Update on Project "Monitoring the Effects of Weather Conditions on Evapotranspiration North Platte River Basin"

Wendy Ryan and Nolan Doesken
Colorado Climate Center
Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

30 June 2011

Introduction

Beginning in the spring of 2009, three CoAgMet (Colorado Agricultural Meteorological Network) stations were installed in North Park, CO. Station metadata can be found in Table 1. Each station is equipped with the following sensors: temperature, relative humidity, wind speed and direction, solar radiation, precipitation and soil temperatures at 2 and 6 inches. The stations are equipped with radio frequency (RF) telemetry radios that transmit data to the Walden Cooperative Extension Office where a network interface transmits the data directly to the Colorado Climate Center in Fort Collins, CO. Both daily and hourly data are available and their descriptions can be found here: http://ccc.atmos.colostate.edu/~coagmet/rawdata_docs.php

Table 1: North Park CoAgMet Station Metadata

Station ID	Name	Location	Latitude	Longitude	Elevation (ft)
COW01	Cowdrey	9 miles north of Walden	40.8659	-106.336	7895
HEB01	Hebron	13 miles SW of Walden	40.5455	-106.388	8170
LAR01	Larand	8 miles south of Walden	40.6126	-106.3	8252

The goal of this research project is to correlate various methods of consumptive use quantification including: atmometer readings from low cost gages that mimic evapotranspiration, evaporation pan readings, weather station based calculations and lysimeter operations at the Arapahoe National Wildlife Refuge. Once these methods are analyzed, crop coefficients for the high altitude hay meadows in North Park can be derived. With the exception of the weather station estimates, these data are collected by Colorado Division of Water Resources Division 6 staff.

Maintenance Update

In the spring of 2011, all three stations were serviced to ensure quality data for the irrigation season. This service visit entailed removing the temperature/humidity and solar sensors and replacing them with recalibrated sensors. Wind bearings were also changed. The rain gage at HEB01 was replaced with a new gage due to intermittent problems with the other gage. The solar sensor at LAR01 had been under-reporting by approximately 5%. This sensor was replaced

and will be compared to last year; however bird droppings did seem abundant when servicing this station and the solution may be as simple as mounting a bird perch.

Observations and Findings

The following sections provide a review and comparison of meteorological conditions observed from the time of installation of these three North Park weather stations in the spring of 2009 through the end of 2010. 2011 data will be included in later reports. This report focuses on the meteorological parameters that are used in the calculation of evapotranspiration – temperature, vapor pressure (humidity), wind speed (wind run) and solar radiation. Each section concludes with a summary of how the results of that element should affect the amount of ET calculated.

Temperature

A feature of the CoAgMet data delivery system is a daily comparison of regional data from stations in close proximity to one another. The North Park region includes: HEB01, LAR01, COW01 and WFD01 (Wolford Mountain Reservoir). This quick comparison pointed out the fact that LAR01 is generally warmer (in some cases 10+ degrees F) on overnight minimum temperatures than the stations in HEB01 or COW01, even though all three stations are generally within 2 degrees Fahrenheit of one another on daily maximum temperatures.

Figures 1 – 2 illustrate the monthly temperature differences at the three sites. All sites are very similar on maximum temperatures but with COW01 slightly warmer than the other stations in spring and late summer/fall. Minimum temperatures are where the three locations show the largest differences. COW01 is generally the coldest site in the fall and winter months, and LAR01 consistently shows higher minimum temperatures than the other two sites. Minor differences in daily maximum temperatures are consistent with elevation differences with COW01 being the lowest elevation of the 3 sites. Differences in minimum temperatures are related to nocturnal wind patterns and areas of cold air trapping (COW01) and draining (LAR01).

From the maximum temperature comparison, one would expect COW01 to exhibit the highest ET due to higher maximum temperatures in the summer, followed by HEB01 then LAR01. Because minimum temperatures normally occur while plants are not transpiring, no conclusions on ET rates will be speculated from minimum temperatures.

Maximum Temperature Comparison

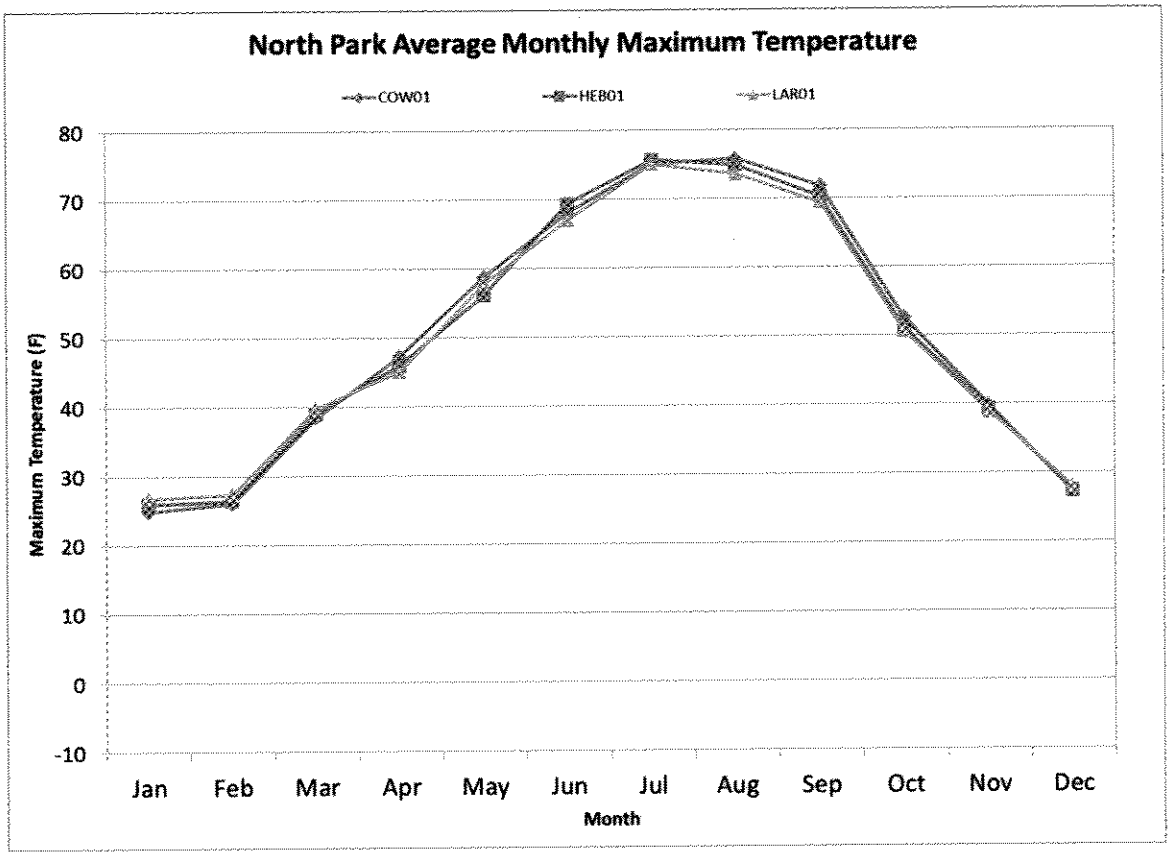

Figure 1: Monthly Average Maximum Temperatures (F)

(based on data from spring 2009 through 2010).

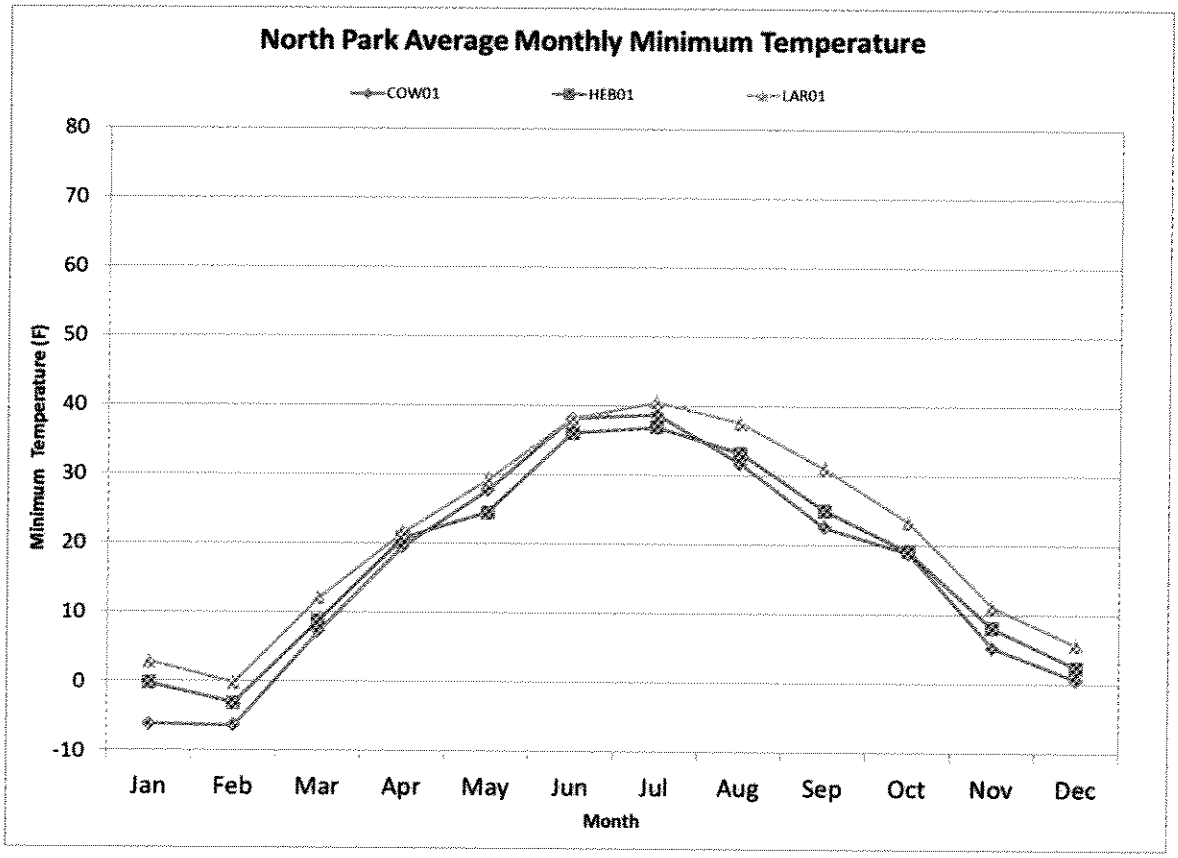

Figure 2: Monthly Average Minimum Temperatures (F)
(based on data from spring 2009 through 2010).

Vapor Pressure

Vapor pressure is the measure of the partial pressure of water vapor present in the atmosphere. Vapor pressure is similar to relative humidity in that it is a measure of the amount of water vapor present in the atmosphere. Relative humidity, however, is normalized to the amount of vapor the atmosphere could potentially hold at air temperature *x* and reported as a percentage of that saturation level. For example, the vapor pressure associated with 100% relative humidity and an air temperature of 60 degrees F is much more than the vapor pressure when the relative humidity is 100% at a temperature of 35 F. This is because air can "hold" much more water vapor at warmer temperatures. If all other conditions (temperature, wind, solar radiation) were constant (which they rarely are), when vapor pressure in the atmosphere is lower then there is less water vapor in the air which translates to higher vapor pressure gradients above plant canopies and higher evapotranspiration rates. When vapor pressure is higher, less evapotranspiration occurs due to the air having abundant moisture. . l.

Figure 3 graphically shows the mean monthly vapor pressure at the three sites. Not surprisingly, vapor pressure is highest in the summer when temperatures are warmer and the atmosphere can "hold" more water vapor. From these results alone, one would expect COW01 to have less ET in June, July and August than the other two sites due to the higher vapor pressure in those months. HEB01 generally shows lower vapor pressure in most months and would therefore exhibit a higher ET rate than the other two locations based on Figure 3.

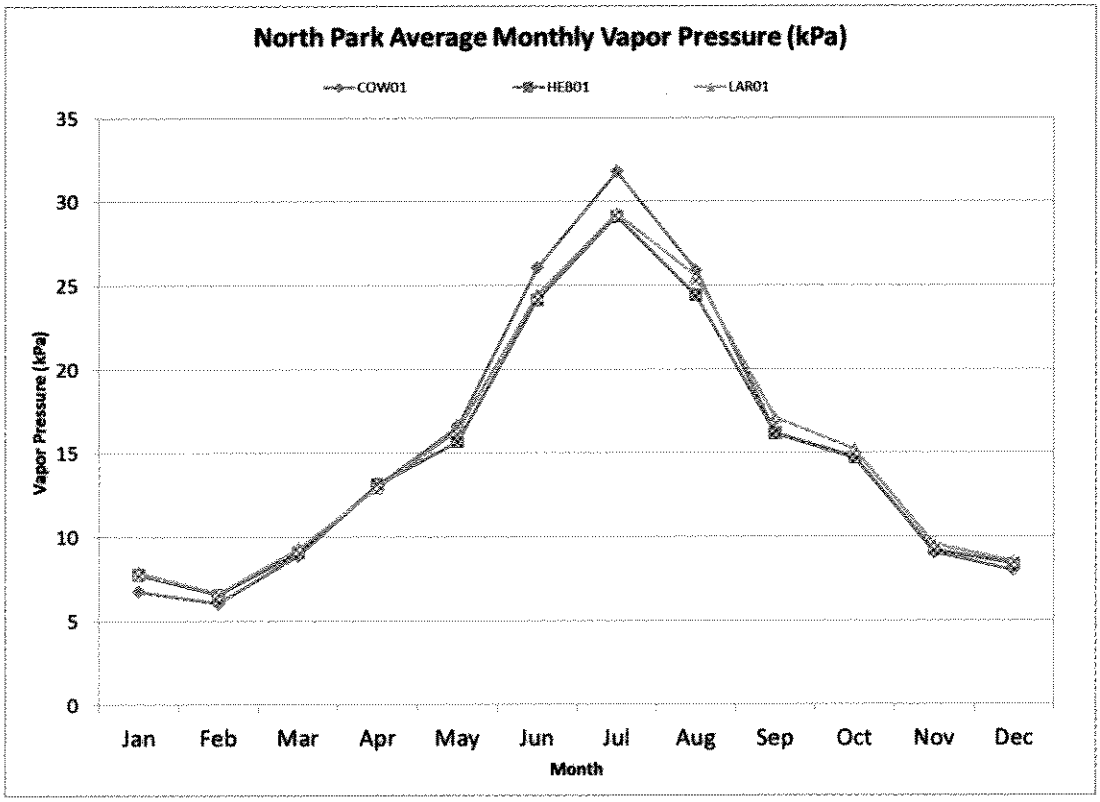

Figure 3: Monthly Mean Vapor Pressure (kPa)

(based on data from spring 2009 through 2010).

Wind Run

Wind run is defined as the amount of wind blowing past the anemometer on any given day, measured in miles/day which can then be summed over the month. Divide that number by 24 and it is then the average wind speed in miles per hour. Figure 4 compares the wind run at the three sites. All sites show similar patterns through the year with wind speeds lowest in summer. LAR01 is consistently the windiest of the three sites and therefore, would exhibit the highest ET rates based on wind alone. Conversely, COW01 exhibited the least amount of wind in nearly every month which would translate to lower ET values than the other two sites, if other factors were uniform.0

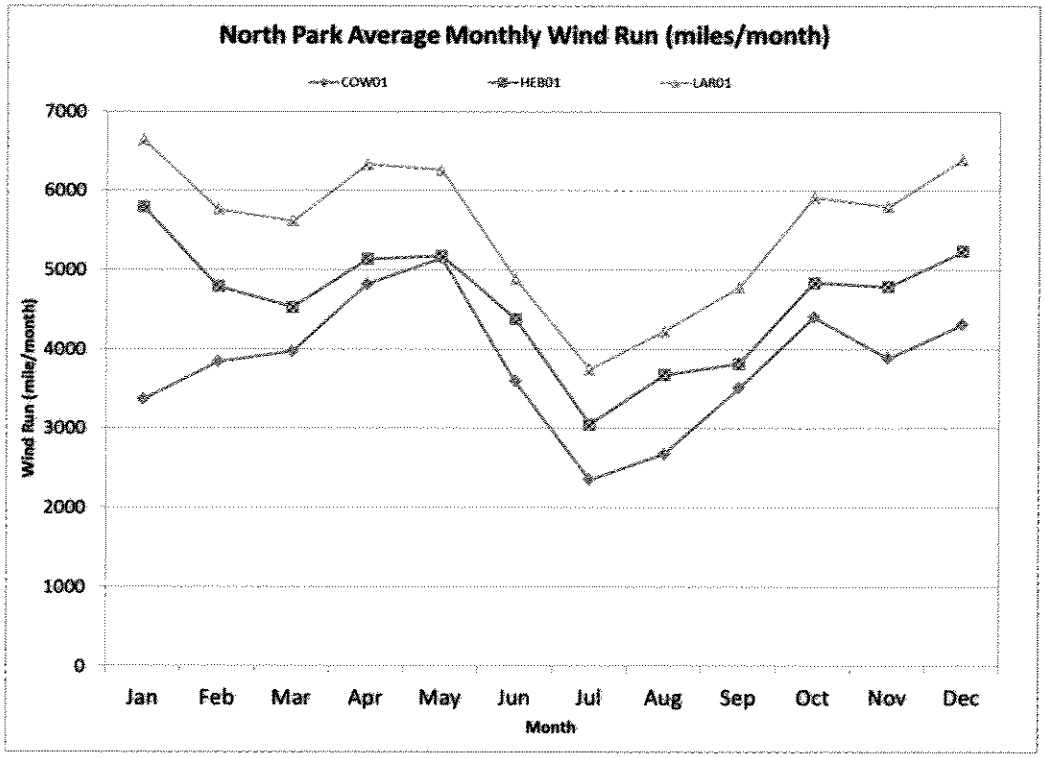

Figure 4: Monthly Mean Wind Run (miles/month)

(based on data from spring 2009 through 2010).

Solar Radiation

The comparison of solar radiation across the basin is a complex one due to factors affecting the amount of solar radiation at a site including: latitude, elevation, cloud cover differences, time of year, and the levelness of the sensors. This monthly comparison points to one issue worthy of further investigation and that is the sensor at the LAR01 site in Figure 5. If cloudiness patterns were similar across North Park (which they probably aren't) then you would expect the highest elevation site to receive the most solar radiation. That is not the case here. This graphic shows that both COW01 and HEB01 are experiencing greater solar radiation than LAR01. It seems unlikely that LAR01 would be the cloudiest of the three locations, which is pointing to a potential sensor issue. This could simply be the presence of "bird droppings" on the sensor, as birds are active at the LAR01 site. It could also point to a sensor that has drifted out of calibration. This sensor was replaced in early May 2011.

For further investigation, clear sky solar radiation values where calculated (based off day of year, elevation, latitude, etc.) following the ASCE guidelines for days deemed "cloudless" by visual inspection of the data. On days with no clouds, the readings at LAR01 were approximately 5% lower than expected clear sky radiation calculation.

A more rigorous site visit and sensor checking schedule may be needed to make sure that sensors are kept clean and level. The impact on data quality has not been severe so far, but it does raise questions worthy of care and consideration.

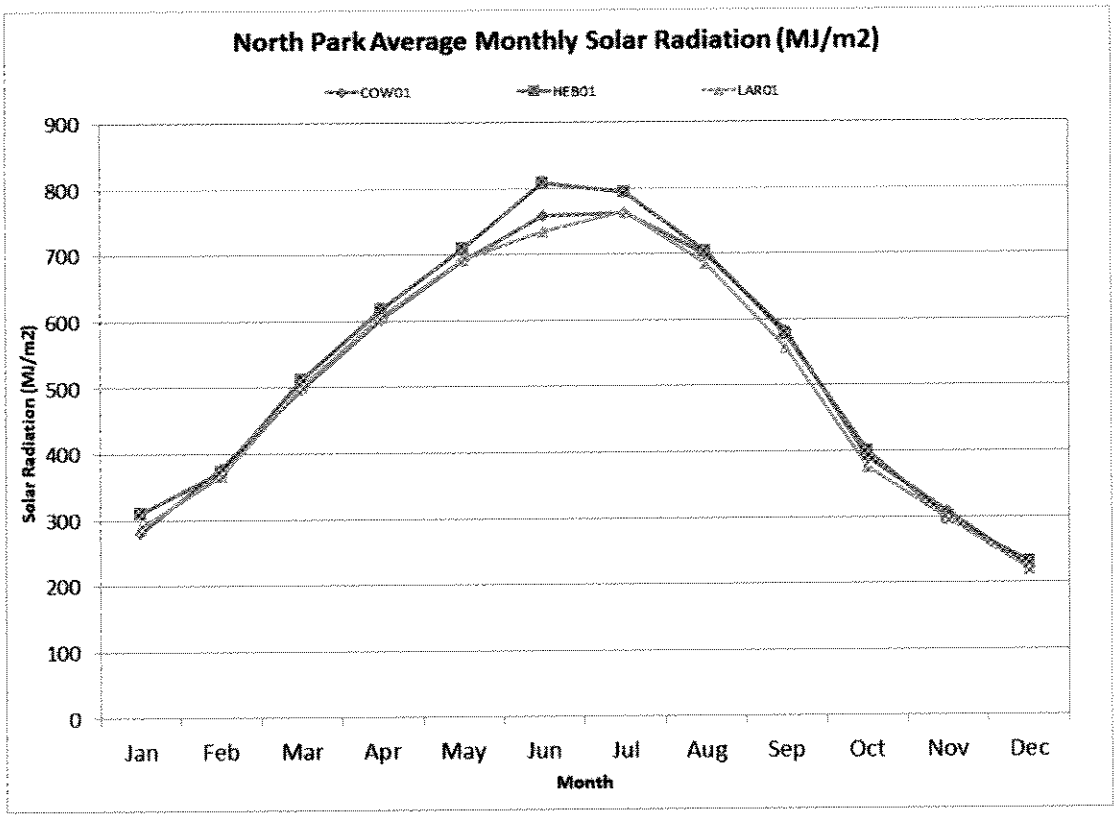

Figure 5: Monthly Solar Radiation (MJ/m2)

(based on data from spring 2009 through 2010).

Reference ET and Crop Coefficients

In order to compare reference ET across the basin, the weather station data can be used to calculate alfalfa reference ET and a variety of crop ET values for comparison to the in situ measurement at the lysimeter and evaporation pan sites. The lysimeters located at the Arapahoe Wildlife Refuge have been operated by Colorado Division of Water Resources since 2001. These are compensating lysimeters that require one to fill them and measure the amount of water added each time. The main, and most important, assumption of this type of lyismeter is that water is NOT limited to the plants in the lysimeter. This assumption may not be valid for Walden due to infrequent filling of the lysimeter plot due to time/staff constraints.

A Class A evaporation pan has also been operated in Walden since 1983, although it has been recently moved to the new observer's house. This method uses a metal pan full of water that is

measured, compensated for precipitation and used to estimate evaporation. A time series of growing season (May-Sept) pan evaporation, lysimeter data and weather station calculated ET is shown in Figure 6. There is seemingly a recent shift in the evaporation pan data due to the change of location; however this will take several years at the new location to quantify. It is also apparent that the pan evaporation and weather station measurements show the highest water loss. Because the weather station calculations are close to pan evaporation values (not edited with a pan coefficient), this suggest that the alfalfa reference in not representative for North Park which is what one would expect

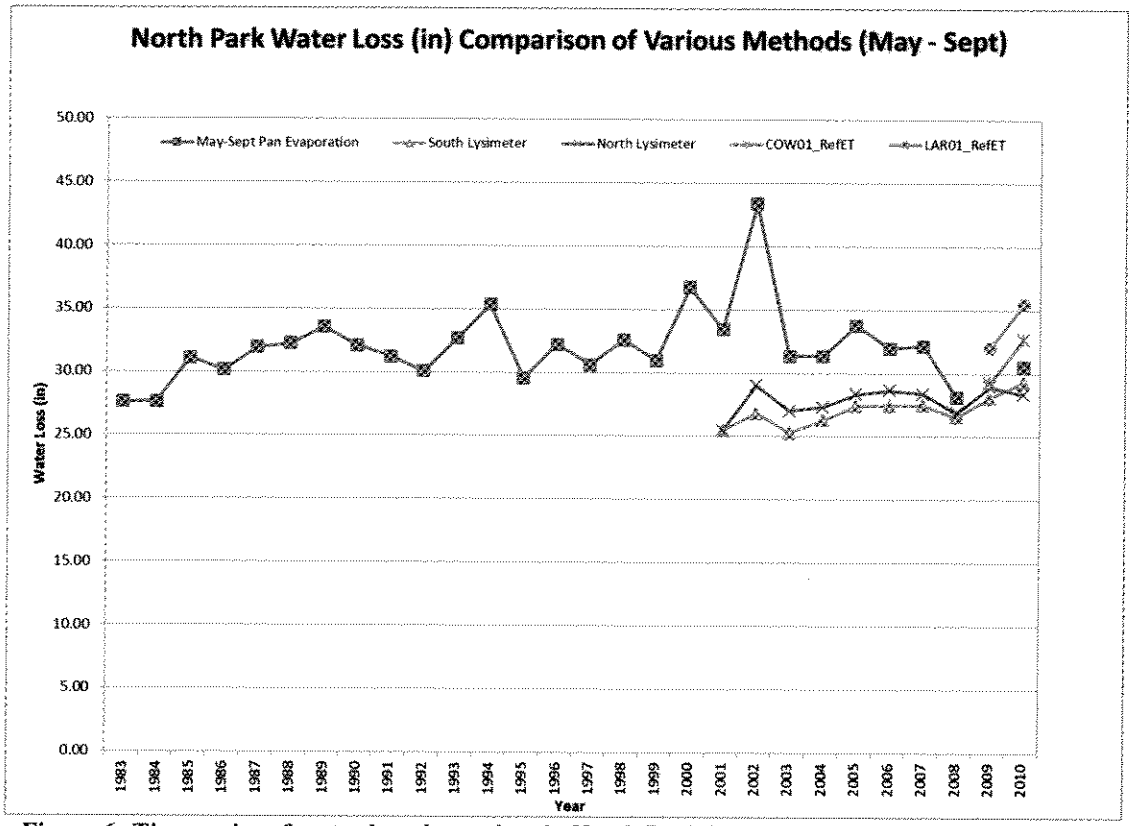

Figure 6: Time series of water loss data taken in North Park including: pan evaporation, lysimeter readings, weather station calculated alfalfa reference ET.

Figure 7 illustrates the cumulative growing season reference ET for the Kimberly-Penman alfalfa reference equation, cool season turf ET and lysimeter data. If the lysimeter data are accurate, which is questionable, this graphic shows that alfalfa reference ET is an overestimate of consumptive use in the North Park area, which is also what was seen in Figure 6. For comparison, crop ET for cool season turf was also considered. This graphic shows that cool season turf provides an underestimate of ET compared to the lysimeter data. No conclusive results can be gleaned from this data due to issues with the lysimeter measurements this year due to flooding of the lysimeters with river water during a high runoff season and also the infrequent watering problem discussed earlier. The infrequent visits are troublesome because when large amounts of water (>50 gallons) are added in one visit, it can be ascertained that water was limited to the plant during the time period resulting in an underestimate of actual ET for that period.

This figure also illustrates how all of the meteorological variables discussed above interact and contribute to reference ET values. It seems that the reduced wind and increased vapor pressures experienced at COW01 results in lower ET values than at the other two locations where reference ET estimates and patterns are quite similar.

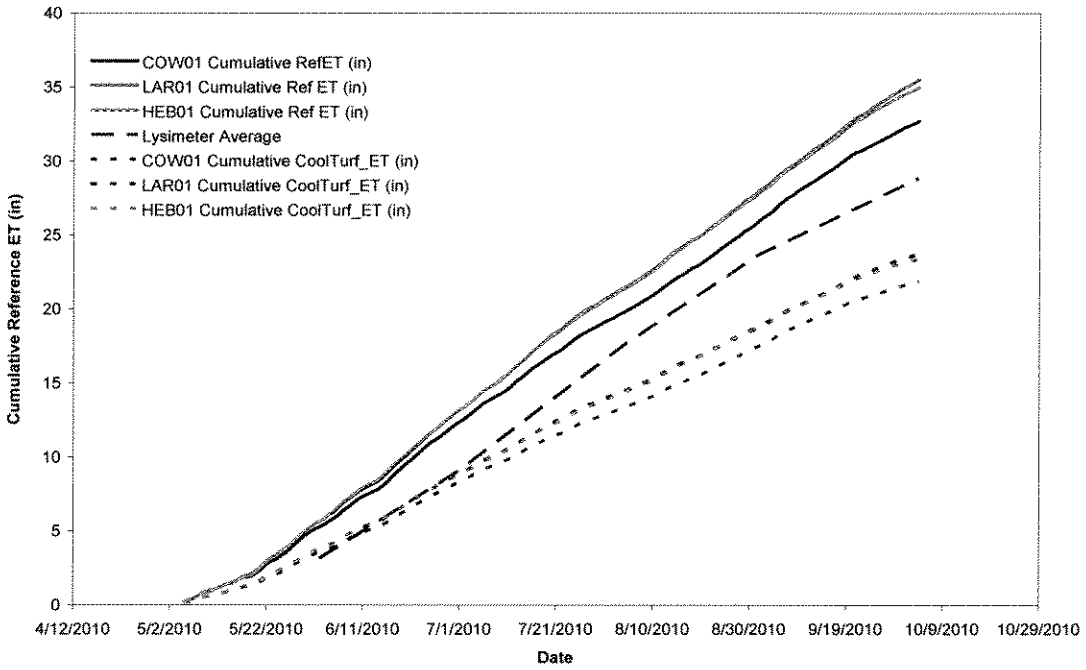

Figure 7: Cumulative Alfalfa Reference ET, Cool Season Turf ET and Lysimeter Data for Growing Season 2010.

In response to the non-ideal lysimeter data, the weather station data was used to calculate reference ET using both the Blaney-Criddle and Kimberly-Penman equations. Figure 8 illustrates the results from LAR01. It is clear that the Blaney-Criddle estimated reference ET is much lower than the Kimberly-Penman equation. May and September illustrated the highest difference at all sites.

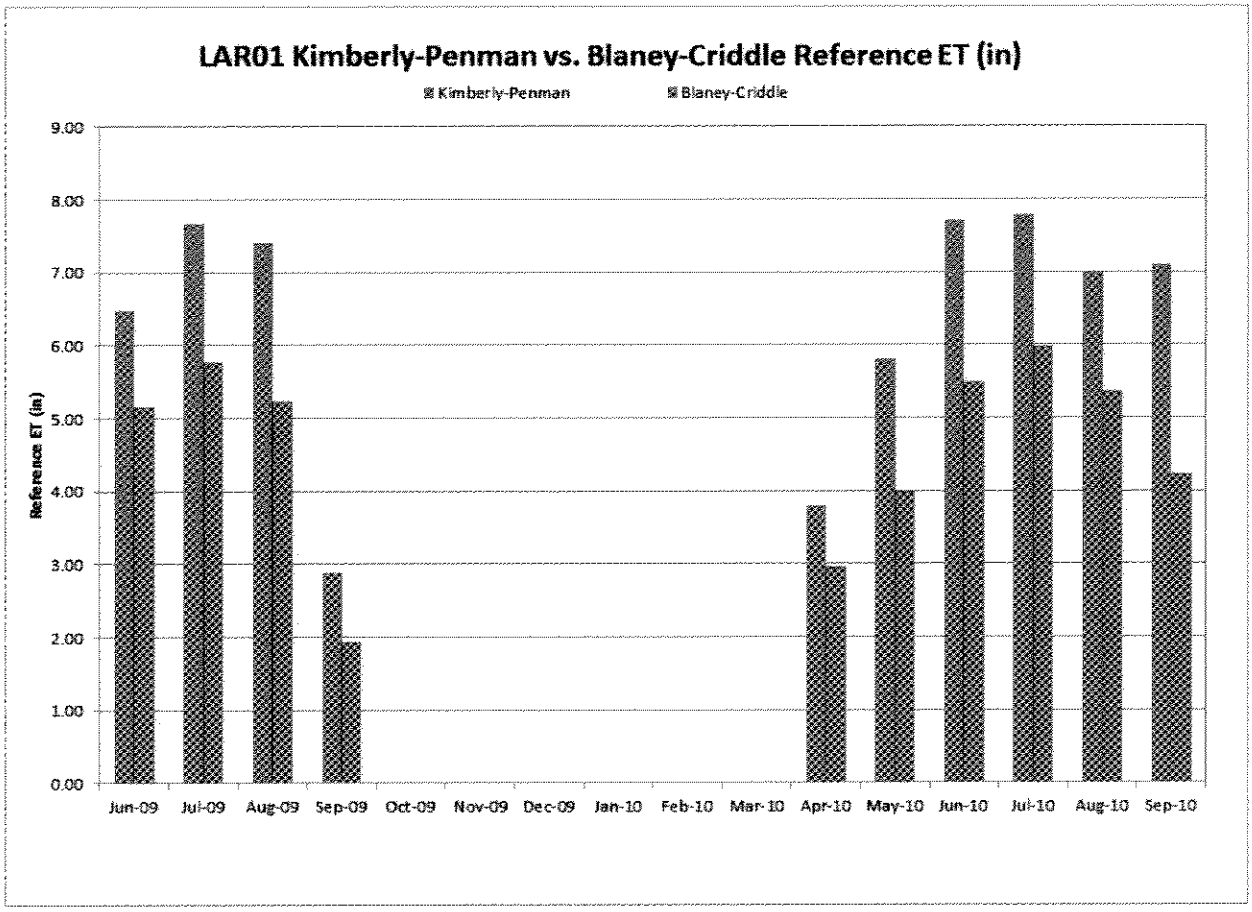

Figure 8: Blaney-Criddle vs. Kimberly-Penman Reference ET

Although the lysimeter data are not perfect, they can still be used to calculate preliminary crop coefficients for North Park. The calculation of the crop coefficient simply takes the lysimeter ET value and divides it by the weather station reference ET value to figure out what fraction of the reference ET is the actual crop ET. Figure 9 shows these ***very preliminary*** values calculated for 2010. As one would expect from the rest of the weather data analysis, LAR01 and HEB01 show very similar patterns in crop coefficient and COW01 has a higher crop coefficient in most months due to the suppressed ET seen at the COW01 site. This analysis will be revisited after the 2011 growing season to see how those values compared to 2010.

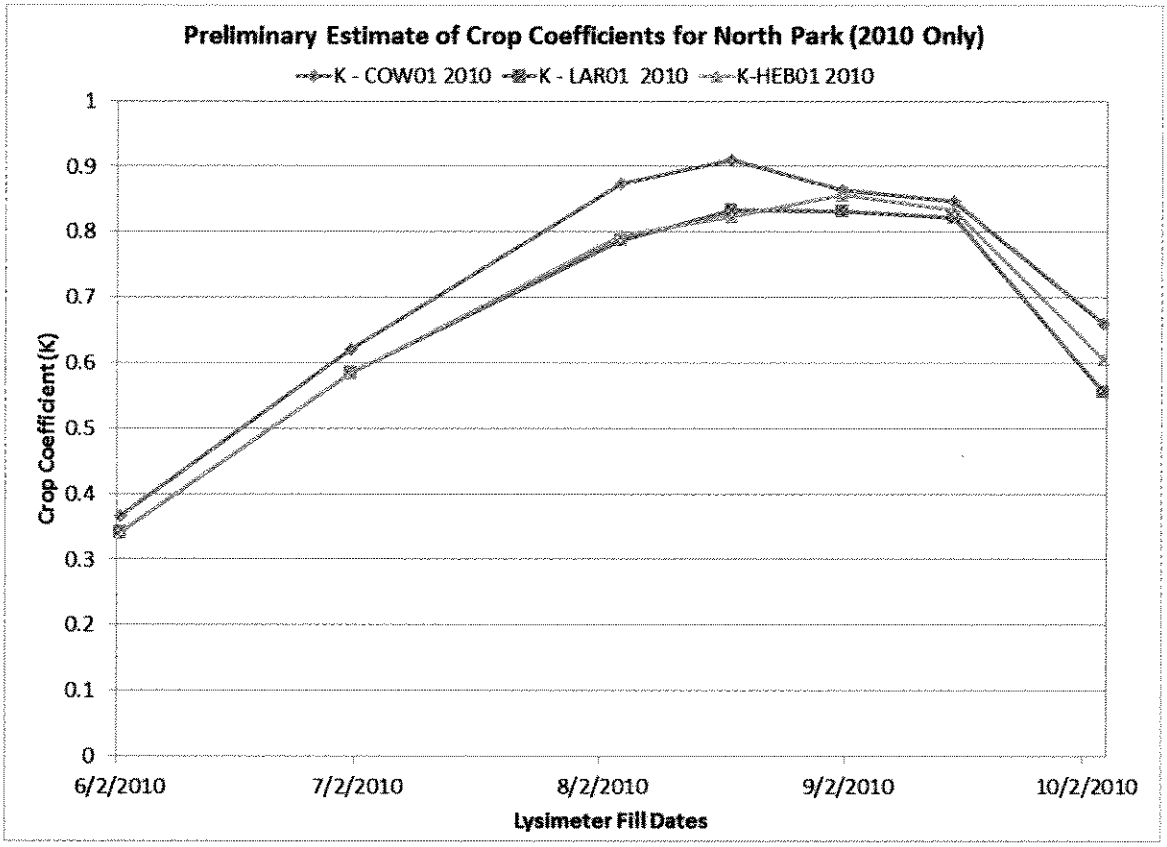

Figure 9: Preliminary Crop Coefficients for North Park Weather Station Reference ET.

ETgage Data Collection, Data Entry and Mapping

An additional goal of this project was to look more closely at spatial patterns and daily variations of ET by using low costs ETgages set up in several location in North Park. Up to this point, the use of these gauges in North Park has not been successful. It has been difficult to find volunteers, and the automated ETgages set up at the 3 CoAgMet sites have not worked well.

While it has not worked well so far, we are not ready to give up on this effort. In order to improve the ETgage network, the data entry page features are now available (see examples in Figures 10 and 11). The mapping feature that pulls ETgage data as well as CoAgMet data is still in development. These pages will hopefully encourage not only participation but also local comparisons between the weather station estimates and volunteers with ETgages (Figure 11).

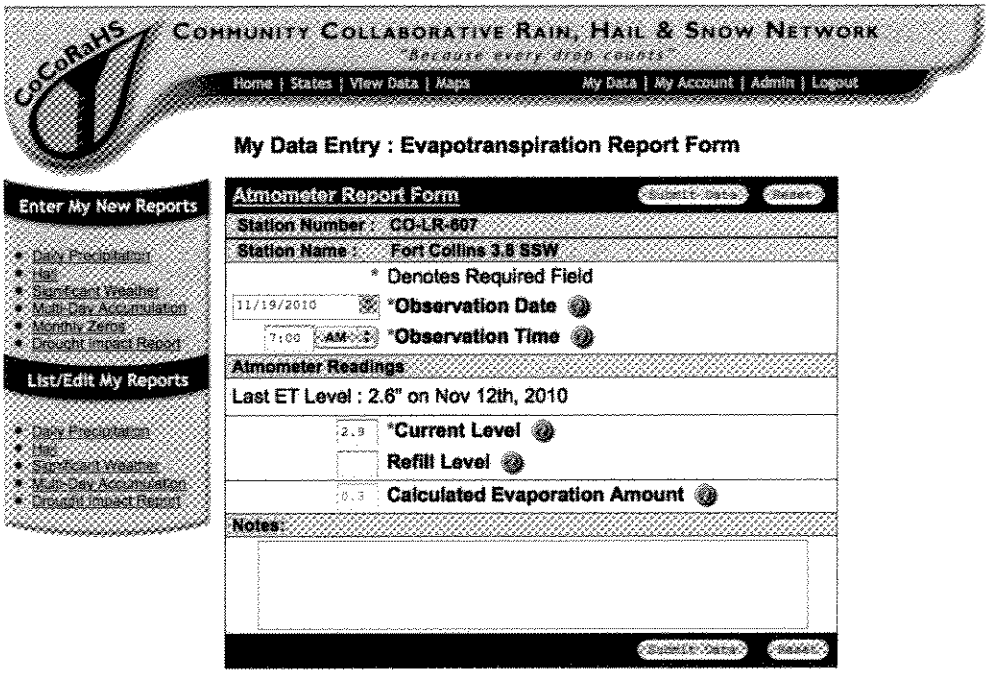

Figure 10: ETgage data entry page on the CoCoRaHS website.

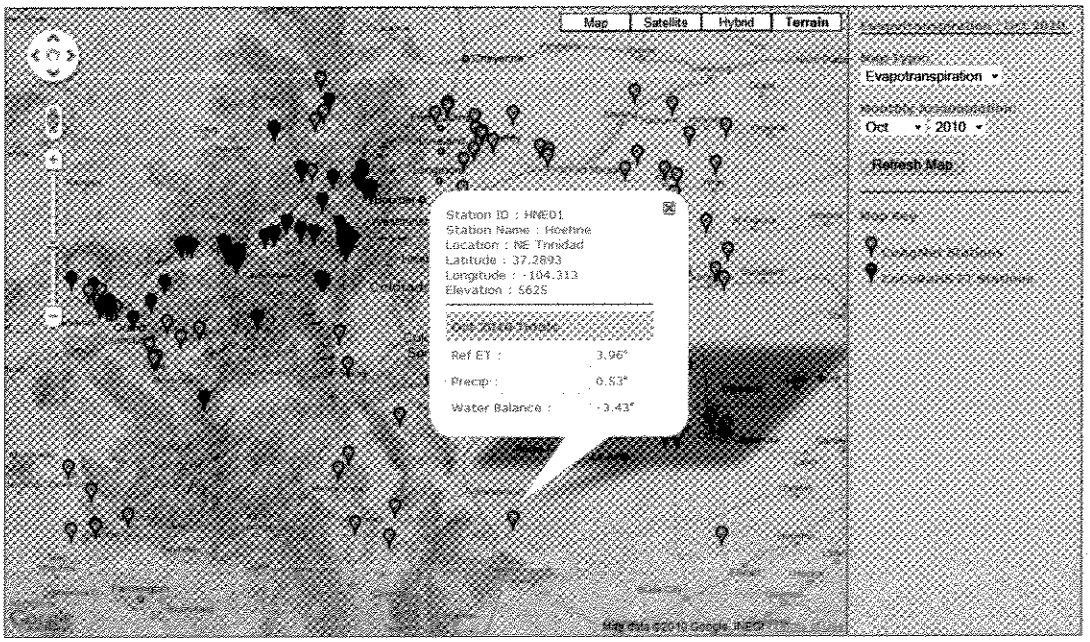

Figure 11: Mapping example of ETgage data vs. automated CoAgMet weather stations

Moving Forward and Completion of Proposal Tasks

Tasks 1- 6 in the proposal are complete. The three weather stations have been installed and have been collecting data since spring 2009. Data is archived, displayable and retrievable via the CoAgMet website:
http://ccc.atmos.colostate.edu/~coagmet

Task 7 is still in progress as volunteers to read ETgages have not been easily identified. Deb Alpe of CSU extension has been manually reading a few gages across North Park in an effort to help perform this task.

Task 8, operation and maintenance, has been completed for this year and will continue to be completed each year.

Task 9 is also a work in progress, but is showing promise this year. The current lysimeter and ETgage network are not providing adequate data for the determination of crop coefficients in the North Park area. At the Roundtable meeting on 29 March 2011, it was decided that the Arapahoe Wildlife Refuge staff would take a more active role in reading/filling the lysimeter plot to ensure constant saturation. This does not remedy the fact that the lysimeters likely flooded again this year, and ET will be difficult to resolve for periods of flooding.

Task 10 is also ongoing. Data are continually made publicly available and our data collection efforts have been adapting to provide the best data possible for quantification of consumptive use in the North Park area. Summaries and accomplishments (much like what is presented in this report) were presented to the roundtable in March 2011.