



# BASICS

## of Evaporation and Evapotranspiration

▶▶▶ Paul Brown, Associate Director, Programs, CALS Cooperative Extension and Biometeorology Specialist, Department of Soil, Water and Environmental Science, University of Arizona

### Introduction

Local information on evapotranspiration (ET) is now readily available from on-site weather stations and/or public weather networks to assist turfgrass professionals with irrigation management decisions. Proper utilization of ET information can provide accurate estimates of daily water use and thus can assist irrigation managers with the all important decisions of when to apply water and how much water to apply. The concept of ET can be confusing and often is presented in a highly technical manner. This article provides some basic background on the related subjects of evaporation and evapotranspiration.

### Evaporation

Water can exist in the natural environment in three different forms or states — solid (ice), liquid and gas. The process by which water changes from a liquid to a gas is known as evaporation. We are all familiar with liquid water as we drink, bath and irrigate with it daily. The gaseous form of water, known as water vapor, is less familiar since it exists as an invisible gas. However, we all have a feel for water vapor during the late summer months when it is called by the more common name of humidity. To the irrigation manager, the most important points about evaporation are 1) it is the process by which most of the liquid water we apply as irrigation leaves vegetation and 2) that evaporation requires energy (Fig. 1).

Two common household items — the clothes dryer and the evaporative cooler — clearly show the energy requirement of evaporation. In the case of the dryer, a gas burner or an electric heating element provides the heat energy required to evaporate water from the wet clothes. The evaporative cooler works in a somewhat opposite manner. Energy stored in the hot, dry, outside air is consumed by the evaporation process as the air passes through the wet pads. This energy consumption reduces the temperature of the air and allows us to use evaporative cooling as a means of air conditioning.

Energy is also required for evaporation to proceed from vegetation. Meteorological conditions impact the amount of energy available in the natural world and therefore play a key role in regulating evaporation from vegetation. A more detailed discussion of the impact of meteorological conditions on evaporation is provided in the next section of this report.

### Evapotranspiration (ET)

Evaporation from vegetation is generally given a more specific term — evapotranspiration or ET for short. By definition, ET is the loss of water from a vegetated surface through the combined processes of soil evaporation and plant transpiration (Fig. 2). The term evapotranspiration comes from combining the prefix “evapo” (for soil evaporation) with the word transpiration. Both soil evaporation and plant transpiration represent evaporative processes; the difference between the two rests in

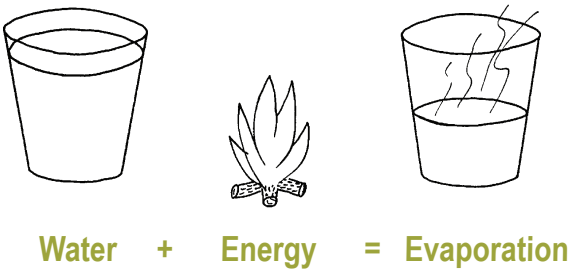


Figure 1. Energy is required for evaporation.

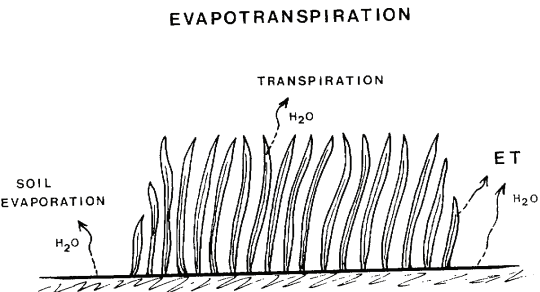


Figure 2. Evapotranspiration (ET) is the loss of water (H<sub>2</sub>O) from vegetation through the combined processes of soil evaporation and plant transpiration.

the path by which water moves from the soil to the atmosphere. Water lost by transpiration must enter the plant via the roots, then pass to the foliage where it is vaporized and lost to the atmosphere through tiny pores in the leaves known as stomata. In contrast, water lost through soil evaporation passes directly from the soil to the atmosphere. Evapotranspiration data are usually presented as a depth of water loss over a particular time period in a manner similar to that of precipitation. Common units for ET are inches/day or millimeters/day.

The rate of ET for a given environment (vegetation) is a function of four critical factors. The first and most critical factor is soil moisture. Evaporation (ET) simply can not take place if there is no water in the soil. However, if adequate soil moisture is available, three additional factors — plant type, stage of plant development and weather — affect ET rate.

Plant type refers to the species or variety of plant being grown and can greatly influence the rate of ET. Grass and many non-native plants require considerable water when grown in the desert. In contrast, many native plants are adapted to the desert and require much less water.

Stage of plant development also plays a critical role in determining ET. Plant development encompasses both the relative activity of the plant (e.g. dormant vs. actively growing) and plant size. For example, dormant plants use and therefore need very little water, while lush, actively growing plants (under similar conditions) will require considerably more water. Plant size and density also impact ET. Small plants and areas with sparse plant canopies use far less water than large plants and areas with dense plant canopies.

Weather is the fourth and last of the critical factors affecting ET. Weather conditions dictate the amount of energy available for evaporation and therefore play a crucial role in determining ET rate. Four weather parameters — solar radiation (amount of sunshine), wind speed, humidity, and temperature — impact the rate of ET. Solar radiation contributes huge amounts of energy to vegetation in the desert and thus is the meteorological parameter with the greatest impact on ET on most days. In actuality, solar radiation is one component of the total radiant energy balance of vegetation referred to as net radiation. Invisible, infrared radiation represents the other component of net radiation. On most days, however, solar radiation is the dominant component of net radiation because the infrared balance is negative and often small.

Wind is the second most important factor in determining ET rate. The wind has two major roles; first, it transports heat that builds up on adjacent surfaces such as dry desert or asphalt to vegetation which accelerates evaporation (a process referred to as advection). Wind also serves to accelerate evaporation by enhancing turbulent transfer of water vapor from moist vegetation to the dry atmosphere. In this case, the wind is constantly replacing the moist air located within and just above the plant canopy with dry air from above.

Humidity and temperature work in concert with each other to determine the dryness or drying power of the atmosphere. The vapor pressure deficit (VPD) is the meteorological variable used to quantify the drying power of the atmosphere. The VPD estimates the difference (or gradient) in vapor pressure (concentration of water vapor) between the moist vegetation and the drier atmosphere above. Relative humidity, the humidity variable most commonly reported in weather forecasts, is a poor indicator atmospheric dryness. For example, the drying power (VPD) of an atmosphere with a 30% relative humidity and a 86°F temperature is 2 times that of an atmosphere with the same 30% relative humidity and a 68°F temperature.

The final parameter affecting ET rate is temperature. We have already indicated that temperature impacts ET through its impact on VPD and advection. In addition to these factors temperature impacts ET is some more subtle ways. When all other factors are equal, ET will be higher for warm as compared to cool vegetation because less energy is required to evaporate water from the warm vegetation. Temperature also impacts the relative effectiveness of the radiant energy and wind in evaporating water. Radiant energy is more effectively utilized for ET when temperatures are high. In contrast, wind has more impact on ET when temperatures are low.

### Reference Evapotranspiration (ET<sub>o</sub>)

Reference ET (ET<sub>o</sub>) is defined as the ET rate from a uniform surface of dense, actively growing vegetation having a specified height and surface resistance (to transfer of water vapor), not short of soil water, and

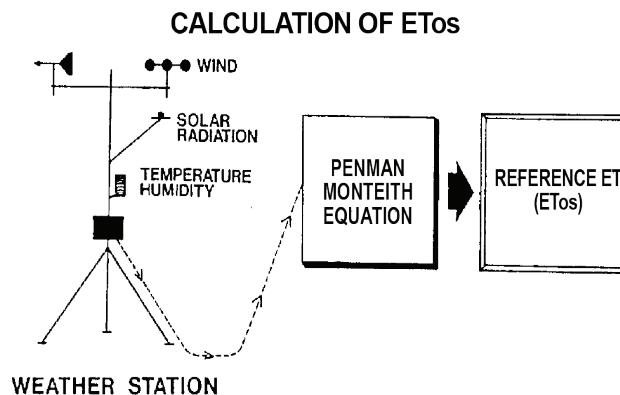


Figure 3. Schematic depicting how ET<sub>o</sub> is determined. Wind, solar radiation, temperature and humidity data from a weather station are used as inputs to the Penman Monteith Equation which, in turn, provides the ET<sub>o</sub> value.

representing an expanse of at least 100 m of the same or similar vegetation (Allen et al., 2005). This definition leaves open the option of using more than one reference surface when measuring or computing ET<sub>o</sub>. The Arizona Meteorological Network has chosen to use the short crop reference as defined by the American Society of Civil Engineers which is equivalent to a 12-cm-tall, cool-season grass (e.g., fescue). Reference ET computed using a short crop reference is abbreviated as ET<sub>o</sub>. In the real world, ET<sub>o</sub> is not routinely measured but instead is computed using a meteorological model known as the Penman-Monteith Equation (Allen et al., 2005). Weather data are required for the computation of ET<sub>o</sub> (Fig. 3). The four meteorological parameters used in the computation of ET<sub>o</sub> are solar radiation, wind speed, temperature and humidity.

Because the ET<sub>o</sub> computation is always made for the same reference surface (12-cm-tall, cool-season grass) three of the four factors that can affect ET: crop type, stage of crop development and soil moisture do not change and cannot affect the ET<sub>o</sub> calculation. Only the fourth factor – weather – is allowed to vary in the computation process. One can therefore consider ET<sub>o</sub> a measure of atmospheric (or environmental) demand for water. Any difference in ET<sub>o</sub> between two days is caused by changes in the weather, not changes in the reference surface or soil moisture.

The relative size of the ET<sub>o</sub> value is a function of weather conditions. Three of the four weather parameters used in the ET<sub>o</sub> computation – solar radiation, temperature and vapor pressure deficit (VPD) – have distinct annual cycles with minimum values in winter and peak values in summer (Fig. 4,5, and 6). Wind speed is more variable on a day to day basis and exhibits a less definitive annual cycle that varies with location (Fig. 7). The cyclical nature of solar radiation, temperature and VPD produce a distinct annual ET<sub>o</sub> cycle (Fig. 8). Notice that ET<sub>o</sub> in the Phoenix area will vary by about a factor of five over the course of the year. Over shorter periods of time, say a week, ET<sub>o</sub> is relatively stable provided skies are clear. However, winter and fall storm systems or periods when the monsoon is quite active can create large day-to-day swings in ET<sub>o</sub>.

### Variation of ET<sub>o</sub> Across Metropolitan Areas

Potential users of ET<sub>o</sub> may worry that local differences in weather conditions could render the ET<sub>o</sub> value from a nearby weather station useless. After all, weather phenomena such as rainfall can vary drastically from one location to another. ET<sub>o</sub> values are, however, surprisingly stable over large areas. This stability results because the weather variable that most affects ET<sub>o</sub>—solar radiation—tends to be fairly constant across large areas in the desert. Except on rare days, the level of solar radiation in Phoenix and Tucson is nearly uniform across the respective metropolitan areas. Temperature and humidity have a much lower impact on ET<sub>o</sub> (relative to solar radiation) and the observed local variations do not greatly impact ET<sub>o</sub>. This leaves wind speed as the only weather parameter with substantial local variation. However, even wind speed variations, unless quite extreme, do not cause a large change in ET<sub>o</sub>. For example the 20–30% variation in

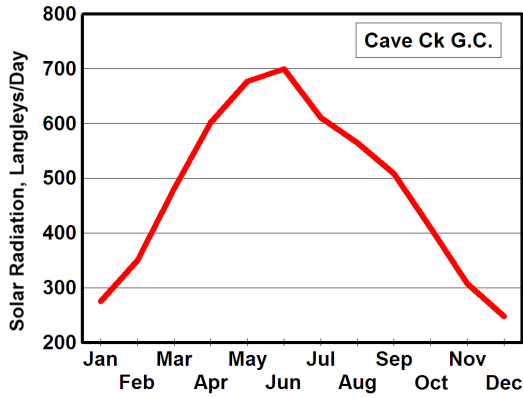


Figure 4. Annual trend of solar radiation at Cave Creek Golf Course in Phoenix, AZ.

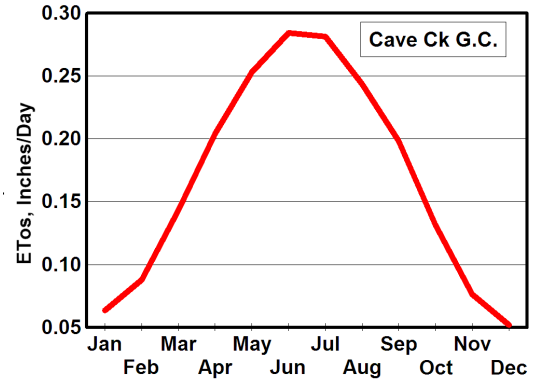


Figure 8. Annual trend of reference evapotranspiration (ETos) at Cave Creek Golf Course in Phoenix, AZ.

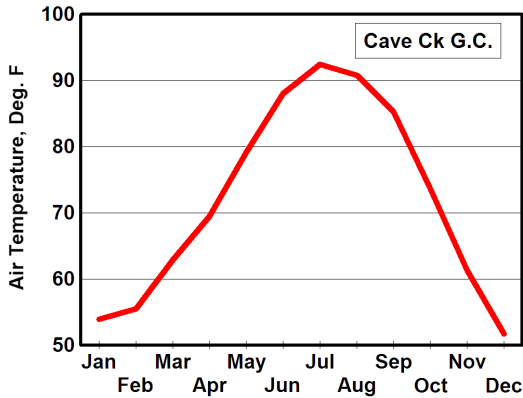


Figure 5. Annual trend of air temperature at Cave Creek Golf Course in Phoenix, AZ.

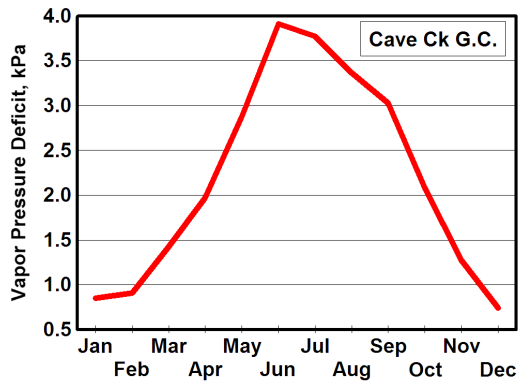


Figure 6. Annual trend of vapor pressure deficit at Cave Creek Golf Course in Phoenix, AZ.

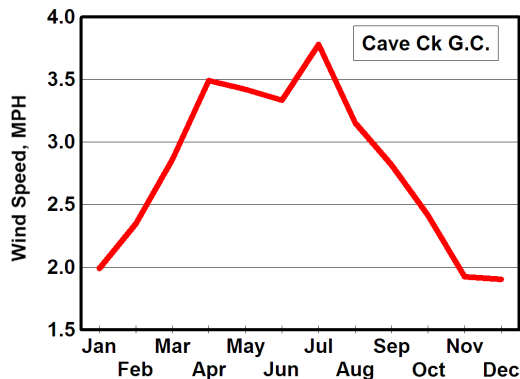


Figure 7. Annual trend of wind speed at Cave Creek Golf Course in Phoenix, AZ.

mean wind speed observed (by AZMET) across the Phoenix metropolitan area impacts ETos by about 5–10%.

To summarize, most of the local variation in ETos is due to changes in wind speed. Typically, this variation is less than 10% across a metropolitan area. The highest rates of ETos will occur in open areas with high winds. Areas with large buildings and trees that inhibit wind flow will typically have lower ETos values.

#### A Precaution on Procedures for Estimation of Reference ET

Scientists have developed a number of meteorological procedures for estimating reference ET over the past six decades. The Penman and the Penman Monteith equations represent the two most commonly used methods today. Both procedures have been subjected to modifications in an effort to improve the estimates of reference ET. Unfortunately, this proliferation of “modified” Penman and Penman-Monteith Equations has led to considerable confusion, particularly when using reference ET in operational irrigation management where the use of crop coefficients is required (see next report in this series). The scientific community has addressed this issue in recent years and has developed a standardized computation procedure for estimating reference ET that is based on the Penman-Monteith Equation (Allen et al., 1998, Allen et al., 2005). This standardized computation procedure has been adopted by the research community, most manufacturers of weather stations and the public weather networks that disseminate reference ET data. Turf Managers should be aware that older weather stations manufactured by Rain Bird, Toro and other irrigation companies may still use the older, non-standardized procedures for estimating reference ET. These older procedures may produce reference ET values with a bias relative to the new standardized procedure. Turf Managers are encouraged to upgrade their weather stations and/or irrigation management software to provide reference ET computed using this new standardized procedure so they can more effectively utilize future research on irrigation scheduling and management.

#### References

- Allen, R. G., L. S. Pereira, D. Raes and M. Smith. 1998. Crop Evapotranspiration: Guidelines for computing crop water requirements. Irrig. And Drain. Paper 56, Food and Agriculture Organization of the United Nations, Rome.
- Allen, R. G., I. A. Walter, R. Elliott, T. Howell, D. Itenfisu and M. Jensen (ed.). 2005. The ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers, Reston, VA.