BASICS OF EVAPORATION AND EVAPOTRANSPIRATION

Turf Irrigation Management Series: I

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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. The objective of this and subsequent bulletins in the *Turf Water Management Series* is to simplify the subject of ET and thereby increase the effective utilization of ET in irrigation management. This bulletin 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 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^{o}F temperature is 2 times that of an atmosphere with the same 30% relative humidity and a 68^{o}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_o)

Reference ET (ET_o) is defined as the ET from a 3-6" tall cool season grass that completely covers the ground, and is supplied with adequate water. This turf surface -- equivalent to a very tall cool season grass rough on a golf course -- is known as the reference crop or reference surface. In the real world, ET_o is not routinely measured but instead computed from a mathematical formula such as the Penman or Penman-Monteith Equation. Weather data are required for the Penman computation of ET_o (Fig. 3). The four weather parameters used in the Penman Equation are solar radiation, wind, temperature and humidity.

The ET_o computation is always made for the same reference surface -- a tall, well-watered, cool season grass -- therefore, three of the four factors that can affect ET: crop type, stage of crop development and soil moisture do not change and can not affect the ET_o calculation. Only the fourth factor -- weather -- is allowed to vary in the ET_o calculation. One can therefore consider ET_o a measure of atmospheric (or meteorological) demand for water. Any difference in ET_o between two days is caused by changes in the weather, not changes in the grass reference or changes in soil moisture.

The relative size of the ET_o value is a function of weather conditions. Three of the four weather parameters used in the ET_o computation -- solar radiation, temperature and vapor pressure deficit (VPD) -- have distinct annual cycles in Arizona (Fig. 4, 5 and 6). Wind speed, by contrast, varies considerably from day to day but follows a much less distinct annual cycle (Fig. 7). The cyclical nature of solar radiation, temperature, and VPD produce a distinct annual ET_o cycle (Fig.8). Notice that ET_o in the Phoenix area will vary by about a factor of four (Fig.8) over the year. Over shorter periods of time, say a week, ET_o is relatively stable provided skies are clear. However, winter and fall storm systems or intense monsoon periods can create large day-to-day swings in ET_o.

Variation of ET_o Across Metropolitan Areas

Potential users of ET_o may worry that local differences in weather conditions could render the ET_o value from a nearby weather station useless. After all, weather phenomena such as rainfall can vary drastically from one location to another. ET_o values are, however, surprisingly stable over large areas. This stability results because the weather variable that most affects ET_o -- 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_o (relative to solar radiation) and the observed local variations do not greatly impact ET_o. 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_o. For example the 20-30% variation in mean wind speed observed (by AZMET) across the Phoenix metropolitan area impacts ET_o by about 5-10%.

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

A Precaution on Penman and Penman-Monteith Procedures for ET_o Estimation

There are several forms of the Penman and Penman-Monteith Equations in existence today. Most true Penman Equations are referred to as "modified" Penman Equations because they are modifications of the procedure described by Penman in 1948. Unfortunately, each modified Penman Equation (and Penman-Monteith procedure) differs slightly and will, if supplied with the same weather data, produce a different ET_o value. For example if you had access to three different versions of the modified Penman Equation -- say the versions used by AZMET, Rainbird and Toro -- and you used each equation to compute ET_o using the same weather data, you would likely get three different answers. The importance of this problem becomes evident when one begins to apply crop coefficients to ET_o to estimate actual turf water use -- the subject of the next report in this series. However, turf managers should be aware that irrigation companies (e.g. Rainbird, Toro, etc.) that sell weather stations for ET_o assessment often use different forms of the Penman or Penman-Monteith Equation. Managers of neighboring turf facilities that use different Penman Equations (weather stations) will likely see systematic differences in ET_o that are caused by the Penman Equation <u>itself</u> not differences in local weather conditions.

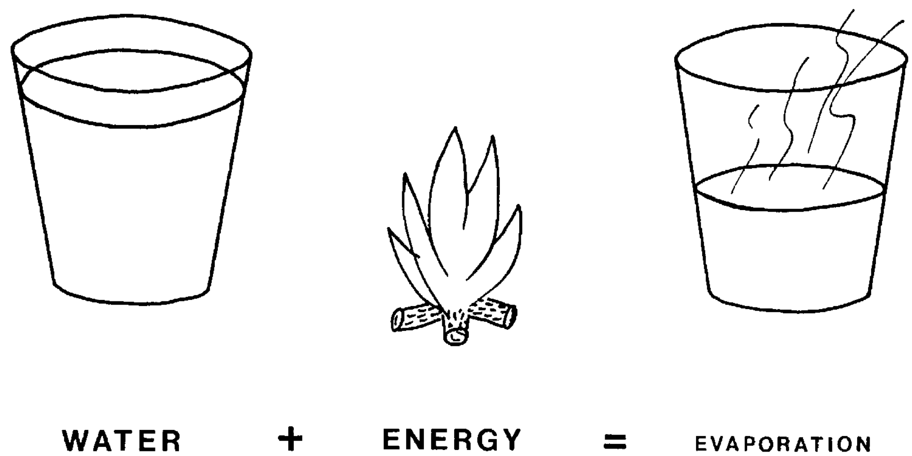

Figure 1. Energy is required for evaporation.

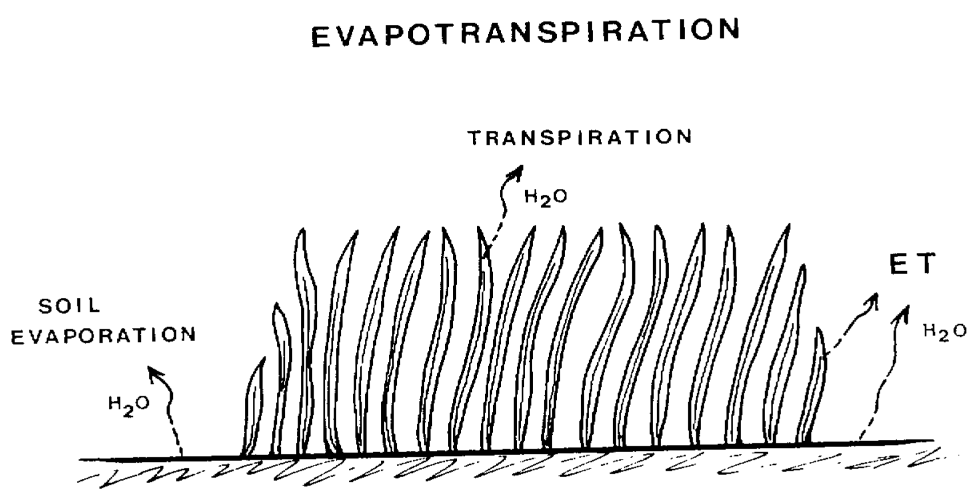

Figure 2. Evapotranspiration (ET) is the loss of water (H_2O) from vegetation through the combined processes of soil evaporation and plant transpiration.

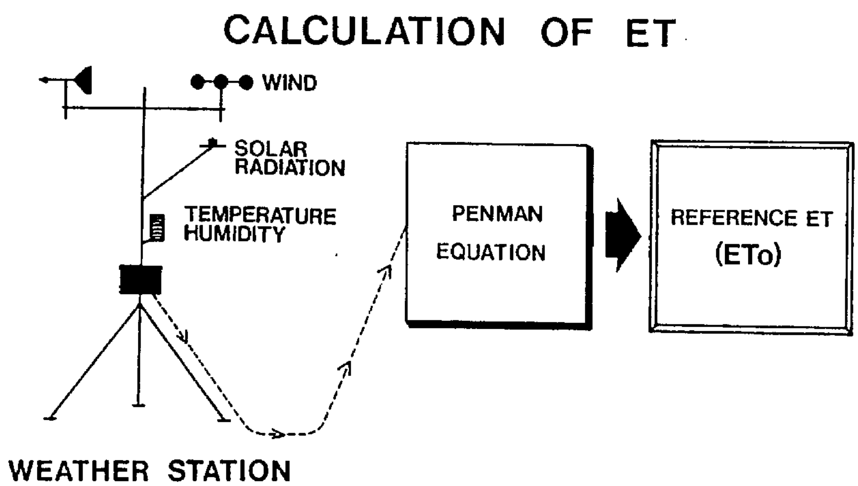

Figure 3. Schematic depicting how ET_o is determined. Wind, solar radiation, temperature and humidity data from a weather station are used as inputs to the Penman Equation which, in turn, provides the ET_o value.

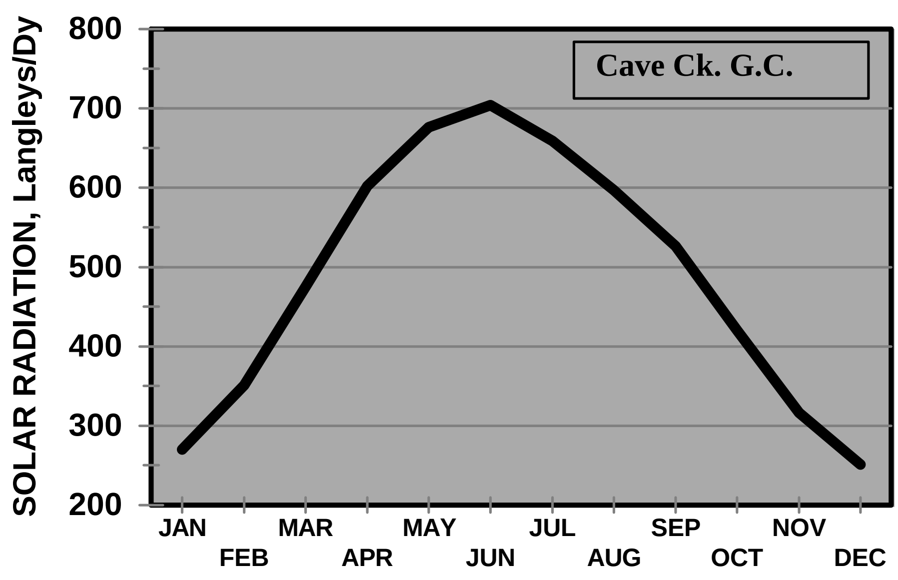

Figure 4. Annual trend of solar radiation at Cave Creek Golf Course in Phoenix, AZ.

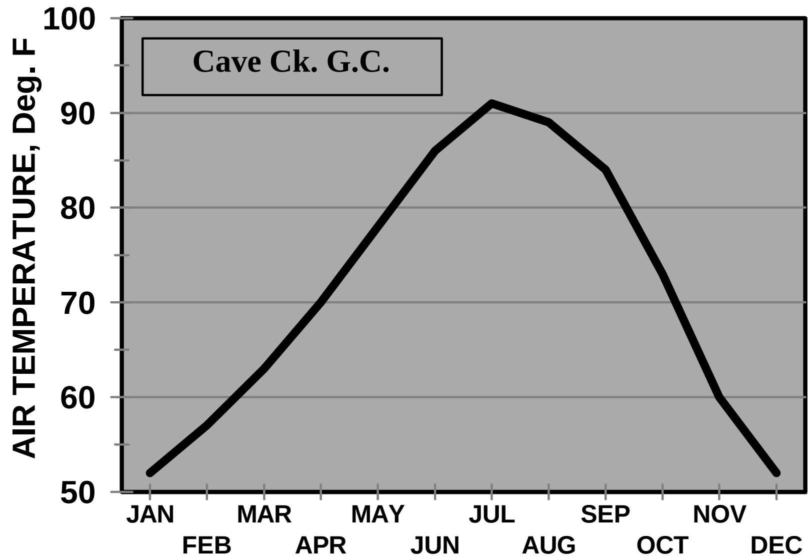

Figure 5. Annual trend of air temperature at Cave Creek Golf Course in Phoenix, AZ.

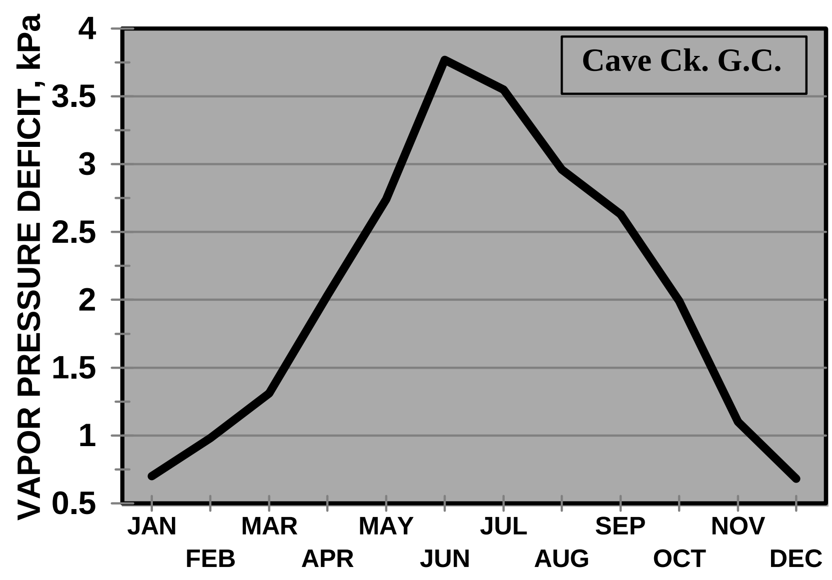

Figure 6. Annual trend of vapor pressure deficit at Cave Creek Golf Course in Phoenix, AZ.

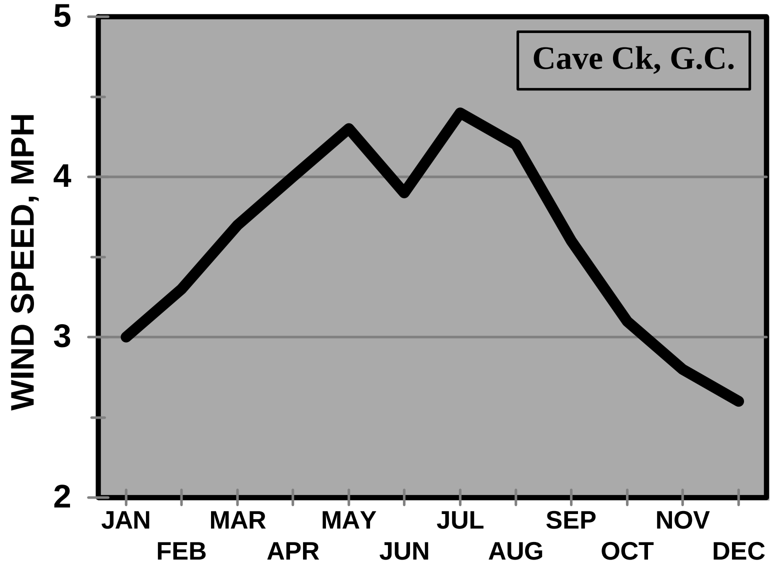

Figure 7. Annual trend of wind speed at Cave Creek Golf Course in Phoenix, AZ.

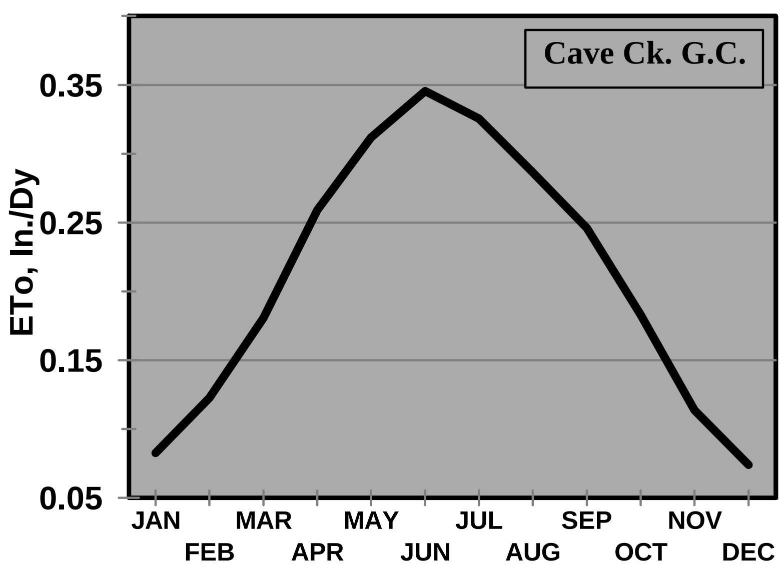

Figure 8. Annual trend of reference evapotranspiration (ET_o) at Cave Creek Golf Course in Phoenix, AZ.