ASCE's Standardized Reference Evapotranspiration Equation

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Abstract

The ASCE Evapotranspiration in Irrigation and Hydrology Committee (ASCE-ET) is recommending for the intended purpose of establishing uniform evapotranspiration (ET) estimates and transferable crop coefficients, *two standardized* reference evapotranspiration *surfaces*: (1) a short crop (similar to grass) and (2) a tall crop (similar to alfalfa), and *one Standardized* Reference Evapotranspiration *equation*. The equation is derived from the ASCE-Penman Monteith equation (Jensen et al., 1990), by simplifying several terms within that equation. The equation with appropriate constants provided in an accompanying table is used to calculate evapotranspiration for the standardized short reference (ET_{os}) or evapotranspiration for the standardized tall reference (ET_{rs}). One constant is in the numerator and one is in the denominator. The constant in the right-hand side of the numerator (C_n) is a function of the time step and aerodynamic resistance (i.e., reference type). The constant in the denominator (C_d) is a function of the time step, bulk surface resistance, and aerodynamic resistance (the latter two terms vary with reference type, time step, and daytime/nighttime).

The standardized reference evapotranspiration surfaces and equation will provide:

1. A standardized calculated evaporative demand that can be used in developing transferable crop coefficients.
2. A clear methodology for practicing engineers to use for estimating reference evapotranspiration; therefore, the K_{cr}*ET_{rs} or K_{co}* ET_{os} procedure will more readily be adopted by the private sector, federal, and state agencies.
3. More universal hourly equations that will provide better comparisons between summed hourly reference ET and daily reference ET.

The equation was selected based on the criteria that it be understandable, defensible, accepted by science/engineering communities, be simple, and enable the use of existing data and technology. Based upon comparisons to lysimeter data and calculated reference evapotranspiration using 1982 Kimberly Penman, FAO-56 Penman, and ASCE Penman Monteith, ASCE-ET found the equations to be sufficiently accurate to recommend their use for calculation of reference evapotranspiration, the development of crop coefficients, and estimation of crop evapotranspiration. ASCE recommends using the symbols K_{co} for crop coefficients to be used with "short" crop reference ET_{os}, and to use K_{cr} for crop coefficients to be used with "tall" crop reference ET_{rs}

NOTE: This paper was presented at the National Irrigation Symposium in Phoenix, Arizona, 2000.

Introduction

In May 1999, The Irrigation Association (IA) requested that the ASCE-ET help establish and define a benchmark reference evapotranspiration (ET) equation. The purpose of the equation is to bring commonality to the various reference ET equations and crop coefficients now in use.

The request to ASCE-ET was transmitted in a letter from IA's Executive Director to ASCE-ET. IA envisioned an equation that would be accepted by the U.S. scientific community, engineers, courts, policy makers, and end users. An equation that would be applicable to agricultural and landscape irrigation and facilitate the use and transfer of crop and landscape coefficients was requested. In addition, IA requested guidelines for using the equation in regions where climatic data was limited. Also, IA requested that ASCE-ET recommend methods for incorporating existing crop and landscape coefficients and existing reference ET calculations.

ASCE-ET Meetings

In response to IA, ASCE-ET members met three times to discuss the issues. ASCE-ET met with members of IA's Water Management Committee in Denver, Colorado on May 25 and 26, 1999. At the Denver meeting attendees the IA request in detail. It was decided in Denver that the equation would be labeled the ASCE Standardized Reference Evapotranspiration Equation. In August 1999, ASCE-ET held its annual meeting in Seattle, Washington, and the ASCE Task Committee on Standardization of Reference Evapotranspiration (TC) was formed. Additionally, equations were selected by ASCE-ET to be evaluated as candidate standardized reference ET equations. The third meeting held November 18 and 19, 1999 in Phoenix, Arizona involved TC members only (although some TC members are members of the ASCE-ET and/or the IA water management committee). The purpose of that meeting was twofold: (1) to evaluate the results of evapotranspiration estimates calculated using 13 equations, data from 12 states, 36 sites and 61 site-years, and (2) to develop a recommended Standardized Reference Evapotranspiration Equation. Prior to the Denver meeting and continuing on after the Phoenix meeting, an extensive amount of e-mail communication between ASCE-ET and TC members shared opinions and data on several of the technical issues that needed to be standardized for incorporation into the standardized reference equation. Several issues such as the calculation of net radiation, latent heat of vaporization, and measurement unit for meteorological were discussed by e-mail for several weeks.

Additional Motivations for Implementation

1. A standardized equation or equations will provide a standardized calculated evaporative demand that can be used in developing transferable coefficients.
2. Numerous reference crop equations have been developed and published which have created some confusion for practitioners as to which equation to use. For example, the TC evaluated seven basic reference evapotranspiration

equations that calculate reference evapotranspiration for grass, alfalfa or both.

3. The K_{cr}*ET_{rs} or K_{co}* ET_{os} calculated crop evapotranspiration procedure will more readily be adopted by the private sector and federal and state agencies if a scientific body recommends a standardized equation(s).
4. Both the public and private sectors are now operating automated weather stations that calculate reference ET directly and guidance as to which equation to use is needed.
5. Some reference crop equations have not worked well in coastal areas, and better hourly equations are needed.
6. Calculated hourly ET when summed for a 24-hour period should approximate calculated daily ET.

Criteria

The TC established several criteria for the selection of the equation. The criteria were that the product should be understandable, defensible, accepted by science/engineering communities, be simple, enable use of existing data and technology, and be based on (or traceable to) measured or experimental data. Specifically, the user of the equation should be able to relate the equation to a known reference crop, evaporative index or hypothetical surface. Additionally, the equation should be a derivation of accepted methods as described in Jensen et al. (1990), Allen et al (1989), Allen, et al. (1994), and Allen et al. (1996). Simplification of an accepted method without significant loss of accuracy was an important element of the criteria. Lastly, but of equal importance, the equation should be able to use existing hourly and/or daily data, and the sums of hourly calculated ET should closely approximate daily computed ET values.

Definition of the Equation

In its early discussions, ASCE-ET concluded that use of the term *standard* or *benchmark* could lead users to assume that the calculated values determined using the "equation" were for comparison purposes or were a level to be measured against. That is not the purpose. At the Denver meeting prior to an testing of equations, ASCE-ET and IA members decided that two *standardized* reference ET surfaces along with *standardized* computational procedures were most appropriate for meeting the IA request. The two standardized reference ET surfaces to be adopted would be: (1) a short crop (similar to grass) and (2) a tall crop (similar to alfalfa). Additionally, the TC recognized the need to have both hourly and daily reference ET equations.

Equations Evaluated

ASCE-ET members have hundreds of years of combined experience with numerous reference evapotranspiration equations. Remarkably, the number of equations presently preferred by the members was relatively limited. They included ASCE-Penman Monteith (grass w/ h=0.12 m and alfalfa w/ h=0.50 m), FAO-56 Penman Monteith (grass), 1982 Kimberly Penman (alfalfa), CIMIS Penman (grass), NRCS Chapter 2 Penman Monteith (grass) and 1985 Hargreaves (grass). In their many years of research and practical experience, TC members have found that the

ASCE Penman Monteith equation, when applied using aerodynamic and surface resistance algorithms presented in ASCE Manual 70 to match the particular reference type (0.12 m grass and 0.50 m alfalfa), provided accurate ET estimates compared with measured ET using a lysimeter with a reference crop. Since measured reference lysimeter ET data are limited worldwide and especially within the United States, the TC selected the ASCE-PM reference ET values as the measure against which to evaluate the proposed equations. The Penman-Monteith form of the combination equation is:

$$ET = \left(\frac{\Delta(R_n - G) + K_{time}\,\rho_a\, c_p \dfrac{(e_s - e_a)}{r_a}}{\Delta + \gamma\left(1 + \dfrac{r_s}{r_a}\right)} \right) / \lambda \qquad (1)$$

where ET is the reference evapotranspiration, (mm d^{-1} or mm h^{-1}); R_n is the net radiation, (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1}); G is the soil heat flux, (MJ m^{-2} d^{-1} or MJ m^{-2} h^{-1}); (e_s - e_a) represents the vapor pressure deficit of the air, (kPa); e_s is saturation vapor pressure of the air, (kPa); e_a is the actual vapor pressure of the air, (kPa); ρ_a is the mean air density at constant pressure, (kg m^{-3}); c_p is the specific heat of the air, (MJ kg^{-1} $^oC^{-1}$); Δ is the slope of the saturation vapor pressure temperature relationship, (kPa $^oC^{-1}$); γ is the psychrometric constant, (kPa $^oC^{-1}$); r_s is the (bulk) surface resistance, (s m^{-1}); r_a is the aerodynamic resistance, (s m^{-1}); λ is latent heat of vaporization, (MJ kg^{-1}); K_{time} is a unit conversion, (86,400 s d^{-1} for ET in mm d^{-1} and 3600 s h^{-1} for ET in mm h^{-1}).

Initially, TC members evaluated the performance of 12 ET_o equations and 8 ET_r equations. A listing of the equations and a brief description is provided in Table 1. More detail is provided in Allen's paper that is being presented at this symposium.

Table 1. Reference Evapotranspiration Equations and Procedures Evaluated

Abbreviation	Method or Procedure	Description
R_n 56	Net radiation	Net radiation calculated using FAO-56 procedures (Allen et al., 1998)
$R_{n\ Wright}$	Net radiation	Net radiation calculated using Wright (1982) procedure
G 56	Soil heat flux	Soil heat flux calculated using FAO-56 procedures (Allen et al., 1998)
ASCE-PM	ET_o & ET_r	ASCE-Penman Monteith, Jensen et al. al. (1990) w/Rn56, G56, r_a & r_s = F(ht)
FAO-56-PM	ET_o	ASCE-PM w/ ht = 0.12 m, r_s = 70 s/m and albedo = 0.23, R_n 56, G = 0, λ = 2.45 MJ kg^{-1} (Allen et al., 1998)
ASCE-PMD	ET_o & ET_r	ASCE-PM, r_a = f(ht), albedo=0.23, daily ET_o r_s = 70 s/m, hourly ET_o r_s = 50 & 200 s m^{-1}; daily ET_r r_s = 45 s m^{-1}, hourly ET_r r_s = 30s/m & 200 s m^{-1}
ASCE-PMDL	ET_o & ET_r	ASCE-PMD, lambda = 2.45 MJ kg^{-1}
ASCE-PMv	ET_o & ET_r	ASCE-PMD & r_s specified by user
ASCE-PMDR	ET_o & ET_r	ASCE-PM with R_n = R_n (Wright)
1982-Kpen	ET_r	1982 Kimberly Penman (Wright, 1982;1987)
FAO24-Pen	ET_o	FAO24 Modified Penman (Doorenbos and Pruitt, 1977),
1963-Pen	ET_o	1963 Version of Penman (Penman, 1963)
1985-Harg	ET_o	1985, Hargreaves (Hargreaves et al., 1985)
ASCE-PMrf	ET_o & ET_r	ASCE-PM, reduced form: R_n56, G56, ET_o rs = 70 s m^{-1}; ET_r rs = 45 s m^{-1}; ET_o

		zw & zh = 2 m; ET_r zw & zh = 1.5 m, d = 0.8 m.
ASCE-PMrfh	ET_o & ET_r	ASCE-PM reduced form hourly only: ET_o rs = 50 s m^{-1}; ET_r rs = 30 s m^{-1}.
CIMIS-Pen	ET_o	CIMIS Penman (hourly only) with FAO-56 Rn and G = 0

Issues Addressed

By careful examination of Table 1, it can be seen that the TC evaluated several components of reference evapotranspiration. Practically every component of the Penman and Penman Monteith equations was evaluated, discussed, standardized and if possible simplified. The methods for calculating net radiation and soil heat flux described in Jensen, et al. (1990), Wright (1982), Doorenbos and Pruitt (1977), and Allen et al. (1998) were examined in detail. The use of a constant (2.45 MJ kg^{-1}) for the latent heat of vaporization (λ) was evaluated not only for how it changed with temperature, but the impact of that change on ET. The adoption of set values for surface and aerodynamic resistance occurred only after intense review and discussion by e-mail between TC members. The matter was also re-addressed at the Phoenix meeting. Other components discussed in detail included the calculation of vapor pressure deficit and measurement units for meteorological data. The TC worked diligently to ensure that its recommendation for each component was within the criteria established.

Description of Evaluation

The equations in Table 1 and the standardized reference evapotranspiration equation were evaluated using REF-ET. REF-ET is a software program capable of calculating reference ET by using up to fifteen of the more common methods, (Allen, 1999). Prior to the Phoenix meeting, Allen modified REF-ET to incorporate the 12 ET_o equations and 8 ET_r equations the TC selected for its initial evaluation. Following the Phoenix meeting, REF-ET was modified for testing the recommended reference ET equation. Data evaluated for the Phoenix meeting was from 36 sites at 12 states and covered 61 site years of data. Post-Phoenix analysis involved additional data from four states. The final data analysis involved 82 site-years from 49 sites in 16 years. ET in the states of Arizona, California, Colorado, Idaho, Montana, Nebraska, Oklahoma, Oregon, South Carolina, Texas, Utah, Washington Florida, Georgia, Illinois, and New York was evaluated. The data were collected by TC members. The TC made a concerted effort to insure that the data span a wide range of elevation (2 to 2,895 meters), mean annual precipitation (152 to 2,032 mm) and peak monthly ET (2.78 to 9.68 mm d^{-1}. REF-ET was provided to TC members, who had volunteered to calculate ET_o and ET_r using meteorological data within their region. The significant benefit of using REF-ET was that the output was standardized which improved the efficiency of the analysis.

Daily and hourly ET amounts from all the sites were sent to the Biosystems and Agricultural Engineering Department at Oklahoma State University. There the ET was complied and several equation-to-equation comparisons were conducted. The key comparisons were daily ET versus daily ASCE PM, summed hourly ET versus daily ASCE-PM and summed hourly ET versus daily ET (same method). The comparisons were made for both ET_o and ET_r. Oklahoma analyzed the ratio of each equation's ET estimate to that of ASCE PM, the Root Mean Square Difference (RMSD) and the RMSD as a percentage of ASCE-PM. For each of the site years, the statistics were summarized growing season and if available, the full year.

Discussion of Phoenix Results

At the meeting in Phoenix, the TC spent the better part of two days reviewing and discussing the results of the 61 site-years of data. A summary of the more pertinent findings follows:

Daily ET_o vs. ASCE-PM ET_o: Briefly the TC found that differences in R_n are minor when the FAO-56 procedure (Allen et al., 1998) is compared to Wright (1982). The 1985 Hargreaves should be calibrated at most sites. The 1963 Penman tends to over estimate by about 6 percent. The FAO-24 Penman overestimates by about 17 to 19 percent. Most importantly, the TC found that reduced forms of ASCE-PM using constants for lambda (heat of vaporization) and r_S (surface resistance) resulted in a limited loss in accuracy (ranging from –2% to 0.07% error

Daily ET_r vs. ASCE-PM ET_r: The TC found that the use of Wright's (1982) Rn procedure instead of FAO-56's R_n procedure caused a reduction in ET_r estimates of about 2 to 3 percent. The ratio of 1982 Kimberly Penman to ASCE PM for yearly data ranged from 0.86 to 1.15. The average ratio was about 0.94. The same ratio, growing season only, ranged from 0.89 to 1.18 and averaged 0.98. Similar to the ET_o comparison, the use of constants for lambda and r_s resulted in limited loss of accuracy.

Summed hourly ET_o to Daily ASCE ET_o: The TC investigated in detail procedures and coefficients for calculation of soil heat flux as it impacts hourly calculations. It was concluded that the procedures in Allen, 1998 provided reasonably good estimates. The results showed that the ratio of the summed hourly ASCE PM to the daily ASCE PM ranged from 0.86 to 1.01 and averaged 0.95 annually. For the growing season, the range was from 0.76 to 1.05 and averaged 0.95. The summed hourly ASCE PM did not agree with daily ASCE PM at sites with strong nighttime winds. However, overall the hourly r_S values of 50 and 200 (day and nighttime) were concluded to be fairly accurate in matching ET_O calculated with daily data. The ratio of ASCE PMDL to ASCE-PM ranged from 0.94 to 1.05 and averaged 1.00, annually. For the growing season, the range was from 0.87 to 1.08 and averaged 1.00. The CIMIS equation showed the most variability from site to site relative to the daily ASCE PM with ratios for the growing seasons ranging from 0.97 to 1.25 and averaging about 1.08.

Summed hourly ET_r to Daily ASCE ET_r: The review of these comparisons found results similar to the ET_O comparisons. The results showed that the ratio of the summed hourly ASCE PM to the daily ASCE PM ranged from 0.86 to 1.02 and averaged 0.935 annually. For the growing season, the range was from 0.84 to 1.03 and averaged 0.94. The ratio of ASCE PMDL to ASCE PM ranged from 0.86 to 1.02 and averaged 0.93, annually. The comparison of growing season values ranged from 0.90 to 1.07 and averaged 0.99. The ASCE PMDL was within acceptable accuracy.

Based upon that review and the extensive sharing of information prior to the meeting, the TC agreed upon the form of the standardized reference evapotranspiration equation.

Recommendation

The TC recommends that two Standardized Reference Evapotranspiration surfaces can be modeled using a Standardized Reference Evapotranspiration Equation with appropriate constants and standardized computational procedures be adopted. The surfaces/equations are defined as:

Standardized Reference Evapotranspiration Equation, Short (ET_{os}): Reference ET for a *short* crop with an approximate height of *0.12* m (similar to grass).

Standardized Reference Evapotranspiration Equation, Tall (ET_{rs}): Reference ET for a *tall* crop with an approximate height of *0.50* m (similar to alfalfa).

Two reference surfaces that are similar to known crops were recommended by the TC due to the widespread use of grass and alfalfa across the United States and due to their individual advantages for specific applications and times of the year. As a part of the standardization, the "full" form of the Penman-Monteith equation and associated equations for calculating aerodynamic and bulk surface resistance have been combined and reduced to a single equation having two constants. The constants vary as a function of the reference surface (ET_{os} or ET_{rs}) and time step (hourly or daily). This was done to simplify the presentation and application of the methods. The constant in the right-hand side of the numerator (C_n) is a function of the time step and aerodynamic resistance (i.e., reference type). The constant in the denominator (C_d) is a function of the time step, bulk surface resistance, and aerodynamic resistance (the latter two terms vary with reference type, time step and daytime/nighttime). Equation 2 presents the form of the Standardized Reference Evapotranspiration Equation for all hourly and daily calculation time steps. Table 2 provides values for the constants C_n and C_d.

$$ET_{ref} = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \qquad (2)$$

where ET_{ref} is Short (ET_{os}) or tall (ET_{rs}) standardized reference crop evapotranspiration (mm day^{-1} for daily time steps or mm hour^{-1} for hourly time steps); R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}for daily time steps or MJ m^{-2} hour^{-1} for hourly time steps); G is soil heat flux density at the soil surface (MJ m^{-2} day^{-1} for daily time steps or MJ m^{-2} hour^{-1} for hourly time steps); T is mean daily or hourly air temperature at 1.5 to 2.5-m height (°C); u_2 is mean daily or hourly wind speed at 2-m height (m s^{-1}); e_s is mean saturation vapor pressure at 1.5 to 2.5-m height (kPa); for daily computation, the value is the average of e_s at maximum and minimum air temperature; e_a is mean actual vapor pressure at 1.5 to 2.5-m height (kPa); Δ is slope of the vapor pressure-temperature curve (kPa °C^{-1}); γ is psychrometric constant (kPa °C^{-1}); C_n is numerator constant for reference type and calculation time step, and C_d is denominator constant for reference type and calculation time step.

Table 2. Values for C_n and C_d in Equation 1

Calculation Time Step	*Short Reference, ET_{os}*		*Tall Reference, ET_{rs}*		*Units for ET_{os}, ET_{rs}*	*Units for R_n, G*
	C_n	C_d	C_n	C_d		
Daily	900	0.34	1600	0.38	mm d^{-1}	MJ m^{-2} d^{-1}
Hourly -daytime	37	0.24	66	0.25	mm h^{-1}	MJ m^{-2} h^{-1}
Hourly - nighttime	37	0.96	66	1.7	mm h^{-1}	MJ m^{-2} h^{-1}

Briefly, C_n and C_d are based upon simplifying several terms within the ASCE-PM and limited rounding. The simplified terms are summarized in Table 3. Equations associated with calculation of required parameters in Equation 2, the detailed derivation of the constants in Table 2 and simplification of the terms listed in Table 3 are explained in more detail in Allen's paper.

Table 3. ASCE Penman Monteith Terms Standardized for the Standardized Reference Evapotranspiration Equation

Term	**ET_{os}**	**ET_{rs}**
Reference vegetation height, h	0.12 m	0.50 m
height of air temperature and humidity measurements, z_h	1.5 - 2.5 m	1.5 – 2.5 m
height of wind measurements, z_w	2.0 m	2.0 m
zero plane displacement height	0.08 m	0.08 m
Lambda	2.45 MJ kg^{-1}	2.45 MJ kg^{-1}
Surface resistance, r_s, daily	70 s m^{-1}	45 s m^{-1}
Surface resistance, r_s, daytime	50 s m^{-1}	30 s m^{-1}
Surface resistance, r_s, nighttime	200 s m^{-1}	200 s m^{-1}
R_n to predict daytime	> 0	> 0
R_n to predict nighttime	≤ 0	≤ 0

The standardized equation has been presented to IA in a brief four-page report. More detailed report and journal articles that will contain specifics and refer to available publications for additional details will be prepared.

Performance of the Standardized Reference Evapotranspiration Equation

A comprehensive summary of the final comparison of ET_{os} and ET_{rs} to the ASCE-PM at the 49 sites is presented in Itenfisu, et al. (2000). A partial listing of the Itenfisu, et al. 2000 results is provided in Table 4.

Table 4. Statistical summary of the comparisons between the Standardized Reference Evapotranspiration Equations and ASCE- Penman Montieth.

METHOD	RATIO				RMSD (mm d^{-1})				RMSD as % of Mean Daily ET
	Max	**Min**	**Mean**	**Std Dev**	**Max**	**Min**	**Mean**	**Std Dev**	**Mean**
Hourly Sum ET_o vs. Daily ET_o (within method)									
ASCE-PM	1.047	0.903	0.964	0.033	0.829	0.156	0.353	0.136	8.2
ASCE Stand'zed	1.107	0.941	1.016	0.028	0.663	0.228	0.334	0.088	7.7
Hourly Sum ET_r vs. Daily ET_r (within method)									
ASCE-PM	1.106	0.875	0.950	0.044	1.367	0.232	0.558	0.241	10.1
ASCE Stand'zed	1.196	0.933	1.029	0.041	1.048	0.315	0.546	0.160	9.7
Daily ET_o vs. Daily ASCE-PM ET_o									
ASCE Stand'zed	1.007	0.982	0.995	0.006	0.146	0.008	0.041	0.032	0.9
Daily ET_r vs. Daily ASCE-PM ET_r									
ASCE Stand'zed	1.025	0.974	0.998	0.010	0.300	0.014	0.069	0.058	1.28
Hourly Sum ET_o vs. Daily ASCE-PM ET_o									
ASCE-PM	1.047	0.903	0.964	0.033	0.829	0.156	0.353	0.136	8.2
ASCE Stand'zed	1.101	0.937	1.011	0.029	0.678	0.234	0.334	0.090	7.9
Hourly Sum ET_r vs. Daily ASCE-PM ET_r									
ASCE-PM	1.106	0.875	0.950	0.044	1.367	0.232	0.558	0.241	10.1
ASCE Stand'zed	1.199	0.935	1.026	0.041	1.067	0.331	0.538	0.152	10.1

The statistical summary listed in Table 4 show that the hourly summed ET versus daily ET for the standardized equation as well or better than the ASCE-PM hourly summed ET versus to daily ET. The comparisons of daily ET_{os} to daily ASCE-PM ET_o and daily ET_{rs} to daily ASCE-PM ET_r show a very small difference; therefore the simplifications have a minimal impact on reference ET estimates. The third comparison of hourly sums of ETos and ETrs to daily ASCE-PM show that the ETos and ETrs agree more closely to the ASCE-PM daily values.

Definition of Crop Coefficients

Selection of appropriate crop coefficient for use with each standardized reference evapotranspiration surface is very important for the calculation of crop evapotranspiration (ET_c). The TC, therefore, recommends that the abbreviation for crop coefficients developed for use with ET_{os} be denoted as Kc_o and the abbreviation for crop coefficients developed for use with ET_{rs} be denoted as K_{cr}. ET_c is to be calculated as shown in equation 3.

$$ET_c = K_{co} * ET_{os} \quad \underline{\text{or}} \quad ET_c = K_{cr} * ET_{rs} \qquad \textbf{(3)}$$

Conclusions

The ASCE Evapotranspiration in Irrigation and Hydrology Committee (ASCE-ET) is recommending for the intended purpose of establishing uniform evapotranspiration (ET) estimates and transferable crop coefficients, *two standardized* reference evapotranspiration *surfaces*: (1) a short crop (similar to grass) and (2) a tall crop (similar to alfalfa), and *one Standardized* Reference Evapotranspiration *equation*. The equation is derived from the ASCE-Penman Monteith equation (Jensen et al., 1990), by simplifying several terms within that equation. The performance of the two surfaces and equation was evaluated at 49 sites across the US using 81 sites years of data. The evaluation involved a comparison of the two surfaces and equation to the ASCE Penman Monteith. It is ASCE-ET 's opinion that ASCE Penman Monteith equation, when applied as described in ASCE Manual 70 provides accurate ET estimates of lysimeter reference ET. The evaluation found that the standardized reference evapotranspiration equation described in this paper provides accurate estimates of ET_o and ET_r.

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