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Efficient Urban Water Management

Smart Weather-Based Irrigation Controllers

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This publication is the second in a series on urban water management.

INTRODUCTION

Landscape plantings play important roles in urban communities. Well-placed plants reduce soil evaporation, cool urban heat islands, prevent soil erosion, provide habitat and ecosystem diversity, and increase aesthetics and property values. In addition, landscape trees store carbon produced by fossil fuels and provide shade.

Landscape plants require supplemental irrigation to augment natural precipitation supplied by rain and snow in most areas of California. Supplying adequate irrigation water while conserving as much water as possible is vital due to the anticipated increase of the state's population to 60 million by 2050 (Dieter and Maupin 2017), coupled with impacts of climate change already stretching limited water resources (Hanak and Lund 2012). Increasing landscape irrigation efficiency is an effective way of reducing overall residential water use, since homeowners use up to half of their water outdoors (The Alliance for Water Efficiency 2019; Buck et al. 2016).

This publication focuses on the selection and use of smart weather-based irrigation controllers in California to increase landscape water conservation while maintaining healthy, attractive landscapes.

Figure 1. Example of a weather-based smart irrigation controller. *Photo:* http://www.oldfaithfulsprinklers.com.

Significant water savings have been associated with their use in Florida, California, North Carolina, and Nevada (Haghverdi et al. 2019; Davis et al. 2009; Devitt et al. 2008; Dobbs et al. 2014; Nautiyal et al. 2015).

This publication includes a description of standard terms and concepts related to landscape irrigation, typical controller settings, guidelines regarding selection, proper use and maintenance of smart controllers, and information about rebate programs to acquire smart controllers offered by major retail water agencies in California. This publication is the second part of a series of UC ANR publications on efficient urban water management.

SMART LANDSCAPE IRRIGATION CONTROLLERS

A residential irrigation system typically consists of a sprinkler and/or drip system, pipes, electric valves (solenoid valves), and an irrigation timer. The irrigation timer automatically turns electric valves on and off on preprogrammed schedules. Efficient irrigation is achieved by maintaining an optimum amount of water in the active root zone of plants while minimizing surface runoff and deep percolation. Over- or underwatering tend to happen if irrigation application is not calculated based on site conditions as well as plant water needs.

What makes an irrigation controller "smart"? The answer is its ability to receive and to respond to feedback from on-site or nearby sensors, allowing it to adjust water applications accurately based on site conditions. The two main categories of smart irrigation controllers are weather-based and soil moisture-based. The focus of this publication is on weather-based smart irrigation controllers (fig. 1), which are also called evapotranspiration (ET)-based smart controllers. Soil moisture-based smart controllers will be discussed in the next publication in this series.

FUNDAMENTALS OF WEATHER-BASED SMART IRRIGATION SCHEDULING

Evapotranspiration is the sum of water lost by evaporation from the soil and water lost by the plant back to the atmosphere through transpiration. The amount of water lost through ET needs to be replaced by natural precipitation and supplemental irrigation. A critical question is how to avoid overwatering and underwatering landscape plants while adapting to the changes in seasonal weather conditions (fig. 2). For example, landscape plants require more water on hot, dry days than they do on cold and cloudy days, and they require no irrigation when it is raining.

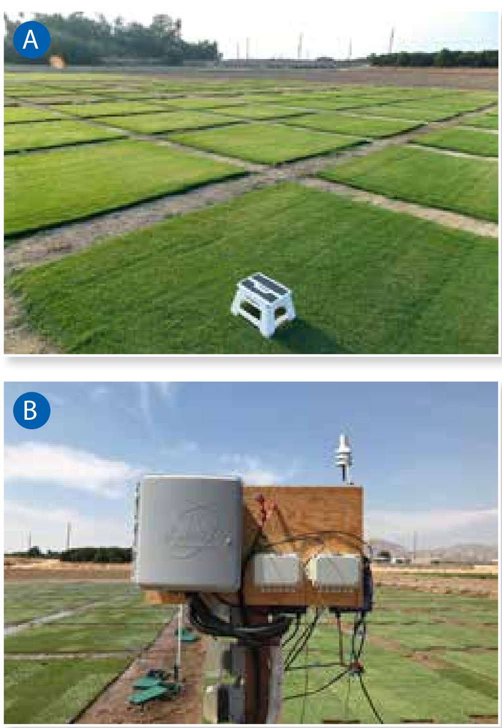

Figure 2. A turfgrass irrigation research trial at UC Riverside Agricultural Experiment Station (A), where irrigation applications are autonomously regulated by a weather-based smart irrigation controller (B). *Photos:* http://www.ucrwater.com.

Reference crop evapotranspiration (ET_{ref}) is the amount of water required by a well-irrigated and healthy, 2-inch tall, cool-season grass that is completely shading the soil. ET_{ref} is estimated by weather stations based on air temperature, soil radiation, wind speed, and relative humidity. The California Irrigation Management Information System (CIMIS), developed in 1982, consists of a statewide network of over 145 automated weather stations that regularly measure these weather parameters to estimate ET_{ref} (fig. 3). The maximum ET for a particular landscape species may be determined by multiplying the ET_{ref} by a plant factor (PF) or crop coefficient (Kc) determined for that species.

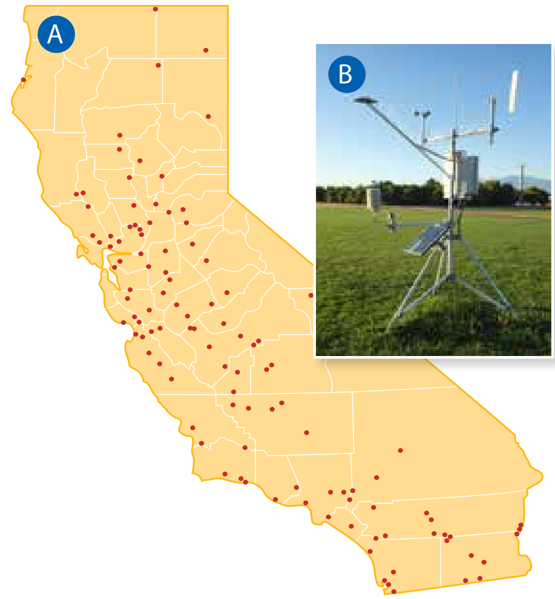

Figure 3. (A) Distribution of CIMIS weather stations across the state of California, and (B) a typical CIMIS weather station. *Sources:* (A) CIMIS Urban Resource Book, and (B) http://www.ucrwater.com.

Californians are encouraged to conserve water by irrigating landscape plants only as much as is needed to maintain their health and function. In almost all cases, established, well-rooted landscape plants can grow and function adequately at 20 to 60 percent of their maximum ET (Hartin et al. 2018; Pittenger et al. 2009). Thus, the final step is dividing the percent of ET required to maintain plant health by the irrigation system efficiency (see appendix 2 for a simple practical example).

There are many theoretical and empirical equations to estimate ET_{ref}. The choice of the equation depends on the accuracy of the equation under a given set of conditions and the availability of the required input data. A weather station with a full set of sensors that regularly measures air temperature, solar radiation, wind speed, and relative humidity will give a better estimation of ET_{ref} than a weather station with a limited set of sensors. However, since installing fully functional weather stations at residences is not economically feasible, controllers usually use more simplified methods for ET_{ref} calculations, which are easier to implement but are often less accurate (see table 1). The Hargreaves equation (Hargreaves and Samani 1985) is an alternative approach to estimate ET_{ref} and can be calculated based on only maximum and minimum air temperatures along with solar radiation. Some weather-based smart controllers estimate solar radiation as the average of the historical (averaged over several years) data for the given latitude of the site, measuring only air temperature on-site.

COMMON SETTINGS AND TERMINOLOGY OF WEATHER-BASED SMART CONTROLLERS

It is essential to understand the use of various terms and acronyms related to weather-based smart controllers as well as standard settings. The following is a summary of the most common terms and settings. Users should refer to the manufacturer instruction manuals for additional information regarding the installation and programming of specific brands of smart controllers.

- **Irrigation system program:** Allows users to set irrigation system start times, run times, and schedules to maximize precision and versatility. Multiple programs allow the user to maximize water conservation by irrigating hydrozones containing plants with similar water needs on the same schedule.
- **Zone:** A part of the irrigation system served by a single control valve that allows hydrozones containing plants with similar water needs to be irrigated independently from hydrozones with different water requirements and hydrozone designations.
- **Days to water:** This setting allows a user to select the days of the week to irrigate. Typical options include irrigating every other day, every 3 days, etc. This is a useful option to conform to restrictions imposed by water districts during a drought.
- **Start time:** This setting allows a user to select a start time to begin the irrigation event on the scheduled watering days. The first zone in the program will typically start watering at the set start time, and the other zones follow in sequence.
- **Run time:** This setting allows a user to select the amount of time each zone is irrigated during an irrigation event. It could vary from a few minutes to hours and mostly depends on the type of irrigation system, soil conditions, and plant type.
- **Cycle and soak:** This setting allows the user to divide the total zone run time into shorter periods of watering (cycle) and pause (soak). The cycle is intended to allow the proper water infiltration into the root zone to avoid runoff. The actual cycle

Table 1. The average percent difference for each month in the last 2 decades between temperature-based ET (Hargreaves equation) and CIMIS ET for some CIMIS stations across the state of California

City	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
Five Points (2)*	26	17	16	18	16	12	9	11	14	18	21	29	17
Shafter (5)	17	12	9	10	9	5	5	5	6	9	12	17	10
Riverside (44)	23	18	14	12	7	5	5	6	8	12	20	25	13
Temecula (62)	29	22	13	9	7	5	5	5	9	17	26	30	15
Modesto (71)	23	17	15	15	14	12	9	7	8	12	16	24	14
Irvine (75)	19	14	9	7	6	5	5	5	7	11	17	24	11
Pomona (78)	14	12	7	7	6	6	5	4	6	10	12	15	9
Fresno State (80)	17	12	9	10	10	8	6	6	7	8	11	18	10
Santa Monica (99)	17	13	9	7	6	8	9	8	10	12	16	19	11
Fair Oaks (131)	18	12	9	8	7	5	8	4	5	9	14	19	10
Long Beach (174)	13	10	8	6	6	8	9	8	9	12	14	15	10
San Diego (184)	18	11	8	6	6	7	9	7	8	11	15	16	10
Gilroy (211)	17	18	15	16	14	12	10	9	12	16	16	21	15
Hollywood (223)	15	7	6	5	4	6	5	6	9	9	11	19	8
Oakland (254)	13	12	8	6	4	3	2	3	3	11	13	17	8

Note: *Number in parenthesis after each city refers to the ID of the CIMIS station.

and soak times can be determined by the user in some cases or can be automatically calculated in others, depending on the specific model of controllers. This setting is especially useful when there is a significant slope that would cause water to run off before being taken up and when water enters the soil slowly to cause runoff on flatter surfaces.

- **Rain shut-off:** This automatic setting interrupts (stops) the cycle of automatic irrigation for a specified period during or after an event of rainfall.
- **Water budget:** This setting allows the user to set the controller to increase or decrease station run times by a certain percentage to adjust for changes in weather.
- **Distribution uniformity (DU):** This is a measurement of how evenly the water is applied across the landscape during irrigation. A low DU can result in large amounts of water being lost in sprinkler-irrigated turf and groundcover plantings, and it is a major cause of high-tier water bills.
- **Plant factor (PF):** (also called crop coefficient, Kc): These are coefficients that convert ET_{ref} to ET for specific landscape species ($ET = PF$ or $Kc \times ET_{ref}$).
- **Application rate (precipitation rate):** It is usually expressed as inches of water per hour and should be specified for each zone.

HOW TO SET UP AND PROGRAM THE WEATHER-BASED SMART IRRIGATION CONTROLLERS

During the initial setup of the controllers, users need to provide various information regarding the irrigation system (e.g., sprinkler type, uniformity of the system and application rate), landscape (e.g., plant type, plant factor for each species, rooting depth), site conditions (e.g., soil type, shading, slope), and intended irrigation schedule (e.g., irrigation days, irrigation time, number of zones). Based on the user inputs and weather data collected, controllers adjust the irrigation run times and cycles, thus regulating the amount of water applied.

During the initial setup when the user provides information for each hydrozone, the controller uses preprogrammed plant factors set by the manufacturer to convert ET_{ref} to irrigation water requirements for each hydrozone. Custom plant factors may also be programmed by the user, depending on the controller. This feature can be advantageous, since plant factors typically vary geographically, and preprogrammed plant factor information is only available for a small selection of species. In California, a popular option for obtaining water-use data based on very low ($PF < 0.1$), low ($PF = 0.1$-0.3), medium ($PF = 0.4$-0.6), and high ($PF = 0.7$-0.9) water use plant categories is the Water Use Classification of Landscape Plants (WUCOLS) database, which includes over 3,000 plants (Costello and Jones 2014). WUCOLS was compiled by the consensus of professionals knowledgeable about plant performance under various irrigation regimes in each of six climate zones in California. The controller then converts the irrigation water requirement values to zone run times based on the irrigation system information, irrigation scheduling criteria, and site conditions.

For a specific amount of water, a higher precipitation rate results in a relatively shorter run time to complete the irrigation requirement. Application rate estimations for typical irrigation packages (i.e., spray, rotor, drip, and bubbler) are often preprogrammed in the smart irrigation controllers for users to select. Sprinkler specifications can also be obtained from manufacturers' sprinkler specifications guidelines. If the application rate is unknown, homeowners can estimate the application rate (see appendix 1 for a practical example of calculating the application rate). Slope and soil type information is typically used to automatically calculate the maximum run time (cycle/soak) to avoid runoff.

TYPES OF WEATHER-BASED SMART IRRIGATION CONTROLLERS

Table 2 summarizes the settings and features of some commercially available weather-based smart irrigation controllers. Readers should note that not all manufactured products labeled as "smart controllers" follow the science-based approaches articulated in this publication to estimate crop water needs accurately and to schedule irrigation efficiently. Recommended controllers have been evaluated and certified by Irrigation Association (IA)'s Smart Water Applications Technology (https://www.irrigation.org/SWAT) and EPA Water Sense programs.

Currently available weather-based irrigation controllers can be divided into multiple groups, as follows:

- **Fully automatic versus semiautomatic controllers:** Semiautomatic controllers require the user to enter a base daily irrigation schedule from which the controller adjusts the frequency of irrigation and/or irrigation run time. In contrast, fully automatic controllers generate an irrigation schedule and run times based on the inputs that the user provides during the initial setup. Based on the programming inputs, some of these controllers adjust irrigation schedules by

Table 2. Product features for ET-based smart irrigation controllers on the market

Features	Hunter (Solar Sync)	Hunter (Hydrawise)	Hydropoint	Skydrop	Toro Evolution	Weathermatic	Irritol	Orbit
Weather data source	On-site sensors, historical data	On-site sensors (optional), public and private weather stations, weather forecasts	Public and private weather stations	Public and private weather stations	Historical data, on-site temperature, solar and rain sensors	On-site temperature, rain sensor. solar radiation estimated based on latitude	Historic data, on-site temperature, solar and rain sensors	Public and private weather stations
Stand-alone/add-on						stand-alone	controller with add-on	stand-alone
Fully automatic		X	X	X		X	X	
Base schedule required	X				X			X
Can operated in manual mode	X	X	X		X	X	X	X
Zone capacity		4–54	6–48		4–16	4–96		4–12
On-site rain sensor	X	optional	optional	optional	X	X	X	optional
Wind shut-off			optional					
Temperature sensor/ freeze shut off	X		optional	X	X	X	X	X
On-site solar radiation sensor	X				X		X	
On-site humidity sensor								
Available start times						8	9	
Schedule periods			odd/even, weekdays	odd/even, manual selection	odd/even days, manual selection, interval (1–30 days)	odd/even days, manual selection	31 or 365	odd/even, intervals, manual select
Number of programs		28			4	4	3	
Cycle/soak periods		X	X	X	X	X	X	
Computer interface/ smart phone app						X	optional	X
Irrigation adjust feature		X	X		X	X	X	X
SWAT test report	X		X		X	X	X	
EPA watersense certificate	X	X	X	X	X	X	X	X
Residential models	2	3	1	1	1	1	2	4
Commercial models	2	2	2			3	3	

Table 2. Product features for ET-based smart irrigation controllers on the market, continued

Features	Radio	Rainbird (ST8 Wifi)	Rainbird (ESP-SMTe)	Aeon Matrix/ Yardian	Calsense	GreenIQ	Netro Inc.	Rain Master
Weather data source	Weather data from public and private stations	Public and private weather stations	On-site rain/ temperature sensor	Weather forecast	Historical data, evaporative atometertype ET sensor, weather station or CIMIS data	Public and private weather stations, optional on-site sensors	Weather forecast, rainfall data from internet, and optional on-site sensor	Automatic (by internet), historic, manually entered ET, or optional on-site weather station
Stand-alone/add-on		stand-alone and add-on	stand-alone	stand-alone	stand-alone	stand-alone	stand-alone	stand-alone
Fully automatic	X		X	X			X	optional
Base schedule required	X	X			X	X		X
Can operated in manual mode	X	X	X	X	X	X	X	X
Zone capacity	8–16	4–22	4–22		8–48	8,16	6–12	6–200
On-site rain sensor	optional	X		optional	tipping bucket rain gauge	optional	rain shut-off from forecast	tipping bucket rain gauge (optional)
Wind shut-off	optional	X			optional	optional		optional
Temperature sensor/ freeze shut off	optional		X			optional	optional	optional
On-site solar radiation sensor	optional				optional		optional	optional
On-site humidity sensor	optional				optional	optional		optional
Available start times		3–4	6	8	6			5–8
Schedule periods	1 to every 21 days	days of week, odd/even, cyclical	days of week, odd/even, cyclical		7, 14, 21, or 28 day			7 or 30 day
Number of programs	X	3–4	2	9–13	7		unlimited	4–16
Cycle/soak periods		X	X	X	X	X	X	X
Computer interface/ smart phone app		X		X	X		X	X
Irrigation adjust feature	X	X	X	X	X	X		X
SWAT test report	X	X						
EPA watersense certificate	X	X	X	X	X	X	X	X
Residential models		8	2	4		2	2	
Commercial models					1	2		2

controlling irrigation run frequency or run times. In addition, almost all the commercially available smart controllers allow the user to set watering days and can also be overridden manually.

- **On-site versus remotely programmable controllers:** Some new versions of weather-based smart irrigation controllers come with telemetry capability, which makes it possible for users to change the settings, view and control the irrigation schedules, and execute programs remotely via a mobile phone application or web-based interface. The web-based interface usually provides additional information, including current weather conditions, weather forecasts, and historical water applications in the form of tables and graphs.
- **Stand-alone controllers versus add-on devices:** Smart controllers are typically

stand-alone products, although some can be connected to existing controllers and allow modification of irrigation schedules. The stand-alone controllers are more sophisticated and provide more options to schedule irrigation events with greater precision. The add-on devices (also called plug-in devices) are typically more affordable, but they may not be compatible with existing controllers. In addition, the add-on devices sometimes are not capable of calculating run times and, instead, either adjust only present run times or act as an on/off switch to bypass scheduled irrigation events when specific user-defined, weather-related criteria are met.

- **On-site measurements versus remote and historical ET:** Controllers with on-site measurement capabilities utilize devices such as temperature and solar radiation sensors to calculate real-time ET_{ref} and adjust irrigation accordingly. Signal-based controllers do not collect on-site data but instead receive data remotely from local weather stations. ET_{ref} data could be sent directly to this type of controller, or the controller itself can calculate it on-site, based on received weather data. A major disadvantage of signal-based controllers is that the remote data might not be representative of the local site conditions. Another type of controller relies solely on historical, long-term average ET_{ref} data to schedule irrigations. As discussed previously, using this method can result in plants receiving too much or not enough water based on the actual weather conditions.

Table 3. Summary statistics of the number of agencies that provided rebate programs for weather-based smart irrigation controllers in 2019

Southern California region		
County	**Number of agencies in the survey**	**Number of agencies with rebate programs for weather-based smart irrigation controllers**
Imperial	2	1
Los Angeles	44	21
Orange	22	8
Riverside	14	8
San Bernardino	18	11
San Diego	18	14
Ventura	8	6
Northern California region		
County	**Number of agencies in the survey**	**Number of agencies with rebate programs for weather-based smart irrigation controllers**
Alameda	8	3
Butte	3	1
Contra Costa	7	3
San Luis Obispo	4	1
San Mateo	9	1
Santa Clara	12	4
Solano	6	1
Total	**175**	**83**

REBATE PROGRAMS ON WEATHER-BASED IRRIGATION CONTROLLERS

Water agencies in California often offer residential rebate programs to offset the purchase of smart irrigation controllers in the interest of water conservation. We have collected information through an online survey of 175 water agencies across California to showcase the number of agencies with rebate programs for smart irrigation controllers in 2019. As indicated in table 3, almost half of the major water agencies in the survey provided a rebate for installing weather-based smart irrigation controllers. There are a variety of terms used by agencies to refer to smart controllers, such as smart irrigation devices, smart controllers, weather-based irrigation, and weather-based irrigation controllers. Terms and conditions for eligibility vary among water agencies as well, leading to different rebate amounts and criteria based on landscape size and other criteria. In 2019, among the water agencies in this survey, the rebate amount ranged from $45 to $300. Most agencies provide rebates for only one controller per residential household. Additional information about the rebate programs is available on websites of the water agencies.

SUMMARY AND CONCLUDING REMARKS

- A wide range of weather-based smart controllers are commercially available. To maximize water savings and reduce water bills, it is important to select a controller that is compatible with the technical ability of the end user. Proper installation, programming, and maintenance remain critical for achieving the full potential of smart irrigation controllers. A detailed technical review of the commercially available smart irrigation controllers on the market has been recently published by the Bureau of Reclamation (Bureau of Reclamation 2018). (See their website, https://www.usbr.gov/watersmart/docs/2018/6thEd_WeatherSoilMoisture-BasedLandscapeIrrigationSchedulingDevices.pdf.)

- Weather-based controllers differ substantially in their scheduling algorithms, and not all controllers manufactured as smart controllers follow science-based approaches to estimate crop water needs and schedule irrigation. Only controllers that have been evaluated and tested by university researchers or programs such as Irrigation Association's (IA) Smart Water Applications Technology (https://www.irrigation.org/SWAT) program and EPA Water Sense (https://www.epa.gov/watersense) are recommended.
- Users can contact their water provider via their website or by calling a representative to obtain specific information on currently available rebate programs for weather-based smart irrigation controllers. Water agencies may limit the dollar amount or number of controllers per rebate, and the rebate amount might vary based on the size of the landscape.

REFERENCES

Alliance for Water Efficiency, The. 2019. Landscape transformation: Assessment of water utility programs and market readiness evaluation. The Alliance for Water Efficiency website, https://www.allianceforwaterefficiency.org/sites/www.allianceforwaterefficiency.org/files/assets/LT_Analytics_Report_NonMember_Final.pdf.

American Society of Agricultural and Biological Engineers. 2016. Landscape irrigation system uniformity and application rate testing. American Society of Agricultural Biological Engineers Standards S626(Sep).

Buck, S., M. Nemati, and D. L. Sunding. 2016. The welfare consequences of the 2015 California drought mandate: Evidence from new results on monthly water demand. In Prepared for presentation at the Agricultural and Applied Economics Association and Western Agricultural Economics Association Annual Meeting. Boston, MA.

Bureau of Reclamation. 2018. Weather- and soil moisture-based landscape irrigation scheduling devices. Technical review report. 6th edition. Bureau of Reclamation website, https://www.usbr.gov/watersmart/docs/2018/6thEd_WeatherSoilMoistureBasedLandscapeIrrigationSchedulingDevices.pdf.

Costello, L. R., and K. S. Jones. 2014. WUCOLS IV: Water use classification of landscape species. California Center for Urban Horticulture, UC Davis. WUCOLS IV website, https://ucanr.edu/sites/WUCOLS/.

Davis, S. L., M. D. Dukes, and G. L. Miller. 2009. Landscape irrigation by evapotranspiration-based irrigation controllers under dry conditions in Southwest Florida. Agricultural Water Management 96(12): 1828–1836.

Devitt, D. A., K. Carstensen, and R. L. Morris. 2008. Residential water savings associated with satellite-based ET irrigation controllers. Journal of Irrigation and Drainage Engineering 134(Feb): 74–82.

Dieter, C. A., and M. A. Maupin. 2017. Public supply and domestic water use in the United States, 2015. U.S. Geological Survey.

Dobbs, N. A., K. W. Migliaccio, Y. Li, M. D. Dukes, and K. T. Morgan. 2014. Evaluating irrigation applied and nitrogen leached using different smart irrigation technologies on bahiagrass (Paspalum notatum). Irrigation Science 32(3): 193–203.

Dukes, M. D., and D. Z. Haman, D. Z. 2002. Operation of residential irrigation controllers. CIR1421, University of Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, EDIS.

Dukes, M. D., M. L. Shedd, and S. L. Davis. 2009. Smart irrigation controllers: Programming guidelines for evapotranspiration-based irrigation controllers. AE445. Gainesville: University of Florida Institute of Food and Agricultural Sciences.

———. 2009. Smart irrigation controllers: Operation of evapotranspiration-based controllers. AE446. Gainesville: University of Florida Institute of Food and Agricultural Sciences.

Haghverdi, A., M. Reiter, S. Ghodsi, and A. Singh. 2019. Evaluating the performance of smart evapotranspiration-based controllers in Southern and Central California. San Diego, CA: Soil Science Society of America International Soils Meeting.

Hanak, E., and J. R. Lund. 2012. Adapting California's water management to climate change. Climatic Change 111(1): 17–44.

Hargreaves, G. H., and Z. A. Samani. 1985. Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture 1(2): 96–99.

Hartin, J. S., D. W. Fujino, L. R. Oki, S. K. Reid, and C. E. Ingels. 2018. Water requirements of landscape plants studies conducted by the University of California researchers. HortTechnology 28(4): 422–426.

Jensen, M. E., and R. G. A. Allen. 2016. Evaporation, evapotranspiration, and irrigation water requirements. American Society of Civil Engineers (ASCE) Manuals and Reports on Engineering Practice 70, 2nd ed. Reston, VA: ASCE.

Nautiyal, M., G. L. Grabow, R. L. Huffman, G. L. Miller, and D. Bowman. 2015. Residential irrigation water use in the central Piedmont of North Carolina. II: Evaluation of Smart Irrigation Technologies. Journal of Irrigation and Drainage Engineering 141(4): 0401–4062.

Pittenger, D., A. J. Downer, D. Hodel, M. Mochizuki. 2009. Estimating water needs of landscape palms in Mediterranean climates. HortTechnology 19(4): 70–4.

APPENDIX 1: IRRIGATION APPLICATION RATE CALCULATION EXAMPLES

Example 1: When flow readings are available:

A homeowner has installed a dedicated flow meter to monitor the outdoor irrigation water application for her 750-square-foot sprinkler-irrigated yard. She ran the irrigation system for 100 minutes and recorded the flow data. If the flow meter values before and after the irrigation are 1,530 and 2,465 gallons, what is the average precipitation rate (PR, inches per hour) for her sprinkler system?

$$PR = (96.3 \times gal)/(Area \times time) = (96.3 \times (2{,}465 - 1{,}530))/(750 \times 100) = 1.2 \text{ inches per hour}$$

Example 2: When catch-can test result is available:

On a day that was not windy, a homeowner ran an irrigation uniformity test by putting 30 identical catch devices in his 300-square-foot sprinkler-irrigated yard and running the irrigation system for 12 minutes. He then measured the collected water in each catch device. What is the average precipitation rate for the sprinkler system if the average volume of water collected in catch devices is equal to 27 millimeters and the area of the catch-can throat is 9.5 square inches?

$$PR = (3.66 \times \text{Average volume})/(\text{Throat area} \times time) = (3.66 \times 27)/(9.5 \times 12) = 0.87 \text{ inches per hour}$$

APPENDIX 2: IRRIGATION RUN TIME CALCULATION EXAMPLES

A homeowner divided her sprinkler-irrigated landscape into three hydrozones. She is interested in using evapotranspiration data from a nearby CIMIS station to calculate appropriate irrigation run times for each hydrozone for the first week of July. Hydrozone 1 is planted in warm-season turfgrass with a plant factor of 0.6. Hydrozone 2 and 3 consist of multiple shrubs and flowers with a plant factor of 0.4 and 0.5, respectively. The irrigation efficiency (IE) for her sprinkler system is 75 percent and the total reference evapotranspiration (ET_{ref}, obtained from CIMIS) for the first week of July is equal to 1.8 inches. What is the total irrigation water requirement (IWR) for each hydrozone for this week?

$$\text{Hydrozone 1} = (PF \times ET_{ref})/IE = (0.6 \times 1.8)/0.75 = 1.44 \text{ inches of water}$$

$$\text{Hydrozone 2} = (PF \times ET_{ref})/IE = (0.4 \times 1.8)/0.75 = 0.96 \text{ inches of water}$$

$$\text{Hydrozone 3} = (PF \times ET_{ref})/IE = (0.5 \times 1.8)/0.75 = 1.20 \text{ inches of water}$$

The homeowner calculated a precipitation rate of 0.92 inches per hour for her sprinkler system (using the appendix 1 method). What is the total irrigation run time per day for each hydrozone for the first week of July, assuming the watering days are restricted to 3 days per week?

$$\text{Hydrozone 1} = (IWR \times 60)/PR = (1.44 \times 60)/0.92 = 94 \text{ min} \rightarrow \text{run time per day} = 94/3 \cong 31 \text{ minutes}$$

$$\text{Hydrozone 2} = (IWR \times 60)/PR = (0.96 \times 60)/0.92 = 93 \text{ min} \rightarrow \text{run time per day} = 93/3 \cong 21 \text{ minutes}$$

$$\text{Hydrozone 3} = (IWR \times 60)/PR = (1.2 \times 60)/0.92 = 78 \text{ min} \rightarrow \text{run time per day} = 78/3 \cong 26 \text{ minutes}$$

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