Calculated Consumptive Use of Applied Water of Alfalfa in Truckee Meadows

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Executive Summary

This report details the data, methods, and assumptions used to calculate consumptive use of applied water (CUAW) of alfalfa in the Truckee Meadows. Alfalfa was selected because historically it was the principal crop grown in the Truckee Meadows (Talbot, 1925), has previously been used in legal rulings such as U.S. v. Alpine Land and Reservoir Co., and has been used as a reference crop for calculating evapotranspiration (ET) throughout the United States. The analysis involved the use of weather data from two stations located in the Truckee Meadows to calculate a reference ET. The American Society of Civil Engineers (ASCE) Standardized Reference ET Equation was used to calculate a daily reference ET which was multiplied by crop coefficients for the four growth stages of alfalfa. The resulting daily crop ET was used to determine mean monthly crop ET at the stations. Mean monthly crop ET and precipitation data were used to estimate effective precipitation using a method developed by the United States Department of Agriculture (USDA), Natural Resource Conservation Service (NRCS). Mean monthly effective precipitation was subtracted from mean monthly crop ET to calculate the CUAW of alfalfa.

The average seasonal CUAW of alfalfa in the Truckee Meadows for the period of analysis from 2000 through 2006 is 3.1 feet. A comparison of the period of analysis to long-term records of precipitation and temperature indicate the period of analysis was one of below average precipitation and above average temperature. Precipitation and temperature were adjusted to more closely match long-term averages. These adjustments reduce the average seasonal CUAW of alfalfa to 2.9 feet.

Based on measured estimates of CUAW of alfalfa in and around the Truckee Meadows (Houston, 1955; Tovey, 1963), and a recent estimate calculated by Mr. J. Huntington, Nevada Department of Conservation and Natural Resources, Department of Water Resources for the Washoe Valley (Huntington, 2006), it is my opinion that this is a conservative estimate of the historical CUAW of alfalfa in the Truckee Meadows.

Background

The purpose of this analysis is to determine the CUAW of alfalfa in the Truckee Meadows. This analysis was performed using the ASCE Standardized Reference Evapotranspiration Equation (ASCE Equation). The ASCE Equation was developed by the Evapotranspiration in Irrigation and Hydrology Committee – Environmental and Water Resources Institute (the Committee). Reference ET is a function of local weather and represents the crop water use from a defined vegetated surface (ASCE Task Committee, 2005). Reference ET serves as an evaporative index by which engineers, hydrologists, water managers and other technical professionals can predict ET for a range of conditions by applying crop coefficients for agricultural and landscape use (ASCE Task Committee, 2005).

The ASCE Equation was developed to define a benchmark reference evapotranspiration equation to standardize the calculation of reference evapotranspiration. The equation was designed to be acceptable to the U.S. scientific community, engineers, policy makers, and end users (ASCE Task Committee, 2005). The Committee also provided guidelines for assessing the integrity of weather data used for estimating ET.

The Irrigation Association has endorsed the ASCE Equation, and the United States Committee on Irrigation and Drainage in cooperation with the California Department of Water Resources and University of California, Davis, have conducted a workshop on the development and application of the ASCE Equation.

The CUAW calculated in this analysis with the ASCE Equation was compared to reports of measured CUAW of alfalfa in the Truckee Meadows from two experiments conducted in the 1950s and 1960s. Results of studies conducted by Houston (1955) and Tovey (1963) were reported in University of Nevada, Agricultural Experiment Station Bulletins 191 and 232, respectively. Both studies used lysimeters to measure the consumptive use of alfalfa. Houston measured the "irrigation water use" from four lysimeters for 1950, 1951, 1952, and 1953 as 33, 33, 40, and 44 inches, respectively. For 1950 and 1951 Houston's measurements were for a period beginning May 9th and ending September 26th. Houston did not report the period of measurement for 1952 or 1953. Tovey measured the consumptive use of alfalfa from 63 lysimeters from mid May through mid October in 1959, 1960, and 1961. Tovey's study measured consumptive use in the presence of different static water table depths of 2, 4, and 8 feet, and well drained soil. The three-year average measured consumptive use for each static water table depth was 42.0, 38.3, 39.9, and 31.2 inches, respectively. It should be noted that both Houston and Tovey's measurement studies were conducted for less than the full growing season.

Mr. J. Huntington, Nevada Department of Conservation and Natural Resources, Department of Water Resources prepared a technical memorandum in 2006 on the calculation of CUAW for alfalfa in Washoe Valley. The memorandum was in response to several applications to transfer irrigation water rights in one part of the basin to quasi-municipal use in another area of the basin. The memorandum provided a thorough description of the approach and methods used to calculate reference ET, the crop coefficients, and calculation of effective precipitation. Additionally, Huntington references measurement studies conducted in Truckee Meadows, Fallon, and Carson Valley (Huntington, 2006). Results of those studies are similar to this analysis, and measurements by Houston and Tovey.

The first step in my approach is review and assessment of the quality of available weather station data. Second, a reference ET is calculated from available weather station data. The third step is to multiply a crop coefficient by the reference ET to account for the differences in ET between the full-growth reference crop and the actual crop and its growth phases. The result of the third step is total crop ET which is then reduced by the calculated effective precipitation. The remaining portion of the total crop ET not met from effective precipitation is met from applied water and referred to as CUAW.

Weather Stations

The analysis utilized weather data from two stations located in the Truckee Meadows. The following table summarizes these stations and the periods of available data. The following figure shows the approximate locations of the stations.

Table 1: Truckee Meadows Weather Station Information

Station Name	Latitude	Longitude	Elevation (feet)[1]	Period of Analysis	
				Start	End
Reno – Valley Road Farm	39° 32' 21"	119° 48' 21"	4,500	Jan. 2000	Dec. 2006
South Reno	39° 24' 59"	119° 48' 05"	5,020	Apr. 2000	Dec. 2006

[1] Approximate elevation based on NGVD 29.

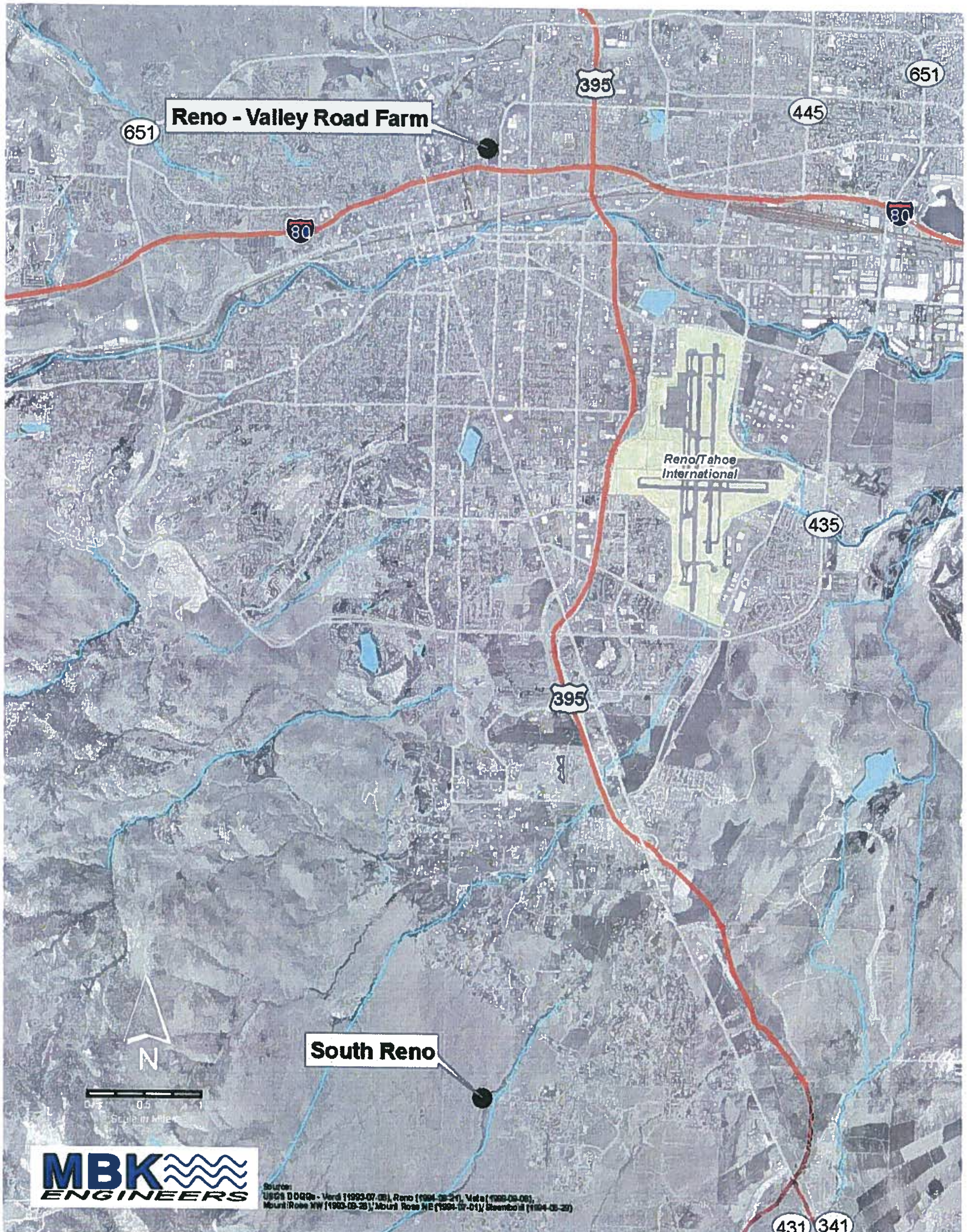

Figure 1: Truckee Meadows Weather Station Locations

Weather Data Quality Control

The quality of weather data collected at automatic weather stations can vary. Therefore, all weather data used in this analysis were reviewed following the procedures outlined in the ASCE Task Committee on Standardization of Reference Evapotranspiration, Appendix D (ASCE Task Committee, 2005). This review included discussion with Mr. Greg McCurdy at the Desert Research Institute (DRI) who collects data at the stations.

According to Mr. McCurdy, DRI performs maintenance on the stations once or twice each year and the sensors are calibrated annually. Only limited quality assurance/quality control procedures are applied, such as removing obviously erroneous or missing periods, prior to posting the data on the website. The Reno - Valley Road Farm station is located in an irrigated field of various crops, surrounded by nearby urban areas. The South Reno station is located above irrigated grass at the Wolf Run Golf Course adjacent to non-irrigated vegetation.

Solar radiation data were screened by plotting measured values against the theoretical clear-sky solar radiation envelope for the station location. Measured solar radiation should approach the clear-sky solar radiation envelope on cloud-free days, but should never exceed the clear-sky solar radiation envelope that is the theoretical maximum radiation. The clear-sky solar radiation envelope was calculated using the detailed procedures recommended in ASCE Appendix D (ASCE Task Committee, 2005). These plots illustrated an inconsistency with the measured solar radiation at the Reno – Valley Road Farm station from January 2000 through July 2001. During this period the measured values routinely exceeded the clear-sky solar radiation envelope, see Figure 2. These data were replaced with the data for the same days from the South Reno station. The South Reno station period of record begins in April 2000. Therefore, the analysis at both stations was limited to the period from April 2000 through December 2006.

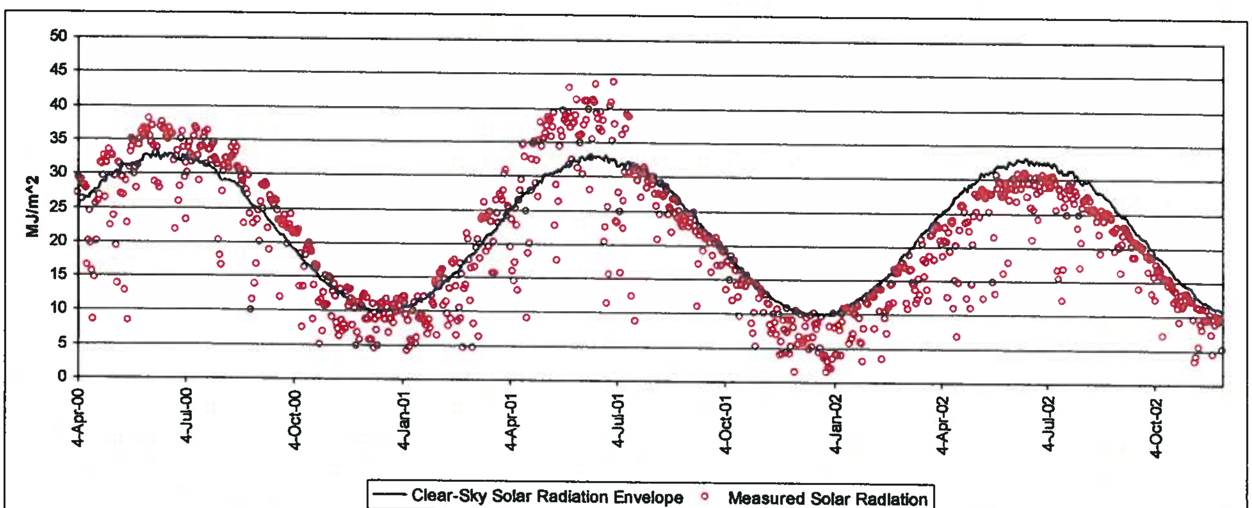

Figure 2: Measured Solar Radiation and Clear-Sky Solar Radiation Envelope at Reno – Valley Road Farm Weather Station

Maximum relative humidity data were screened for values greater than 100 percent. Measured relative humidity exceeded 100 percent on some days at both stations; most frequently at the Reno – Valley Road Farm station where it occurred on approximately six percent of all days. All values exceeding 100 percent were set to 100 percent for use in calculations, per the recommendation in ASCE Appendix D (ASCE Task Committee, 2005).

Wind speed data were reviewed for prolonged periods of low mean daily wind speed and periods with large gust factors (ratio of maximum to mean daily wind speeds).

Maximum and minimum temperature data were compared to historical monthly maximum and minimum records for the Reno Airport. Temperature data at both stations were within the range of the historical maximum and minimum values. Temperature data for both stations were plotted together for comparison and were typically very similar between stations. On a few days at the South Reno station the reported maximum temperature was less than the reported minimum temperature. This occurred on less than one percent of the days during the period of analysis. These data were reviewed and adjusted or replaced with data from the Reno – Valley Road Farm station.

Solar radiation, wind speed, temperature, humidity, and precipitation data were reviewed by plotting each variable for both stations on a single plot. This provided an understanding of the correlation between the stations, as well as identified additional anomalies in the data for review and correction.

Calculation of Reference ET

The ASCE Standardized Reference Evapotranspiration Equation can be used for both a short reference crop (similar to clipped grass) and a long reference crop (similar to alfalfa) (ASCE Task Committee, 2005). Calculations for a long reference crop resulted in values of CUAW that exceeded any of the measured values reported by Houston (1955) and Tovey (1963). For this reason, only values for the short reference crop are reported here. Huntington reached this same conclusion in the Washoe Valley analysis (Huntington, 2006).

The calculation of reference ET was performed on a daily time-step in the manner described in the ASCE Report (ASCE Task Committee, 2005). The ASCE Standardized Reference Evapotranspiration Equation for a short reference crop is:

$$ET_{os} = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

where

ET_{os} = standardized reference crop evapotranspiration for short surfaces (mm/day)
R_n = calculated net radiation at the crop surface (MJ/m^2/day)
G = soil heat flux density at the soil surface (MJ/m^2/day)
T = mean daily air temperature at 1.5 to 2.5 meters height (°C)
u_2 = mean daily wind speed at 2 meters height (m/second)
e_s = saturation vapor pressure at 1.5 to 2.5 meters height (kPa), calculated as the average of saturation vapor pressure at maximum and minimum air temperature

e_a = mean actual vapor pressure at 1.5 to 2.5 meters height (kPa)
Δ = slope of the saturation vapor pressure-temperature curve (kPa/°C)
γ = psychrometric constant (kPa/°C)
C_n = numerator constant, varies by reference crop and calculation time-step
C_d = denominator constant, varies by reference crop and calculation time-step

The use of the reference ET equation requires numerous preceding calculations for some of the listed variables. The reader is referred to the ASCE Task Committee Report for a thorough review and discussion of these methods and sub-calculations.

One adjustment was made to the wind speed data because at both stations the anemometers are located at a height of three meters, while the reference equation is based on wind speed at two meters. Wind speed was adjusted to the two meter height by the following equation from the ASCE Task Committee Report (ASCE Task Committee, 2005):

$$u_2 = u_z\left(\frac{4.87}{\ln(67.8z_w - 5.42)}\right)$$

where

u_2 = mean daily wind speed at 2 meters height (m/second)
u_z = measured wind speed at z_w above ground surface (m/second)
z_w = height of measurement above ground surface (m)

Growing Season and Crop Coefficients

The reference ET equation accounts for the meteorological influences on ET for an actively growing reference crop with adequate water supply, at full cover and peak height. The resulting reference ET is then multiplied by a crop coefficient that accounts for the differences in ET from an actual crop that grows to full cover and is harvested over the course of an irrigation season. The crop coefficient also accounts for differences in the crop surface and geometry from the specified reference crop. Reference ET is combined with crop specific information such as growing season and crop coefficients to calculate a total crop evapotranspiration, ET_c.

The growing season in Truckee Meadows begins after the last killing frost of spring and continues until the first killing frost in the fall. The killing frost temperature for alfalfa of 20° F (-6° C) was used, as reported by Huntington based on discussion with Dr. Allen (Huntington, 2006). Median annual dates for these temperatures were estimated based on historical temperature data at the Reno Airport. The Western Regional Climate Center provides probabilities of temperatures occurring before and after dates in the spring and fall. These plots are provided as Figure 3 and Figure 4.

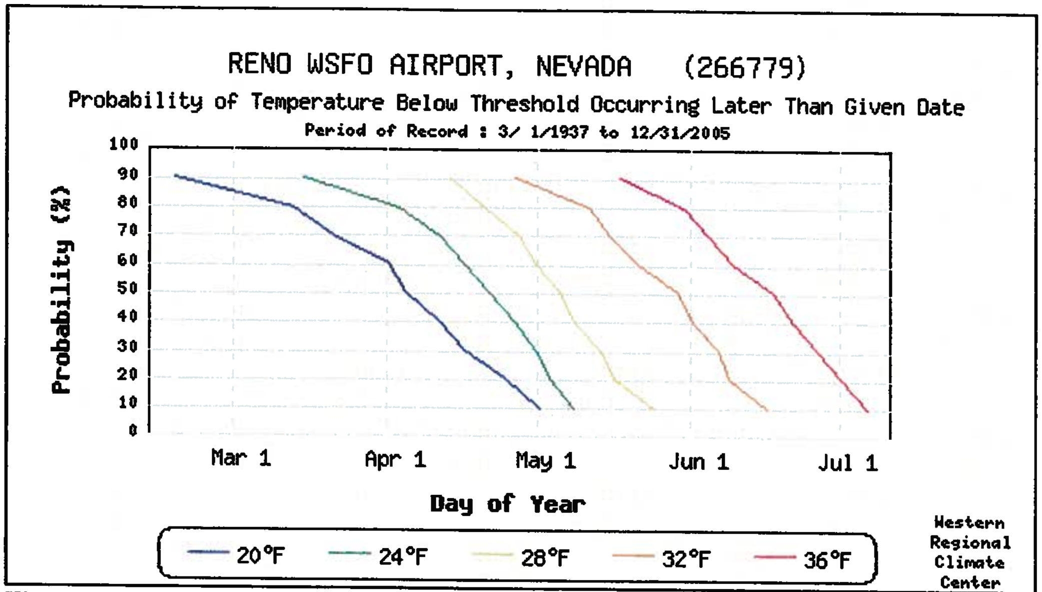

Figure 3: Date and Temperature Probability Plot, Spring

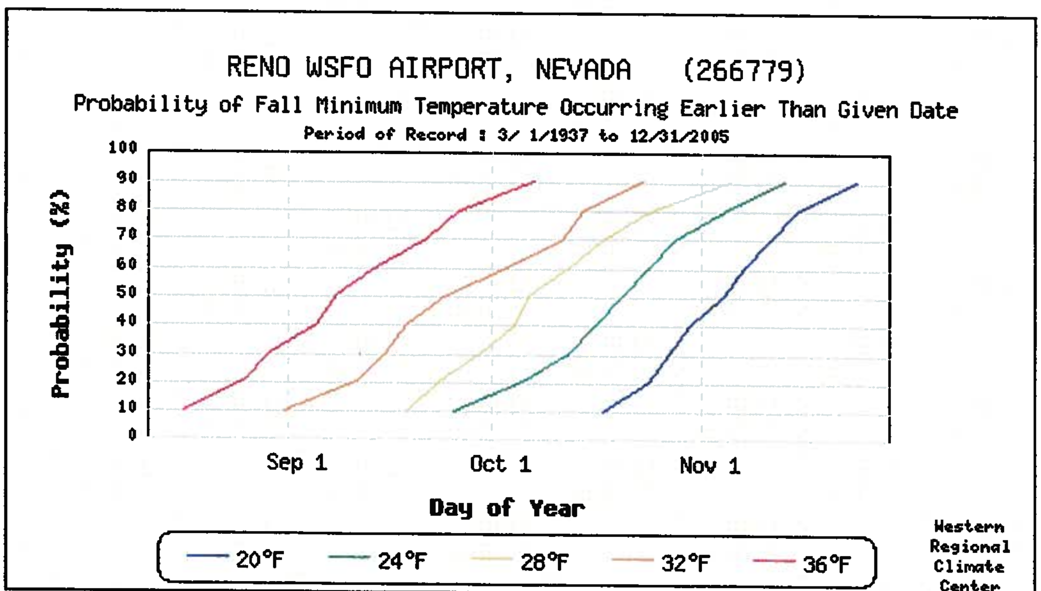

Figure 4: Date and Temperature Probability Plot, Fall

The 50 percent exceedance probability for 20° F for the spring and fall periods results in a growing season for alfalfa from approximately April 1 through October 31. Historically however, the irrigation season in the Truckee Meadows began April 15th (Talbot, 1925). Since any water used prior to the start of irrigation is from precipitation, this analysis calculates the CUAW for the period of April 15th through October 31st.

Crop coefficients (K_c) are identified for various stages of the crop growth cycle, such as the initial, development, middle, and late growth stage. Alfalfa is harvested several times during the growing season and these periodic cuttings affect the K_c throughout the growing season. Two approaches can be used to account for these changes in K_c. One approach is to use an average K_c value during the middle and late growth stages that incorporates the effects of cutting on the crop coefficient. This is the approach used in this analysis. Averaged crop coefficients were taken from Food and Agriculture Organization of the United Nations, *Irrigation and Drainage Paper 56* (FAO 56) (Allen et al., 1998). The published crop coefficients and corresponding lengths of the growth stages are summarized in the following table. A second approach is to estimate the number and timing of cuttings that may occur throughout the growing season and adjust the K_c. A separate analysis using this method was also performed with minimal affect on the total growing season CUAW.

Table 2: FAO Crop Coefficients and Growth Stages

Growth Stage	K_c	Stage Length (days)
Initial	0.40	10
Development	Changes linearly from 0.4 to 0.95	30
Mid	0.95	129
Late	0.90	30

The crop coefficients were multiplied by the calculated daily reference ET to calculate the final crop ET. Daily crop ET was aggregated to monthly crop ET and mean monthly crop ET was used to calculate the final crop CUAW.

Effective Precipitation

Effective precipitation is the portion of total precipitation available to meet the evapotranspiration needs of the crop. Effective precipitation is a function of numerous parameters including soil characteristics, rainfall duration and intensity, ambient soil moisture, topography, and crop characteristics. Several methods have been developed to estimate effective precipitation (Dastane, 1978). The Natural Resource Conservation Service (NRCS) developed a method for calculating effective precipitation from analysis of 50 years of precipitation data at 22 different weather stations for a range of different climatic and soil conditions (USDA, 1993). The NRCS developed empirical equations based on approximate daily soil moisture budgets. This method has been shown to be appropriate for use in areas receiving low intensity rainfall and soils with high infiltration rates (USDA, 1993). This analysis uses the NRCS method to estimate the effective precipitation with the following equation. Huntington used the same method to calculate effective precipitation during the growing season (Huntington, 2006).

$$P_e = SF\left(0.70917 P_t^{0.82416} - 0.11556\right)\left(10^{0.02426 ET_c}\right)$$

where

P_e = mean monthly effective precipitation (in)
P_t = mean monthly precipitation (in)
ET_c = mean monthly crop evapotranspiration (in)
SF = soil water storage factor

Weather station data at both stations include daily precipitation volumes. Daily precipitation and crop ET were aggregated to monthly totals and mean monthly precipitation and crop ET were calculated for the period of analysis at each station. The soil water storage factor is defined by:

$$SF = \left(0.531747 + 0.295164D - 0.057697D^2 + 0.003804D^3\right)$$

where

D = usable soil water storage (in)

The usable soil water storage is approximated as 50% of the available water capacity of the soil in the crop root zone (USDA, 1993). The NRCS National Engineering Handbook provides a range of usable soil water storage values from 0.75 to 7.0 inches (USDA, 1993). Higher values of usable soil water storage result in higher calculated effective precipitation that in turn reduces the CUAW. The full range of usable water storage values recommended by NRCS was evaluated providing a range of effective precipitation during the growing season of 1.3 to 1.9 inches for usable water storage values of 0.75 to 7.0 inches, respectively. The calculation of effective precipitation in the Truckee Meadows by the NRCS method is therefore not sensitive to variations in the usable soil water storage.

The available water capacity of the soil in the Truckee Meadows was calculated from the NRCS SSURGO GIS database. Based on the NRCS database, the area weighted average available water capacity for the Truckee Meadows is 0.14 inches per inch of soil. The available water capacity within a five foot root zone for alfalfa is then 8.4 inches, and the usable soil water storage is 4.2 inches.

The NRCS method was used in this analysis to calculate the effective precipitation for all months. Effective precipitation in March, immediately preceding the start of the growing season, may be available in the root zone to help offset the crop ET during the growing season. Therefore, the volume of effective precipitation available to the crop during the April through October growing season is the sum of the March through October effective precipitation. Precipitation in earlier months, November through February, is not likely to be available due to a combination of non-growing season ET, surface runoff, and deep percolation past the root zone.

Consumptive Use of Applied Water

The calculation of effective precipitation using the NRCS method provides an estimate of the mean monthly effective precipitation. Mean monthly effective precipitation is subtracted from the mean monthly crop ET to calculate the mean monthly CUAW. Mean monthly values were calculated for the period of April 2000 through December 2006. The calculation of CUAW was performed using the data from each weather station and an average of both stations was also computed. The following tables provide the mean monthly values and the totals for the growing season. The growing season total CUAW is calculated as the sum of the April 15th through October 31st crop ET minus the sum of the March through October effective precipitation.

Table 3: Reno - Valley Road Farm Weather Station ET, Precipitation, and CUAW in inches

Month	Reference ET	Crop ET	Precipitation	Effective Precipitation	CUAW
March			0.42	0.26	
April	2.36	1.51	0.59	0.39	1.12
May	6.39	5.92	0.24	0.15	5.78
June	7.52	7.15	0.16	0.07	7.08
July	8.31	7.90	0.29	0.23	7.67
August	7.18	6.82	0.20	0.11	6.70
September	5.11	4.85	0.06	0.00	4.85
October	3.11	2.81	0.37	0.24	2.56
Season[1]	**40.0**	**37.0**	**2.3**	**1.5**	**35.5**

[1] Reference ET, Crop ET, and CUAW are summed April 15th through October. Precipitation and Effective Precipitation are summed March through October.

Table 4: South Reno Weather Station ET, Precipitation, and CUAW in inches

Month	Reference ET	Crop ET	Precipitation	Effective Precipitation	CUAW
March			0.83	0.55	
April	2.47	1.58	0.98	0.66	0.92
May	6.90	6.39	0.26	0.17	6.22
June	8.11	7.71	0.22	0.14	7.57
July	9.03	8.58	0.27	0.21	8.37
August	8.07	7.67	0.20	0.12	7.55
September	6.07	5.77	0.08	0.00	5.77
October	3.80	3.43	0.46	0.33	3.11
Season[1]	**44.5**	**41.1**	**3.3**	**2.2**	**39.0**

[1] Reference ET, Crop ET, and CUAW are summed April 15th through October. Precipitation and Effective Precipitation are summed March through October.

Table 5: Average of Both Weather Stations ET, Precipitation, and CUAW in inches

Month	Reference ET	Crop ET	Precipitation	Effective Precipitation	CUAW
March			0.62	0.40	
April	2.41	1.54	0.79	0.52	1.02
May	6.65	6.16	0.25	0.16	6.00
June	7.82	7.43	0.19	0.10	7.32
July	8.67	8.24	0.28	0.22	8.02
August	7.62	7.24	0.20	0.12	7.13
September	5.59	5.31	0.07	0.00	5.31
October	3.46	3.12	0.42	0.28	2.83
Season[1]	**42.2**	**39.0**	**2.8**	**1.8**	**37.2**

[1] Reference ET, Crop ET, and CUAW are summed April 15th through October. Precipitation and Effective Precipitation are summed March through October.

The average CUAW of alfalfa in the Truckee Meadows during the April 15th through October irrigation seasons of 2000 through 2006 is calculated to be 37.2 inches or 3.1 feet. These values compare well with measured crop ET from studies conducted by Houston (1955) and Tovey (1963). Those measurement studies were conducted for shorter seasons so the fact that this analysis produced similar results indicates it is a conservative estimate. 37.2 inches also compares with the 39.75 inches calculated by Huntington using data from the Reno - Valley Road Farm station. Huntington's results vary from results presented here for the same station due to differences in the period analyzed, irrigation season, and calculation of effective precipitation outside of the growing season. Huntington used an April 1st through October irrigation season. If using an April 1st through October irrigation season for this analysis, the calculated average CUAW of alfalfa is 38.0 inches or 3.17 feet.

Period of Analysis Compared to Long-Term Average

The analysis presented above was limited to the period of 2000 through 2006 by the availability of weather station data. The period of analysis was compared to the long-term record of available data at the Reno Airport. Daily maximum, minimum, and average temperature and daily total precipitation data are available for the Reno Airport for the period March 1, 1937 through present. Daily data were summarized as total March through October precipitation and total April through October degree days for each year from 1937 through 2007. These seasons were selected to be consistent with the above analysis. Comparisons of the seasonal averages for the period 1937 through 2007 with the seasonal averages for 2000 through 2006 are presented in the following table.

Table 6: Comparison of Period of Analysis and Long-Term Period of Record at Reno Airport

	1937-2007 Average	2000-2006 Average
March-October Precipitation (inches)	3.4	2.8
April-October Degree Days (^{o}F-days)	12,875	13,878

Based on the data presented in Table 6 it appears the period of analysis was a period of below average precipitation and above average temperature. Since both precipitation and temperature are used in the calculation of CUAW, additional analysis was conducted to determine the effect of using long-term average monthly precipitation data and scaling the measured temperature data so that average monthly temperatures used in the analysis were similar to long-term average monthly temperatures. Additional analysis of Reno Airport temperature data showed consistently above average temperatures in more recent years, after approximately 1998. To account for this effect, average monthly temperatures for the period 1937 through 1998 were used as representative of the long-term average. Daily measured temperature data were uniformly reduced by ten percent at the Reno – Valley Road Farm station and seven percent at the South Reno station. Reductions were made so that average monthly temperatures at each station were approximately equal to average monthly temperatures for the period 1937 through 1998. The result of this sensitivity analysis for both temperature and precipitation was to reduce the calculated CUAW of alfalfa from 3.1 to 2.9 feet.

Conclusion

Based on the calculations described above, review of historical measurement studies, and review of recent analysis in the Washoe Valley, the average seasonal CUAW of alfalfa in the Truckee Meadows is approximately 2.9 feet.

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