THE ASCE STANDARDIZED REFERENCE EVAPOTRANSPIRATION EQUATION

Task Committee on Standardization of Reference Evapotranspiration[1] of the Environmental and Water Resources Institute of the American Society of Civil Engineers

INTRODUCTION

In May 1999, The Irrigation Association (IA) requested the Evapotranspiration in Irrigation and Hydrology Committee – Environmental and Water Resources Institute (American Society of Civil Engineers) (ASCE-ET) to establish and define a benchmark reference evapotranspiration equation. The purpose of the benchmark equation is to standardize the calculation of reference evapotranspiration and to improve transferability of crop coefficients.

IA envisioned an equation that would be accepted by the U.S. scientific community, engineers, courts, policy makers, and end users. The equation would be applicable to agricultural and landscape irrigation and would facilitate the use and transfer of crop and landscape coefficients. In addition, IA requested guidelines for using the equation in regions where climatic data are limited and recommendations for

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incorporating existing crop and landscape coefficients and existing reference ET calculations.

An ASCE-ET Task Committee (TC) comprised of the authors of this report responded to the request by IA. Their initial response is included in Appendix A. Members of the TC jointly authored several papers (Allen, et al., 2000; Itenfisu, et al., 2000; Walter, et al., 2000) at the IA 4th National Irrigation Symposium in November 2000 that described issues, challenges and analyses conducted by the TC. This report provides detail on development of the ASCE Standardized equation, recommendations on use of the equation, and example calculations. In addition, this report provides guidelines for assessing the integrity of weather data used for estimating ET and methodologies that can be used where data are limited or missing.

DEFINITION OF THE EQUATION

Evapotranspiration (ET) represents the loss of water from the earth's surface through the combined processes of evaporation (from soil and plant surfaces) and plant transpiration (i.e., internal evaporation). Reference evapotranspiration (ET_{ref}) is the rate at which readily available soil water is vaporized from specified vegetated surfaces (Jensen et al., 1990). For convenience and reproducibility, the reference surface has recently been expressed as a hypothetical crop (vegetative) surface with specific characteristics (Smith et al., 1991, Allen et al., 1994a, Allen et al., 1998). In the context of this standardization report, reference evapotranspiration is defined as the ET rate from a uniform surface of dense, actively growing vegetation having specified height and surface resistance, not short of soil water, and representing an expanse of at least 100 m of the same or similar vegetation.

ASCE-ET recommends that the equation be referred to as the "Standardized Reference Evapotranspiration Equation" (ET_{sz}). ASCE-ET is of the opinion that use of the terms *standard* or *benchmark* may lead users to assume that the equation is intended for comparative purposes (i.e., a level to be measured against). Rather, the use of the term "standardized" is intended to infer that the computation procedures have been fixed, and not that the equation is a standard or a benchmark or that the equation has undergone the degree of review in the approval process necessary for standards adopted by ASCE, ASAE, American National Standards Institute, or the International Organization for Standardization.

ASCE-ET and IA-WM members concluded that two ET_{ref} surfaces with *standardized* computational procedures were needed. The two adopted ET_{ref} surfaces are (1) a short crop (similar to clipped grass) and (2) a tall crop (similar to full-cover alfalfa). Additionally, the TC recognized that an equation capable of calculating both hourly and daily ET_{ref} was needed.

RECOMMENDATION

ET_{ref} from each of the two surfaces is modeled using a single Standardized Reference Evapotranspiration equation with appropriate constants and standardized computational procedures. The surfaces/equation are defined as:

<u>Standardized Reference Evapotranspiration Equation, Short (ET_{os}):</u> Reference ET for a *short* crop with an approximate height of *0.12* m (similar to clipped, cool-season grass).

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

The two surfaces are similar to known full-cover crops of alfalfa and clipped, cool-season grass that have received widespread use as ET_{ref} across the United States. Each reference has unique advantages for specific applications and times of the year. As a part of the standardization, the ASCE Penman-Monteith (ASCE-PM) equation

(Appendix B and Jensen et al., 1990), and associated equations for calculating aerodynamic and bulk surface resistance have been combined and condensed into a single equation that is applicable to both surfaces.

The Standardized Reference Evapotranspiration Equation is intended to simplify and clarify the presentation and application of the method. As used in this report, the term ET_{sz} refers to both ET_{os} and ET_{rs}. Eq. 1 presents the form of the Standardized Reference Evapotranspiration Equation:

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

where:

ET_{sz}	= standardized reference crop evapotranspiration for short (ET_{os}) or tall (ET_{rs}) surfaces (mm d^{-1} for daily time steps or mm h^{-1} for hourly time steps),
R_n	= calculated net radiation at the crop surface (MJ m^{-2} d^{-1} for daily time steps or MJ m^{-2} h^{-1} for hourly time steps),
G	= soil heat flux density at the soil surface (MJ m^{-2} d^{-1} for daily time steps or MJ m^{-2} h^{-1} for hourly time steps),
T	= mean daily or hourly air temperature at 1.5 to 2.5-m height (°C),
u_2	= mean daily or hourly wind speed at 2-m height (m s^{-1}),
e_s	= saturation vapor pressure at 1.5 to 2.5-m height (kPa), calculated for daily time steps 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-m height (kPa),
Δ	= slope of the saturation vapor pressure-temperature curve (kPa °C^{-1}),
γ	= psychrometric constant (kPa °C^{-1}),
C_n	= numerator constant that changes with reference type and calculation time step (K mm s^3 Mg^{-1} d^{-1} or K mm s^3 Mg^{-1} h^{-1}) and
C_d	= denominator constant that changes with reference type and calculation time step (s m^{-1}).

Units for the 0.408 coefficient are m^2 mm MJ^{-1}.

Table 1 provides values for C_n and C_d. The values for C_n consider the time step and aerodynamic roughness of the surface (i.e., reference type). The constant in the denominator, C_d, considers the time step, bulk surface resistance, and aerodynamic roughness of the surface (the latter two terms vary with reference type, time step and daytime/nighttime). C_n and C_d were derived by simplifying several terms within the ASCE-PM equation and rounding the result. Equations associated with calculation of required parameters in Eq. 1, the detailed derivation of the parameters in Table 1 and simplification of the terms listed in Table 2 are explained in more detail in Appendix B. Daytime is defined as occurring when the average net radiation, R_n, during an hourly period is positive.

Table 1. Values for C_n and C_d in Eq. 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 during daytime	37	0.24	66	0.25	mm h^{-1}	MJ m^{-2} h^{-1}
Hourly during nighttime	37	0.96	66	1.7	mm h^{-1}	MJ m^{-2} h^{-1}

Table 2. ASCE Penman-Monteith Terms Standardized for Application of 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 corresponding to wind speed, z_w	2.0 m	2.0 m
Zero plane displacement height	0.08 m	0.08 m [a]
Latent heat of vaporization	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}
Value of R_n for predicting daytime	> 0	> 0
Value of R_n for predicting nighttime	≤ 0	≤ 0

[a] The zero plane displacement height for ET_{rs} assumes that the wind speed measurement is over clipped grass, even though the reference type is tall. This is done to accommodate a majority of weather stations that are located over