Technical Memo

To: Jeff Johnson and Sean Collier, Southern Nevada Water Authority
From: Justin Huntington, Charles Morton, Matt Bromley, Ryan Liebert, Desert Research Institute
Date: June 4, 2013
Re: Analysis of Evapotranspiration for the Muddy River Springs Area

Purpose and Scope

This technical memo provides estimates of evapotranspiration (*ET*) for the Muddy River Springs area from 2001-2012. This work is part of a larger effort toward mapping historical *ET* along the Muddy River and Muddy River Springs (Figure 1) utilizing surface energy balance and vegetation indices from 2001-2012. The Muddy River Springs focused study area (Figure 2) primarily consists of pasture grass, mesquite trees, cotton woods, palm trees, and several species of vines (DeMeo et al., 2008). Previous studies have estimated *ET* in the Muddy River Springs area using a water budget approach (Eakin 1964; 1966), and more recently with *ET* station measurements and remote sensing (DeMeo et al., 2008). This study builds on previous work, and attempts to identify trends in *ET* over the study period of 2001-2012 to identify potential impact on *ET* due to land management and vegetation changes.

Surface Energy Balance and Vegetation Index Approaches

Surface energy balance estimates are made in this study using the Mapping EvapoTranspiration at high Resolution with Internalized Calibration, METRIC, model (Allen et al., 2007). METRIC relies Landsat imagery and locally collected meteorological data to calculate actual *ET*. METRIC recently has been applied by state and federal agencies to estimate ET from rainfed and irrigated vegetation in Nevada, New Mexico, Oregon, Wyoming, Montana, Nebraska, and Colorado (Hendrickx, 2010; Kjaersagaard and Allen, 2010; Sullivan et al., 2011; Snyder et al., 2012). This study also applies a vegetation index reference ET fraction approach to estimate actual *ET* in the Muddy River Springs area similar to Allen et al. (2011), Tasumi and Allen (2007), and Singh and Irmak (2009).

Methods

Estimating actual *ET* required numerous weather data and image processing steps that are briefly described below. Landsat 5 Thematic Mapper (TM) and 7 Enhanced Thematic Mapper Plus (ETM+) images were acquired for the study period of 2001-2012 from the U.S. Geological Survey (USGS) Global Visualization web page (http://glovis.usgs.gov/) totaling 323

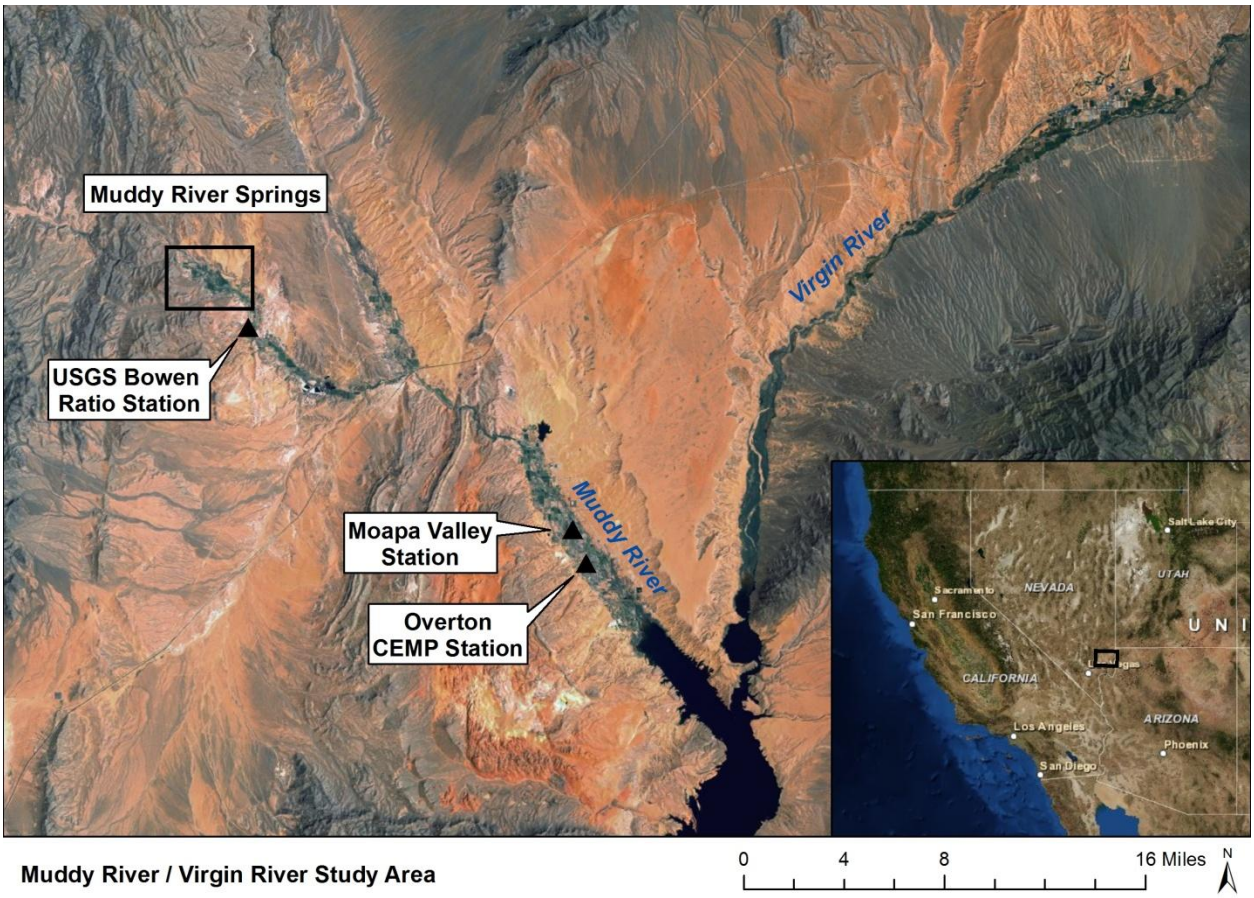

Figure 1. General study area with highlighted Muddy River Springs area.

images (Table A1). Landsat data processing was handled using Python scripts, many of which are described in Morton (2013). General processing steps include performing radiometric and atmospheric corrections using the Landsat Ecosystem Disturbance and Adaptive Processing System (LEDAPS) (Masek et al., 2006) to compute at surface reflectance, with following computations of the Normalized Difference Vegetation Index (NDVI), surface temperature, albedo, and various energy balance components following Allen et al. (2007) and Morton et al. (2013). The land surface energy balance is simulated by METRIC as

$$LE = R_n - H - G$$

where LE is latent heat flux (W/m^2), R_n is net radiation (W/m^2), H is sensible heat flux (W/m^2), and G is ground heat flux in (W/m^2). The reader is referred to Allen et al. (2007) and Morton et al. (2013) for detail on METRIC and how each component of the energy balance is computed from Landsat data. Once LE is computed for each pixel, the equivalent amount of instantaneous ET (mm/hr) is computed by dividing by the latent heat of vaporization (λ). Instantaneous ET at the time of the Landsat image is estimated over the day as

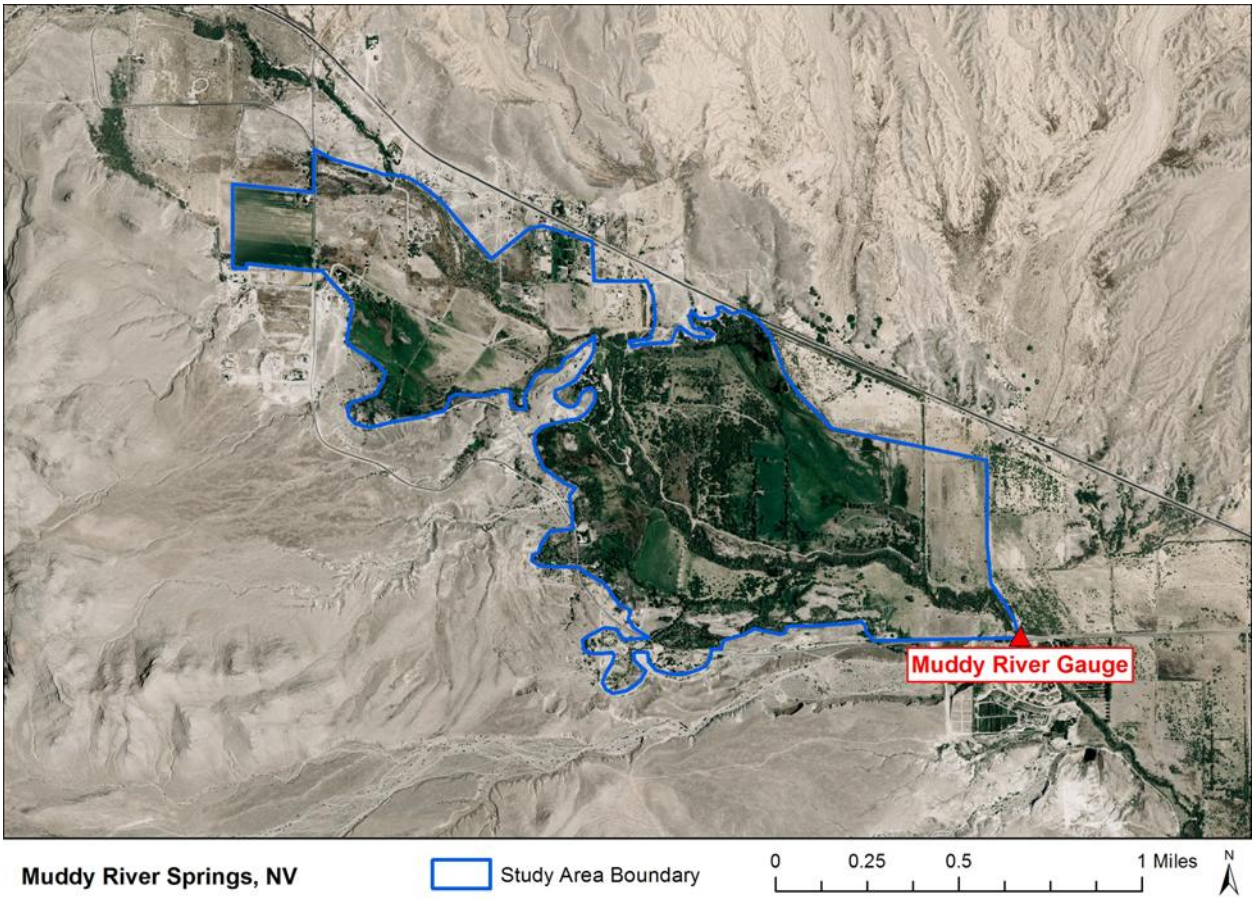

Figure 2. Warm Springs (Muddy River Springs) study area for estimating ET from 2001-2012.

$$ET_{24} = (ET_{inst} / ET_r) * ET_{r24}$$

where the ratio of ET_{inst} (mm/hr) to ET_r (mm/hr) is the reference ET fraction (ET_rF) measured at the satellite overpass time and ET_{r24} is the cumulative ET_r for the day (mm/day). Seasonal total *ET* is estimated by linearly interpolating the daily ET_rF per pixel in between Landsat images, and multiplying daily ET_rF pixel values by the ET_{r24} for respective days. The reference *ET* fraction is commonly referred to as the crop coefficient. In this method, the computation and application of ET_rF simulates vegetation growth stages and phenology changes, roughness of the vegetation surface to account for turbulent effects, and vegetation geometry. Simply put, the effects of weather are incorporated into ET_r, whereas the effects that distinguish vegetated and bare surfaces from the reference surface are integrated into the ET_rF (Allen et al., 1998). There are many physiological and physical variables that determine *ET*, and the ET_r*ET_rF method incorporates the majority of these variables (Bos et al., 2008).

The vegetation index reference *ET* fraction approach is similar to the METRIC surface energy balance approach for estimating *ET* through time, but ET_rF is derived from the NDVI instead of an instantaneous surface energy balance. The reason for applying both approaches is due to the fact that it currently requires a relatively large amount of time and effort to process METRIC for multiple years, whereas it requires significantly less time and effort to compute

NDVI. Heilman et al. (1982) proposed a linear relationship between a vegetation index and fraction of reference ET, and has been supported by various other studies (Choudhury et al., 1994; Tasumi et al., 2005; Tasumi and Allen, 2007; Singh and Irmak, 2009; Calera-Belmonte et al., 2005). If no local calibration data exists, Allen et al. (2011) suggests that ET_rF can be generally estimated as

$$ET_rF = 1.25 * \text{NDVI}$$

where ET_rF is the relative fraction of the alfalfa reference ET. NDVI is defined as

$$\text{NDVI} = (\rho_{\text{NIR}} - \rho_{\text{Red}}) / (\rho_{\text{NIR}} + \rho_{\text{Red}})$$

where ρ is the at-surface reflectance, *NIR* is near infrared waveband from 0.76 to 0.90 µm, *Red* is the visible waveband from 0.63 to 0.69 µm. The relationship suggested by Allen et al. (2011) was modified in this work to more accurately represent the conditions specific to the study area using METRIC derived ET_rF and NDVI for all pixels in the Muddy River Springs study area (Figure 2). Seasonal average slopes between ET_rF and NDVI for 2006-2012 were found to vary between 1.21 and 1.37, with an average of 1.30, and intercepts ranging from 0.02 to 0.1, with an average of 0.06, and R^2 values ranging from 0.66 to 0.80, with an average of 0.74. Figure 3 illustrates an example of the correlation between ET_rF and NDVI for 2006. The fairly large scatter exists due to the fact that NDVI is not capable of detecting evaporation from wet soil due to irrigation, where METRIC is able to detect soil evaporation using the Landsat derived surface temperature, which results in high ET_rF and low NDVI. Additionally, NDVI is not able to detect acute vegetation stress due to water limitations, whereas the use of surface temperature in METRIC detects this acute water stress, which results in relatively high NDVI and low ET_rF due to low predicted evaporation by METRIC. While the use of NDVI does have limitations, for the sake of simplicity and providing the ability to estimate changes in *ET* for years before 2006 over the Muddy River Springs area, the equation

$$ET_rF = 1.30 * \text{NDVI} + 0.06$$

was applied in this work over the Muddy River Springs area to all cloud free Landsat 5 TM and 7 ETM+ images from 2001-2012 period (Table A1). A typical annual time series of spatially averaged NDVI from 2006 is illustrated for the Muddy River Springs study area in Figure 4, where greenup and senescence periods are clearly evident. Once NDVI is transformed into ET_rF at each pixel, ET_rF is linearly interpolated per pixel in between Landsat image dates, and then multiplied by the ET_r, ET_rF, to estimate *ET*.

Reference ET (ET_r) Estimates

Hourly weather data of solar radiation, air temperature, dewpoint temperature, and windspeed collected at SNWA's Moapa agricultural weather station and DRI's Overton Community Environmental Monitoring Program (CEMP) weather station (Figure 1) were downloaded and quality assured and controlled (QAQCed) according to Allen et al. (1996).

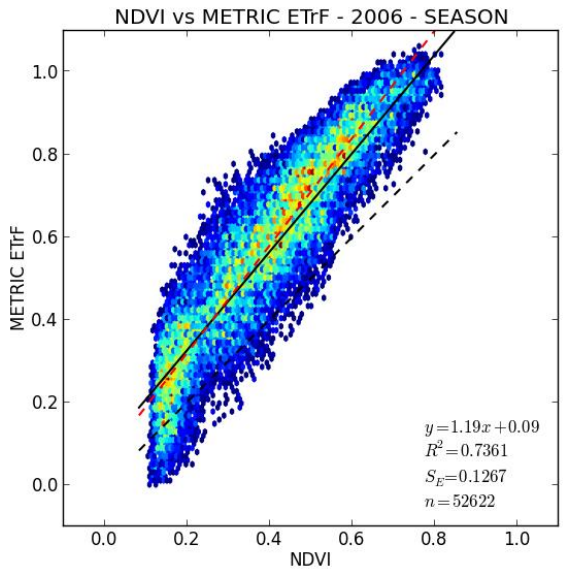

Figure 3. Scatter plot of ET_rF and NDVI for the 2006 growing season (February-November). Colors of the scatter plot represent point density where red is high density, and blue is low density. The red hatched line is the average regression line used to compute ET_rF from NDVI in this study, and the black hatched line is the 1:1 line.

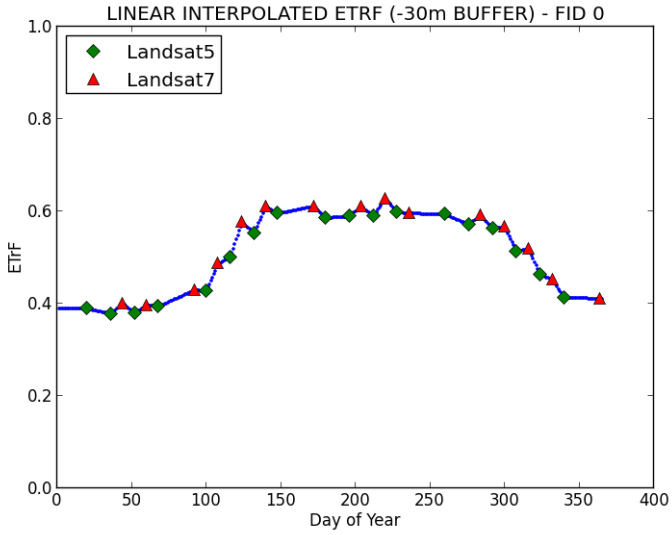

Figure 4. Time series of NDVI derived ET_rF for 2006 spatially averaged over the Muddy River Springs area shown in Figure 2. Interpolation of ET_rF in between Landsat image dates occurs on a pixel by pixel basis; however, this figure shows interpolation ET_rF averaged over the study area simply for illustrative purposes.

Overton CEMP weather data was analyzed from 2001-2012, and SNWA Moapa weather data was analyzed from 2010-2012, the available period of record for Moapa. Following adjustment procedures outlined in Allen et al. (1998) and Allen et al. (2011a), reported windspeed measured at respective measurement heights were logarithmically transformed to 2m height equivalent windspeed estimates, as required for input into the ASCE standardized reference ET equation. Windspeed measurement heights are 2.3m and 6m (7.5ft and 20ft) at the Moapa and Overton stations, respectively. Many years of solar radiation (R_s) measurements required some level of correction to better match clear sky solar radiation curves (R_{so}). Such needed corrections are common due to pyronometer sensor calibration drift (Allen, 1996). Figure 5 illustrates raw and corrected R_s from the Overton CEMP station. In this case it is evident that sensor calibration is in error due to the fact that measured R_s over a day never reaches the theoretical R_s that would occur for a clear sky day (R_{so}). Overton CEMP hourly solar radiation data was found to be corrupt from 2011 and 2012 and the data were not salvageable. Therefore, Moapa QAQCed hourly R_s was used to fill Overton CEMP hourly R_s for years 2011 and 2012. After QAQC was completed, ET_r was computed for both stations utilizing the standardized reference ET equation (ASCE-EWRI, 2005) for an alfalfa reference surface using the Ref-ET program (Allen, 2011).

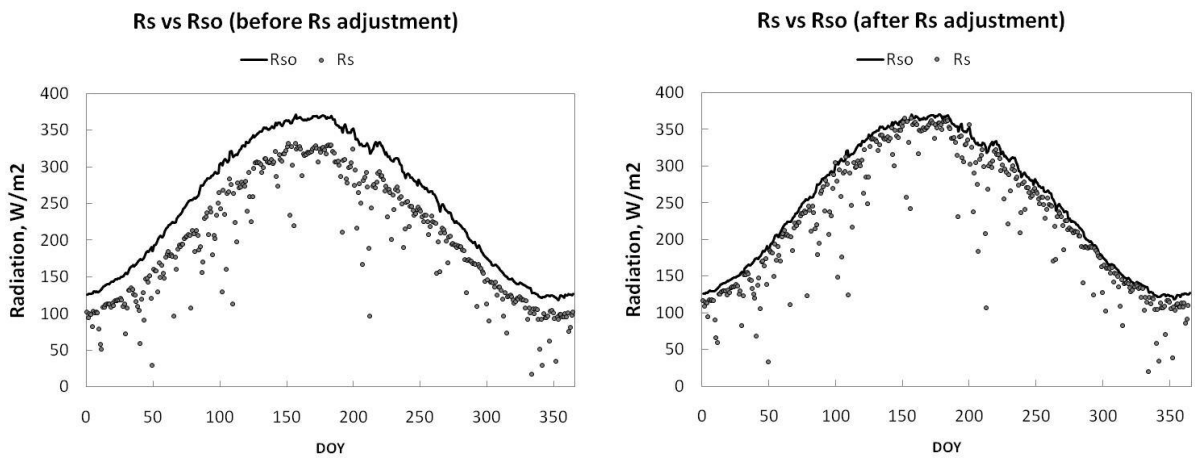

Figure 5. Overton CEMP 2007 measured solar radiation (R_s) (left), and corrected solar radiation to the theoretical clear sky solar radiation (R_{so}) (right) following recommendations of Allen (1996). Solar radiation corrections are typically needed due to pyronometer calibration drift, as is evident in this figure.

Because the desired study period was from 2001-2012 and Moapa weather data was only available from 2010-2012, a comparative analysis between Overton and Moapa computed ET_r was completed to potentially develop ET_r adjustment factors for Overton computed ET_r to simulate Moapa ET_r from 2001-2010. Figures 6 and 7 illustrate monthly ET_r computed from Overton and Moapa weather data for 2010-2012. It is evident that ET_r is nearly the same for most months, even though the Overton CEMP station is not located in an optimal reference environment that reflects the climate of agricultural and active *ET* conditions. As previously discussed, 2011 and 2012 Moapa R_s was substituted for Overton R_s, however, from inspection

of Figure 6 it is evident that 2011 Moapa ET_r is lower than Overton ET_r during mid-summer months. After investigating the potential cause of this difference, it was found that, raw, pre-QAQCed hourly windspeed for the Moapa station was often zero at night and during some hours of the day. In comparing windspeed between Moapa and Overton for 2010 and 2012, it was found that Overton 2m equivalent windspeed was typically lower than Moapa, except for this mid-summer period of 2011, where Moapa was lower than Overton. Due to the consistency of Overton having lower 2m equivalent windspeed in all months except for these three mid-summer months, and the fact that there were many reported zero values, it was assumed that the Moapa measured windspeed was in error for this period.

Due to the nearly identical computed ET_r between Overton and Moapa, Overton computed ET_r was utilized in this work to estimate *ET* using METRIC and NDVI-ET_rF approaches from 2001-2009, and 2011, while Moapa computed ET_r was used to estimate *ET* for 2010 and 2012. Growing season (February-November) and annual ET_r from 2001-2012 is illustrated in Figure 8 where it is evident that ET_r has generally decreased from 2001. This is significant, because any decreasing trends in ET_r will cause decreasing trends in *ET*. This result was cause for concern due to possible sensor drift and or data quality, therefore, an analysis was conducted to investigate if any trends were present in driving ET_r weather variables of solar radiation, temperature, dewpoint, and windspeed. While the analysis showed slight decreasing trends in annual averages, a more focused analysis was conducted for warm season months of May-September, since most of the annual *ET* occurs during these months. Results of the warm season trend analysis indicate that warm season average daily maximum and minimum temperatures, windspeed, and solar radiation all have decreasing trends from 2001-2012, while warm season average daily minimum temperature minus dewpoint temperature (i.e. dewpoint depression) is rising during this same period, indicating drying conditions (Appendix Figures A1-A5).

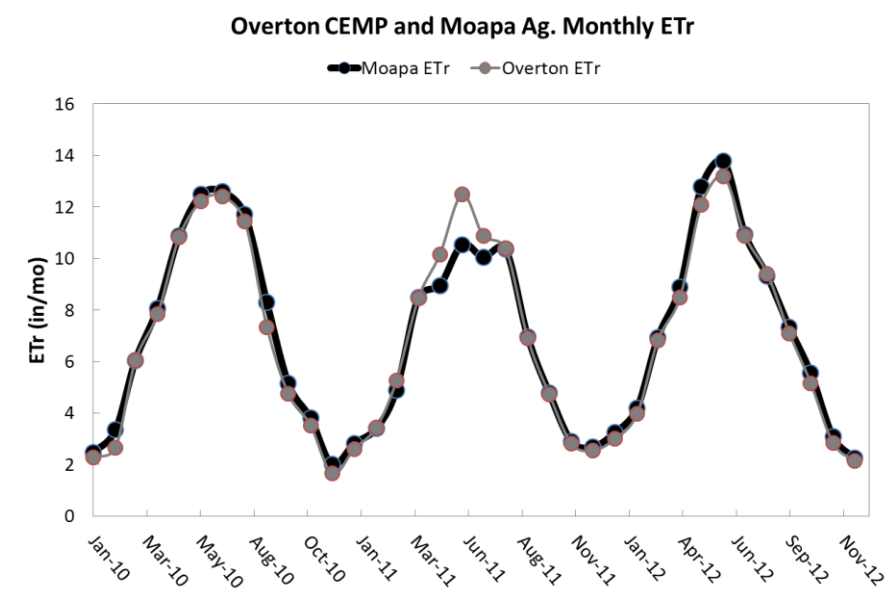

Figure 6. Monthly time series comparison of ET_r from Overton CEMP and Moapa agricultural weather stations

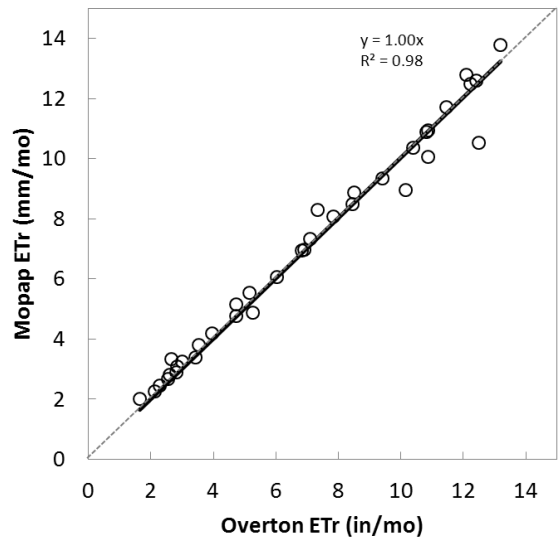

Figure 7. Scatter plot comparison of monthly ET_r from Overton CEMP and Moapa agricultural weather stations.

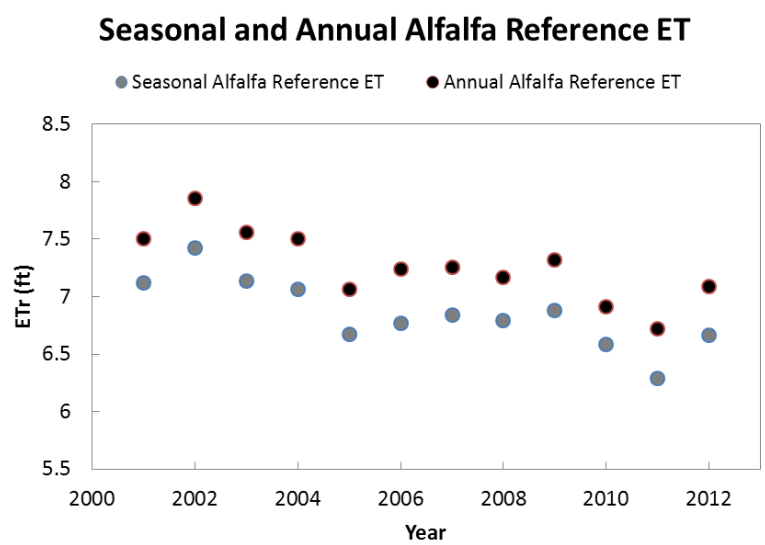

Figure 8. Seasonal (February – November) and annual ET_r from 2001-2012. As illustrated, ET_r has generally decreased over the study period of 2001-2012.

To confirm that these trends are real and not an artifact of possible weather station sensor drift, weather data from the closest weather station measuring temperature and windspeed was acquired and analyzed over the same period for warm season months of May-September. Results indicate very similar trends, where warm season average daily maximum and minimum temperatures and windspeed exhibit decreasing trends from 2001-2012, and warm season average daily minimum temperature minus dewpoint temperature is rising during the same period (Appendix Figures A6-A9). The comparative weather variable trend analysis between Overton and Nellis weather stations suggests that the trend in Overton computed ET_r from 2001-2012 is likely real and not artificial, and thus thought to be valid.

Evapotranspiration Estimates

Annual and seasonal *ET* from the Muddy River Springs study area was estimated using METRIC and the NDVI approaches, as previously described, by utilizing all available and cloud free images during each year from 2001-2012 (listed in Table A1). Mechanically, for both approaches, ET_rF is estimated for each image date and linearly interpolated, per pixel, in between image dates, and then multiplied by the respective daily reference *ET* (ET_r), to estimate the daily *ET*. Graphically, Figure 4 illustrates interpolation of ET_rF in between image dates for the Muddy River Springs area. Figure 9 illustrates respective ET_r, and the product of Figure 4 and Figure 9 for respective days results in estimated daily *ET* for 2006, shown in Figure 9. The use of ET_r to estimate *ET* in between image dates is critical for properly accounting for daily variations in atmospheric water demand (i.e., solar radiation, windspeed, temperature, humidity), and resulting impacts on *ET*. The translation of the daily variability in ET_r to *ET* can be seen in Figure 9, a process that would be missing, and in error, if *ET* were to be simply interpolated in between image dates (shown as green triangles on right panel of Figure 9).

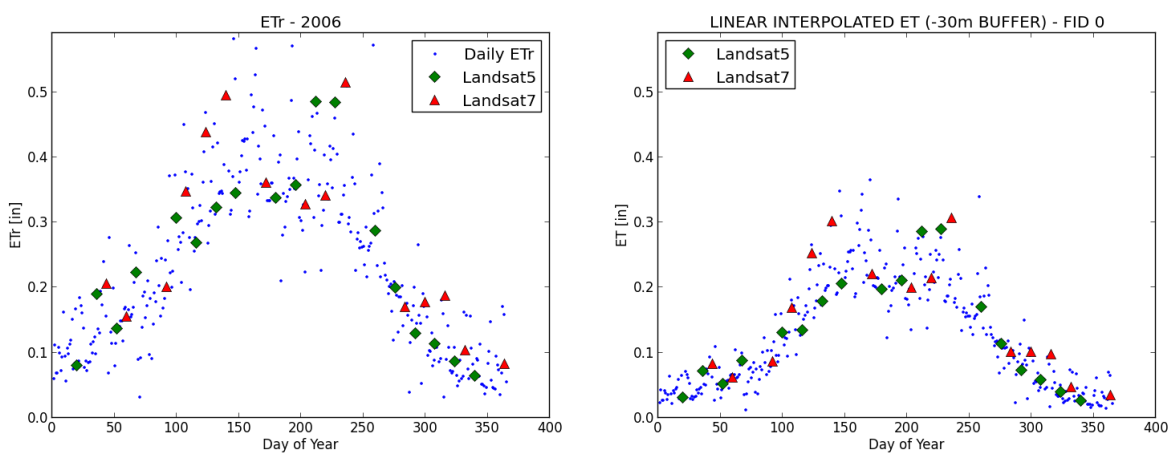

Figure 9. Daily reference *ET*, ET_r, (left) is multiplied by daily interpolated ET_rF (shown in Figure 4) to estimate daily *ET* for 2006 (right).

Seasonal (February-November) and annual *ET* totals were estimated utilizing METRIC from 2006-2012 and NDVI from 2001-2012, and results are shown in Figure 10 and Figure 11. A slight decrease in METRIC estimated *ET* is noticeable, however, this is largely due to the decrease in ET_r over this period, as the ratio of METRIC *ET* to ET_r (ET_rF) is fairly stable, as shown in Figure 12. The trend in NDVI estimated *ET* from 2001-2012 is more pronounced. The ratio of NDVI estimated *ET* to ET_r (ET_rF) is also fairly stable for 2006-2012, but decreases over the entire study period of 2001-2012 (Figure 13). Because *ET* is a function of precipitation (*PPT*), and *PPT* is highly variable from year to year, normalizing *ET* by removing the influence of *PPT* is needed for trend analysis. To accomplish this, annual *PPT* was subtracted from seasonal and annual METRIC and NDVI estimated *ET*. Monthly and annual *PPT* totals for the Muddy River Springs area were estimated from 2001-2011 using 800m spatial resolution PRISM data (Daly et al., 1994) for a single pixel within the study area to remove potential elevation biases from spatial averaging multiple pixels that fell outside the study area. A comparison between measured *PPT* at the Overton COOP station and estimated PRISM *PPT* for a single pixel at the Overton COOP station location is shown in Figure 14, where the correspondence between COOP measured and PRISM estimated *PPT* is good, although this was expected since the PRISM process uses the COOP station as a control point. Missing *PPT* in the Overton COOP precipitation record was filled with *PPT* from the Overton CEMP station, which totaled 424 days from 2001-2007. A comparison was also made between the Overton COOP *PPT* and Muddy River Springs area PRISM 800m *PPT* (Figure 15). Because 800m PRISM *PPT* was not available for 2012, and effectively no bias exists between Overton COOP *PPT* and 800m PRISM *PPT* for the Muddy River Springs area, Overton COOP monthly *PPT* was used for the Muddy River Springs area for 2012.

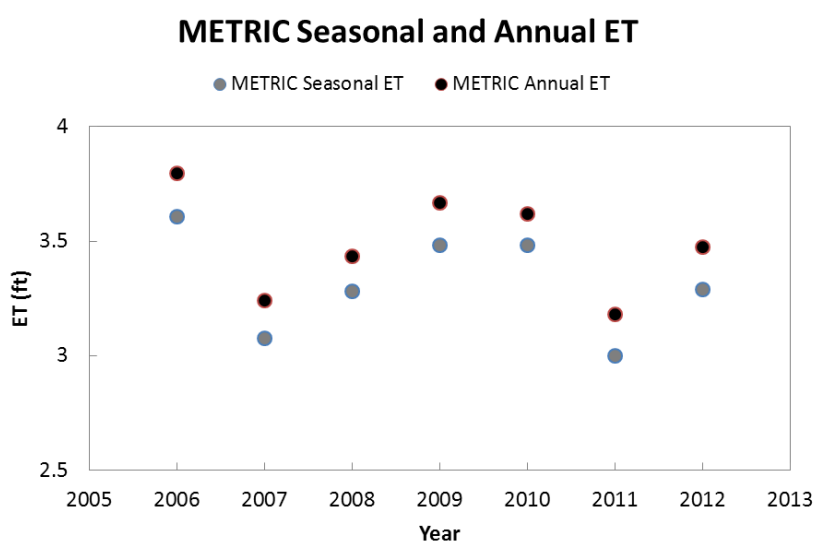

Figure 10. Seasonal and annual METRIC derived *ET* from 2006-2012. Seasonal totals are for the growing season, estimated to be February-November.

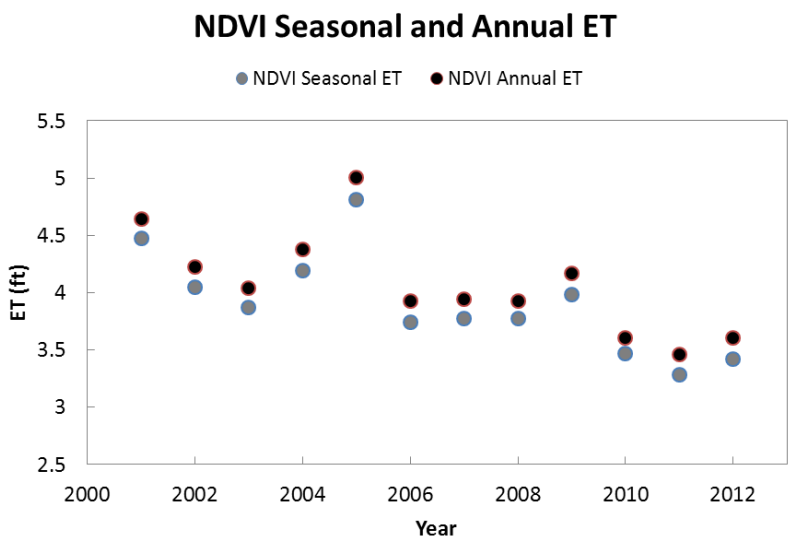

Figure 11. Seasonal and annual NDVI derived *ET* from 2001-2012. Seasonal totals are for the growing season, estimated to be February-November.

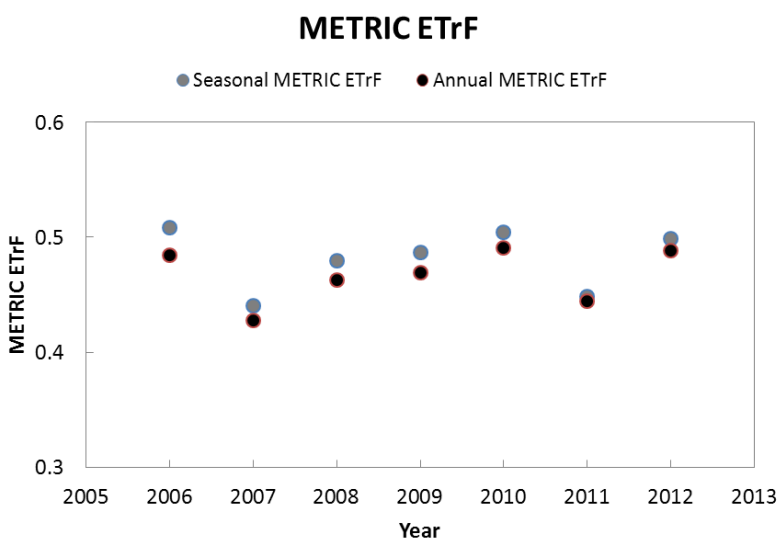

Figure 12. Seasonal and annual METRIC derived ET_rF from 2006-2012.

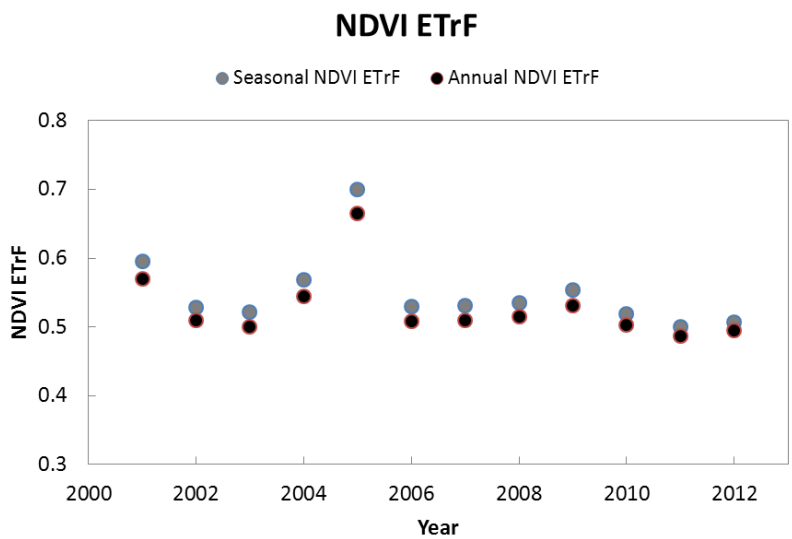

Figure 13. Seasonal and annual NDVI derived *ET,F* from 2001-2012.

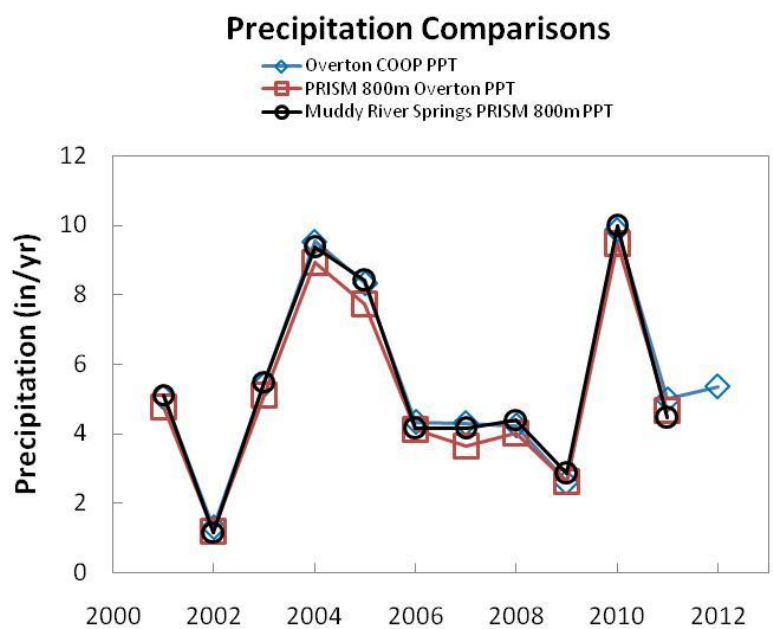

Figure 14. Comparison of Overton COOP *PPT*, 800m PRISM *PPT* for the Overton COOP location, and 800m PRISM *PPT* for the Muddy River Springs area. PRISM *PPT* at the 800m spatial resolution was not available for 2012, therefore, Overton COOP data was used due to the low bias between Overton COOP and Muddy River Springs PRISM *PPT* (Figure 15, right).

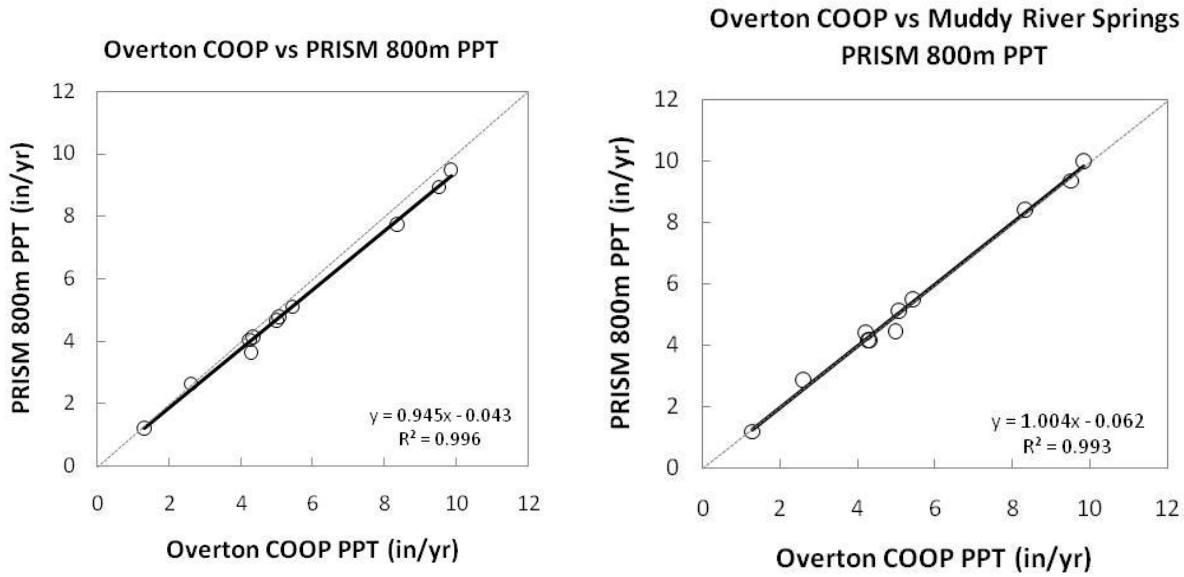

Figure 15. Overton COOP *PPT* vs. 800m PRISM *PPT* for the Overton COOP location (left), and Overton COOP *PPT* vs. 800m PRISM *PPT* for the Muddy River Springs area (right). PRISM *PPT* at the 800m spatial resolution was not available for 2012, therefore, Overton COOP data was used due to the low bias between Overton COOP and Muddy River Springs PRISM PPT.

Utilizing PRISM and COOP *PPT* estimates, seasonal and annual METRIC and NDVI estimated *ET-PPT* was computed (Figures 16 and 17). As previously mentioned, reduced *ET* over the study period is largely due to the decline in ET_r from 2001-2012, and this impact is also evident in the estimated *ET-PPT*. Both METRIC and NDVI estimated ET_rF of *ET-PPT* slightly decline over the 2006-2012 and 2001-2012 periods by 0.07 and 0.10, respectively, indicating that *ET* has declined independent of ET_r and *PPT* due to changes in vegetation and or water management in the study area (Tables A7 and A10). METRIC and NDVI annual estimated ET and ET_rF for 2006-2012 are illustrated in Figures 18 and 19, where it is evident that NDVI estimated *ET* is slightly higher than METRIC estimated *ET* (Figures 20-22). This is due to the fact that bare soil evaporation, potential vegetation stress, and changing surface conditions causes the relationship between NDVI and ET_rF for the Muddy River Springs area to be different from year to year, therefore no average regression will perform well over all years. Average annual METRIC estimated *ET* and *ET-PPT* for 2006-2012 is 3.5 ft/yr and 3.1 ft/yr, respectively. Average annual NDVI estimated *ET* and *ET-PPT* for 2006-2012 is 3.8 ft/yr and 3.4 ft/yr, respectively. For the period of 2006-2012, annual bias between NDVI and METRIC estimated *ET* and ET_rF ranges from 0 to 0.7 ft/yr, and 0.01 to 0.08, respectively, and the average annual bias is 0.32 ft/yr and 0.04, respectively (Figure 23).

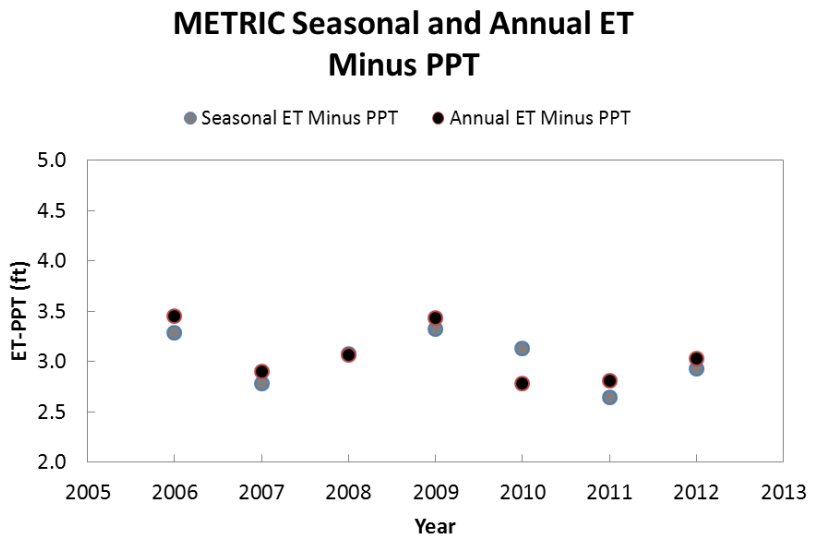

Figure 16. Seasonal and annual METRIC derived *ET-PPT* from 2006-2012.

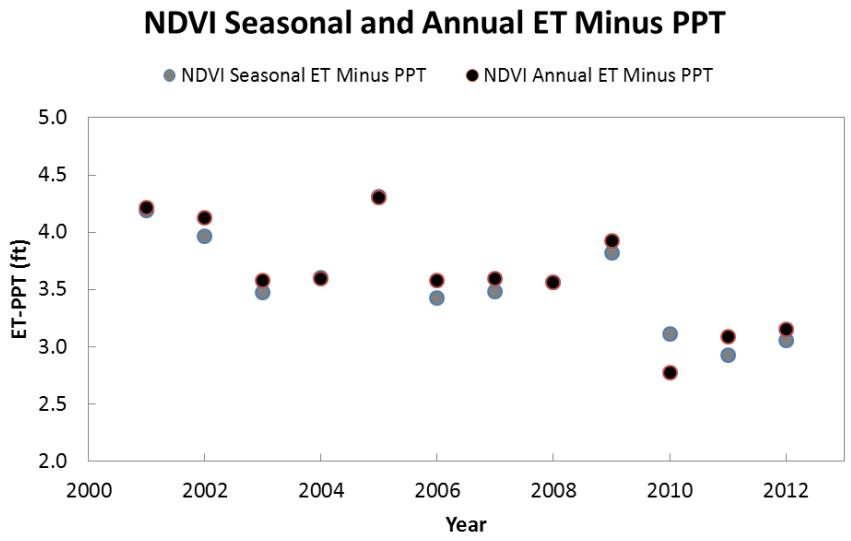

Figure 17. Seasonal and annual NDVI derived *ET-PPT* from 2001-2012.

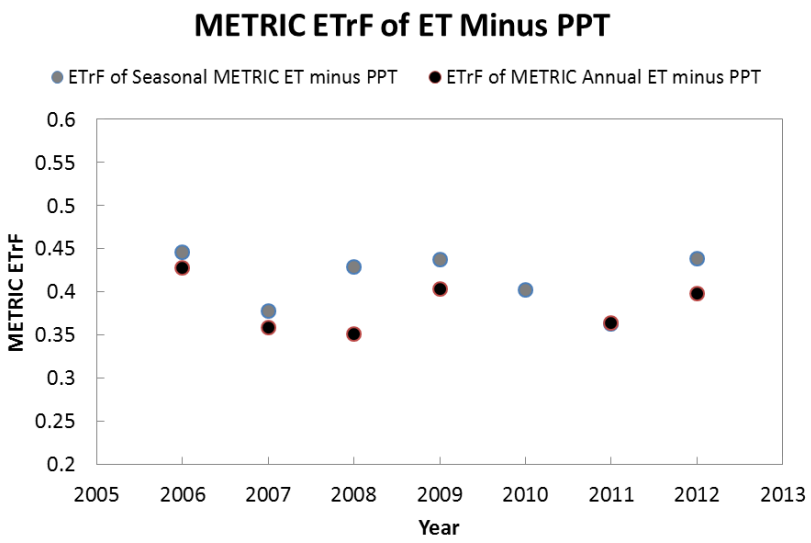

Figure 18. Seasonal and annual METRIC derived ET_rF from 2006-2012.

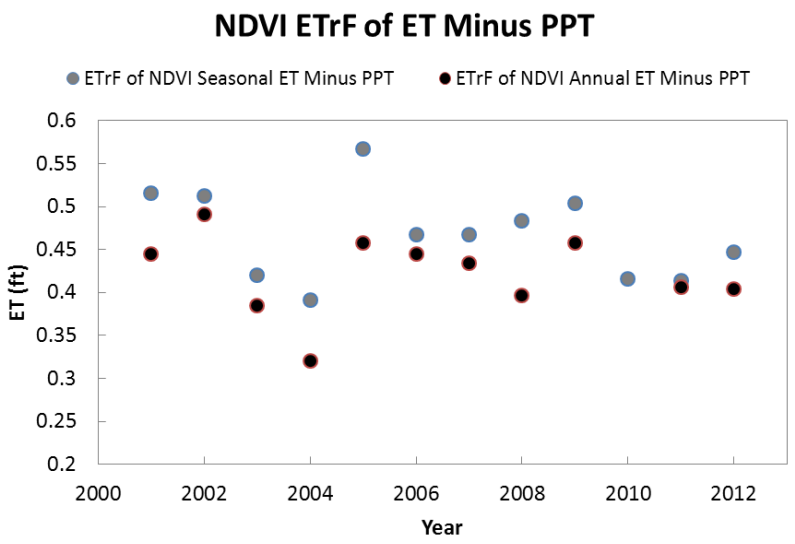

Figure 19. Seasonal and annual NDVI derived ET_rF from 2001-2012.

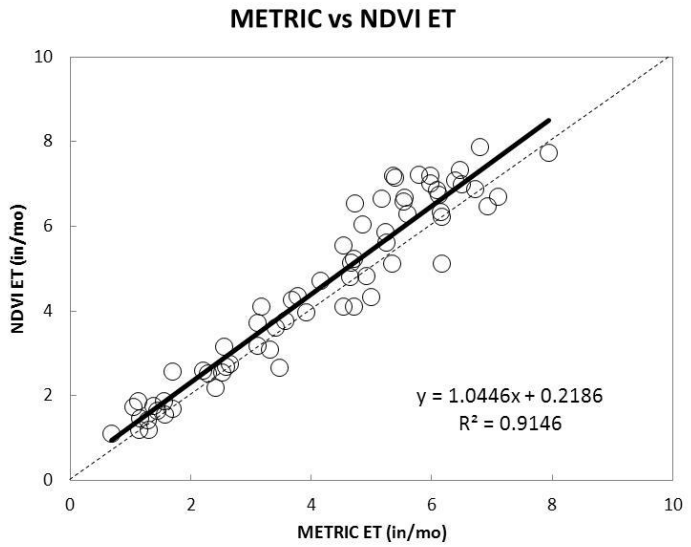

Figure 20. METRIC and NDVI estimated monthly *ET* from 2006-2012.

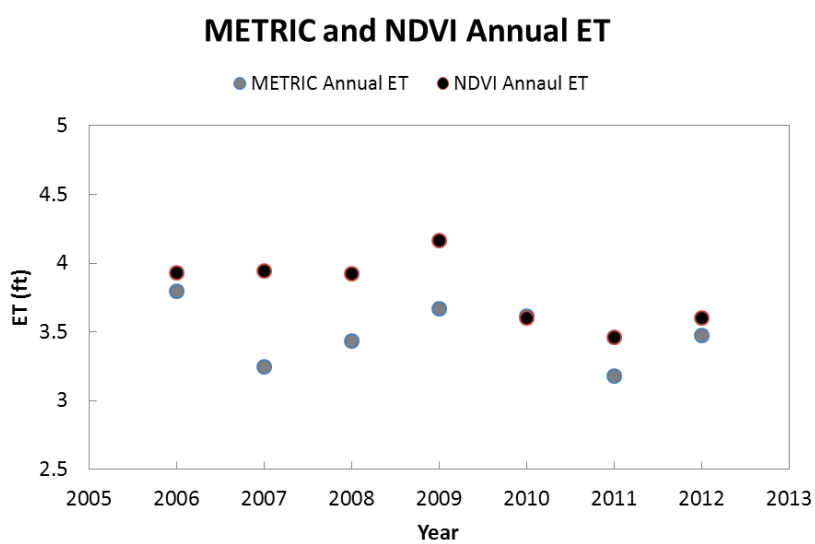

Figure 21. METRIC and NDVI estimated annual *ET* from 2006-2012.

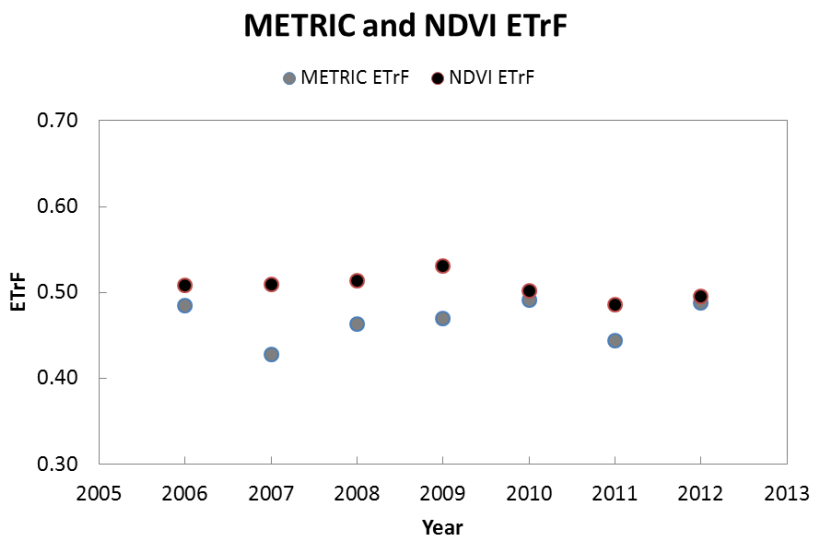

Figure 22. METRIC and NDVI estimated annual *ETrF* from 2006-2012.

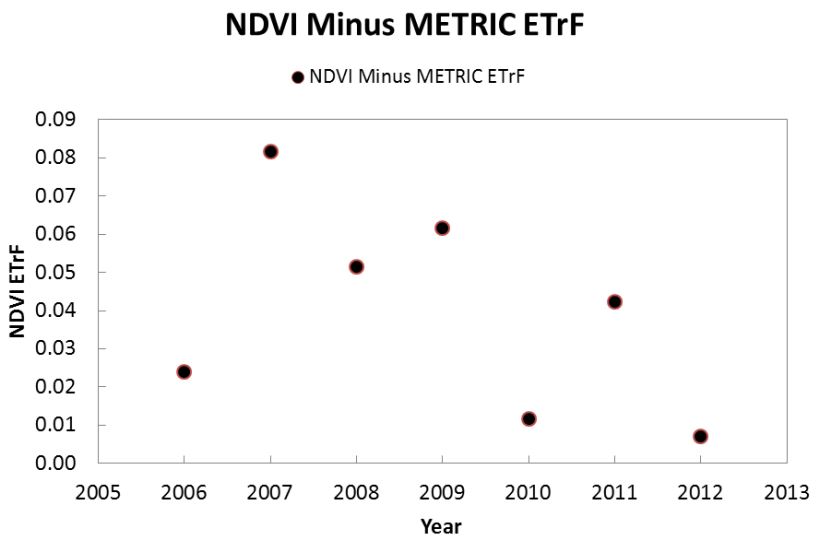

Figure 23. NDVI minus METRIC estimated annual *ETrF* from 2006-2012.

Considering that METRIC estimated *ET* relies on a surface energy balance based on surface temperature, and NDVI strictly relies on optical reflectance and a simple linear index, and the fact that the average annual bias between NDVI and METRIC ET_rF is only 0.04, the comparison between NDVI and METRIC estimated *ET* is thought to be fairly good. As previously mentioned, the use of NDVI does have weaknesses, especially in detecting bare soil evaporation, however, due to the fact that bare soil evaporation is thought to be a fairly small component of *ET* in the Muddy River Springs area due to irrigation practices and moderate vegetation cover. For this reason, the use of NDVI for estimating *ET* is considered to be fairly robust in this work.

Evapotranspiration Reductions

Average METRIC and NDVI estimated annual *ET-PPT* reductions for the Muddy River Springs area for the period of 2006-2012 range from -0.062 ft/yr to -0.11 ft/yr, respectively, with total reductions of METRIC and NDVI annual *ET-PPT* over the 2006-2012 period being -0.43ft and -0.77ft, respectively. Average NDVI estimated annual *ET-PPT* decline for the Muddy River Springs area over the period of 2001-2012 is estimated to be -0.095 ft/yr, with a total reduction in annual *ET-PPT* of -1.14 ft (Tables A6 and A9). For the period 2006-2012, METRIC and NDVI estimated annual *ET-PPT* volume reductions over the 797 acre Muddy River Springs study area are estimated to be -344 ac-ft and -613 ac-ft, respectively. For the period 2001-2012, the NDVI estimated annual *ET-PPT* volume reduction over the 797 acre study area is estimated to be -910 ac-ft. These results along with monthly, seasonal, and annual results of METRIC *ET*, ET_r, PRISM *PPT*, NDVI *ET*, METRIC *ET-PPT*, NDVI *ET-PPT*, METRIC ET_rF, and NDVI ET_rF are listed in Appendix Tables A2-A10. Differences in reductions between METRIC and NDVI from 2006-2012 are due to differences in the computed slopes in ET-PPT during this period. METRIC estimates of *ET* and *ET-PPT* are noticeably lower than NDVI estimates of *ET* and *ET-PPT* for 2007-2009, a period of relatively low precipitation, potentially causing water limited stress conditions that NDVI is not sensitive to. To support this argument METRIC seems to compare well with NDVI estimated *ET* and *ET-PPT* during years of relatively higher precipitation. Also, calibration of METRIC during 2007-2009 could possibly be abnormally low, however, it is thought that calibration during these years are relatively robust and consistent.

Comparison to Previous ET Work

For comparison purposes, METRIC and NDVI derived *ET* was compared to a recent study by DeMeo et al. (2008), who estimated *ET* in the Muddy River Springs area using the Bowen Ratio Energy Balance (BREB) approach from July 2003-October 2006. The Bowen ratio station location is shown in Figure 24, and is surrounded by a dense grove of 10 to 15 ft tall mesquite trees (DeMeo et al., 2008) (Figure 25). DeMeo et al. (2008) reports the average annual *ET* to be 3.6 ft/yr from summing 2003-2006 daily average *ET* estimates from the Muddy River Bowen station. No monthly totals were reported. To compare METRIC *ET* and NDVI *ET* to the Muddy River station estimated *ET* for respective years, 20 minute *ET* data was acquired from the USGS and summed into daily and monthly totals. METRIC and NDVI *ET* estimates were extracted from a 75m buffer around the USGS Muddy River station (Figure 24). Previous work has shown that roughly 80% of the turbulent fluxes measured at many Nevada ET stations with surrounding riparian and shrubland vegetation originates within a 30 to 100m radius of the *ET* station, with the lower range being associated with taller riparian vegetation (Moreo et al., 2007; Allander et al., 2009).

Monthly METRIC and NDVI *ET* estimates were compared to Bowen ratio station *ET* estimates from 2003-2006 (Figures 25 and 26). Results suggest that METRIC and NDVI over predict *ET* at the low *ET* range, but is fairly accurate at the moderate to high *ET* range. The comparisons are considered favorable given that a large part of the annual *ET* in the study area is derived from high *ET* months.

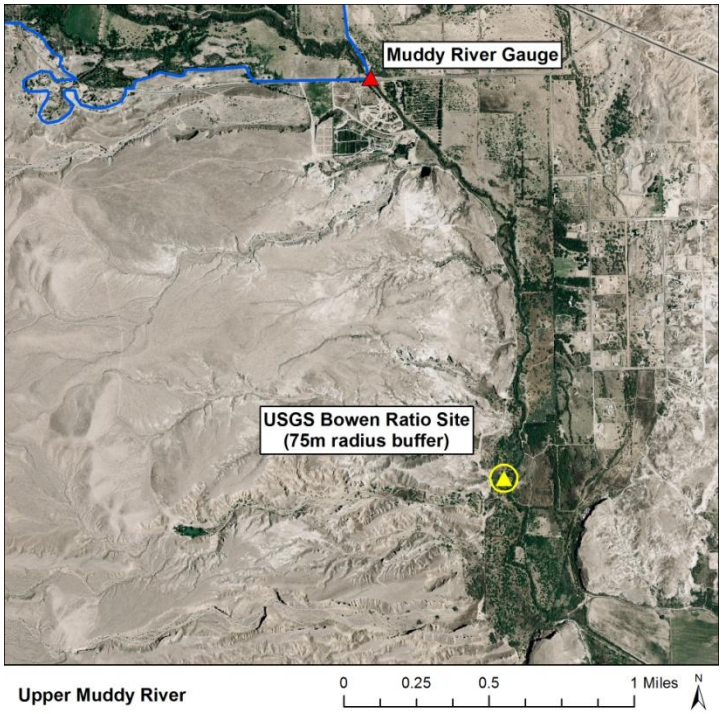

Figure 24. USGS Bowen Ratio Energy Balance station to compare METRIC and NDVI ET estimates to for 2003-2006.

Figure 25. USGS Bowen Ratio Energy Balance station located in the Muddy River area. Modified figure from DeMeo et al. (2008).

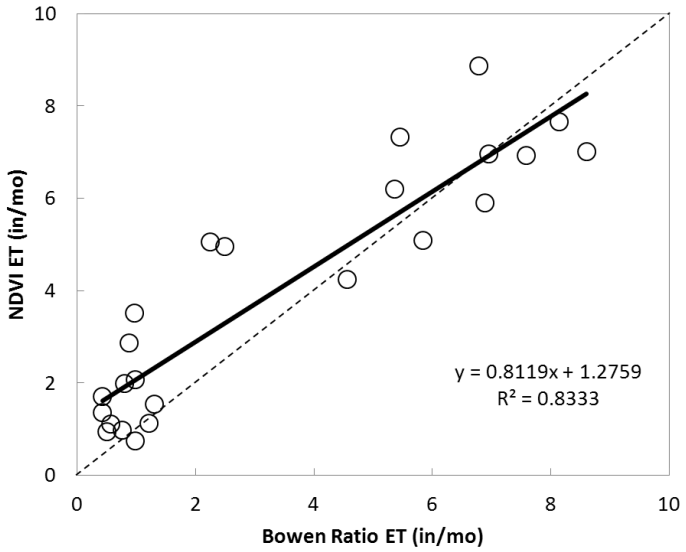

Figure 25. Bowen Ratio Energy Balance estimated monthly ET and NDVI estimated monthly ET from 2003-2006 (with several months of missing data).

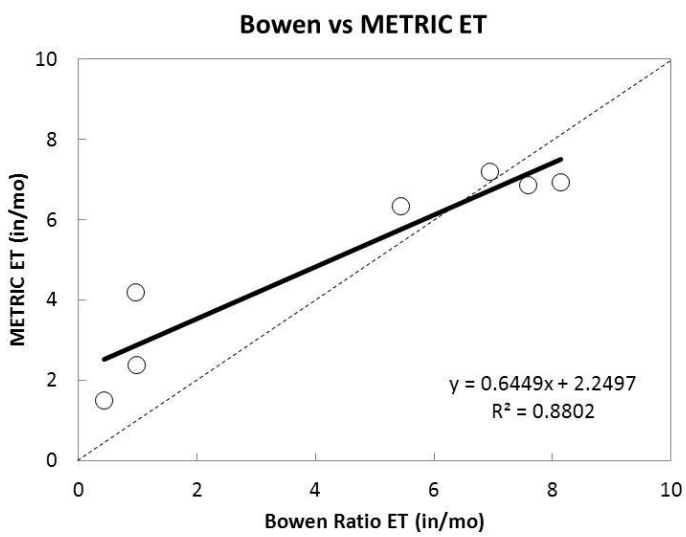

Figure 26. Bowen Ratio Energy Balance estimated monthly ET and METRIC estimated monthly ET from February-August of 2006 (only data available for METRIC comparison).

While the DeMeo et al. (2008) study from 2003-2006 estimated the average *ET* to be 3.6 ft/yr, there were over 271 missing days, many of which were in the spring and summer of 2004 and 2005. As previously indicated, annual *ET* totals reported by DeMeo et al. (2008) were computed by summing period of record daily average *ET* rates (i.e., 365 daily average values). Using daily averages from multiple years is a general approach for gap filling daily *ET* data, and in this case for computing an average annual *ET* rate, however, such averaging and filling approaches do not consider *ET* variability caused by precipitation. For example, a large portion of summer 2005, which was exceptionally wet in the preceding months, was filled with daily average summer values from 2004 and 2006, which were preceded by relatively wet and dry periods, respectively (Figure 14, Table A5). The impact of this type of summation is likely causing a biased low average annual *ET* estimate in this case. As a result of missing data, an accurate comparison of METRIC and NDVI estimated annual *ET* is not possible. For reporting purposes, Bowen station NDVI estimated *ET* ranged from 5.6 ft/yr to 3.9 ft/yr for 2005 and 2006, respectively, with an average annual estimate of 4.3 ft/yr from 2003 -2006. For purposes of making a more respective cumulative *ET* comparison, a comparison was made between the Bowen station, METRIC, and NDVI *ET* over the longest continuous record at the Bowen *ET* station from February-August 2006. Results indicate that Bowen station, METRIC, and NDVI estimated *ET* over this period is 30.5 in, 35.4 in, and 36.2 in, respectively (Figure 27).

Comparing to previous work of DeMeo et al. (2008) revealed that METRIC and NDVI estimated *ET* is likely biased high during low *ET* periods. This bias could be due to inaccuracies of METRIC during the cool season caused by small differences in METRIC surface temperatures at extreme ET conditions (i.e., hot and cold pixel temperature values at dry and well irrigated conditions are nearly the same). Additionally, NDVI bias during the cool period likely exists due to the presence of background NDVI from bare soil and vegetation during fall and winter senescence and dormancy periods, along with inaccuracies in the statistical model between NDVI and ET_rF. In general, the comparison between Bowen station *ET* and METRIC and NDVI estimated *ET* is considered fairly robust given that *ET* estimates generally fall within the uncertainty of Bowen station *ET* estimates, which is likely around 10-15% (Allander et al., 2009). It is difficult to judge the quality of these Bowen ratio *ET* data given that there is extremely limited description on Bowen ratio station instrumentation, and station setup and deployment, such as reporting the make and model of net radiometer and ground heat flux plates, number of soil heat flux plates used, discussion on methods for computing soil heat storage and soil heat flux, filtering of erroneous Bowen ratio values, QAQC of net radiation and ground heat flux, soil moisture measurements, etc., all of which are critical aspects for *ET* measurement reporting (Allen et al., 2011b).

Summary

This study evaluated over 300 Landsat TM and ETM+ images to assess potential changes in *ET* over the Muddy River Springs area from 2001-2012. Results suggest that *ET* has declined from 2001-2012 independent of *PPT* changes. Changes in *ET* are primarily due to to changes in ET_r, and to a lesser extent, due to changes in ET_rF. Reduction of annual *ET-PPT* ranges between -600 to -900 ac-ft. The -600 ac-ft rounded value is derived from the METRIC estimated *ET-PPT* rate of change of -0.062 ft/yr over the period of 2006-2012, and applied to the 12 year period

of 2001-2012 (Table A6). The -900 ac-ft rounded value is derived from the NDVI estimated *ET-PPT* rate of change of -0.095 ft/yr over the period of 2001-2012, and is applied to the 12 year period of 2001-2012 (Table A9). Comparisons between METRIC and NDVI, and Bowen ratio station estimated *ET* in the Muddy River Springs area from 2003-2006 are favorable and are generally within the uncertainty of Bowen station *ET* estimates.

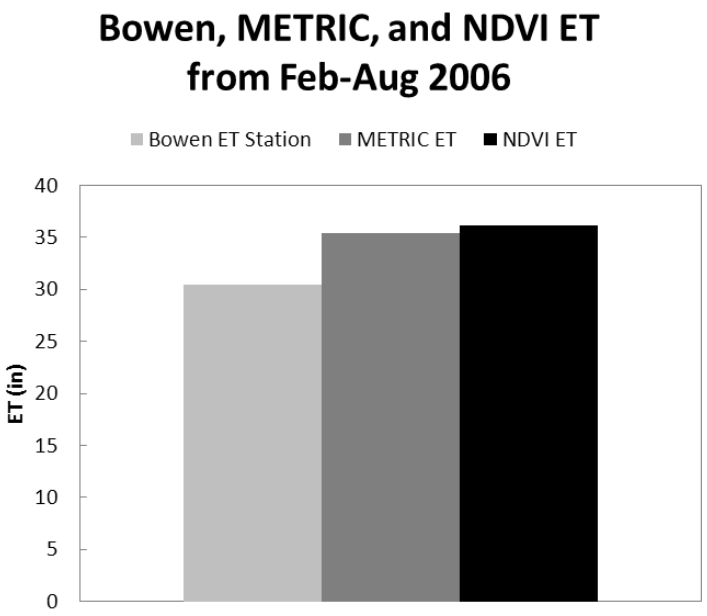

Figure 27. Comparison of total estimated ET from Feb-Aug. 2006 between the Bowen station METRIC, and NDVI. The Feb-Aug. 2006 period was the longest continuous data record for the Bowen station.

References

Allander, K. K., J. L. Smith, and M. J. Johnson (2009). Evapotranspiration from the lower Walker River basin, west-central Nevada, water years 2005–07, U.S. Geol. Sur. Sci. Invest. Rep. 2009-5079, 62 pp.

Allen, R.G. (1996). Assessing Integrity of Weather Data for use in Reference Evapotranspiration estimation. Journal of Irrigation and Drainage Engineering, ASCE. 122(2), 97-106 pp.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998). Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome, 300 p.

Allen, R. G. (2011). *REF-ET: Version - Windows 3.1.10*. University of Idaho.

Allen, R.G., Pereira, L., Howell, T., and M. E. Jensen (2011a). Evapotranspiration information reporting: I. Factors governing measurement accuracy. *Agricultural Water Management*, 98, 899-920.

Allen, R.G., Pereira, L., Howell, T., and M. E. Jensen (2011b). Evapotranspiration information reporting: II. Recommended documentation. *Agricultural Water Management*, 98, 921-929.

ASCI-EWRI (2005). The ASCE Standardized Reference Evapotranspiration Equation. Report 0-7844-0805-X, ASCE Task Committee on Standardization of Reference Evapotranspiration. Reston, VA., American Society of Civil Engineers.

Bos, M., Kselik, R., Allen, R., & Molden, D. (2008). *Water Requirements for Irrigation and the Environment.* Springer.

Calera-Belmonte, A., Jochum, A.M., Cuesta-Garcia, A., Montoro-Rodriguez, A., Lopez- Fuster, P. (2005). Irrigation management from space: towards user-friendly products. *Irrigation Drainage Systems* 19, 337–353.

Choudhury, B.J., Ahmed, N.U., Idaho, S.B., Reginato, R.J., Daughtry, C.S.T. (1994). Relations between evaporation coefficients and vegetation indices: studies by model simulation. *Remote Sensing Environment* 50, 1–17.

Daly, C., R. P. Neilson, and D. L. Phillips (1994). A statistical-topographic model for mapping climatological precipitation over mountainous terrain. *Journal of Applied Meteorology* 33, 140-158.

DeMeo, G.A., Smith, J.L., Damar, N.A., and Darnell, Jon (2008). Quantifying ground-water and surface-water discharge from evapotranspiration processes in 12 hydrographic areas of the Colorado Regional Ground-Water Flow System, Nevada, Utah, and Arizona: U.S. Geological Survey Scientific Investigations Report 2008-5116, 22 p.

Eakin, T.E. (1964). Ground-water appraisal of Coyote Spring and Kane Spring Valleys and Muddy River Springs area, Lincoln and Clark Counties, Nevada: Nevada Department of Conservation and Natural Resources, Ground-Water Resources Reconnaissance Series, Report 25, 40 p.

Eakin, T. E. (1966). A Regional Interbasin Groundwater System in the White River Area, Southeastern Nevada. *Water Resources Research* 2, 251-271.

Heilman, J. L., Heilman, W. E., and Moore, D. G. (1982). Evaluating the Crop Coefficient Using Spectral Radiance. *Agronomy Journal 74*, 967-971.

Hendrickx, J.M.H. (2010). ET Mapping in the Green River Basin - Second Stage, Growing Season (2009). Final Report to the University of Wyoming. Soil Hydrology Associates, LLC, Los Lunas, NM.

Groeneveld, D.P., W.M. Baugh, J.S. Sanderson, and D.J. Cooper (2007). Annual Groundwater Evapotranspiration Mapped from Single Satellite Scenes. *Journal of Hydrology* 344:146-156. DOI:10.1016/j.jhydrol.2007.07.002.

Kjaersagaard, J. and R.G. Allen (2010). Remote Sensing Technology to Produce Consumptive Water Use Maps for the Nebraska Panhandle. Final completion report submitted to the University of Nebraska. 60 p.

Masek, J. G., E. F. Vermote, N. Saleous, R. Wolfe, F. G. Hall, F. Huemmrich, F. Gao, J. Kutler, and T. K. Lim (2006). A Landsat surface reflectance data set for North America, 1990–2000, *Geoscience Remote Sensing Letters* 3, 68–72.

Moreo, M.T., R.J. Laczniak, and D.I. Stannard (2007). Evapotranspiration Rate Measurements of Vegetation Typical of Groundwater Discharge Areas in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah, September 2005-August 2006. U.S. Geological Survey Scientific Investigations Report 2007-5078, 36 pp. http://pubs.usgs.gov/sir/2007/5078.

Morton, C., Huntington, J.L., Pohll, G., Allen, R., McGwire, K., Bassett, S. (2013). Assessing Calibration Uncertainty and Automation for Estimating Evapotranspiration from Agricultural Areas Using METRIC. *Journal of the American Water Resources Association.* In Press.

Nagler, P.L., R.L. Scott, C. Westenburg, J.R. Cleverly, E.P. Glenn, and A.H. Huete (2005). Evapotranspiration on Western U.S. Rivers Estimated Using the Enhanced Vegetation Index from MODIS and Data from Eddy Covariance and Bowen Ratio Flux Towers. *Remote Sensing of Environment* 97(3):337-351. DOI:10.1016/j.rse.2005.05.011

Schuepp, P.H., LeClerc, M.Y., Macpherson, J.I., and Desjardins, R.L. (1990). Footprint prediction of scalar fluxes from analytical solutions of the diffusion equation: Boundary-Layer Meteorology, v. 50, p. 355-373.

Singh, R. and Irmak, A. (2009). Estimation of crop coefficients using satellite remote sensing. *Journal of Irrigation Drainage Engineering, ASCE* 135 (5), 597–608.

Smith, J.L., R.J. Laczniak, M.T. Moreo, and T.L. Welborn (2007). Mapping Evapotranspiration units in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah. U.S. Geological Survey Scientific Investigations Report 2007–5087, 31 p. http://pubs.usgs.gov/sir/2007/5087/

Snyder, D.T., Risley, J.C., and Haynes, J.V. (2012). Hydrological information products for the Off-Project Water Program of the Klamath Basin Restoration Agreement: U.S. Geological Survey Open-File Report 2012–1199, 20 p., http://pubs.usgs.gov/of/2012/1199

Sullivan, A., Huntington, J., and Morton, C. (2011). Remote Sensing of Consumptive Use in the Walker River Basin, Nevada. American Water Resource Association Annual Conference, Albuquerque, NM, 2011. http://www.awra.org/meetings/ABQ2011/doc/abs/Sess%2029%20abs.pdf, http://awra.org/annual2011/doc/pres/S29-Sullivan.pdf

Tasumi, M., Allen, R.G. (2007). Satellite-based ET mapping to assess variation in ET with timing of crop development. *Agriculture Water Management* 88 (1–3), 54–62.

Tasumi, M., Allen, R.G., Trezza, R., and Wright, J.L. (2005). Satellite-based energy balance to assess within-population variance of crop coefficient curves. *Journal Irrigation Drainage Engineering* 131 (1), 94–109.

Appendix

Table A1. Listing of Landsat scenes and ET and precipitation results using METIC, NDVI, and EVI methods. Landsat 5 (TM), Landsat ETM, and Landsat ETM SLC off were all used for NDVI and METRIC ET estimates. Landsat ETM SLC off did not impact the quality of ET estimates in the Muddy River Springs area, as SLC gaps were not present in the study area due to the Muddy River Springs area being located in the center of Landsat ETM scenes.

Count	SCENE_ID	DATE	YEAR	DOY	SENSOR	NDVI ET	METRIC ET
1	LT50390352001006XXX02	1/6/2001	2001	6	LANDSAT_TM	x	
2	LE70390352001014EDC00	1/14/2001	2001	14	LANDSAT_ETM	x	
3	LE70390352001030EDC00	1/30/2001	2001	30	LANDSAT_ETM	x	
4	LE70390352001046EDC00	2/15/2001	2001	46	LANDSAT_ETM	x	
5	LT50390352001054XXX02	2/23/2001	2001	54	LANDSAT_TM	x	
6	LE70390352001062EDC01	3/3/2001	2001	62	LANDSAT_ETM	x	
7	LE70390352001078EDC00	3/19/2001	2001	78	LANDSAT_ETM	x	
8	LT50390352001102XXX02	4/12/2001	2001	102	LANDSAT_TM	x	
9	LT50390352001118XXX02	4/28/2001	2001	118	LANDSAT_TM	x	
10	LE70390352001126EDC00	5/6/2001	2001	126	LANDSAT_ETM	x	
11	LT50390352001134AAA02	5/14/2001	2001	134	LANDSAT_TM	x	
12	LE70390352001142EDC00	5/22/2001	2001	142	LANDSAT_ETM	x	
13	LT50390352001150AAA02	5/30/2001	2001	150	LANDSAT_TM	x	
14	LE70390352001158EDC00	6/7/2001	2001	158	LANDSAT_ETM	x	
15	LT50390352001166XXX02	6/15/2001	2001	166	LANDSAT_TM	x	
16	LE70390352001174EDC00	6/23/2001	2001	174	LANDSAT_ETM	x	
17	LT50390352001182LGS03	7/1/2001	2001	182	LANDSAT_TM	x	
18	LE70390352001190EDC00	7/9/2001	2001	190	LANDSAT_ETM	x	
19	LT50390352001214LGS01	8/2/2001	2001	214	LANDSAT_TM	x	
20	LE70390352001222EDC00	8/10/2001	2001	222	LANDSAT_ETM	x	
21	LT50390352001230LGS01	8/18/2001	2001	230	LANDSAT_TM	x	
22	LE70390352001238EDC00	8/26/2001	2001	238	LANDSAT_ETM	x	
23	LT50390352001246LGS01	9/3/2001	2001	246	LANDSAT_TM	x	
24	LT50390352001262LGS01	9/19/2001	2001	262	LANDSAT_TM	x	
25	LE70390352001270EDC00	9/27/2001	2001	270	LANDSAT_ETM	x	
26	LE70390352001286EDC00	10/13/2001	2001	286	LANDSAT_ETM	x	
27	LT50390352001310LGS01	11/6/2001	2001	310	LANDSAT_TM	x	
28	LE70390352001318EDC00	11/14/2001	2001	318	LANDSAT_ETM	x	
29	LT50390352001342LGS01	12/8/2001	2001	342	LANDSAT_TM	x	
30	LE70390352001350EDC00	12/16/2001	2001	350	LANDSAT_ETM	x	
31	LT50390352001358LGS01	12/24/2001	2001	358	LANDSAT_TM	x	

32	LE70390352002017EDC00	1/17/2002	2002	17	LANDSAT_ETM	x	
33	LE70390352002033EDC00	2/2/2002	2002	33	LANDSAT_ETM	x	
34	LT50390352002041EDC01	2/10/2002	2002	41	LANDSAT_TM	x	
35	LT50390352002057LGS01	2/26/2002	2002	57	LANDSAT_TM	x	
36	LE70390352002081EDC00	3/22/2002	2002	81	LANDSAT_ETM	x	
37	LT50390352002089LGS01	3/30/2002	2002	89	LANDSAT_TM	x	
38	LE70390352002097EDC00	4/7/2002	2002	97	LANDSAT_ETM	x	
39	LT50390352002105LGS01	4/15/2002	2002	105	LANDSAT_TM	x	
40	LT50390352002121LGS03	5/1/2002	2002	121	LANDSAT_TM	x	
41	LE70390352002129EDC00	5/9/2002	2002	129	LANDSAT_ETM	x	
42	LT50390352002137LGS01	5/17/2002	2002	137	LANDSAT_TM	x	
43	LE70390352002145EDC01	5/25/2002	2002	145	LANDSAT_ETM	x	
44	LE70390352002161EDC00	6/10/2002	2002	161	LANDSAT_ETM	x	
45	LT50390352002169LGS03	6/18/2002	2002	169	LANDSAT_TM	x	
46	LE70390352002177EDC00	6/26/2002	2002	177	LANDSAT_ETM	x	
47	LT50390352002185EDC02	7/4/2002	2002	185	LANDSAT_TM	x	
48	LE70390352002193EDC00	7/12/2002	2002	193	LANDSAT_ETM	x	
49	LT50390352002201LGS01	7/20/2002	2002	201	LANDSAT_TM	x	
50	LE70390352002209EDC00	7/28/2002	2002	209	LANDSAT_ETM	x	
51	LE70390352002225EDC00	8/13/2002	2002	225	LANDSAT_ETM	x	
52	LT50390352002233LGS01	8/21/2002	2002	233	LANDSAT_TM	x	
53	LE70390352002241EDC00	8/29/2002	2002	241	LANDSAT_ETM	x	
54	LE70390352002257EDC00	9/14/2002	2002	257	LANDSAT_ETM	x	
55	LT50390352002265LGS01	9/22/2002	2002	265	LANDSAT_TM	x	
56	LE70390352002273EDC00	9/30/2002	2002	273	LANDSAT_ETM	x	
57	LT50390352002281LGS01	10/8/2002	2002	281	LANDSAT_TM	x	
58	LE70390352002289EDC00	10/16/2002	2002	289	LANDSAT_ETM	x	
59	LT50390352002297LGS01	10/24/2002	2002	297	LANDSAT_TM	x	
60	LE70390352002305EDC00	11/1/2002	2002	305	LANDSAT_ETM	x	
61	LE70390352002337EDC00	12/3/2002	2002	337	LANDSAT_ETM	x	
62	LE70390352002353EDC00	12/19/2002	2002	353	LANDSAT_ETM	x	
63	LT50390352002361LGS01	12/27/2002	2002	361	LANDSAT_TM	x	
64	LE70390352003020EDC00	1/20/2003	2003	20	LANDSAT_ETM	x	
65	LT50390352003028LGS01	1/28/2003	2003	28	LANDSAT_TM	x	
66	LE70390352003052EDC01	2/21/2003	2003	52	LANDSAT_ETM	x	
67	LE70390352003068EDC00	3/9/2003	2003	68	LANDSAT_ETM	x	
68	LT50390352003092LGS01	4/2/2003	2003	92	LANDSAT_TM	x	
69	LE70390352003100EDC00	4/10/2003	2003	100	LANDSAT_ETM	x	
70	LE70390352003116EDC00	4/26/2003	2003	116	LANDSAT_ETM	x	
71	LT50390352003124LGS01	5/4/2003	2003	124	LANDSAT_TM	x	
72	LT50390352003140LGS01	5/20/2003	2003	140	LANDSAT_TM	x	

73	LE70390352003148EDC00	5/28/2003	2003	148	LANDSAT_ETM	x	
74	LT50390352003156LGS01	6/5/2003	2003	156	LANDSAT_TM	x	
75	LT50390352003172EDC03	6/21/2003	2003	172	LANDSAT_TM	x	
76	LT50390352003188PAC02	7/7/2003	2003	188	LANDSAT_TM	x	
77	LE70390352003212EDC02	7/31/2003	2003	212	LANDSAT_ETM_SLC_OFF	x	
78	LT50390352003220PAC04	8/8/2003	2003	220	LANDSAT_TM	x	
79	LE70390352003244EDC01	9/1/2003	2003	244	LANDSAT_ETM_SLC_OFF	x	
80	LT50390352003252PAC02	9/9/2003	2003	252	LANDSAT_TM	x	
81	LE70390352003260EDC02	9/17/2003	2003	260	LANDSAT_ETM_SLC_OFF	x	
82	LE70390352003276EDC02	10/3/2003	2003	276	LANDSAT_ETM_SLC_OFF	x	
83	LT50390352003284LGS01	10/11/2003	2003	284	LANDSAT_TM	x	
84	LE70390352003308EDC01	11/4/2003	2003	308	LANDSAT_ETM_SLC_OFF	x	
85	LT50390352003348PAC02	12/14/2003	2003	348	LANDSAT_TM	x	
86	LE70390352003356EDC01	12/22/2003	2003	356	LANDSAT_ETM_SLC_OFF	x	
87	LT50390352004015PAC02	1/15/2004	2004	15	LANDSAT_TM	x	
88	LE70390352004023EDC01	1/23/2004	2004	23	LANDSAT_ETM_SLC_OFF	x	
89	LE70390352004039EDC01	2/8/2004	2004	39	LANDSAT_ETM_SLC_OFF	x	
90	LT50390352004063PAC02	3/3/2004	2004	63	LANDSAT_TM	x	
91	LE70390352004071EDC02	3/11/2004	2004	71	LANDSAT_ETM_SLC_OFF	x	
92	LT50390352004079PAC02	3/19/2004	2004	79	LANDSAT_TM	x	
93	LE70390352004087EDC02	3/27/2004	2004	87	LANDSAT_ETM_SLC_OFF	x	
94	LE70390352004103EDC02	4/12/2004	2004	103	LANDSAT_ETM_SLC_OFF	x	
95	LE70390352004119EDC03	4/28/2004	2004	119	LANDSAT_ETM_SLC_OFF	x	
96	LE70390352004135EDC01	5/14/2004	2004	135	LANDSAT_ETM_SLC_OFF	x	
97	LT50390352004143PAC02	5/22/2004	2004	143	LANDSAT_TM	x	
98	LE70390352004151EDC01	5/30/2004	2004	151	LANDSAT_ETM_SLC_OFF	x	
99	LT50390352004159PAC02	6/7/2004	2004	159	LANDSAT_TM	x	
100	LE70390352004167EDC01	6/15/2004	2004	167	LANDSAT_ETM_SLC_OFF	x	
101	LT50390352004175PAC02	6/23/2004	2004	175	LANDSAT_TM	x	
102	LT50390352004191PAC01	7/9/2004	2004	191	LANDSAT_TM	x	
103	LT50390352004207PAC02	7/25/2004	2004	207	LANDSAT_TM	x	
104	LT50390352004223PAC01	8/10/2004	2004	223	LANDSAT_TM	x	
105	LT50390352004239PAC01	8/26/2004	2004	239	LANDSAT_TM	x	
106	LE70390352004247EDC02	9/3/2004	2004	247	LANDSAT_ETM_SLC_OFF	x	
107	LE70390352004263EDC02	9/19/2004	2004	263	LANDSAT_ETM_SLC_OFF	x	
108	LT50390352004271EDC00	9/27/2004	2004	271	LANDSAT_TM	x	
109	LT50390352004287PAC01	10/13/2004	2004	287	LANDSAT_TM	x	
110	LT50390352004303PAC01	10/29/2004	2004	303	LANDSAT_TM	x	
111	LT50390352004319PAC01	11/14/2004	2004	319	LANDSAT_TM	x	
112	LT50390352004351PAC01	12/16/2004	2004	351	LANDSAT_TM	x	
113	LE70390352004359EDC00	12/24/2004	2004	359	LANDSAT_ETM_SLC_OFF	x	

114	LT50390352005017PAC01	1/17/2005	2005	17	LANDSAT_TM	x	
115	LT50390352005033PAC01	2/2/2005	2005	33	LANDSAT_TM	x	
116	LT50390352005065PAC01	3/6/2005	2005	65	LANDSAT_TM	x	
117	LE70390352005089EDC00	3/30/2005	2005	89	LANDSAT_ETM_SLC_OFF	x	
118	LE70390352005105EDC00	4/15/2005	2005	105	LANDSAT_ETM_SLC_OFF	x	
119	LT50390352005129PAC01	5/9/2005	2005	129	LANDSAT_TM	x	
120	LE70390352005137EDC00	5/17/2005	2005	137	LANDSAT_ETM_SLC_OFF	x	
121	LT50390352005145EDC00	5/25/2005	2005	145	LANDSAT_TM	x	
122	LE70390352005153EDC00	6/2/2005	2005	153	LANDSAT_ETM_SLC_OFF	x	
123	LT50390352005161PAC01	6/10/2005	2005	161	LANDSAT_TM	x	
124	LE70390352005169EDC00	6/18/2005	2005	169	LANDSAT_ETM_SLC_OFF	x	
125	LT50390352005177PAC01	6/26/2005	2005	177	LANDSAT_TM	x	
126	LT50390352005193PAC01	7/12/2005	2005	193	LANDSAT_TM	x	
127	LT50390352005209PAC01	7/28/2005	2005	209	LANDSAT_TM	x	
128	LT50390352005225PAC01	8/13/2005	2005	225	LANDSAT_TM	x	
129	LE70390352005233EDC00	8/21/2005	2005	233	LANDSAT_ETM_SLC_OFF	x	
130	LT50390352005241PAC01	8/29/2005	2005	241	LANDSAT_TM	x	
131	LE70390352005249EDC00	9/6/2005	2005	249	LANDSAT_ETM_SLC_OFF	x	
132	LT50390352005257PAC01	9/14/2005	2005	257	LANDSAT_TM	x	
133	LE70390352005265EDC00	9/22/2005	2005	265	LANDSAT_ETM_SLC_OFF	x	
134	LT50390352005273PAC01	9/30/2005	2005	273	LANDSAT_TM	x	
135	LT50390352005289PAC01	10/16/2005	2005	289	LANDSAT_TM	x	
136	LE70390352005297EDC00	10/24/2005	2005	297	LANDSAT_ETM_SLC_OFF	x	
137	LT50390352005321PAC01	11/17/2005	2005	321	LANDSAT_TM	x	
138	LE70390352005345EDC00	12/11/2005	2005	345	LANDSAT_ETM_SLC_OFF	x	
139	LT50390352006020EDC00	1/20/2006	2006	20	LANDSAT_TM	x	
140	LT50390352006036PAC01	2/5/2006	2006	36	LANDSAT_TM	x	x
141	LE70390352006044EDC00	2/13/2006	2006	44	LANDSAT_ETM_SLC_OFF	x	
142	LT50390352006052PAC01	2/21/2006	2006	52	LANDSAT_TM	x	
143	LE70390352006060EDC00	3/1/2006	2006	60	LANDSAT_ETM_SLC_OFF	x	
144	LT50390352006068PAC01	3/9/2006	2006	68	LANDSAT_TM	x	x
145	LE70390352006092EDC00	4/2/2006	2006	92	LANDSAT_ETM_SLC_OFF	x	
146	LT50390352006100PAC01	4/10/2006	2006	100	LANDSAT_TM	x	x
147	LT50390352006116PAC01	4/26/2006	2006	116	LANDSAT_TM	x	x
148	LE70390352006124EDC00	5/4/2006	2006	124	LANDSAT_ETM_SLC_OFF	x	
149	LT50390352006132PAC01	5/12/2006	2006	132	LANDSAT_TM	x	x
150	LE70390352006140EDC00	5/20/2006	2006	140	LANDSAT_ETM_SLC_OFF	x	
151	LT50390352006148PAC01	5/28/2006	2006	148	LANDSAT_TM	x	x
152	LE70390352006156EDC00	6/5/2006	2006	156	LANDSAT_ETM_SLC_OFF	x	
153	LE70390352006172EDC00	6/21/2006	2006	172	LANDSAT_ETM_SLC_OFF	x	
154	LT50390352006180PAC01	6/29/2006	2006	180	LANDSAT_TM	x	x

155	LT50390352006196PAC01	7/15/2006	2006	196	LANDSAT_TM	x	x
156	LE70390352006204EDC00	7/23/2006	2006	204	LANDSAT_ETM_SLC_OFF	x	
157	LT50390352006212PAC02	7/31/2006	2006	212	LANDSAT_TM	x	x
158	LE70390352006220EDC00	8/8/2006	2006	220	LANDSAT_ETM_SLC_OFF	x	
159	LT50390352006228PAC01	8/16/2006	2006	228	LANDSAT_TM	x	x
160	LE70390352006236EDC00	8/24/2006	2006	236	LANDSAT_ETM_SLC_OFF	x	
161	LT50390352006260PAC01	9/17/2006	2006	260	LANDSAT_TM	x	x
162	LT50390352006276PAC01	10/3/2006	2006	276	LANDSAT_TM	x	x
163	LE70390352006284EDC00	10/11/2006	2006	284	LANDSAT_ETM_SLC_OFF	x	
164	LT50390352006292PAC01	10/19/2006	2006	292	LANDSAT_TM	x	x
165	LE70390352006300EDC00	10/27/2006	2006	300	LANDSAT_ETM_SLC_OFF	x	
166	LT50390352006308PAC01	11/4/2006	2006	308	LANDSAT_TM	x	x
167	LE70390352006316EDC00	11/12/2006	2006	316	LANDSAT_ETM_SLC_OFF	x	
168	LT50390352006324PAC01	11/20/2006	2006	324	LANDSAT_TM	x	x
169	LE70390352006332EDC00	11/28/2006	2006	332	LANDSAT_ETM_SLC_OFF	x	
170	LT50390352006340PAC01	12/6/2006	2006	340	LANDSAT_TM	x	x
171	LE70390352006364EDC00	12/30/2006	2006	364	LANDSAT_ETM_SLC_OFF	x	
172	LT50390352007007PAC01	1/7/2007	2007	7	LANDSAT_TM	x	
173	LE70390352007015EDC00	1/15/2007	2007	15	LANDSAT_ETM_SLC_OFF	x	
174	LT50390352007023PAC01	1/23/2007	2007	23	LANDSAT_TM	x	
175	LE70390352007047EDC00	2/16/2007	2007	47	LANDSAT_ETM_SLC_OFF	x	x
176	LT50390352007055PAC01	2/24/2007	2007	55	LANDSAT_TM	x	x
177	LE70390352007063EDC00	3/4/2007	2007	63	LANDSAT_ETM_SLC_OFF	x	
178	LT50390352007071PAC01	3/12/2007	2007	71	LANDSAT_TM	x	
179	LT50390352007103PAC01	4/13/2007	2007	103	LANDSAT_TM	x	
180	LE70390352007111EDC00	4/21/2007	2007	111	LANDSAT_ETM_SLC_OFF	x	
181	LT50390352007119PAC01	4/29/2007	2007	119	LANDSAT_TM	x	x
182	LE70390352007127EDC00	5/7/2007	2007	127	LANDSAT_ETM_SLC_OFF	x	x
183	LT50390352007135PAC01	5/15/2007	2007	135	LANDSAT_TM	x	x
184	LE70390352007143EDC00	5/23/2007	2007	143	LANDSAT_ETM_SLC_OFF	x	x
185	LT50390352007151PAC01	5/31/2007	2007	151	LANDSAT_TM	x	x
186	LE70390352007159EDC00	6/8/2007	2007	159	LANDSAT_ETM_SLC_OFF	x	x
187	LT50390352007167PAC01	6/16/2007	2007	167	LANDSAT_TM	x	x
188	LE70390352007175EDC00	6/24/2007	2007	175	LANDSAT_ETM_SLC_OFF	x	x
189	LT50390352007183PAC01	7/2/2007	2007	183	LANDSAT_TM	x	x
190	LE70390352007191EDC00	7/10/2007	2007	191	LANDSAT_ETM_SLC_OFF	x	
191	LT50390352007199PAC01	7/18/2007	2007	199	LANDSAT_TM	x	x
192	LT50390352007215PAC01	8/3/2007	2007	215	LANDSAT_TM	x	x
193	LE70390352007223EDC00	8/11/2007	2007	223	LANDSAT_ETM_SLC_OFF	x	x
194	LT50390352007247PAC01	9/4/2007	2007	247	LANDSAT_TM	x	x
195	LE70390352007255EDC00	9/12/2007	2007	255	LANDSAT_ETM_SLC_OFF	x	x

196	LE70390352007287EDC00	10/14/2007	2007	287	LANDSAT_ETM_SLC_OFF	x	x
197	LE70390352007303EDC00	10/30/2007	2007	303	LANDSAT_ETM_SLC_OFF	x	x
198	LE70390352007319EDC00	11/15/2007	2007	319	LANDSAT_ETM_SLC_OFF	x	x
199	LE70390352007351EDC00	12/17/2007	2007	351	LANDSAT_ETM_SLC_OFF	x	
200	LE70390352008018EDC00	1/18/2008	2008	18	LANDSAT_ETM_SLC_OFF	x	
201	LT50390352008026EDC00	1/26/2008	2008	26	LANDSAT_TM	x	
202	LT50390352008042EDC00	2/11/2008	2008	42	LANDSAT_TM	x	
203	LT50390352008058PAC01	2/27/2008	2008	58	LANDSAT_TM	x	
204	LE70390352008066EDC00	3/6/2008	2008	66	LANDSAT_ETM_SLC_OFF	x	x
205	LT50390352008074PAC01	3/14/2008	2008	74	LANDSAT_TM	x	
206	LE70390352008082EDC00	3/22/2008	2008	82	LANDSAT_ETM_SLC_OFF	x	x
207	LE70390352008098EDC00	4/7/2008	2008	98	LANDSAT_ETM_SLC_OFF	x	x
208	LT50390352008106PAC01	4/15/2008	2008	106	LANDSAT_TM	x	
209	LE70390352008114EDC00	4/23/2008	2008	114	LANDSAT_ETM_SLC_OFF	x	x
210	LT50390352008122PAC01	5/1/2008	2008	122	LANDSAT_TM	x	x
211	LE70390352008130EDC00	5/9/2008	2008	130	LANDSAT_ETM_SLC_OFF	x	x
212	LT50390352008138PAC01	5/17/2008	2008	138	LANDSAT_TM	x	x
213	LT50390352008154PAC01	6/2/2008	2008	154	LANDSAT_TM	x	x
214	LE70390352008162EDC00	6/10/2008	2008	162	LANDSAT_ETM_SLC_OFF	x	
215	LT50390352008170PAC01	6/18/2008	2008	170	LANDSAT_TM	x	x
216	LE70390352008178EDC00	6/26/2008	2008	178	LANDSAT_ETM_SLC_OFF	x	x
217	LT50390352008234PAC01	8/21/2008	2008	234	LANDSAT_TM	x	x
218	LE70390352008242EDC00	8/29/2008	2008	242	LANDSAT_ETM_SLC_OFF	x	x
219	LT50390352008250PAC01	9/6/2008	2008	250	LANDSAT_TM	x	x
220	LE70390352008258EDC00	9/14/2008	2008	258	LANDSAT_ETM_SLC_OFF	x	x
221	LT50390352008266PAC01	9/22/2008	2008	266	LANDSAT_TM	x	x
222	LE70390352008274EDC00	9/30/2008	2008	274	LANDSAT_ETM_SLC_OFF	x	x
223	LT50390352008282PAC01	10/8/2008	2008	282	LANDSAT_TM	x	x
224	LE70390352008290EDC00	10/16/2008	2008	290	LANDSAT_ETM_SLC_OFF	x	x
225	LT50390352008298PAC01	10/24/2008	2008	298	LANDSAT_TM	x	x
226	LE70390352008322EDC00	11/17/2008	2008	322	LANDSAT_ETM_SLC_OFF	x	x
227	LE70390352008338EDC00	12/3/2008	2008	338	LANDSAT_ETM_SLC_OFF	x	
228	LE70390352009004EDC00	1/4/2009	2009	4	LANDSAT_ETM_SLC_OFF	x	
229	LT50390352009012PAC01	1/12/2009	2009	12	LANDSAT_TM	x	
230	LE70390352009020EDC00	1/20/2009	2009	20	LANDSAT_ETM_SLC_OFF	x	
231	LT50390352009092PAC01	4/2/2009	2009	92	LANDSAT_TM	x	x
232	LT50390352009108PAC01	4/18/2009	2009	108	LANDSAT_TM	x	x
233	LE70390352009116EDC00	4/26/2009	2009	116	LANDSAT_ETM_SLC_OFF	x	x
234	LE70390352009132EDC02	5/12/2009	2009	132	LANDSAT_ETM_SLC_OFF	x	x
235	LT50390352009140PAC01	5/20/2009	2009	140	LANDSAT_TM	x	x
236	LE70390352009148EDC00	5/28/2009	2009	148	LANDSAT_ETM_SLC_OFF	x	x

237	LT50390352009172PAC01	6/21/2009	2009	172	LANDSAT_TM	x	x
238	LE70390352009180EDC00	6/29/2009	2009	180	LANDSAT_ETM_SLC_OFF	x	x
239	LT50390352009188PAC01	7/7/2009	2009	188	LANDSAT_TM	x	x
240	LE70390352009196EDC00	7/15/2009	2009	196	LANDSAT_ETM_SLC_OFF	x	x
241	LE70390352009212EDC00	7/31/2009	2009	212	LANDSAT_ETM_SLC_OFF	x	x
242	LT50390352009220PAC01	8/8/2009	2009	220	LANDSAT_TM	x	x
243	LE70390352009228EDC00	8/16/2009	2009	228	LANDSAT_ETM_SLC_OFF	x	x
244	LT50390352009236PAC01	8/24/2009	2009	236	LANDSAT_TM	x	x
245	LT50390352009252PAC01	9/9/2009	2009	252	LANDSAT_TM	x	x
246	LE70390352009260EDC00	9/17/2009	2009	260	LANDSAT_ETM_SLC_OFF	x	x
247	LT50390352009268PAC01	9/25/2009	2009	268	LANDSAT_TM	x	x
248	LT50390352009284PAC01	10/11/2009	2009	284	LANDSAT_TM	x	x
249	LE70390352009292EDC00	10/19/2009	2009	292	LANDSAT_ETM_SLC_OFF	x	x
250	LE70390352009308EDC00	11/4/2009	2009	308	LANDSAT_ETM_SLC_OFF	x	x
251	LE70390352009324EDC00	11/20/2009	2009	324	LANDSAT_ETM_SLC_OFF	x	x
252	LT50390352009332PAC01	11/28/2009	2009	332	LANDSAT_TM	x	x
253	LE70390352009340EDC00	12/6/2009	2009	340	LANDSAT_ETM_SLC_OFF	x	
254	LT50390352009348PAC01	12/14/2009	2009	348	LANDSAT_TM	x	
255	LT50390352010015PAC01	1/15/2010	2010	15	LANDSAT_TM	x	
256	LT50390352010031PAC01	1/31/2010	2010	31	LANDSAT_TM	x	
257	LT50390352010047PAC01	2/16/2010	2010	47	LANDSAT_TM	x	x
258	LE70390352010071EDC00	3/12/2010	2010	71	LANDSAT_ETM_SLC_OFF	x	
259	LT50390352010079PAC01	3/20/2010	2010	79	LANDSAT_TM	x	
260	LE70390352010087EDC00	3/28/2010	2010	87	LANDSAT_ETM_SLC_OFF	x	x
261	LE70390352010103EDC00	4/13/2010	2010	103	LANDSAT_ETM_SLC_OFF	x	x
262	LT50390352010111PAC01	4/21/2010	2010	111	LANDSAT_TM	x	
263	LT50390352010127PAC01	5/7/2010	2010	127	LANDSAT_TM	x	x
264	LE70390352010135EDC00	5/15/2010	2010	135	LANDSAT_ETM_SLC_OFF	x	x
265	LT50390352010143PAC01	5/23/2010	2010	143	LANDSAT_TM	x	x
266	LE70390352010151EDC00	5/31/2010	2010	151	LANDSAT_ETM_SLC_OFF	x	x
267	LE70390352010167EDC00	6/16/2010	2010	167	LANDSAT_ETM_SLC_OFF	x	x
268	LT50390352010175EDC00	6/24/2010	2010	175	LANDSAT_TM	x	x
269	LE70390352010183EDC00	7/2/2010	2010	183	LANDSAT_ETM_SLC_OFF	x	
270	LE70390352010199EDC00	7/18/2010	2010	199	LANDSAT_ETM_SLC_OFF	x	x
271	LE70390352010215EDC00	8/3/2010	2010	215	LANDSAT_ETM_SLC_OFF	x	x
272	LT50390352010223EDC00	8/11/2010	2010	223	LANDSAT_TM	x	x
273	LE70390352010231EDC00	8/19/2010	2010	231	LANDSAT_ETM_SLC_OFF	x	x
274	LT50390352010239EDC00	8/27/2010	2010	239	LANDSAT_TM	x	x
275	LE70390352010247EDC00	9/4/2010	2010	247	LANDSAT_ETM_SLC_OFF	x	x
276	LE70390352010263EDC00	9/20/2010	2010	263	LANDSAT_ETM_SLC_OFF	x	x
277	LT50390352010271EDC00	9/28/2010	2010	271	LANDSAT_TM	x	x

278	LE70390352010279EDC00	10/6/2010	2010	279	LANDSAT_ETM_SLC_OFF	x	
279	LT50390352010287EDC00	10/14/2010	2010	287	LANDSAT_TM	x	x
280	LE70390352010311EDC00	11/7/2010	2010	311	LANDSAT_ETM_SLC_OFF	x	x
281	LT50390352010319PAC01	11/15/2010	2010	319	LANDSAT_TM	x	x
282	LE70390352010327EDC00	11/23/2010	2010	327	LANDSAT_ETM_SLC_OFF	x	
283	LT50390352010335EDC00	12/1/2010	2010	335	LANDSAT_TM	x	x
284	LE70390352011042EDC00	2/11/2011	2011	42	LANDSAT_ETM_SLC_OFF	x	x
285	LT50390352011082PAC01	3/23/2011	2011	82	LANDSAT_TM	x	x
286	LE70390352011090EDC00	3/31/2011	2011	90	LANDSAT_ETM_SLC_OFF	x	x
287	LE70390352011106EDC00	4/16/2011	2011	106	LANDSAT_ETM_SLC_OFF	x	x
288	LT50390352011114PAC01	4/24/2011	2011	114	LANDSAT_TM	x	x
289	LT50390352011146PAC01	5/26/2011	2011	146	LANDSAT_TM	x	x
290	LE70390352011154EDC00	6/3/2011	2011	154	LANDSAT_ETM_SLC_OFF	x	x
291	LT50390352011162PAC01	6/11/2011	2011	162	LANDSAT_TM	x	x
292	LE70390352011170EDC00	6/19/2011	2011	170	LANDSAT_ETM_SLC_OFF	x	x
293	LT50390352011178PAC01	6/27/2011	2011	178	LANDSAT_TM	x	x
294	LT50390352011194PAC01	7/13/2011	2011	194	LANDSAT_TM	x	x
295	LE70390352011202EDC00	7/21/2011	2011	202	LANDSAT_ETM_SLC_OFF	x	x
296	LT50390352011210PAC01	7/29/2011	2011	210	LANDSAT_TM	x	x
297	LE70390352011218EDC00	8/6/2011	2011	218	LANDSAT_ETM_SLC_OFF	x	x
298	LT50390352011226PAC01	8/14/2011	2011	226	LANDSAT_TM	x	x
299	LE70390352011234EDC00	8/22/2011	2011	234	LANDSAT_ETM_SLC_OFF	x	x
300	LT50390352011242PAC01	8/30/2011	2011	242	LANDSAT_TM	x	x
301	LE70390352011250EDC00	9/7/2011	2011	250	LANDSAT_ETM_SLC_OFF	x	x
302	LT50390352011258PAC01	9/15/2011	2011	258	LANDSAT_TM	x	x
303	LE70390352011266EDC00	9/23/2011	2011	266	LANDSAT_ETM_SLC_OFF	x	x
304	LE70390352011298EDC00	10/25/2011	2011	298	LANDSAT_ETM_SLC_OFF	x	x
305	LT50390352011306PAC01	11/2/2011	2011	306	LANDSAT_TM	x	x
306	LE70390352011330EDC00	11/26/2011	2011	330	LANDSAT_ETM_SLC_OFF	x	x
307	LE70390352012013EDC00	1/13/2012	2012	13	LANDSAT_ETM_SLC_OFF	x	
308	LE70390352012029EDC00	1/29/2012	2012	29	LANDSAT_ETM_SLC_OFF	x	
309	LE70390352012061EDC00	3/1/2012	2012	61	LANDSAT_ETM_SLC_OFF	x	x
310	LE70390352012093EDC00	4/2/2012	2012	93	LANDSAT_ETM_SLC_OFF	x	x
311	LE70390352012109EDC04	4/18/2012	2012	109	LANDSAT_ETM_SLC_OFF	x	x
312	LE70390352012125EDC00	5/4/2012	2012	125	LANDSAT_ETM_SLC_OFF	x	x
313	LE70390352012141EDC00	5/20/2012	2012	141	LANDSAT_ETM_SLC_OFF	x	x
314	LE70390352012157EDC00	6/5/2012	2012	157	LANDSAT_ETM_SLC_OFF	x	x
315	LE70390352012173EDC00	6/21/2012	2012	173	LANDSAT_ETM_SLC_OFF	x	x
316	LE70390352012189EDC01	7/7/2012	2012	189	LANDSAT_ETM_SLC_OFF	x	x
317	LE70390352012205EDC00	7/23/2012	2012	205	LANDSAT_ETM_SLC_OFF	x	
318	LE70390352012221EDC00	8/8/2012	2012	221	LANDSAT_ETM_SLC_OFF	x	x

319	LE70390352012237EDC00	8/24/2012	2012	237	LANDSAT_ETM_SLC_OFF	x	x
320	LE70390352012269EDC00	9/25/2012	2012	269	LANDSAT_ETM_SLC_OFF	x	x
321	LE70390352012301EDC00	10/27/2012	2012	301	LANDSAT_ETM_SLC_OFF	x	x
322	LE70390352012317EDC00	11/12/2012	2012	317	LANDSAT_ETM_SLC_OFF	x	x
323	LE70390352012333EDC00	11/28/2012	2012	333	LANDSAT_ETM_SLC_OFF	x	x

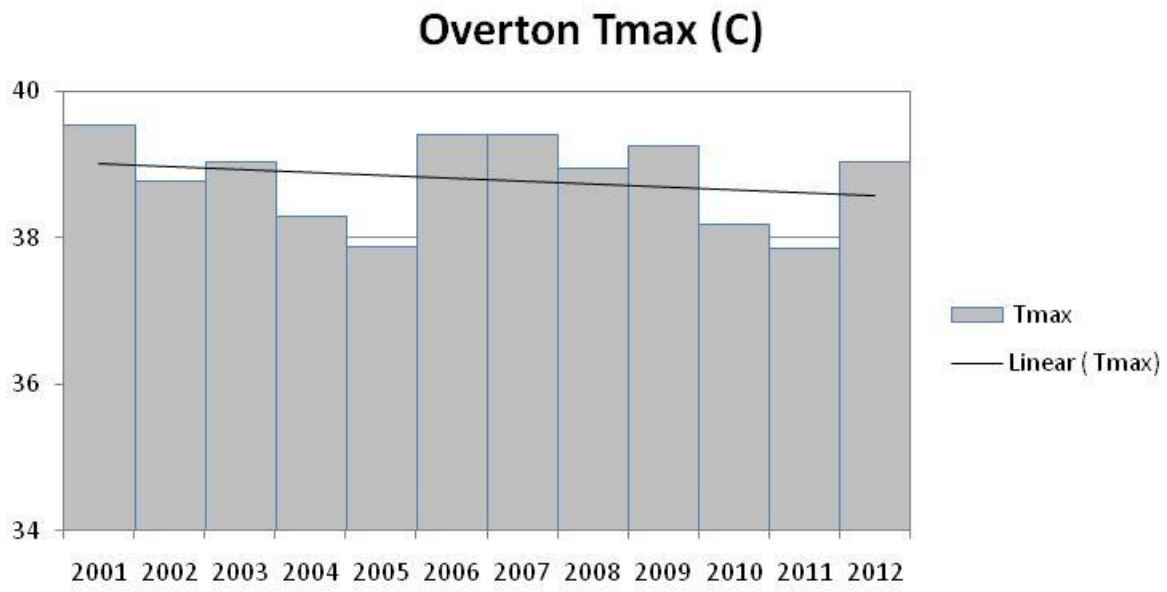

Figure A1. Overton CEMP warm season (May-September) average daily maximum temperature (Tmax).

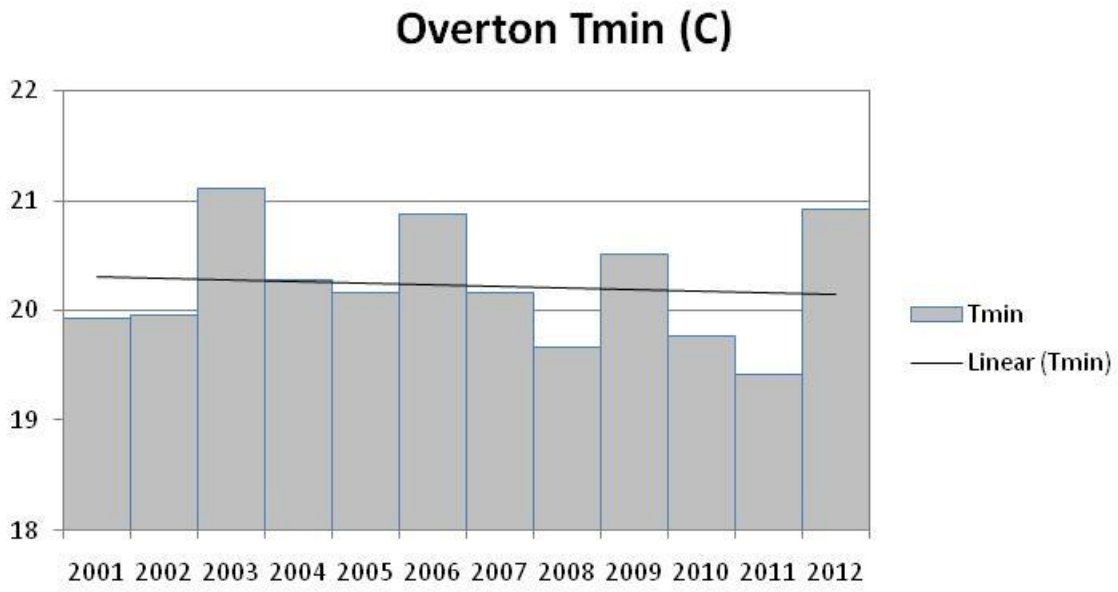

Figure A2. Overton CEMP warm season (May-September) average daily minimum temperature (Tmin).

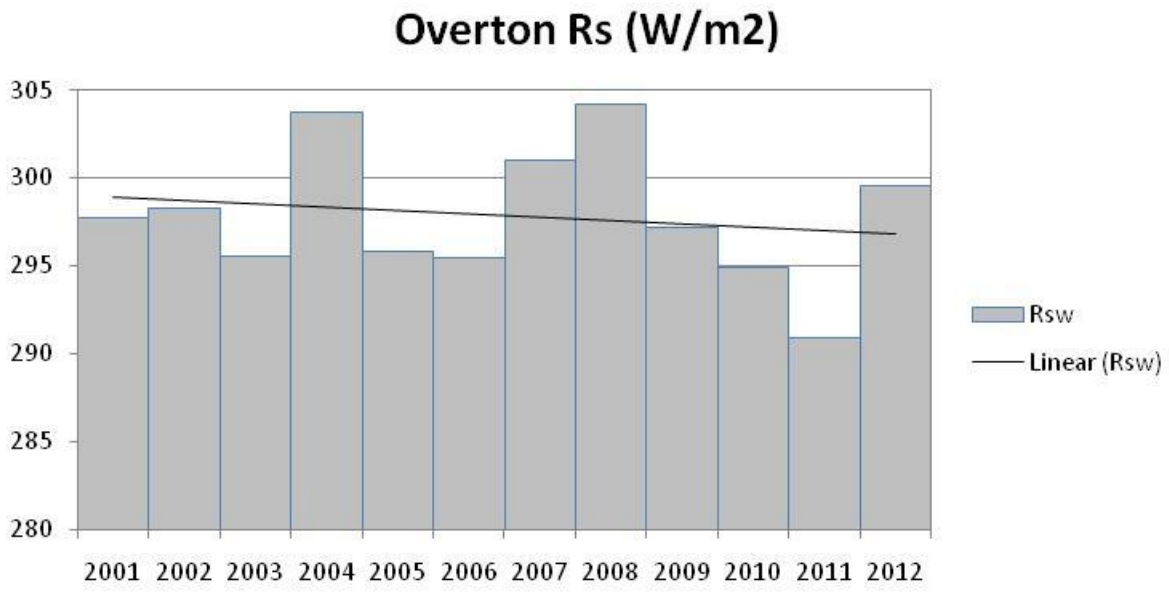

Figure A3. Overton CEMP warm season (May-September) average daily solar radiation (Rs).

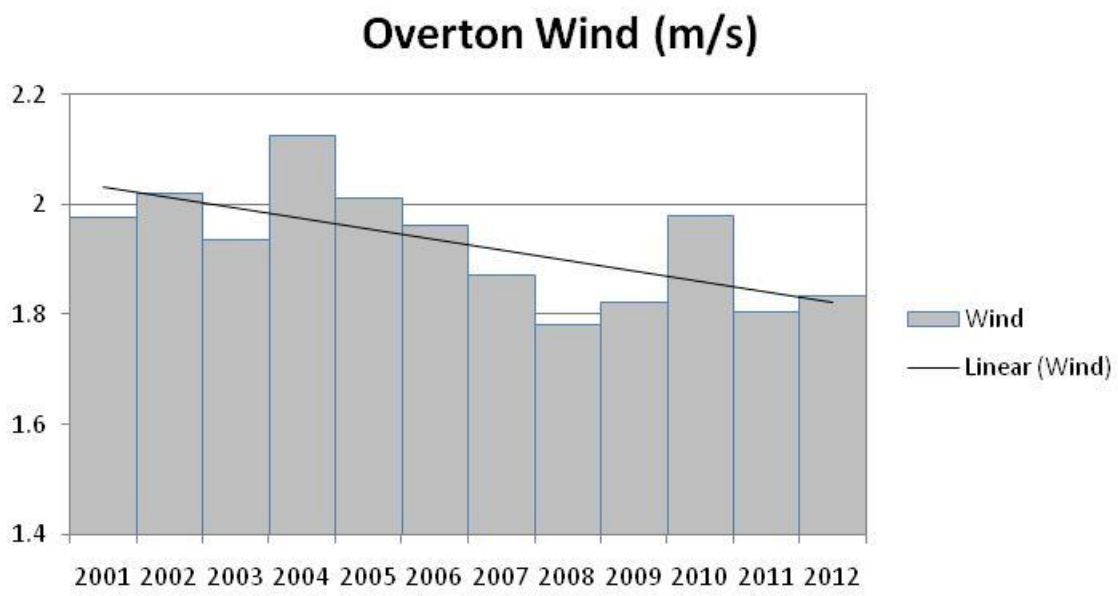

Figure A4. Overton CEMP warm season (May-September) average daily 6m height windspeed.

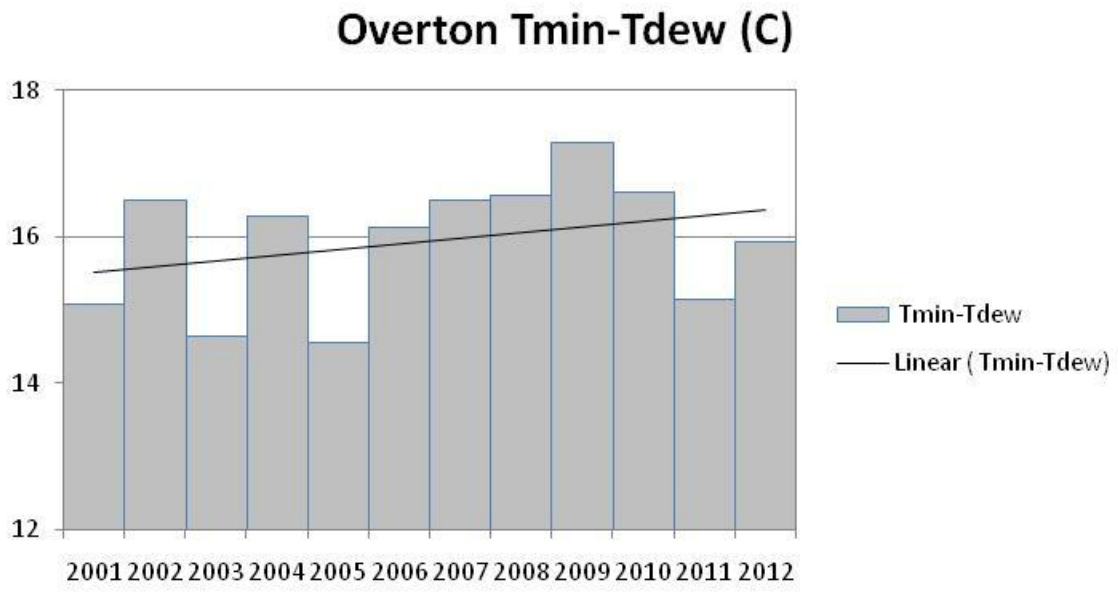

Figure A5. Overton CEMP warm season (May-September) average daily minimum temperature minus dewpoint temperature (i.e. dewpoint depression).

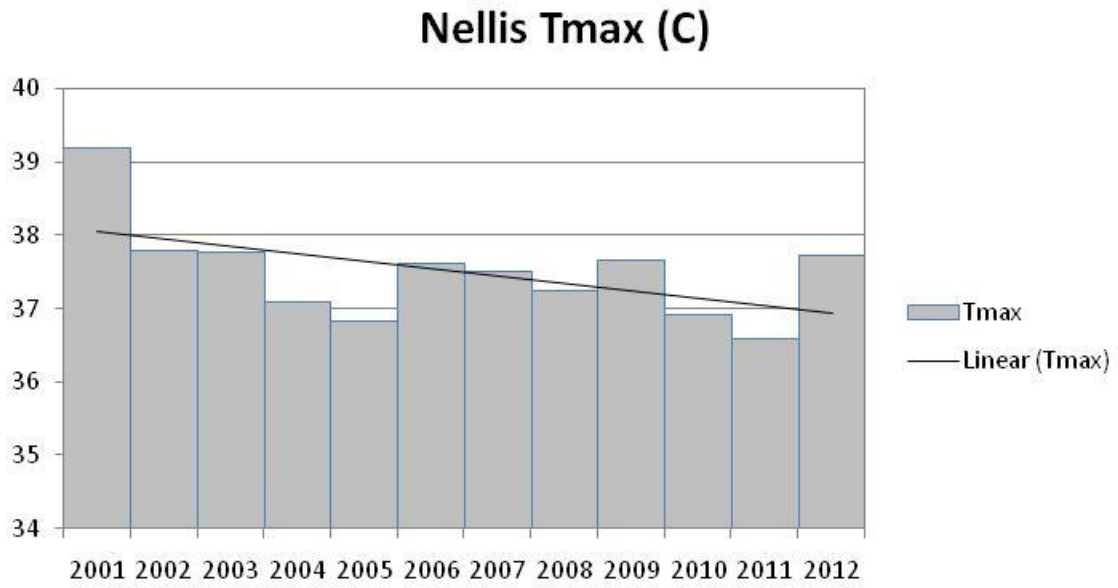

Figure A6. Nellis AFB warm season (May-September) average daily maximum temperature (Tmax).

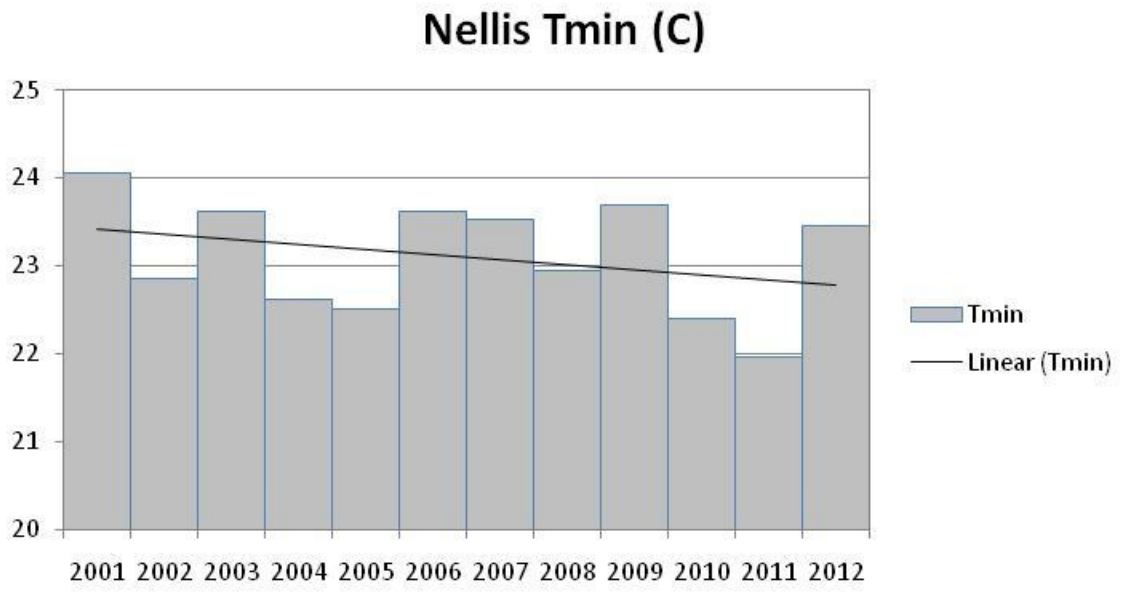

Figure A7. Nellis AFB warm season (May-September) average daily minimum temperature (Tmin).

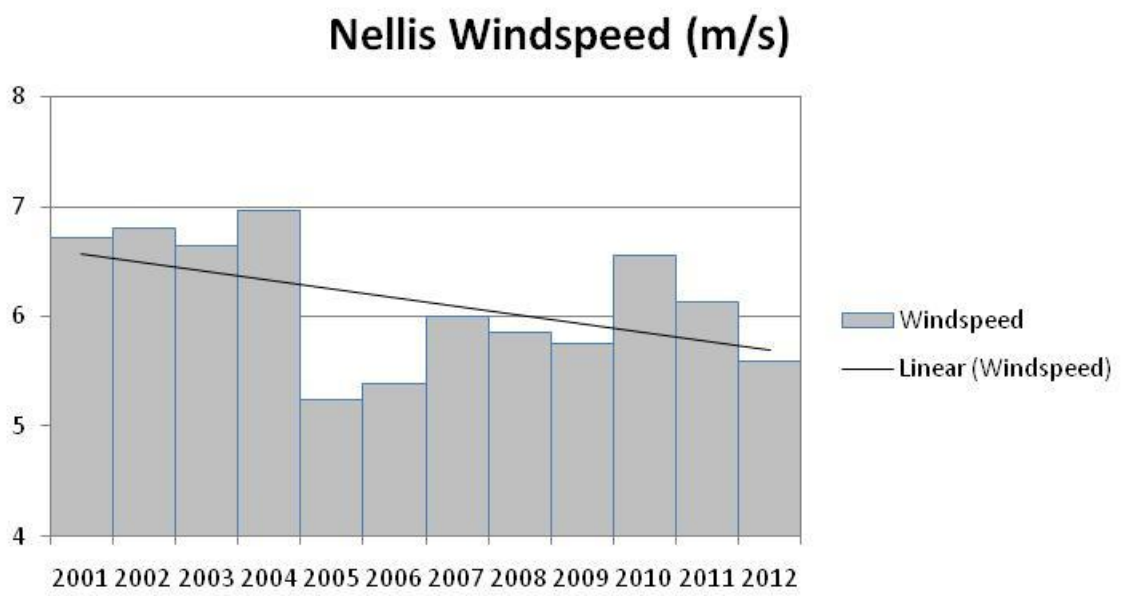

Figure A8. Nellis AFB warm season (May-September) average daily 10m height windspeed.

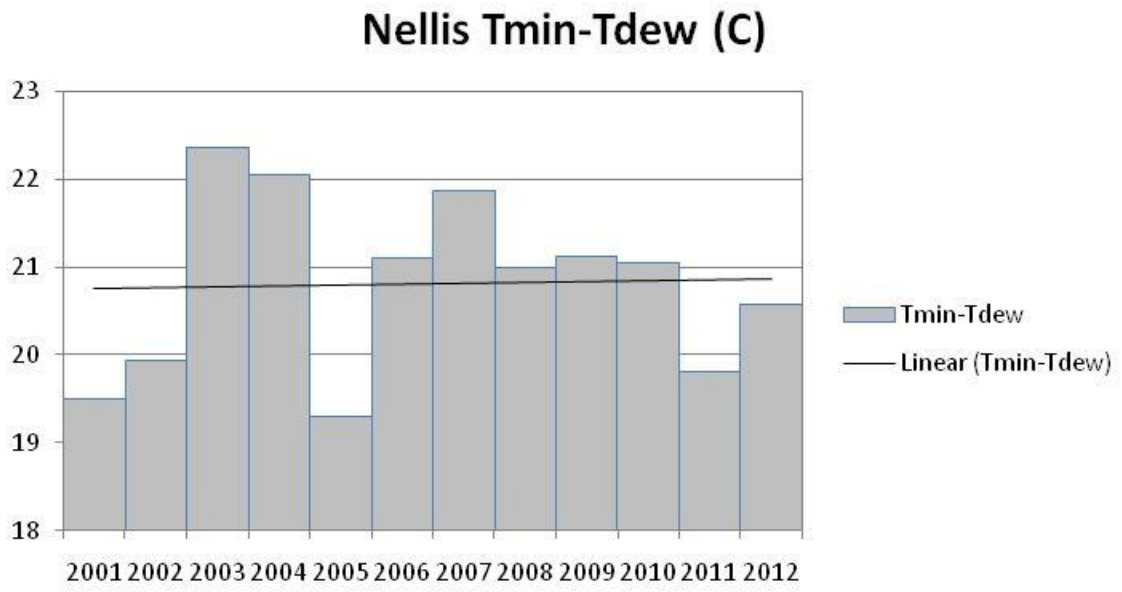

Figure A9. Nellis AFB warm season (May-September) average daily minimum temperature minus dewpoint temperature (i.e. dewpoint depression).

Table A2. Muddy River Springs METRIC *ET* from 2006-2012.

Warm Springs Area METRIC ET (ft)

Month	2006	2007	2008	2009	2010	2011	2012
1	0.11	0.09	0.09	0.10	0.08	0.08	0.11
2	0.12	0.10	0.10	0.10	0.11	0.06	0.13
3	0.20	0.21	0.19	0.23	0.29	0.09	0.18
4	0.38	0.31	0.35	0.26	0.42	0.28	0.30
5	0.54	0.39	0.40	0.46	0.58	0.39	0.47
6	0.54	0.45	0.45	0.48	0.66	0.50	0.53
7	0.59	0.46	0.50	0.57	0.51	0.51	0.44
8	0.51	0.43	0.51	0.56	0.38	0.51	0.44
9	0.41	0.39	0.39	0.44	0.31	0.33	0.39
10	0.22	0.21	0.26	0.26	0.14	0.22	0.28
11	0.10	0.12	0.14	0.13	0.09	0.11	0.13
12	0.09	0.08	0.07	0.09	0.06	0.10	0.08
Seasonal (ft)	3.61	3.08	3.28	3.48	3.48	3.00	3.29
Annual (ft)	3.80	3.24	3.44	3.67	3.62	3.18	3.48

Mean Seasonal (ft)	3.32
Mean Annual (ft)	3.49
Seasonal Slope (ft/yr)	-0.03
Annual Slope (ft/yr)	-0.03
Warm Springs Area (acres)	797
2006-2012 Seasonal Change (ft)	-0.23
2006-2012 Seasonal Change (ac-ft)	-181
2006-2012 Annual Change (ft)	-0.23
2006-2012 Annual Change (ac-ft)	-181

Table A3. Overton CEMP alfalfa reference *ET* (ET_r) for estimating of METRIC *ET* and NDVI *ET*.

Alfalfa Reference ET (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	0.21	0.25	0.25	0.24	0.17	0.27	0.25	0.23	0.25	0.19	0.22	0.25
2	0.27	0.38	0.29	0.26	0.26	0.35	0.29	0.30	0.25	0.22	0.29	0.33
3	0.39	0.52	0.49	0.62	0.52	0.45	0.53	0.55	0.56	0.50	0.44	0.57
4	0.73	0.76	0.78	0.71	0.65	0.73	0.70	0.82	0.72	0.65	0.70	0.71
5	1.04	1.00	0.93	1.00	0.90	1.00	0.96	0.91	0.93	0.90	0.85	1.01
6	1.14	1.13	1.14	1.04	1.05	1.02	1.02	1.01	0.94	1.02	1.04	1.10
7	1.14	1.08	1.05	1.04	0.97	0.94	0.99	0.98	1.00	1.03	0.91	0.91
8	0.92	1.05	0.86	0.94	0.80	0.95	0.90	0.88	0.90	0.95	0.87	0.78
9	0.73	0.71	0.77	0.76	0.75	0.68	0.71	0.63	0.75	0.61	0.57	0.59
10	0.48	0.46	0.58	0.46	0.50	0.40	0.46	0.45	0.54	0.40	0.39	0.43
11	0.29	0.35	0.23	0.24	0.27	0.25	0.28	0.26	0.29	0.29	0.23	0.24
12	0.17	0.17	0.18	0.20	0.22	0.21	0.17	0.15	0.19	0.14	0.21	0.18
Seasonal (ft)	7.12	7.43	7.13	7.06	6.67	6.76	6.84	6.79	6.88	6.59	6.29	6.66
Annual (ft)	7.51	7.85	7.56	7.51	7.06	7.24	7.26	7.17	7.32	6.92	6.72	7.09

2001-2012 Mean Seasonal (ft)	6.85
2001-2012 Mean Annual (ft)	7.27
2006-2012 Mean Seasonal (ft)	6.69
2006-2012 Mean Annual (ft)	7.10
2001-2012 Seasonal Slope (ft/yr)	-0.068
2001-2012 Annual Slope (ft/yr)	-0.069
2006-2012 Seasonal Slope (ft/yr)	-0.057
2006-2012 Annual Slope (ft/yr)	-0.064
2001-2012 Seasonal Change (ft)	-0.82
2006-2012 Seasonal Change (ft)	-0.40
2001-2012 Annual Change (ft)	-0.83
2006-2012 Annual Change (ft)	-0.45

Table A4. Muddy River Springs METRIC fraction of alfalfa reference ET (ET_rF) from 2006-2012. Values with * indicate that NDVI was used to estimate ET_rF using function described in text.

METRIC ETrF

Month	2006	2007	2008	2009	2010	2011	2012
1	0.39*	0.36*	0.37*	0.38*	0.40*	0.39*	0.42*
2	0.34	0.33	0.33*	0.39*	0.49	0.20	0.38*
3	0.45	0.40	0.35	0.41*	0.57	0.22	0.32
4	0.52	0.45	0.42	0.37	0.64	0.40	0.42
5	0.54	0.41	0.45	0.50	0.64	0.46	0.46
6	0.53	0.44	0.44	0.51	0.65	0.48	0.48
7	0.63	0.47	0.51	0.56	0.50	0.57	0.48
8	0.53	0.48	0.58	0.62	0.40	0.59	0.57
9	0.60	0.55	0.61	0.59	0.50	0.57	0.66
10	0.55	0.47	0.58	0.48	0.36	0.55	0.64
11	0.39	0.41	0.54	0.44	0.30	0.45	0.56
12	0.34*	0.38*	0.38*	0.38*	0.45*	0.45*	0.45*
Seasonal	0.51	0.44	0.48	0.49	0.50	0.45	0.50
Annual	0.48	0.43	0.46	0.47	0.49	0.44	0.49
Mean Seasonal	0.48						
Mean Annual	0.47						
Seasonal Slope	0.0005						
Annual Slope	0.0026						
Seasonal Change	0.003						
Annual Change	0.018						

Table A5. Muddy River Springs PRISM Precipitation from 2001-2012.

Warm Springs Area PRISM Precipitation (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	0.123	0.001	0.004	0.010	0.192	0.016	0.013	0.069	0.025	0.187	0.002	0.003
2	0.122	0.000	0.154	0.156	0.215	0.001	0.025	0.050	0.107	0.115	0.073	0.018
3	0.073	0.006	0.072	0.016	0.046	0.092	0.004	0.006	0.000	0.053	0.026	0.023
4	0.016	0.000	0.041	0.083	0.044	0.007	0.010	0.000	0.014	0.009	0.010	0.037
5	0.001	0.000	0.002	0.001	0.004	0.001	0.000	0.017	0.001	0.002	0.021	0.000
6	0.000	0.000	0.000	0.002	0.009	0.010	0.000	0.000	0.002	0.000	0.000	0.000
7	0.013	0.014	0.012	0.009	0.033	0.069	0.052	0.034	0.021	0.003	0.043	0.007
8	0.033	0.000	0.056	0.027	0.039	0.000	0.039	0.021	0.002	0.047	0.004	0.142
9	0.000	0.019	0.009	0.009	0.004	0.015	0.075	0.005	0.005	0.002	0.048	0.068
10	0.000	0.029	0.001	0.119	0.104	0.121	0.000	0.020	0.002	0.108	0.095	0.063
11	0.023	0.015	0.044	0.171	0.007	0.000	0.090	0.055	0.004	0.014	0.030	0.000
12	0.022	0.013	0.065	0.176	0.005	0.016	0.039	0.089	0.054	0.292	0.018	0.085
Seasonal (ft)	0.281	0.084	0.389	0.593	0.505	0.315	0.294	0.208	0.158	0.353	0.351	0.358
Annual (ft)	0.426	0.097	0.458	0.779	0.701	0.346	0.346	0.366	0.238	0.832	0.371	0.446

2001-2012 Mean Seasonal (ft)	0.32
2001-2012 Mean Annual (ft)	0.45
2006-2012 Mean Seasonal (ft)	0.29
2006-2012 Mean Annual (ft)	0.42
2001-2012 Seasonal Slope (ft/yr)	0.000
2001-2012 Annual Slope (ft/yr)	0.006
2006-2012 Seasonal Slope (ft/yr)	0.014
2006-2012 Annual Slope (ft/yr)	0.029
Warm Springs Area (acres)	797
2001-2012 Seasonal Change (ft)	0.00
2001-2012 Seasonal Change (ac-ft)	-3
2006-2012 Seasonal Change (ft)	0.10

2006-2012 Seasonal Change (ac-ft)	78
2001-2012 Annual Change (ft)	0.07
2001-2012 Annual Change (ac-ft)	53
2006-2012 Annual Change (ft)	0.20
2006-2012 Annual Change (ac-ft)	162

Table A6. Muddy River Springs METRIC ET minus PRISM precipitation from 2006-2012.

Warm Springs Area METRIC ET minus PRISM Precipitation (ft)

Month	2006	2007	2008	2009	2010	2011	2012
1	0.09	0.07	0.02	0.07	-0.11	0.08	0.10
2	0.12	0.07	0.05	-0.01	-0.01	-0.02	0.11
3	0.11	0.21	0.18	0.22	0.24	0.07	0.16
4	0.37	0.31	0.35	0.25	0.41	0.28	0.26
5	0.54	0.39	0.39	0.46	0.57	0.37	0.47
6	0.53	0.45	0.45	0.48	0.66	0.50	0.53
7	0.52	0.41	0.46	0.55	0.51	0.47	0.43
8	0.51	0.39	0.49	0.56	0.33	0.51	0.30
9	0.40	0.32	0.38	0.43	0.30	0.28	0.33
10	0.10	0.21	0.24	0.26	0.03	0.12	0.21
11	0.10	0.03	0.09	0.13	0.07	0.08	0.13
12	0.07	0.04	-0.02	0.03	-0.23	0.08	-0.01
Seasonal (ft)	3.29	2.78	3.07	3.33	3.13	2.65	2.93
Annual (ft)	3.45	2.90	3.07	3.43	2.79	2.81	3.03

Mean Seasonal (ft)	3.03
Mean Annual (ft)	3.07
Seasonal Slope (ft/yr)	-0.046
Annual Slope (ft/yr)	-0.062
Warm Springs Area (acres)	797
2006-2012 Seasonal Change (ft)	-0.32
2006-2012 Seasonal Change (ac-ft)	-258
2006-2012 Annual Change (ft)	-0.43
2006-2012 Annual Change (ac-ft)	-344

Table A7. Muddy River Springs ETrF of METRIC ET minus PRISM precipitation (METRIC ET-PPT)/ETr from 2006-2012.

METRIC ETrF of ET minus PRISM Precipitation

Month	2006	2007	2008	2009	2010	2011	2012
1	0.33	0.30	0.07	0.28	-0.59	0.38	0.41
2	0.34	0.24	0.16	-0.03	-0.03	-0.06	0.33
3	0.24	0.39	0.34	0.40	0.47	0.16	0.28
4	0.51	0.43	0.42	0.35	0.62	0.39	0.37
5	0.54	0.41	0.43	0.50	0.64	0.43	0.46
6	0.52	0.44	0.44	0.51	0.65	0.48	0.48
7	0.56	0.41	0.47	0.54	0.49	0.52	0.47
8	0.53	0.43	0.55	0.62	0.35	0.59	0.39
9	0.58	0.45	0.60	0.58	0.50	0.48	0.55
10	0.25	0.47	0.54	0.48	0.09	0.30	0.50
11	0.39	0.09	0.33	0.43	0.25	0.33	0.56
12	0.34	0.23	-0.15	0.18	-1.67	0.36	-0.03
Seasonal	0.45	0.38	0.43	0.44	0.40	0.36	0.44
Annual	0.43	0.36	0.35	0.40	0.15	0.36	0.40
Mean Seasonal	0.41						
Mean Annual	0.35						
Seasonal Slope	-0.003						
Annual Slope	-0.010						
Seasonal Change	-0.02						
Annual Change	-0.07						

Table A8. Muddy River Springs NDVI ET from 2001-2012.

Warm Springs Area NDVI Estimated ET (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	0.09	0.10	0.09	0.09	0.08	0.11	0.09	0.09	0.10	0.08	0.08	0.11
2	0.10	0.15	0.11	0.09	0.14	0.14	0.10	0.10	0.10	0.10	0.09	0.13
3	0.19	0.21	0.19	0.26	0.36	0.18	0.21	0.21	0.23	0.22	0.16	0.22
4	0.45	0.37	0.38	0.42	0.48	0.34	0.36	0.39	0.34	0.36	0.30	0.31
5	0.72	0.55	0.54	0.60	0.67	0.58	0.55	0.50	0.55	0.54	0.43	0.52
6	0.77	0.65	0.64	0.66	0.79	0.61	0.60	0.60	0.60	0.64	0.58	0.59
7	0.74	0.63	0.60	0.66	0.68	0.56	0.56	0.60	0.66	0.43	0.53	0.49
8	0.58	0.61	0.51	0.60	0.61	0.57	0.56	0.56	0.57	0.46	0.52	0.43
9	0.46	0.44	0.45	0.49	0.57	0.40	0.44	0.40	0.47	0.35	0.33	0.34
10	0.30	0.27	0.34	0.29	0.34	0.23	0.26	0.27	0.31	0.21	0.22	0.26
11	0.16	0.17	0.12	0.13	0.16	0.12	0.15	0.14	0.16	0.15	0.12	0.13
12	0.08	0.07	0.07	0.10	0.11	0.09	0.08	0.07	0.09	0.06	0.10	0.08
Seasonal (ft)	4.47	4.05	3.87	4.19	4.81	3.74	3.78	3.77	3.98	3.47	3.28	3.42
Annual (ft)	4.64	4.23	4.04	4.38	5.00	3.93	3.94	3.93	4.17	3.60	3.46	3.60

2001-2012 Mean Seasonal (ft)	3.90
2001-2012 Mean Annual (ft)	4.08
2006-2012 Mean Seasonal (ft)	3.63
2006-2012 Mean Annual (ft)	3.80
2001-2012 Seasonal Slope (ft/yr)	-0.089
2001-2012 Annual Slope (ft/yr)	-0.090
2006-2012 Seasonal Slope (ft/yr)	-0.081
2006-2012 Annual Slope (ft/yr)	-0.081
Warm Springs Area (acres)	797
2001-2012 Seasonal Change (ft)	-1.07
2001-2012 Seasonal Change (ac-ft)	-851
2006-2012 Seasonal Change (ft)	-0.56

2006-2012 Seasonal Change (ac-ft)	-450
2001-2012 Annual Change (ft)	-1.07
2001-2012 Annual Change (ac-ft)	-856
2006-2012 Annual Change (ft)	-0.57
2006-2012 Annual Change (ac-ft)	-451

Table A9. Muddy River Springs NDVI ET minus PRISM Precipitation from 2001-2012.

Warm Springs Area NDVI Estimated ET minus PRISM Precipitation (ft)

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	-0.04	0.10	0.09	0.08	-0.11	0.09	0.07	0.02	0.07	-0.11	0.08	0.10
2	-0.02	0.15	-0.05	-0.06	-0.07	0.14	0.07	0.05	-0.01	-0.02	0.02	0.11
3	0.12	0.20	0.12	0.25	0.31	0.09	0.21	0.20	0.22	0.17	0.13	0.19
4	0.43	0.37	0.34	0.34	0.43	0.34	0.35	0.39	0.33	0.35	0.29	0.28
5	0.72	0.55	0.53	0.60	0.67	0.58	0.55	0.49	0.55	0.54	0.41	0.52
6	0.77	0.65	0.64	0.66	0.78	0.60	0.60	0.60	0.60	0.64	0.58	0.59
7	0.73	0.62	0.59	0.65	0.65	0.49	0.51	0.57	0.64	0.42	0.48	0.48
8	0.55	0.61	0.45	0.57	0.57	0.57	0.52	0.54	0.57	0.41	0.51	0.28
9	0.45	0.42	0.44	0.48	0.57	0.39	0.36	0.39	0.46	0.35	0.28	0.28
10	0.30	0.24	0.33	0.17	0.24	0.11	0.26	0.25	0.31	0.11	0.13	0.19
11	0.14	0.16	0.08	-0.04	0.16	0.12	0.06	0.09	0.15	0.13	0.09	0.13
12	0.06	0.06	0.01	-0.08	0.10	0.07	0.04	-0.02	0.03	-0.23	0.08	-0.01
Seasonal (ft)	4.19	3.97	3.48	3.60	4.31	3.42	3.48	3.57	3.82	3.11	2.93	3.06
Annual (ft)	4.21	4.13	3.58	3.60	4.30	3.58	3.59	3.56	3.93	2.77	3.09	3.16

2001-2012 Mean Seasonal (ft)	3.58
2001-2012 Mean Annual (ft)	3.63
2006-2012 Mean Seasonal (ft)	3.34
2006-2012 Mean Annual (ft)	3.38
2001-2012 Seasonal Slope (ft/yr)	-0.089
2001-2012 Annual Slope (ft/yr)	-0.095
2006-2012 Seasonal Slope (ft/yr)	-0.095
2006-2012 Annual Slope (ft/yr)	-0.110
Warm Springs Area (acres)	797
2001-2012 Seasonal Change (ft)	-1.06
2001-2012 Seasonal Change (ac-ft)	-849
2006-2012 Seasonal Change (ft)	-0.66

2006-2012 Seasonal Change (ac-ft)	-528
2001-2012 Annual Change (ft)	-1.14
2001-2012 Annual Change (ac-ft)	-910
2006-2012 Annual Change (ft)	-0.77
2006-2012 Annual Change (ac-ft)	-613

Table A10. Muddy River Springs ETrF of NDVI ET minus PRISM precipitation (NDVI ET-PPT)/ETr) from 2001-2012.

NDVI ETrF of ET minus PRISM Precipitation

Month	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
1	-0.17	0.42	0.36	0.32	-0.66	0.33	0.30	0.07	0.28	-0.59	0.38	0.41
2	-0.07	0.39	-0.17	-0.24	-0.27	0.39	0.26	0.16	-0.03	-0.07	0.07	0.33
3	0.30	0.40	0.25	0.40	0.60	0.20	0.39	0.38	0.40	0.33	0.29	0.34
4	0.60	0.49	0.44	0.47	0.66	0.46	0.50	0.48	0.46	0.54	0.41	0.39
5	0.69	0.55	0.57	0.60	0.74	0.58	0.57	0.54	0.59	0.60	0.48	0.52
6	0.68	0.57	0.56	0.63	0.74	0.59	0.58	0.59	0.64	0.63	0.56	0.54
7	0.64	0.57	0.56	0.63	0.67	0.52	0.51	0.58	0.63	0.41	0.54	0.53
8	0.59	0.58	0.52	0.61	0.71	0.60	0.57	0.61	0.63	0.43	0.59	0.36
9	0.62	0.59	0.57	0.63	0.76	0.57	0.51	0.62	0.62	0.58	0.49	0.46
10	0.62	0.53	0.57	0.37	0.48	0.27	0.58	0.55	0.57	0.27	0.32	0.45
11	0.48	0.46	0.32	-0.18	0.58	0.49	0.20	0.32	0.52	0.44	0.37	0.54
12	0.36	0.34	0.05	-0.39	0.48	0.34	0.23	-0.15	0.18	-1.67	0.36	-0.03
Seasonal	0.52	0.51	0.42	0.39	0.57	0.47	0.47	0.48	0.50	0.42	0.41	0.45
Annual	0.45	0.49	0.38	0.32	0.46	0.45	0.43	0.40	0.46	0.16	0.41	0.40
Mean Seasonal	0.47											
Mean Annual	0.40											
Seasonal Slope	-0.005											
Annual Slope	-0.008											
Seasonal Change	-0.06											
Annual Change	-0.10											