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Efficient Urban Water Management

Smart Soil Moisture Sensor-Based Irrigation Controllers

UCANR South Coast Research and Extension center in Irvine

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Introduction

In California, irrigation accounts for more than 50 percent of the total urban water demand and significantly influences the growth and health of landscape plants (Brown Jr. et al. 2013; Lee 2021). Beyond recreational use, irrigated urban landscapes provide valuable ecosystem services that are highly needed in the semiarid region of Southern California, including capturing runoff, reducing the urban heat island effect, minimizing dust and noise, and fostering biodiversity. Excess irrigation reduces soil aeration, increases disease occurrence, leaches nutrients from the root zone, and generates runoff that contributes to soil erosion. Insufficient irrigation causes stress that can adversely affect plant appearance and overall aesthetics.

This publication focuses on the selection and use of smart soil moisture sensor (SMS)-based irrigation controllers in California to enhance water use efficiency and promote water conservation while maintaining healthy, attractive landscapes. Significant water savings from SMS-based irrigation controllers have been reported in Florida, California, and North Carolina (Bijoor et al. 2014; Cardenas-Lailhacar and Dukes 2012; Grabow et al. 2013; Singh et al. 2024).

This publication also provides definitions of key terms related to soil moisture-based irrigation scheduling, explains typical settings of smart SMS-based controllers, offers guidelines for their selection, proper use, and maintenance, and summarizes rebate programs offered by major retail water agencies in California.

Smart landscape irrigation controllers

Irrigation timers have traditionally been used to schedule the days and times for watering lawns and outdoor landscapes. These timers apply a fixed amount of water at user-defined, preprogrammed dates and times. Traditional fixed-schedule timers often lead to over- or under-irrigation unless users frequently adjust the schedule to match seasonal changes in their plant's water needs. An irrigation controller is considered "smart" when it receives feedback from weather or soil moisture sensors and automatically adjusts to provide the landscape with the right amount of water.

Irrigation controllers can generally be divided into two categories: weather-based and SMS-based controllers. For information on weather-based (or

Figure 1. Example of an SMS-based smart irrigation controller. *Photo*: http://toro.com.

evapotranspiration-based) smart controllers, see Efficient Urban Water management: Smart Weather-Based Irrigation Controllers. Several research projects have demonstrated the weather-based smart controllers' potential for water conservation in Central and Southern California (Haghverdi et al. 2021a, 2021b; Sapkota et al. 2023). This publication focuses on SMS-based smart irrigation controllers (fig. 1).

Fundamentals of SMS-based smart irrigation scheduling

The amount of water that soil can hold depends on its texture, structure, and the size and distribution of its pore spaces. Soil is said to be saturated when all its pore spaces are filled with water following rainfall or an irrigation event. After irrigation or rainfall, water from the largest pores rapidly drains downward under the influence of gravity. The rate of drainage depends on soil type; sandy soils drain more quickly than clay soils. Soil reaches field capacity (FC) when drainage becomes negligible, typically 1 to 3 days after saturation. After this point, plants continue to extract water from the root zone to meet their transpiration needs. The soil moisture level at which plants can no longer absorb water and begin to wilt is known as the permanent wilting point (PWP). Water held between FC and PWP is referred to as plant available water (PAW). FC is often considered the upper limit of soil moisture storage in the root zone, representing the maximum amount of PAW the soil can hold. Depleting soil moisture to the PWP can severely affect plant growth; therefore, a maximum allowable depletion (MAD) level is used. MAD represents the percentage of PAW that can be removed from the root zone before irrigation becomes necessary. This value is often treated as the lower limit of soil moisture storage. Irrigation scheduling based on soil moisture aims to begin irrigation at the lower limit and avoid exceeding the upper limit.

Irrigation scheduling seeks to maintain a desired soil moisture storage (ΔS) within the root zone, representing the difference between water inputs and outputs (fig. 2). The soil water balance can be expressed as:

$$I+P=ET+R+D+\Delta S \qquad (1)$$

In this equation, ΔS is the soil water storage, I is irrigation, P is precipitation, R is runoff, ET is evapotranspiration, and D is drainage.

If R and D are negligible:

$$\Delta S=I+P-ET \qquad (2)$$

Between irrigation or rainfall events, soil moisture measurements (ΔS) obtained from sensors can provide direct estimates of plant water consumption (ET) within the root zone.

$$ET=\Delta S \qquad (3)$$

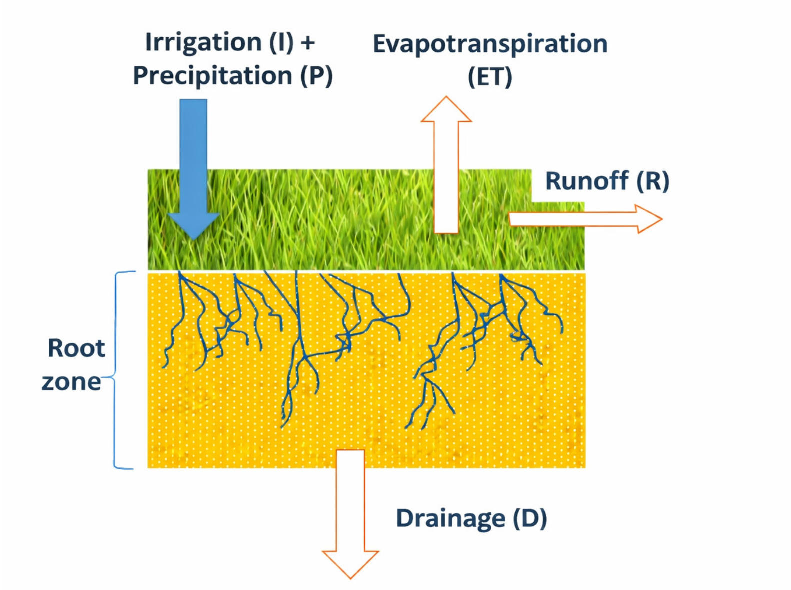

Figure 2. Soil moisture balance in the root zone.

With rapid advances in soil moisture sensing technology, many commercially available irrigation management systems have been developed. Various soil moisture sensors are available on the market, and users should ensure that the selected sensor is compatible with the irrigation controller installed on the site (fig. 3). Soil moisture sensors typically measure either soil volumetric water content or soil moisture tension. Most reliable sensors that measure volumetric water content are generally categorized into time-domain reflectometry (TDR) and time-domain transmission (TDT) types. Soil moisture tension, on the other hand, is measured using tensiometric sensors, which contain a porous material in contact with the soil that allows water movement.

Common settings and terminology of SMS-based smart controllers

The following section summarizes common settings and terminology used in smart SMS-based controllers. Since settings may vary among controllers, users should refer to the manufacturer's manual for proper programming of each product.

Programs/schedule: Many controllers allow users to create multiple programs or schedules with different settings depending on irrigation goals. This feature is especially useful at sites where one controller manages multiple plant groups with different irrigation needs. Plant types such as lawns, shrubs, and trees require different irrigation schedules, and each group can be assigned its own program.

Zone: A zone (or hydrozone) is a section of an irrigation system controlled by a single valve. Each hydrozone should contain plants with similar water requirements and operate under its own irrigation schedule. Zones can also be defined based on other

Figure 3. Some commercially available soil moisture sensors: Irrometer Watermark sensor (left), Toro precision soil moisture sensor center), Acclima digital TDT sensor (right).

factors affecting irrigation such as soil type, slope, or shade.

Days to water: This setting allows users to customize which days of the week the lawn or landscape will be irrigated. Options such as watering every other day or every 2 days may also be available. These custom settings help users comply with local watering restrictions and coordinate with mowing or plant maintenance schedules.

Start time: The time of day the user selects for irrigation to begin on scheduled watering days. The first zone in the program starts watering, followed by the remaining zones in sequence.

Run-time: The amount of time each zone is irrigated during an irrigation event. Run-time can range from a few minutes to several hours depending on soil type and plant needs.

Evapotranspiration (ET): The total water lost to the atmosphere through the combined processes of soil evaporation and plant transpiration.

Soil moisture content: The amount of water present in the soil. It can be expressed as either gravimetric or volumetric water content.

Soil tension: Also known as soil matric potential, soil suction, or soil water potential, soil tension indicates how available the water in the soil is for plant uptake.

Soil gravimetric water content (θg): The ratio of the mass of water to the mass of dry soil.

Soil volumetric water content (θw): The ratio of the volume of water in the soil to the total bulk volume of the soil.

Table 1. Features of SMS-based smart controllers on the market (Region 2018)

	Baseline Watersec S100	Baseline Base station	Dynamax GP1	Hunter Soil Clik	Irrometer	MorpH20	Rainbed (SMRT Y)	Tucor (RKx)	UgMO Tech nologies
Standalone (S) or Add-on (AO)	AO	S	AO	S	AO	AO	AO	S	S
Bypass (B) vs. On-demand (OD)	B	OD	OD	B	B	OD	OD	OD	OD
Number of sensors: Single (S) vs. Multiple (M)	S	M	S & M	S	S & M	M	S	S & M	M
Moisture Sensor type: volumetric (V) vs. soil tension (T)	V	V	V	T	T	V	V	V	V
Installation Requirement: professional (P) vs. user (U)		P	U	U/P	P	U	P	P	P
SWAT testing record	yes	yes	yes	yes	yes	yes	yes	yes	yes
EPA Water Sense certificate	yes	yes							
Start time		8							
Fully automatic		yes				yes			yes
Computer interface/smart app		yes						yes	yes
Adjustable cycle/soak period		yes							
Number of programs		99/40						10	
Zone capacity		200/100	6		8		2		36
Warranty (years)	10	10	1	5	1	2	1	1–5	Life of the contract

Field capacity (FC): The amount of water remaining in the soil after it has been saturated and free drainage has become negligible.

Management allowed depletion (MAD): The maximum amount of water that can be used by plant roots before the next irrigation is needed.

Permanent wilting point (PWP): The minimum soil moisture level at which plants begin to wilt and can no longer recover.

Types of SMS-based smart irrigation controllers

Features of several commercially available SMS-based controllers are summarized in table 1. Figure 4 illustrates irrigation research trials conducted in Southern California to evaluate the performance of several commercially available SMS-based smart controllers. Most SMS-based controllers consist of two main components: a sensor placed in the plant's active root zone and a controller that turns irrigation on or off depending on whether the soil moisture is sufficient to meet plant needs. The simplest type of SMS-based controller is an add-on system, where a soil moisture sensor is connected to an existing irrigation controller or timer. Some manufacturers offer systems in which the soil moisture sensor and controller are sold together rather than as separate add-on components. SMS-based controllers can be further classified into two categories: bypass and on-demand.

Bypass: These controllers skip or delay a scheduled irrigation event when soil moisture is above a user-defined threshold. The user sets this threshold based on soil and plant type, typically using the plant's available water content as a guide.

On-demand: This approach initiates or terminates irrigation when soil moisture reaches lower or upper threshold levels, rather than simply bypassing scheduled events. This is a more advanced system that allows users to set two threshold levels for precise control of irrigation timing and water application.

How to set up and program the SMS-based smart irrigation controllers

To ensure accurate operation, the soil moisture sensor must be installed in the active root zone of the plants (for example, 2–5 in. deep for turfgrass) and at a site representative of the plants and zones it will irrigate. Rooting depth varies among plant species and is also influenced by soil texture, management practices, and the degree of soil compaction. Sensors should be installed away from tree roots, sprinkler heads, and shaded areas. They should also be kept away from sidewalks, hose

Figure 4. Two SMS-based irrigation trials at UC Riverside Experiment Station in Riverside (top) and UCANR South Coast Research and Extension center in Irvine (bottom). *Photo*: http://www.ucrwater.com.

connections, and areas where water frequently accumulates, such as car wash zones. After installation, sensors must maintain good contact with the surrounding soil, meaning there are no air gaps between the sensors and the soil. The soil should be packed firmly—but not too tightly—around the sensor, and applying a small amount of water can help ensure good soil-to-sensor contact.

Sensors should not be placed in locations where water tends to pool or accumulate. For example, if a single sensor controls the entire irrigation system, it should be installed in the driest zone to ensure all areas receive adequate watering. The zone containing the sensor should be designated as the primary zone, with other zones linked to irrigate on the same schedule as the primary zone. It is recommended to mark or record the sensor's location to prevent accidental damage during mowing or digging, and to make it easy to locate.

SMS-based smart controllers automatically override a scheduled irrigation event when soil moisture exceeds the user-defined threshold level. This feature improves irrigation efficiency by adjusting watering frequency according to soil moisture conditions and threshold settings.

Some SMS-based controllers require only one threshold setting, while others operate using both upper and lower threshold limits. After installing and connecting the sensor to the controller, the soil around the sensor should be saturated with water. The upper threshold, or FC, is the soil moisture level reached after water has drained for 1 to 3 days in medium- to heavy-textured soils or about 12 hours in sandy soils. The lower threshold is then set as a fraction of FC (typically around 75%), representing the MAD for optimal plant growth. Controllers with two thresholds maintain soil moisture between the lower and upper limits by initiating irrigation when moisture drops below the lower threshold and stopping it once the upper threshold is reached (fig. 5). Controllers with a single threshold allow irrigation only when soil moisture falls below that threshold.

Rebate programs on SMS-based irrigation controllers

Water utilities across California offer rebate programs to encourage the adoption of water-saving technologies. These programs can take many forms, including rebates for high-efficiency fixtures and appliances, lawn removal and replacement, and installation of weather-based or SMS-based irrigation controllers and soil moisture sensors. To provide an overview of available programs, we surveyed eighty-five major water utilities (both retailers and wholesalers) throughout California. Of these, thirty-eight utilities currently offer rebates for installing smart weather-based irrigation controllers and SMS-based controllers. Table 2 lists these utilities along with program descriptions and rebate amounts.

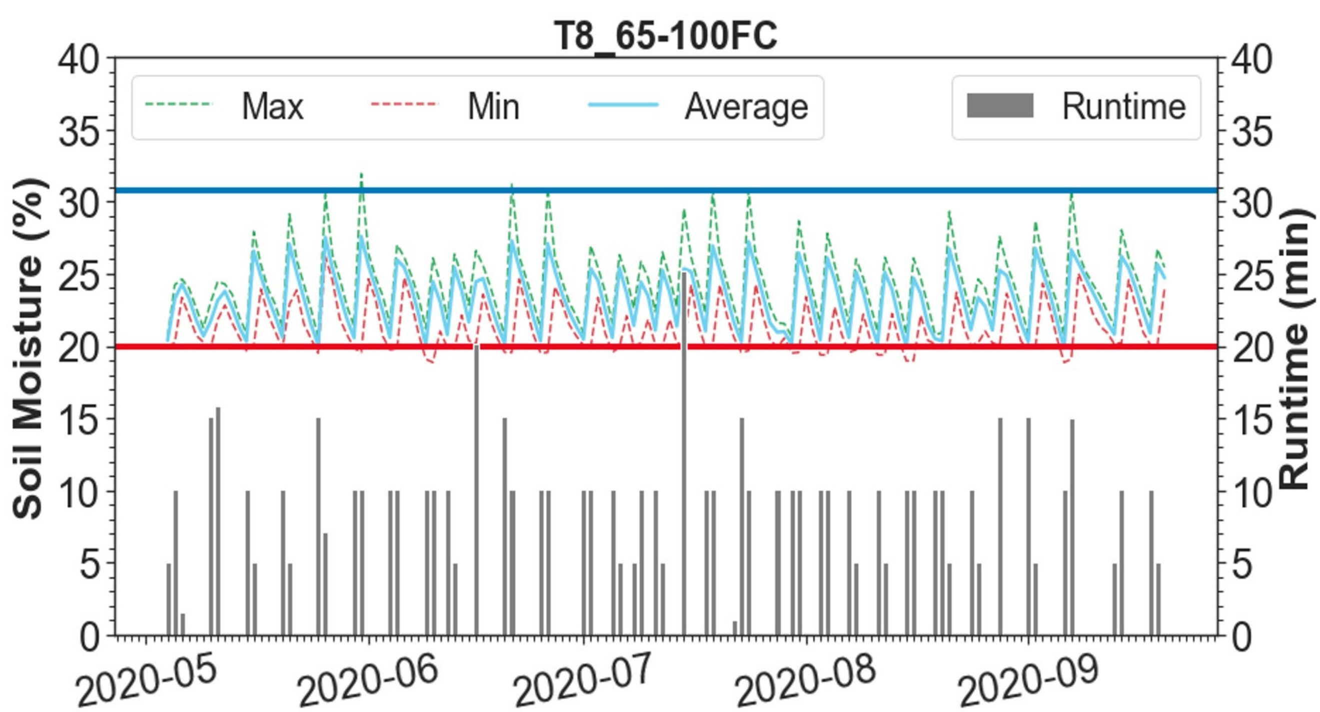

Figure 5. Soil mosture threshold-based irrigation controller from June to September 2020. Redline is the lower moisture threshold (65% of the field capacity), and the blue line is the upper soil moisture threshold (field capacity).

Table 2. Available rebate programs for installing smart controllers and soil moisture across water utilities in California

Water utility	Rebate	Rebate program description
Antelope Valley	Smart Irrigation Controller	Rebate up to $125, not to exceed actual cost
Bakersfield	Smart Irrigation Controller	Rebate up to $125, not to exceed actual cost
Bakersfield, North Garden	Smart Irrigation Controller	Rebate up to $125, not to exceed actual cost
Bayshore	Smart Irrigation Controller	Rebate up to $125, not to exceed actual cost
Bear Gulch	Smart Irrigation Controller	Rebate up to $125, not to exceed actual cost
Chico	Smart Irrigation Controller	Rebate up to $125, not to exceed actual cost
City of Roseville	Weather Based Irrigation Controller	Up to $150 rebate for upgrading your non-current weather-based irrigation controller to a new weather-based irrigation controller
City of West Sacramento	Smart Irrigation Controller	Rebate up to $150 for replacing your existing conventional irrigation controller with a WaterSense-labeled irrigation controller
Contra Costa County Water District	Smart Irrigation Controller	Rebate up to $150 for replacing your existing conventional irrigation controller with a WaterSense-labeled irrigation controller
Dixon	Smart Irrigation Controller	Rebate up to $125, not to exceed actual cost
Foster City	Smart Irrigation Controller	100% of the cost of the controller up to $250 maximum rebate

Concluding remarks and places to find additional information

Several soil moisture sensors can be integrated with existing timers, while some manufacturers offer standalone smart SMS-based controllers. Although these technologies show great promise for saving water by avoiding excess irrigation, proper sensor placement and controller programming are critical for optimal performance.

Understanding soil properties is essential for setting the optimal thresholds in SMS-based controllers. Information on soil texture and water-holding capacity by location is available at UC Davis's California Soil Resource Lab (https://casoilresource.lawr.ucdavis.edu/gmap/).

Smart Water Application Technologies (SWAT) has tested various commercially available products for performance following the protocols available at irrigation. The US Bureau of Reclamation (Region 2018) has also published a detailed technical review of commercially available smart SMS-based irrigation controllers.

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