (ROIs) that were distinguished prior to summing ET pixel values. The ROIs that were defined include: ag/meadow (red); off edge of scene (yellow); water (blue); cloud (cyan); and cloud shadow (purple).**

Appendix (Figures)

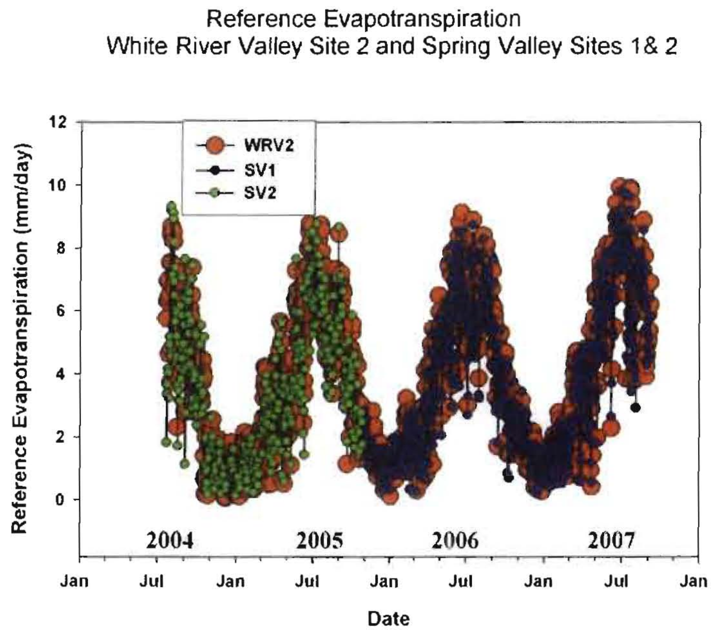



**Figure 1 Reference evapotranspiration ($ET_{ref}$) for White River Valley and Spring Valley in 2005, 2006 and 2007.**

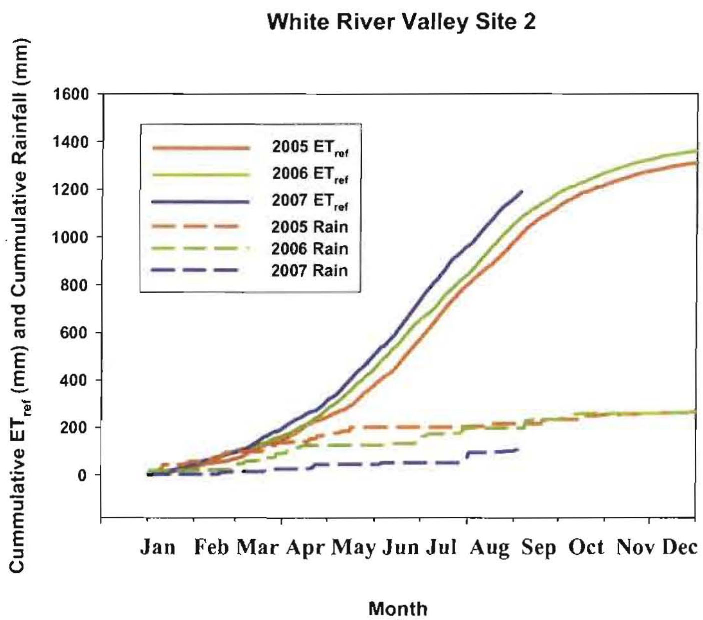



**Figure 2a. Cumulative reference evapotranspiration and rainfall for WRV2 in 2005, 2006 and 2007.**

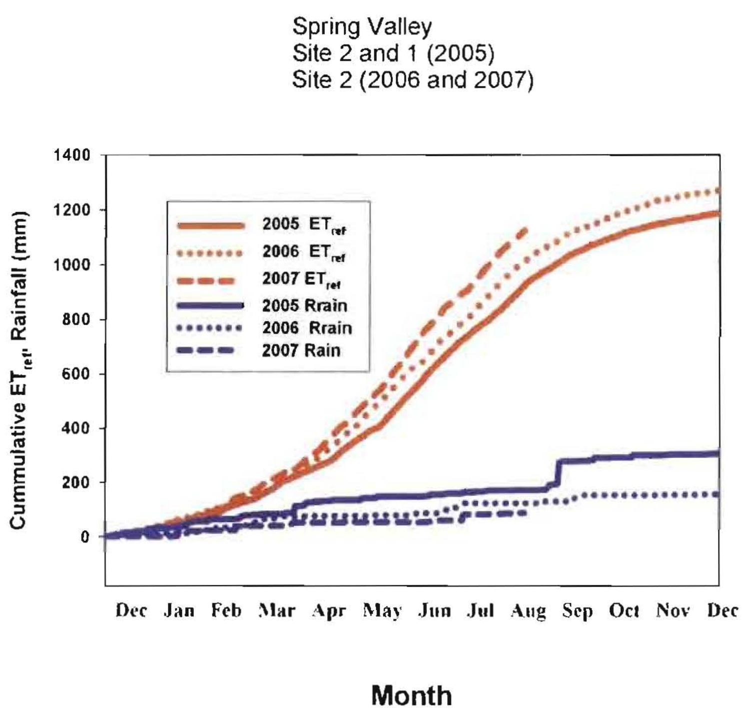



**Figure 2b Cumulative reference evapotranspiration and rainfall for SV1 and SV2 in 2005, 2006 and 2007.**

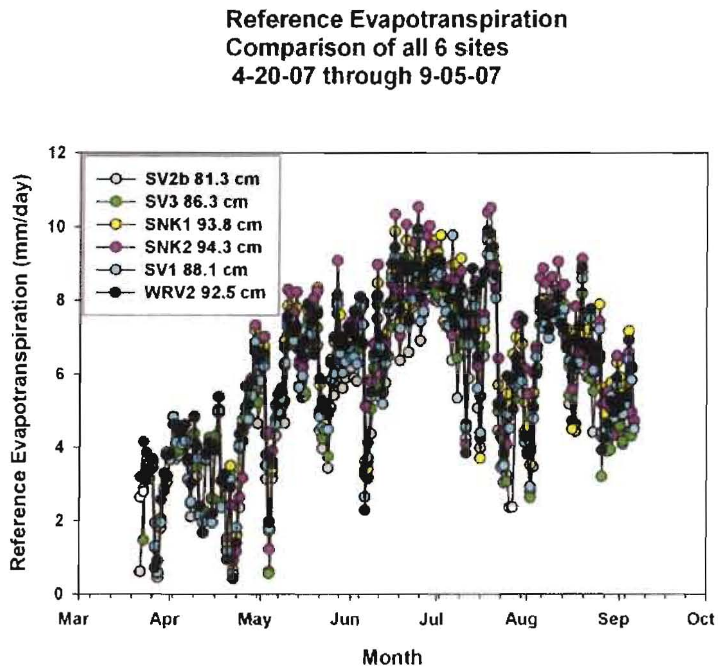



**Figure 3. Reference evapotranspiration comparison for all 6 sites monitored from 4/20/07 to 9/05/07.**

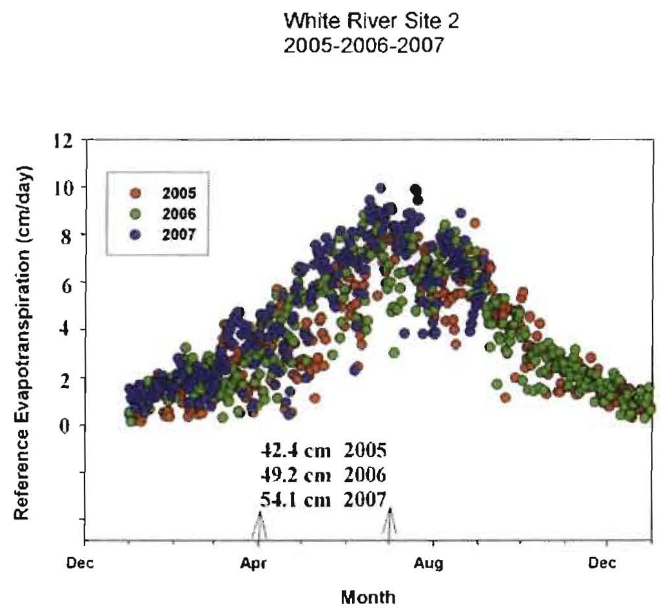



**Figure 4a. Reference evapotranspiration for WRV2 in 2005, 2006 and 2007. Reference evapotranspiration totals are included for the April, May and June period in each year.**

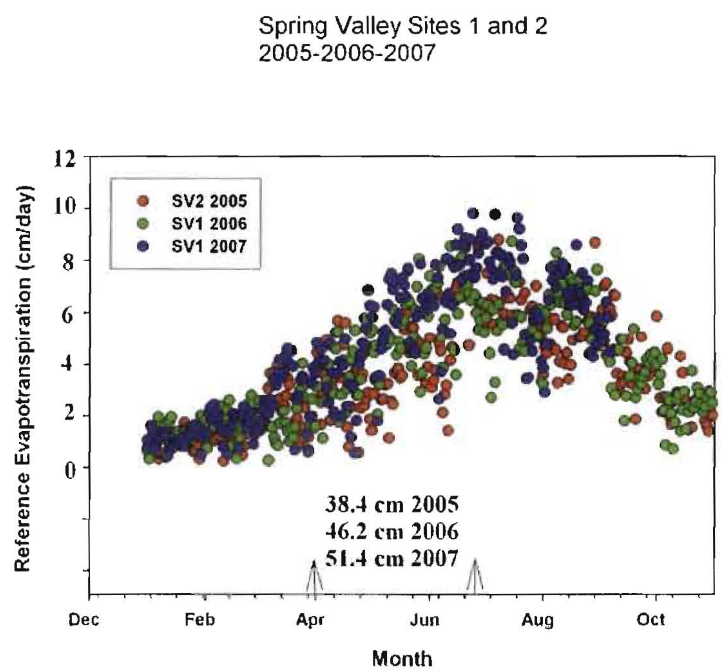



**Figure 4b. Reference evapotranspiration for SV2/SV1 in 2005, 2006 and 2007. Reference evapotranspiration totals are included for the April, May and June period in each year.**

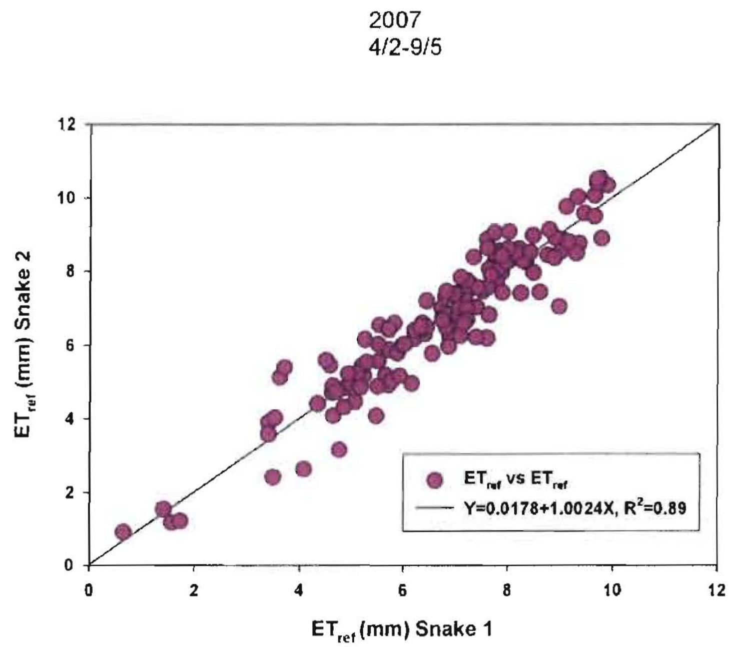



**Figure 5a. Reference evapotranspiration comparison between SNK1 and SNK2 sites in 2007.**

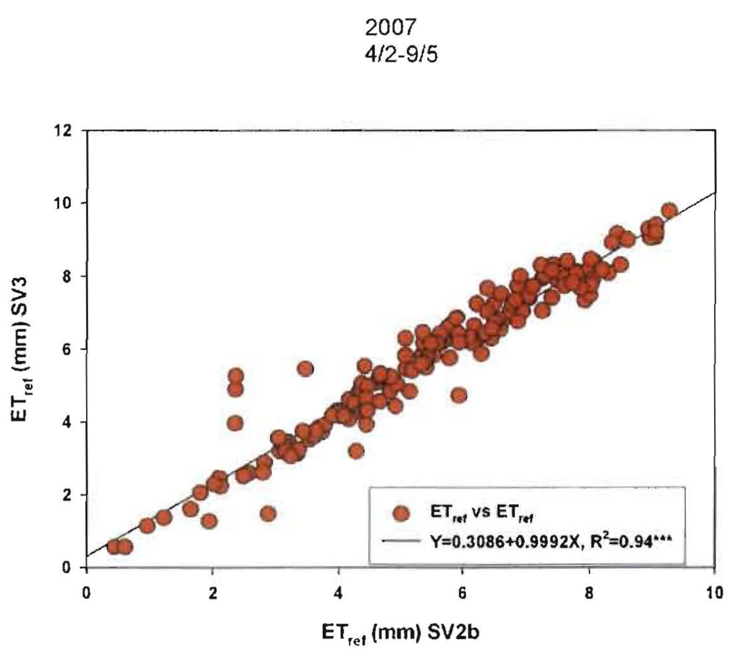



**Figure 5b. Reference evapotranspiration comparison between SV2b and SV3 sites in 2007.**

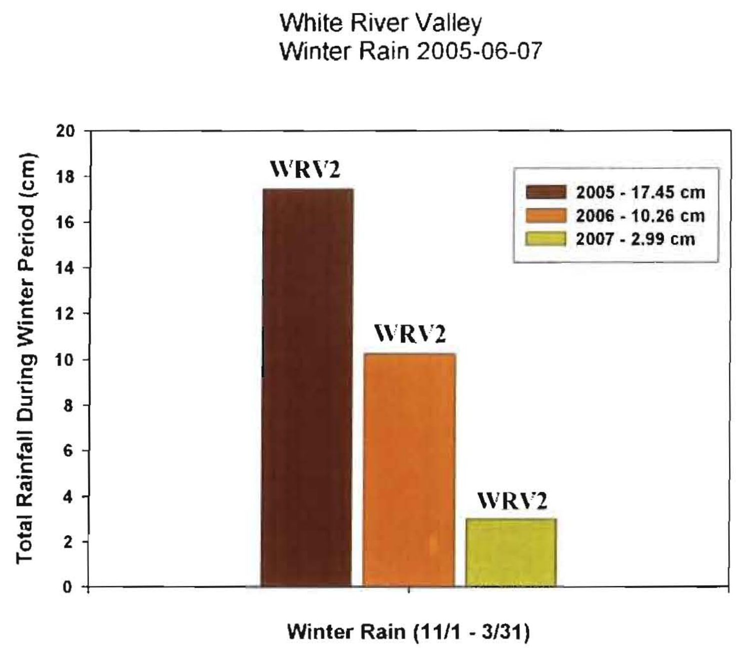



**Figure 6. Total winter rainfall measured in White River Valley in 2005, 2006 and 2007, where the winter period is defined as November-March.**

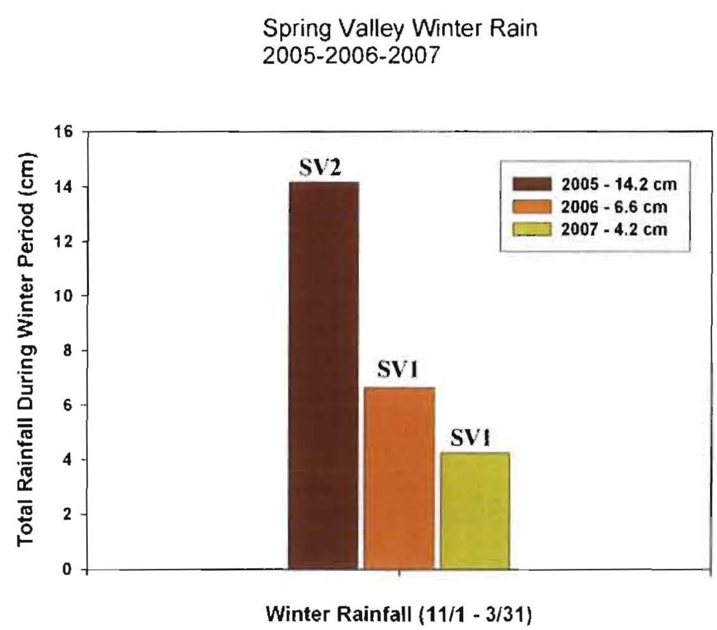



**Figure 7. Total winter rainfall measured in Spring Valley in 2005, 2006 and 2007, where the winter period is defined as November-March.**

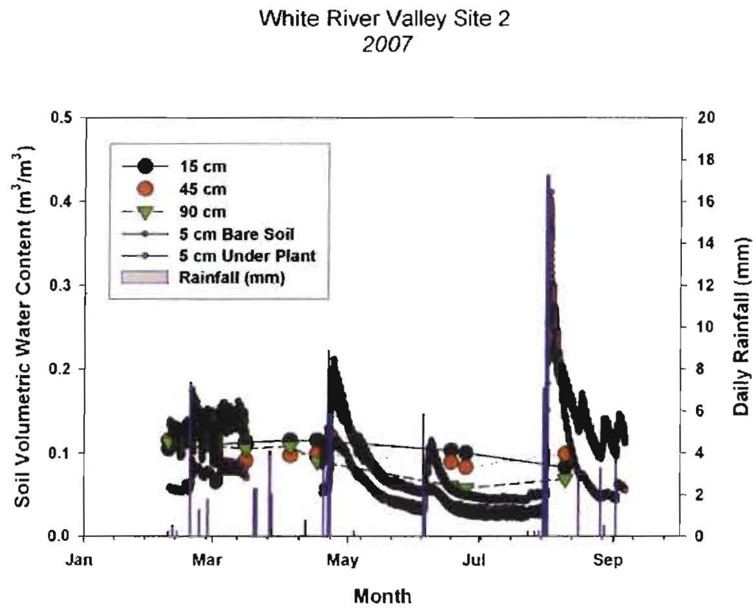



**Figure 8a. Soil volumetric water content at 5, 15, 45 and 90 cm at WRV2 during 2007, along with daily rainfall totals.**

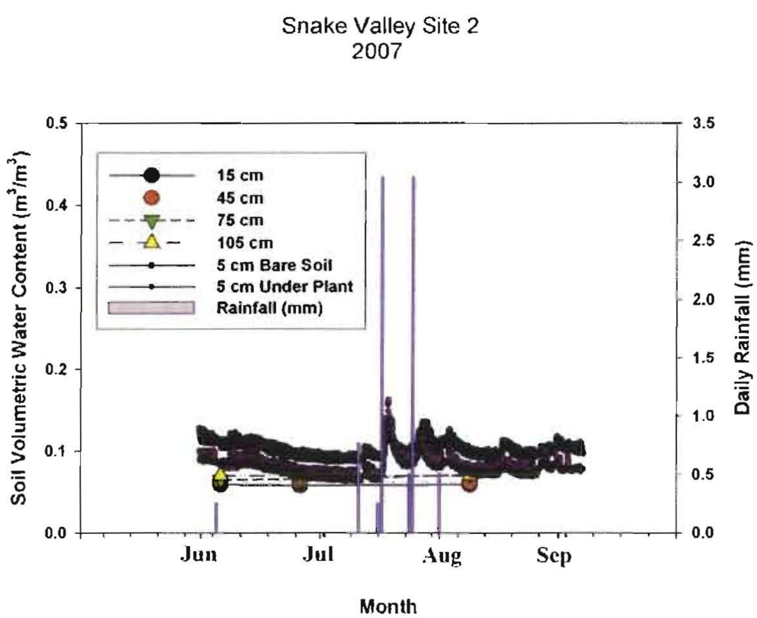



**Figure 8b. Soil volumetric water content at 5, 15, 45, 75 and 105 cm at SNK2 during 2007, along with daily rainfall totals.**

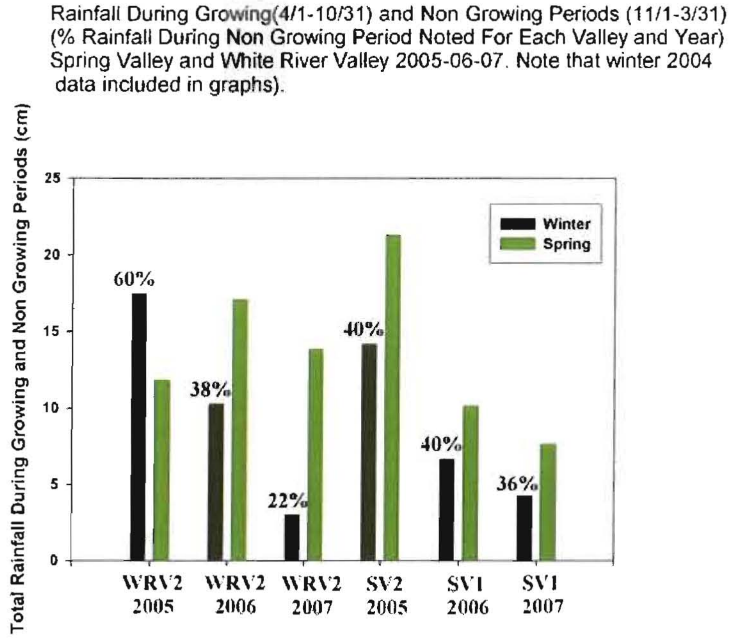



**Figure 9. Total rainfall during growing and non growing periods at WRV2 and SV2/SV1 during 2005, 2006 and 2007.**

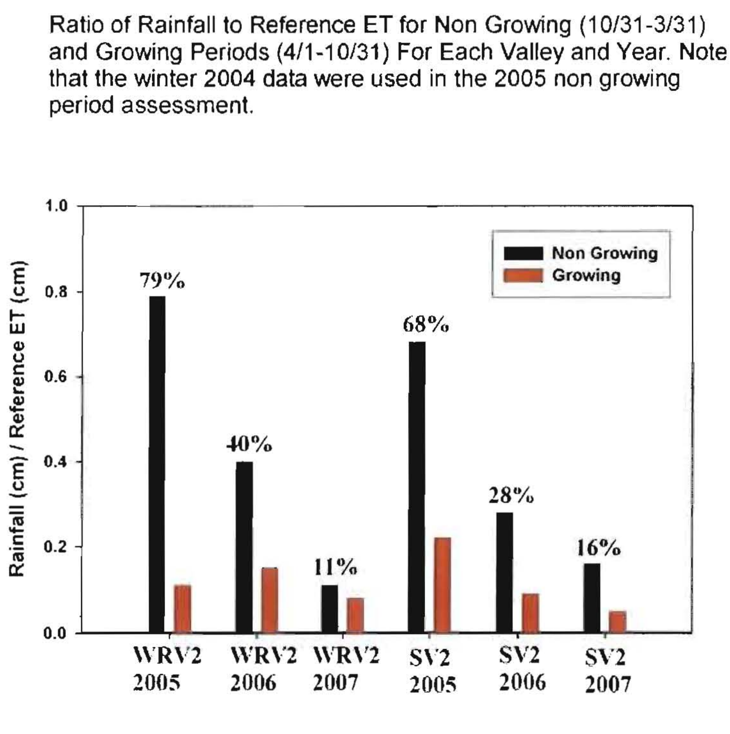



**Figure 10. Ratio of rainfall to reference evapotranspiration during the growing and non growing periods at WRV2, and SV2/SV1 during 2005, 2006 and 2007.**

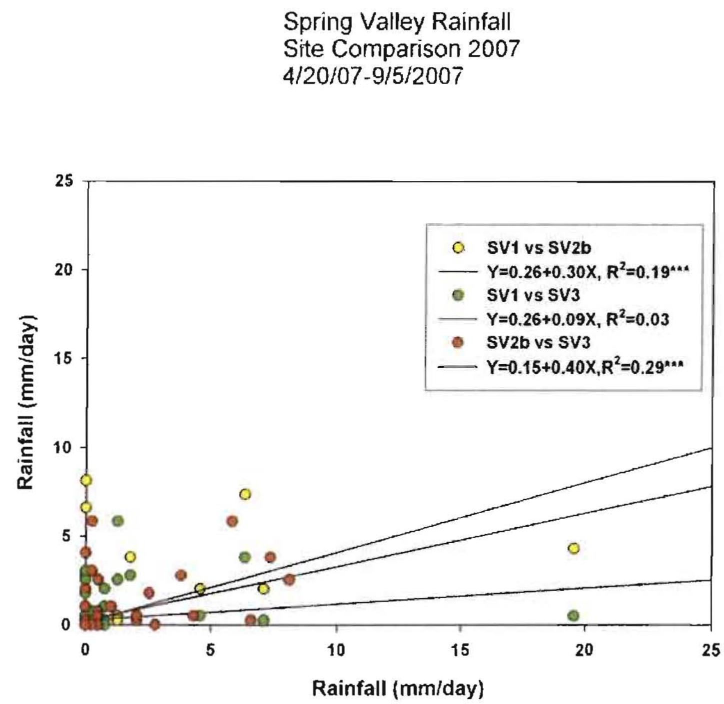



**Figure 11a. Daily rainfall correlation between SV1 and SV2b, SV1 and SV3 and SV2b and SV3 during 2007.**

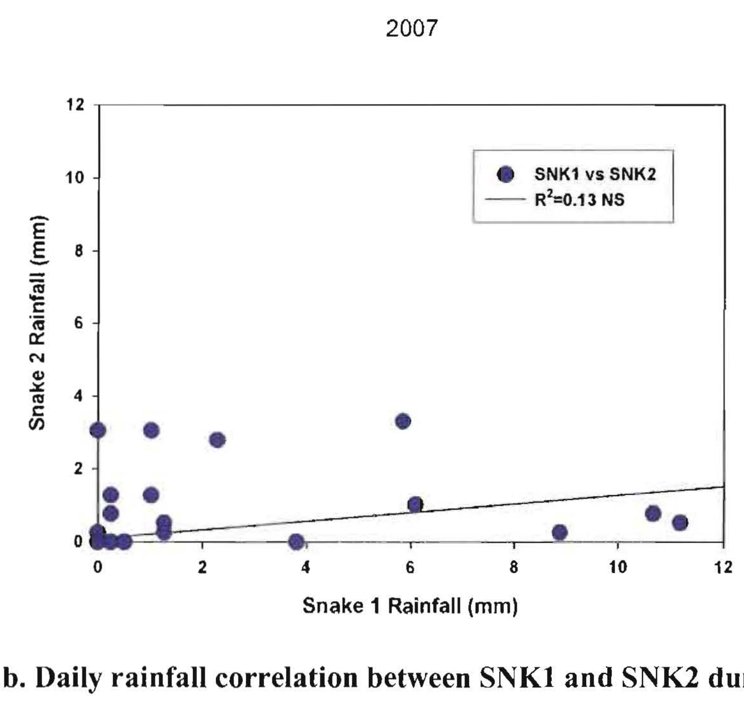



**Figure 11b. Daily rainfall correlation between SNK1 and SNK2 during 2007.**

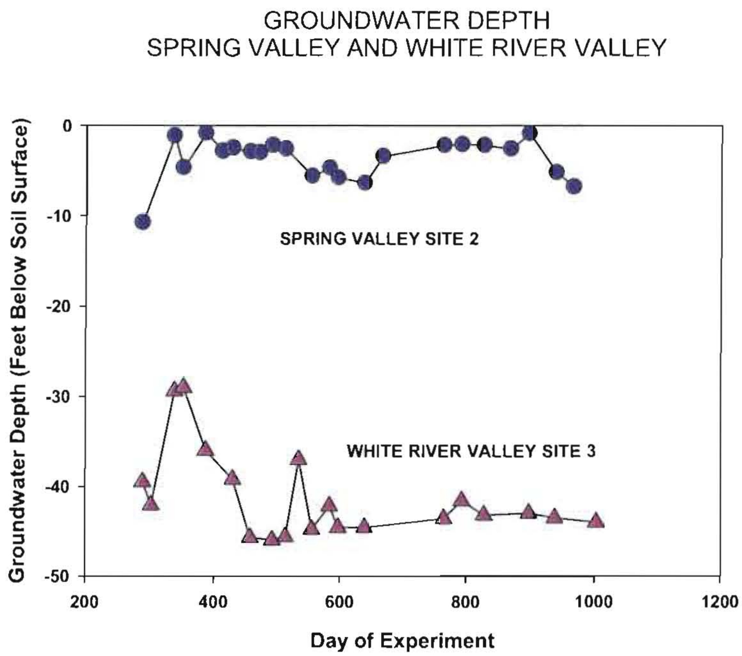



**Figure 12. Depth to ground water at SV2a and WRV3 monitored during the first 1000 days of the study.**

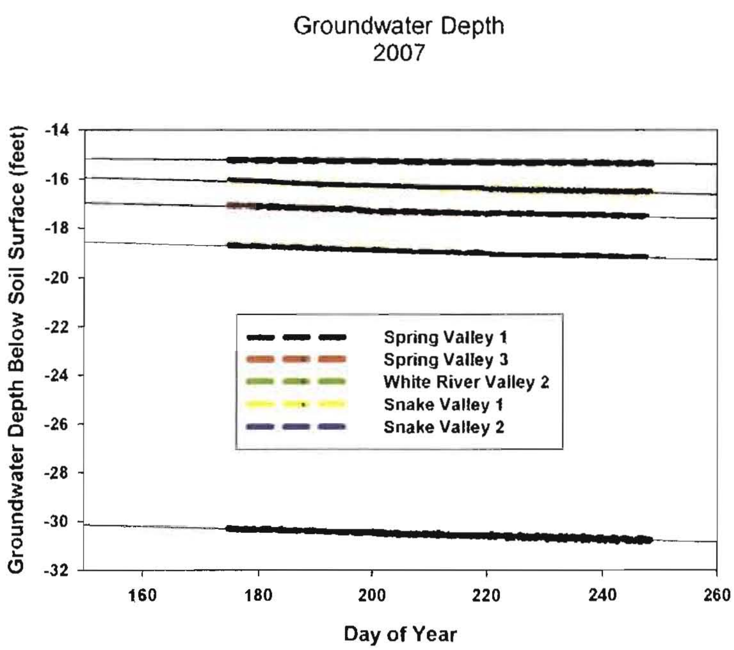



**Figure 13. Continuous depth to ground water at SV1, SV3, WRV2, SNK1 and SNK2 during 2007.**

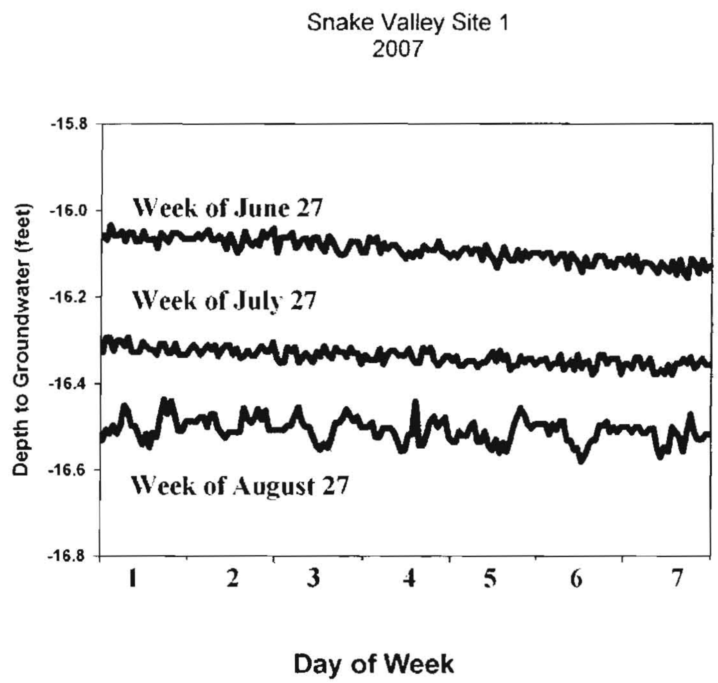



**Figure 14a. Continuous depth to ground water at SNK1 during three different weeks in 2007.**

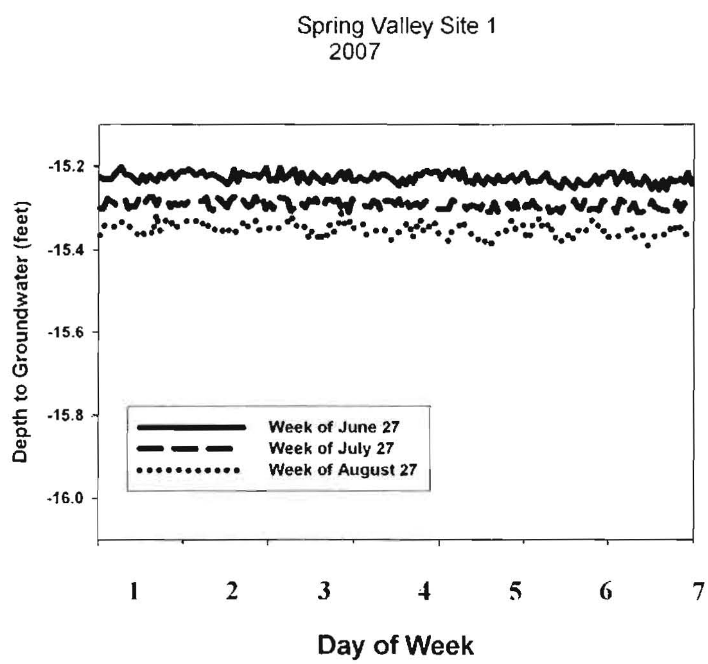



**Figure 14b. Continuous depth to ground water at SV1 during three different weeks in 2007.**

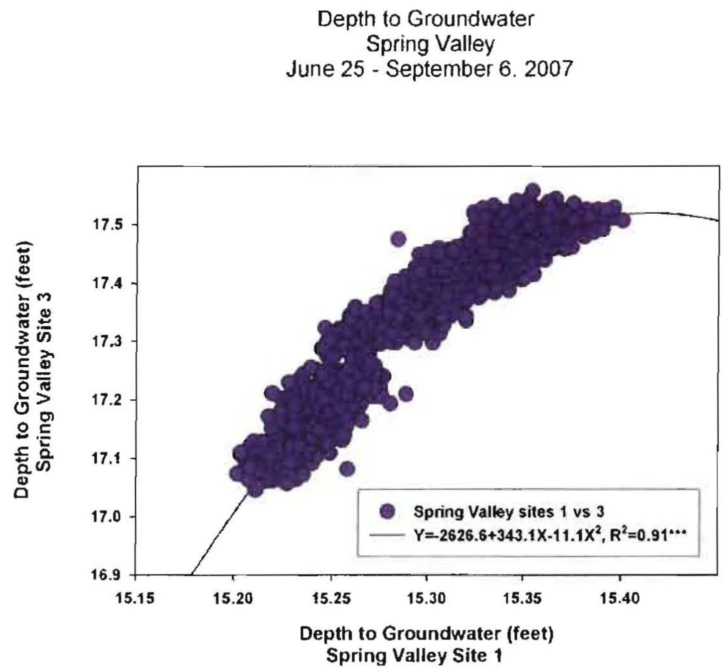



**Figure 15a. Depth to ground water correlation between SV1 and SV3 during 2007.**

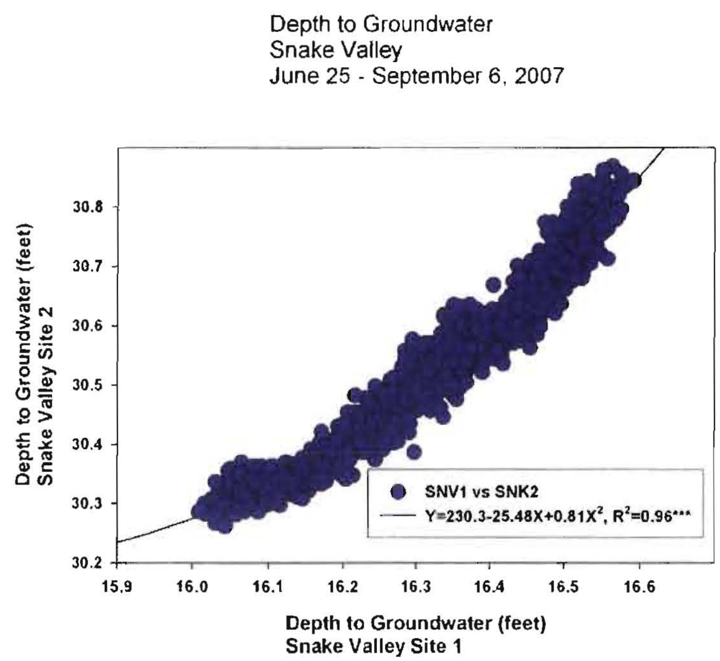



**Figure 15b. Depth to ground water correlation between SNK1 and SNK2 during 2007.**

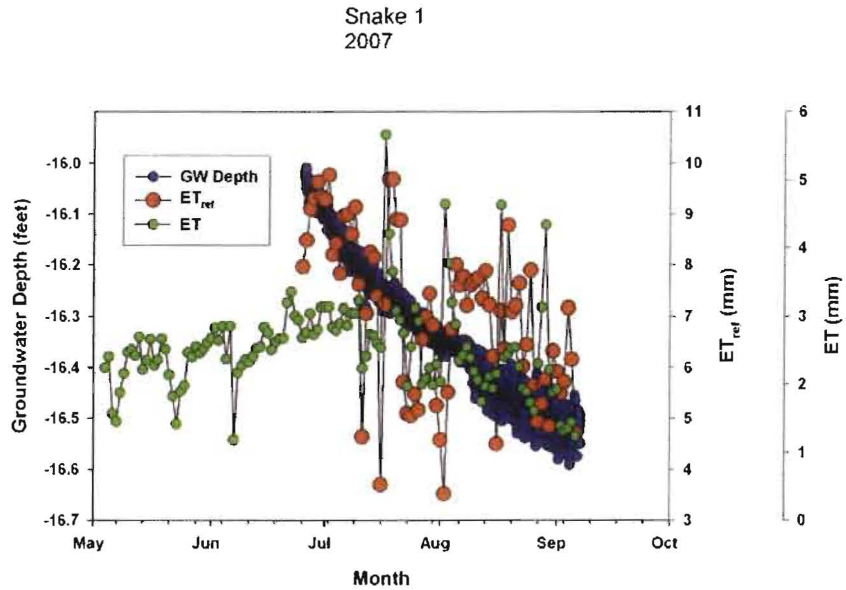



**Figure 16. Relationship between depth to ground water, evapotranspiration and reference evapotranspiration at SNK1 during 2007.**

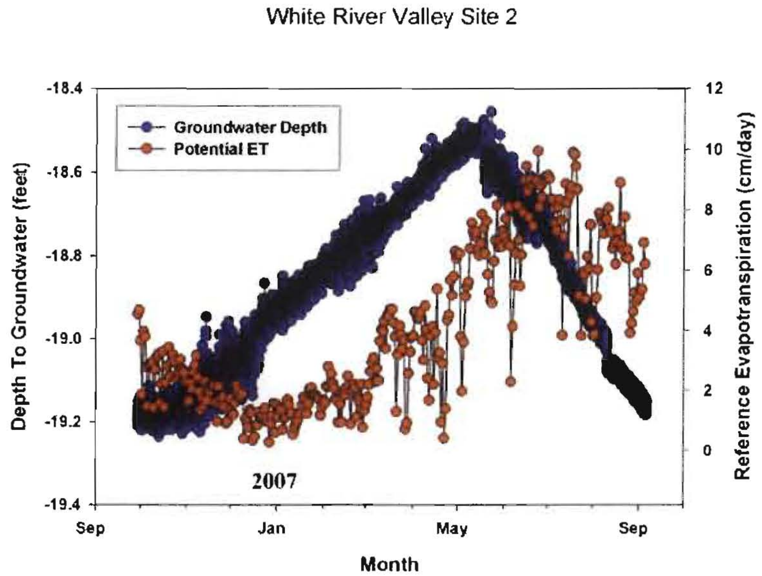



**Figure 17a. Relationship between depth to ground water and reference evapotranspiration at WRV2 during 2006 and 2007.**

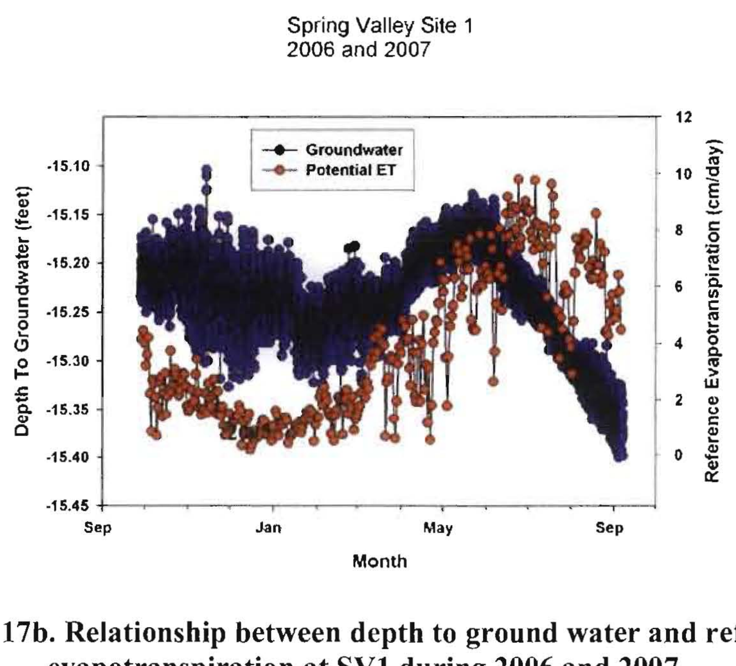



**Figure 17b. Relationship between depth to ground water and reference evapotranspiration at SV1 during 2006 and 2007.**

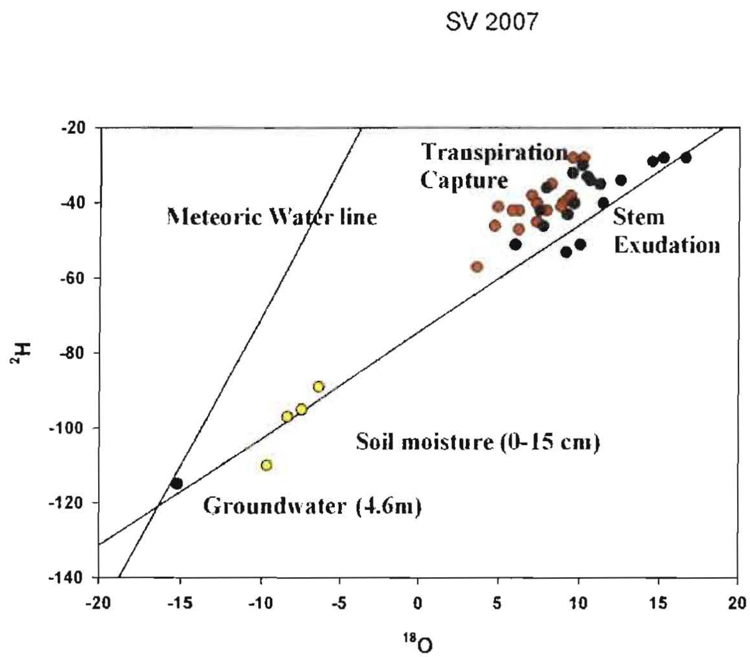



**Figure 18a. Relationship between the deviation in per thousand parts (‰) of $^2$H and $^{18}$O in ground water, soil moisture, transpiration capture and stem exudation at SV1 in 2007.**

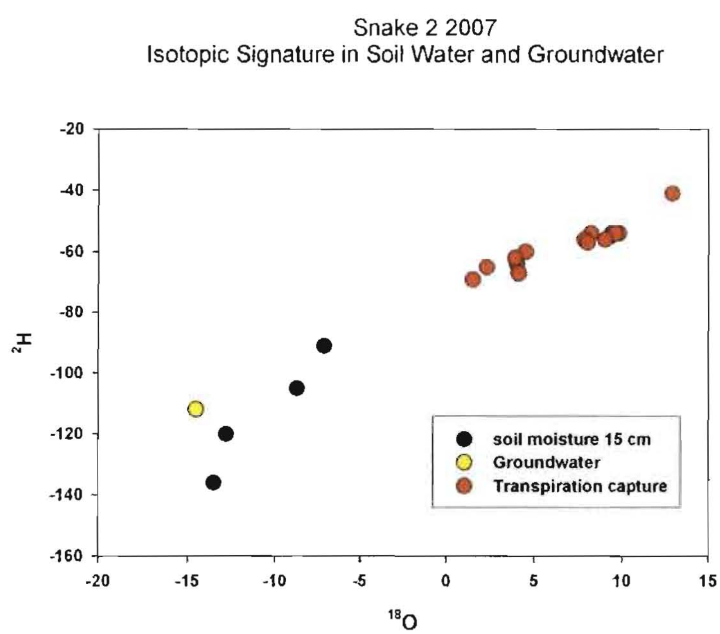



**Figure 18b. Relationship between the deviation in per thousand parts (‰) of $^2$H and $^{18}$O in ground water, soil moisture and transpiration capture at SNK2 in 2007.**

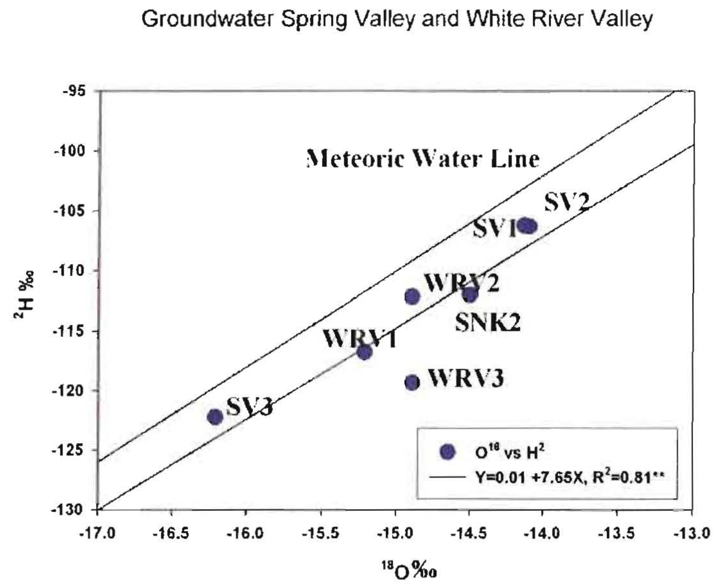



**Figure 19. Relationship between the deviation in per thousand parts (‰) of $^{2}H$ and $^{18}O$ in ground water sampled at the various sites, along with the Meteoric Water Line.**

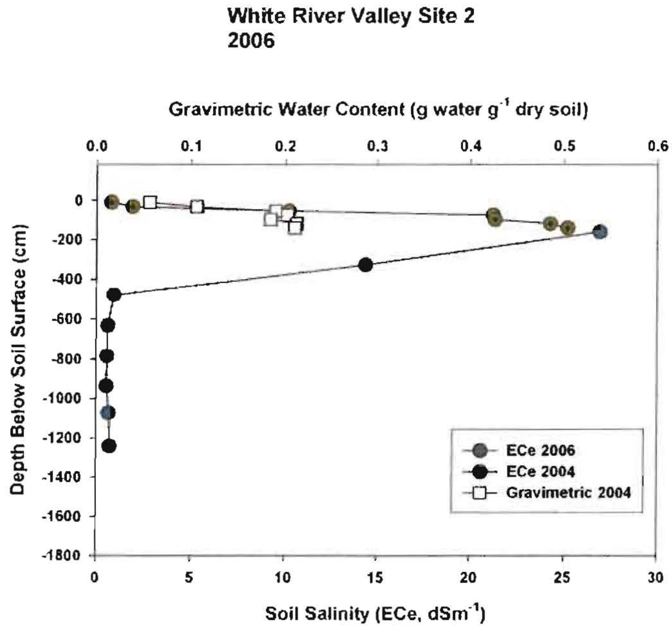



**Figure 20a. Soil salinity (ECe) and gravimetric water content with depth at WRV2 in 2006.**

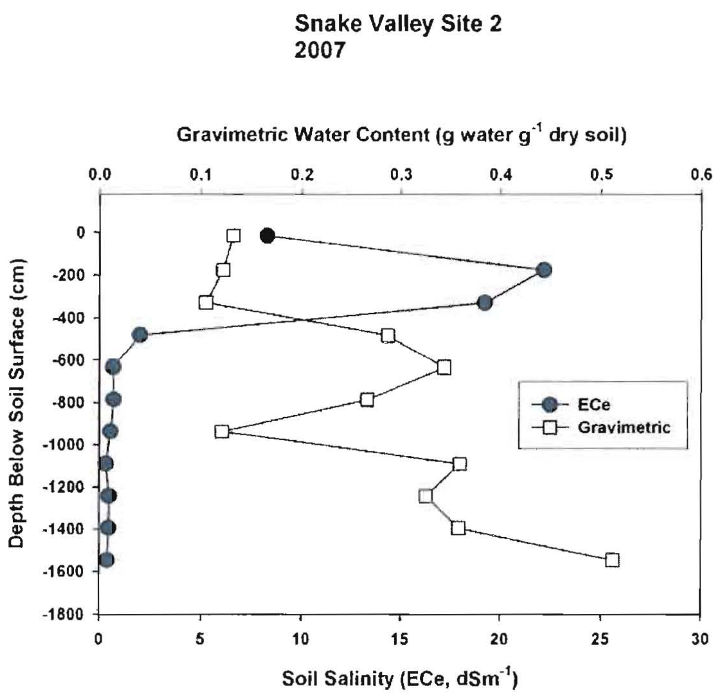



**Figure 20b. Soil salinity (ECe) and gravimetric water content with depth at SNK2.**

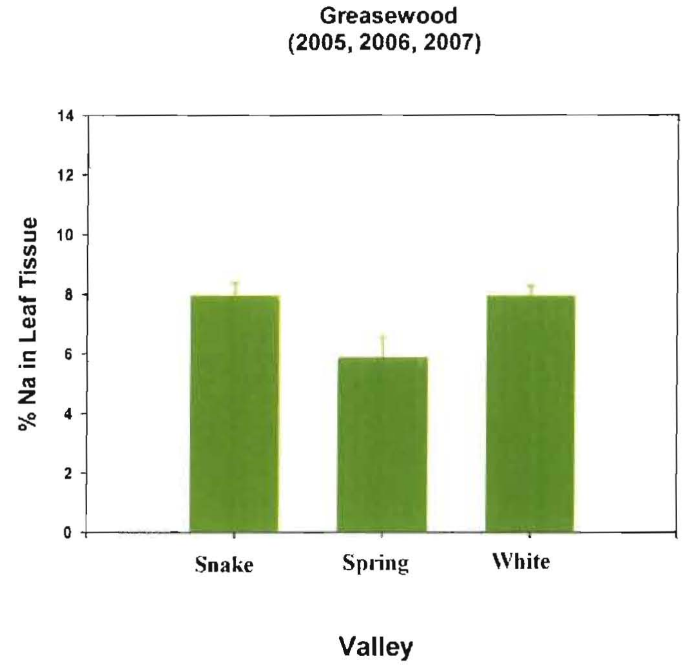



**Figure 21a. Percent sodium in leaf tissue of greasewood sampled in Snake Valley, Spring Valley and White River Valley during 2005, 2006 and 2007.**

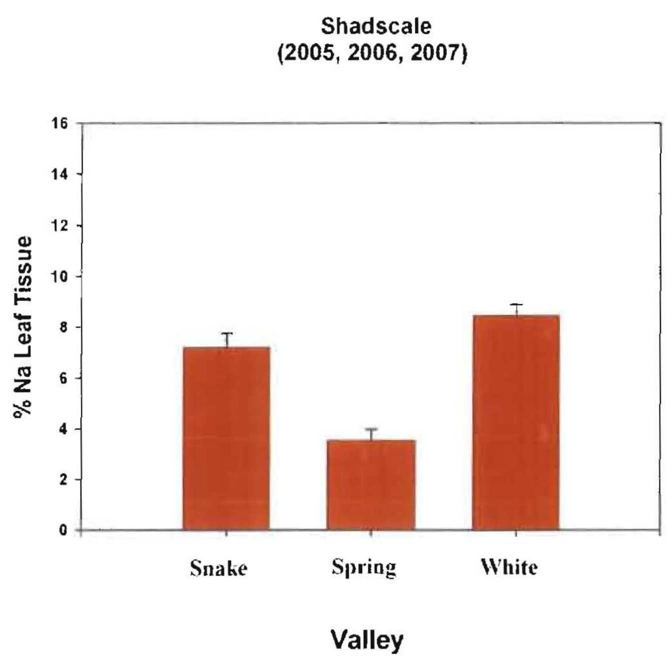



**Figure 21b. Percent sodium in leaf tissue of shadscale sampled in Snake Valley, Spring Valley and White River Valley in 2005, 2006 and 2007.**

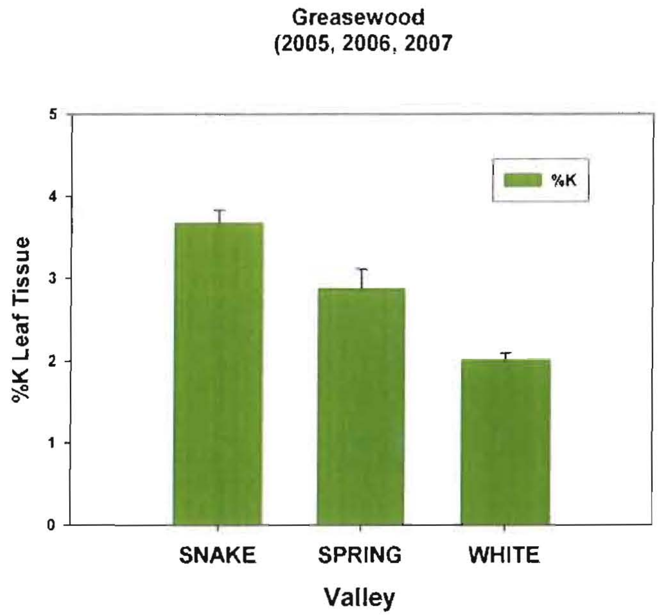



**Figure 22a. Percent potassium in leaf tissue of greasewood sampled in Snake Valley, Spring Valley and White River Valley in 2005, 2006 and 2007.**

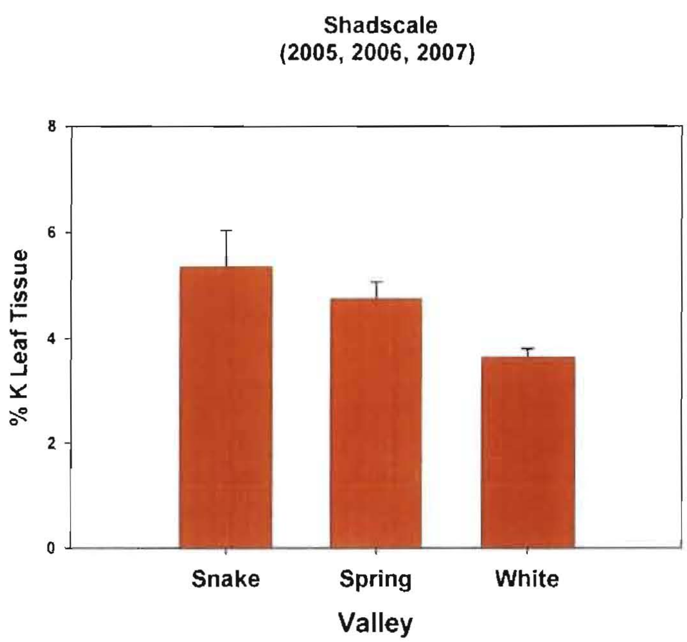



**Figure 22b. Percent potassium in leaf tissue of shadscale sampled in Snake Valley, Spring Valley and White River Valley in 2005, 2006 and 2007.**

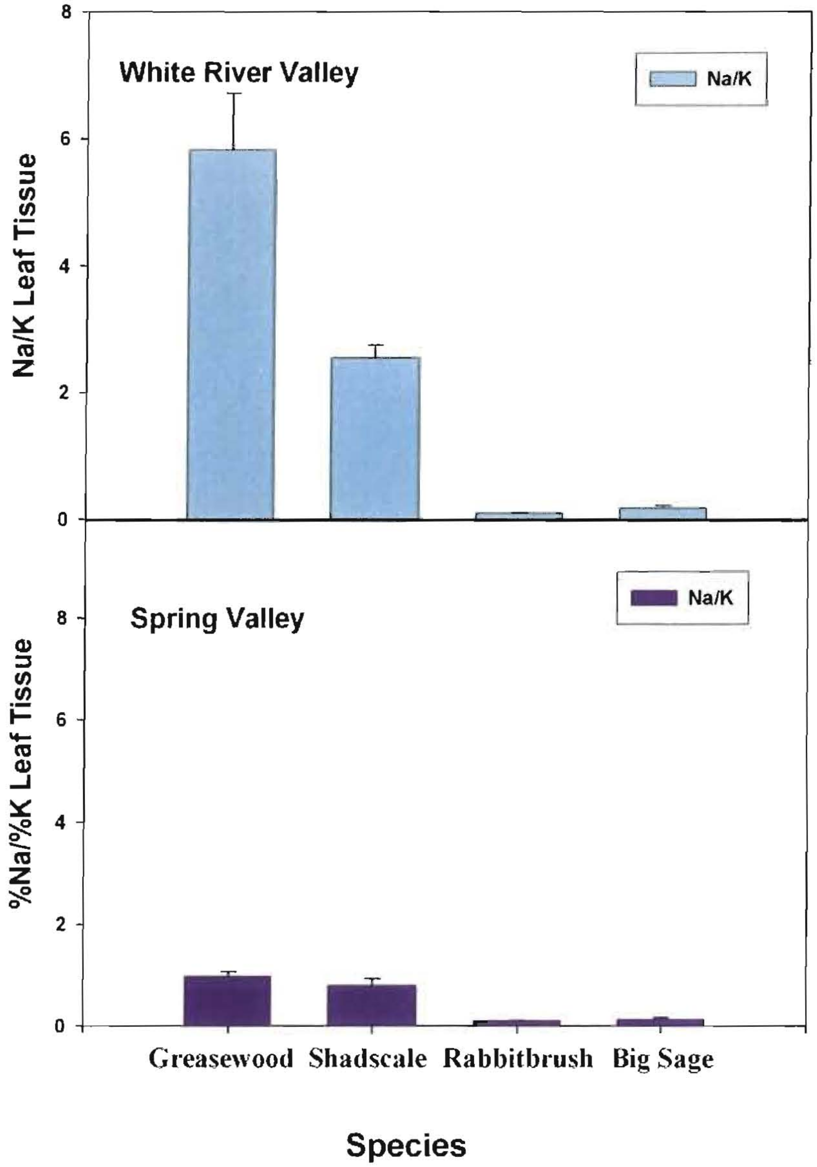



**Figure 23a. Sodium/potassium ratio in leaf tissue of greasewood, shadscale, rabbitbrush and big sage sampled in White River Valley and Spring Valley.**

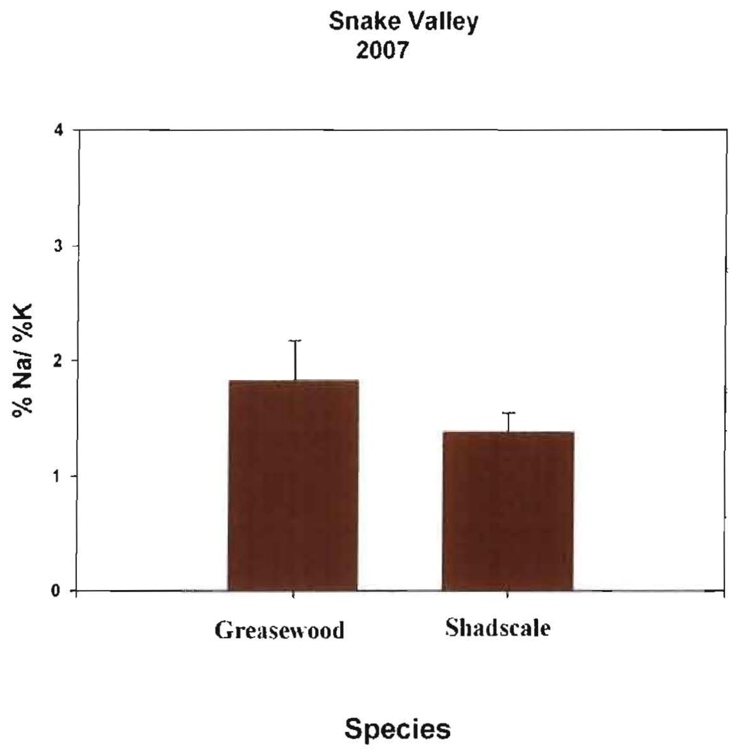



**Figure 23b. Sodium/potassium ratio in leaf tissue of greasewood and shadscale sampled in Snake Valley in 2007.**

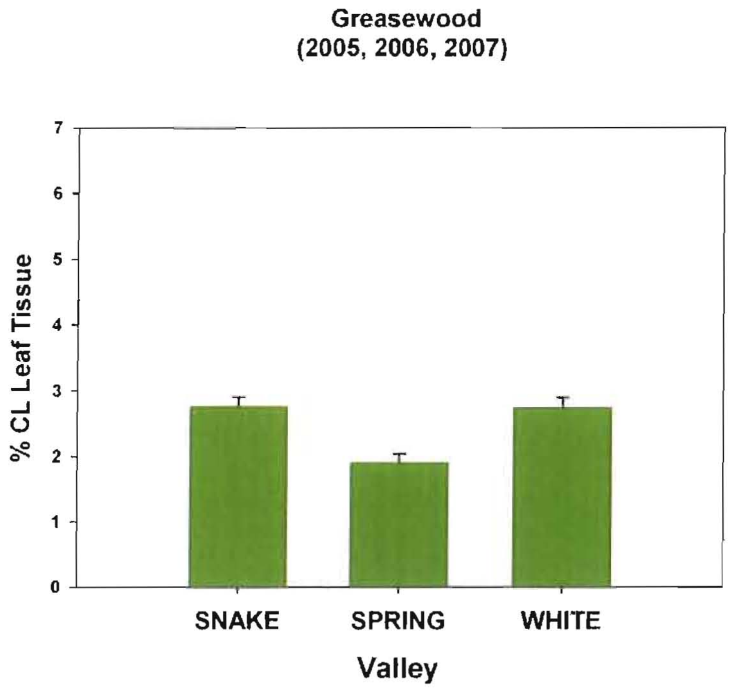



**Figure 24a. Percent chloride in leaf tissue of greasewood sampled in Snake Valley, Spring Valley, and White River Valley in 2005, 2006 and 2007.**

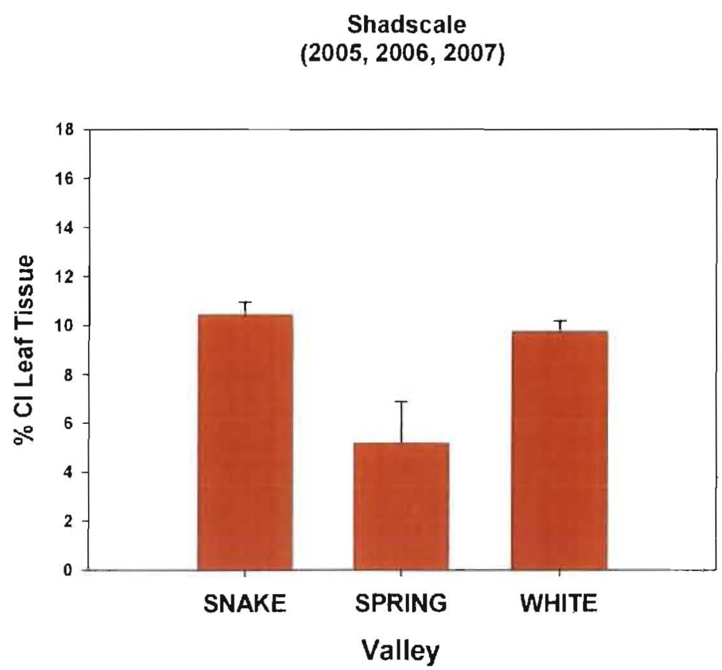



**Figure 24b. Percent chloride in leaf tissue of shadscale sampled in Snake Valley, Spring Valley and White River Valley in 2005, 2006 and 2007.**

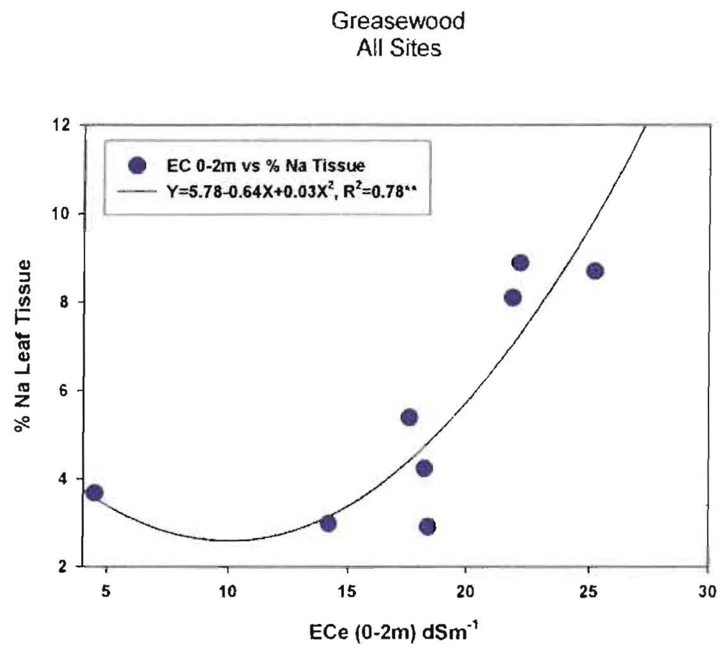



**Figure 25. Relationship between percent sodium in leaf tissue and soil salinity ($EC_e$) at depths between zero and two meters.**

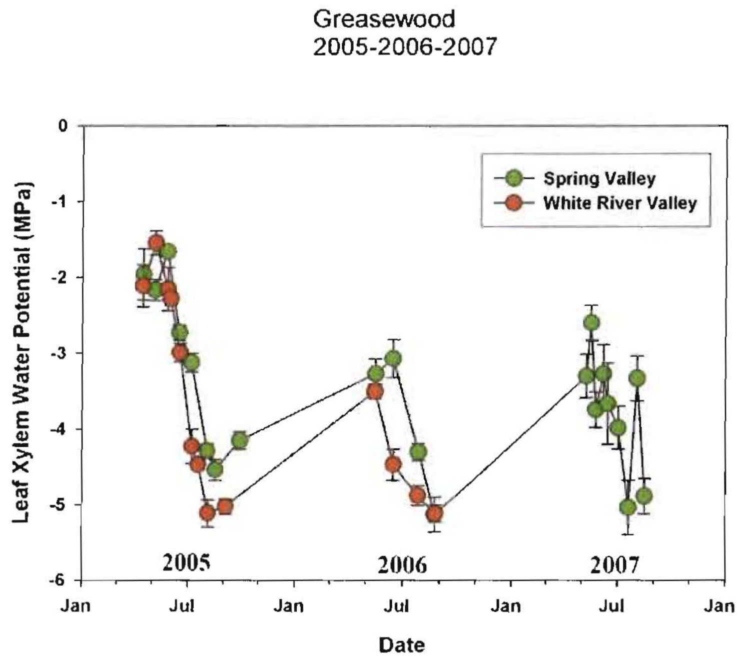



**Figure 26a. Leaf xylem water potential (MPa) for greasewood in Spring Valley and White River Valley in 2005, 2006 and 2007.**

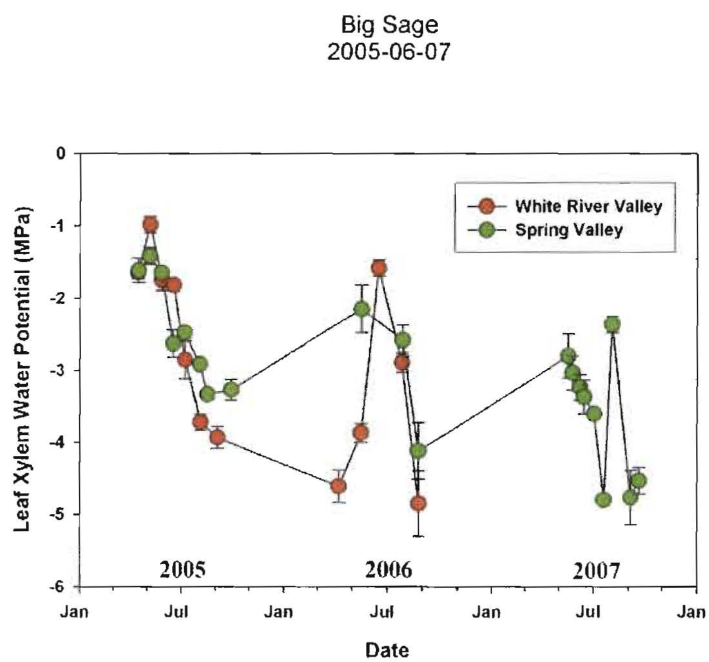



**Figure 26b. Leaf xylem water potential (MPa) for big sage in White River Valley and Spring Valley in 2005, 2006 and 2007.**

2007

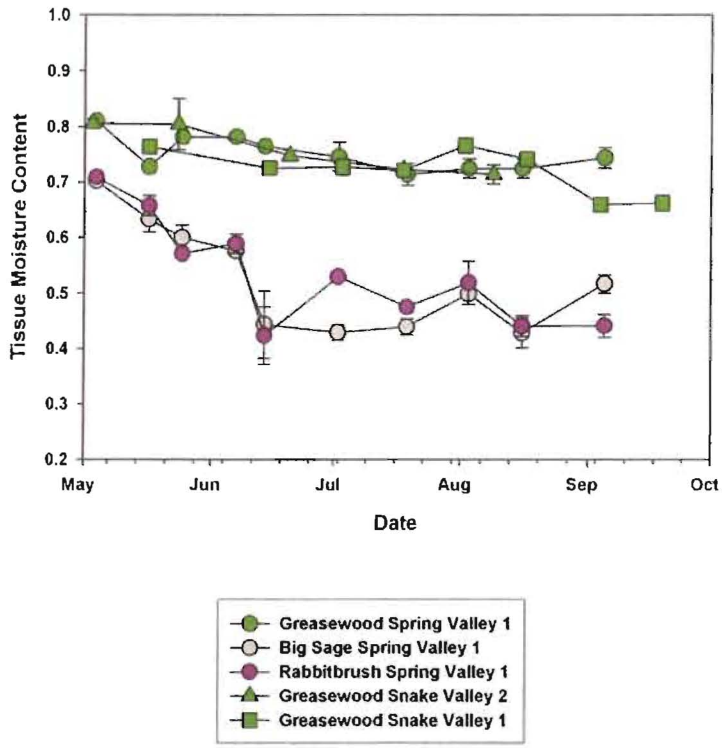



**Figure 27a. Tissue moisture content for greasewood, big sage and rabbitbrush in Spring Valley and greasewood in Snake Valley during 2007.**

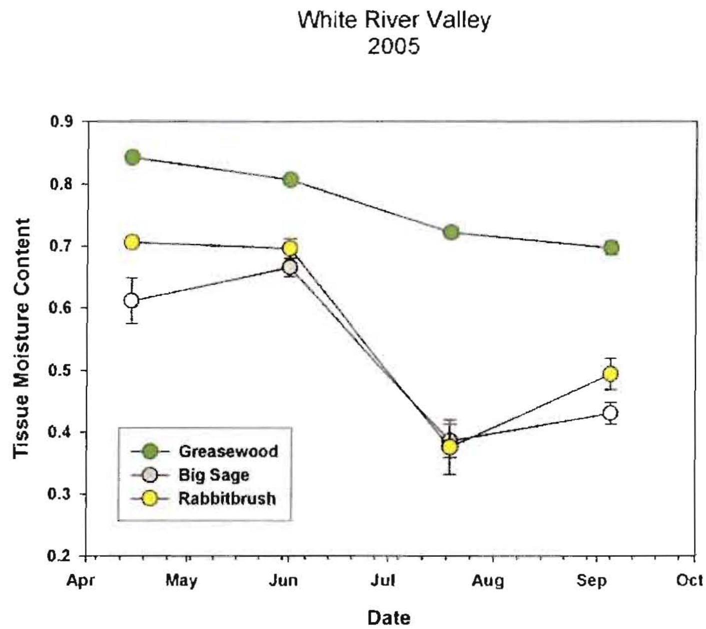



**Figure 27b. Tissue moisture content for greasewood, big sage and rabbitbrush in White River Valley in 2005.**

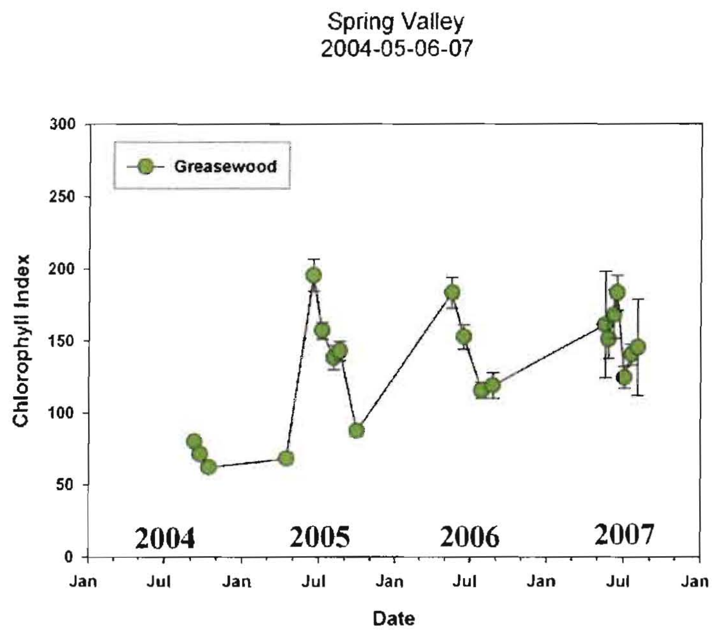



**Figure 28a. Chlorophyll index of greasewood in Spring Valley in 2004, 2005, 2006 and 2007.**

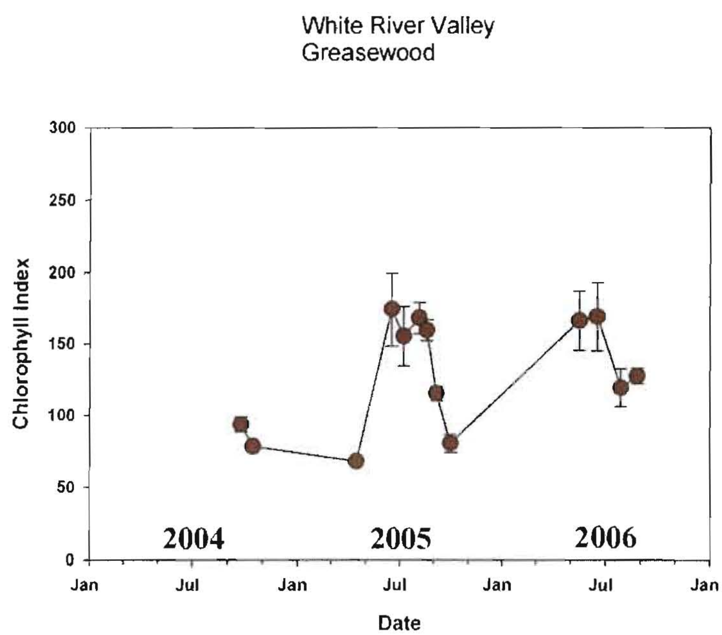



**Figure 28b. Chlorophyll index of greasewood in White River Valley in 2004, 2005 and 2006.**

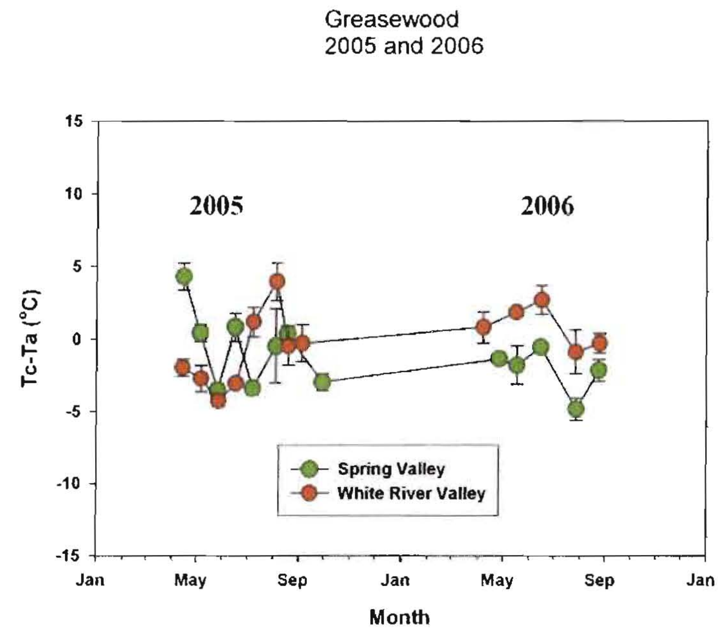



**Figure 29a. Canopy temperature (Tc) minus ambient temperature (Ta) for greasewood in Spring Valley and White River Valley in 2005 and 2006.**

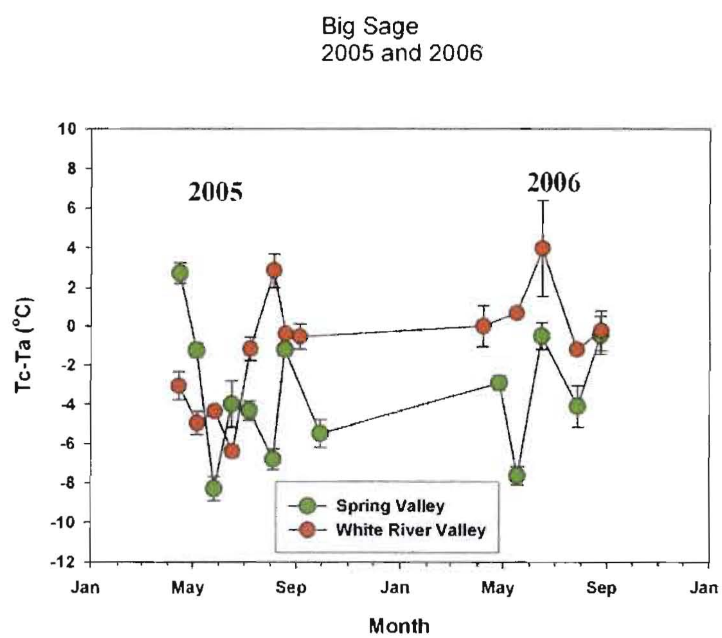



**Figure 29b. Canopy temperature (Tc) minus ambient temperature (Ta) for big sage in Spring Valley and White River Valley in 2005 and 2006.**

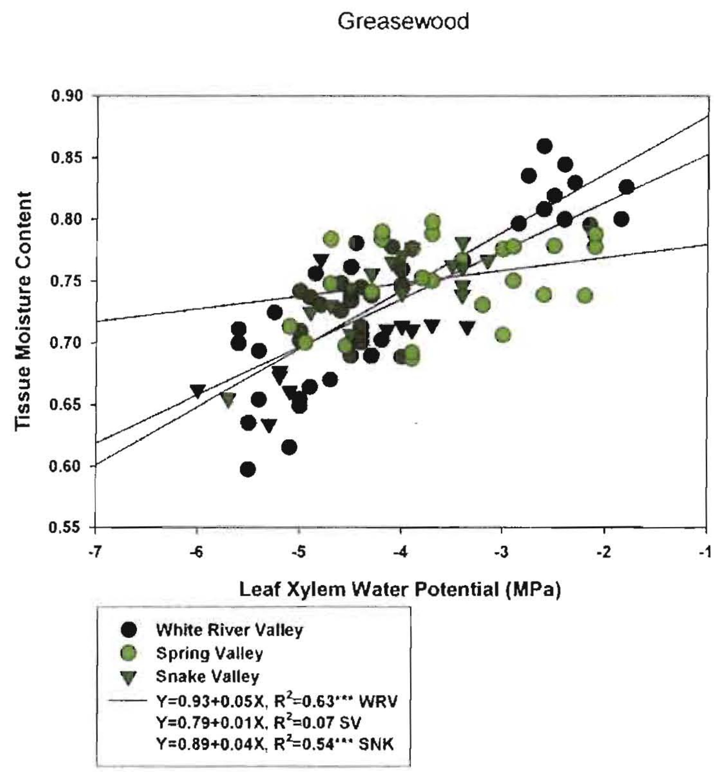



**Figure 30a. Relationship between tissue moisture content and leaf xylem water potential for greasewood in White River Valley, Spring Valley and Snake Valley.**

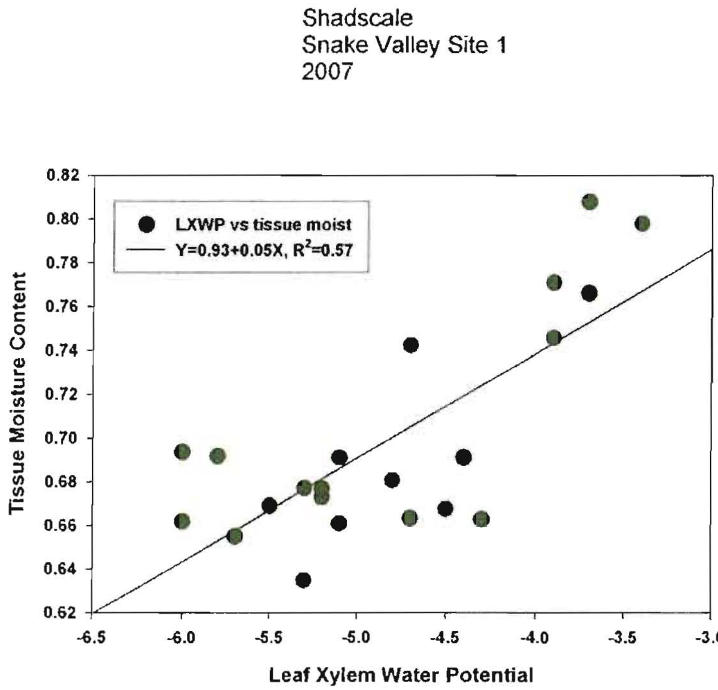



**Figure 30b. Relationship between tissue moisture content and leaf xylem water potential for shadscale at Snake Valley Site 1 in 2007.**

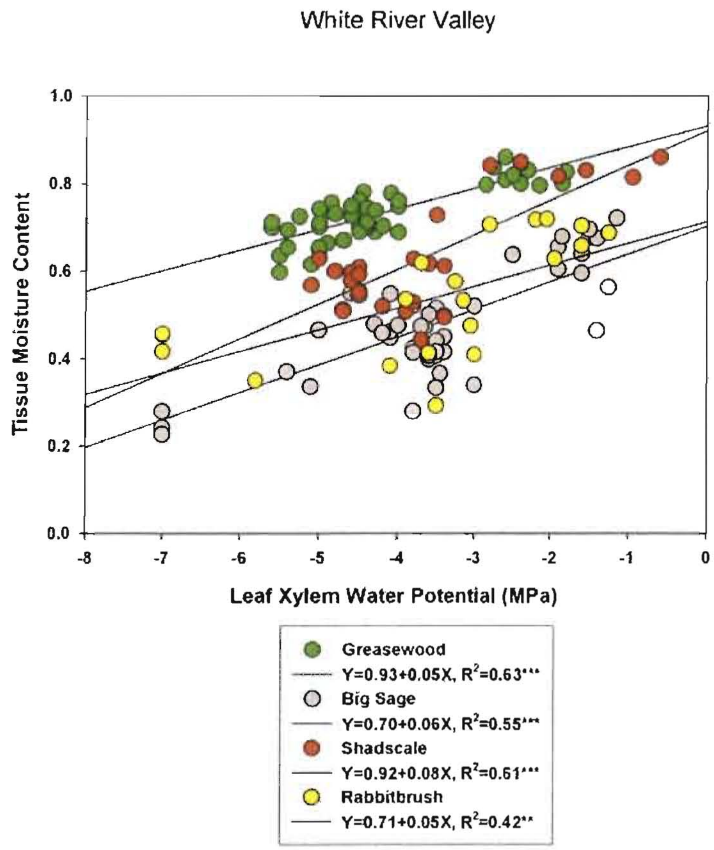



**Figure 31a. Relationship between tissue moisture content and leaf xylem water potential for greasewood, big sage, shadscale and rabbitbrush in White River Valley.**

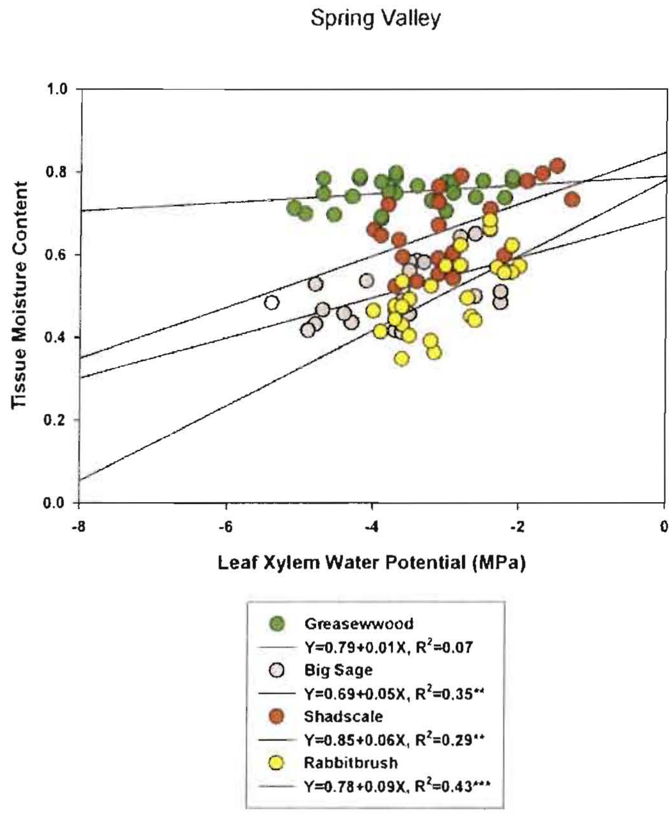



**Figure 31b. Relationship between tissue moisture content and leaf xylem water potential for greasewood, big sage, shadscale and rabbitbrush in Spring Valley.**

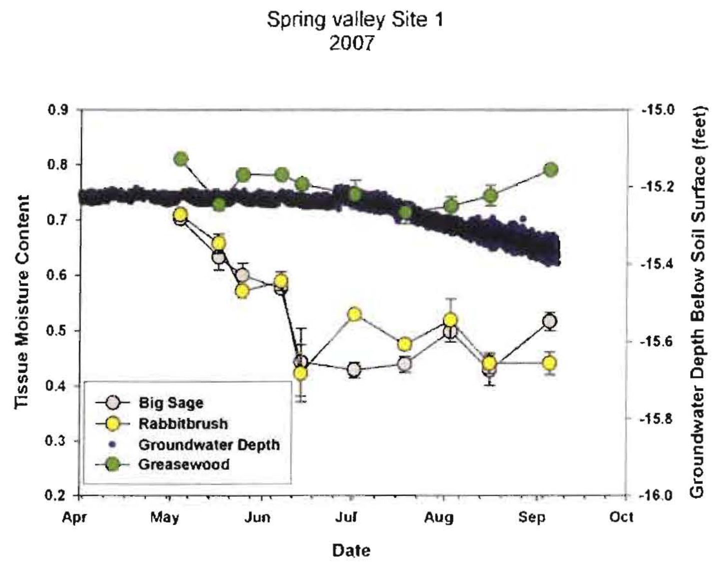



**Figure 32a. Tissue moisture content of big sage, rabbitbrush and greasewood with groundwater depth below soil surface in feet at the SV1 site in 2007.**

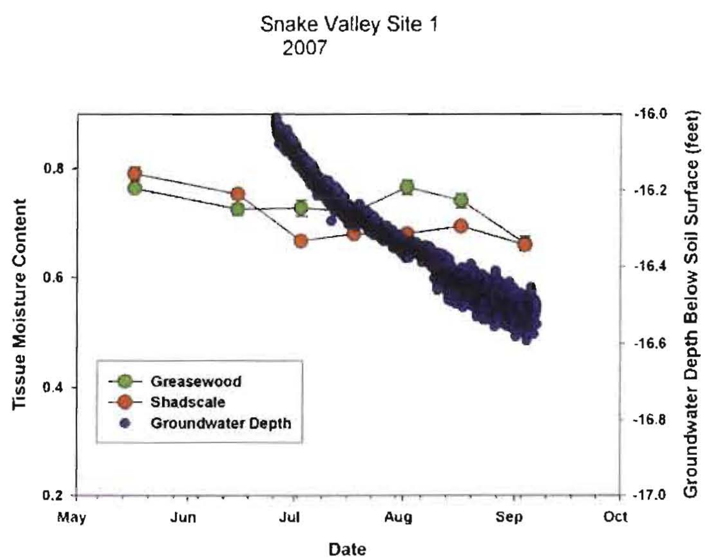



**Figure 32b. Tissue moisture content of greasewood and shadscale with groundwater depth below soil surface in feet at the SNK1 site in 2007.**

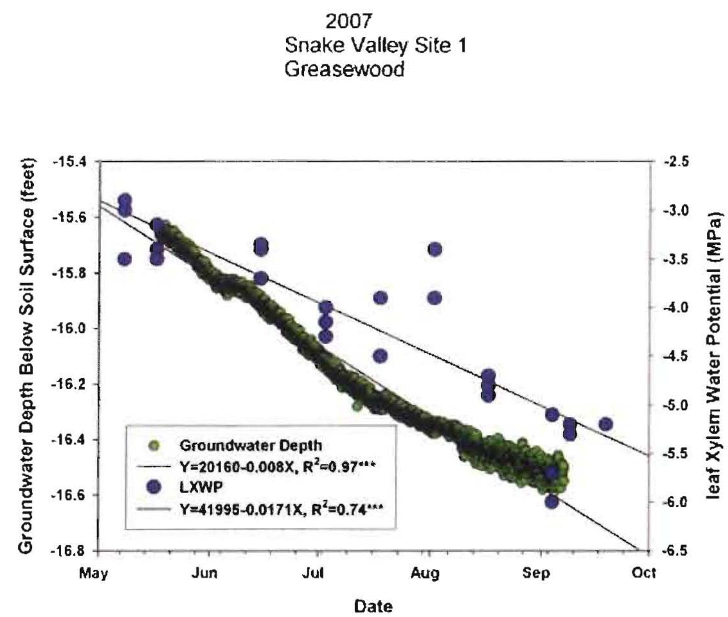



**Figure 33a. Comparison of groundwater depth below soil surface in feet and leaf xylem water potential of greasewood at the SNK1 site in 2007.**

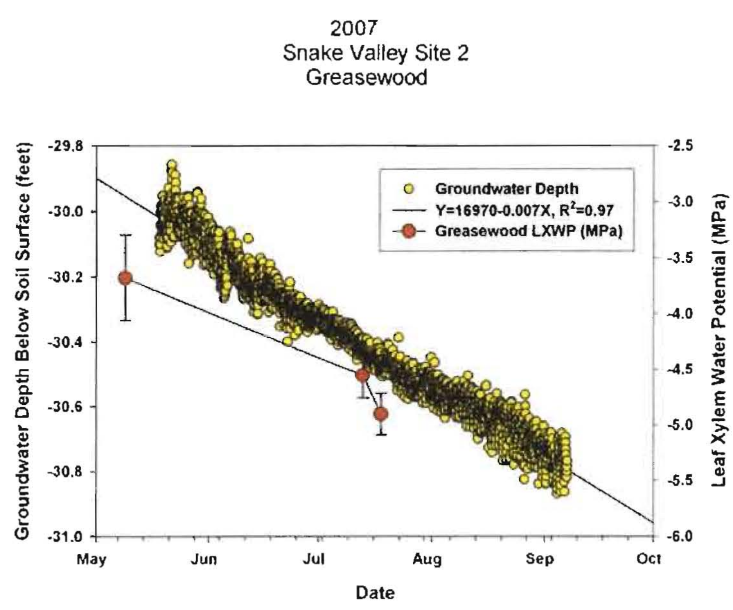



**Figure 33b. Comparison of groundwater depth below soil surface in feet and leaf xylem water potential of greasewood at the SNK2 site in 2007.**

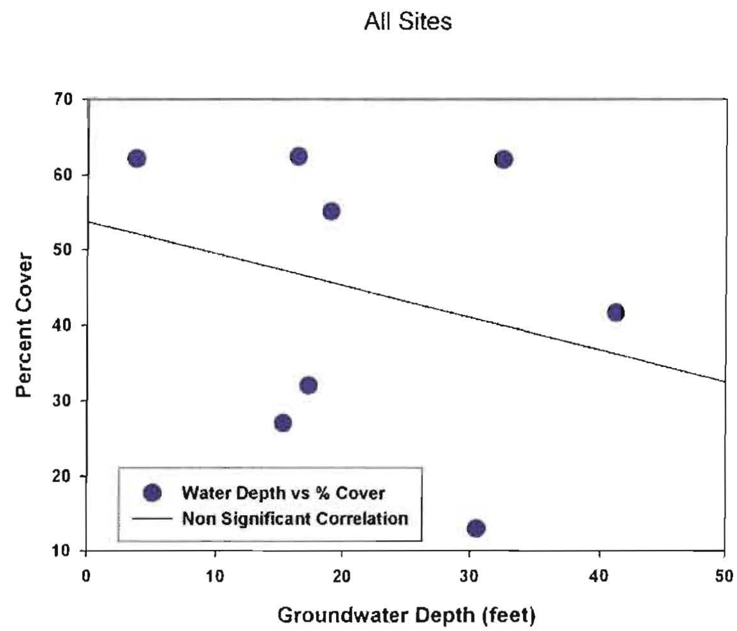



**Figure 34a. Relationship of percent cover with groundwater depth for all sites.**

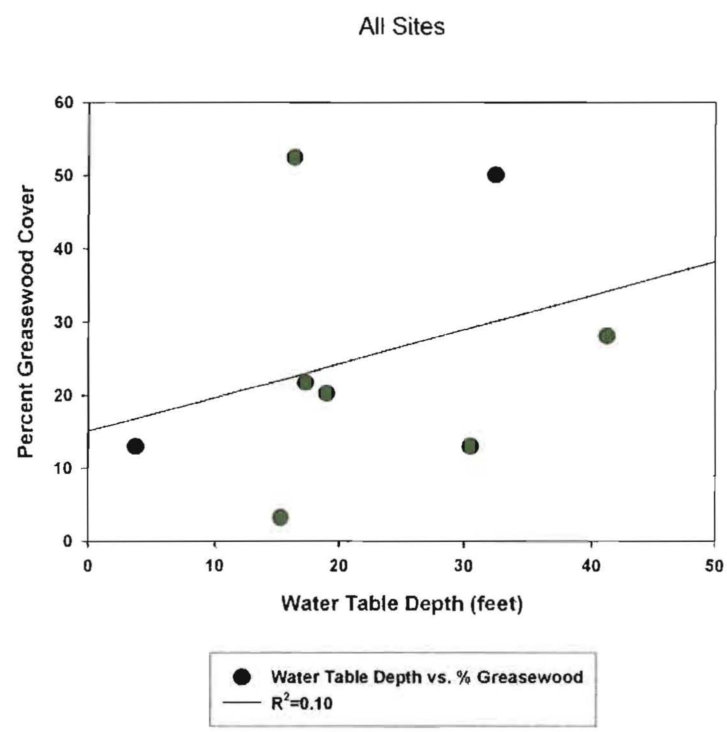



**Figure 34b. Relationship of percent cover of greasewood with water table depth for all sites.**

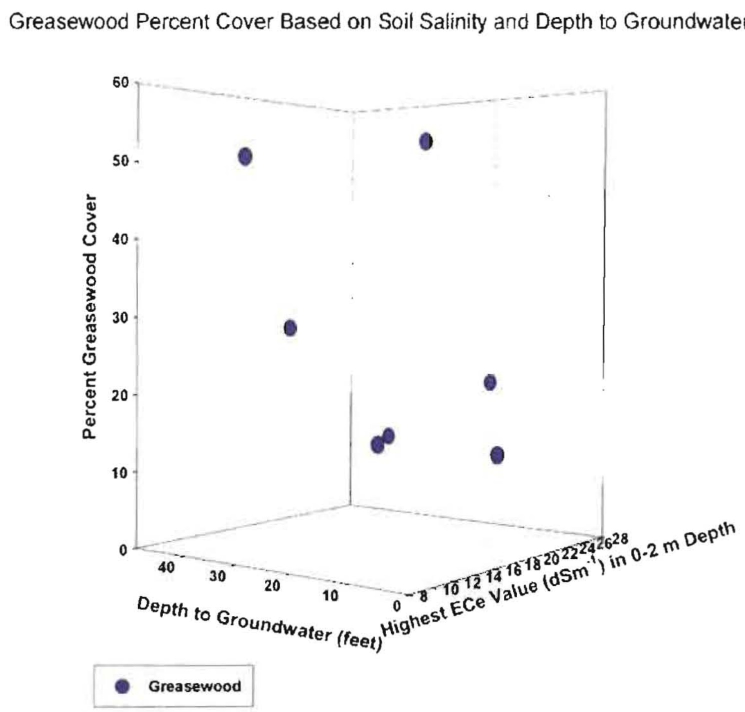



**Figure 35. Greasewood percent cover based on soil salinity and depth to groundwater.**

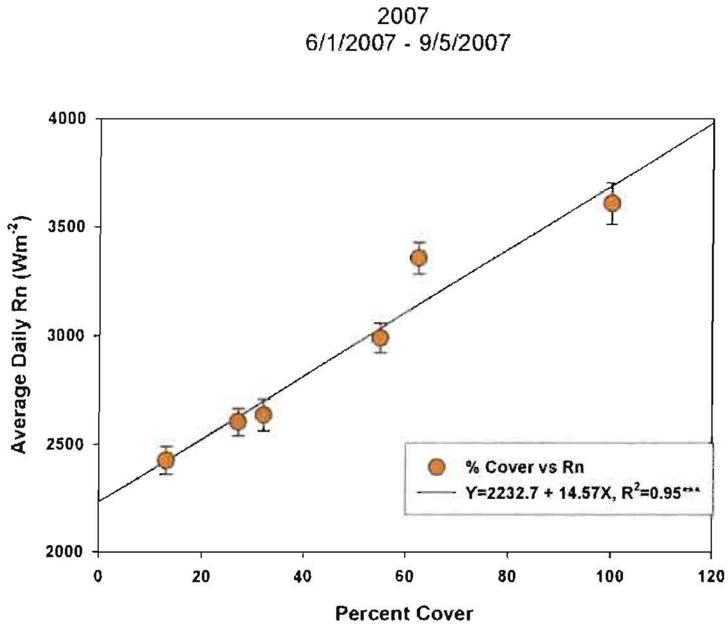



**Figure 36a. Relationship between average daily net radiation (Rn) and percent cover in 2007 between 6/1 and 9/5.**

2007

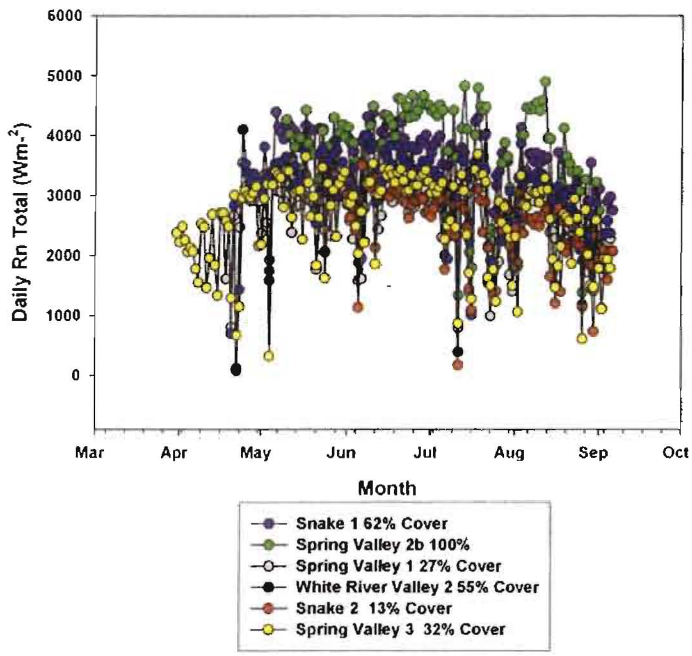



**Figure 36b. Daily total net radiation for Snake Valley 1, Spring Valley 2b, Spring Valley 1, White River Valley 2, Snake Valley 2 and Spring Valley 3 with their respective percent cover in 2007.**

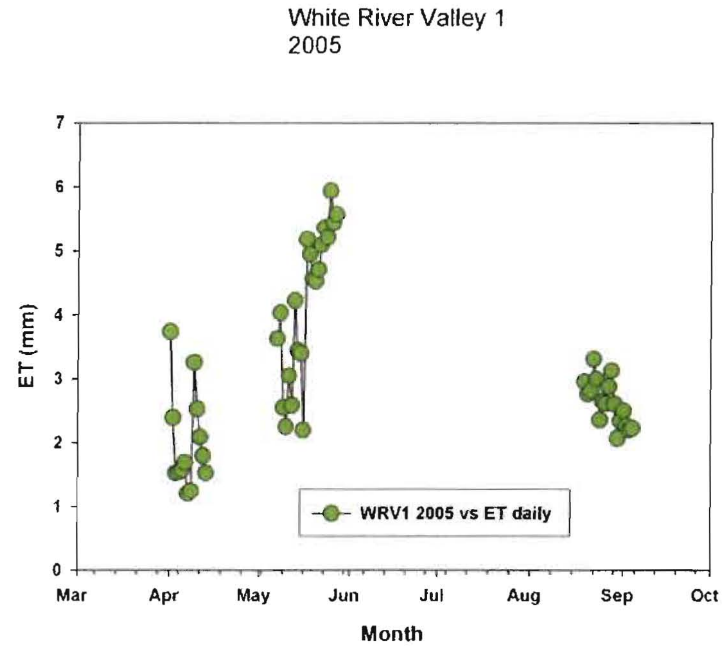



**Figure 37a. Daily evapotranspiration for White River Valley 1 in 2005.**

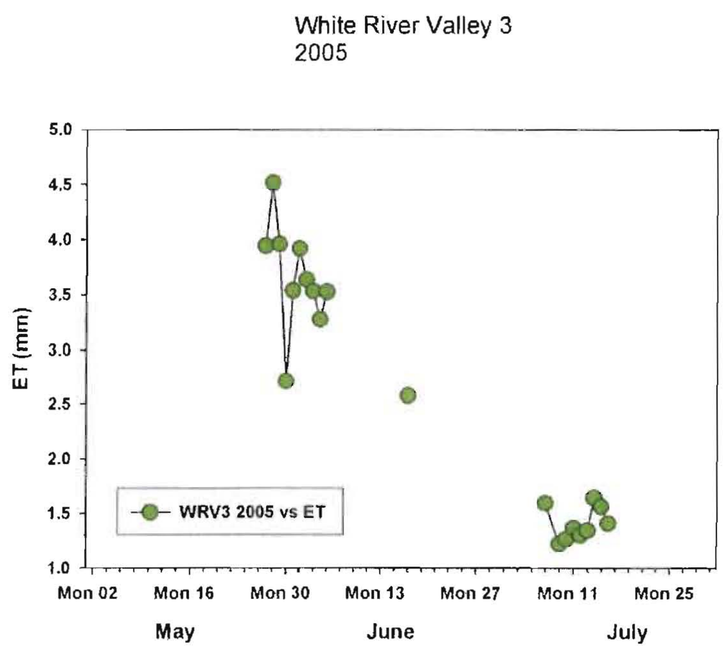



**Figure 37b. Daily evapotranspiration for White River Valley 3 in 2005.**

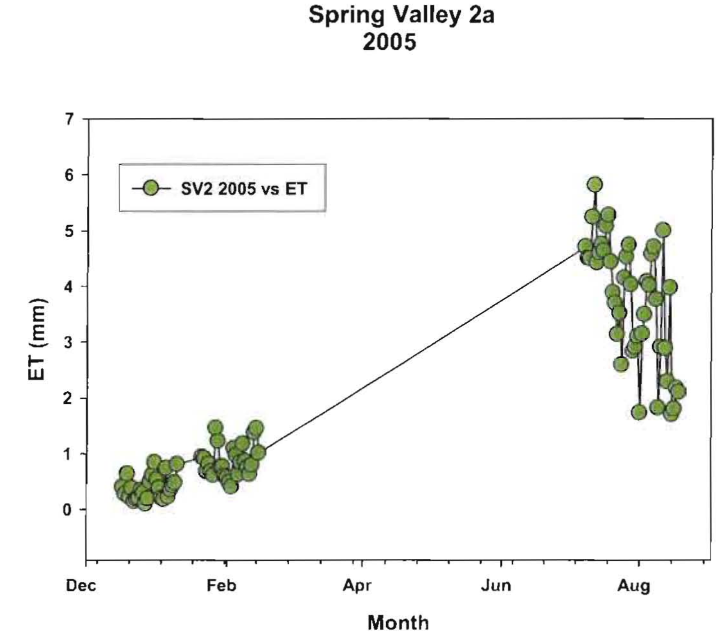



**Figure 38a. Daily evapotranspiration for Spring Valley 2a in 2005.**

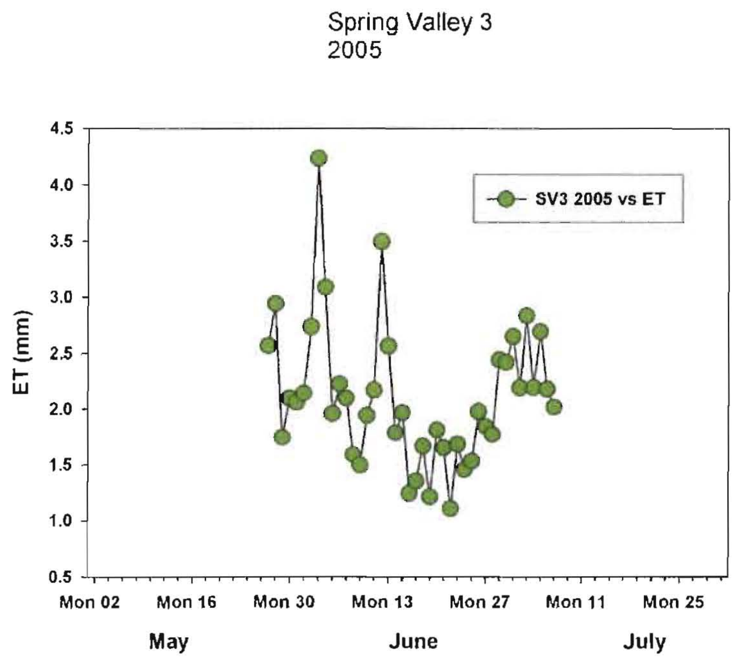



**Figure 38b. Daily evapotranspiration for Spring Valley 3 in 2005.**

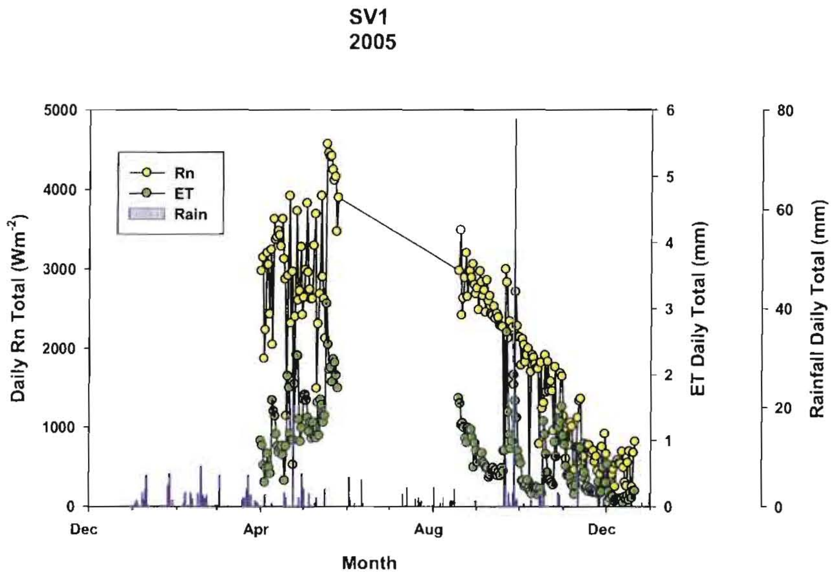



**Figure 39a. Comparison of daily net radiation total, evapotranspiration daily total and rainfall daily total for Spring Valley 1 in 2005.**

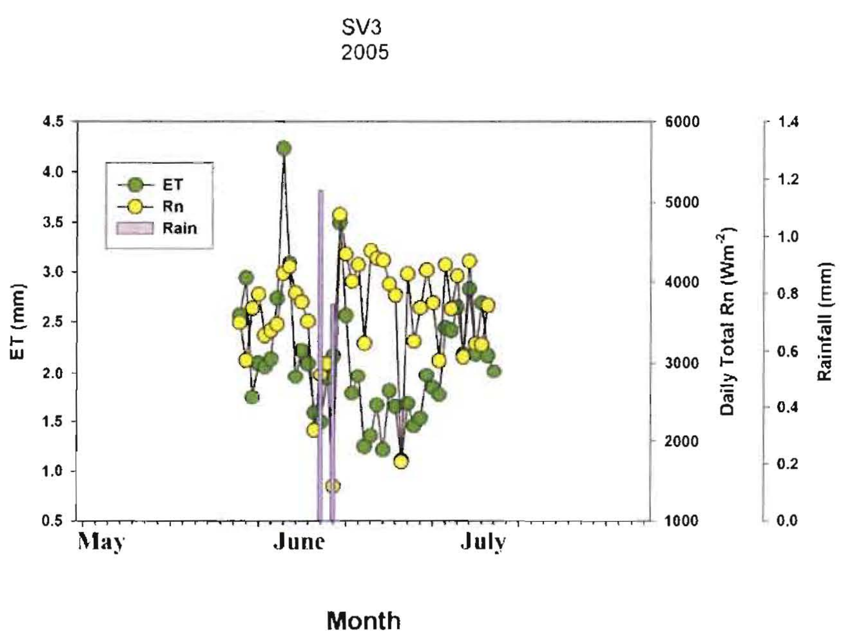



**Figure 39b. Comparison of daily net radiation total, evapotranspiration daily total and rainfall daily total for Spring Valley 3 in 2005.**

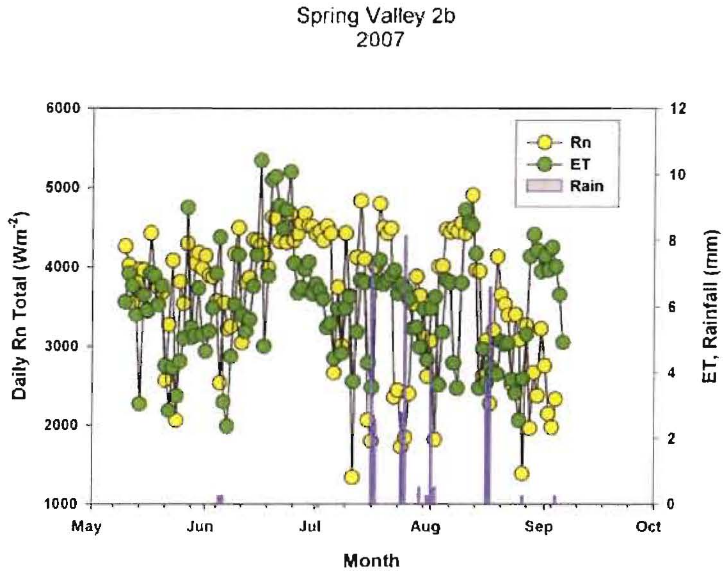



**Figure 39c. Relationship between daily net radiation total, evapotranspiration and rainfall for Spring Valley 2b in 2007.**

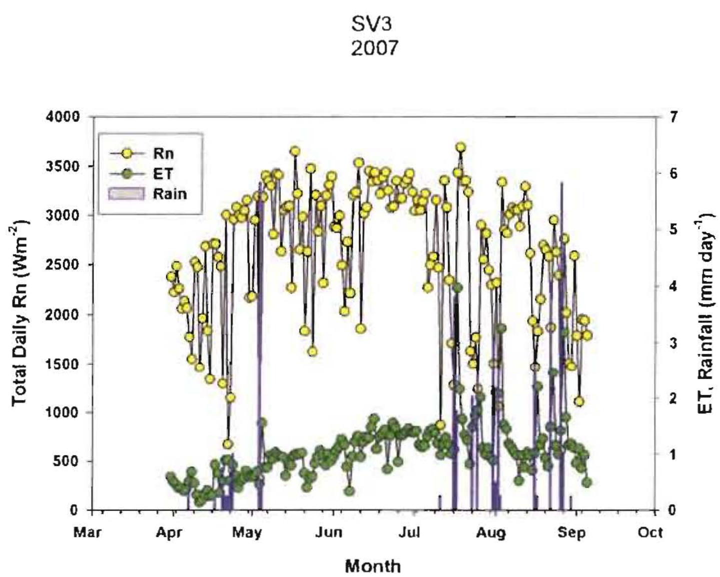



**Figure 39d. Relationship between daily net radiation total, evapotranspiration and rainfall for Spring Valley 3 in 2007.**

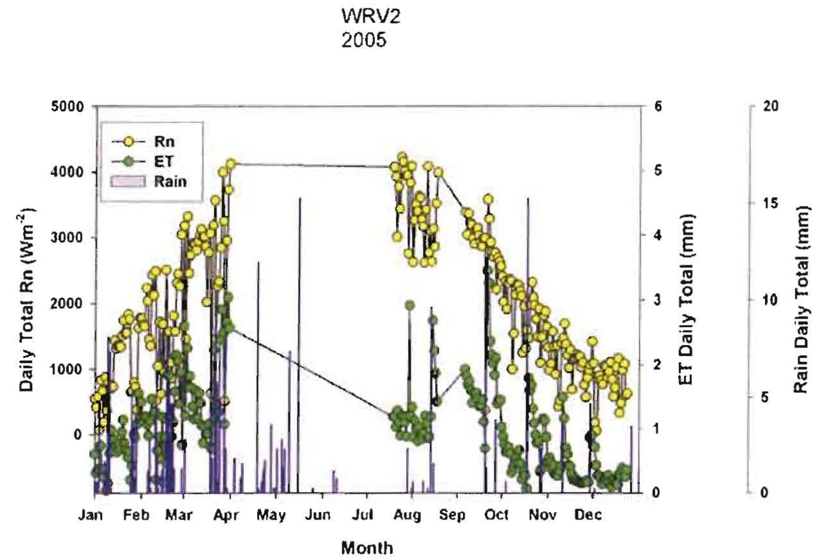



**Figure 39e. Comparison of daily total net radiation, evapotranspiration daily total and rainfall daily total for White River Valley 2 for 2005.**

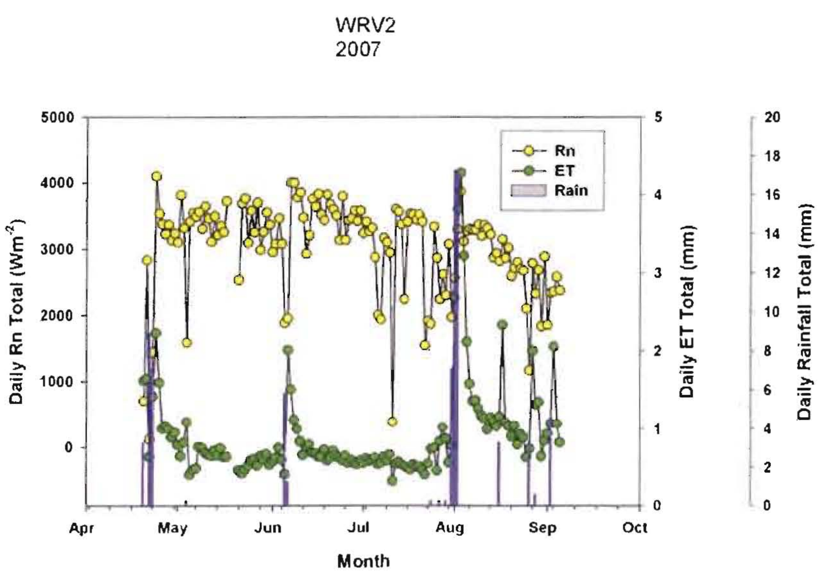



**Figure 39f. Comparison of daily total net radiation, evapotranspiration daily total and rainfall daily total for White River Valley 2 for 2007.**

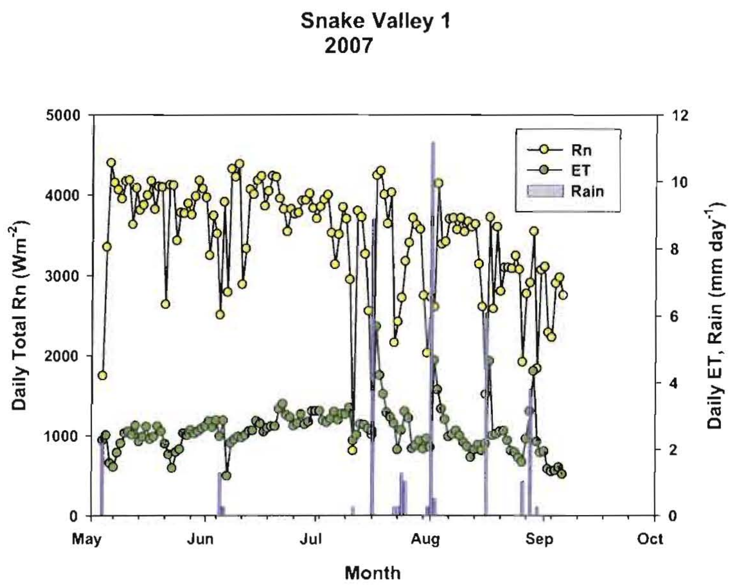



**Figure 39g. Relationship between daily total net radiation, daily evapotranspiration and daily rain total for Snake Valley 1 in 2007.**

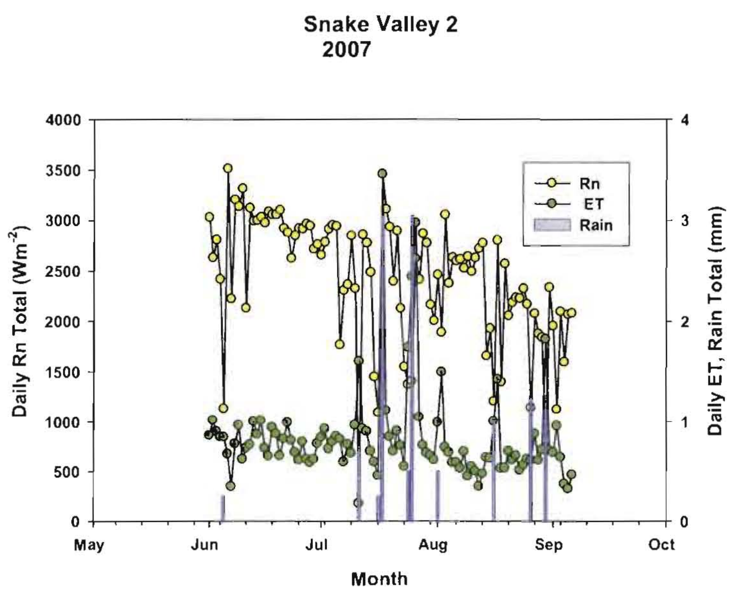



**Figure 39h. Relationship between daily total net radiation, daily evapotranspiration and daily rain total for Snake Valley 2 in 2007.**

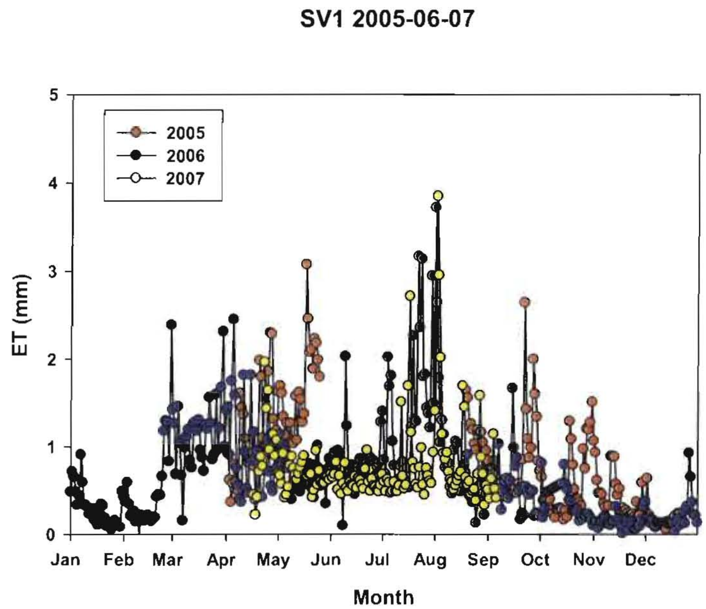



**Figure 40a. Evapotranspiration for Spring Valley 1 in 2005, 2006 and 2007.**

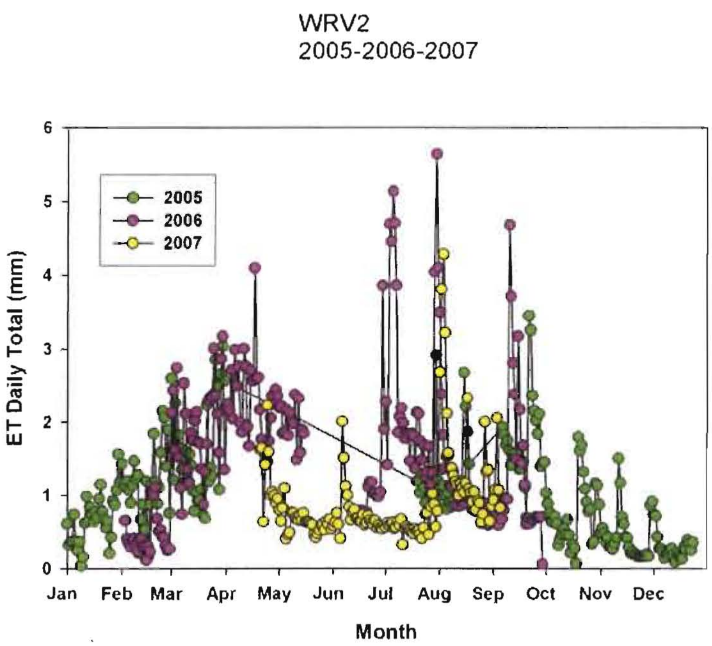



**Figure 40b. Evapotranspiration daily total for White River Valley 2 in 2005, 2006 and 2007.**

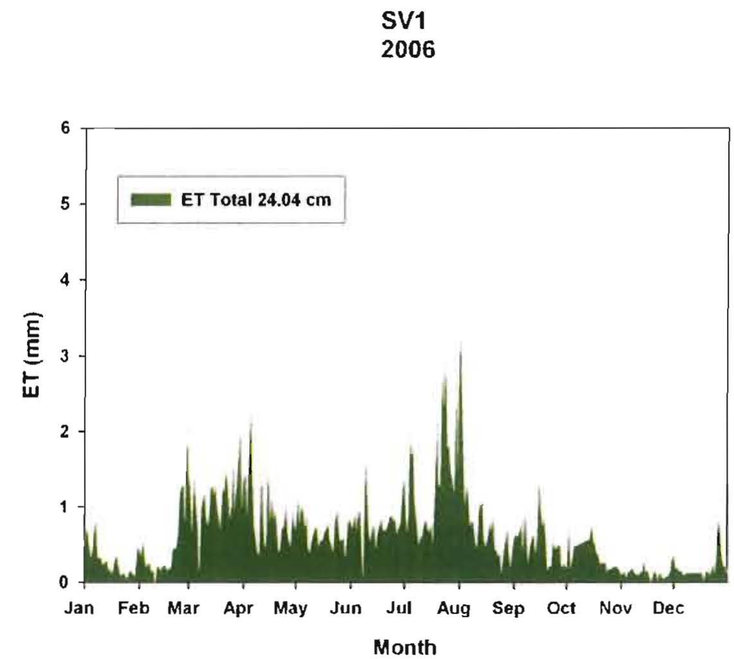



**Figure 41a. Evapotranspiration for Spring Valley 1 in 2006 with yearly total.**

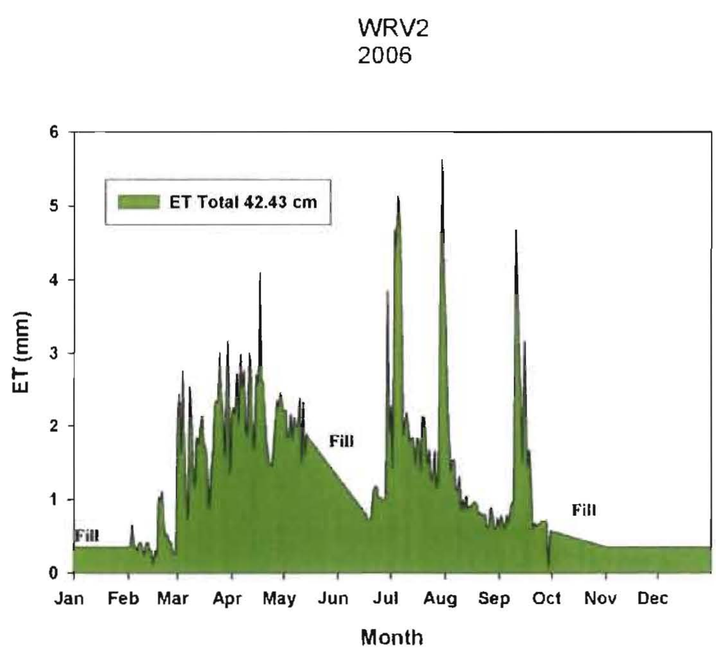



**Figure 41b. Evapotranspiration for White River Valley 2 in 2006 with yearly total.**

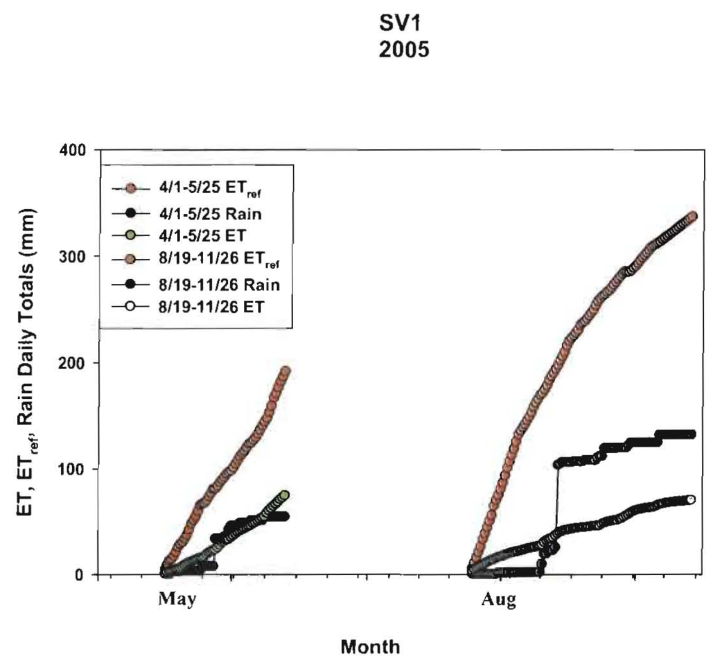



**Figure 42a. Comparison of evapotranspiration, reference transpiration and rain daily totals in Spring Valley 1 for 4/1 through 5/25 and 8/19 through 11/26 in 2005.**

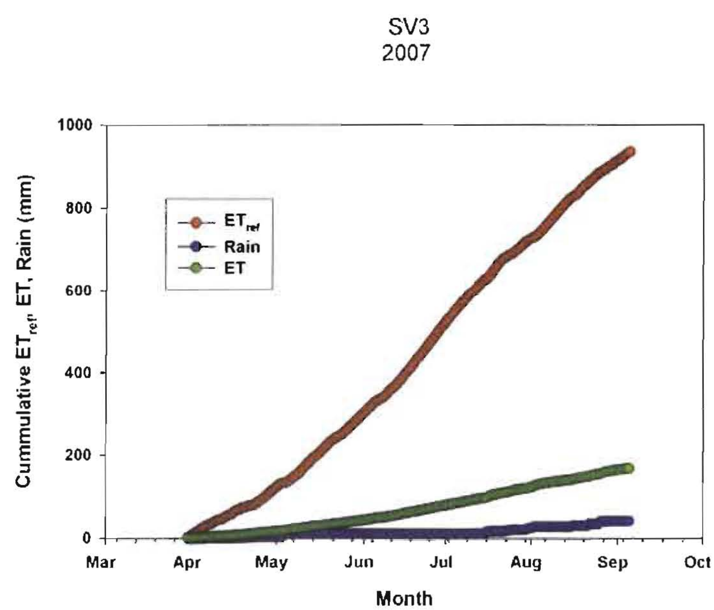



**Figure 42b. Comparison of cumulative reference evapotranspiration, evapotranspiration and rainfall for Spring Valley 3 in 2007.**

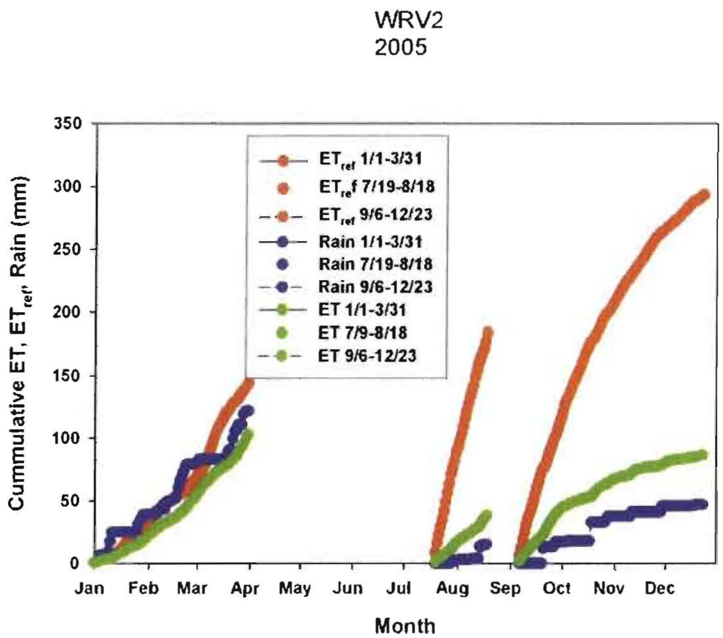



**Figure 42c. Comparison of cumulative evapotranspiration, reference evapotranspiration and rain for White River Valley 2 for 1/1-3/31, 7/19-8/18, and 9/6-12/23 in 2005.**

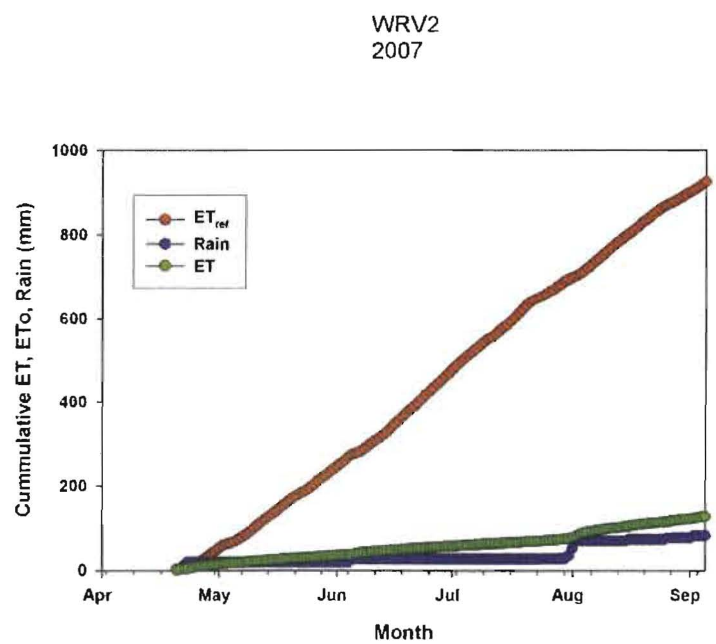



**Figure 42d. Cumulative evapotranspiration, reference evapotranspiration and rain for White River Valley in 2007.**

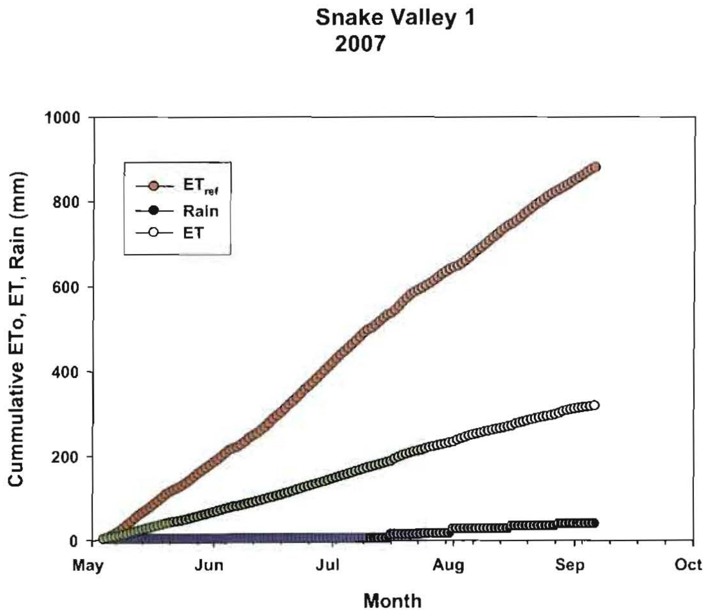



**Figure 42e. Comparison of cumulative reference evapotranspiration, evapotranspiration and rain for Snake Valley 1 in 2007.**

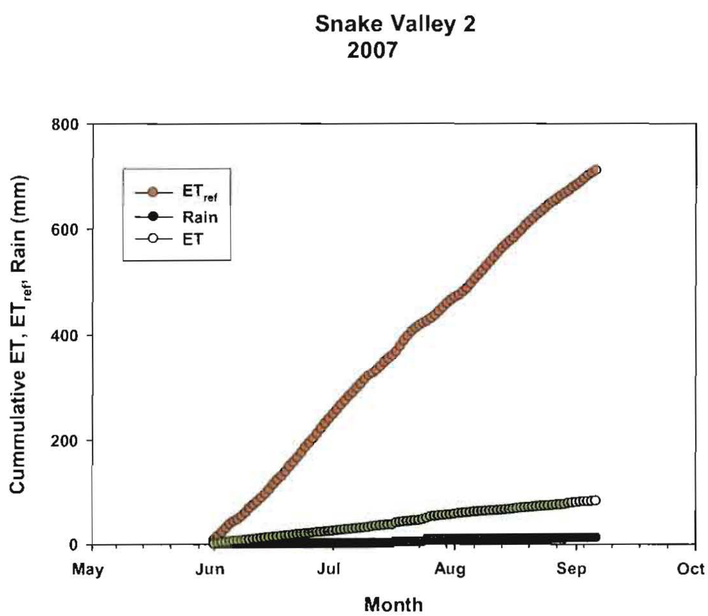



**Figure 42f. Comparison of cumulative evapotranspiration, reference evapotranspiration and rain for Snake Valley 2 in 2007.**

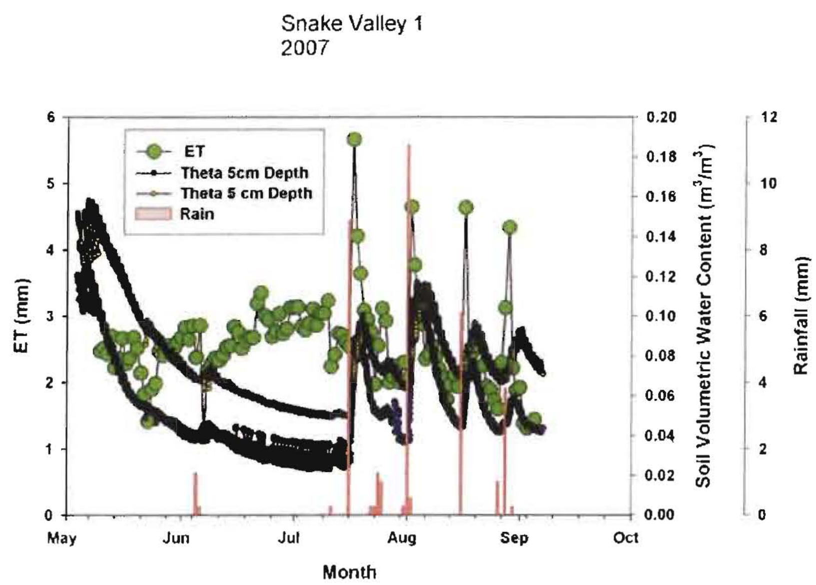



**Figure 43a. Relationship between evapotranspiration, soil volumetric water content and rainfall at Snake Valley 1 in 2007.**

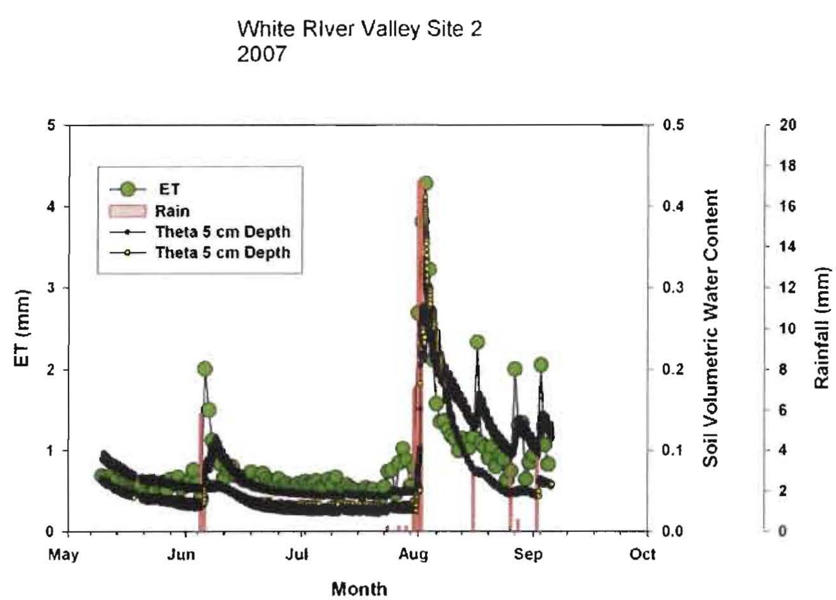



**Figure 43b. Relationship between evapotranspiration, soil volumetric water content and rainfall at White River Valley 2 in 2007.**

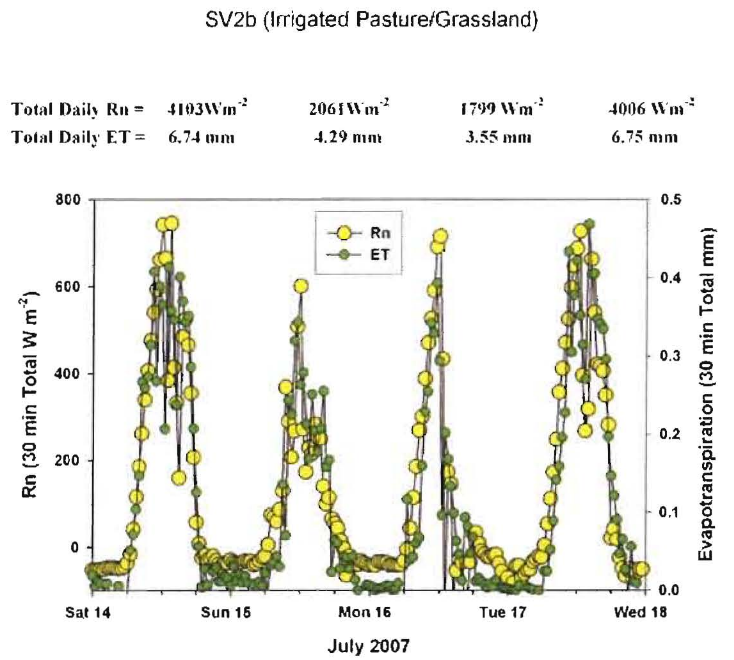



**Figure 44. Relationship between 30 minute net radiation and 30 minute evapotranspiration for Spring Valley 2b, with daily totals for net radiation and evapotranspiration, for 7/14/07 through 7/18/07.**

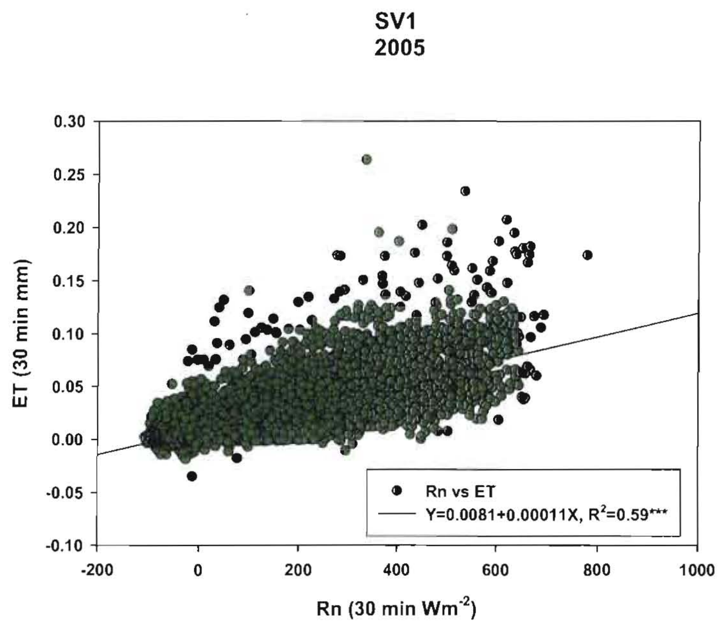



Figure 45a. Relationship between 30 minute evapotranspiration and 30 minute net radiation for Spring Valley 1 in 2005.

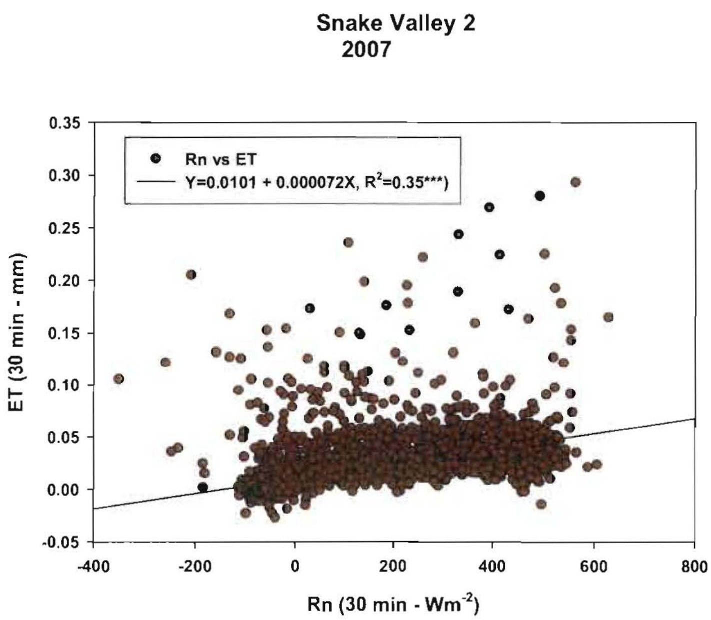



Figure 45b. Relationship between 30 minute evapotranspiration and 30 minute net radiation for Snake Valley 2 in 2007.

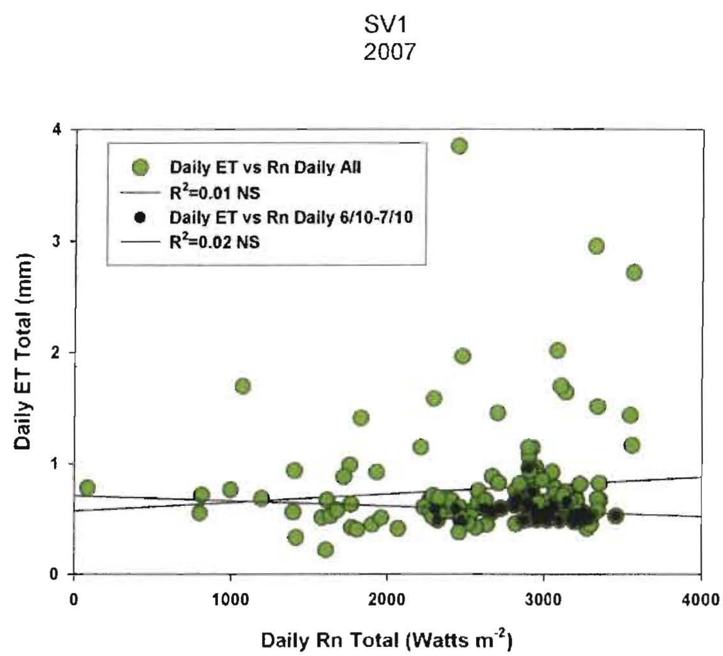



**Figure 46a. Relationship between daily evapotranspiration total and daily net radiation total for Spring Valley 1 in 2007 and relationship between daily evapotranspiration total and daily net radiation total for 6/10/07 through 7/10/07 in Spring Valley 1.**

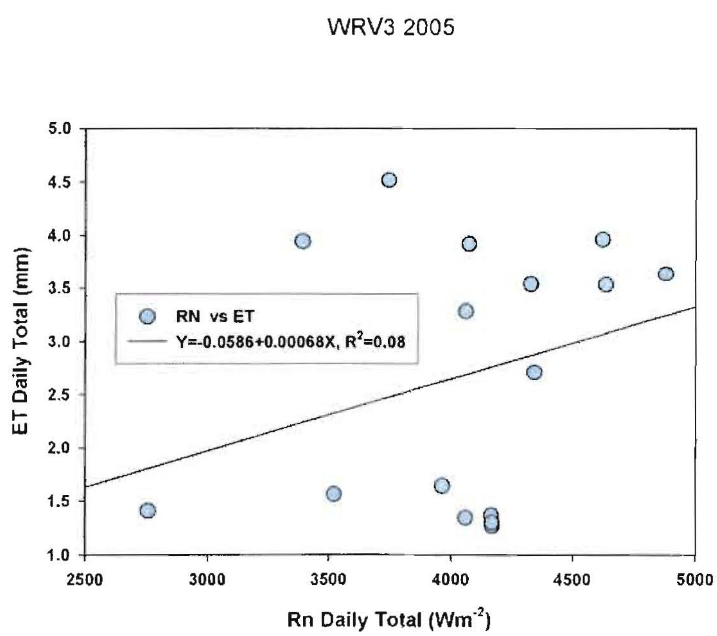



**Figure 46b. Relationship between evapotranspiration daily total and net radiation daily total in White River Valley in 2005.**

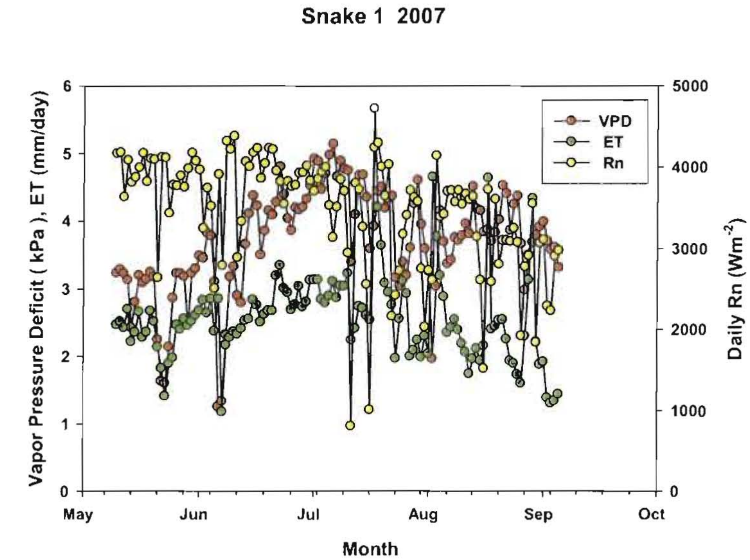



**Figure 47a. Comparison of vapor pressure deficit, evapotranspiration and daily net radiation in Snake Valley in 2007.**

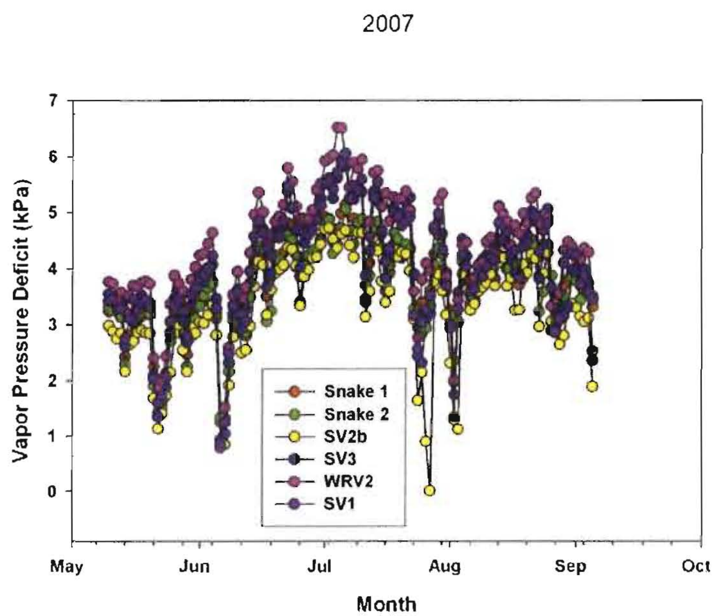



**Figure 47b. Comparison of vapor pressure deficit for Snake Valley 1, Snake Valley 2, Spring Valley 2b, Spring Valley 3, White River Valley 2, and Spring Valley 1 for 2007.**

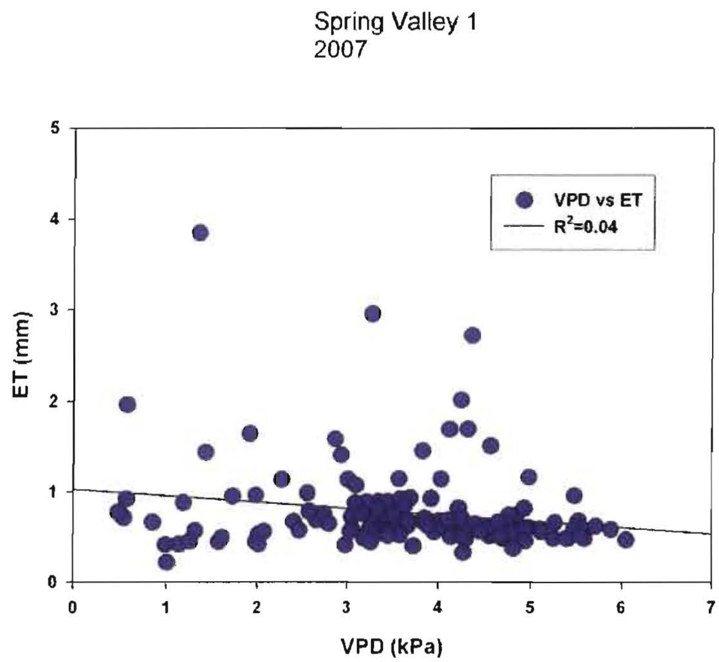



**Figure 48a. Relationship between evapotranspiration and vapor pressure deficit for Spring Valley 1 in 2007.**

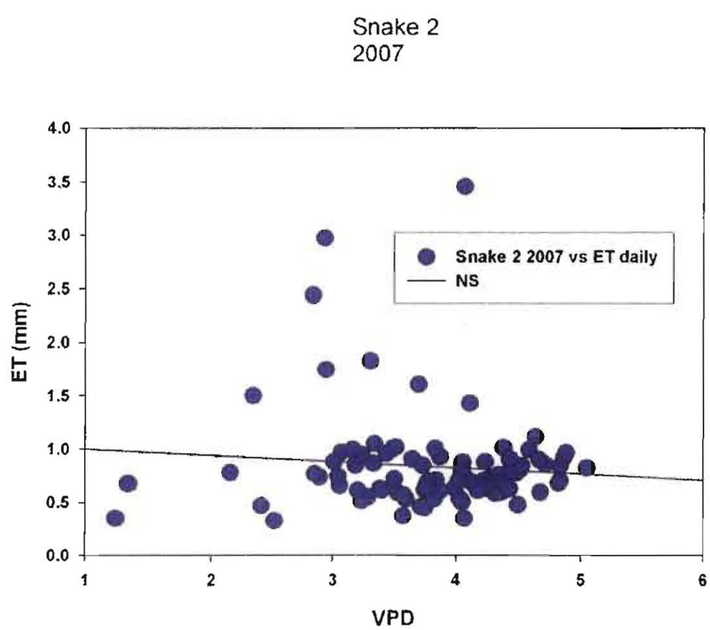



**Figure 48b. Relationship between daily evapotranspiration and vapor pressure deficit for Snake Valley 2 in 2007.**

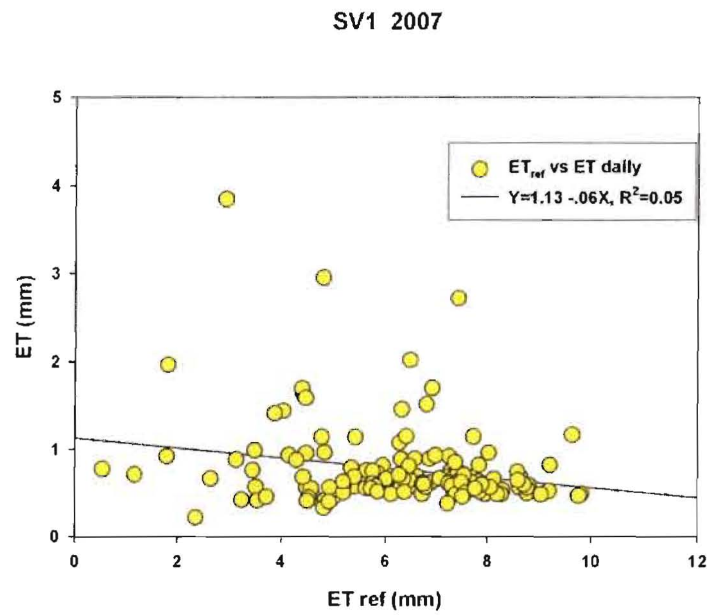



**Figure 49a. Relationship between daily evapotranspiration and reference evapotranspiration for Spring Valley in 2007.**

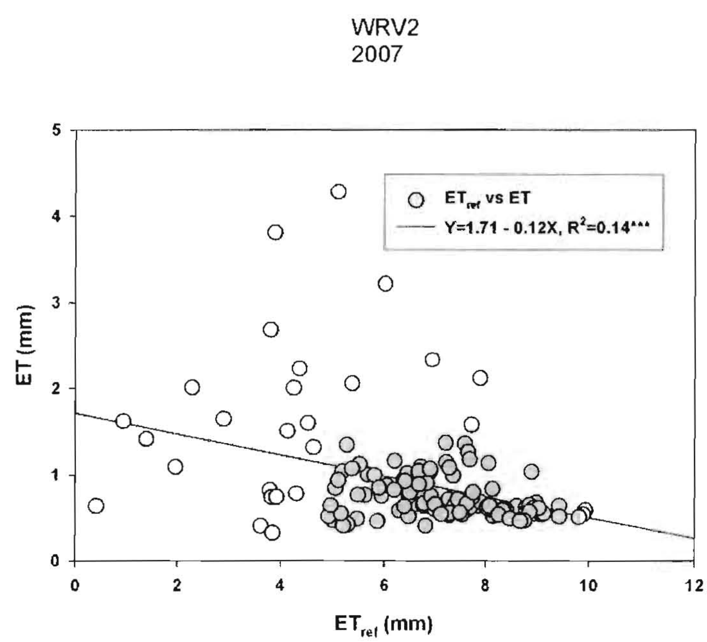



**Figure 49b. Relationship between daily evapotranspiration and reference evapotranspiration for White River Valley in 2007.**

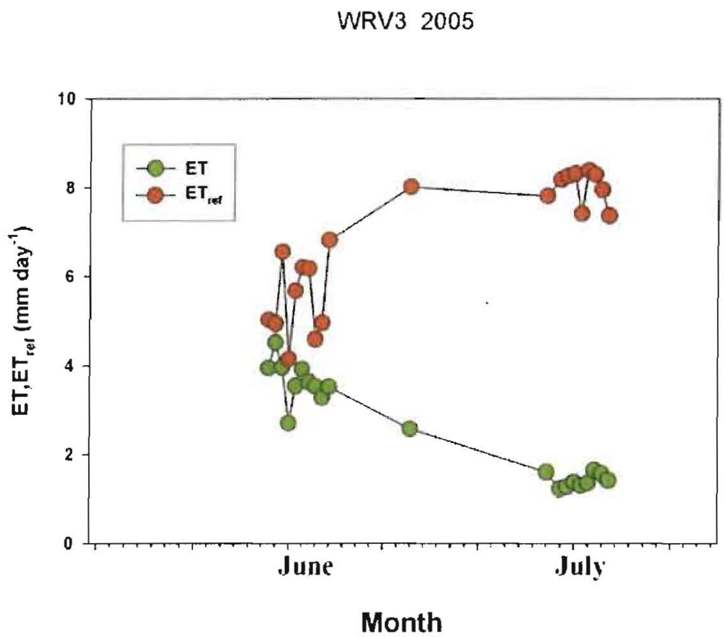



**Figure 50a. Evapotranspiration and reference evapotranspiration in 2005 for White River Valley.**

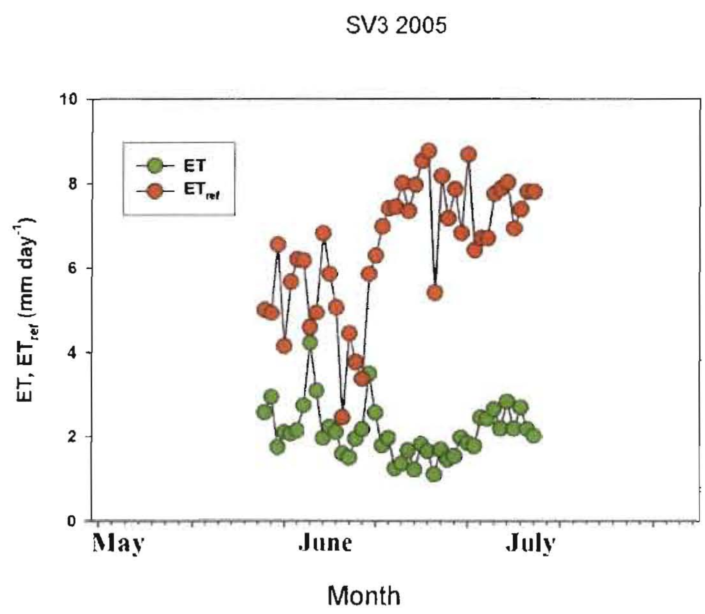



**Figure 50b. Evapotranspiration and reference evapotranspiration in 2005 for Spring Valley.**

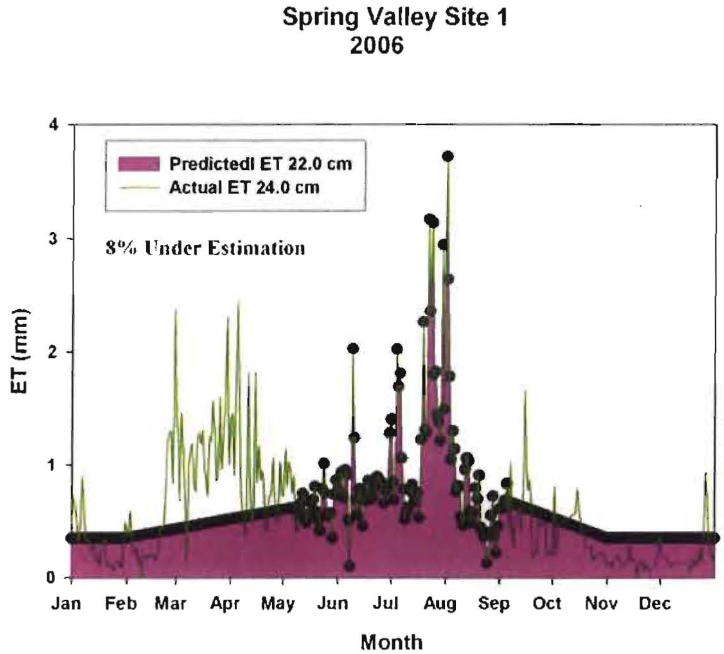



**Figure 51. Predicted and actual evapotranspiration in 2006 for Spring Valley Site 1 with yearly totals.**

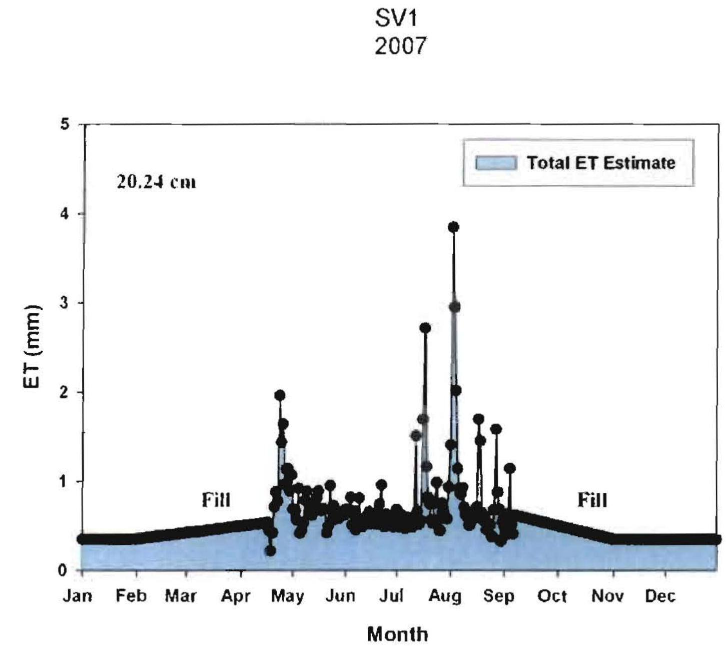



**Figure 52a. Estimated evapotranspiration in 2007 for Spring Valley Site 1 with yearly total.**

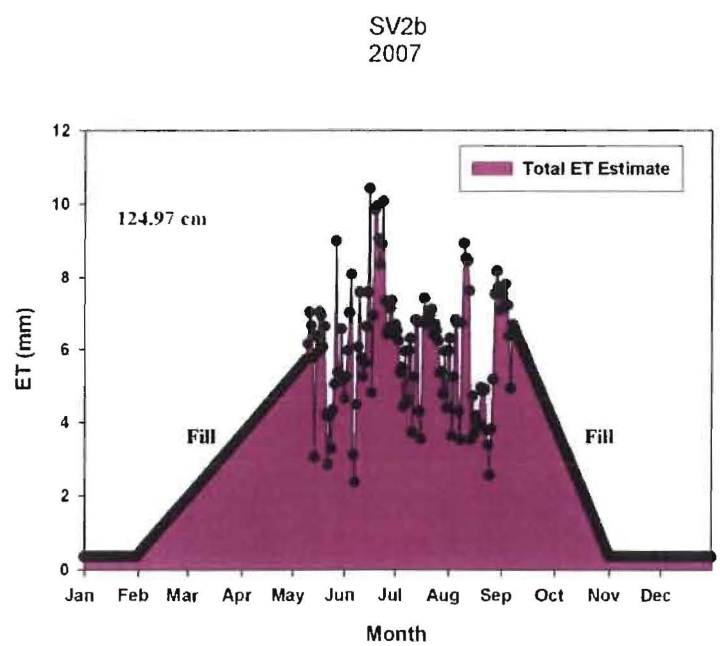



**Figure 52b. Estimated evapotranspiration in 2007 for Spring Valley Site 2b with yearly total.**

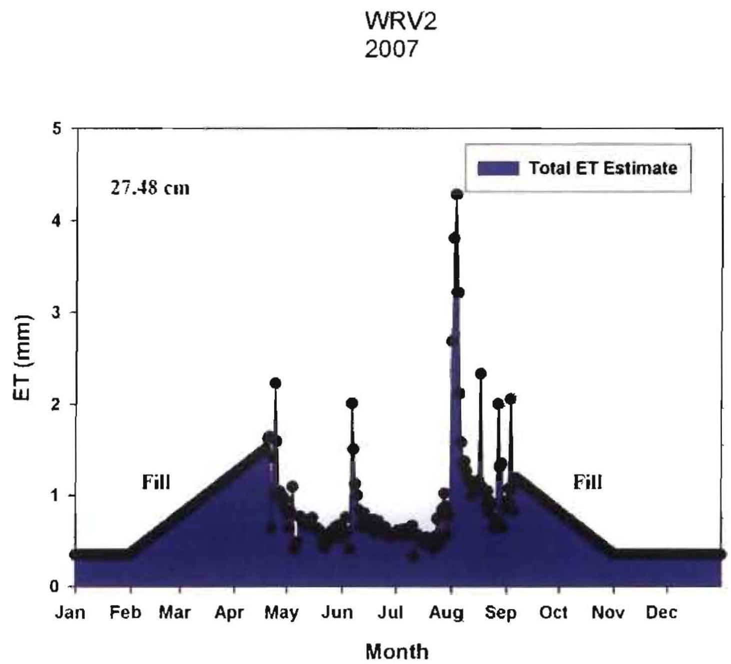



**Figure 52c. Estimated evapotranspiration in 2007 for White River Valley Site 2 with yearly total. Note that an additional 20 day period was available prior to May 10.**

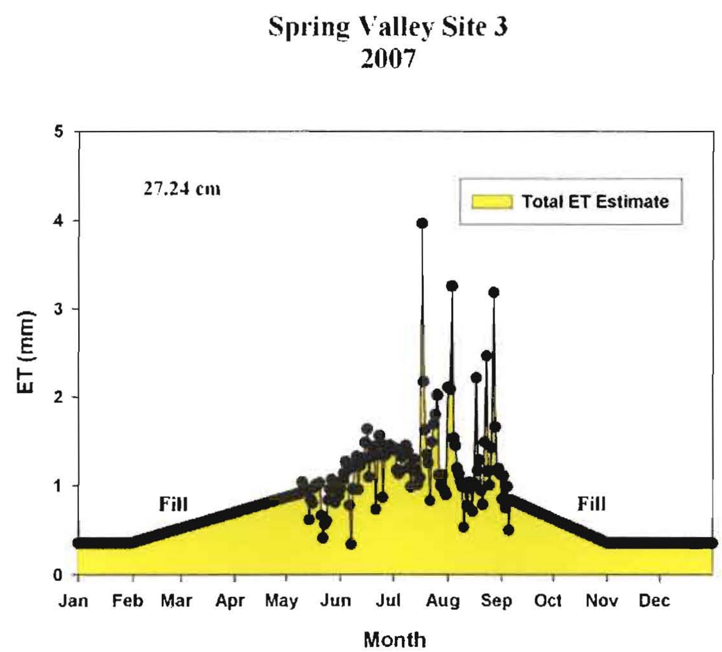



**Figure 52d. Estimated evapotranspiration in 2007 for Spring Valley Site 3 with yearly total.**

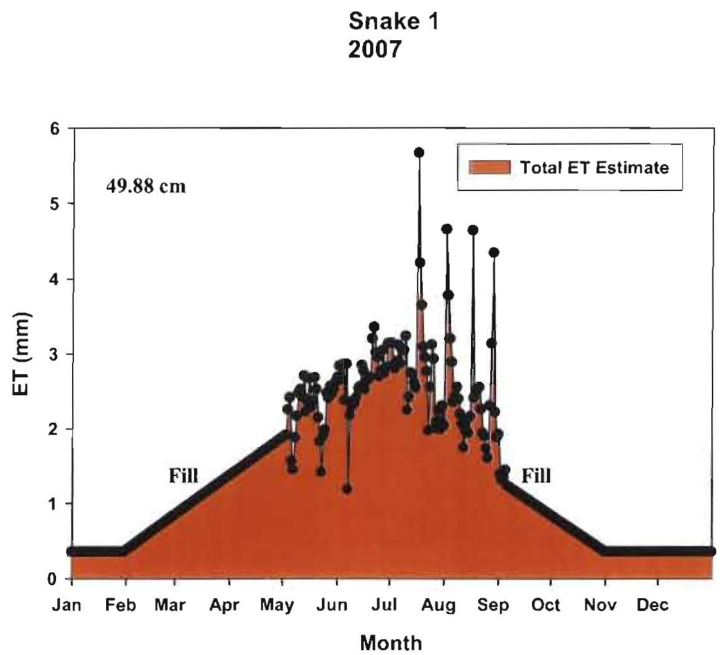



**Figure 52e. Estimated evapotranspiration in 2007 for Snake Valley Site 1 with yearly total.**

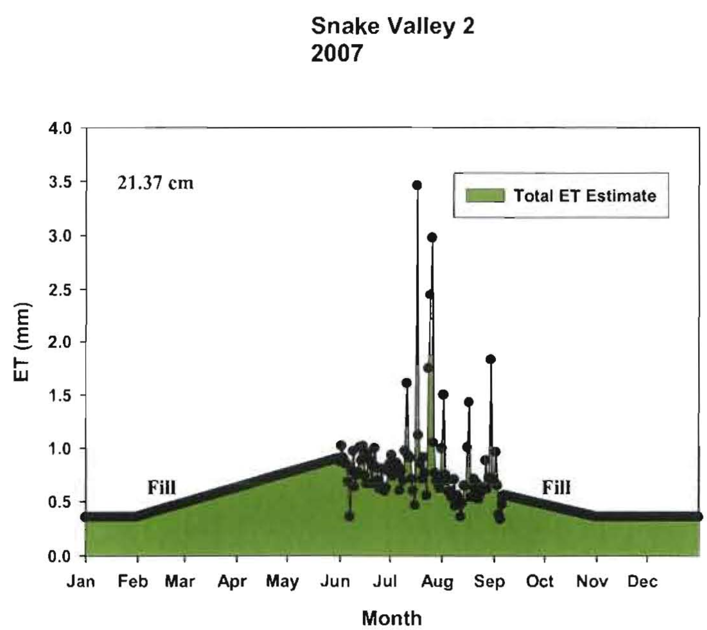



**Figure 52f. Estimated evapotranspiration in 2007 for Snake Valley Site 2 with yearly total.**

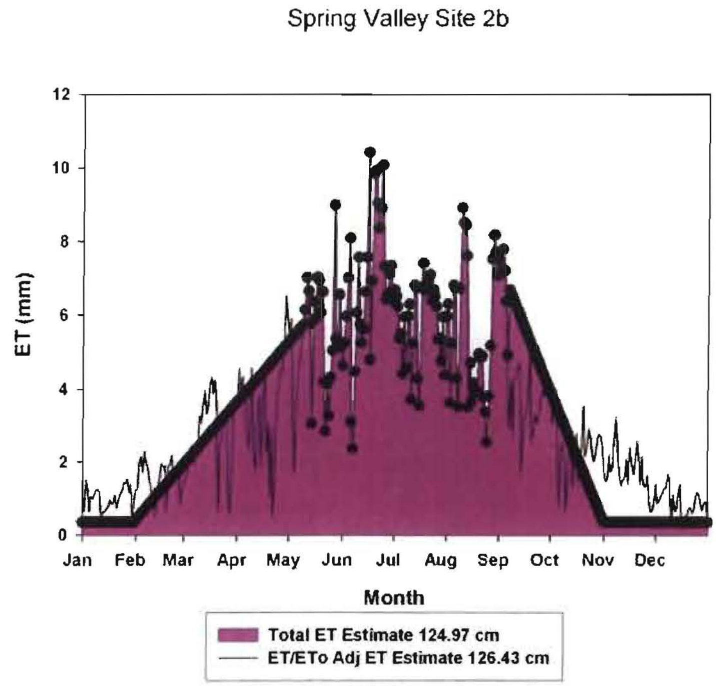



**Figure 53. Comparison of total evapotranspiration to $ET/ET_{ref}$ adjusted evapotranspiration estimate, with respective yearly totals, for Spring Valley Site 2b.**

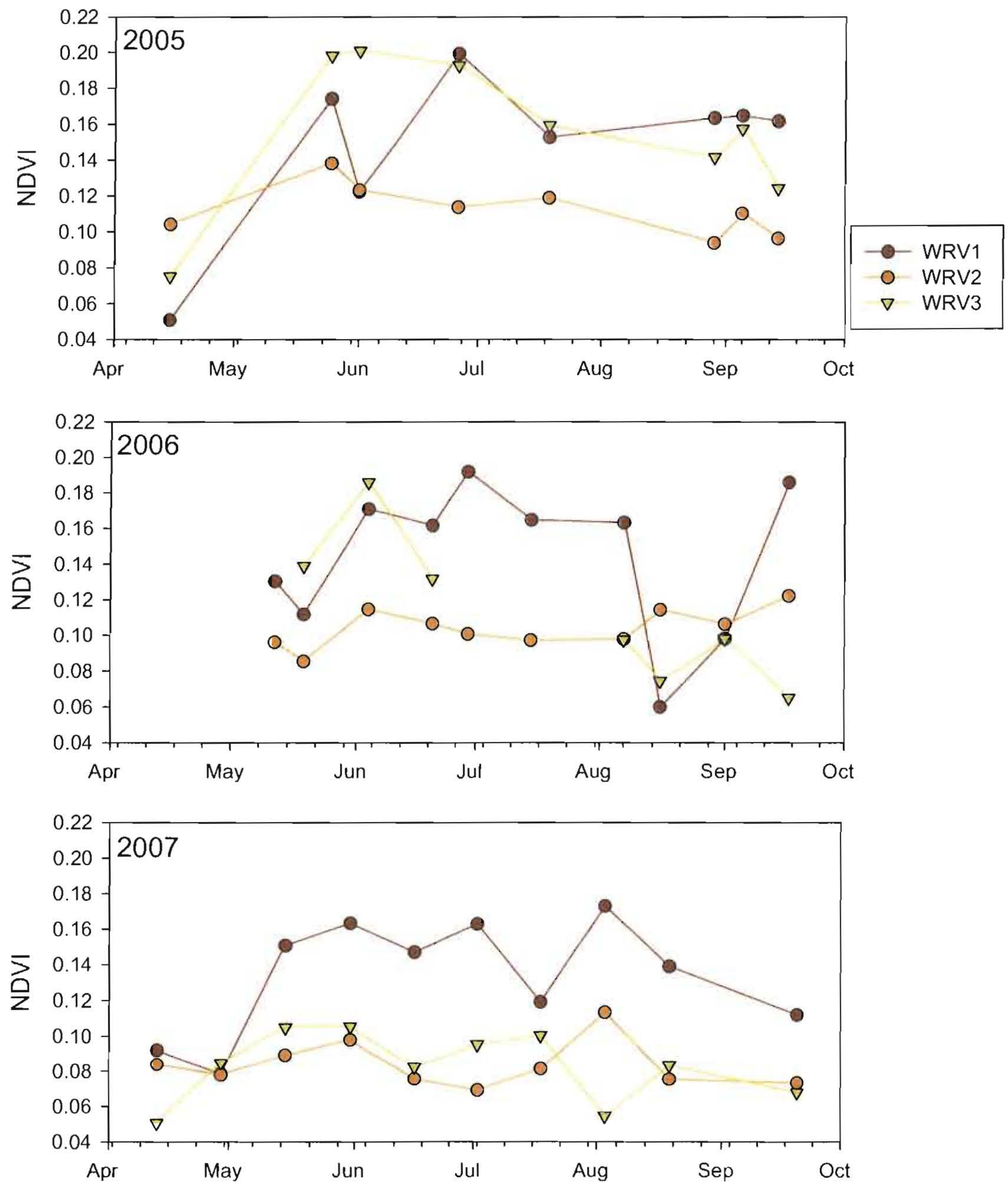



**Figure 54. The above graphs depict the change in NDVI values at the three White River Valley EC tower sites during the growing seasons in 2005, 2006 and 2007. While there are seasonal differences during the three years, a decline in NDVI at all three sites is observed from 2005 to 2007, particularly for sites WRV2 and WRV3.**

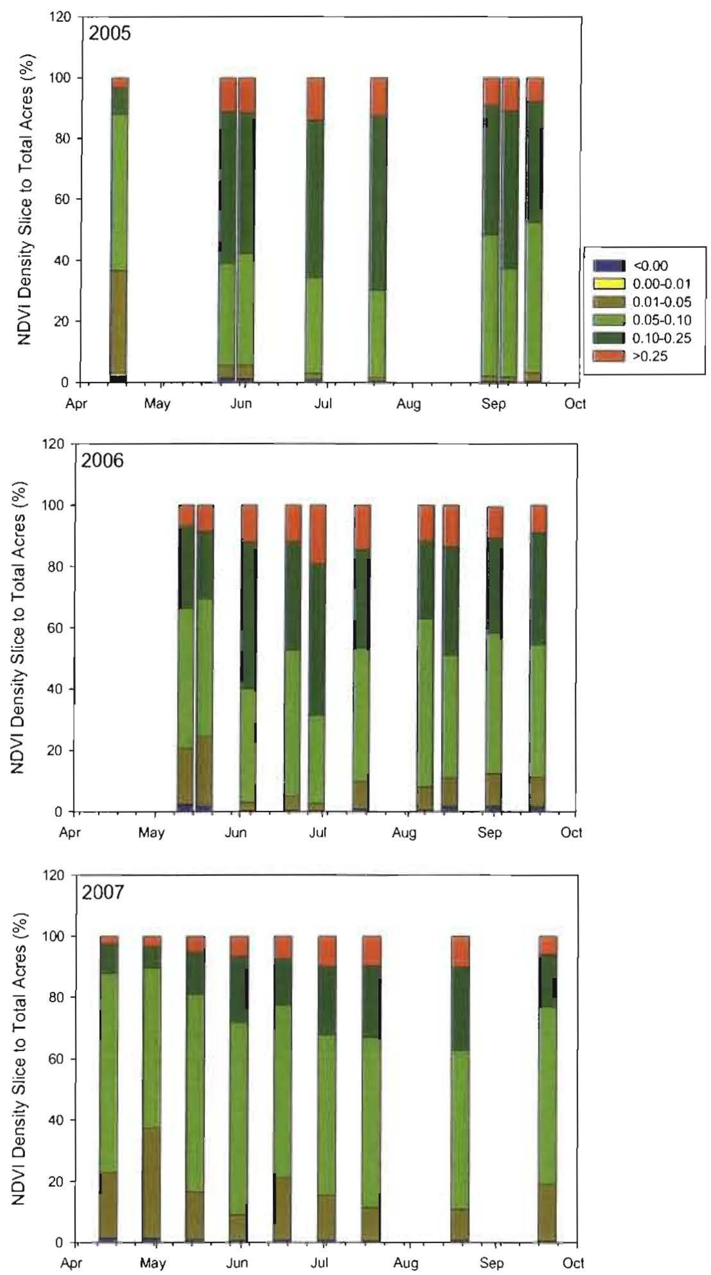



**Figure 55. The above graphs depict the changes in percent acreage of several NDVI ranges respective to the entire White River Valley phreatophyte polygon acres (minus any clouds, cloud shadows or missing acres) during 2005, 2006 and 2007. The arbitrary NDVI ranges presented roughly correspond to: water (<0); bare soil (0.00-0.01); low shrub cover (0.01-0.05); moderate shrub cover (0.05-0.10), high shrub cover or moderate herbaceous cover (0.10-0.25); and agricultural fields and meadows (>0.25). An overall decline in the more dense canopy cover ranges is observable as well as a corresponding increase in the moderate and low shrub cover ranges.**

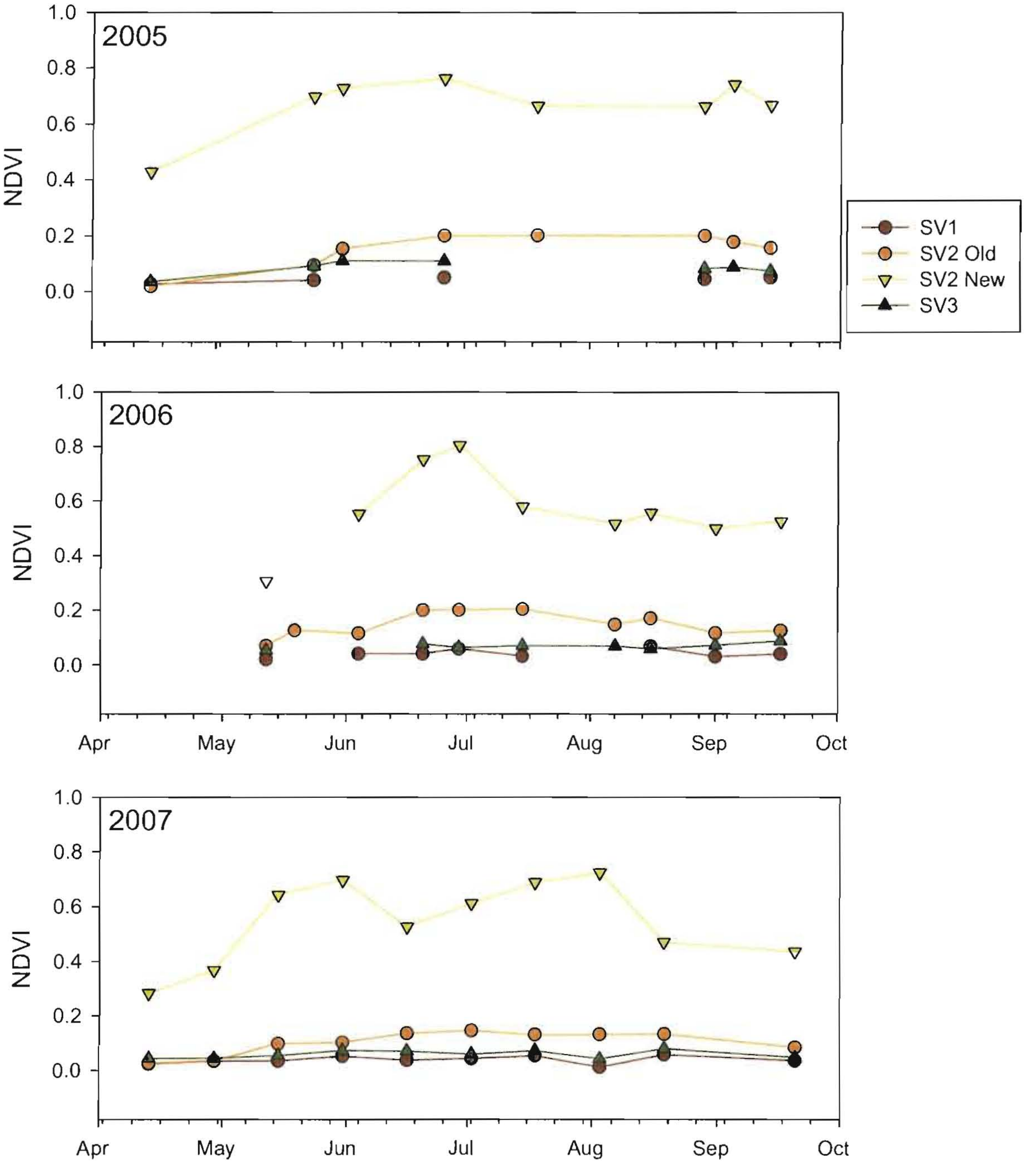



**Figure 56. The above graphs depict the change in NDVI values at the four Spring Valley EC tower sites during the growing seasons in 2005, 2006 and 2007. While there are seasonal differences during the three years, a decline in NDVI at all three shrub sites is observed from 2005 to 2007.**

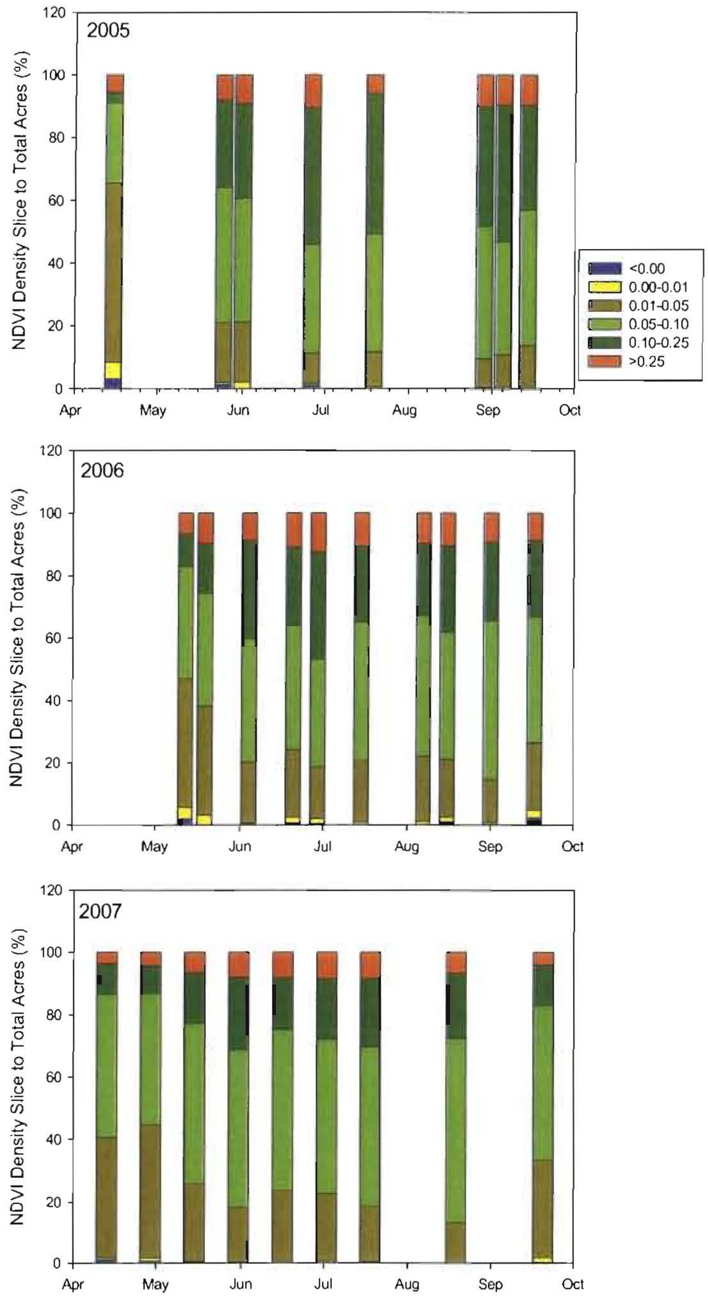



**Figure 57. The above graphs depict the changes in percent acreage of several NDVI ranges respective to the entire Spring Valley phreatophyte polygon acres (minus any clouds, cloud shadows or missing acres) during 2005, 2006 and 2007. The arbitrary NDVI ranges presented roughly correspond to: water (<0); bare soil (0.00-0.01); low shrub cover (0.01-0.05); moderate shrub cover (0.05-0.10), high shrub cover or moderate herbaceous cover (0.10-0.25); and agricultural fields and meadows (>0.25). An overall decline in the more dense canopy cover ranges is observable as well as a corresponding increase in the moderate and low shrub cover ranges.**

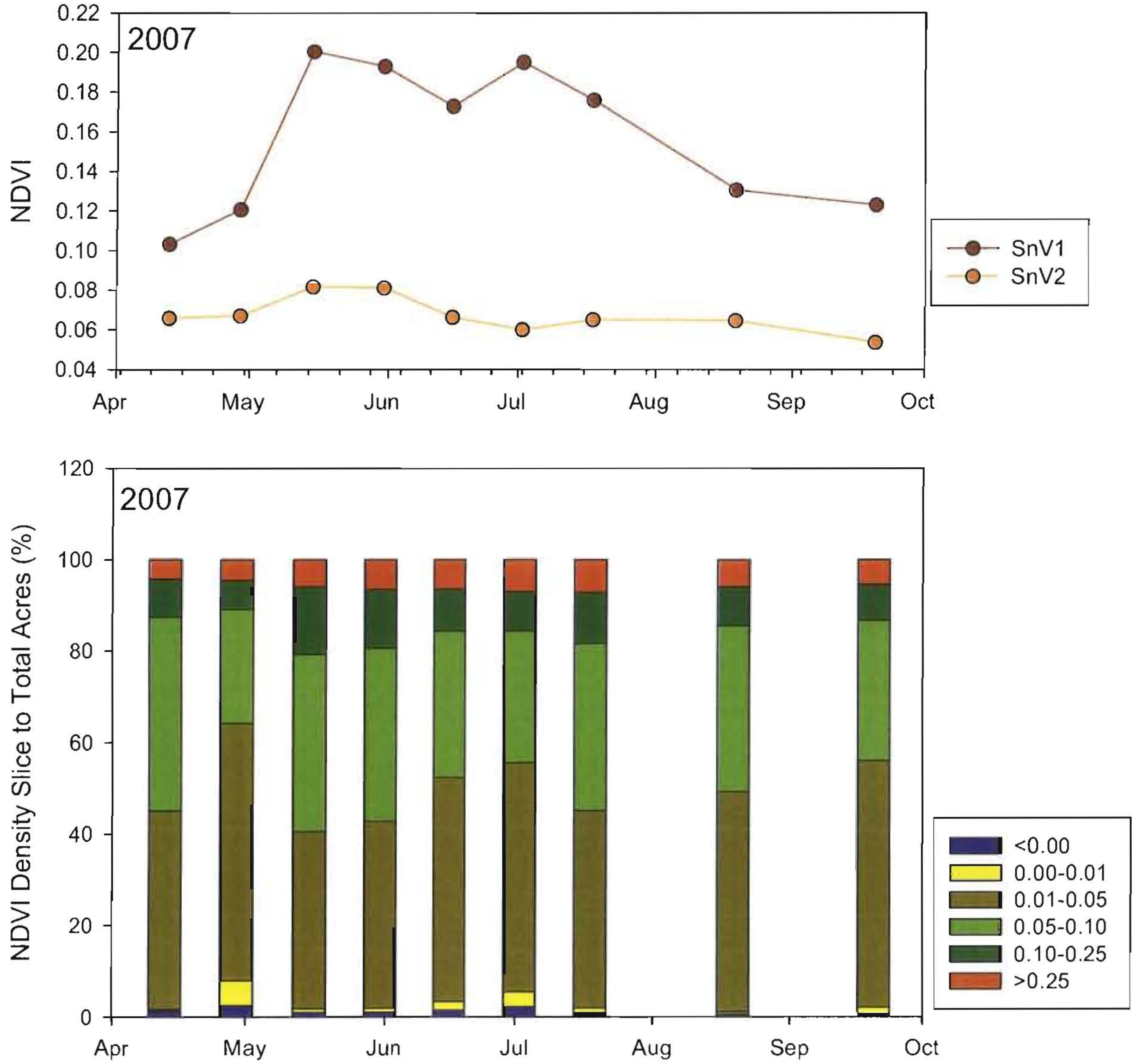



**Figure 58. The top figure depicts the changes in NDVI during the 2007 growing season at the Eddy Covariance sites designated SnV1 and SnV2. The NDVI curve for SnV1 is significantly greater than that of SnV2 due to the larger density and size shrub cover, which is predominantly Greasewood. The bottom figure depicts the changes in percent acreage of several NDVI ranges respective to the entire Snake Valley phreatophyte polygon acres (minus any clouds or cloud shadows) during 2007. The NDVI ranges presented roughly correspond to: water (<0); bare soil (0.00-0.01); low shrub cover (0.01-0.05); moderate shrub cover (0.05-0.10), high shrub cover or moderate herbaceous cover (0.10-0.25); and agricultural fields and meadows (>0.25).**

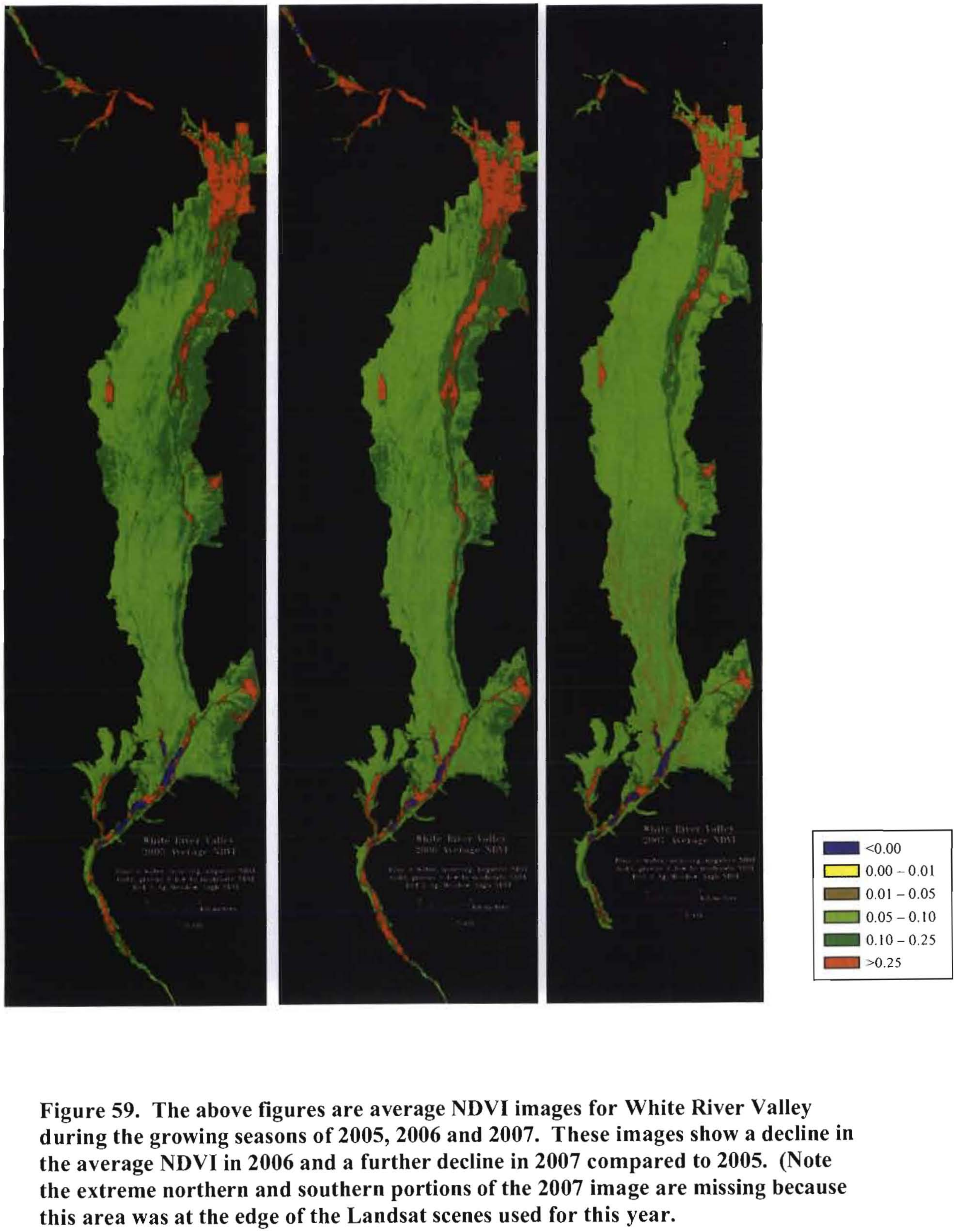



**Figure 59. The above figures are average NDVI images for White River Valley during the growing seasons of 2005, 2006 and 2007. These images show a decline in the average NDVI in 2006 and a further decline in 2007 compared to 2005. (Note the extreme northern and southern portions of the 2007 image are missing because this area was at the edge of the Landsat scenes used for this year.**

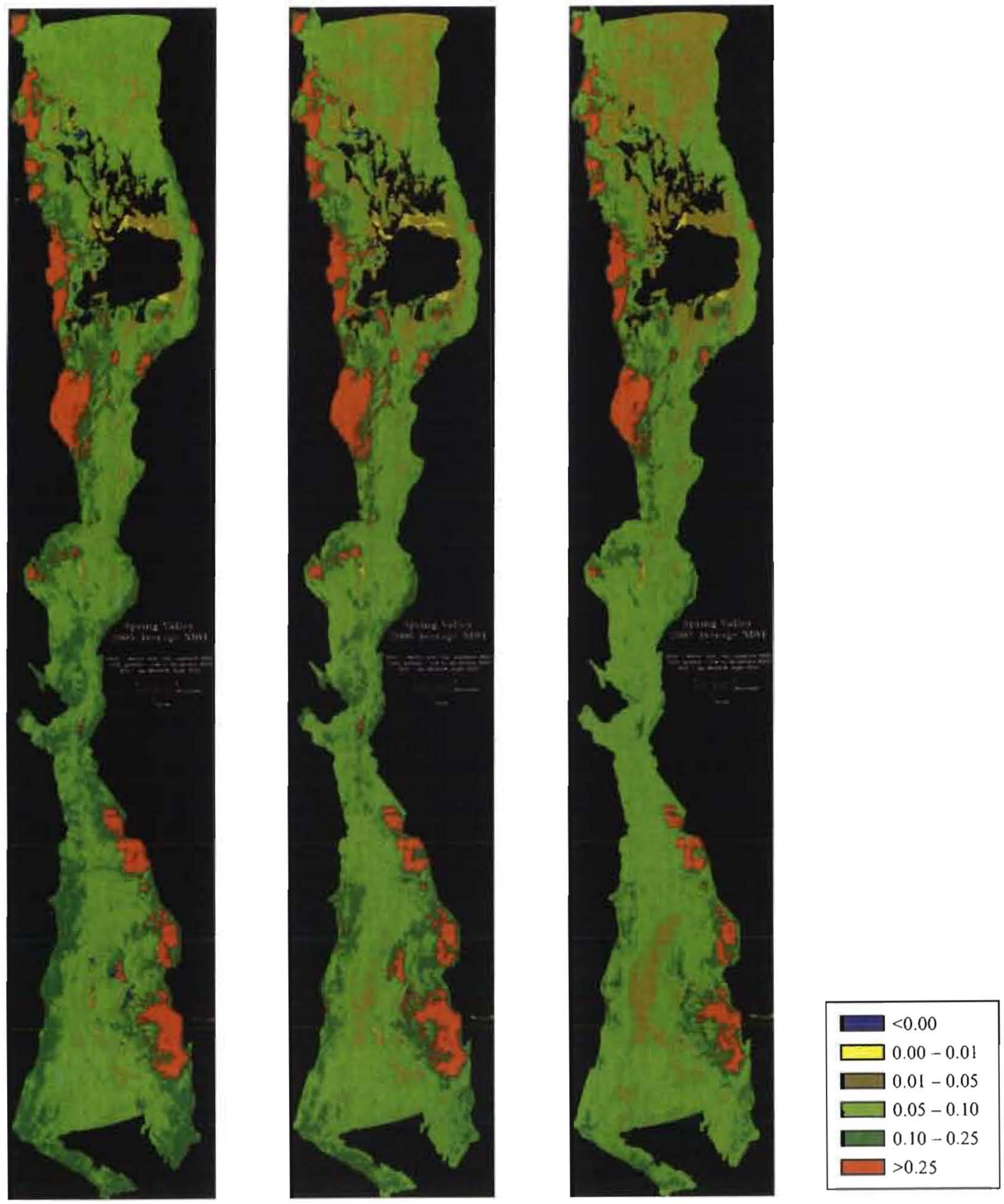
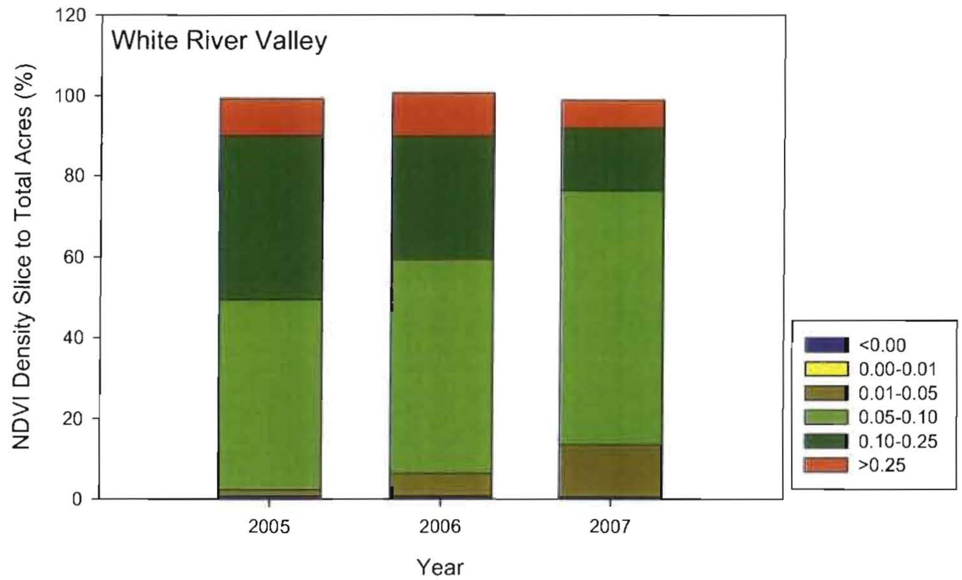



**Figure 60. The above figures are average NDVI images for Spring Valley during the growing seasons of 2005, 2006 and 2007. Similar to the average NDVI images for the White River Valley there is a decline in NDVI values during the period of 2005 through 2007.**



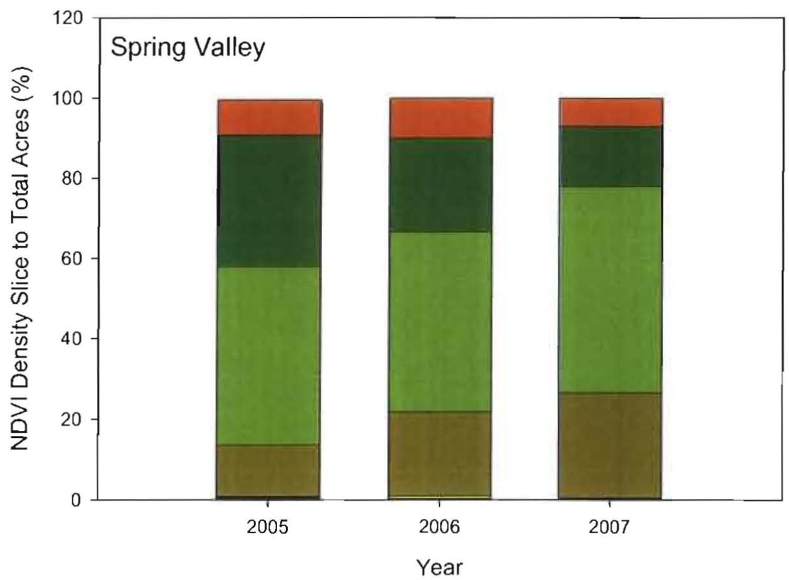
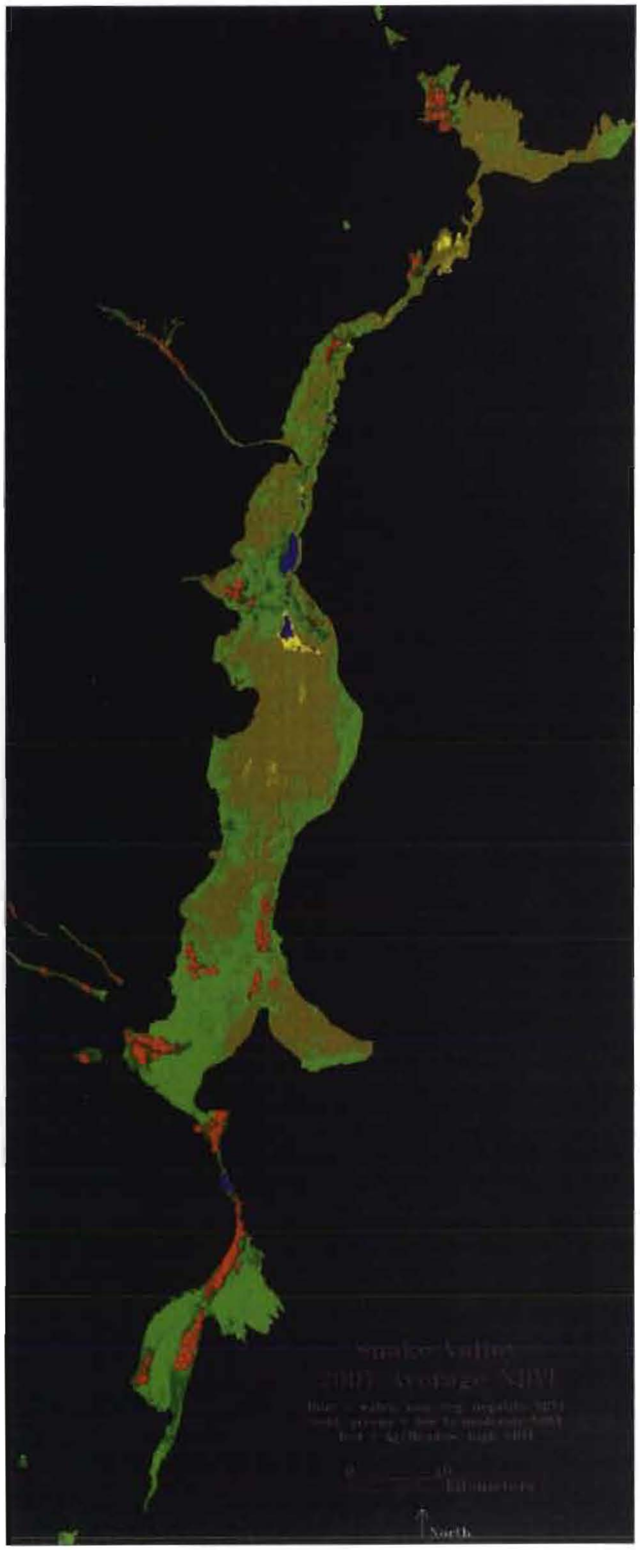




**Figure 61. The above figures depict the distribution of acres for a set of NDVI values within the White River and Spring Valley average NDVI images for each study year, e.g., 2005, 2006 and 2007. It is quite clear for both valleys that there is a decline of acres with higher NDVI values and an increase in acres with low NDVI values. These data correspond to the decreasing winter precipitation.**



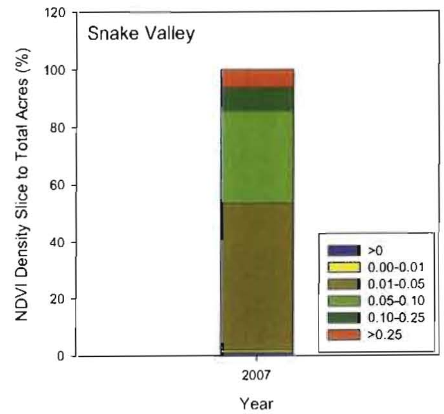
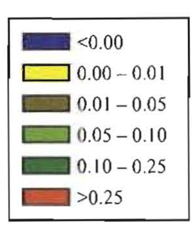



**Figure 62. The Snake Valley image to the left depicts average NDVI values for 2007. The acres within each color assigned to this image correspond to the NDVI ranges defined in the graph above.**



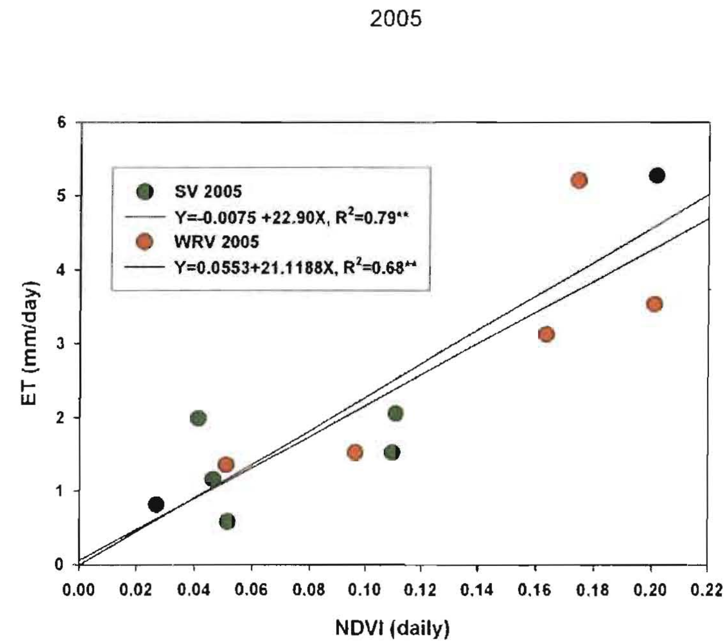



**Figure 63. Relationship between evapotranspiration (ET) and daily normalized difference vegetation index (NDVI) for Spring Valley and White River Valley in 2005.**

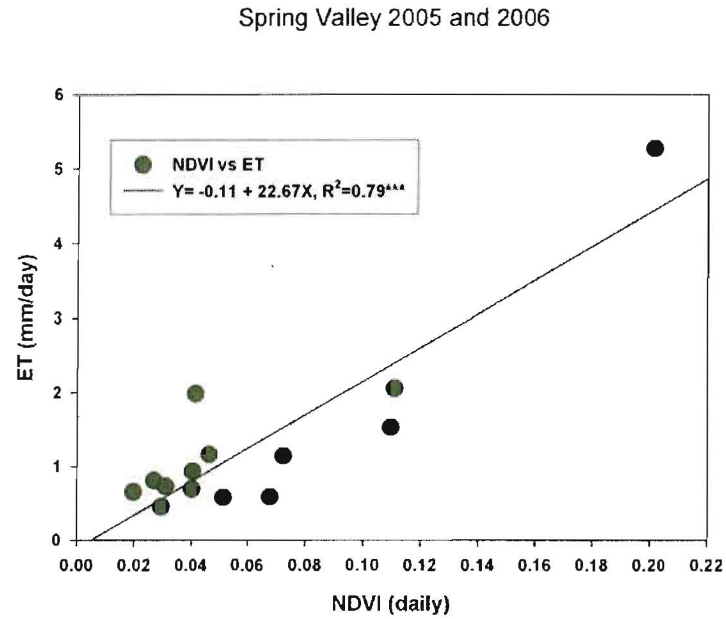



**Figure 64a. Relationship between evapotranspiration (ET) and daily normalized difference vegetation index (NDVI) for Spring Valley in 2005 and 2006.**

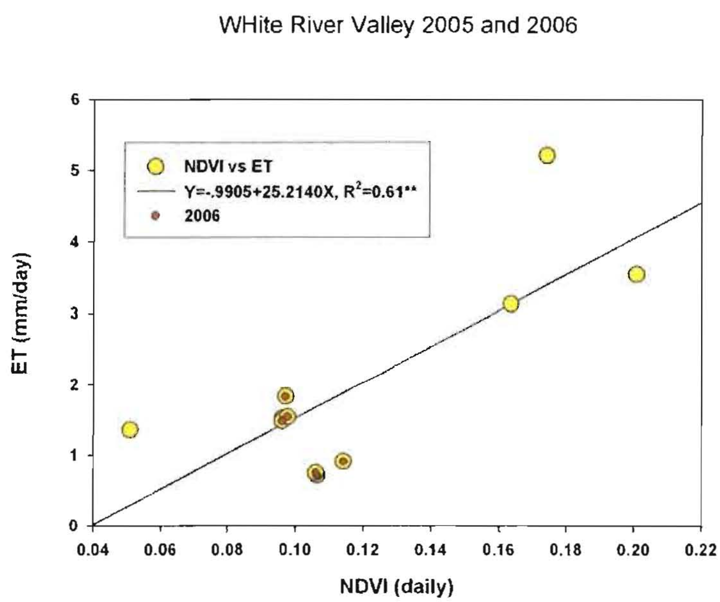



**Figure 64b. Relationship between evapotranspiration (ET) and normalized difference vegetation index (NDVI) for White River Valley in 2005 and 2006 with 2006 points highlighted in red.**

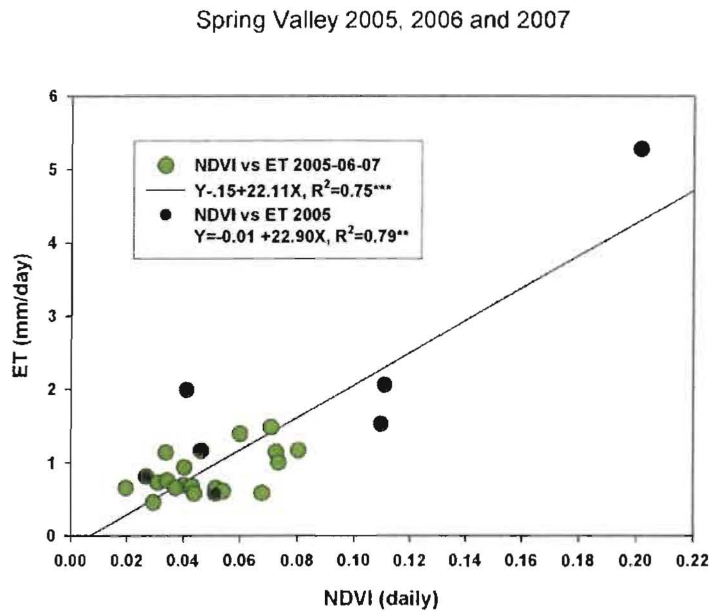



**Figure 65a. Comparison between evaporation and normalized difference vegetation index (NDVI) in Spring Valley for 2005, 2006 and 2007 with relationship between ET and NDVI for 2005 only.**

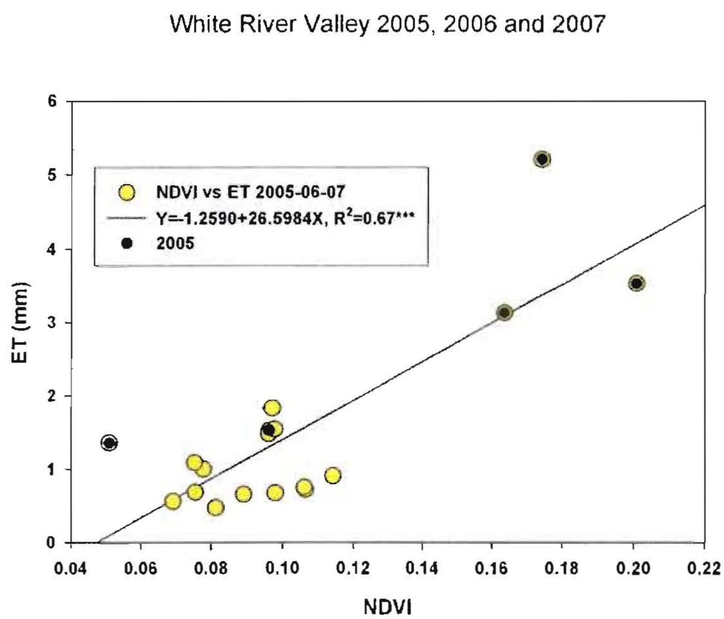



**Figure 65b. Relationship between evapotranspiration (ET) and normalized difference vegetation index (NDVI) for White River Valley in 2005, 2006 and 2007 with 2005 points highlighted in black.**

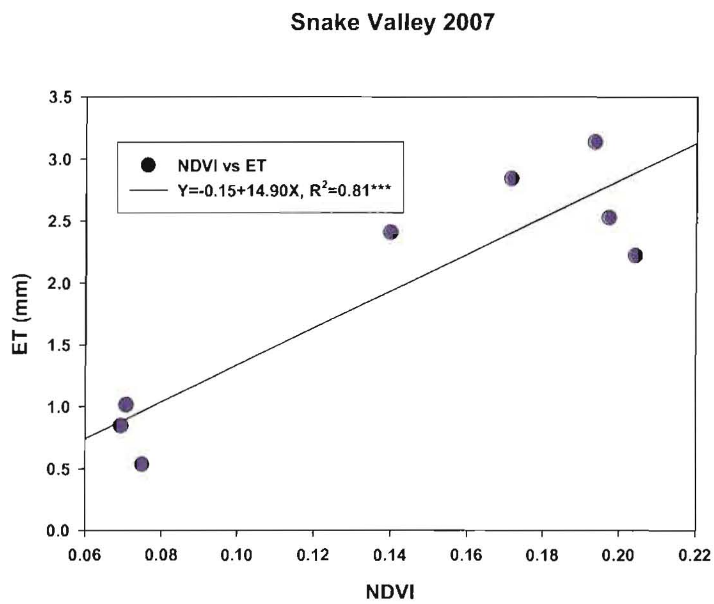



**Figure 66. Relationship between evapotranspiration (ET) and normalized difference vegetation index (NDVI) for Snake Valley in 2007.**

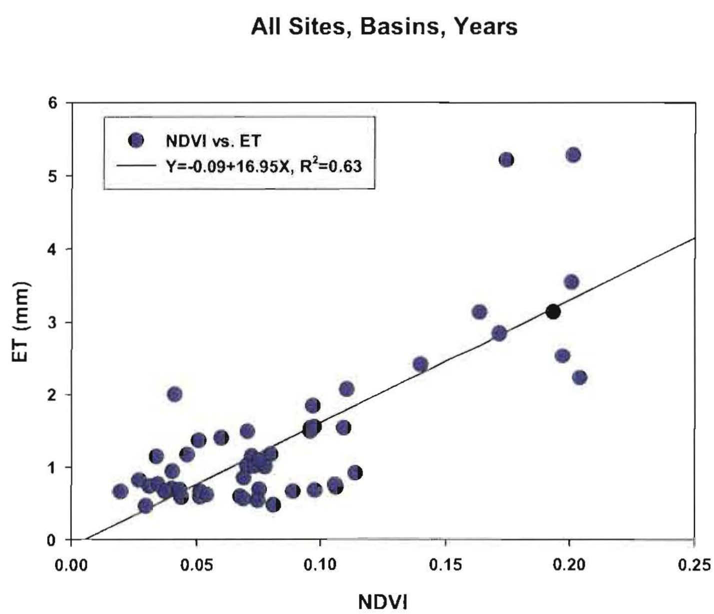



**Figure 67. Relationship between evapotranspiration (ET) and normalized difference vegetation index (NDVI) for all sites, in all basins and all years.**

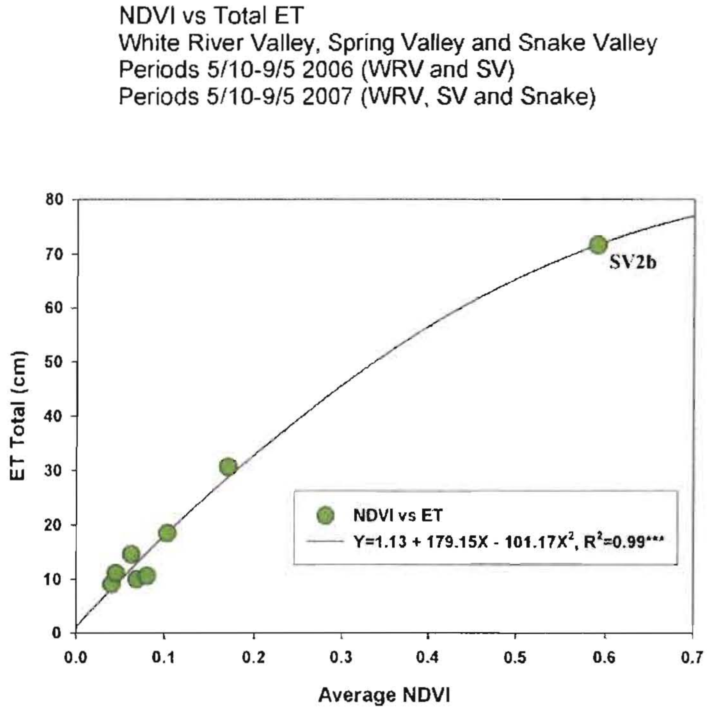



**Figure 68. Comparison between normalized difference vegetation index (NDVI) and total evapotranspiration (ET) for White River Valley, Spring Valley and Snake Valley for periods 5/10-9/5 2006 for White River Valley and Spring Valley and periods 5/10-9/5 2007 for White River Valley, Spring Valley and Snake Valley.**

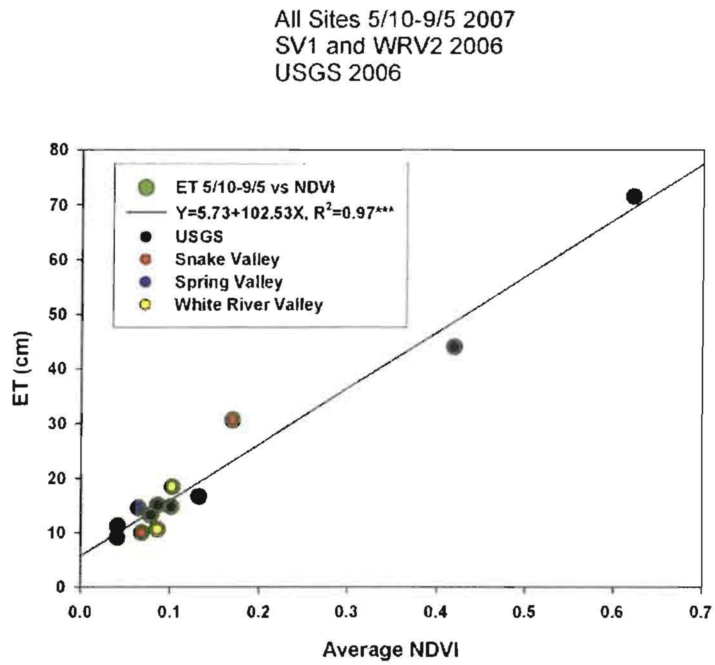



**Figure 69. Relationship between ET and NDVI for all sites for the period 5/10-9/5 2007 and SV1, WRV2 and USGS 2006 with USGS in black, Snake Valley in red, Spring Valley in blue and White River Valley in yellow.**

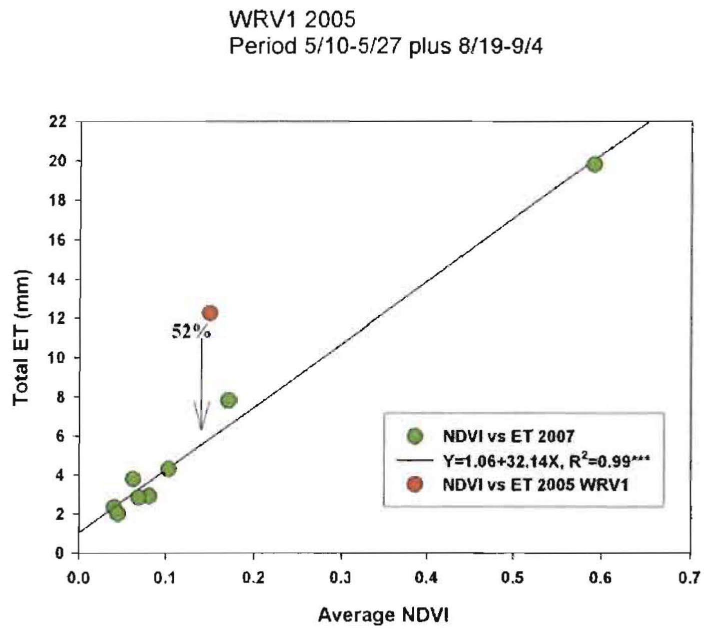



**Figure 70a. Relationship between total evapotranspiration and average NDVI for the periods 5/10-5/27 2005 and 8/19-9/4 2005 in White River Valley 1, compared to the same time relationship based on data from 2006 and 2007 showing 52% underestimation of total evapotranspiration for WRV1 in 2005.**

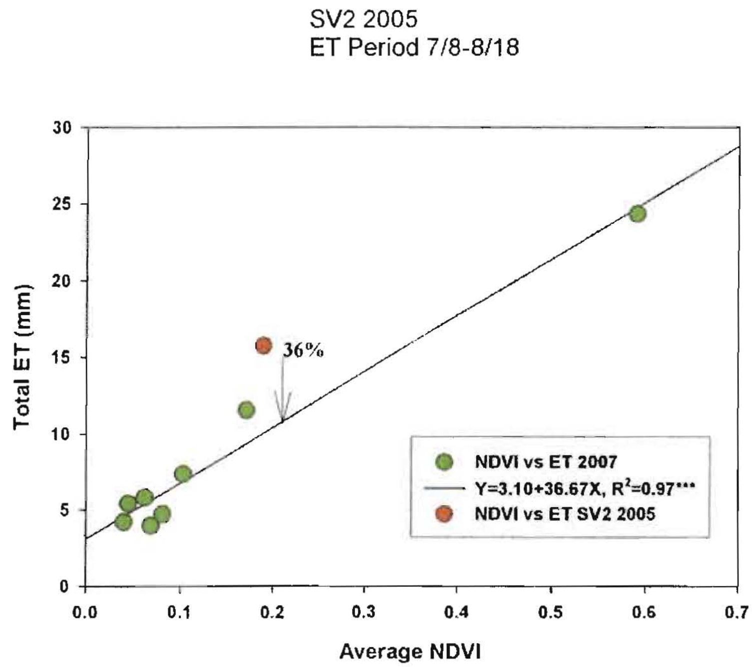



**Figure 70b. Relationship between total evapotranspiration and average NDVI for the period 7/8-8/18 2005 in Spring Valley 2, compared to the same time relationship based on data from 2006 and 2007 showing 36% underestimation of total evapotranspiration for SV2 in 2005.**

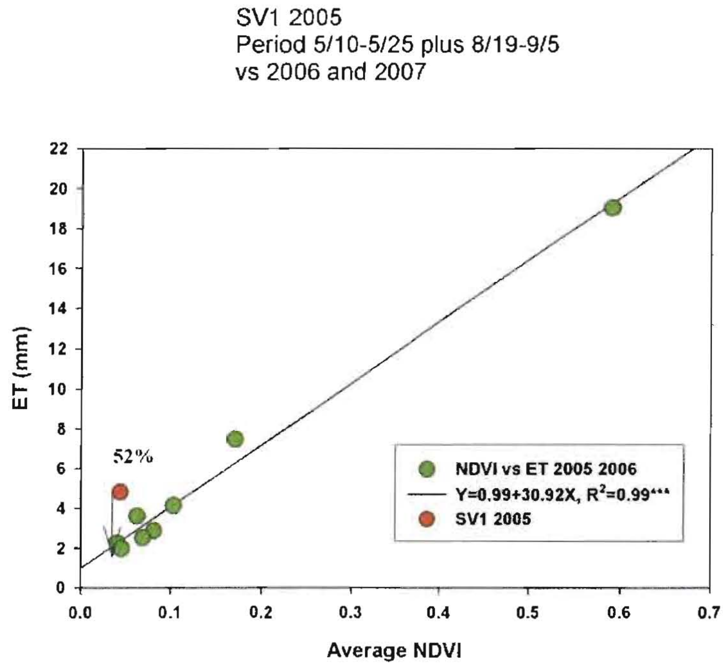



**Figure 70c. Relationship between total evapotranspiration and average NDVI for the periods 5/10-5/25 2005 and 8/19-9/5 2005 in Spring Valley 1, compared to the same time relationship based on data from 2006 and 2007 showing 52% underestimation of total evapotranspiration for SV1 in 2005.**

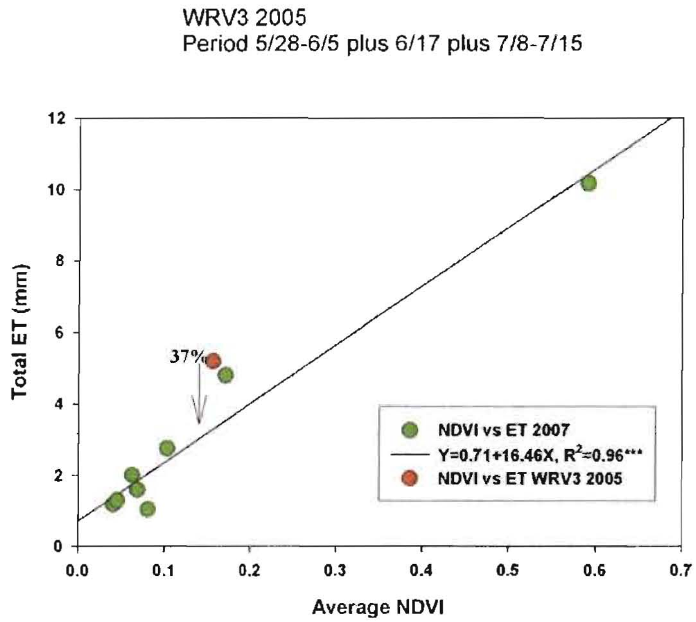



**Figure 70d. Relationship between total evapotranspiration and average NDVI for the periods 5/28-6/5 2005, 6/17 2005 and 7/8-7/15 2005 in White River Valley 3, compared to the same time relationship based on data from 2006 and 2007 showing 37% underestimation of total evapotranspiration for WRV3 in 2005.**

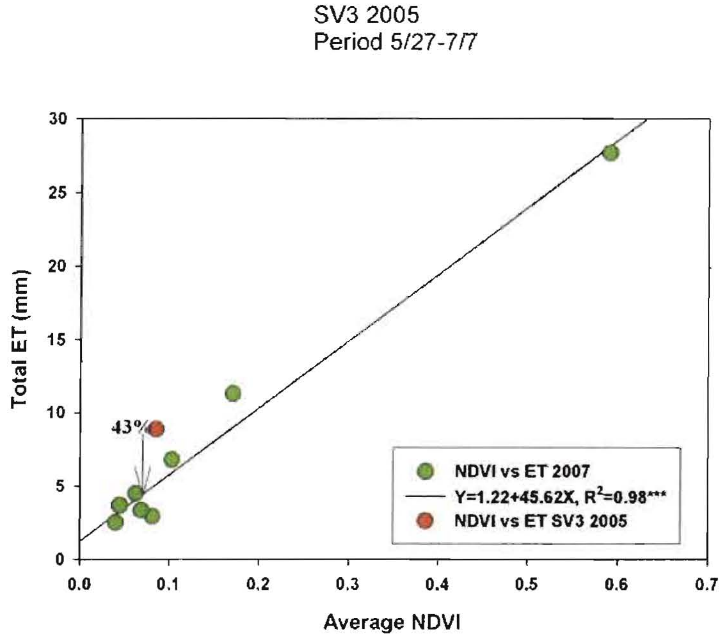



**Figure 70e. Relationship between total evapotranspiration and average NDVI for the period 5/27-7/7 in Spring Valley 3, compared to the same time relationship based on data from 2006 and 2007 showing 43% underestimation of total evapotranspiration for SV3 in 2005.**

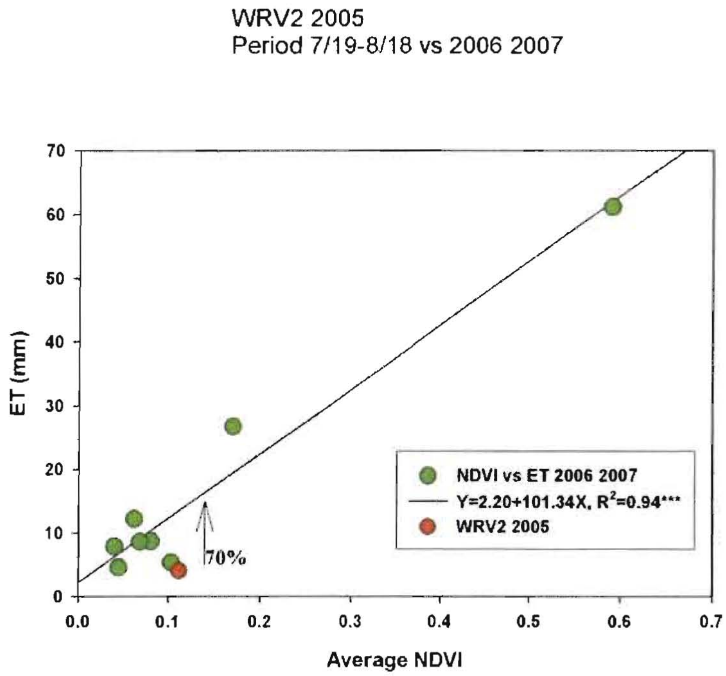



**Figure 70f. Relationship between total evapotranspiration and average NDVI for the period 7/19-8/18 in White River Valley 2, compared to the same time relationship based on data from 2006 and 2007 showing 70% overestimation of total evapotranspiration for WRV2 in 2005.**

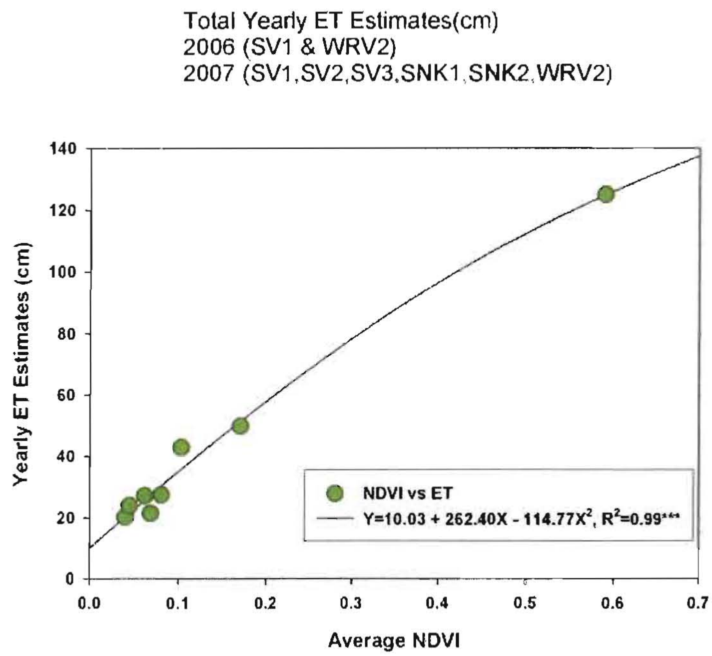



**Figure 71. Relationship between yearly ET estimates and average NDVI for Spring Valley 1 and White River Valley 2 in 2006 and Spring Valley Sites 1, 2, and 3, Snake Valley Sites 1 and 2 and White River Valley 2 in 2007.**

2007 All Sites Yearly Estimates
2006 SV1 and WRV2
2006 USGS

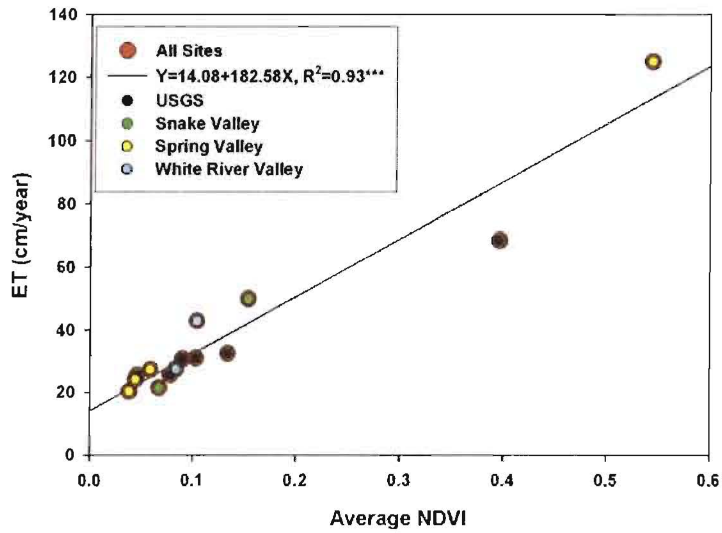



**Figure 72. Relationship of yearly ET estimates and NDVI for all sites in 2007 with Spring Valley 1, White River Valley 2 and USGS for 2006 with USGS in black, Snake Valley in green, Spring Valley in yellow and White River Valley in blue.**

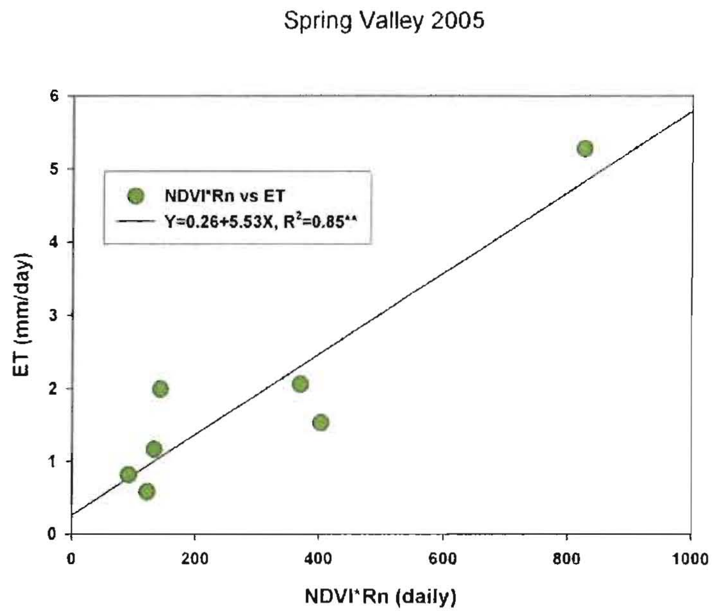



**Figure 73a. Comparison of ET with the product of NDVI and Rn for Spring Valley in 2005.**

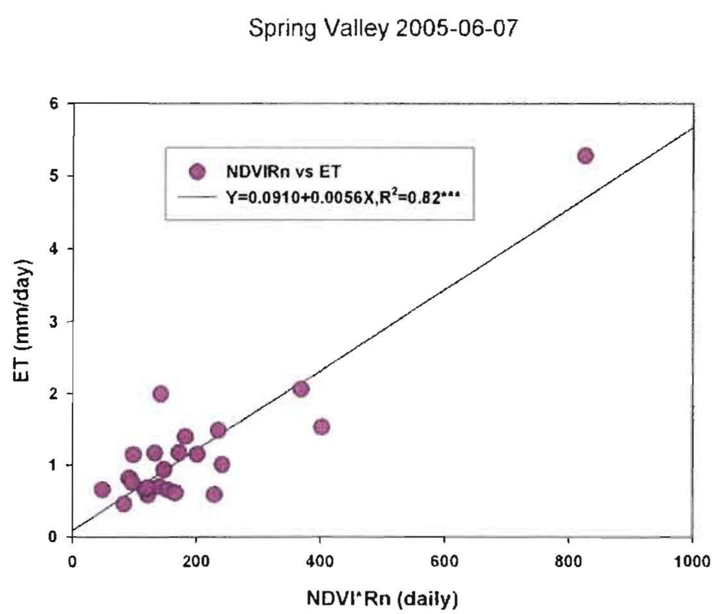



**Figure 73b. Comparison of ET with the product of NDVI and Rn for Spring Valley in 2005, 2006 and 2007.**

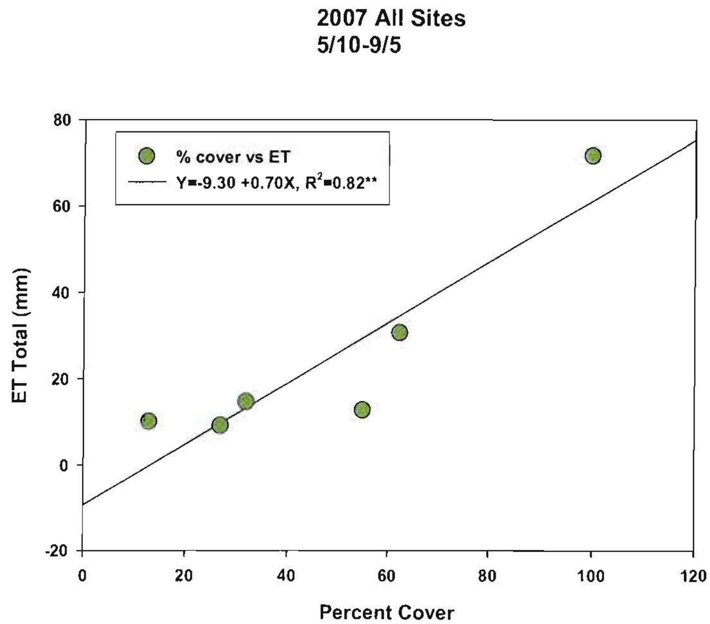



**Figure 74. Relationship between ET total and percent cover for all sites in 2007 for the period 5/10-9/5.**

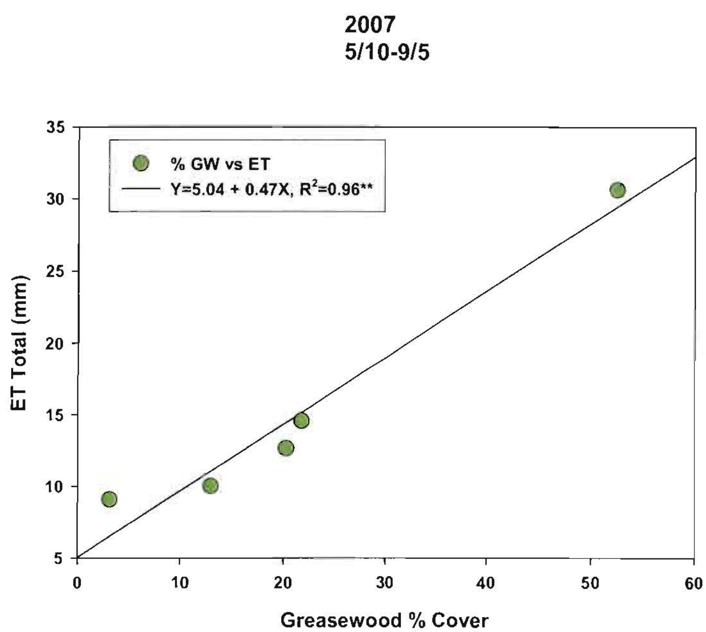



**Figure 75. Relationship between ET total and greasewood percent cover in 2007 for the period 5/10-9/5.**

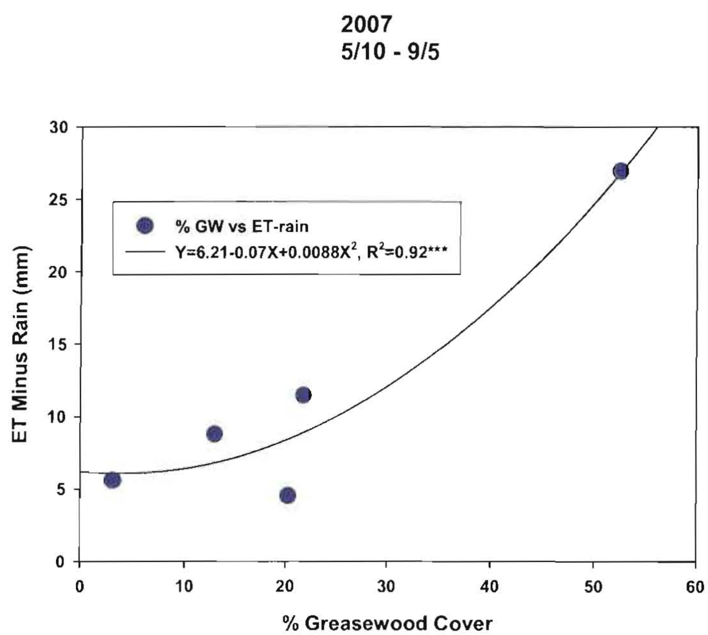



**Figure 76a. Comparison between evapotranspiration rain differential and greasewood percent cover for the period 5/10-9/5 2007.**

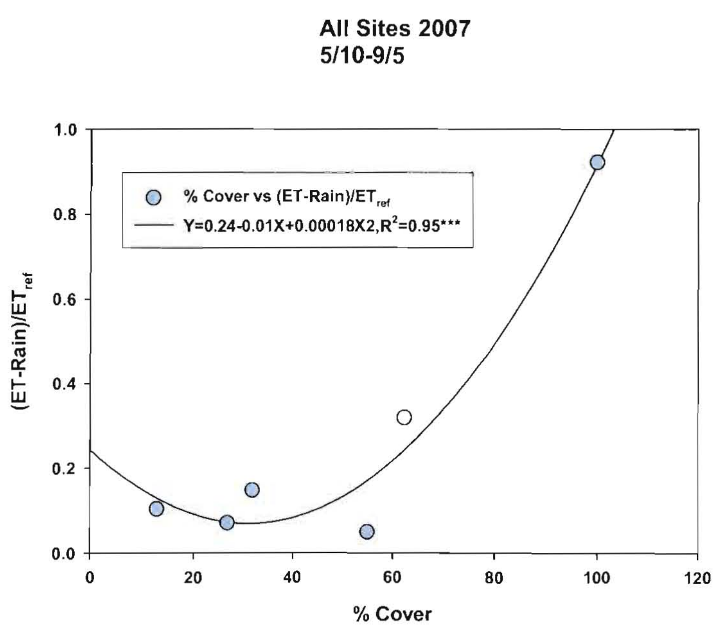



**Figure 76b. Comparison between evapotranspiration rain differential and percent cover of all sites for the period 5/10-9/5 2007.**

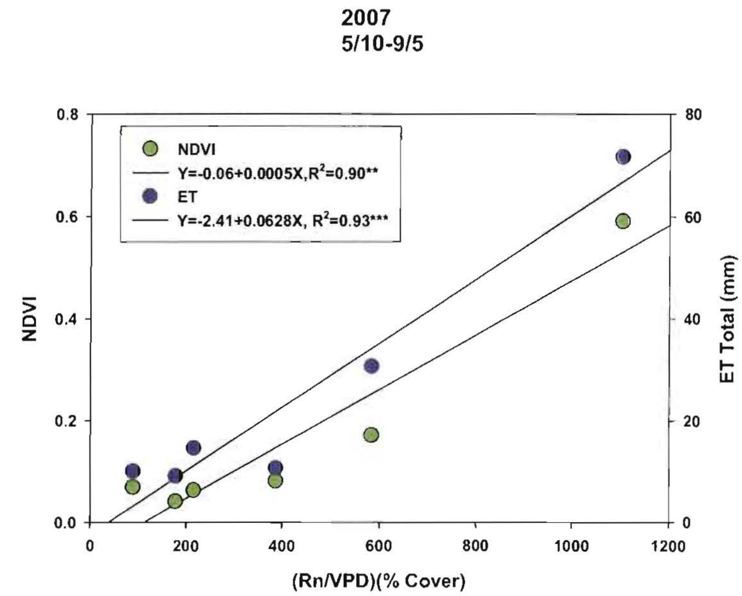



**Figure 77. The relationship between NDVI and ET with the product of (Rn/VPD)(% cover) for the period 5/10-9/5 2007 for all 6 monitoring sites.**

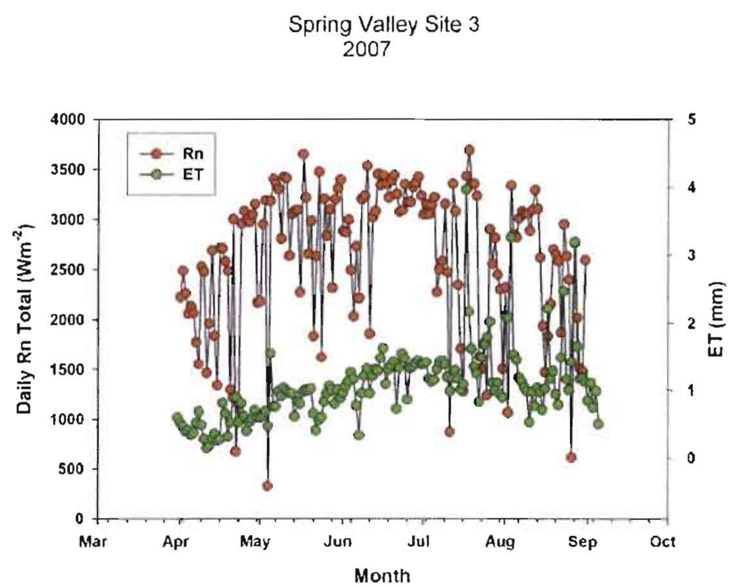



**Figure 78. Comparison of daily net radiation total with evapotranspiration for Spring Valley Site 3 in 2007.**

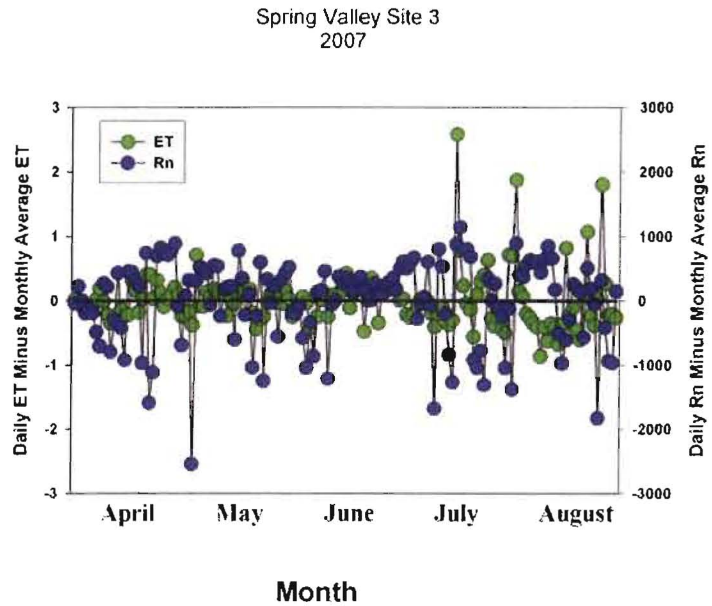



**Figure 79. Daily ET – average monthly ET differential and daily net radiation – average monthly net radiation for Spring Valley Site 3 in 2007.**

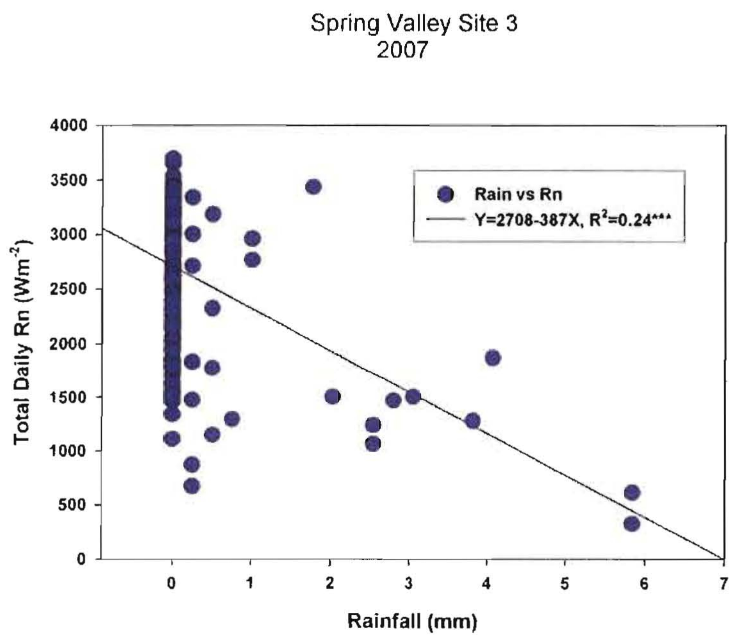



**Figure 80. Relationship between total daily Rn and rainfall for Spring Valley Site 3 in 2007.**

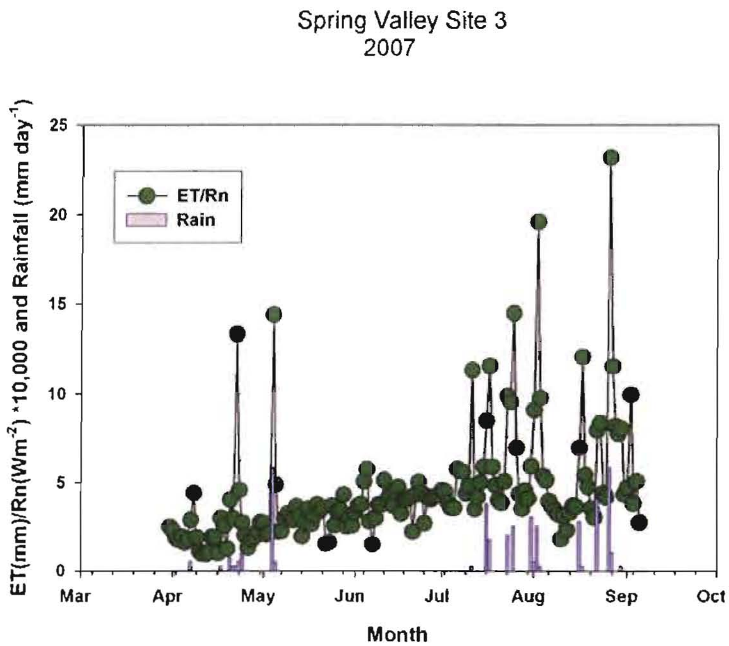



**Figure 81. Changes in the ratio of Rn/ET and rainfall at SV3 during 2007.**

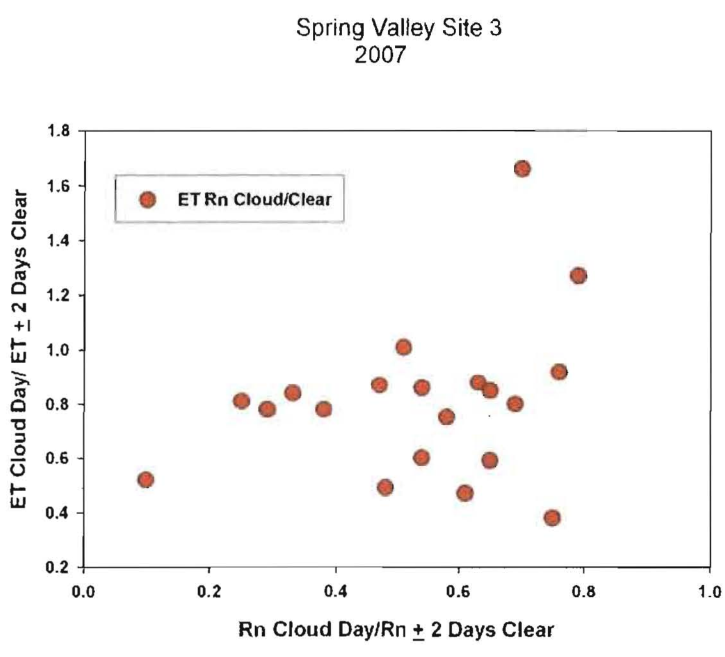



**Figure 82. The relationship between the ratio of ET on selected cloud days divided by ET ± 2 days around the cloud day vs. Rn on the selected cloud day divided by Rn± 2days around the cloud days**

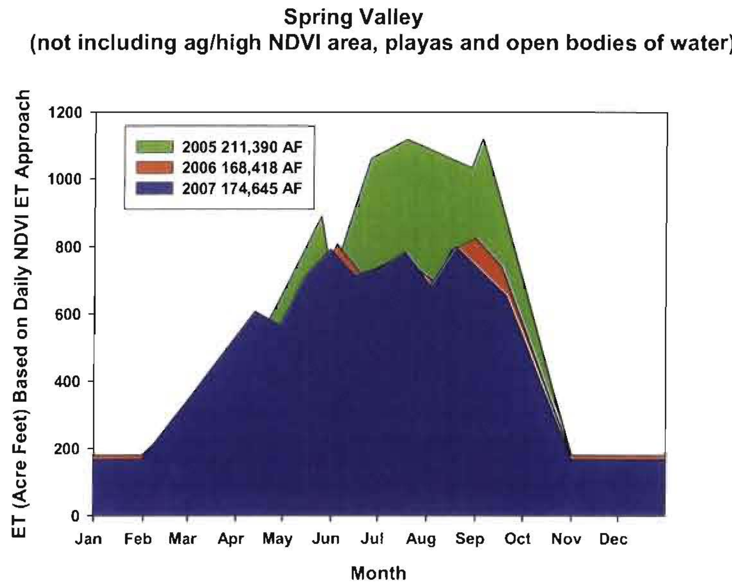



**Figure 83. Evapotranspiration based on daily NDVI-ET approach in Spring Valley for 2005, 2006 and 2007 with yearly totals not including ag/high NDVI area, playas and open bodies of water.**

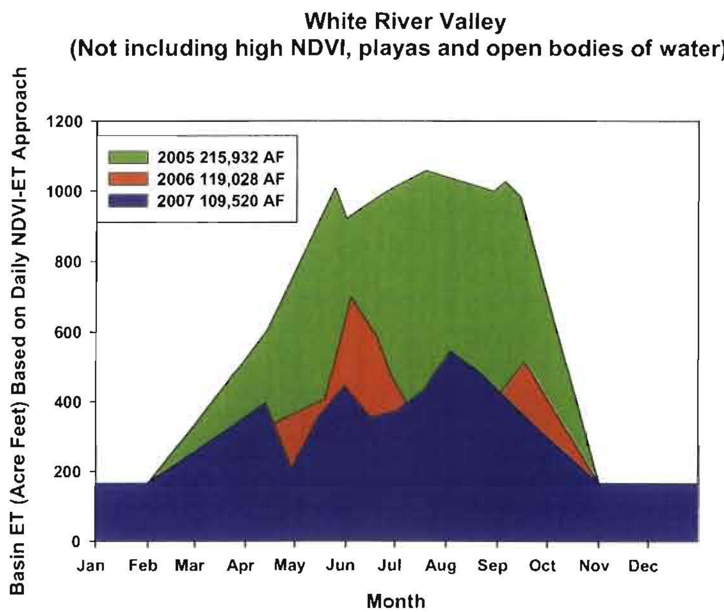



**Figure 84. Evapotranspiration based on daily NDVI-ET approach in White River Valley for 2005, 2006 and 2007 with yearly totals not including ag/high NDVI area, playas and open bodies of water.**

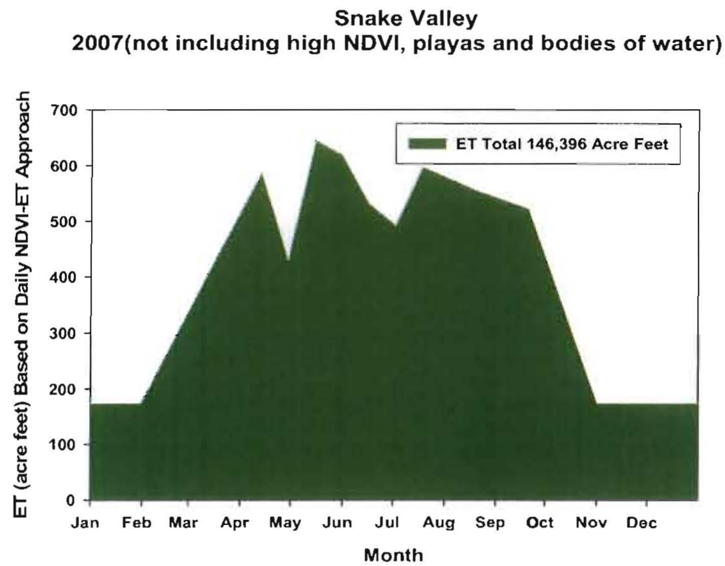



**Figure 85. Evapotranspiration based on daily NDVI-ET approach in Snake Valley for 2007 with yearly total not including ag/high NDVI area, playas and open bodies of water.**

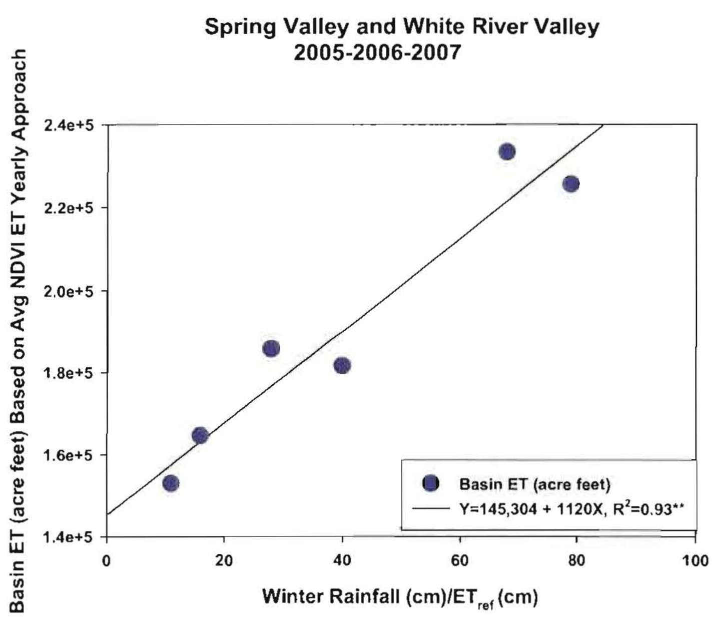



**Figure 86. Basin ET yearly estimates based on the average NDVI-ET yearly approach as a function of the ratio of winter rainfall to ET reference for SV and WRV in 2005, 2006, and 2007.**