GRASS REFERENCED BASED VEGETATION COEFFICIENTS FOR ESTIMATING EVAPOTRANSPIRATION FOR A VARIETY OF NATURAL VEGETATION

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ABSTRACT

In arid and semi-arid regions, evapotranspiration from vegetation results in the significant utilization of available water. Accurate estimates of evapotranspiration are required for surface and subsurface hydrologic evaluations as well as irrigation district water balance studies. A significant amount of transferable information exists for irrigated agricultural crops through past and current research in the form of grass or alfalfa reference based crop coefficients (Kc) and basal crop coefficients (Kcb). However, transferable evapotranspiration information on natural vegetation is limited. Much of the work was conducted in the early to mid-1900's and is presented as actual evapotranspiration from the vegetation at the research site either as annual or monthly values. In some cases, the data may have been referenced to evaporation pan measurements (typically Class A type pans) with unknown site conditions. An intensive literature review was conducted to extract monthly measured evapotranspiration information for natural vegetation types under various conditions. Monthly vegetation coefficients (Kv) for standardized grass reference based evapotranspiration (ETo) were computed using long-term average grass reference evapotranspiration information computed with data from nearby weather stations. Comparisons of the Kv values for similar vegetation indicate higher variability during the non-summer months but results from most of the studies examined are in good agreement. These Kv values provide some level of transferability so that it is possible to compute an accurate estimate of vegetative evapotranspiration with daily or monthly standardized grass reference evapotranspiration values in areas away from the original study.

INTRODUCTION

Estimating plant evapotranspiration accurately for planning and management has long been a challenge. Since the early 1900's, if not earlier, researchers have used an array of methodologies to attempt to measure plant evapotranspiration. While most of the early work on evapotranspiration was problematic because of poor experimental setup (Young and Blaney 1942), much was learned about proper ET measurement.

There has been significant research regarding ET from agricultural crops as well as natural vegetation. However, there is often a major difference in the way the data is presented for agricultural crops versus natural vegetation. For agricultural crops, information is generally presented so that evapotranspiration measurements made during specific times and at specific locations can be used in the future in different locations. In fact, over the past several decades

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there has been a focus on standardizing the way evapotranspiration predictions are made. Through this work, the American Society of Civil Engineers and the Food and Agricultural Organization have standardized the reference crop evapotranspiration computations that are used throughout the agricultural community worldwide (Allen et al. 1998; Allen et al. 2005).

Presenting results that can be used towards prediction of ET from similar plant types and growing conditions has not been a focus of much of the work with natural vegetation. In cases where a relationship between some reference and the measured ET has been presented, there has been no standardization of the reference. Historically, Weather Bureau Class A Pan evaporation was used as the reference. Starting in the early 1970's the Priestley-Taylor method became popular for natural vegetation ET estimation because of the limited amount of input data needed. The Jensen-Haise and Blaney-Criddle Methods have also been used as references (Jensen et al. 1990).

Without some standard reference for computing evapotranspiration from natural vegetation, it is difficult to utilize existing and past research to estimate historical or predict future evapotranspiration from similar vegetation. The goal of this paper is to present grass (short crop) reference evapotranspiration based vegetation coefficients (Kv) for a variety of natural vegetation types from other researchers. Most of the data included here was originally presented as monthly evapotranspiration depths without any reference. A major challenge was to estimate the grass reference evapotranspiration during the time frame and at the location the studies were conducted.

METHODS

An intensive review of natural vegetation evapotranspiration literature was conducted as part of this work. There have been several reviews conducted on this subject (Johns 1989; Drexler et al. 2004; Moore et al. 2004) and it was not the intent to repeat this information here. Within the literature, specific information was sought to develop useful, reliable vegetation coefficients. One of the main criteria for selection was that at least monthly data had to be provided. Interestingly, this was one of the most limiting factors.

The investigators must have measured evapotranspiration from vegetation surrounded by similar vegetation on all sides using a lysimeter/tank, Bowen ratio, eddy correlation, or remote sensing of actual evapotranspiration using an energy balance. Estimates of ET using a larger scale water balance were avoided because of the inaccuracies associated with measurements of inflow and outflow and the change in storage. A number of studies investigated evapotranspiration of vegetation that was not surrounded by vegetation of similar height and density. This was not uncommon in early ET measurements and will lead to significant overestimation of ET due to the clothesline effect (Young and Blaney 1942; Allen et al. 2011). The data gathered from the literature review focused on ET investigation after 1945 unless the site conditions and experimental methods were explained in sufficient detail and the researcher had significant amount of experience to provide confidence in the measurements. A majority of the studies utilized in this paper were conducted in the western U.S., although some information from Florida was used.

The ability to transfer and adjust evapotranspiration estimates made during a specific time frame in one location to a different location during a different time frame has been a challenge. Transferability is commonly attained by using a reference based on local weather conditions and an adjustment coefficient based on the vegetation and growth stage. The standard approach for agricultural crops is to use a reference crop evapotranspiration (ETo) computed from specialized weather station networks along with a crop coefficient (Kc) that was developed through research for specific stages of the crop cycle. Crop evapotranspiration (ETc) can be computed as:

$$\mathrm{ETc} = \mathrm{ETo}*\mathrm{Kc} \qquad (1)$$

The reference crop used is generally grass (short crop) or alfalfa (tall crop). Generally, ETo is used to identify grass and ETr is used to identify alfalfa reference. The 2005 ASCE Standardized Penman-Monteith (ASCE ETo) equation is the current standard for computation for either a grass or alfalfa reference evapotranspiration (Allen et al. 2005). Knowing the reference crop is critical since the crop/vegetation coefficients are different for each reference crop. In this paper all vegetation coefficients are based on a **grass reference crop**.

Using Equation 1, the monthly vegetation coefficients (Kv) were developed from the monthly ETc measurements obtained from the literature review as:

$$\mathrm{Kv} = \mathrm{ETc}/\mathrm{ETo} \qquad (2)$$

The grass reference evapotranspiration had to be estimated on a monthly basis for the time frame and the location that the study was conducted. Since most ETo weather stations were not installed in the western U.S. until the 1980's, it was not possible to use the standardized reference evapotranspiration equation for many of the datasets. Alternatively, the Hargreaves ETo equation was used in many cases where the full set of weather parameters was not available. The Hargreaves equation has been shown to provide relatively accurate ETo estimates with limited data (maximum and minimum temperature only) in arid regions (Jensen et al. 1990; Allen et al. 1998). Hargreaves ETo is computed based on temperature and extraterrestrial radiation (R_a) as:

$$\text{Hargreaves ETo} = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5}\, R_a \qquad (3)$$

where temperatures are in degrees Celsius and R_a and ETo are in millimeters per unit time. The Hargreaves equation does not include input information for wind or relative humidity. The lack of this information can lead to inaccuracies associated with the Hargreaves ETo. Allen et al. (1998) discusses a calibration method to improve the accuracy of the Hargreaves ETo estimate on a monthly or annual basis by comparing it to the ASCE ETo for years with overlapping data.

ETo was determined for each site depending on the data availability. The list below is used to identify the method used to compute ETo for each study in Tables 1 and 2. The priority for determining ETo was:

1. In cases where the vegetation coefficient was provided and ETo was not needed, if the Kv provided was based on an alfalfa reference crop, these Kv values were multiplied by

1.15 to estimate Kv based on a grass reference. When possible, a conversion factor was computed on a monthly basis by dividing ETr/ETo over a period of two or more years to increase the accuracy of the grass reference based Kv.

2. If an ETo weather station existed near the study location during the study period, ASCE ETo was used.
3. If an ETo weather station was placed near the location (within 10-20 miles depending on the climate variability and terrain) of the study site after the study was conducted, a monthly calibrated Hargreaves ETo was used. Calibration was conducted based on years when weather station ETo was available.
4. If no ETo weather station was near the weather station but monthly temperature data was provided with the study data, Hargreaves ETo was used based on this temperature data.
5. If no ETo weather station was near the weather station and monthly temperature data for the study period was not provided, Hargreaves ETo was used based on PRISM data for the location and time frame of the study.

If (4) or (5) were used to estimate ETo, a check on these ETo values was made by checking against long-term average ASCE ETo, on an annual basis. The long-term average ASCE ETo used for the check was either from weather stations within 20-40 miles with similar climate conditions or, for studies in California, from Spatial CIMIS for the location of the study site (http://wwwcimis.water.ca.gov/cimis/cimiSatSpatialCimis.jsp). The difference between the annual ETo values was set at a threshold of a +/-15%. This reality check ensured that gross errors in the ETo were avoided. If the Hargreaves ETo was outside of this threshold, alternative means of computing ETo was attempted or the dataset was abandoned. The alternative method was to find a nearby NCDC weather station with temperature data for the time frame and use the Hargreaves equation to compute the ETo based on this data.

The PRISM (Parameter-elevation Regressions on Independent Slopes Model) system maintained by Oregon State University provides a grid of monthly temperatures (minimum and maximum) from 1895 to present (Daly et al. 2002; Daly et al. 2008). PRISM temperature data is computed based on surface weather station data and is interpolated based on factors such as location, coastal proximity, elevation and topography (Daly et al. 2008).

RESULTS

The following tables show the vegetation coefficient computed using Equation 2. Table 1 shows monthly Kv values for vegetation that is not lacking for water. The vegetation types include wetland tules and cattails in standing water, riparian habitat with access to the shallow groundwater table year-round, and native pasture grass with access to shallow groundwater. For the wetland and riparian vegetation (willows, cottonwoods, etc.), the tables have been split into two categories for each of these types of vegetation to differentiate between large and small stand (isolated patches) of vegetation.

Native pasture grass and irrigated pasture are shown following the riparian vegetation. Studies were selected for the pasture where the water tables were shallow. Native perennial grasses often have access to water through a shallow groundwater aquifer. The Kv values shown would represent relatively large meadow/grassland areas under these conditions.

Basic statistics are shown by month for vegetation with more than one value. The average, sample standard deviation (SD), and the coefficient of variation (CV) of monthly Kv's are shown. The CV is computed as the SD divided by the average monthly Kv.

For the large stand wetland vegetation, several of the published ETc values resulted in an relatively high Kv value for certain months. The amount of evapotranspiration is limited by the available energy to convert water as a liquid into a gas. For large stands of vegetation (>200 m of similar vegetation), the maximum potential Kv is 1.2-1.4 (Allen et al. 2011). Allen et al. (2011) recommends that values that exceed 1.4 should be excluded for large stands of vegetation. The highest Kv value for any single month for a study was 1.37 which is less than 1.4 so no values were excluded from these tables.

The limitation of Kv to 1.2-1.4 based on a grass reference ETo does not apply for small stands of vegetation. Very high ETc rates can occur in situations where a small, taller, stand of vegetation is surrounded by shorter vegetation. This is termed the "clothesline effect", whereby air can more efficiently move between the vegetation, lowering the humidity outside of the leaf and creating a greater potential for higher ETc (Allen et al. 2011). For this reason Kv values were differentiated between large and small stands in Table 1 for wetland and riparian vegetation.

Monthly grass reference based Kv values for other types of vegetation are shown in Table 2. These vegetation types may not have access to the shallow groundwater, and are therefore reliant on precipitation. In arid climates where vegetation will undergo water stress, Kv values will be dependent on the amount of available water. The Kv values shown in Table 2 should be used with caution.

Table 1. Grass reference based vegetation coefficient (Kv) for vegetation types that had continuous access to water (no water stress).

Large Stand Wetland Vegetation	Long-Term Freeze	ETo Est.	Location	Vegetation Coefficient (ETc/ETo) based on Grass Reference												Method	Source
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec		
Cattails	No	1	Fort Drum, Florida	0.51	0.61	0.64	0.73	0.87	0.87	0.78	0.76	0.86	0.78	0.65	0.56	lysimeter	(Mao et al. 2002)
Cattails	No	1	Southern Florida		0.69	0.73	1.00	1.15	1.15	1.15	1.15	1.09				lysimeter	(Abtew and Obeysekera 1995) Reported in (Allen 1998)
Tules and Cattails	No	1	Twitchell Island, CA					0.80	0.92	1.02	1.09	1.01	0.90			surface renewal	(Drexler et al. 2008)
Tules/Bulrush	No	5	Bonsall, Ca	0.36	0.61	0.76	1.09	1.21	1.20	1.21	1.16	1.15	1.33	0.98	0.78	tank within vegetation	(Muckel and Blaney 1945)
Tules/Bulrush	No	5	Bonsall, Ca	0.83	0.61	0.94	1.11	1.24	1.24	1.14	1.14	1.12	1.06	0.78	0.97	tank within vegetation	(Muckel and Blaney 1945)
Tules/Bulrush	No	5	Bonsall, Ca	0.98	0.77	0.66	0.83	0.99	1.22	1.27	1.37	1.25	1.23	1.20	0.70	tank within vegetation	(Muckel and Blaney 1945)
Cattails	Yes	1	Logan, Utah				0.35	0.75	1.27	1.30	1.30	0.73				Bowen ratio	(Allen 1998)
Tules, cattails, wocus lily	Yes	1	Upper Klamath NWR	0.91	0.91	0.91	0.91	0.92	1.06	1.10	1.12	0.72	0.91	0.91	0.91	eddy covariance	(Stannard 2013)
Tules/Bulrush	Yes	1	Upper Klamath NWR	1.01	1.01	1.01	1.01	0.97	1.08	1.09	1.20	0.83	1.01	1.01	1.01	eddy covariance	(Stannard 2013)
			Average	**0.77**	**0.74**	**0.81**	**0.88**	**0.99**	**1.11**	**1.12**	**1.14**	**0.97**	**1.03**	**0.92**	**0.82**		
			SD	**0.27**	**0.16**	**0.15**	**0.25**	**0.18**	**0.14**	**0.15**	**0.17**	**0.19**	**0.19**	**0.19**	**0.17**		
			CV	**0.35**	**0.22**	**0.18**	**0.28**	**0.18**	**0.13**	**0.14**	**0.15**	**0.20**	**0.19**	**0.21**	**0.21**		

Italicized values are likely measurement errors and were not included in the statistics

Table 1. (continued)

Small Stand Wetland Vegetation	**Long-Term Freeze**	**ETo Est.**	**Location**	**Vegetation Coefficient (ETc/ETo) based on Grass Reference**												**Method**	**Source**
				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Cattails	No	5	King Island, CA	1.28	1.47	1.61	1.18	1.79	1.46	1.87	1.43	1.52	1.70	1.97	1.36	tank within vegetation	(Young and Blaney 1942)
Cattails	No	5	King Island, CA	0.75	1.09	1.80	1.96	2.64	1.85	1.88	1.40	1.59	2.38	1.97	0.60	tank within vegetation	(Young and Blaney 1942)
Tules/Bulrush	No	3	Victorville, CA	0.46	0.56	0.75	0.81	1.08	1.33	1.39	1.42	1.58	1.26	0.89	0.73	tank within vegetation	(Young and Blaney 1942)
Tules/Bulrush	Yes	1	Logan, Utah				0.35	0.96	1.76	1.81	1.81	0.97				Bowen ratio	(Allen 1998)
Cattails	Yes	1	Logan, Utah				0.35	0.82	1.60	2.03	1.54	0.52				Bowen ratio	(Allen 1998)
			Average	**0.83**	**1.04**	**1.39**	**0.93**	**1.46**	**1.60**	**1.80**	**1.52**	**1.24**	**1.78**	**1.61**	**0.90**		
			SD	**0.42**	**0.46**	**0.56**	**0.67**	**0.76**	**0.21**	**0.24**	**0.17**	**0.47**	**0.56**	**0.63**	**0.40**		
			CV	**0.50**	**0.44**	**0.40**	**0.73**	**0.52**	**0.13**	**0.14**	**0.11**	**0.38**	**0.32**	**0.39**	**0.45**		

Large Stand Riparian Vegetation	**Long-Term Freeze**	**ETo Est.**	**Location**	**Vegetation Coefficient (ETc/ETo) based on Grass Reference**												**Measurement Method**	**Source**
				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Willows	No	4	Santa Ana, CA		0.68	0.78	1.05	0.82	0.90	1.13	1.20	1.43	1.21	1.09	0.80	tank within vegetation	(Young and Blaney 1942)
Cottonwood	Yes	1	Middle Rio Grande, NM	0.81	0.72	0.61	0.66	0.82	0.94	1.02	1.02	1.07	1.08	0.88	0.89	tank within vegetation	(Allen et al. 2005)
R.Olive	Yes	1	Middle Rio Grande, NM	0.83	0.74	0.64	0.70	0.86	0.99	1.06	1.06	1.12	1.12	0.92	0.92	remote sensing (METRIC)	(Allen et al. 2005)
Willow	Yes	1	Middle Rio Grande, NM	0.81	0.67	0.55	0.59	0.74	0.86	0.93	0.95	1.07	1.05	0.86	0.89	remote sensing (METRIC)	(Allen et al. 2005)
			Average	**0.82**	**0.70**	**0.65**	**0.75**	**0.81**	**0.93**	**1.03**	**1.06**	**1.17**	**1.11**	**0.94**	**0.87**		
			SD	**0.02**	**0.03**	**0.10**	**0.21**	**0.05**	**0.06**	**0.09**	**0.11**	**0.18**	**0.07**	**0.10**	**0.05**		
			CV	**0.02**	**0.05**	**0.15**	**0.28**	**0.06**	**0.06**	**0.08**	**0.10**	**0.15**	**0.06**	**0.11**	**0.06**		

Table 1. (continued)

Small Stand Riparian Vegetation	**Long-Term Freeze**	**ETo Est.**	**Location**	**Vegetation Coefficient (ETc/ETo) based on Grass Reference**												**Measurement Method**	**Source**
				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Common reed, willow, cottonwood	Yes	1	Platte River Basin, Central City, Nebraska					0.80	1.24	1.40	1.50	1.13	0.91			Bowen ratio	(Irmak et al. 2013)
Common reed, willow, cottonwood	Yes	1	Platte River Basin, Central City, Nebraska					1.00	1.69	1.75	1.79	1.97	1.66			Bowen ratio	(Irmak et al. 2013)
			Average					**0.90**	**1.46**	**1.57**	**1.64**	**1.55**	**1.28**				
			SD					**0.14**	**0.32**	**0.25**	**0.21**	**0.60**	**0.53**				
			CV					**0.16**	**0.22**	**0.16**	**0.13**	**0.39**	**0.42**				

Large Stand Saltcedar	**Long-Term Freeze**	**High WT**	**Location**	**Vegetation Coefficient (ETc/ETo) based on Grass Reference**												**Measurement Method**	**Source**
				Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**		
Saltcedar	No	8 ft	Havasu NWR, AZ	0.22	0.22	0.28	0.50	0.72	0.76	0.76	0.76	0.75	0.59	0.34	0.22	Bowen ratio	(Westenburg et al. 2006)
Saltcedar	Yes	>10 ft	Bosque del Apache, NM		0.44	0.23	0.30	0.53	0.85	0.96		0.78				eddy covariance	(Bawazir et al. 2009)*
Saltcedar	Yes	3ft to 15ft	Bosque del Apache, NM				0.50	0.76	0.87	1.05	1.21	1.14	0.97	0.43		eddy covariance	(Bawazir et al. 2006)
Saltcedar	Yes		Middle Rio Grande, NM	0.75	0.61	0.47	0.49	0.58	0.68	0.79	0.85	1.00	1.02	0.82	0.83	remote sensing (METRIC)	(Allen et al. 2005)
			Average	**0.49**	**0.42**	**0.33**	**0.45**	**0.65**	**0.79**	**0.89**	**0.94**	**0.92**	**0.86**	**0.53**	**0.53**		
			SD	**0.37**	**0.19**	**0.13**	**0.10**	**0.11**	**0.09**	**0.14**	**0.24**	**0.19**	**0.24**	**0.26**	**0.43**		
			CV	**0.77**	**0.45**	**0.40**	**0.22**	**0.17**	**0.11**	**0.16**	**0.25**	**0.20**	**0.28**	**0.48**	**0.81**		

*Values are single day measurements within the months shown, not monthly averages

Table 1. (continued)

Large Stand Non-stressed Pasture	Long-Term Freeze	ETo Est.	Location	Vegetation Coefficient (ETc/ETo) based on Grass Reference Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Measurement Method	Source
Native Pasture	Yes	5	Alturas, CA	0.46	0.43	0.51	0.97	0.97	1.13	1.21	1.28	1.20	1.07	0.69		tank within vegetation	(MacGillivray 1975)
Native Pasture	Yes	5	Shasta County, CA	0.29	0.29	0.38	0.90	0.95	1.02	1.09	1.12	1.10	0.99	0.93	0.86	tank within vegetation	(MacGillivray 1975)
Irrig. Pasture (WT 0-2 ft)	Yes	5	Carson Valley, NV	0.82	0.82	0.90	1.23	1.17	0.93	0.99	0.98	1.09	0.86			eddy covariance	(Maurer et al. 2006)
Irrig. Pasture (WT 2-5ft)	Yes	5	Carson Valley, NV	0.75	0.70	0.63	0.76	1.00	0.84	0.77	0.56	0.50	0.48			Bowen ratio	(Maurer et al. 2006)
			Average	**0.58**	**0.56**	**0.60**	**0.96**	**1.02**	**0.98**	**1.02**	**0.98**	**0.97**	**0.85**	**0.81**	**0.86**		
			SD	**0.25**	**0.24**	**0.22**	**0.20**	**0.10**	**0.13**	**0.18**	**0.31**	**0.32**	**0.26**	**0.17**			
			CV	**0.43**	**0.43**	**0.37**	**0.20**	**0.10**	**0.13**	**0.18**	**0.31**	**0.33**	**0.31**	**0.21**			
			CV	**0.77**	**0.45**	**0.40**	**0.22**	**0.17**	**0.11**	**0.16**	**0.25**	**0.20**	**0.28**	**0.48**	**0.81**		

Table 2. Grass reference based vegetation coefficient (Kv) for other types of vegetation types that were primarily rainfed.

				Vegetation Coefficient (ETc/ETo) based on Grass Reference													
Other Vegetation	**ETo Est.**	**WT Depth**	**Location**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Method**	**Source**
Oak-Grass Savanna	2	None	Near Iona, CA	0.54	0.39	0.49	0.59	0.55	0.30	0.18	0.11	0.07	0.04	0.36	1.06	eddy covariance	(Baldocchi et al. 2004)
Bermuda grass	4	2 ft	San Bernardino, CA	0.58	0.35	0.43	0.59	0.61	0.89	1.02	0.87	0.74	0.75	0.88	0.84	tank within vegetation	(Taylor 1934)
Bermuda grass	4	3 ft	San Bernardino, CA	0.55	0.33	0.30	0.48	0.45	0.76	0.84	0.71	0.61	0.66	0.82	0.60	tank within vegetation	(Taylor 1934)
Arrowweed	1	8 ft	Havasu NWR, AZ	0.21	0.21	0.32	0.46	0.56	0.56	0.56	0.55	0.45	0.34	0.23	0.21	Bowen ratio	(Westenburg et al. 2006)
Mesquite, saltcedar, salt grass	1	4-8 ft	Havasu NWR, AZ	0.30	0.30	0.37	0.46	0.53	0.53	0.53	0.47	0.40	0.33	0.30	0.30	Bowen ratio	(Westenburg et al. 2006)
chaparral	5	No	Sierra Ancha Forest, AZ	0.30	0.32	0.26	0.34	0.35	0.04	0.21	0.33	0.30	0.21	0.34	0.40	lysimeter	(Rich 1951)
Sacaton	5	25 in	Carlsbad, NM			0.47	0.72	0.84	0.74	0.96	0.92	0.49	0.78	0.72	0.16	tank within vegetation	(Blaney 1954)
Saltgrass	4	12 in	Santa Ana, California	0.51	0.54	0.44	0.67	0.64	0.89	1.15	1.00	0.81	0.72	0.75	0.66	tank within vegetation	(Young and Blaney 1942)
Saltgrass	4	24 in	Santa Ana, California	0.19	0.20	0.17	0.26	0.27	0.35	0.45	0.40	0.33	0.29	0.29	0.25	tank within vegetation	(Young and Blaney 1942)
Saltgrass	4	36 in	Santa Ana, California	0.79	0.63	0.64	0.61	0.00	0.27	0.38	0.33	0.33	0.35	0.70	0.89	tank within vegetation	(Young and Blaney 1942)
Saltgrass	4	48 in	Santa Ana, California	0.12	0.11	0.09	0.19	0.06	0.12	0.37	0.49	0.31	0.39	0.29	0.29	tank within vegetation	(Young and Blaney 1942)

DISCUSSION

The Kv values show relatively good agreement between studies from Table 1. As one might expect, fall and winter Kv values have higher coefficients of variation than those from late spring through summer in most cases. This is likely due to variable precipitation amounts resulting in different amounts of evaporation. Additionally, this variability can be attributed to data from studies where the vegetation that may have been dormant (long-term winter freeze) was grouped with studies that had lower levels of dormancy.

Since the higher variability in Kv's occurs during the portion of the year where ETo is lower, the potential resulting inaccuracy toward the annual ETc estimate will be less significant. This is illustrated in Table 3. Long-term ETo for an area near Stockton, CA was used to compute the ETc for large stands of wetland vegetation. Kv values from the study by Muckel and Blaney (1945) for an area near San Diego were compared with the average monthly Kv values shown in Table 1. The resulting difference in annual ET estimates was approximately -9%. However, if the studies from Florida are not included in the average, the error is reduced to -1.7% (not shown). On a monthly basis the differences were higher during the fall, winter and spring because of the variability in Kv during these months. However, during the highest ETo months, the differences were smaller.

Table 3. Comparison of ETc computed using Kv values estimated from Muckel and Blaney (1945) for Bonsall, CA and the overall average Kv for large stand wetlands.

Large Stand Wetlands	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
ETo (inches)	1.59	2.2	3.66	5.08	6.83	7.8	8.67	7.81	5.67	4.03	2.13	1.59	57.06
Bonsall, CA													
Kv	0.36	0.61	0.76	1.09	1.21	1.20	1.21	1.16	1.15	1.33	0.98	0.78	
ETc (inches)	**0.58**	**1.33**	**2.78**	**5.53**	**8.27**	**9.36**	**10.51**	**9.10**	**6.54**	**5.37**	**2.09**	**1.25**	**62.70**
Average													
Kv	0.67	0.66	0.75	0.85	1.00	1.12	1.12	1.14	1.03	1.06	0.90	0.75	
ETc (inches)	**1.07**	**1.45**	**2.73**	**4.32**	**6.83**	**8.77**	**9.74**	**8.90**	**5.84**	**4.28**	**1.92**	**1.20**	**57.04**
ETc Difference (inches)	**0.49**	**0.11**	**-0.05**	**-1.21**	**-1.44**	**-0.59**	**-0.76**	**-0.20**	**-0.70**	**-1.10**	**-0.17**	**-0.05**	**-5.66**

Most of the studies examined were conducted in arid environments. Kv values can be different in areas with higher relative humidity. Transferability of Kv values should be limited to similar general climate conditions.

The values in Table 2 should be examined with caution. Computing ETc using a single vegetation coefficient method can result in significant error since the ETc rate will depend on water availability to the plant. A more appropriate method would be to use the dual crop coefficient method (Allen et al. 1998) using a daily, or more frequent, root zone soil water balance to account for potential water stress with limited soil moisture. The values in Table 2 along with information from the studies themselves may be useful for model calibration or as a reality check to a root zone soil water balance model.

CONCLUSION

A list of grass reference based vegetation coefficients estimated from previous research on natural vegetation is presented. While the list is not exhaustive, there is good agreement between studies for similar vegetation types and site conditions especially during the high evapotranspiration months. During the winter, Kv values showed more variability due to dormancy and precipitation. The Kv values presented in this study will hopefully assist water managers and planners more accurately estimate natural vegetation ETc.

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