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Smart Irrigation Controllers: Operation of Evapotranspiration-Based Controllers[1]

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This article is part of a series on smart irrigation controllers. The rest of the series can be found at https://edis.ifas.ufl.edu/entity/topic/SERIES_Smart_Irrigation_Controllers.

Introduction

Many areas of Florida have sandy soils, which typically have poor water retention capacity to meet plant water needs. During dry periods, rainfall may be insufficient to maintain acceptable landscape quality. Conversely, rainy periods are often characterized by infrequent, high-intensity events, where only a small portion of water infiltrates and remains in the root zone, while the rest is lost through deep percolation and runoff. As a result, drought conditions can develop within just a few days without rain. To overcome this and sustain a good landscape quality, irrigation is applied to supplement rainfall.

Research has shown that homeowners with in-ground, automatic irrigation systems—common in Florida—apply 47% more water for landscape irrigation than those without such systems. This over-irrigation is largely driven by a “set it and forget it” mentality, despite seasonal fluctuations in plant water needs (Mayer et al., 1999). Similarly, DeOreo et al. (2016) found that homes with automatic irrigation timers applied water at 2.6 times the rate of homes without timers.

"Smart Irrigation Control" technologies for irrigation have been developed to apply irrigation to the landscape based on plant water needs while conserving increasingly limited water resources. One type of technology is an evapotranspiration-based irrigation controller, or ET controller (also known as weather-based irrigation controllers [WBICs]). General information on ET controllers and other smart irrigation technologies can be found in What Makes an Irrigation Controller Smart*?* (https://edis.ifas.ufl.edu/publication/ae442).

The purpose of this publication is to familiarize irrigation managers, contractors, Extension agents, homeowners, and other stakeholders with the different types of ET controllers, irrigation scheduling devices that determine amounts and timing based on soil water balance principles.

Irrigation Scheduling Calculations

Soil Water Balance

The water requirement of plants could be determined by the balance of water inputs and outputs in the root zone, known as the soil water balance (Figure 1, Equation 1). In the absence of a shallow water table supplying water through capillarity, the primary inputs are rainfall (R) and irrigation (I). Outputs include runoff (RO), deep percolation (D), evaporation, and transpiration. Evaporation refers to water lost from the soil to the atmosphere, while transpiration is the loss of water through plant respiration (Allen et al., 1998). For soil water balance calculations, evaporation and transpiration are combined into a single term: evapotranspiration (ET). When ET is specific to a particular plant or crop, it is referred to as crop evapotranspiration (ET_C).

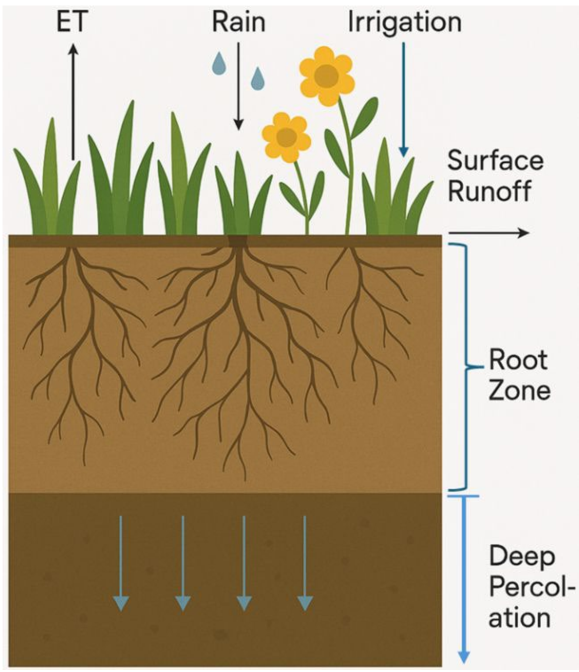

Figure 1. Water inputs and outputs in the root zone of a plant, assuming well-drained conditions and no shallow water table. Credit: Bernard Cardenas, UF/IFAS

$$\Delta S = R - ET_C + I - D - RO$$

ΔS = Change in soil water storage (in)
R = Rainfall (in)
ET_C = Crop evapotranspiration (in)
I = Net irrigation (in)
D = Deep percolation (in)
RO = Surface runoff (in)

Equation 1. Equation used to balance the change in soil water storage in the root zone of a plant, also termed the soil water balance equation.
Credit: UF/IFAS

When irrigation is applied at the appropriate amount, neither runoff nor deep percolation should occur. By assuming negligible runoff, deep percolation, and changes in storage, Equation 1 can be simplified to Equation 2, and used to calculate the net irrigation required by the plant.

$$I = ET_C - R_E$$

I = Net irrigation (in)
ET_C = Crop evapotranspiration (in)
R_E = Effective rainfall (in)

Equation 2. Simplified version of Equation 1 used to calculate net irrigation depth required, by assuming negligible drainage, runoff, and change in storage.
Credit: UF/IFAS

The ability of soil to retain water is known as its soil water holding capacity. Rainfall that exceeds this water holding capacity within the root zone is assumed to drain or run off, making it no longer available to the plant. The portion of rainfall that is retained in the root zone and available for plant use is referred to as effective rainfall (R_E) (IA, 2005).

So how much water can your soil hold?

Calculating Soil Water Content

The root zone of a plant is the depth of soil from the surface that can be used by the plants to obtain water for physiological processes. The amount of water stored in the root zone depends on the soil's texture and structure.

An example of the soil water content over time is shown in Figure 2. After a saturation event (e.g., heavy rain or irrigation), water drains from the soil due to gravity until it reaches field capacity (FC), the point at which gravitational drainage becomes negligible. From FC, water is gradually lost through evapotranspiration (ET_C) until the soil moisture reaches the permanent wilting point (PWP), where plants can no longer extract water from the soil and begin to wilt irreversibly.

The available water (AW) is the amount of water held between FC and PWP that is accessible to plants (Equation 3, Figure 2). To avoid plant stress, irrigation should be applied before reaching PWP. The readily available water (RAW) is the portion of AW that plants can use without experiencing water stress (Equation 4), and it is defined by a threshold called maximum or manageable allowable depletion (MAD). At that point, irrigation should be scheduled to refill the soil moisture back to FC. A common rule of thumb for MAD is 50% of AW, though this can vary depending on crop type and soil conditions.

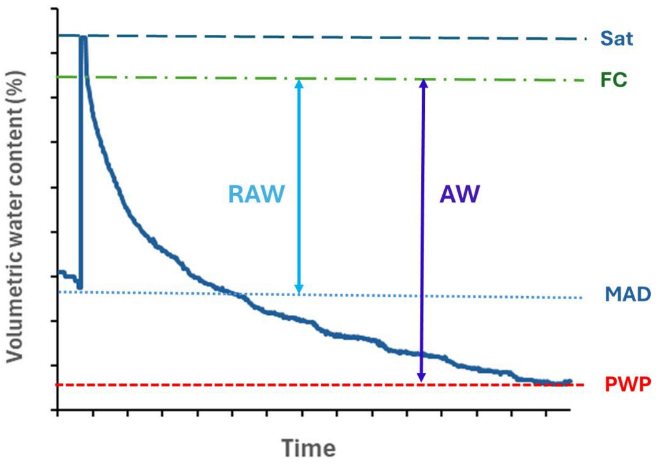

Figure 2. Example of volumetric water content in the root zone over time, illustrating key soil moisture states—saturation (Sat), field capacity (FC), and permanent wilting point (PWP). Irrigation management concepts are also illustrated, including available water (AW), readily available water (RAW), and maximum allowable depletion (MAD).
Credit: Bernard Cardenas, UF/IFAS

$$AW = \frac{(FC - PWP) \times RZ}{100}$$

AW = Available water (in)
FC = Field capacity (%)
PWP = Permanent wilting point (%)
RZ = Root zone of plant (in)

Equation 3. Formula used to calculate the available water in the root zone.
Credit: UF/IFAS

$$RAW = MAD \times AW$$

RAW = Readily available water (in)
MAD = Maximum allowable depletion

Equation 4. Formula used to calculate the readily available water in a root zone where MAD is a fraction from 0 to 1.
Credit: UF/IFAS

Calculating Evapotranspiration

Reference evapotranspiration (ET_0) is defined as the evapotranspiration from a reference grass surface that is 0.12 meters in height, well-watered, actively growing, completely covering the soil, and has a fixed surface resistance (Allen et al. 2005). To enhance consistency in ET calculations, the American Society of Civil Engineers (ASCE) developed a standardized version of the FAO-56 Penman-Monteith equation (Allen et al. 1998), which is now widely considered the standard method for calculating ET_0 (Allen et al. 2005) (Equation 5, Figure 3). More information on this method and calculation details can be found at https://ascelibrary.org/doi/book/10.1061/9780784408056 and at https://edis.ifas.ufl.edu/publication/AE459.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T+273}(e_s - e_a)u_2}{\Delta + \gamma(1 + C_d u_2)}$$

Equation 5. ASCE standardized reference evapotranspiration equation (Allen et al. 2005).
Credit: UF/IFAS

ET_0 = Reference ET (mm/day)
R_n = Net radiation ($MJ/m^2/day$)
G = Heat flux ($MJ/m^2/day$)
U_2 = Wind speed (m/s)
T = Temperature (°C)
Δ = Vapor pressure (kPa/°C)
γ = Psychometric constant (kPa/°C)
e_s = saturation vapor pressure (kPa)
e_a = actual vapor pressure (kPa)
C_n = Constant (900)
C_d = Constant (0.34)

Figure 3. The variables used in the ASCE standardized reference evapotranspiration equation (Allen et al. 2005).
Credit: UF/IFAS

Plant evapotranspiration (ET_C) is defined as the evapotranspiration of a specific crop or plant, as opposed to the reference crop. ET_C can be calculated for a specific plant material by applying a crop coefficient (K_C), using the following equation:

$$ET_C = K_C \times ET_0$$

ET_C = Crop evapotranspiration (in/day)
K_C = Crop coefficient

Equation 6. Equation used to calculate ET of a specific crop or plant from reference ET using a crop coefficient.
Credit: UF/IFAS

Crop coefficients can be found in a number of references depending on the specific crop, horticultural practices, and geographical location.

ET Controller Types

There are generally four types of ET controllers:

1. Historical ET Controllers

Historical ET controllers use pre-programmed ET_0 data based on long-term weather records for a specific region. These controllers do not rely on real-time weather inputs or on-site sensors. Instead, they estimate irrigation needs using typical seasonal ET patterns, sometimes adjusted by basic inputs such as temperature or day of year. This approach simplifies scheduling and reduces hardware and communication requirements.

While historical ET controllers are cost-effective and easy to install, they may not respond accurately to unusual or extreme weather events, and their performance can vary depending on how closely current conditions match historical averages. They are best suited for regions with consistent climate patterns or for low-maintenance residential landscapes where precision is less critical. Due to Florida's highly variable and localized rainfall patterns, relying solely on historical ET data can lead to inaccurate irrigation scheduling.

2. Signal-Based Controllers

Signal-based ET controllers use wired (e.g., landline) or wireless communication technologies—including cellular, paging, or Wi-Fi—to receive ET_0 data. Weather information is collected from publicly available networks or dedicated weather stations near the controller's location. Depending on the manufacturer, the ET_0 value may be computed centrally and broadcasted directly to the controller or calculated locally by the controller using transmitted weather data. Once ET_0 is available, ET_c is calculated by applying a K_c value based on the selected plant type.

Although signal-based controllers primarily rely on real-time weather data, they may also use historical ET_0 values as a backup when communication is lost. Some models revert to historical averages, while others continue using the last received ET_0 value until the signal is restored. Most offer the option to add an external antenna to improve reception. Newer models increasingly use Wi-Fi connectivity, enhancing flexibility and reducing reliance on proprietary networks.

The main advantage of signal-based controllers is their ability to adjust irrigation schedules based on real-time weather conditions, improving water use efficiency. However, a key limitation is that weather station data may not accurately reflect site-specific conditions, especially in regions like Florida where localized rainfall can significantly impact plant water needs.

3. Standalone Controllers

Standalone ET controllers use on-site sensors to measure weather conditions and calculate real-time ET_0. These sensors may record data at intervals ranging from seconds to minutes, and the controller aggregates this data to compute daily ET_0 values. Common sensors include those for rain, air temperature, and solar radiation, and in some cases, complete weather stations (Riley 2005).

Because installing full weather stations at every site is often impractical and costly, many controllers use simplified ET estimation methods. For example, some controllers use the Hargreaves equation, which estimates ET_0 based primarily on temperature (Jensen and Allen 2016), allowing the system to function with minimal sensor input. These simplified models may incorporate historical climate data to calibrate or validate ET estimates.

The advantage of standalone controllers is that they provide site-specific ET measurements without relying on external signals or subscription fees. However, some models rely on simplified ET methods, which may be less accurate under diverse climate conditions (Jensen and Allen, 2016), potentially affecting irrigation precision.

4. Add-on ET Controllers

Add-on ET controllers are supplemental devices that integrate with existing automatic irrigation timers. These controllers typically do not calculate irrigation runtimes directly. Instead, they use a soil water balance approach to determine whether an irrigation event should occur.

When the soil moisture drops below a predefined threshold—often based on maximum allowable depletion (MAD)—the controller signals the timer to allow irrigation. Some add-on controllers may use historical ET_0 data or crop water use curves to estimate depletion rates when real-time data is unavailable.

This approach allows for more efficient water use without replacing the entire irrigation system, making it a cost-effective upgrade for homeowners and landscape managers seeking smarter irrigation control.

Conclusion

ET controllers are designed to enhance irrigation efficiency by aligning water application with plant needs and prevailing weather conditions. Understanding the different types of ET controllers—Historical, Signal-Based, Standalone, and Add-on—is essential for selecting the most appropriate technology for a given site.

Each controller type uses ET_0 data differently:

- **Historical ET controllers** rely entirely on long-term weather averages, making them less suitable for regions like Florida with highly variable rainfall.
- **Signal-Based controllers** use real-time weather data from nearby stations and may fall back on historical data when communication is interrupted.
- **Standalone controllers** generate ET_0 on-site using sensors and may use historical data to support simplified estimation methods.
- **Add-on controllers** typically use historical ET_0 or crop water use curves to estimate soil moisture depletion when real-time data is unavailable.

All ET controllers calculate crop evapotranspiration (ET_c) by applying a crop coefficient (K_c) to the reference ET_0 value. This calculation is central to determining how much irrigation is needed and when it should be applied. However, the accuracy of ET_0 estimation is critical. Simplified ET methods—often used in some controller models—may not account for critical climatic variables, leading to under- or over-irrigation, especially in regions with diverse or highly variable weather conditions like Florida. This highlights the importance of selecting controllers that use robust ET estimation methods and, when possible, incorporate site-specific data through on-site weather sensors.

By understanding how each controller type operates and how ET_0 and ET_c are calculated, irrigation managers, contractors, Extension agents, and homeowners can make informed decisions that promote water conservation, landscape health, and system efficiency.

Detailed programming recommendations for several controllers in Florida conditions can be found in Programming Guidelines for Evapotranspiration-Based Irrigation Controllers (https://edis.ifas.ufl.edu/publication/AE445).

Note: The University of Florida does not endorse any particular brand. The information contained here is for illustrative purposes only.

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