Soil Moisture-Based Irrigation Control Technologies: WaterSense® Specification Update

I. Introduction

In May 2013, the U. S. Environmental Protection Agency's WaterSense program published a Notice of Intent (NOI) to develop a specification for soil moisture-based control technologies. These products control irrigation based on plant water needs by measuring the amount of moisture in the soil and tailoring irrigation schedules accordingly. Soil moisture-based control technologies will complement the existing suite of WaterSense labeled irrigation products, including weather-based irrigation controllers (WBICs) and spray sprinkler bodies.

Since the release of the NOI, WaterSense has been working with an American Society of Agricultural and Biological Engineers (ASABE) standard development committee to develop a repeatable, reproducible test method that can be used to evaluate the performance of soil moisture-based control technologies. This report serves to update stakeholders and interested parties on the progress made to date to develop a test method and relay the outstanding data gaps that need to be filled in order to move forward with a draft specification for this product category.

II. Overview of Soil Moisture-Based Technologies

The most common technology used to schedule irrigation is a manually programmed clock-timer controller that irrigates for a specified amount of time on a preset schedule programmed by the user (e.g., 20 minutes, three days per week). In these systems, the responsibility of changing the irrigation schedule to meet landscape water needs lies with the end user or a hired irrigation professional. Clock-timer controllers can be a significant source of wasted water because irrigation schedules are often set to water at the height of the growing season, and the home or building owner may not adjust the schedule to reflect seasonal changes, precipitation events, or changes in plant watering needs. For example, plant water requirements decrease in the fall, but many home or building owners neglect to reset their irrigation schedules to reflect this change (see Figure 1). Therefore, an irrigation system could be watering in January as if it were July.

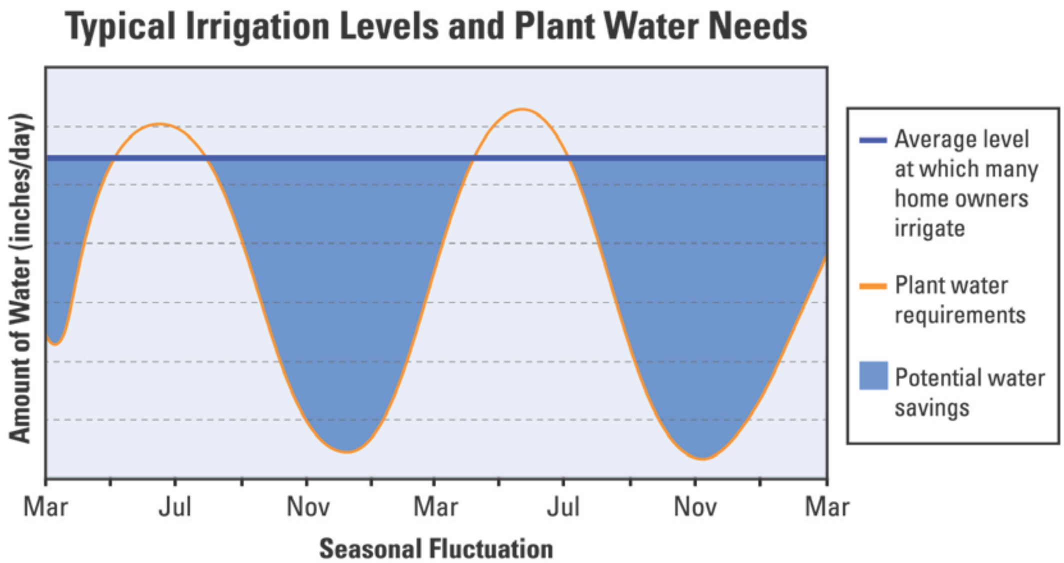


Figure 1. Potential Water Savings From Adjusting Irrigation Scheduling Based on Landscape Water Needs

As an alternative to clock-timer controllers, soil moisture-based control technologies make irrigation schedule adjustments by automatically tailoring the amount and/or frequency and timing of irrigation events based on the moisture content of the soil in the landscape. There are currently two types of soil moisture-based control technologies: bypass and on-demand technologies.

- Bypass technologies include a soil moisture sensor that communicates with a device that is attached to a traditional clock-timer controller with a pre-programmed watering schedule. The attached device will inhibit or suspend an irrigation event based on a reading from the soil moisture sensor, if the soil moisture meets a set moisture threshold. Otherwise, it will allow the irrigation event to occur. Bypass technologies are usually installed on residential and light commercial landscapes and are the most commonly used type of soil moisture-based control technology.

- On-demand technologies are stand-alone controllers that communicate with associated soil moisture sensors. These controllers automatically adjust irrigation schedules based on soil moisture levels. For example, in some technologies, a lower and upper soil moisture threshold is set in the controller. When the soil moisture sensor reads moisture content below the lower threshold, the controller will initiate irrigation until the upper threshold is reached. On-demand technologies are typically installed on larger commercial landscapes and are not as common as bypass technologies.

III. WaterSense NOI and ASABE Committee Development

WaterSense has been interested in labeling soil moisture-based control technologies since 2007, when the program moved forward with specification development for WBICs. At that time, WaterSense began conducting initial research and coordinating with manufacturers to identify a viable test method and performance metrics. Like WBICs, soil moisture-based control technologies schedule irrigation based on landscape water needs, and once labeled, will help further transform the market from traditional clock timer-based irrigation controllers.

Typically, WaterSense relies on industry-accepted test methods and standards to form the basis of its water efficiency and performance specifications, aiming to label products that are at least 20 percent more efficient and that perform as well or better than conventional models on the market. While there were no published standards for soil moisture-based control technologies at the time initial research began, in 2012 ASABE initiated an effort to create a standardized testing protocol for weather-based or soil moisture-based irrigation controllers under X627, *Standardized Testing Protocol for Weather-based or Soil Moisture-based Landscape Irrigation Control Devices*. In early 2013, ASABE broke out standard development for bypass soil-moisture based control technologies as X633, *Testing of Soil Moisture Sensors for Landscape Irrigation.* This standard aims to specifically address the performance of bypass technologies, as they are less complex and function very differently than WBICs or on-demand soil moisture-based technologies.

In May 2013, WaterSense published its NOI to develop a specification for soil moisture-based control technologies. The NOI communicated EPA's intent to develop separate specifications for bypass and on-demand technologies, focusing first on bypass technologies, because test method development was underway in the ASABE X633 committee. WaterSense continues to focus its specification development efforts on bypass technologies, because the ASABE X633 committee has defined the fundamental aspects of the performance test method for that technology. WaterSense plans to address on-demand technology at a later date, once a test method is more fully defined. Therefore, the remainder of this report focuses on EPA's plans for developing a draft WaterSense specification for bypass soil moisture-based control technologies and serves to update stakeholders and interested parties on the committee developments that have occurred and progress made since the release of the NOI.

IV. Bypass Technology Test Method Development

Soon after the X633 committee formed, a subset of committee members, plus additional manufacturers (herein referred to as the subcommittee) began to develop a test method that was based on a dry-down method. This included packing containers with soil to a specified bulk density, then installing the sensors. The method called for containers to be wetted to saturation and regularly weighed to measure the weight of the soil as it dried out. From these measurements, the laboratory would calculate the volumetric water content of the soil at the end of the test, which allowed back calculation of container moisture content for the entire test. The test aimed to measure the accuracy of the sensor readings compared to the actual soil moisture content during the dry-down process. This version of the test method did not include a provision to evaluate the switching (i.e. irrigation bypass) function of the sensors.

In early 2014, the East Bay Municipal Utility District (EBMUD), with conservation research funding from the California Department of Water Resources, expressed interest in the test method development and helped organize beta testing using the dry-down method. To prepare for the testing, the subcommittee refined the test protocol to evaluate products in three soil types (sandy loam, loam, and silty clay loam). Testing was to occur in one of those soil types (loam) at three temperatures (15°, 23°, and 30°C) and three salinity contents (0, 1.5, and 3 electrical conductivity [EC]) for a total of six tests for that soil. Testing was to occur in the other two soils (sandy loam and silty clay loam) at only one temperature and salinity (23°C and 0 EC, respectively). Each test container was to hold three sensors of the same model. The initial dry-down test method included four dry-down cycles, run sequentially. The results from the first dry-down cycle were to be discarded due to soil redistribution and inconsistencies associated with initial wetting of dry soil. Additionally, each product would undergo a freeze test in which it would be exposed to temperatures below freezing for three days, then allowed to thaw before assessing performance. In early 2015, EBMUD enlisted the Texas A&M Biological and Agricultural Engineering Department and the Center for Irrigation Technology (CIT) at California State University, Fresno to evaluate the dry-down method feasibility, clarify points of ambiguity, and begin to assess the method repeatability.

The results from the initial testing showed consistent readings among multiple sensors installed in each container; however, several issues surfaced with the dry-down method. First, the comparison of the sensor readings with the known volumetric water content of the soil varied within each container over the dry-down period (e.g., sensor accuracy in measuring soil moisture content varied). Second, it was difficult to obtain consistent depletion levels for the soils between the two laboratories, because the soils dried at different rates at each laboratory, making comparisons between them difficult. In addition, it took about two months to complete the test for one product in one soil and one salinity. The manufacturer-supplied mesh containers were expensive to produce and didn't accelerate drying enough to reduce the test time to a reasonable level. The subcommittee also determined that an accuracy-based test was not fully representative of how soil moisture-based control technologies work in the field. While a certain level of accuracy is necessary, soil moisture-based control technologies operate via an adjustable, site-specific threshold soil moisture content that allows/prevents irrigation. The test for accuracy alone does not evaluate the ability of the sensors to consistently interrupt (i.e., bypass) the irrigation event when the threshold is reached.

Based on the results of the initial interlaboratory testing, and to address some of the issues identified, the subcommittee decided to modify the protocol. The subcommittee decided to pre-wet test soils to pre-determined volumetric water content and evaluate sensor accuracy at fixed depletion levels (i.e., depletion of water content relative to the field capacity water content) of 20, 40, and 60, percent as a way to determine a range of target soil moisture content for testing. The subcommittee also decided to measure the ability of sensors to consistently bypass an irrigation event once the threshold soil moisture content was reached across test samples at given depletions (i.e., a measure of sensor precision to bypass irrigation). For this evaluation, the subcommittee revised the protocol to include a manual adjustment of the sensor until the control mechanisms switched to allow irrigation and recorded the values at which that occurred, indicating whether the products triggered the bypass mechanism consistently.

In late 2015, Texas A&M and CIT continued testing using the revised test method, and the laboratories were able to produce somewhat consistent results. However, the subcommittee remained concerned about the time required to complete the test. The subcommittee revised the test method to pack a predetermined weight of dry soil and water volume in three separate containers (packed container method) to achieve the target depletion levels of 20, 40 and 60 percent, so that the testing could be done concurrently rather than waiting for the soil to dry down naturally. To help streamline the testing, the subcommittee decided that a moderately coarse soil (sandy loam) and a moderately fine soil (clay loam) were representative of most landscape soils in the United States, eliminating the need for testing in a third soil type. The subcommittee also decided that one test temperature (23°C) and two water salinities were sufficient (0 and 3 EC, representing fresh and saline water). In addition, the freeze test was retained.

The two laboratories continued to conduct testing using the packed container method and revised soil types and conditions from mid-2016 through early 2017, and continued identifying minor refinements to the test method. In 2017, WaterSense coordinated with the subcommittee and the two laboratories to conduct a series of performance tests using the refined test method to generate a body of performance data that could be used for specification development. The subcommittee identified four product models for testing, representing most of the bypass soil moisture-based control technology products on the market, including products that use various methodologies to bypass irrigation. The laboratories were to test three samples (all of the same model) in one container for each combination of the following parameters, resulting in 12 individual tests (i.e., containers) for each product model:

- Two soils (sandy loam and clay loam)[1]
- Two salinities (0 EC and 3 EC)
- Three depletions (20, 40, and 60 percent)

V. X633 Performance Testing Results

Texas A&M and CIT conducted the most recent round of performance testing from May 24 to June 12, 2017. Due to time and funding constraints, each laboratory was only able to test three of the four products (Products A, B and D) in the sandy loam soil at two salinities (0 and 3 EC) and three depletions (20, 40 and 60 percent) each. None of the products has been tested in the clay loam soil. In addition, the fourth product has yet to undergo any testing.

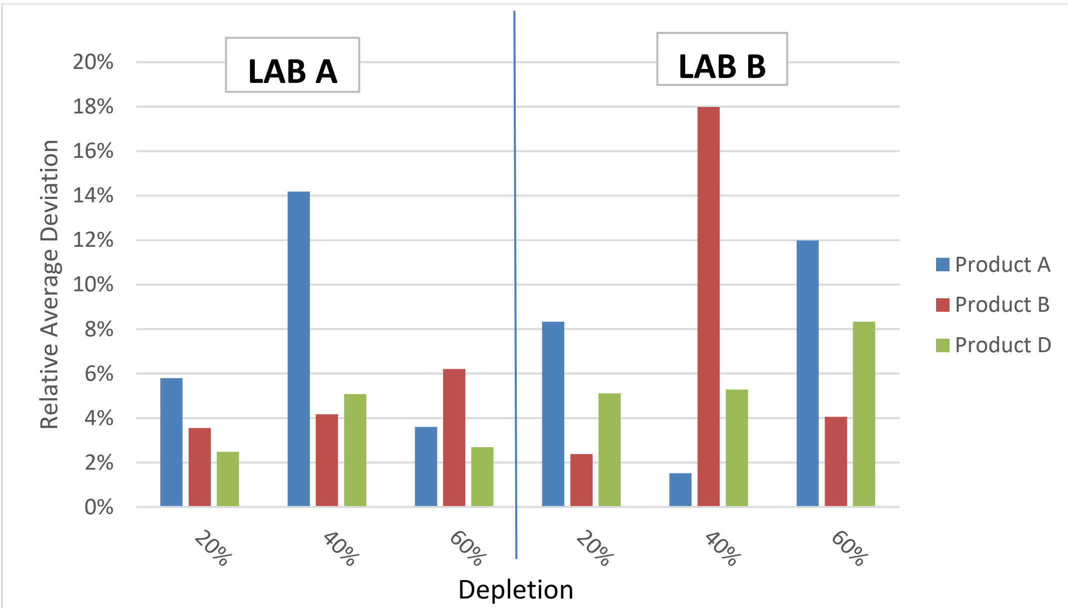
The subcommittee compiled and analyzed the data from the two laboratories and explored possible metrics that could be used to assess the product performance. One such metric is the relative average deviation (RAD), which is a measure of precision. As an example, Figures 2 and 3 display the RAD for the three products tested at the two laboratories (laboratory A and B) at each depletion level (20, 40 and 60 percent) in a sandy loam soil at two salinities (0 and 3

[1] Throughout this testing process and refinement of the test method, the laboratories used soils obtained from CIT. Each laboratory prepared its own soils. However, these soils must to be available to independent laboratories in the future when the standard and a WaterSense specification are published. The subcommittee went to considerable effort to obtain soils outside CIT and recognized the need for a consistent source that is not cost-prohibitive. By mid-2016, the subcommittee had contacted several suppliers of soil (e.g. sand blast media and golf course spec material); however, none of these sources proved to have sufficient soil in the composition required by the test protocol. In addition, these soil sources tended to be extremely expensive. Additional exploration of sources was conducted in 2017, but the subcommittee had not identified a consistent and reliable soil source at a reasonable price.

EC). Each column (or RAD) indicates the precision, or the ability of three sensors of the same product brand in one container to provide similar readings of soil moisture at a given depletion level under the same test conditions (soil and salinity). This evaluation of precision (agreement) highlights some remaining issues with the test method that still need to be resolved, as discussed below.

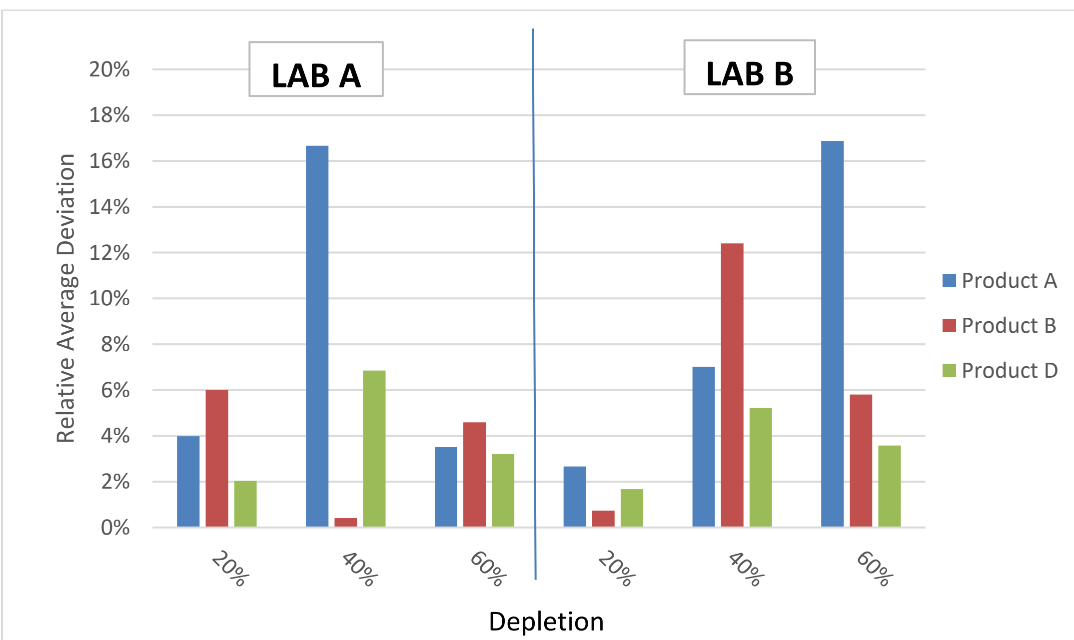
Results demonstrate some level of variability in the ability of the products to provide consistent results, as indicated by higher RADs. As a frame of reference, a RAD of zero would indicate zero deviation of the readings among the individual sensors (and thus a higher level of agreement). While several of the test results demonstrated a high level of precision (those with low RADs), several factors still created variability within the test results. This variation could be related to a variety of factors. For example, the subcommittee suspected the variation in Product A was caused by its sensitivity to variability in packing the containers with soil, which is an issue that has yet to be resolved. Product D produced more precise results than either of the other two products, and Product B had some variability in one test container for unknown reasons, possibly related to laboratory error. In summary, consistent results are obtainable, though there are still some variability issues that need to be addressed before the test method is finalized.

Overall test results indicate that the test method used to generate the performance data collected to date can be repeatable and is able to generate somewhat consistent results between laboratories and among products. However, several data gaps and additional performance data are needed to move forward with a final test method and WaterSense draft specification, as discussed in the following section.



*Note that Product C is excluded because it was not tested as part of the initial performance testing.

Figure 2. Relative Average Deviation (Precision) of Sensor Performance in Freshwater (0 EC)



*Note that Product C is excluded because it was not tested as part of the initial performance testing.

Figure 3. Relative Average Deviation (Precision) of Sensor Performance in Saline Water (3 EC)

VI. Data Gaps

At the time of this report's publication, a number of data gaps remain in order to finalize a test method and complete a full suite of performance testing for bypass soil moisture-based control technologies. Regarding the test method, the subcommittee is currently working to resolve the following items:

- Soil Source: The subcommittee is working to determine a reliable soil source for both soils (sandy loam and clay loam) at a reasonable cost. The soil source needs to be finalized prior to a WaterSense specification, so that licensed certifying bodies (LCBs) can obtain the soil for testing.
- Soil Preparation: The soil preparation methodology is not currently included in the test method and must be added to the draft standard to ensure uniformity of soil preparation.
- Container packing: As noted above, some products are sensitive to packing. This issue needs to be resolved before the test method is finalized.
- Number of replicates (i.e., cycles): The current test method requires three sensors of one model in one container for each set of soil test conditions (i.e., depletion, soil, salinity) with the test being run only one time. Testing should be conducted to determine if one cycle of testing is sufficient, or if multiple cycles should be conducted.

Several tests must be completed to allow the subcommittee to analyze a full set of performance data, and to allow WaterSense to include performance criteria and associated thresholds in its draft specification. These criteria might include the performance metric described above, or other metrics measuring the ability of the controller to bypass irrigation. Regarding the full suite of performance data, the following tests currently remain incomplete:

- One of the four products (Product C) has not been tested and must undergo the full suite of tests including two soils, two salinities, and three depletions.
- Product A should be retested in both soils once the test method is final and the packing variability issue is resolved.
- The two remaining products (Product B and D) need to be tested in the second soil (clay loam), with two salinities and three depletions.
- The freeze test needs to be completed for all four products.

VII. Next Steps

ASABE and WaterSense plan to continue coordinating as ASABE develops a standard and WaterSense pursues a specification. Once the test method is final, a draft standard is published, and the remaining performance testing is completed, WaterSense will be able to move forward with draft specification development.

EBMUD is continuing to seek funding partners to finalize the test method and/or complete the remaining performance testing. If you are interested in participating or have other information that would help WaterSense to move this product forward, please contact the WaterSense Helpline at (866) WTR-SENS (987-7367) or watersense@epa.gov.

EPA appreciates the continued interest in a WaterSense specification for soil moisture-based control technologies and will keep the public and stakeholders informed of its progress throughout the specification development process.