Basin Wide Evapotranspiration Estimates for Spring Valley and White River Valley (Monitoring Year August 2004-August 2005)

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Submitted by:

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Executive Summary

Evapotranspiration (ET_a -actual) was estimated for Spring Valley and White River Valley for a 12 month period beginning in August of 2004. ET_a estimates were made based on an energy balance approach (eddy flux estimates of latent heat) combined with remote sensing (Landsat images) and leaf level measurements. Both valleys are large and were found to contain plant communities that had a range in density and species composition. Potential ET (ET_o) and rainfall were shown to be similar for both valleys (ET_o Spring Valley 116.4 cm vs. White River Valley 127.4 cm, rain Spring Valley 32.5 cm vs. White River Valley 32.8 cm), however depth to groundwater was significantly deeper in White River Valley compared to Spring Valley (14 m vs. 2 m). Depending on site location, both valleys showed an ET_a decoupling from ET_o during early to mid summer. This decoupling occurred at the same time surface soil moisture was depleted, suggesting that groundwater use (if occurring) was not always great enough to meet plant water requirements. However, at site 2 in Spring Valley, where the water table was shallow, such a decoupling event did not occur. Plant level measurements indicated that many species were operating at extremely low levels of internal water status during the summer months (<-6.0 MPa leaf xylem water potential).

Highly significant NDVI – ET_a linear relationships were found for both valleys during the 145 day active growing period ($R^2 = 0.87$, $p < 0.001$ Spring Valley vs. $R^2 = 0.90$, $p < 0.001$ White River Valley). However, not all pixels were assigned positive ET_a values. In White River Valley, 48 to 61 percent of the pixels were assigned positive ET_a values for selected scaling dates compared to 64 to 91 percent in Spring Valley. All pixels with negative ET_a estimates were assigned a value of zero. Based on pixel size,

NDVI converted ET_a values were summed for each basin to generate basin wide ETa estimates in AFY. Cloud free basin wide ET_a estimates were generated for 5 dates in Spring Valley and 7 dates in White River Valley. Growing period ET_a estimates for each basin were obtained by calculating the area under the ET_a response curve for each valley. Basin wide ET_a estimates for the growing period in Spring Valley (213, 948 AFY) was over twice as large as the estimate for White River Valley (97, 455 AFY). If 14 day extensions were added to these estimates to account for a transition period (not an off/on event), ET_a estimates for the growing period might be as high as 228, 251 AFY in Spring Valley and 106, 012 AFY in White River Valley. However, this ET_a estimate does not include pixels that had high NDVI values (>0.35) nor the 192 day non growing period. In White River Valley, 1800 acres were not included in the growing period ET_a total estimate because of high NDVI values, whereas in Spring Valley 22,600 acres were not included (primarily dense grasslands). Based on published ET results for grasslands in the Ruby Valley (72 cm per year), these high NDVI areas were estimated to have an ET_a total of 4,252 AFY in White River Valley and 53, 336 AFY in Spring Valley. The non growing period represented 192 days, a period in which approximately 75 percent of the yearly precipitation occurred. ET_a estimates for this period were estimated at 12,733 AFY in White River Valley and 25,638 AFY in Spring Valley. However, additional work is recommended to refine both the high NDVI ET_a estimates and the non growing period ET_a estimates (on going work). Based on the growing and non-growing periods in the designated phreatophytic zones (not including ag/playas/open bodies of water), the ET_a depth estimate for Spring Valley was 62.4 cm which was above the annual rainfall total of 32.5 cm. In White River Valley the ET_a depth estimate was 28.6 cm which was just below the annual rainfall total of 32.8 cm.

We conclude that rainfall rather than groundwater use was the largest component of the water balance (valley floor) for the native plant communities in White River Valley but not in Spring Valley. However, at specific sites such as site 2 in Spring Valley and site 1 in White River Valley, groundwater contribution may be a significantly higher part of the water balance (continuous ET_a monitoring at these sites would be required). At other sites, although the ground water connection may not be strong on the scale of the plant community, individual species such as the phreatophytic shrub greasewood may be more tightly coupled with groundwater use (isotopic analysis begun in June of 2006).

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 vary in size. Spring Valley and White River Valley both are very large basins, each estimated as having more than one million acres (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 will often reveal 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.

Each basin is unique with regard to soil type, groundwater depth, water availability, climate, and plant communities, and generalizations often cannot be made without detailed field studies. 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 both Spring and White River Valleys 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, we initiated a study to estimate ET rates on a basin-wide scale in both Spring Valley and White River Valley (8/20/04 – 8/19/05, study is on going). Based on current information in the literature, knowledge about available technology, and given time and funding constraints, we decided upon an energy balance approach in combination with leaf level measurements and remote sensing analyses to quantify basin wide ET totals. In this report, we discuss the methodology, data analysis, and scaling approaches taken to generate basin-wide ET estimates for a 12 month period.

2.0 DATA AND DATA TYPES

The types of data used in the Spring Valley and White River Valley basin ET_a (actual evapotranspiration) assessment included the following:

2.1 Data measured and methods used by research team:

Site Information

GPS location (Trimble GPS)

Plant counts and plant canopy area (visual count/meter stick)

Soil texture and chemical analysis (laser light scattering, ion chromatograph, atomic absorption spectrophotometer)

Depth to water table (Solinst Depth Water Meter)

Plant and soil measurements

Leaf xylem water potentials (Scholander pressure bomb)

Stomatal conductance (steady state porometer)

Canopy and ambient temperatures (infrared thermometer)

Chlorophyll index (Spectrum field scout - chlorophyll index meter)

Tissue moisture content (fresh dry weights)

Tissue ion analysis (ion chromatograph, atomic absorption spectrophotometer)

Leaf area index (LI-COR 2000 LAI Wand)

Spectral reflectance (PP Systems Unispec field spectrometer)

Volumetric water content (fresh dry weights)

Soil temperatures (infrared thermometer)

Energy balance measurements

Latent heat (eddy covariance system)

Sensible heat (eddy covariance system)

Net Radiation (eddy covariance system)

Soil heat flux (eddy covariance system)

Scintillometer measurements

Sensible heat (Scintec model BLS900)

Potential Evapotranspiration

Meteorological parameters needed for Penman Monteith equation (Campbell Scientific automated weather station and software)

Rainfall (tipping rain gauge)

Note: all instrumentation were used according to manufacturer's recommendations

2.2 Data acquired by research team:

Remotely sensed spectral data

Landsat 5 satellite data (USGS-EROS)

2.3 Methods of Measurements

2.3.1 Site Selection

In July 2004, we selected three sites in Spring Valley and three sites in White River Valley for long-term monitoring (Figure 1). All sites in each basin were located on the valley floor with extensive fetch in all directions and at a distance far enough from nearby mountains to minimize cold drainage. The sites were selected to be representative of plant communities associated with possible groundwater extraction zones in each valley. Selection was based on achieving a range in percent canopy cover and percent cover of greasewood (*Sarcobatus vermiculatus,* a known phreatophyte*).* Species composition and percent cover at each site was evaluated by counting species and estimating canopy surface area of each plant in a 25m by 25m plot. Site descriptions also included soil textural classification and an assessment of soil salinity (saturation extracts, EC bridge) and major cations and anions (atomic absorption spectrophotometer, ion chromatograph) in the soil to a depth of 150 cm.

2.3.2 Ground Water Depth

Depth to ground water was monitored at White River Valley site 3 (non pumping irrigation well) and Spring Valley site 2 (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, 3 monitoring wells were installed to a depth of 80 feet (WRV2, SV1 and SV3).

2.3.3 Plant and Soil Measurements

To assess plant water status and the effective growing period, all major plant species were monitored during each site visit 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 documenting 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. Volumetric soil water content was monitored with a theta probe in the 0-5 cm depth. Soil surface temperatures were monitored with an infrared thermometer.

2.3.4 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, we monitored latent heat with eddy covariance flux systems. The systems were initially setup at the central location, but during early spring 2005, we began to rotate the systems from one site to another approximately every three weeks. Energy, H_2O and CO_2 fluxes were measured at the multiple sites using the flux system 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 (Li-Cor 7500, Li-Cor Inc, Lincoln NE, USA). Both instantaneous and time-averaged data were collected and stored at the tower by the use of a CS 5000 data logger with external memory cards (Campbell Scientific, Logan, UT, USA). Measurements were aligned with the mean wind streamlines and standard density corrections were applied (Kamial & Finnigan 1994; Webb et al. 1980). 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.

Post-processing of the eddy covariance data included screening for spikes in the anemometer and CO_2 concentration data, and identifying data gaps due to loss of power, sensor malfunction or inclement weather. 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. For gaps occurring at nighttime, flux versus air temperature was used. This protocol was consistent with that identified by AMERIFLUX as a standard data filling scheme (Falge et al. 2001). 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)) ((LE+H)/(R_n-G) =1.00 for perfect closure). Closures of 81% were obtained for White River Valley over greasewood dominated plant communities, whereas in Spring Valley over mixed shrub grassland, closure was 76%, similar to the findings of Scott et al. (2004 and 2006).

2.3.5 Potential Evapotranspiration

An automated weather station was initially located at the central location in each valley. The weather station was equipped with an anemometer to measure wind speed, 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 potential evapotranspiration (ET_o), where the Penman-Montieth equation is an empirical based equation that is used to assess environmental demand (the Penman-Montieth equation as opposed to the Penman equation includes surface and aerodynamic resistances). The data were stored in a data logger and downloaded to a lap top computer every two to three weeks. In November 2005, we relocated the weather station and the eddy flux tower in Spring Valley to the southern most site, whereas in White River Valley, the weather station remained at the central location and the eddy flux tower was relocated to the central site (collection of a continuous stream of data at one site).

2.3.6 Remote Sensing

NASA defines remote sensing as "The acquisition and measurement of data/information on some property(ies) of a phenomenon, object, or material by a recording device not in physical, intimate contact with the feature(s) under surveillance"

Remote sensing, based on measuring spectral reflectance over the visible and near infrared regions of the electromagnetic spectrum, is a powerful tool for assessing the growth and health status of vegetative cover. Remote sensing analysis for this 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). The TM data are comprised of 6 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 either 25 m or 28.5 m spatial resolution. Terrain correction includes "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 is centered over White River Valley, and Landsat Path/Row 39/33-32, which is centered over Spring Valley (Landsat data acquisition approximately every 17 days). The dates for Landsat 5 path/row 40/33 (White River Valley) that were acquired for this project included: 4/11/04, 5/13/04, 5/14/04, 9/18/04, 11/5/04, 1/24/05, 3/13/05, 4/14/05, 6/1/05, 7/19/05, and 9/5/05. The dates for path/row 39/33-32 (Spring Valley) included: 4/4/04, 5/6/04, 6/7/04, 8/26/04, 10/13/04, 2/2/05, 5/25/05, 6/26/05, 8/29/05, and 9/14/05. Multiple Landsat images were acquired to assess changes in green vegetation cover and associated changes in ET estimates throughout the growing season.

Ground-based spectral measurements were acquired with a PP Systems Unispec field spectrometer to assist with atmospheric correction of the Landsat images and to provide a more detailed examination of vegetation greenness within the footprint of the

Eddy Flux towers and scintillometer transects. The spectrometer had an effective spectral range of 400 to 900 nm with 1 nm waveband increments. Field spectra were acquired in White River Valley along transects that included the eddy covariance tower. The transect measurements were acquired approximately every 7.5 meters between the towers. Additional transect measurements were acquired at one meter increments for 60 m within the apparent fetch of the eddy covariance tower; one transect along the primary wind direction axis and the other perpendicular to the primary wind direction. The dates for each data collection were: 4/14/05, 6/1/05, 7/19/05, and 9/5/05 (chosen to cover the growing period). In addition to these data, field spectra were also acquired for easily identified light and dark ground targets within the White River Valley; these included a deep open water area (bottom of pond not visible) at the Kirsch Wildlife Refuge and a bright soil area immediately south of the road to the Wildlife Refuge. The light and dark targets were identified from the Landsat 5 TM images. The size and location of the targets, spectral properties and accessibility were critical in the selection of the two sites. In accordance with recommendations from previous research, the bright soil area had relatively flat, high reflectance values while the pond had relatively flat very low reflectance values (Smith and Milton 1999).

2.3.7 Landsat 5 TM Image Analysis

The ENvironment for Visualizing Images (ENVI) software package (Research Systems, Inc., Boulder, CO) was used to analyze the Landsat TM 5 images. The first step in the processing of the images was a calibration to “at-sensor radiance” performed by the ENVI Landsat TM 5 calibration subroutine. At-sensor radiance is the spectral radiance measured at the Landsat sensor’s aperture in W m^{-2} sr^{-1} μm^{-1}, this radiance is the radiance of the land surface plus any atmospheric affects. The equations, gains and offsets published by Chander and Markham (2003) were used in this calibration algorithm. The second step was atmospheric correction and conversion to ground reflectance values. Several atmospheric correction techniques were examined to determine the best atmospheric correction. The first methods employed were based on within-scene statistics, namely the dark pixel correction, which was determined by Hadjimitsis et al. (2004) to provide the best results in the visible bands, the regression intersection method (Crippen 1987), and FLAASH (Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes), which is based on the latest MODTRAN radiation transfer code (developed by Spectral Sciences, Inc. in collaboration with the U.S. Air Force Research Laboratory and Spectral Information Technology Application Center). The resulting image data from these atmospheric corrections were compared to the field spectra for the dark and light ground targets. For each band and date, the FLAASH atmospheric correction approach provided the best results when compared to ground data. However, the vegetation index images computed from the FLAASH images did not yield an annual vegetation response curve that coincided with visual observations of plant phenology. This was most likely due to atmospheric affects that were not completely removed by the FLAASH algorithm. Therefore the standard two-point empirical line method approach was employed (Farrand et al. 1994; Smith and Milton 1999). This approach is based on the regression of dark and light target field spectra to image radiance values for the same area. The resulting regression equation was then used to atmospherically correct all pixels within the image. The empirical line method is a commonly used approach for atmospheric correction when field spectral for light and dark targets are available. To ensure that differences in sun angle throughout the year did not impact further image analysis, the field spectra were compared and the data closest to the summer solstice (i.e., 7/19/05 had the highest sun angle) was selected for the empirical correction. All images for the September 2004 to September 2005 time period were corrected with regression equations based on the field spectra from 07/19/05.

Nichols (2000) obtained good correlations between the normalized difference vegetation index (NDVI) and ET rates. Where a vegetation index is based on spectral reflectance at specific wavelengths or combinations of wavelengths. Such indices have been demonstrated to be highly correlated with such plant characteristics as chlorophyll content, biomass, leaf area and general health and vigor of surface vegetation. Our primary remote sensing efforts for this study focused on the calculation of vegetation indices to regress with the daily eddy covariance data (latent heat (LE) converted to ET) acquired on the same date of image acquisition. The vegetation indices calculated included (NIR refers to Landsat 5 TM band 4 and Red refers to Landsat 5 TM band 3):

1) the normalized difference vegetation index:

NDVI = (NIR - Red) / (NIR + Red) (Tucker 1979),

2) the simple ratio (SR):

SR = NIR / Red (Peñuelas and Filella 1998),

3) the soil adjusted vegetation index (SAVI):

SAVI = (NIR – Red) / (NIR + Red + L) (Huete 1988),

where L (0.5) is an empirically-derived soil adjustment factor, and

4) the modified soil adjusted vegetation index 2 (MSAVI2):

MSAVI2 = (1/2)*(2(NIR+1)-sqrt($(2*NIR+1)^2$-8(NIR-red))) (Qi et al. 1994)

The resulting vegetation index images were masked to the phreatophytic area within each valley, excluding irrigated crop land, playas and open bodies of water as mapped by the Southern Nevada Water Authority. Additional masking was performed to remove any cloud areas and pixels for which the vegetation index values were below or above the range of vegetation index values associated with the six study sites in Spring and White River Valleys (see results section). Because the empirical relationship between vegetation index and ET measured by the eddy covariance towers (described elsewhere in this report) are only valid for areas with similar vegetation composition and density, only pixels with vegetation index values within the study sites range of values as well as location within the phreatophyte zone were used to compute the ET images.

The empirical relationship between vegetation index and ET measured by the eddy covariance towers (described elsewhere in this report) were used to compute an ET image.

2.3.7 Scaling

The scaling of latent heat estimates (representative of an area measured in hundreds of meters, foot print of eddy flux 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 complex and require datasets that were not possible to obtain in this project given the limitations of time and resources. Thus, to provide timely estimates of evapotranspiration, we chose to develop empirical relationships between evapotranspiration (LE converted to mm evaporation) and vegetation indices obtained from Landsat data, as was demonstrated by Nagler et al. (2005). To further test the reliability of scaling eddy covariance data to larger transects (that would be on a scale close to that obtained with Landsat) we conducted a number of controlled studies evaluating sensible heat measured at the eddy flux site with sensible heat measured over 1.5 km transects using a boundary layer scintillometer (model BLS900, Scintec AG, Tubingen, Germany). The scintillometer uses displaced–beam laser technology, providing extensive turbulence information, including the fluxes of heat and momentum. Scintillometer measurements (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 pathlength 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 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 pathlength 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 flux tower (100's meters) provided validation to the scaling process ($R^2 = 0.94$, $p<0.001$).

2.3.8 Basin Wide ET Estimates

Based on a detailed assessment of vegetation indices (remotely sensed) that could account for the greatest amount of variation (highest coefficient of determination) in ground level estimates of ET_a, we developed an empirical model to transform the spectral data into ET_a values (results section). Basin ET_a estimates were then generated via summation of individual pixel ET_a values. Based on the regression equations generated for each valley, not all pixels were assigned positive ET_a values (intercept of regression lines crossed the Y axis at zero ETa with positive NDVI values). All negative ET_a values were assigned an ET_a value of zero (mm) (no biological meaning to a negative ET_a value). Basin wide ET_a estimates for cloud free days were generated for each valley (greater cloud cover was observed in Spring Valley). Yearly ET_a estimates for growing periods in each valley were made by quantifying the area under the daily basin wide ET_a response curves. Areas under the response curves were estimated by the ratio of the area under the curve in pixels to the total area in pixels (each area assigned different colors). Pixels were counted by using an image processing technique that takes the histogram of an image and counts the number of pixels in the image that fall within assigned color categories (Image Pro Version 3.0).

2.3.9 Data Analysis

Data were analyzed using descriptive analysis, 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 3 and the sum total was less than 10. If the accepted VIF was exceeded, parameters were eliminated and regressions were run a second time.

3.0 RESULTS

3.1 Site Assessment (plants, soil and groundwater)

The six monitoring sites are shown in Figure 1. The sites were selected based on the presence of the groundwater indicator species greasewood (*Sacrobatus vermiculatus*). The percent cover of greasewood varied from a low of 3.2 percent at the Spring Valley 1 site to 50.1 percent at the White River Valley 1 site (Figure 2). Species composition and percent cover of these two contrasting sites are shown in Figures 3-6. The Spring Valley 1 site had more plants and more species than the White River Valley 1 site; however the total percent cover was 2.3 fold lower (27% vs. 62%) due to differences in growing conditions (soil, water availability).

Tissue analysis of the major species at each site in White River Valley revealed contrasting levels of ion accumulation, associated with the different glycophytic and halophytic species (Table 1). Greasewood and shadscale revealed sodium concentrations in the leaf tissues as high as 9 percent, indicating preferential uptake and utilization of sodium for osmotic adjustment to maintain favorable water potential gradients, a clear species advantage under saline and sodic conditions (increased ability to extract soil water).

Soil analysis for the upper 150 cm at each site revealed contrasting texture, salinity and specific ion concentrations (Tables 2 and 3). Contrasting soil salinity profiles are shown in Figure 7 for site 2 in White River Valley and site 2 in Spring Valley. Soil salinity as measured in saturation extracts increased with depth at site 2 in White River Valley to as high as 39 dSm^{-1} at the 150 cm depth. Such a salt concentration when projected to soil solution concentrations (soil water) would exceed that of sea water, indicating that root water extraction and water movement are extremely low at this depth (i.e., suggesting little or no rainwater penetration to this depth, the presence of native salts and root water extraction from upper (rain charged surface soils) and lower regions (capillary fringe above water table)). The salinity profile at the White River Valley site shown in Figure 7 is contrasted with the Spring Valley site where soil salinity decreased with depth to values below 2 dSm^{-1} in the saturation extract. The salinity distribution at site 2 in Spring Valley reflected the influence of shallow groundwater with low soluble salts. Soil salinity increased toward the surface reflecting the influence of capillary rise and evaporation.

Depth to groundwater was monitored at site 3 in White River Valley and site 2 in Spring Valley (Figure 8) to assess if major oscillations in ground water depth occurred during the growing season (other sites did not have monitoring wells or piezometers, 3 wells added in 2006). Both sites revealed a rise in groundwater during the winter of 2004, however in the case of site 3 in White River Valley, groundwater depth receded during the first 100 days of 2005 (water table lowered to 14 m below ground surface). At site 2 in Spring Valley, the depth to groundwater has remained within 2 m of ground surface for the past 500 days, indicating little temporal variability.

3.2 Potential ET, Rainfall, Energy Balance Estimates and Active Growing Periods

Potential evapotranspiration (ET_o) was assessed with the empirical based Penman-Monteith equation, using data collected with the weather station. ET_o values ranged from below 0.5 mm day^{-1} during winter months to over 8 mm day^{-1} during summer months in both valleys. Potential ET (ET_o) in Spring Valley was estimated at 116.4 cm (for the period August 20, 2004 to August 19, 2005) compared to 127.4 cm for White River Valley. The 9% difference in ET_o measured in these two valleys was attributed to higher cloud cover observed on a regular basis in Spring Valley. Total precipitation for this same time period was almost identical in the two valleys based on the central location sites (32.5 cm for Spring Valley versus 32.8 cm for White River Valley). ET_o and ET_a (latent flux from the eddy covariance tower converted to evaporation) are plotted on a daily basis in Figures 9 and 10 for both valleys. In viewing these figures, note that the eddy covariance towers were moved from site to site (about every 3 weeks) starting in spring of 2005. In both valleys, ET_a shifted in a parallel fashion with ET_o during the winter and spring periods, regardless of site location. In June ET_a began to diverge from ET_o in both valleys. However, in the case of Spring Valley, when the eddy covariance tower was moved to site 2 (mid July), ET_a returned to a pattern similar to $ET_{o.}$ Such a return shift did not occur in White River Valley. We believe this response was a clear indication that, at most sites, the plants were not tightly coupled to an easily accessible and reliable groundwater source; thus, they were operating under a condition of limited water resources (soil moisture in the unsaturated zone). We have limited data in White River Valley (site 2) to suggest that surface soil water contents declined rapidly as ETo values increased (Figure 11), suggesting that soil water in shallow rootzones were quickly depleted toward late spring-early summer. However, when the eddy covariance tower was returned to Spring Valley site 2, where the water table was shallow (<2 m) and the water was of high quality, plants transpired at a rate driven by the atmospheric demand (ET_o) (not observed at other sites but response would have been dependent on site location and time of measurement).

Measured ET_a totals for the experimental period were 77.1 cm for Spring Valley and 75.3 cm for White River Valley. However, these ET_a values are cumulative and must be carefully interpreted, as they were influenced by the time period the covariance towers remained at each site, especially Spring Valley site 2 and White River Valley site 1, which had the highest ET_a values. Thus, if the eddy flux towers had remained at each site for the full time period, the total estimates would have deviated from one another, indicating the degree of spatial variability in plant community ET rates in these large valleys. However, moving the stations provided a data set with a wider range in NDVI – ET_a values. This wider range in data was essential in the development of strong regression correlations that could be applied to the entire basins.

Poor correlations existed between ET_o and ET_a in Spring Valley and White River Valley (SV2 and WRV2) based on Landsat data collection dates (Figures 12 and 13). In both valleys, the majority of data fell below the 1:1 line, indicating that at high ET_o values, plant communities rarely evapotranspired at the potential rate, but instead at a lower limiting rate. Such a response clearly indicates that the availability of water (both soil water and/or ground water) was not sufficient to supply the plants at the potential rate. The results also show that estimating ET_a with crop coefficients (ET_a/ET_o) for native plant communities in these valleys would fail, because crop coefficients are valid only under non limiting water conditions. However, based on the response at site in Spring Valley (shallow ground water, ET_a tracking ET_o), crop coefficients might have some value, although conditions would have to be well defined.

Many of the species that comprised the plant communities in each valley are classified as deciduous and lacked leaves during a substantial part of the monitoring period. Clearly during this time period they would not be contributing to the transpiration totals. However, Big Sage (*Artemisia tridentata*) is not deciduous and would continue to transpire at a rate dictated by environmental demand, moisture availability and plant characteristics (e.g., leaf area index LAI). Daily ET_a estimates during winter and early spring were low in each valley, even though a percentage of the cover was Big Sage, suggesting that although these plants maintained a full canopy, conditions were not conducive to increase water uptake and elevate transpiration rates (low environmental demand associated with low levels of solar radiation and low air temperatures).

Many of the vegetation indices acquired from remotely sensed spectral data are sensitive to canopy cover, biomass and/or chlorophyll content. As such, vegetation indices were used to help establish the active growing period. Based on visual observations (digital photos, Figures 14-17 for Spring Valley and Figures 18-21 for White River Valley), we estimated an active growing period of approximately 145 days in each valley (mid April to early September)(similar to Ruby valley reported by Berger et al. 2001). Although the leafing out period was fairly rapid, it does not represent an off/on event. As such, adding a 14 day period (visual assessment) to the front and back side of the growing period during any given year is advisable, yielding a total growing period of approximately 173 days.

3.3 Plant Physiological Measurements

Plant water status was assessed to determine the degree to which plants were operating under water limiting conditions**.** Leaf xylem water potentials (Ψ) and canopy temperature differentials (T_c-T_a) were measured on all species during each site visit, where leaf xylem water potential reflects the energy status of water within the vascular tissue and canopy temperature differentials reflect the extent plant tissue warms relative to atmospheric temperatures. However, because of the time requirement to get to each site, measurements were not obtained at a set time. Thus, measurements obtained during morning hours vs. afternoon hours would be different based on normal diurnal trends in plant water status. To minimize the influence of the diurnal trends, only values obtained between 10 AM and 2 PM were considered in the evaluation. Greasewood leaf xylem water potentials and T_c-T_a differences are plotted as functions of time along with daily ET_o values during the active growing period in White River Valley (site 1) (Figures 22 and 23, respectively). ET_o during the active growing period revealed a two step increase (approximately 30 day periods) peaking by day 170. This was the same critical period when surface soil moisture contents declined rapidly and ET_a diverged from ET_o at many of the sites. Greasewood leaf xylem water potentials at site 1 in White River Valley decreased in a linear fashion (R^2=0.69, p<0.001), becoming more negative during the summer period, with values dropping to as low as -6.0 MPa (Big Sage results were similar but with an R^2=0.81, p<0.001). Although these leaf xylem water potential values would be considered to be extremely low for agricultural crops, many native desert species can continue to operate under low soil moisture availability without suffering catastrophic cavitations. During the peak summer period, when high ET_o values are coupled with low leaf xylem water potentials, T_c-T_a became more positive, indicating that greasewood (and other native species) restrict transpiration by closing stomata, which reduces evaporative cooling and elevates canopy temperatures. Higher T_c-T_a values were associated with lower leaf xylem water potentials during this critical time period. Such a response would suggest that water uptake from ground water sources (if occurring) is not adequate to fully meet plant water requirements.

3.4 Vegetation Index ET_a Relationships

A number of vegetation indices (NDVI, MSAVI, SAVI and SR) were calculated based on Landsat spectral data. Empirical relationships were developed between indices and ET_a values. These correlations were developed based on values for the single pixel containing the eddy covariance tower and for the 25 pixels (5x5 grid, each pixel 25m x 25m or 28.5m x 28.5m) that surrounded the tower. However, in the case of both valleys, higher R^2 values were obtained for correlations based on the single central pixel. Of all the vegetation indices, NDVI was found to account for the highest percentage of variability in ET_a values in both valleys (R^2 values for all other indices were less than those reported for NDVI). Therefore, NDVI correlations were developed for both the active growing period and for the 12-month experimental period from August 2004 – August 2005. NDVI vs. ET_a values based on cloud free days are plotted in Figures 24 and 25. In both valleys, 12 month data were best described by second order polynomials and the active growing periods were best described by linear correlations. Higher R^2 values were obtained for the active growing period versus the 12-month experimental period. Due to greater cloud cover in Spring Valley, 7 Landsat dates were selected for linear regression analysis, compared to 8 in Whiter River Valley (larger robust data sets preferred from a statistical perspective). Although both coefficients of determination were high (R^2 =0.87, $p<0.01$ for Spring Valley and R^2=0.90, $p<0.001$ for White River Valley), a greater separation in the data was achieved in the White River Valley Data set (minimal clustering). The lowest NDVI value was measured at site 1 in Spring Valley (lowest canopy cover) and the highest NDVI value was measured on the large greasewood stand at site 1 in White River Valley. Because the second order polynomial equations over predicted ET_a at both low and high NDVI values, we decided that basin wide ET_a estimates should be confined to the active growing period.

3.5 Basin Wide ET_a Estimates

Basin wide ET_a estimates for cloud free days were obtained for each valley by converting all NDVI pixel values into ET_a values (regression equation for each basin). However, not all pixel conversions resulted in positive ETa values; thus, negative values were assigned a zero mm ET_a value (no biological significance to negative values). NDVI values > 0.35 were not included in the ET_a estimates (these pixels were primarily associated with dense grassland areas and new NDVI – ET_a correlations would need to be established). In White River Valley, NDVI values > 0.35 were associated with 1800 acres. In Spring Valley NDVI values > 0.35 were associated with 22,600 acres. Total pixels assigned positive ET_a values for each basin measurement date (based on linear regression equations) ranged from 64 to 91 percent in Spring Valley and 48 to 61 percent in White River Valley. These ET_a values were then multiplied by the pixel area (25m x 25m or 28.5m x 28.5m) and then summed for each valley based on the total area outlined as containing phreatophytic vegetation. ET_a totals (acre feet per day) were filtered to remove all areas containing irrigated agricultural lands, open bodies of water and playas

(Figure 26). ET_a maps for a selected day in each valley are shown in Figures 27 and 28, reflecting basin wide variability. Although, ET_a–NDVI values from individual sites could be used to develop Figures 27 and 28, ET_a totals for individual days for each valley had to be cloud free for the entire valley, which reduced the data set to 5 days in Spring Valley and to 7 days in White River Valley (larger data sets preferred from a statistical perspective). Basin wide ET_a estimates for each valley were obtained by calculating the area under the response curve in both Figures 29 and 30. Total ET_a for the growing period in Spring Valley was estimated at 213,948 acre feet. In White River Valley the total ET_a for the growing period was estimated at 97,455 acre feet. However, based on the assessment that the active growing period contained at least a 14-day transition period before and after the growing period reported, we believe a conservative approach would be to extend the curves down to zero ET_a during these 14-day periods. Such addition in time to these curves would increase the ET_a totals to 228,251 acre feet in Spring Valley and 106,012 acre feet in White River Valley. These estimates represent only the growing period, and do not include high NDVI areas, agricultural fields, open bodies of water or playas (such additional areas would increase total ET_a estimates).

Based on area estimates for the phreatophytic zone in each valley obtained from SNWA (150,030 acres in Spring Valley versus 131,171 acres in White River Valley) ET_a totals were converted into a depth measurement of ET_a for the active growing period (acre feet/acres = feet = cm). In the case of Spring Valley, the estimate of 228,251 acre feet per year would convert to a depth value of 46.4 cm (growing period only, not including high NDVI values, agricultural fields, open bodies of water or playas), which is greater than the annual rainfall estimate of 32.5 cm (clearly indicating a ground water component must exist). In the case of White River valley, the depth ET_a estimate was 24.6 cm (growing period only, not including high NDVI values, agricultural fields, open bodies of water or playas), which was below the annual rainfall estimate of 32.8 cm (not clear that a ground water component would exist).

3.6 ET_a for the non growing period and high NDVI regions

The non growing period represented 192 days during the monitoring period, assuming a 14 day transition period before and after the observed growing period of 145 days. During the non-growing period, potential ET was low and cloud cover was high in both valleys. Approximately 75% of the yearly precipitation total occurred during this time period. The eddy covariance towers remained at the central location in both valleys during the non growing period. In Spring Valley, ET_a averaged 1.12 mm per day, and in White River Valley, ET_a averaged 1.25 mm per day during this period. However, the coefficient of variation in ET_a during the winter period was high in both valleys (0.90 in Spring Valley, and 0.66 in White River Valley). Obtaining accurate NDVI estimates during winter months was not always possible (low sensor angle, high cloud cover). Due to the uncertainty attached to the estimates during the non growing period (single site (all positive ET_a pixels), potential for wet sensors, lack of accurate NDVI values, etc.), it is questionable to assign a fixed ET_a number. We believe a conservative approach would be to report a range in values based on the mean value and a value that represents one standard deviation below the mean (as a first approximation we also adjusted the values based on an average % positive ET_a pixels for the growing period). Such an approach generated a range in values for Spring Valley of 6 to 18 cm and in White River Valley of 3 to 16 cm. Converting the lower evaporation numbers into acre feet per year (based on the non growing period, not including 22,600 acres in Spring Valley and the 1800 acres in White River Valley with high NDVI values) equated to 12,733 acre feet per year in White River Valley and 25,638 acre feet per year in Spring Valley. Steinwand et al. (2006) reported a similar non growing period ET value (4 cm) for Great Basin phreatophytes in the Owens Valley in California

Yearly total ETa estimates for White River Valley and Spring Valley must also take into consideration the area with NDVI values beyond the regression range developed in this study. In the case of White River Valley this represented 1800 acres, whereas in Spring Valley this represented 22,600 acres. These areas were primarily associated with dense grassland cover. The only reported ETa estimates for grassland areas in close proximity to White River Valley and Spring Valley was reported by Berger et al. (2001) for the Ruby Valley. In the Berger et al. study, a yearly ETa value of 72 cm was reported for grasslands. If we assign the 72 cm value to these high NDVI areas, additional ETa estimates in White River Valley would amount to 4,252 AFY and in Spring Valley, 53,336 AFY.

4.0 LIMITATIONS

1) There is uncertainty in eddy covariance measurements during non turbulent conditions (generally early morning hours) and during rainfall periods. To minimize these effects the data were closely evaluated to 1) identify periods when turbulence was low ($U^* < 0.20$) and when rainfall occurred. If such periods were less than 4 hours, the data were cut and the missing data were estimated by fitting the remaining data with a polynomial equation. If rainfall occurred throughout the day, the entire day was eliminated and an LE value

was assigned based on an average value for a two day period before and after the rain out date.

2) Cloud cover was a major constraint on obtaining enough days to establish an empirical relationship between NDVI and ET_a. Landsat images were available about every 17 days and although much of the valleys were clear on many selected days, they were not 100% clear. Such a limitation resulted in a significant reduction in the number of data points used for the scaling operation. However, based on the existing data set, significant linear correlations were obtained. Additional data points will be added to the regression analysis during the second year of the monitoring.

3) A significant linear relationship between ET_a and NDVI only existed for the growing period. We believe the growing period was on the order of 145 days based on visual observations, NDVI and latent heat values from the eddy covariance towers. However, we realize that it would take more detailed measurements to fine tune this estimate and to better define the transitional period before and after this 145 day growing period (we assumed it to be 14 days)

4) A significant number of pixels were not assigned positive ET_a values. Most of these areas were associated with extremely low vegetation cover; such areas should be more closely evaluated and mapped. A smaller area was associated with NDVI values beyond the working range of the NDVI–ET_a curves and also needs to be more closely assessed. In White River Valley, 1800 acres were associated with high NDVI values and in Spring Valley; 22,600 acres were associated with high NDVI values.

5) The results discussed in this report represented one growing period. Variability in yearly estimates will occur and need to be assessed (second year data collection occurring).

6) Rainfall was measured at one location in each valley; multiple sites were added in 2006.

7) The phreatophytic zone was estimated by SNWA. Upon further evaluation, based on the +/- ET_a/NDVI pixels, we modified the zone to better reflect areas in which plant response would support the phreatophytic zone classification. As such, the acreage in White River Valley decreased by 5,511 acres and in Spring Valley by 15,200 acres based on the original SNWA estimates.

8) Greater uncertainty existed in assigning ET_a values for the 192 day non-growing period. We believe a conservative approach is to report a range in values representing the mean and one standard deviation below the mean. Greater refinement in this number is needed.

5.0 GENERAL CONCLUSIONS

Evapotranspiration (ET_a -actual) was estimated for Spring Valley and White River Valley for a 12 month period beginning in August of 2004. ET_a estimates were made based on an energy balance approach (eddy flux estimates of latent heat) combined with remote sensing (Landsat images) and leaf level measurements. Both valleys are large and were found to contain plant communities that had a range in density and species composition. Potential ET (ET_o) and rainfall were shown to be similar for both valleys (ET_o Spring Valley 116.4 cm vs. White River Valley 127.4 cm, rain Spring Valley 32.5

cm vs. White River Valley 32.8 cm), however depth to groundwater was significantly deeper in White River Valley compared to Spring Valley (14 m vs. 2 m). Depending on site location, both valleys showed an ET_a decoupling from ET_o during early to mid summer. This decoupling occurred at the same time surface soil moisture was depleted, suggesting that groundwater use (if occurring) was not always great enough to meet plant water requirements. However, at site 2 in Spring Valley, where the water table was shallow, such a decoupling event did not occur. Plant level measurements indicated that many species were operating at extremely low levels of internal water status during the summer months (<-6.0 MPa leaf xylem water potential).

Highly significant NDVI – ET_a linear relationships were found for both valleys during the 145 day active growing period (R^2 = 0.87, p <0.001 Spring Valley vs. R^2 =0.90, p<0.001 White River Valley). However, not all pixels were assigned positive ET_a values. In White River Valley, 48 to 61 percent of the pixels were assigned positive ET_a values for selected scaling dates compared to 64 to 91 percent in Spring Valley. All pixels with negative ET_a estimates were assigned a value of zero. Based on pixel size, NDVI converted ET_a values were summed for each basin to generate basin wide ETa estimates in AFY. Cloud free basin wide ET_a estimates were generated for 5 dates in Spring Valley and 7 dates in White River Valley. Growing period ET_a estimates for each basin were obtained by calculating the area under the ET_a response curve for each valley. Basin wide ET_a estimates for the growing period in Spring Valley (213, 948 AFY) was over twice as large as the estimate for White River Valley (97, 455 AFY). If 14 day extensions were added to these estimates to account for a transition period (not an off/on event), ET_a estimates for the growing period might be as high as 228, 251 AFY in Spring

Valley and 106, 012 AFY in White River Valley. However, this ET_a estimate does not include pixels that had high NDVI values (>0.35) nor the 192 day non growing period. In White River Valley, 1800 acres were not included in the growing period ET_a total estimate because of high NDVI values, whereas in Spring Valley 22,600 acres were not included (primarily dense grasslands). Based on published ET results for grasslands in the Ruby Valley (72 cm per year), these high NDVI areas were estimated to have an ET_a total of 4,252 AFY in White River Valley and 53, 336 AFY in Spring Valley. The non growing period represented 192 days, a period in which approximately 75 percent of the yearly precipitation occurred. ET_a estimates for this period were estimated at 12,733 AFY in White River Valley and 25,638 AFY in Spring Valley. However, additional work is recommended to refine both the high NDVI ET_a estimates and the non growing period ET_a estimates (on going work). Based on the growing and non-growing periods in the designated phreatophytic zones (not including ag/playas/open bodies of water), the ET_a depth estimate for Spring Valley was 62.4 cm which was above the annual rainfall total of 32.5 cm. In White River Valley the ET_a depth estimate was 28.6 cm which was just below the annual rainfall total of 32.8 cm.

We conclude that rainfall rather than groundwater use was the largest component of the water balance (valley floor) for the native plant communities in White River Valley but not in Spring Valley. However, at specific sites such as site 2 in Spring Valley and site 1 in White River Valley, groundwater contribution may be a significantly higher part of the water balance (continuous ET_a monitoring at these sites would be required). At other sites, although the ground water connection may not be strong on the scale of the plant community, individual species such as the phreatophytic shrub greasewood may be more tightly coupled with groundwater use (isotopic analysis begun in June of 2006).

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Table 1. Tissue analysis for Big Sage (glycophyte), Greasewood (halophyte), Rabbit Brush (glycophyte) and Shadscale (halophyte).

Site	Species	% Ca	% Mg	% Na	% K	% Cl	% SO_4
WRV1	Big Sage	0.59[a] (0.18)[b]	0.19 (0.05)	0.08 (0.06)	1.15 (0.23)	0.11 (0.09)	0.29 (0.06)
	Greasewood	0.78 (0.34)	0.45 (0.19)	8.86 (2.45)	1.46 (0.70)	2.11 (1.08)	0.25 (0.04)
	Rabbit Brush	0.81 (0.24)	0.26 (0.07)	0.08 (0.05)	1.55 (0.57)	0.28 (0.17)	0.25 (0.01)
WRV2	Big Sage	0.68 (0.20)	0.14 (0.07)	0.14 (0.08)	1.49 (0.22)	0.23 (0.13)	0.30 (0.05)
	Greasewood	0.74 (0.16)	0.26 (0.06)	9.20 (1.52)	2.22 (0.72)	3.76 (0.91)	0.35 (0.18)
	Rabbit Brush	1.05 (0.25)	0.16 (0.05)	0.17 (0.14)	1.65 (0.21)	0.34 (0.14)	0.29 (0.02)
	Shadscale	1.67 (0.53)	0.42 (0.14)	9.83 (1.67)	3.86 (1.05)	11.35 (1.88)	1.24 (0.75)
WRV3	Big Sage	0.73 (0.15)	0.17 (0.04)	0.14 (0.03)	2.10 (0.24)	0.19 (0.14)	0.29 (0.05)
	Greasewood	0.58 (0.14)	0.19 (0.04)	5.82 (1.45)	2.40 (0.26)	1.24 (0.79)	0.29 (0.03)
	Rabbit Brush	1.10 (0.30)	0.22 (0.05)	0.12 (0.02)	2.87 (0.16)	0.15 (0.06)	0.32 (0.05)
	Shadscale	1.68 (0.64)	0.30 (0.07)	7.16 (1.32)	3.04 (0.77)	5.15 (1.90)	0.25 (0.02)

[a] average percent of ion [b] standard deviation

Table 2. Soil Chemical Analysis (saturation extracts) for all sites with depth.

Site	Depth (cm)	EC (dS/m)	Na (mEq/L)	K (mEq/L)	Ca (mEq/L)	Mg (mEq/L)	Cl (mEq/L)	SO_4 (mEq/L)
WRV1	0-22	- *	-	-	-	-	-	-
	22-43	5.827	-	0.10	26.98	22.83	-	-
	43-65	1.039	10.68	-	2.07	2.08	3.85	0.69
	65-86	4.272	21.86	0.02	12.45	24.90	31.97	10.40
	86-108	8.004	20.65	0.07	35.28	89.23	35.74	31.86
	108-130	9.704	22.84	0.10	45.65	116.20	44.19	54.26
	130-151	9.474	26.28	0.41	43.58	118.28	21.14	28.59
WRV2	0-22	0.7946	-	-	-	-	1.37	2.75
	22-43	1.912	17.50	0.82	2.07	4.15	16.33	1.21
	43-65	10.218	115.21	1.25	7.26	5.19	80.51	37.97
	65-86	21.22	173.96	1.91	28.01	62.25	127.03	169.85
	86-108	21.32	218.79	1.96	30.09	61.21	136.10	148.12
	108-130	24.27	197.10	1.90	35.28	77.81	208.90	183.77
	130-151	25.18	240.48	1.69	31.13	95.45	201.59	164.98
	130-140	39.34	405.24	3.09	45.65	194.64	468.11	395.59
WRV3	0-28	0.6655	1.00	1.04	2.49	5.81	0.68	0.85
	28-56	0.6557	2.89	0.93	0.00	2.70	0.61	0.77
	56-84	4.176	40.92	1.49	0.00	3.53	20.54	7.48
	84-112	7.847	94.91	2.07	0.00	0.21	25.97	16.83
	112-140	11.73	142.30	2.48	1.87	3.32	68.30	54.23
	140-168	17.63	196.11	3.69	30.09	42.54	79.48	180.53
	168-196	14.50	149.99	2.53	26.98	47.73	67.43	133.01
SV1	0-28	0.399	0.37	0.41	4.15	2.07	0.24	0.39
	28-56	0.3331	0.15	0.21	4.15	2.08	0.18	0.32
	56-84	0.3052	0.28	0.38	2.07	2.08	0.14	0.27
	84-112	0.3000	0.40	0.39	2.07	1.04	0.18	0.21
	112-140	0.3551	0.63	0.68	2.07	2.08	0.31	0.40
SV2	0-28	17.43	138.54	13.43	37.35	128.65	89.43	194.61
	28-56	18.42	134.75	9.49	25.94	147.33	84.04	207.57
	56-84	7.993	69.19	5.62	10.38	41.50	39.78	63.87
	84-112	3.324	24.09	1.97	6.23	14.53	12.12	23.45
	112-140	2.541	12.63	1.49	6.23	16.60	6.55	15.28
	140-168	1.140	4.06	0.47	6.23	4.15	2.07	5.83
	168-196	0.9548	0.56	0.23	6.23	4.15	2.05	5.95
SV3	0-28	-	-	-	-	-	-	-
	28-56	13.56	0.52	16.50	1.04	1.04	24.31	67.79
	56-84	14.23	146.83	9.74	1.04	0.00	41.15	91.20
	84-112	9.893	99.21	11.21	3.11	0.00	61.40	48.15
	112-140	7.018	67.12	2.24	3.11	4.15	51.68	24.07
	140-168	8.741	102.66	6.35	5.19	6.23	72.03	47.22
	168-196	1.977	18.40	0.85	1.04	3.11	7.23	8.16

Table 3. Soil texture analysis for all sites with depth.

Site	Depth (cm)	Moist (g/g)	Gravel >2 mm	SAND >62.5 um	SILT 15-62.5 um	SILT 3-15 um	CLAY <3 um
WRV1	0-22	0.070	0.0	21.2	27.4	21.7	29.6
	22-43	0.062	0.0	30.2	29.3	19.4	21.1
	43-65	0.073	0.0	30.4	25.5	20.9	23.1
	65-86	0.078	0.0	39.8	20.7	18.8	20.6
	86-108	0.086	0.4	38.4	18.5	20.1	23.1
	108-130	0.120	0.0	19.5	16.8	31.8	32
	130-151	0.133	0.7	15.5	17	34.8	32.7
WRV2	0-22	0.052	1.9	29.0	17.3	28.7	25.1
	22-43	0.093	2.6	34.8	16.6	25.9	22.7
	43-65	0.183	9.8	19.4	13.1	29.2	38.4
	65-86	0.145	2.0	57.3	11.4	14.6	16.7
	86-108	0.163	12.3	46.7	12.4	15.8	25
	108-130	0.196	0.5	41.2	14.6	16.9	27.4
	130-151	0.212	0.3	44.0	14.5	18.8	22.7
	130-140	0.199	0.7	56.2	12.3	14	17.6
WRV3	0-28	0.039	8.5	45.3	16.7	17.1	17.9
	28-56	0.038	10.9	48.0	15.1	16.8	17.4
	56-84	0.069	12.8	52.6	14.7	14.3	17.0
	84-112	0.091	0.7	42.7	17.7	17.6	20.2
	112-140	0.117	24.2	55.2	22.6	11.1	7.3
	140-168	0.088	8.0	43.3	28.2	15.7	8.5
	168-196	0.053	2.2	38.6	27.0	19.1	11.9
SV1	0-28	0.093	11.4	85.2	4.3	4.7	5.9
	28-56	0.104	13.6	81.7	4.3	4.7	9.4
	56-84	0.132	14.3	72.3	4.1	4.7	19
	84-112	0.071	27.2	86.2	2.7	3.3	7.8
	112-140	0.053	18.4	90.4	2.3	2.5	4.8
SV2	0-28	0.226	0.1	11.3	16	34.4	38.3
	28-56	0.234	8.1	10.4	13.5	31.1	45
	56-84	0.302	11.0	4.2	12.5	33.2	50.1
	84-112	0.330	1.4	4.3	12.2	35.3	48.2
	112-140	0.287	0.0	5.2	10.6	34.8	49.5
	140-168	0.241	10.8	4.8	7	25	63.2
	168-196	0.257	0.3	2.8	9.6	33.2	54.4
SV3	0-28	0.103	0.4	12.1	13.1	27.2	47.6
	28-56	0.127	0.2	16.0	15.4	25.9	42.7
	56-84	0.165	0.3	31.7	18.6	21.5	28.2
	84-112	0.182	0.7	34.9	20.7	19.3	25
	112-140	0.150	3.1	27.8	12	16.8	43.4
	140-168	0.043	5.5	57.0	16.2	14.1	12.6
	168-196	0.076	3.6	47.3	21.3	18	13.4

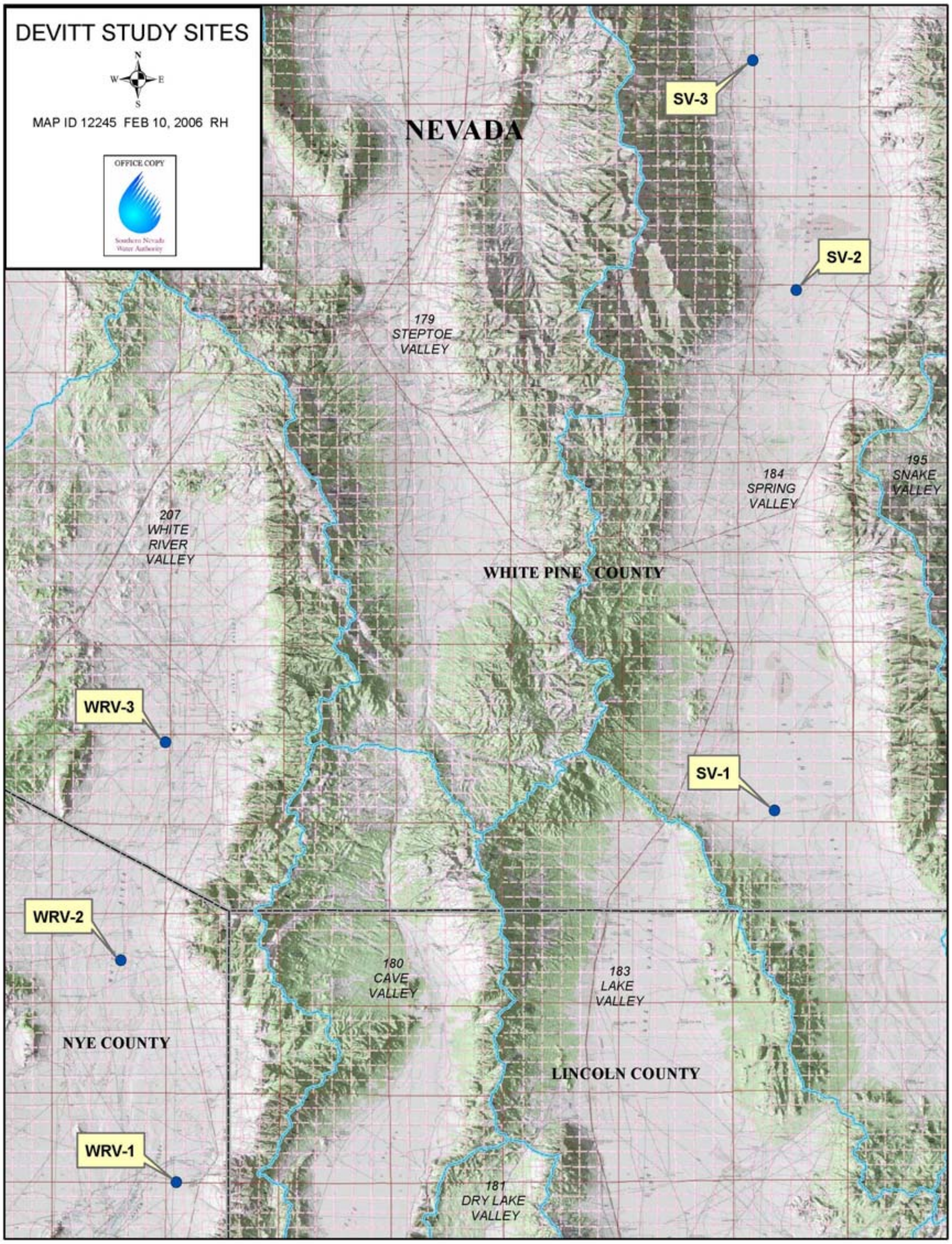


FIGURE 1

Spring Valley site 1: T11N R67E S32 NE ¼, Spring Valley site 2: T16N R67E S4 NW ¼, Spring Valley site 3:T19N R66E S13 SE1/4, White River Valley site 1: T6N R62E S6 NE ¼, White River Valley site 2: T9N R61E S22 NE ¼ and White River Valley site 3: T11N R61E S1 SE ¼.

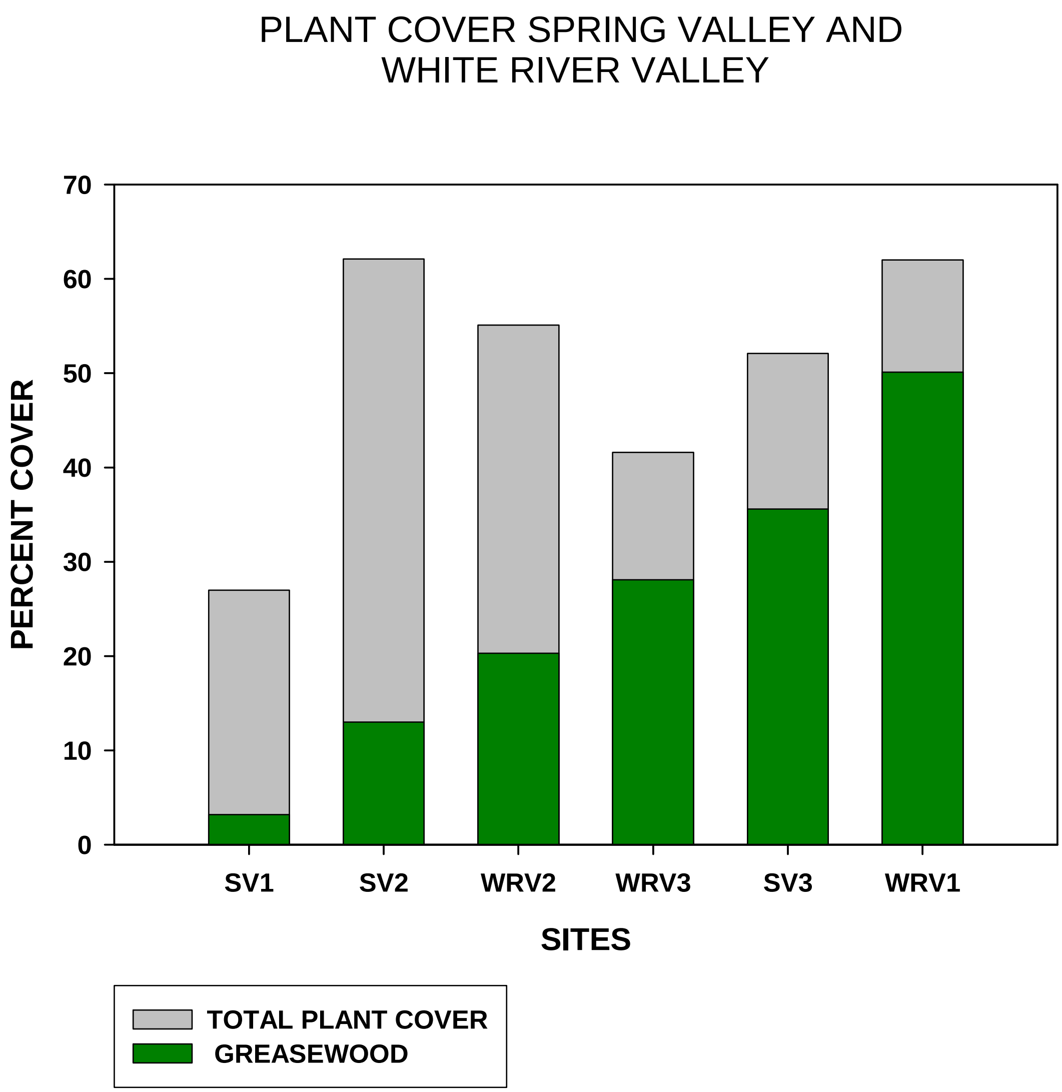

PLANT COVER SPRING VALLEY AND
WHITE RIVER VALLEY
70
60
50
40
30
20
10
0
PERCENT COVER
SV1
SV2
WRV2
WRV3
SV3
WRV1
SITES
TOTAL PLANT COVER
GREASEWOOD

FIGURE 2

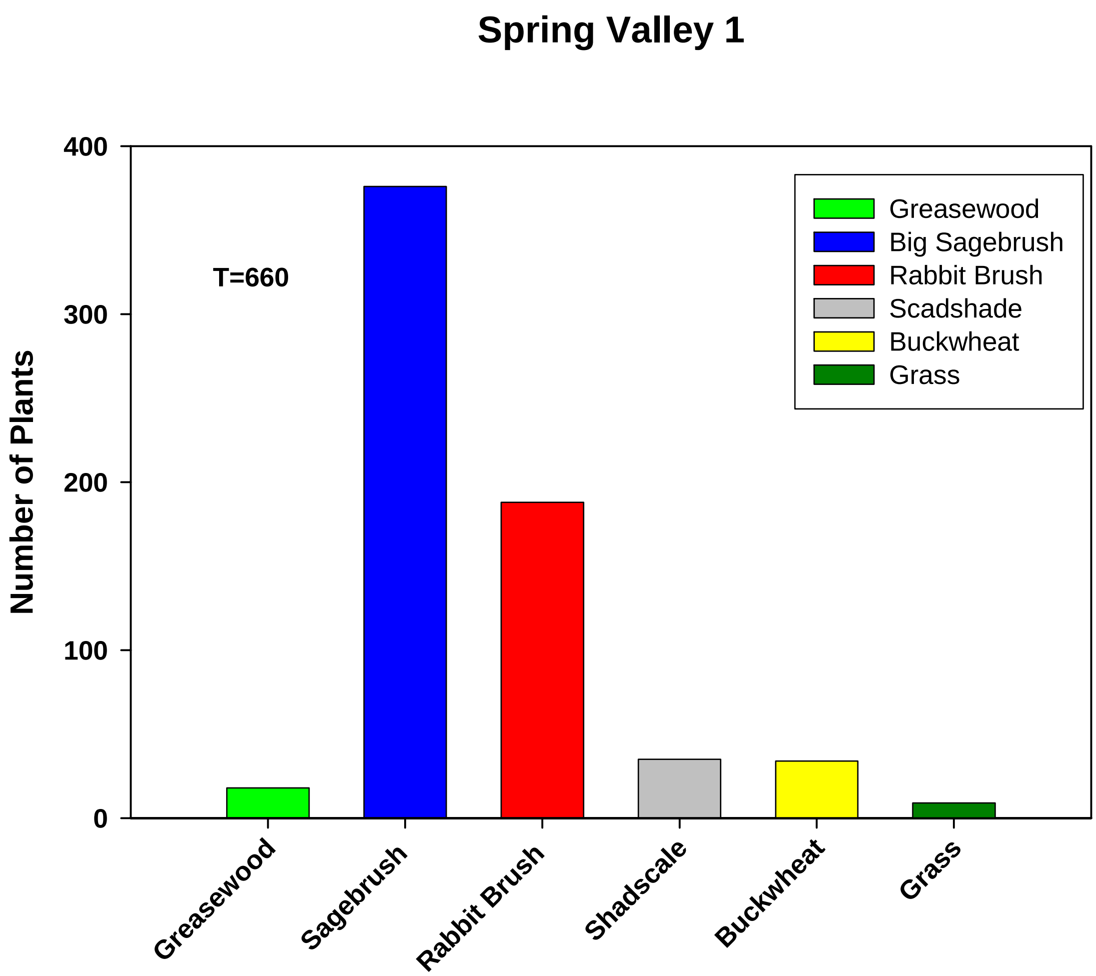

Spring Valley 1
T=660
Number of Plants
400
300
200
100
0
Greasewood
Big Sagebrush
Rabbit Brush
Scadshade
Buckwheat
Grass
Greasewood
Sagebrush
Rabbit Brush
Shadscale
Buckwheat
Grass

FIGURE 3

Spring Valley 1

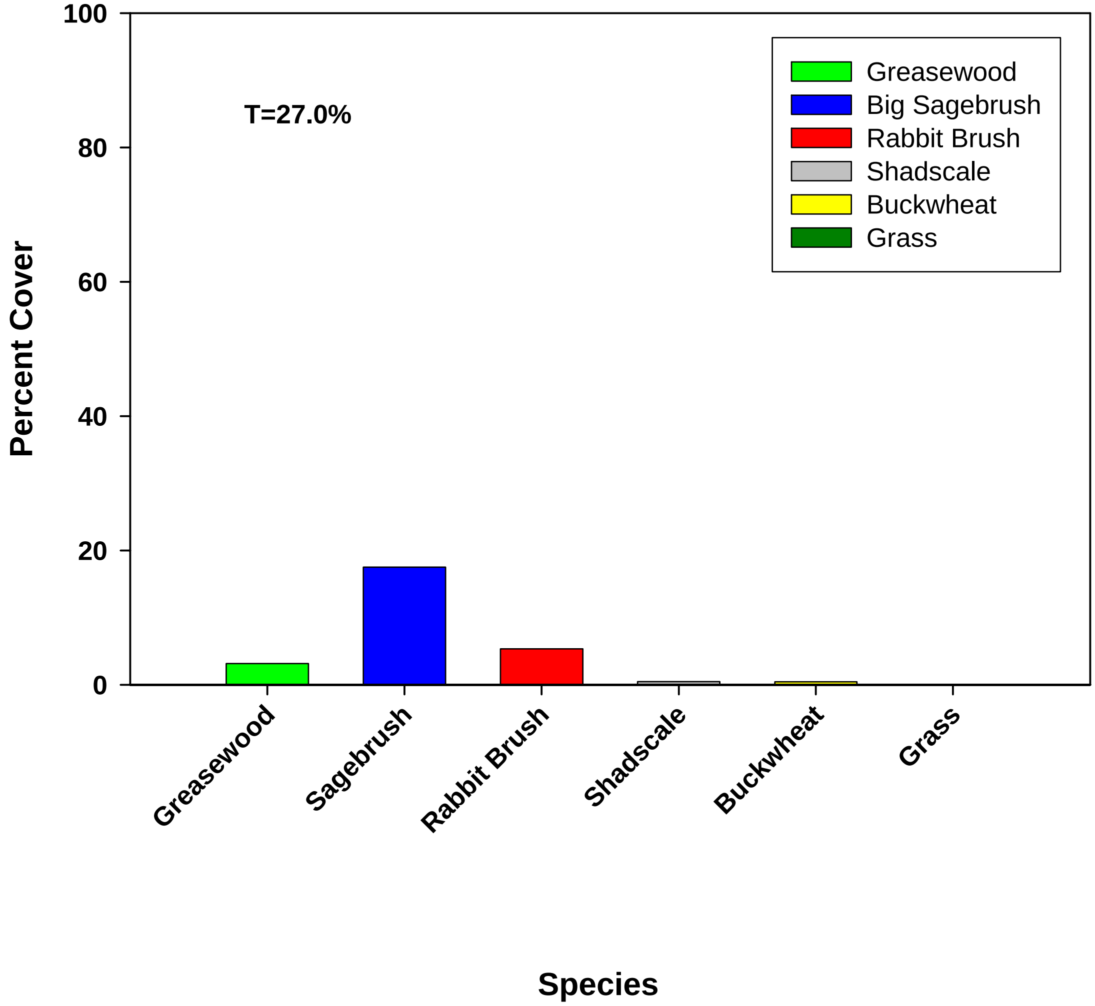


FIGURE 4

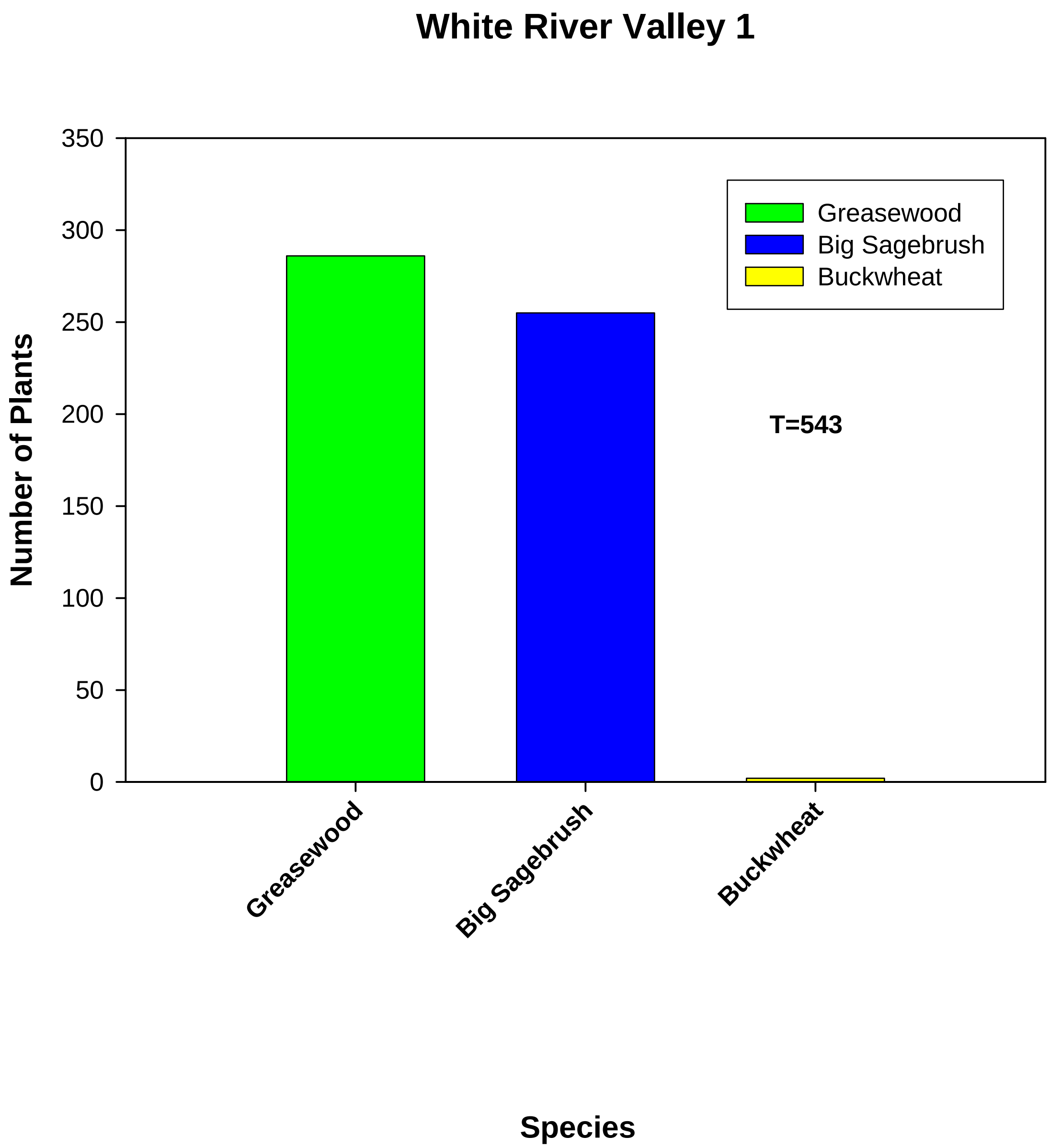

White River Valley 1
350
300
250
200
150
100
50
0
Number of Plants
Greasewood
Big Sagebrush
Buckwheat
T=543
Greasewood
Big Sagebrush
Buckwheat
Species

FIGURE 5

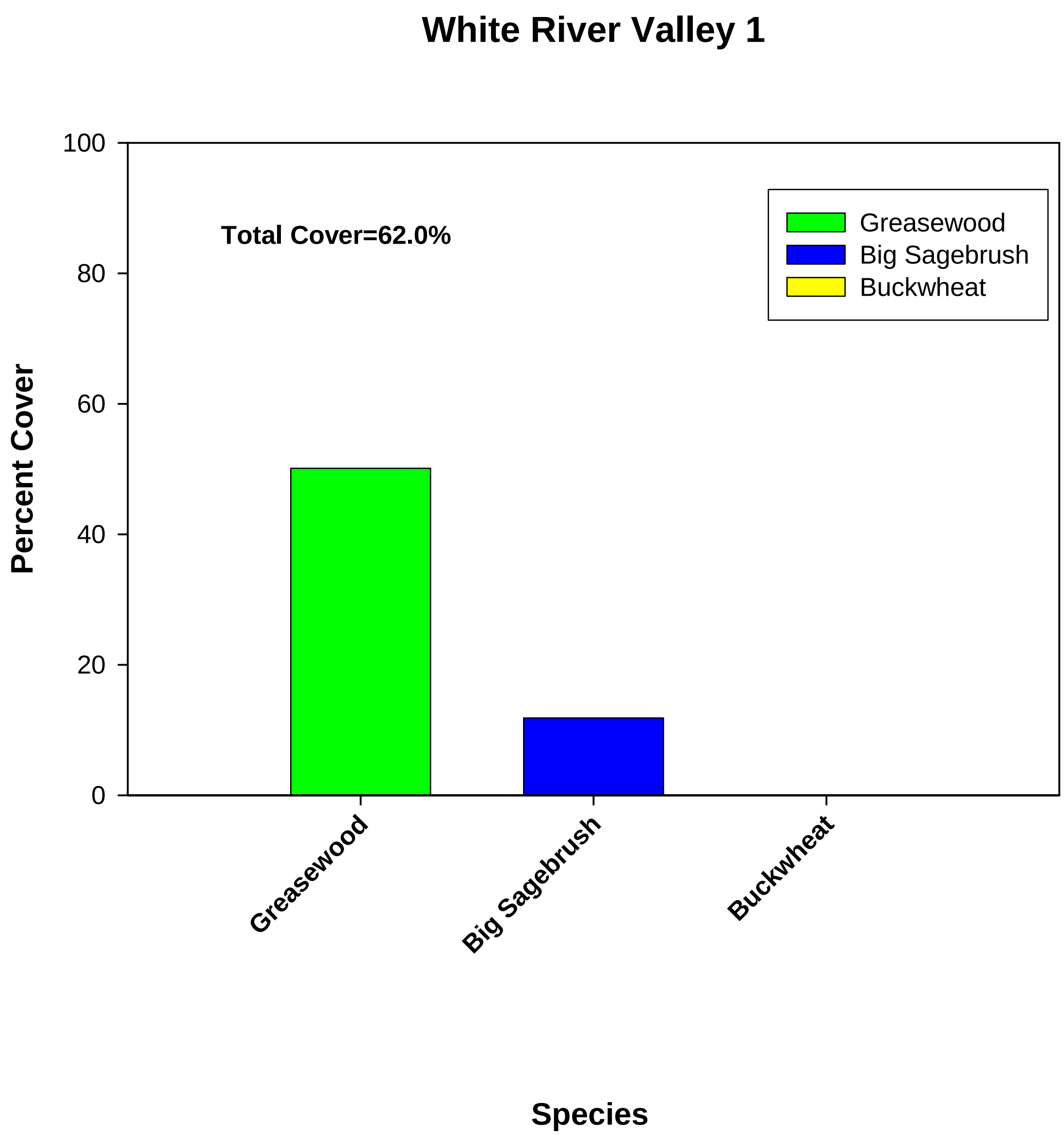

White River Valley 1
Total Cover=62.0%
Greasewood
Big Sagebrush
Buckwheat
Percent Cover
100
80
60
40
20
0
Greasewood
Big Sagebrush
Buckwheat
Species

FIGURE 6

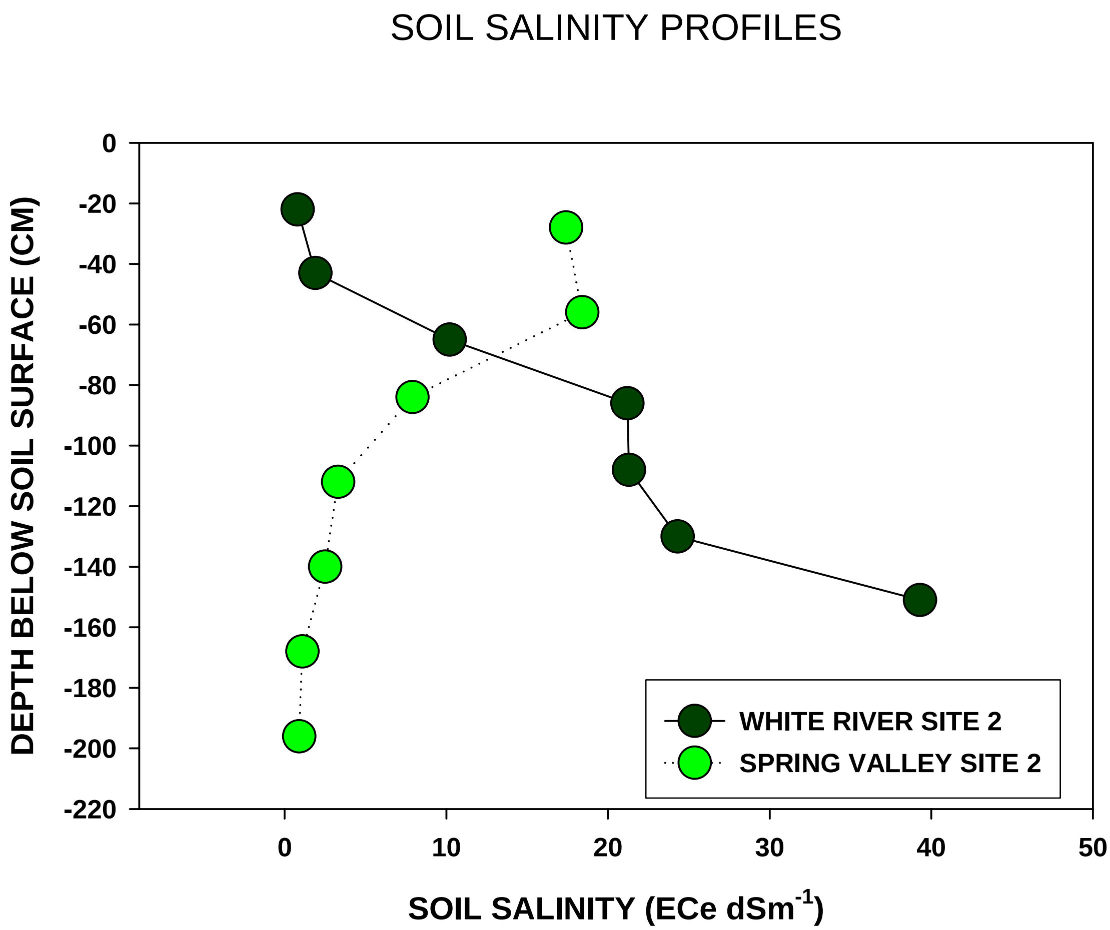

SOIL SALINITY PROFILES
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
-200
-220
DEPTH BELOW SOIL SURFACE (CM)
0
10
20
30
40
50
SOIL SALINITY (ECe dSm-1)
WHITE RIVER SITE 2
SPRING VALLEY SITE 2

FIGURE 7

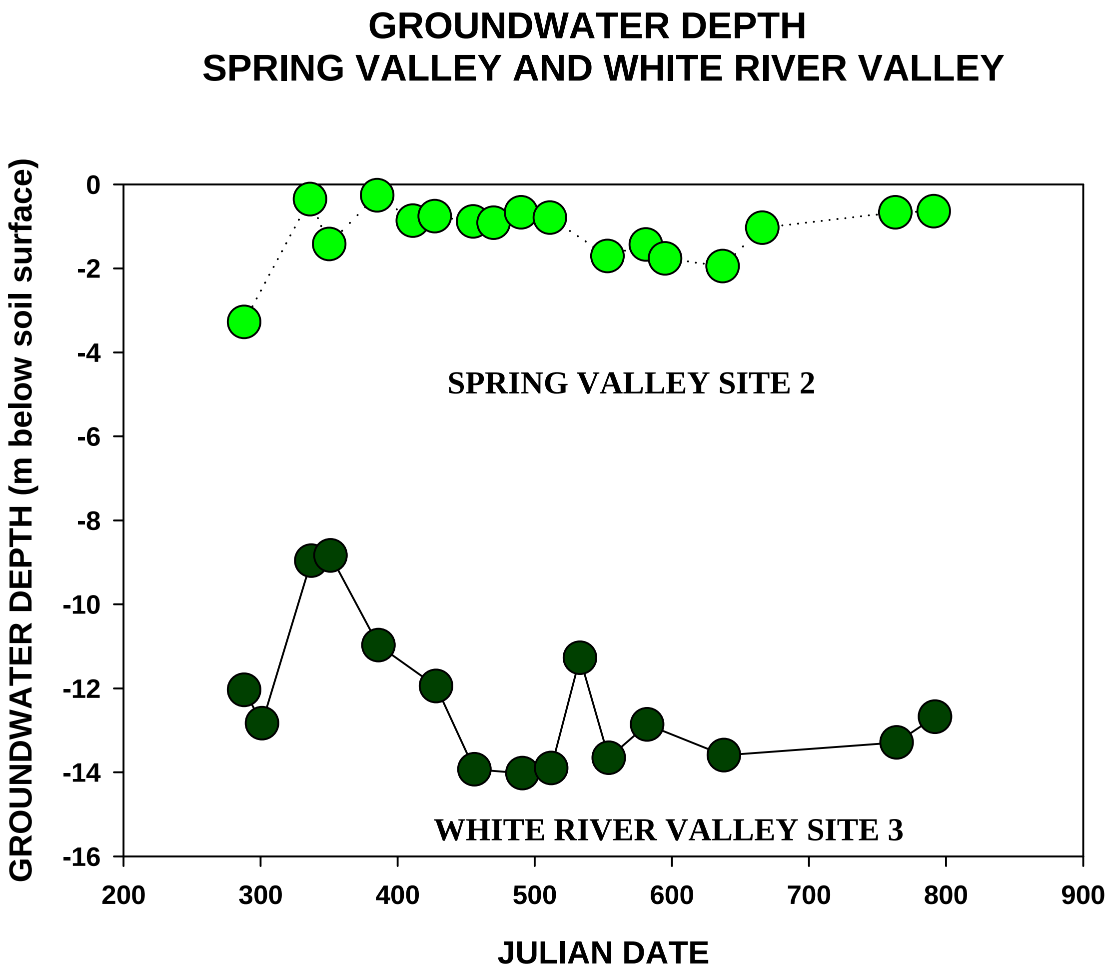


FIGURE 8
Ground water depths measured from September 2004 to February 2006.

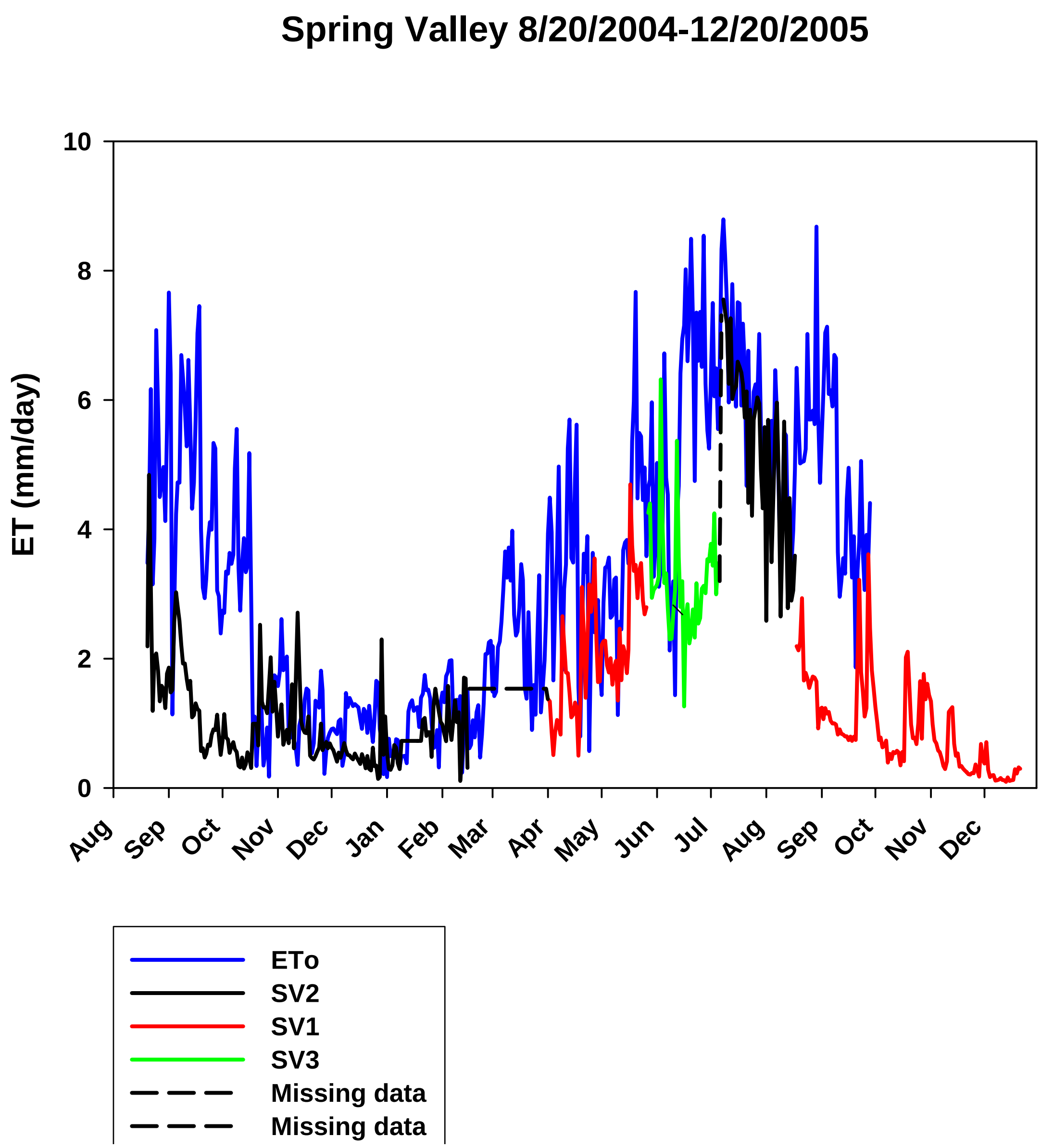

Spring Valley 8/20/2004-12/20/2005
ET (mm/day)
0
2
4
6
8
10
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
ETo
SV2
SV1
SV3
Missing data
Missing data

FIGURE 9

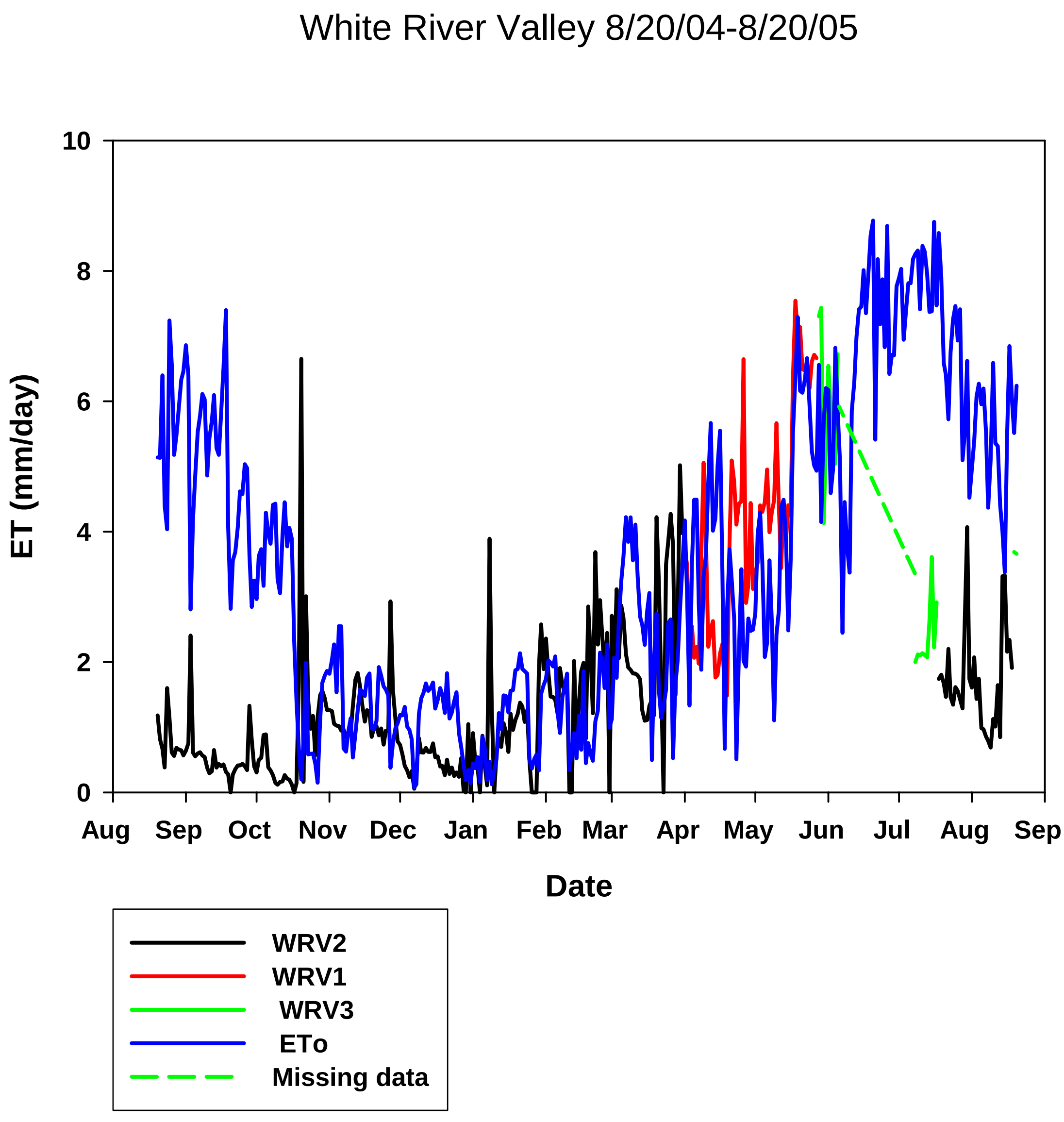
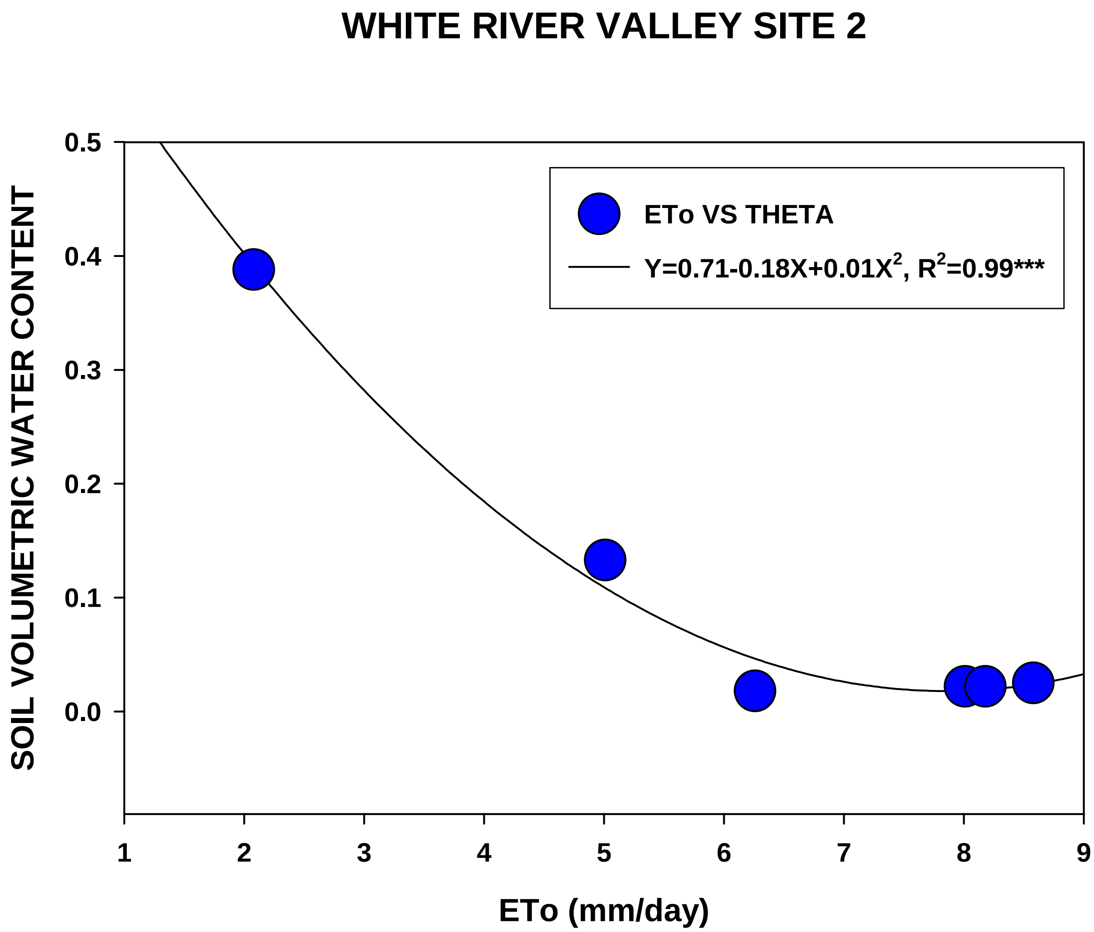

White River Valley 8/20/04-8/20/05
ET (mm/day)
10
8
6
4
2
0
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Date
WRV2
WRV1
WRV3
ETo
Missing data

FIGURE 10



WHITE RIVER VALLEY SITE 2
ETo VS THETA
Y=0.71-0.18X+0.01X2, R2=0.99***
SOIL VOLUMETRIC WATER CONTENT
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
ETo (mm/day)

FIGURE 11

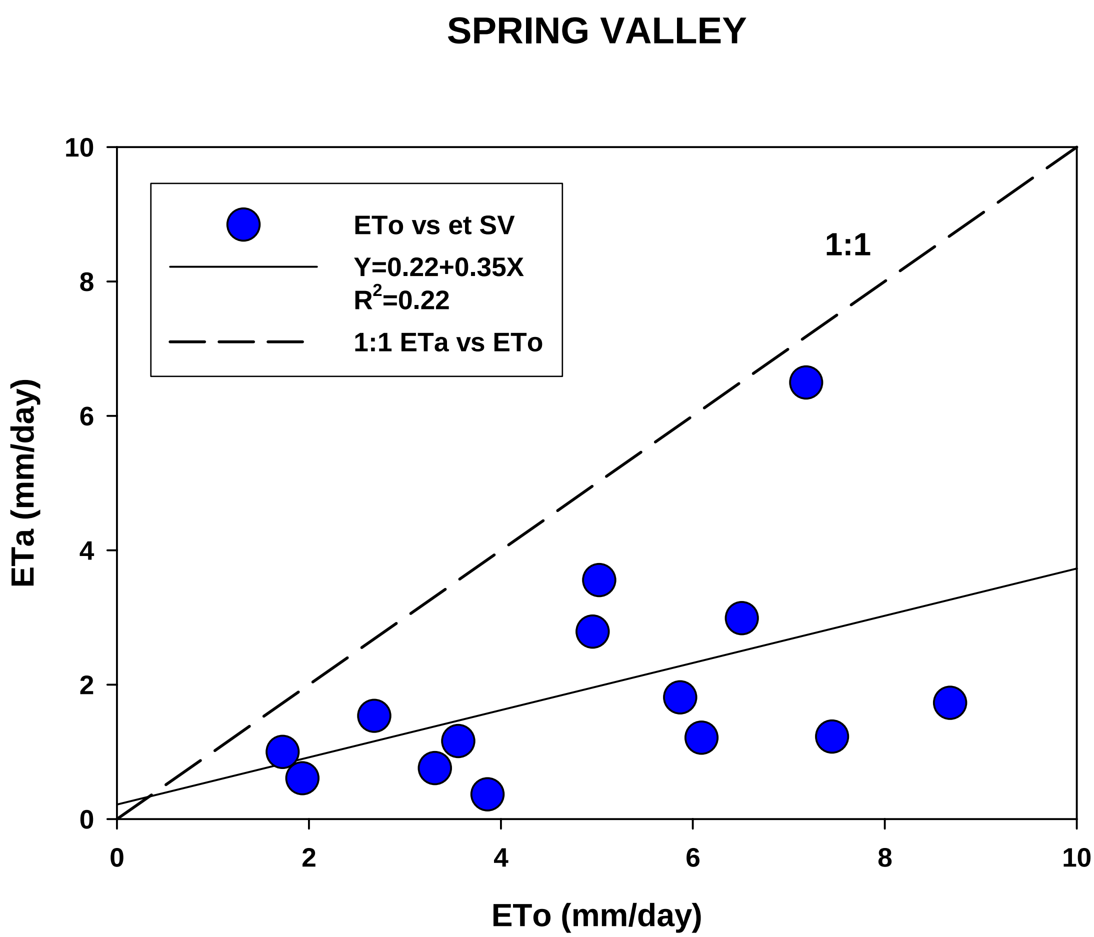


FIGURE 12

ETa vs. ETo measured at the SV2 site for all Landsat collection dates.

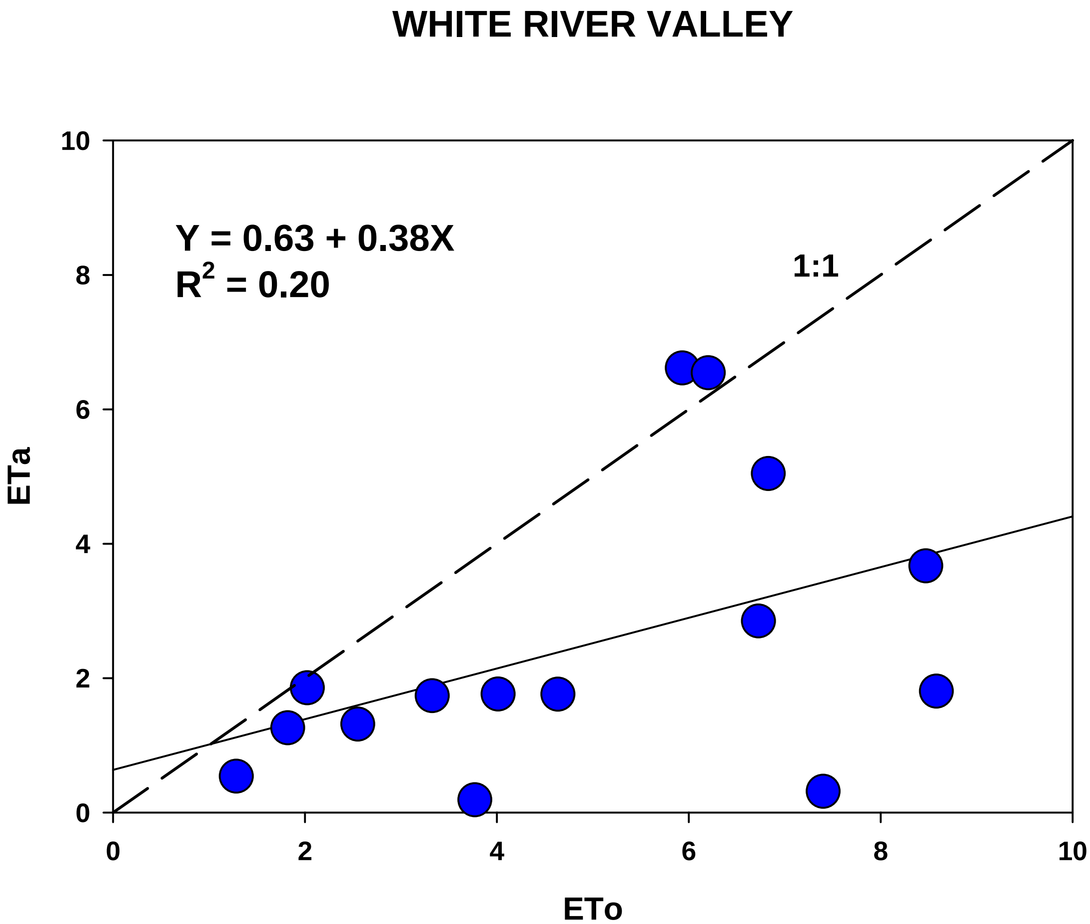


FIGURE 13

ETa vs. ETo measured at the WRV2 site for all Landsat collection dates.

GREASEWOOD SPRING VALLEY 3-31-05

FIGURE 14

GREASEWOOD SPRING VALLEY 4-14-05

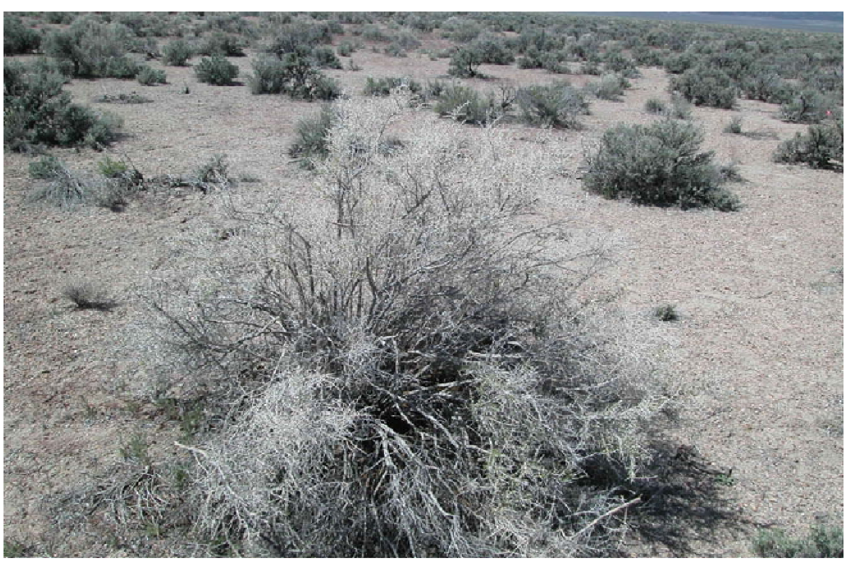


FIGURE 15

GREASEWOOD SPRING VALLEY 5-03-05

FIGURE 16

GREASEWOOD SPRING VALLEY 9-23-05

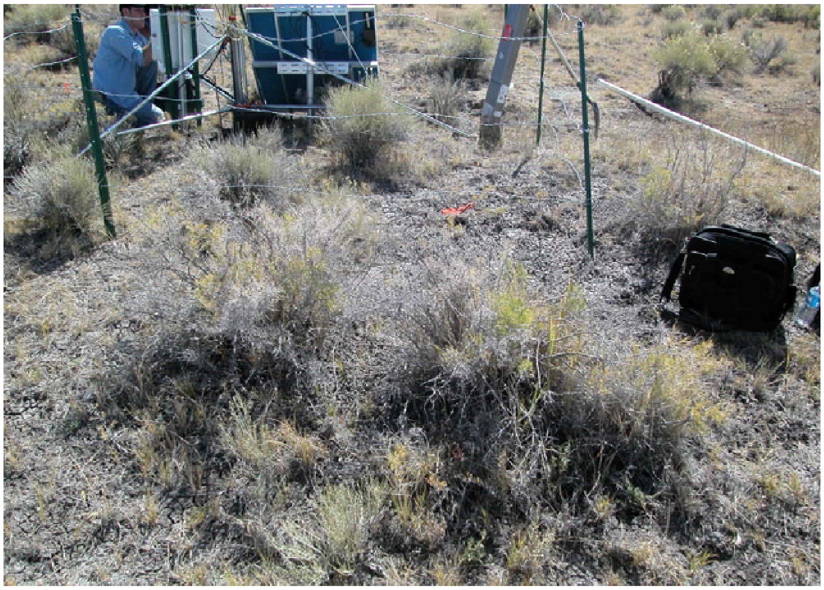


FIGURE 17

GREASEWOOD WHITE RIVER VALLEY 3-31-05

FIGURE 18

GREASEWOOD WHITE RIVER VALLEY 4-14-05

FIGURE 19

GREASEWOOD WHITE RIVER VALLEY 5-05-05

FIGURE 20

GREASEWOOD WHITE RIVER VALLEY 9-23-05

FIGURE 21

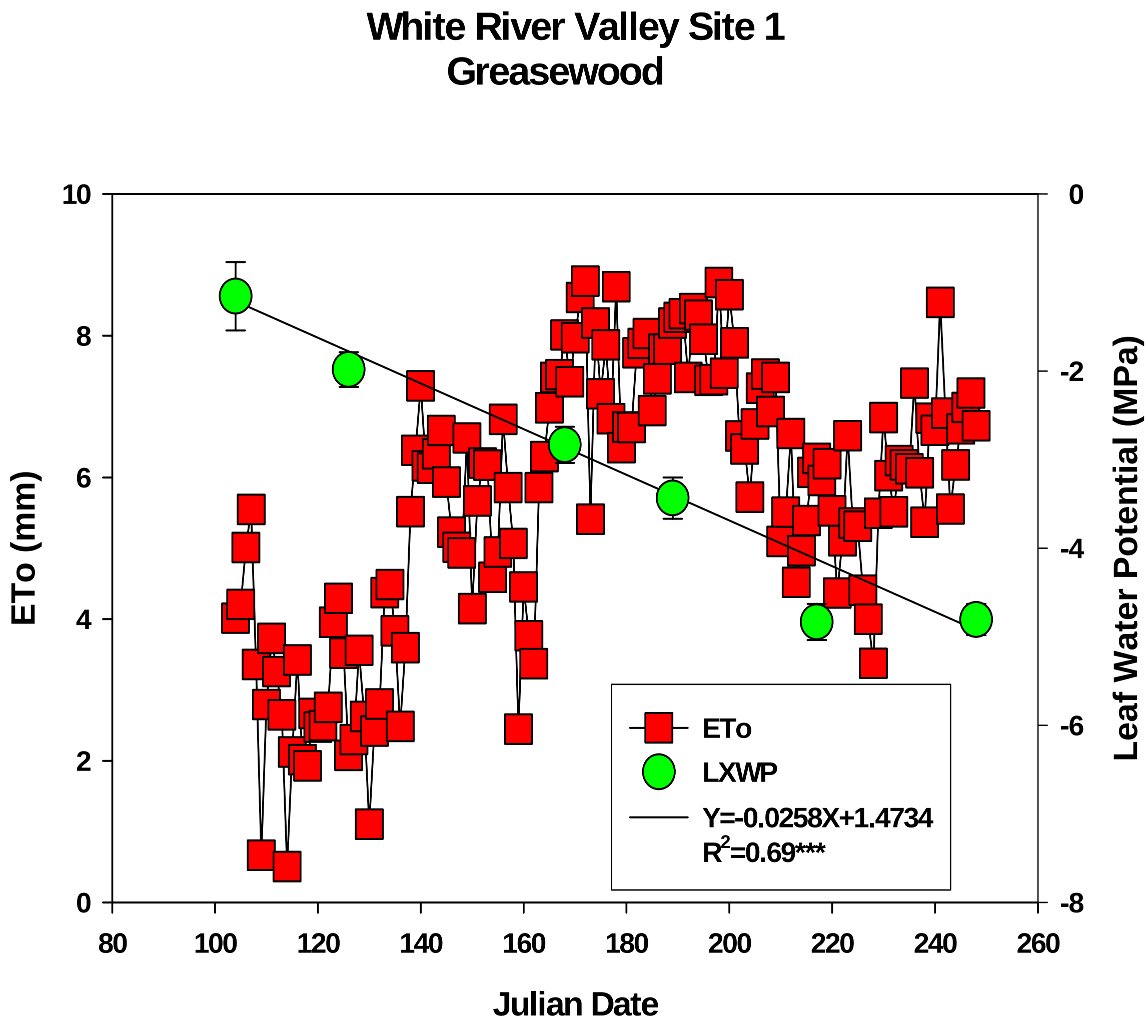


FIGURE 22

ET_o and leaf water potential during the 2005 growing period in White River Valley.

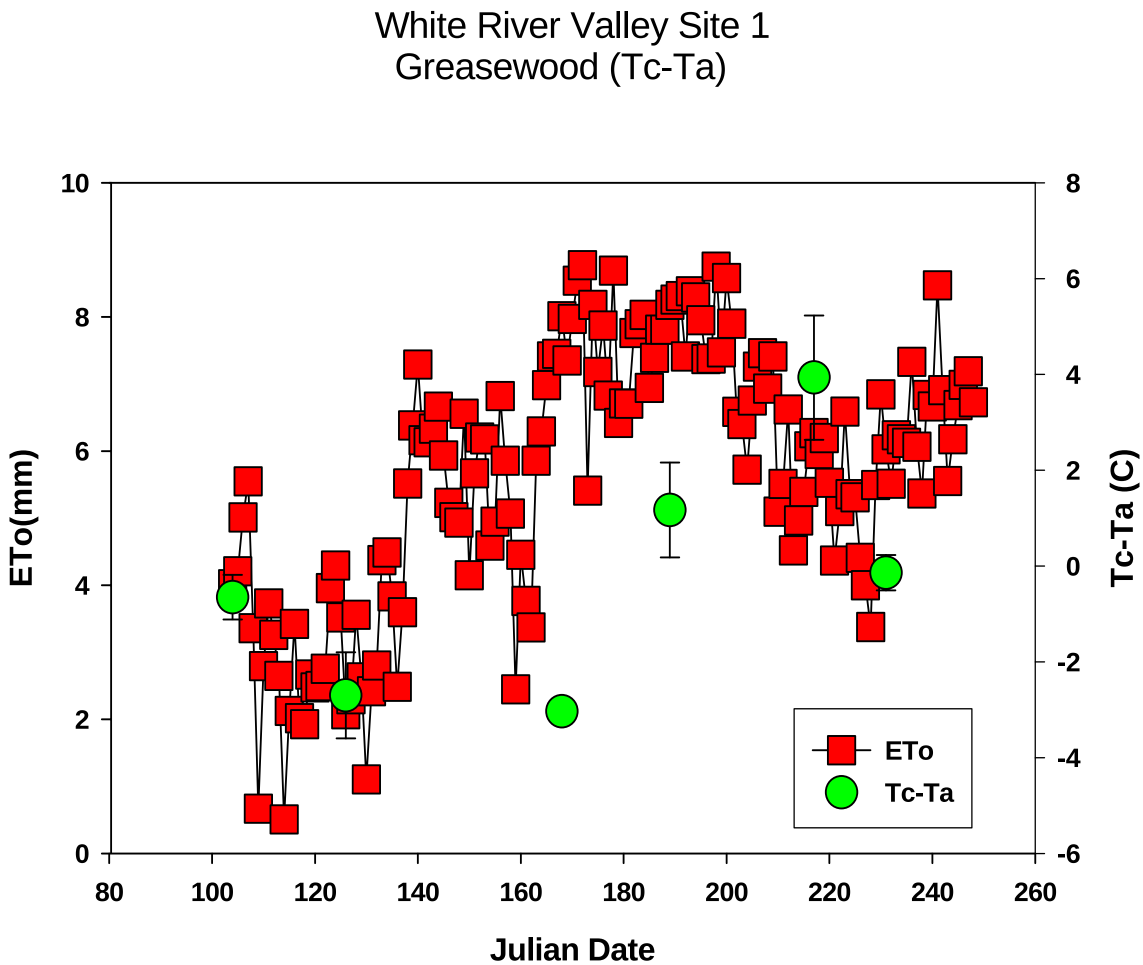


FIGURE 23

ETo and canopy temperature differentials (Tc-Ta, where Tc is canopy temperature in ^{o}C and Ta is ambient temperature in ^{o}C).

WHITE RIVER VALLEY

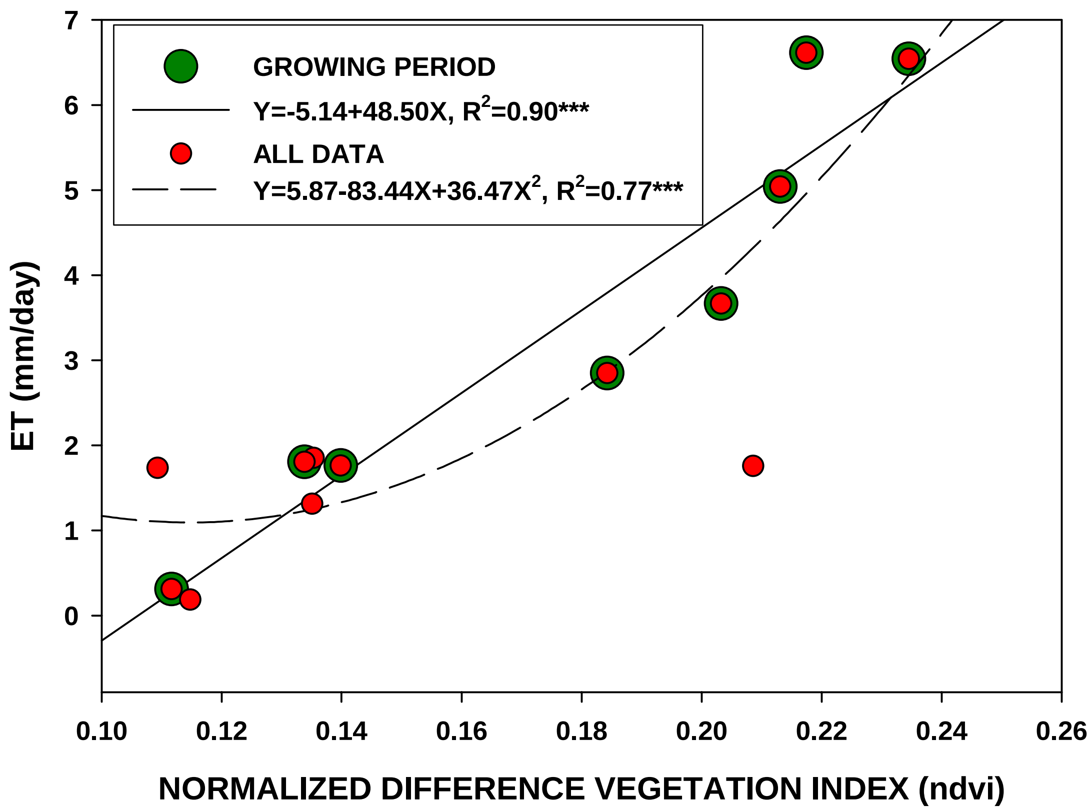


FIGURE 24

SPRING VALLEY

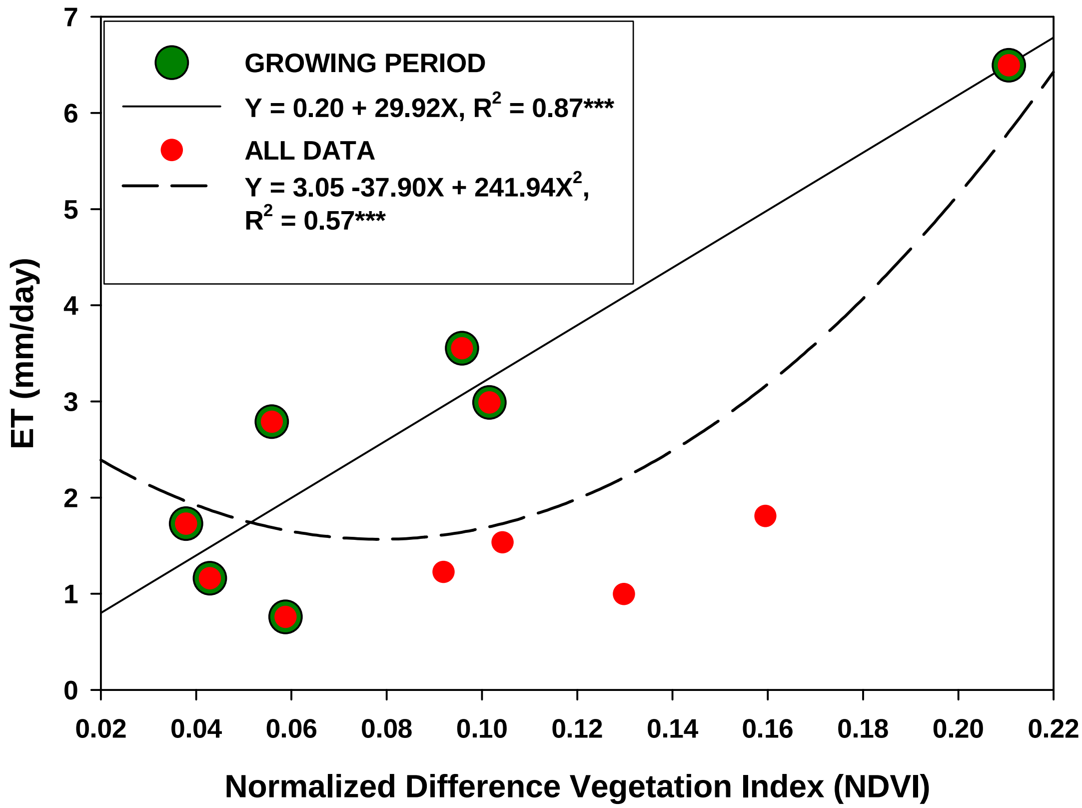
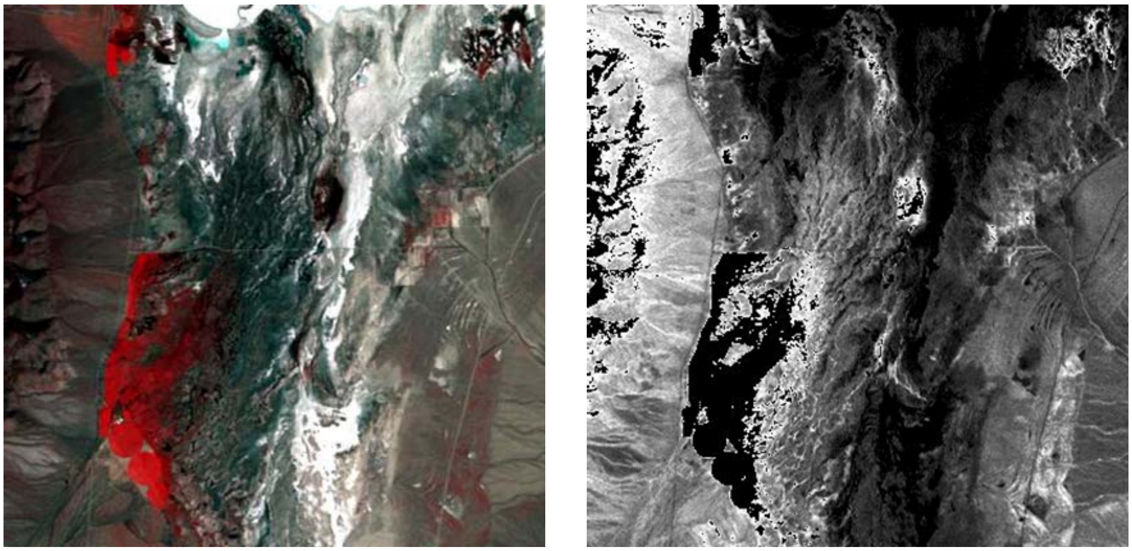


FIGURE 25

SPRING VALLEY FALSE
COLOR COMPOSITE IMAGE

FILTERED ET MAP

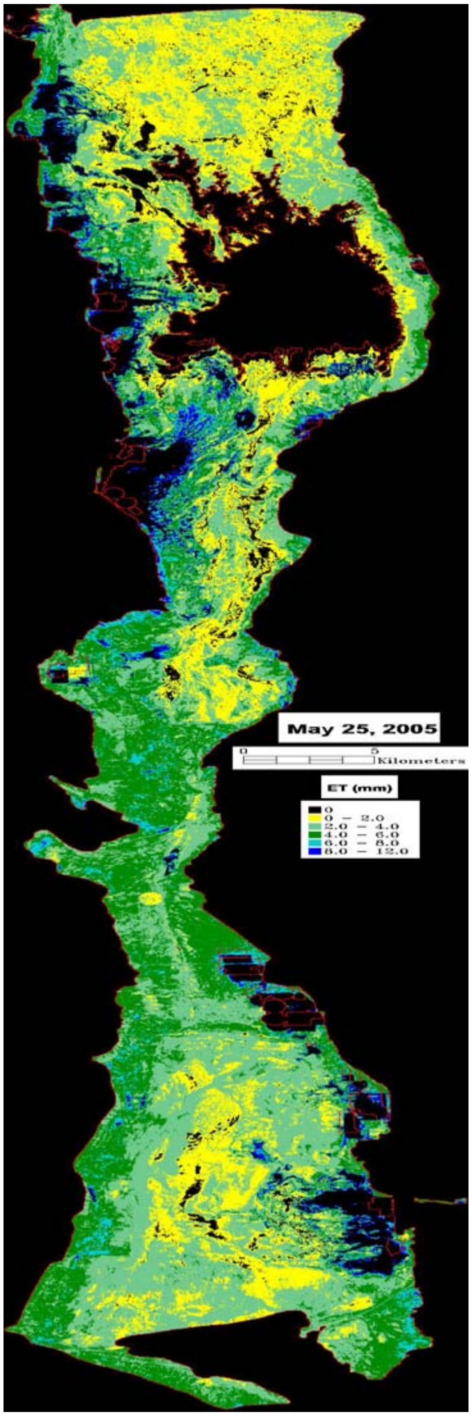


IRRIGATED AG LAND IN RED

AG LAND EXCLUDED
FROM ET ESTIMATE

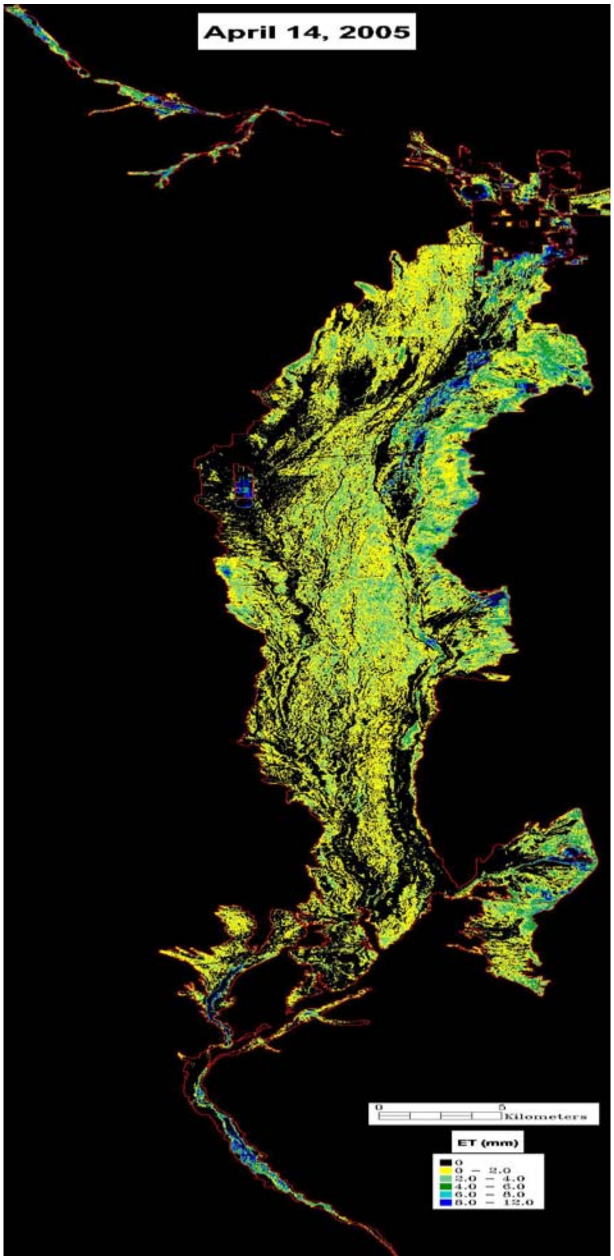
FIGURE 26

Image processing to remove agricultural land, playas and open bodies of water. Images shown above indicate the steps used in removing agricultural land.



Spring Valley ET_a Map
For May 25, 2005

FIGURE 27



White River Valley
ET_a Map for
May 14, 2006

FIGURE 28

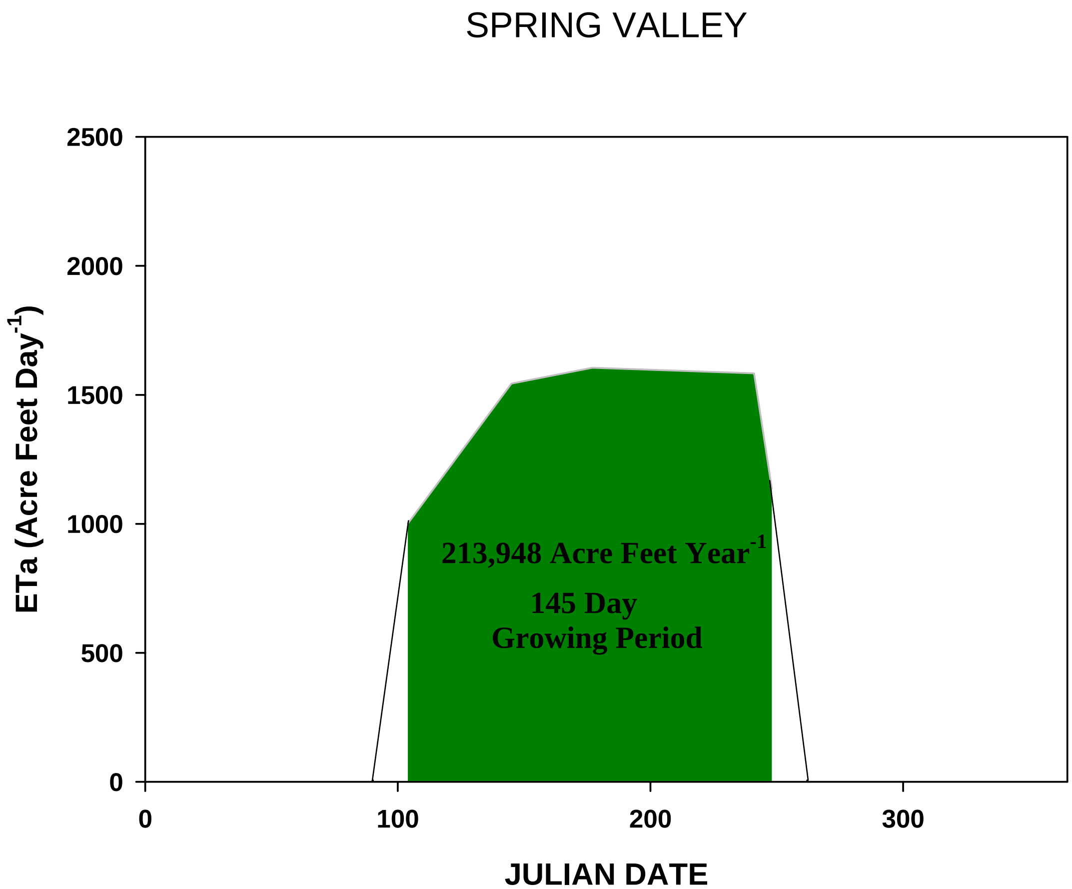


FIGURE 29

2005 growing period defined based on visual observations. However, ET_a was based on Landsat images. Tails to the ET_a curve would exist. A conservative estimate would be to add a 14 day period to the beginning and end of the growing period. Such an addition would add 14,303 AF to the total, raising the ET_a total to 228, 329 AFY.

WHITE RIVER VALLEY

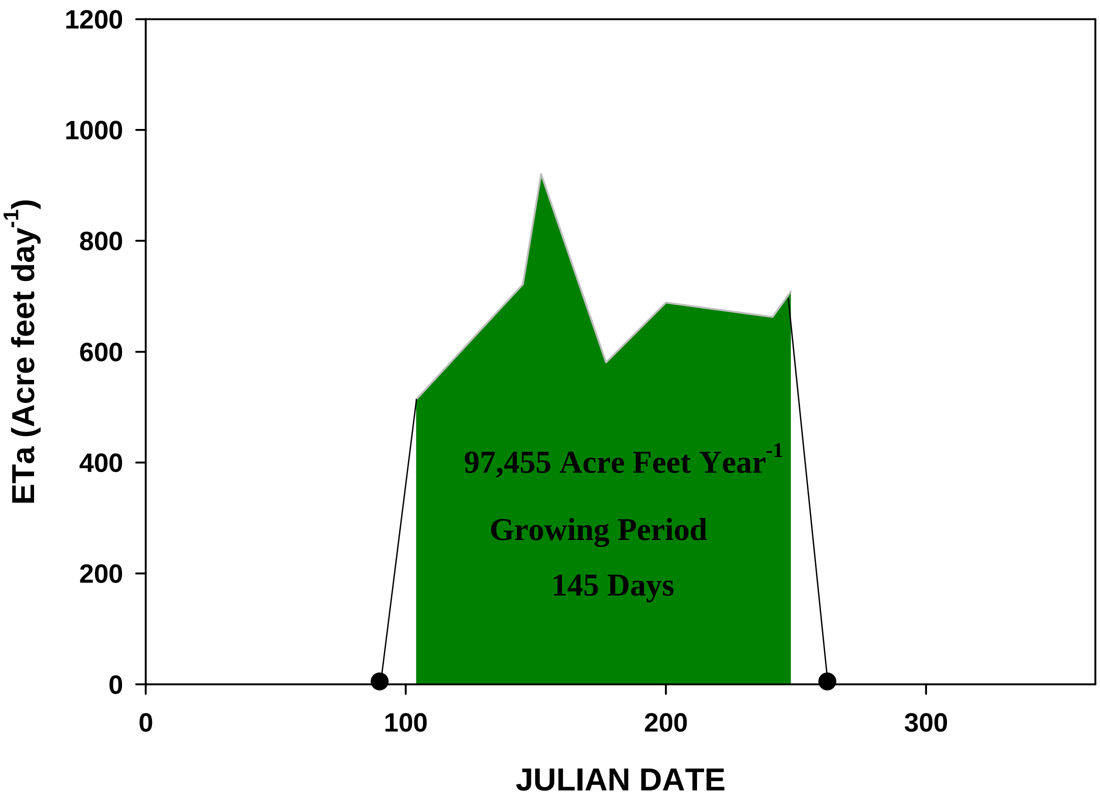


FIGURE 30

2005 growing period defined based on visual observations. However, ET_a was based on Landsat images. Tails to the ETa curve would exist. A conservative estimate would be to add a 14 day period to the beginning and end of the growing period. Such an addition would add 8,557 AF to the total raising the ET_a total to 106, 012 AFY.