Evaluation of
Potential Best Management Practices
-
Soil Moisture Sensors

Prepared for

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January 2014

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INTRODUCTION

"Smart" irrigation controllers such as soil moisture sensor (SMS) systems offer the opportunity to optimize irrigation based on measured plant demand in the irrigated system. Smart controller devices, such as weather-based irrigation controllers (WBIC) or SMS, utilize weather data and/or soil moisture readings to schedule irrigation. These devices can include onsite weather sensors, soil moisture sensors, or offsite weather data sent to the controller. This potential best management (PBMP) report will focus on soil moisture sensor (SMS) systems as a device potential for outdoor water savings. The most common type of soil moisture controllers are designed to bypass a scheduled event from an automatic irrigation system timer if the soil water content is above a certain threshold. This threshold is defined and set by the user.

SOIL MOISTURE SENSORS SYSTEM COMPONENTS

An SMS system is the combination of both the soil moisture sensor and its controller. The sensor which is buried in the root zone relays the measurement of the soil water content to communicate with an irrigation controller. Two types of control methodologies use soil moisture sensors: 1) bypass configuration and 2) on-demand configuration.

The simplest (and most common) is "bypass" control. An SMS system in bypass configuration is a device that connects the SMS to the existing irrigation timer and bypasses the automatic irrigation when the soil moisture content is adequate for plant needs (Figures 1 and 2). A bypass SMS control system is connected in series with a timer to control electric solenoid valves. In bypass control, the SMS controller has a user-adjustable threshold setting where the scheduled timed-based irrigation event is bypassed if the soil moisture content exceeds the user-adjustable threshold. It should be noted that the simplest SMS-based controllers may operate in "interrupt" mode whereby the sensor interrupts the control circuit as soon as soil moisture exceeds the adjustable threshold.

An SMS system with on-demand configuration is a controller that uses a SMS to regulate water content in the plant root zone between low and high moisture thresholds. An on-demand SMS system will both bypass and initiate irrigation events based on the user-defined threshold levels.

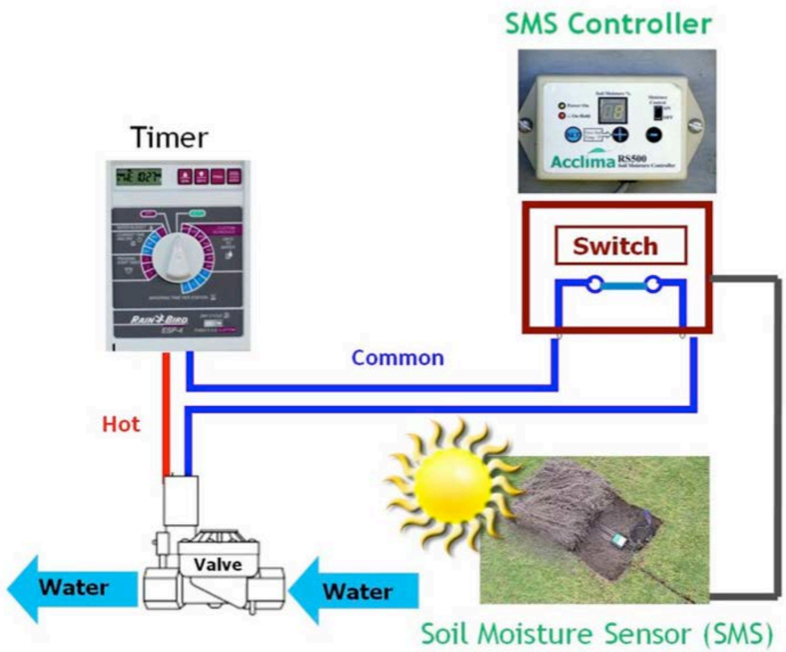

Figure 1. An irrigation timer with a soil moisture sensor allows irrigation events when the soil is dry. Source: Haley et al. 2005

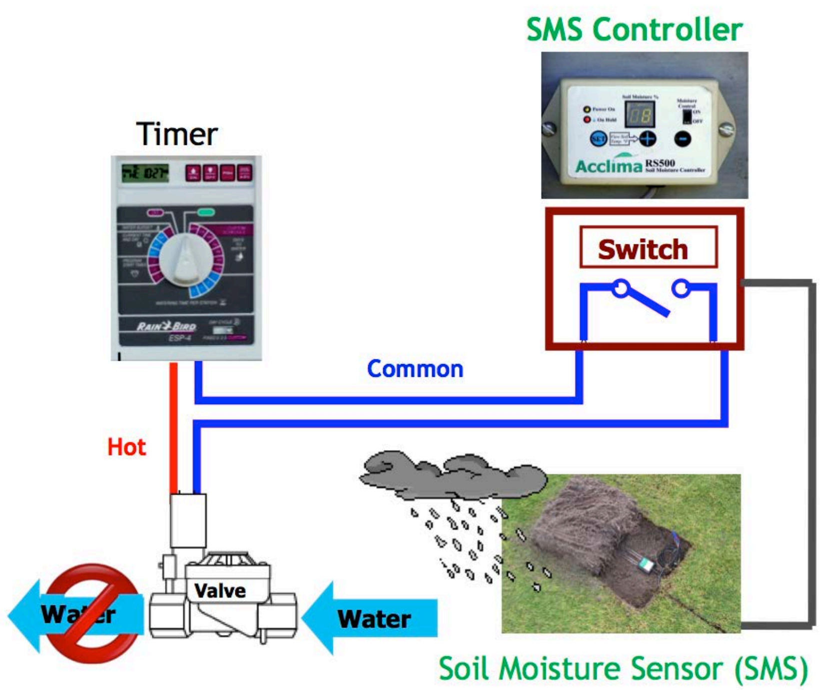

Figure 2. An irrigation timer with a soil moisture sensor bypasses irrigation events when the soil is wet. Source: Haley et al. 2005

PROGRAMMING SOIL MOISTURE SENSOR SYSTEMS

Programming of a soil moisture sensor controller in bypass mode requires input of a run time into a time-based schedule of a standard irrigation controller. This run time should not result in the application depth exceeding the water-holding capacity of the soil[1]. Ideally, frequent irrigation events should be programmed into the irrigation timer, and the sensor will allow irrigation as conditions in the root zone dictate in response to rainfall and evapotranspiration (ET). For example, assume the peak weekly landscape ET at a site is 4 inches/week, and the maximum allowable depletion of the soil/plant system[2] is 1.5 inches. Then, the net[3] irrigation for any particular cycle should not exceed 1.5 inches[4]. For a given week, approximately 3 irrigation events are required to meet the peak ET demands.

Number of events per week = Peak ET per week / Net irrigation per event

3 events per week = 4 inches per week / 1.5 inches per irrigation event

The second type of soil moisture control is “on-demand” control in which the soil moisture based irrigation control system consists of a stand-alone controller and multiple soil moisture sensors. This SMS controller completely replaces the timer. Under on-demand soil moisture based control, high and low limits are set such that irrigation occurs only within those limits. Thus, the water content level at the maximum allowed depletion level or reduction in water extraction point would be the low or irrigation initiation threshold, and field capacity would be the high or irrigation termination threshold. Although performance of all SMS control systems depends on sensor installation, extra care must be taken with an on-demand system to ensure excessively low or high irrigation amounts do not occur. The irrigation manager should track this type of system after initial installation and make adjustments as needed. Many of these systems include data logging capability; therefore, soil-water status can be tracked for excessive values. This type of system is usually much more expensive than bypass controllers and is warranted on larger residential and commercial landscapes.

SENSOR TECHNOLOGY

There are a number of different types of technology to measure the volumetric water content within the soil, depicted in Figure 3. While the SMS has been utilized in agriculture for decades, the most common modern SMS technologies appropriate within the landscape irrigation system are described below:

The Granular Matrix Sensor (GMS) has been utilized for more than 25 years. This sensor is made up of a porous ceramic external shell with an internal matrix structure containing two electrodes. An internal gypsum cylindrical tablet buffers against soil salinity levels that occur in

[1] The water-holding capacity of soil is defined as the difference between the threshold capacities programmed in the SMS controller and field capacity.
[2] The soil plant system considers the plant root zone depth as well as the soil characteristics.
[3] Net irrigation does not account for additional water needed to compensate for system inefficiencies.
[4] In regions where unpredictable rainfall occurs in the irrigation season, the 1.5 inch net irrigation cycle should be divided into multiple events per day to provide a buffer in the soil as storage for rainfall.

most irrigated soils. While GMS do not dissolve in the soil over the time (Irmak and Haman 2001), which generally occurs with a gypsum block, the useable life is only considered 5 to 7 years[5]. GMS calibration is dependent on temperature and soil type, and reaction time is slower than the other modern sensor types.

A Time Domain Transmissometry (TDT) and its precursor Time Domain Reflectometry (TDR) sensor measures the time required for an electromagnetic pulse to travel a finite distance along a rod or wire. TDR measures the travel time based on reflected waveforms, while TDT is an equivalent technique that measures the transmitted (rather than reflected) impulse. The travel time is converted into volumetric water content (VWC) for the soil. Together, they provide a powerful means of analyzing VWC variation based on the soil properties surrounding the rod/wire. These sensors provide increased accuracy that is not affected by low-to-moderate soil salinity levels.

The Frequency Domain Reflectometry (FDR) sensor, which is also known as a Capacitance sensor, measures signal reflections through a medium (e.g. soil) across frequency utilizing a pair of electrodes. The change in frequency is then converted to a soil moisture measurement. FDR sensors which operate at a high frequency[6] are relatively unaffected by soil salinity levels, but are sensitive to undisturbed soil contact.

The modern SMS measures the relative permittivity (dielectric constant) of the water in soil. The increasing adoptions of the dielectric methods (TDT/TDR and FDR) have been observed due to the following advantages:

- No need for calibration
- Minimal or no maintenance[7]
- Installation and use is non-destructive
- Measurements may be made near the surface (i.e. in turfgrass application)
- Provide instantaneous and accurate measurements
- Can be specially adapted for automatic control of irrigation systems

Single Versus Multiple Sensors

In most residential and small commercial irrigation systems, one SMS is adequate for controlling the entire system. To account for variation in zone water needs, independent runtimes should be adjusted. Larger residential and complex commercial systems can accommodate multiple sensors to control groups of zone valves. Some SMS systems have the capacity for the addition of sensors on a single controller, while others may require multiple SMS controllers within the system.

[5] Manufacturer reported (Irrometer)
[6] Greater than 20 megahertz
[7] As compared to tensiometers

Figure 3. Various soil moisture sensors and their sensor technology: Granular Matrix Sensors (GMS), Time Domain Transmissometry (TDT), or Frequency Domain Reflectometry (FDR).

Photo credits: Irromoter Co.; Baseline; Delta-T; The Toro Company; Rain Bird; Netafim; UgMo.

POTENTIAL WATER SAVINGS

In recent years, and in light of modern SMS technology, interest in research has gained steam for bypass-type SMS systems in landscape applications. Of the research that has been conducted proving the effectiveness of technology in the reduction of irrigation water application, most of these studies have, thus far, been primarily conducted in controlled research settings. When attempting to incorporate the recommendations of the research into actual landscapes, savings may not be as significant (Campbell et al. 2004; Geller et al. 1983). When consumers were unaware of the technology in place, the reduction in water use was more similar to the laboratory tests. This supports the notion that when consumers are aware of technological innovations they may react by using water more laxly (Campbell et al. 2004).

Those studies resulting in peer-reviewed publications with sound statistical analysis, may be not representative of the larger populations involved as irrigation customers of a utility. Therefore, the saving results are not directly transferable (Dukes 2010). On the other hand, the larger scale demonstration projects such as smart timer programs in California, which were primarily WBICs, compare water use pre- and post-installation using accepted statistical practices (Kennedy/Jenks Consultants 2008; Mayer et al. 2009; Hunt et al. 2001). With these domestic irrigation studies, there is no guarantee that the watering practices prior to installation of the devices are indicative of the general population, particularly when there isn't a control group.

The controlled research studies indicate substantial water savings (Cardenas-Lailhacar et al. 2008; Cardenas-Lailhacar et al. 2010: McCready et al. 2009). However, "real world" savings in larger scale pilot projects indicate savings typically less than 10% (Kennedy/Jenks Consultants 2008; Mayer et al. 2009). Discrepancy between the potential savings suggested from the controlled studies and reduced actual savings in the pilot projects can be the product of the following deficiencies within the program design (Dukes 2010):

- Targeting high irrigation users (either a relative or absolute scale)
- Education for contractors and end users
- Timely follow-up to assess water savings

It should also be noted that much of the controlled research on smart controllers has been conducted in humid regions, (i.e. Florida) where there is a higher potential for savings due to consistency of rainfall versus arid regions (i.e. California). However, although the magnitude of savings may be greater in humid regions, the use of an SMS can also result in water savings resulting from superfluous events (see section on use of SMS as irrigation governors).

META-ANALYSIS OF STUDIES

Recent research on water savings resulting from SMS based irrigation controllers is detailed in Table 1. The irrigation savings for these studies range from 11% to 72% compared to an irrigation schedule that is either typical or recommended for the region.

Table 1. Summary of modern SMS system irrigation studies

Study	Technology[a]	Conditions	Savings[b] (%)	Statistical Comparison	Comments
Qualls et al., 2001	SMS	Landscape plots	26	Yes	Based on estimated net irrigation requirement.
Pathen et al., 2003	SMS	WaterSmart plots	25	Yes	WaterSmart plots compared to control plots irrigated under best practices, Australia
Shedd et al., 2007	SMS	Zoysiagrass turf plots	11 to 28	Yes	Without detriment to turf quality, at medium threshold settings
Cardenas-Lailhacar and Dukes, 2008	SMS	Bermuda-grass turf plots	72	Yes	Savings range from 27% to 92%. Normal rainfall conditions every 2 to 3 days.
Cardenas-Lailhacar et al., 2010	SMS	Bermuda-grass turf plots	34	Yes	Drought conditions with extended dry periods.
Haley and Dukes, 2012	SMS	Residential landscape	65	Yes	Compared to homes with standard timers.

[a] SMS: soil moisture sensor
[b] Irrigation savings is typically compared to a schedule that is either typical or recommended for the region
Adapted from: USEPA (2013) and Dukes (2012).

The studies, which compare SMS systems directly to WBICs, are listed in Table 2. The water savings resulting from the SMS technology in these studies was similar, ranging from 4.3% to 43%, despite the variation in plant water needs. For example, water needs of a warm season turfgrass has a 14% less water need than a cool season turfgrass (i.e. St. Augustine grass versus Fescue).

Between these studies, there is a large inconsistency within the WBIC water savings, -26% to 38%. WBICs do have the potential to increase water use when installed at sites already employing deficit irrigation practices (Mayer et al., 2009; Devitt et al., 2008; Kennedy/Jenks 2008). This trend may be isolated to WBICs, which are designed to provide well-watered conditions, as opposed to SMS controllers that bypass any irrigation cycles beyond the set water threshold. It should be noted, to achieve the maximum water savings potential, both SMS controllers and WBICs both typically require fine-tuning of the initial installation programming.

Table 2. Summary of smart irrigation controller studies comparing SMS systems to WBICs.

Study	Technology[a]	Conditions	Savings[b] (%)	Statistical Comparison	Comments
Qualls and France, 2007	SMS	Residential landscape	4.3	Unknown	Results compared to the previous two years rather than control group
	WBIC		25		
Vasanth et al., 2007	SMS	Fescue turf plots	33	Yes	Compared to on-demand SMS system. Attributed to drier than normal conditions and overestimated ET_o.
	WBIC		-26		
McCready et al., 2009	SMS	St. Augustine grass turf plots	38	Yes	Drought conditions with extended dry periods.
	WBIC		32		
Davis and Dukes, 2012	SMS	Residential landscape	23 to 43	Yes	Savings increased when technology was combined with user education
	WBIC		16 to 38		

[a] SMS: soil moisture sensor; WBIC: weather based irrigation controller
[b] Irrigation savings is typically compared to a schedule that is either typical or recommended for the region
Adapted from: USEPA (2013) and Dukes (2012).

Soil Moisture Sensors as Irrigation Governors

The water use habits of 58 homes in a 73-week study conducted by Haley and Dukes (2012) were broken into four irrigation categories based on actual weekly irrigation applied (I_A). The theoretical irrigation requirement (TIR) was based on the Soil Water Balance.

- Irrigation was applied at the site and needed ($I_A > 0$ and TIR > 0)
- Irrigation was applied at the site, but not needed ($I_A > 0$ and TIR = 0)
- Irrigation was not applied, but was needed ($I_A = 0$ and TIR> 0)
- Irrigation was not applied and not needed ($I_A = 0$ and TIR = 0)

The most frequent weekly scenario was no-irrigation applied and none was needed, where the SMS treatment made up the highest proportion of this category. Additionally, the SMS treatment had statistically the lowest water use ratio (I_A/TIR), meaning the amount of water applied was close to the TIR. Sites with soil moisture sensor irrigation controllers bypassed unneeded events during both rainy and dry periods, averaging a significant reduction in the number of irrigation events per month by 50% to 67%, as well as a significant reduction in cumulative irrigation water use (65%) compared to homes with a conventional irrigation timer.

This study illustrated how the SMS devices were effectively bypassing unnecessary as well as superfluous irrigation events. This result was further supported by analysis of a second study on survey responses, which yielded a correlation between sensor-based "conservation potential" and trend in watering practices. In short, sensor-based conservation potential not only positively impacts water savings, but also efficient watering behavior.

CONSIDERATIONS OF IRRIGATION TECHNOLOGY

There are two aspects that affect the functionality of the irrigation system: technology and user interaction with the technology. The irrigation conservation devices listed above are technological components that will all electronically bypass unnecessary irrigation events. The regulations stated by the local water management districts have an influence on the use of bypass technology as well as the time and day settings for the automatic irrigation timer. The tendencies to employ automatic settings (i.e. the *set and forget* mentality) versus manual adjustment (i.e. due to seasonal scheduling) are influenced by water use ordinance and conservation knowledge. Other human factors such as the inclination to manually override the automatic system (i.e. due to either rainfall events or desire for additional irrigation events) relate to conservation psychology.

There are three fundamental behavioral barriers to irrigation conservation potential when considering the use of "smart" technologies. The first two are behavioral and the second is non-behavioral:

- How to use the equipment
- When and how long to water
- System efficiency

As previously mentioned, irrigation technology have the potential to yield significant water savings, while maintaining adequate health and appearance of landscapes (Cardenas-Lailhacar et al. 2010; Davis et al. 2009; Haley et al. 2007; Mayer et al. 2009; McCready et al. 2009). However, according to survey responses, based on smart timer programs in California, although programs have yielded success in raising public awareness of irrigation technology, most residential users have "no knowledge of *smart* irrigation control" (Mayer et al. 2009). These results concurred with surveys conducted in Florida regarding outdoor watering practices and perceptions (Haley, 2011).

Evidence from previous smart controller research has indicated common residential irrigators question "How long should I water and how many days should I water?" (Hunt et al. 2001). How long, and when, to irrigate is determined through irrigation scheduling. Irrigation scheduling requires knowledge of local weather conditions, soil type, irrigation equipment, and plant water needs. This can be a process considered too time consuming and technical for most residential irrigators.

Even if these first two barriers are overcome, a properly set irrigation controller cannot make up for poor irrigation system functionality. Irrigation system efficiency is affected by the system design, installation, and maintenance. To achieve the full potential of residential irrigation water savings, a holistic approach to irrigation systems and landscape design and maintenance must considered.

Design Considerations and Installation Location

An SMS should be placed in a location that is representative of the water requirements in the zone(s) it is controlling. Where there are variations due to shade, topography, etc., the sensor should be placed in the driest location (i.e. in full sun, on high elevation points). If one sensor is used for the entire landscape, it should be placed in a turfgrass hydrozone and in a location where it is most representative of the average water requirements of that zone. In larger landscapes, where the use of multiple sensors is most effective, install one sensor per irrigation hydrozone.

An SMS should be placed at least five feet from:

- Structures
- Impervious surfaces
- Depressions/swales
- Property lines (to avoid overspray from neighboring irrigation systems)
- Septic tanks/drainfields
- High moisture areas
- Overhangs
- Hose bibs
- Air conditioning condensate lines
- Tree canopy drip lines

When installing an SMS in the turfgrass root zone, it should be placed at least three feet from:

- Plant beds

Do not bury an SMS under/within:

- Disturbed soil
- Northern shade
- Auxiliary parking
- Dog runs

Buried sensors are often left unmarked and over time are not easily found. It is strongly recommended that the sensor location be marked on the irrigation system design plan or similar map and left with the property owner/manager for future use.

MARKET TRANSOFRMATION

The Smart Water Application Technologies (SWAT) arm of the Irrigation Association is a national partnership initiative of water purveyors, irrigation researchers, and industry representatives. SWAT was created to promote landscape water use efficiency through the application of state-of-the-art irrigation technologies. SWAT protocols are developed and utilized for testing the effectiveness of irrigation technology. Manufacturers submit products for testing and may agree to publish the results on the SWAT webpage. The test reports/summaries present the result of the test; the summary does not label or certify the product. The products listed on the webpage are often those products that are rebate eligible.

Whereas product manufacturers of WBICs have voluntarily published SWAT product testing results for years, their counterparts for SMS controllers have been slower to reach consensus. While a testing protocol for SMS controllers exists, participants have only completed the first phase of testing (sensor calibration). To date, phase one testing of nine sensors has been completed and posted on the SWAT website. The SWAT calibration summary provides sensor performance curves for a range of soil textures, ambient temperatures, and water conductivity (salinity) values. The curves were developed to determine the relationship between sensor readings and soil moisture.

Building upon the phase one testing, phase two will test how the sensor will control irrigation of the same "SWAT described virtual landscape" used for testing of WBICs. Although, thus far no manufacturers have completed phase two of the testing protocol, Southern California water utilities have begun rebating SMS systems at the same level as WBICs.

Concurrently, the American Society of Agricultural and Biological Engineers (ASABE), an American National Standards Institute (ANSI) accredited standards developer, is developing two new landscape irrigation standards for soil moisture sensors based upon the SWAT testing protocols. The United States Environmental Protection Agency (USEPA) WaterSense program is also participating in this process with the aim of eventually adopting a WaterSense labeling criteria based on the ASABE's standards. The two relevant standards in development are:

- Environmentally Responsive Landscape Irrigation Control Systems (X627)[8]
- Testing Soil Moisture Sensors for Landscape Irrigation (X633)

As of October 2013, SMS systems are eligible for rebates within the Metropolitan Water District of Southern California service area at the same levels as WBICs[9]. Including SMS systems within the regional rebate program is step towards market acceptance of this technology.

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[8] Includes both soil moisture sensors and weather-based irrigation controllers. According to ASABE, the standard is currently 85% complete.

[9] Rebate level for installed devices (SMS or WBIC) is $80 per residential device and $25 per station for commercial device.

Table 3. Summary of tested soil moisture sensors.

Date SWAT Posted	Brand	Model	Relationship[a]	Comments
07/30/2009	Acclima	ACC-SEN-TDT	Linear	Stable response to salinity and temperature. Product reliability faltered due to manufacturing variation.
08/27/2008	Acclima	Digital TDT	Linear	
07/08/2010	Baseline[x]	BL-5315B	Linear	Can be sensitive to salinity and temperature in sandy soils.
07/08/2010	Baseline	S-100	Linear	
11/03/2008	Decagon	ECH2O EC-5	Linear	Can be sensitive to salinity and temperature in sandy soils. Sensor only, used for monitoring. Sensor sold under name AquaMiser when combined with controller.
04/10/2010	Delta-T Devices	SM200	Linear	Can be sensitive to salinity and temperature in sandy soils. Sensor only, used for monitoring. Sensor sold under name Dynamax when combined with controller.
08/27/2008	Irrometer	Watermark	Nonlinear	-
09/30/2010	Rain Bird	SMRT-Y08[c]	Linear	New model will be released in November 2013.
08/31/2012	UgMo	ProHome PH100WS	Linear	-
Not listed	Toro[b]	Precision Soil Sensor	N/A	Showing promising results in university research.

[a] A linear designation means the regression equation is best described with a straight line, whereas a nonlinear designation means something other than a straight line will best describe the relationship.

[b] Although the Toro Precision Soil Sensor has not posted SWAT results, the relatively new device has been included in other third-party testing.

Sources: Irrigation Association, SWAT (2012) and Cardenas-Lailhacar, personal communication (2013).

Soil Moisture Sensor Training

The key to effective utilization of SMS technology in the landscape arena will result from outreach and education to the installers. Currently, the SMS technology is virtually unknown within the industry by the contractors and end-users. Workshops can be utilized to provide an initial training session to the target audiences, as well as to provide critical training to personnel involved in SMS installation.

A similar training program was conducted as a one-day workshop, which participants attended for 6 hours. The sessions consisted of lectures on local ordinances, water conservation, sensor research, the Low Impact Development practices, and a question/answer period. The participants also received relevant resource materials from these presentations. Further, time was provided for the participants to meet with various vendors and participate in hands-on instruction with the technology. Nearly two-dozen workshops were held across Florida in cooperation with local water agencies and the University of Florida's Agricultural and Biological Engineering Department, Extension Service, and the Program for Resource Efficient Communities (PREC).

Materials were developed in conjunction with PREC and were developed to fulfilling continuing education requirements when available in the county serviced. The materials are aimed at training clientele on the principles, operation, installation, and maintenance of SMS technologies for landscape irrigation. Potential clientele included but is not limited to, the following: builders, planners, landscape architects, irrigation designers, irrigation contractors, landscape professionals, and other personnel in the green industry.

The logic model for the SMS training program is displayed in Figure 4. From this model, the far left column displays inputs, which are stated as investments, and include the workshop staff, community partners, vendors, and presenters. The logistical investments include location, informational materials, presentation handouts, and sensor research. The middle column lists the program outputs, which are: promote and conduct workshop, create a networking arena for contractors and vendors, train the contractors in SMS installation, and certify the contactors from this training. The output column also lists the recipients of the program: irrigation contractors, landscapers, developers, other SMS vendors or representatives, irrigation sales representatives, government employees, extension agents, and local utility companies. The right column displays the outcomes by short, medium, and long term impacts. The short term outcomes result from learning and include awareness, knowledge, attitudes, skills, opinions, and motivation. The medium term outcomes result from action and include behavioral and practice changes. A behavioral change would be the promotion of SMS use by any program participant. Practices change would be the increase in installations of SMS systems or other types of functioning rain bypass devices. The long term changes are that all systems worked on by these contractors would have some type of rain bypass sensor, which would result in a decrease in irrigation water consumption. Important components to the logic model are the assumptions and external factors. The assumptions are that contractors are willing to use new technology, want to be in compliance with local policies, and want to obtain the SMS certification. The external factors include homeowner wants, policy changes, and weather trends.

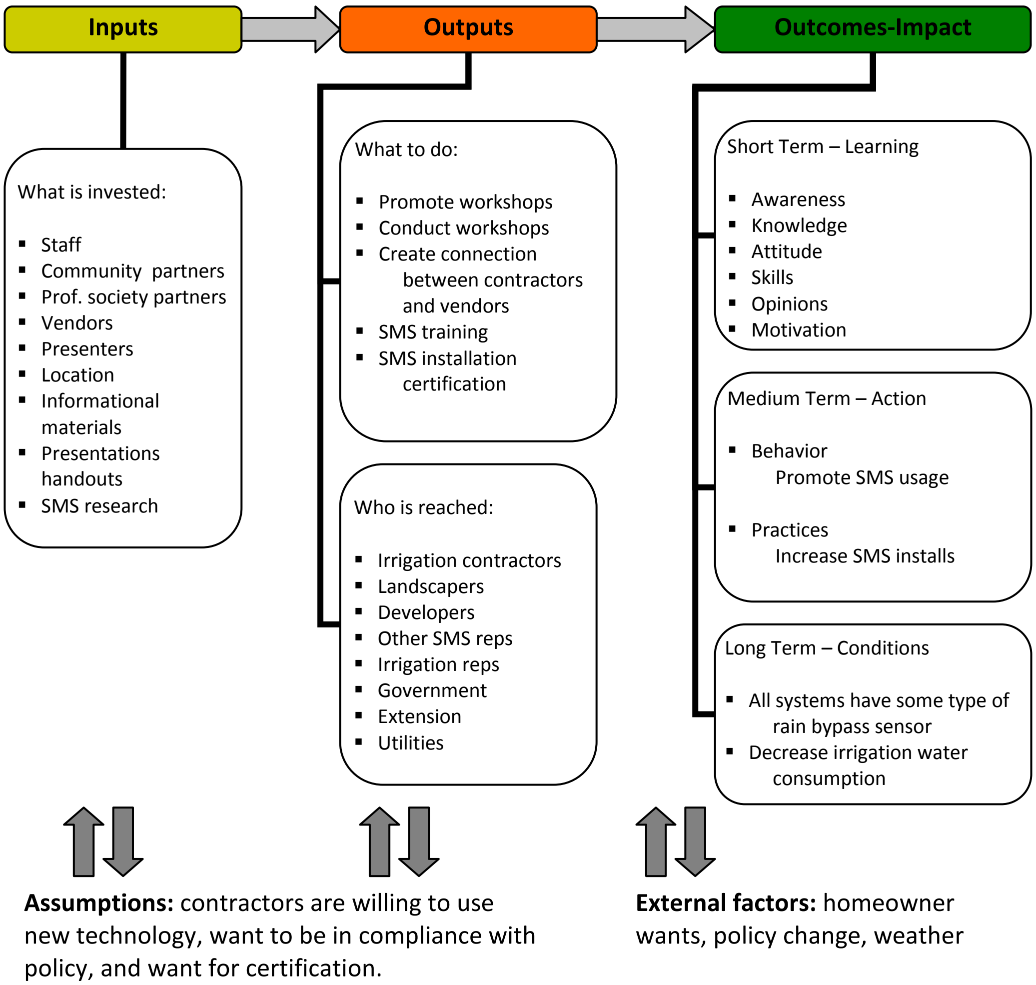

Figure 4. Logic model for SMS training workshop.

The logic model illustrates the major components and outcomes of the program as a complete picture, which is useful for program development. However, the logic model does not show the direct connection between the outputs and outcomes. To relate concepts, relationships, and better describe how the program works, an impact theory model can be used (Figure 5).

A primary difference between a logic model (Figure 4) and more detailed models is the inclusion of confounding factors. In the impact theory model, it can be seen that although the program will lead to SMS installation and the long term goal of the reduction of water use, because of confounding factors this goal could be reached by non-participants as well.

The impact model (Figure 5) traces the path of the program and the subsequent outcomes. Initially, the program is advertised. From seeing this, participants attend the training workshop. At the workshop, the participants obtain knowledge and develop skills regarding SMS technology (action hypothesis). Because the workshop includes the training and networking section, the participant personally meet vendors (intervention hypothesis). This results in contractors recommending and installing SMS devices and the long term outcome of irrigation water use reduction (causal hypothesis).

From this model it can be observed that some confounding factors will facilitate the goal and others will inhibit it. If a contractor is aware of ordinances and SMS certification requirements, they may directly meet with the vendor to obtain certification, without participating in the program. Whereas, if there is no knowledge of water saving principles or local ordinances, or if there is distrust for the technology, the contractor would be less inclined to participate in the workshop. The contractor may also have preexisting beliefs about the program or how it will work. For example, the contractor must be willing to use new technology, want to be in compliance with local policies, and want to obtain the SMS certification. Additional confounding factors include homeowner wants, policy changes enforcing the rain shut-off device ordinance, an increase in water costs, changes in technology, and the introduction of other programs. Consequently, the surveys have included questions regarding the reliability of the sensor technology, awareness of ordinances, irrigation scheduling, establishment, and interest in workshop participation and SMS certification.

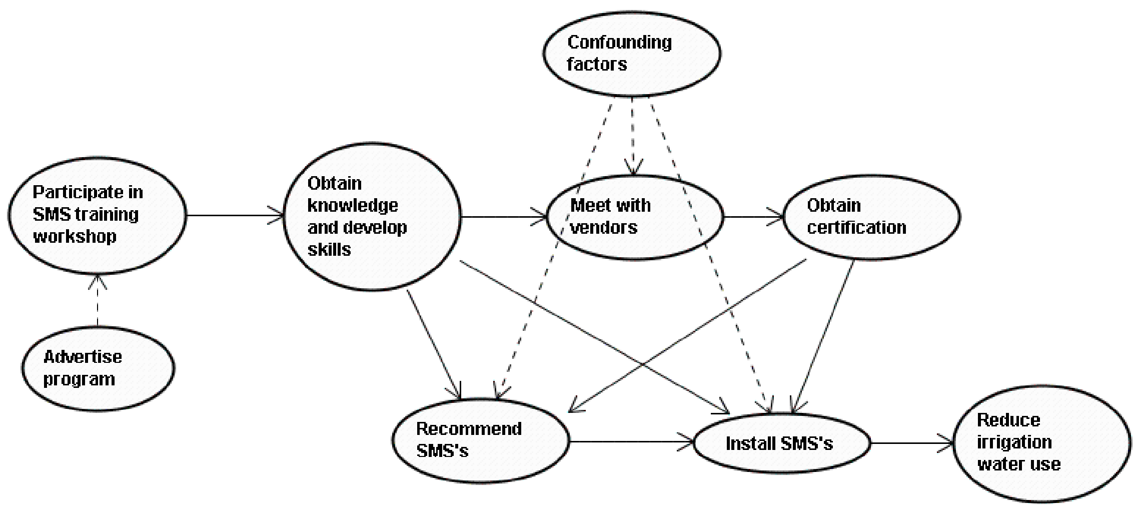

Figure 5. Impact theory model for SMS training workshop.

A process model (Figure 6) is more detailed than an impact theory model (Figure 5). The process model outlines the expected pathways and gaps. From this model, the role of program personnel is also highlighted. The model splits the diagram into two parts: the program's organizational plan and the utilization plan. The organizational plan takes into account the tasks of the program staff and affiliates to set up and host the workshop. The utilization half of the diagram traces the path of the participants from seeing the solicitation to workshop attendance, through the increase in SMS installation.

The dashed lines in the model (Figure 6) represent the pathway that results in gaps or SMS installation from confounding factors. The gaps will result in the following consequences: the contractor does not see the workshop advertisement, the contractor attends the workshop, but does not acquire certification, and the contractor is certified, but does not install the SMS devices. The alternative path that could be taken is that the contractor does not attend the workshop, but independently contacts the vendor and obtains certification, which would also result in increased SMS installations.

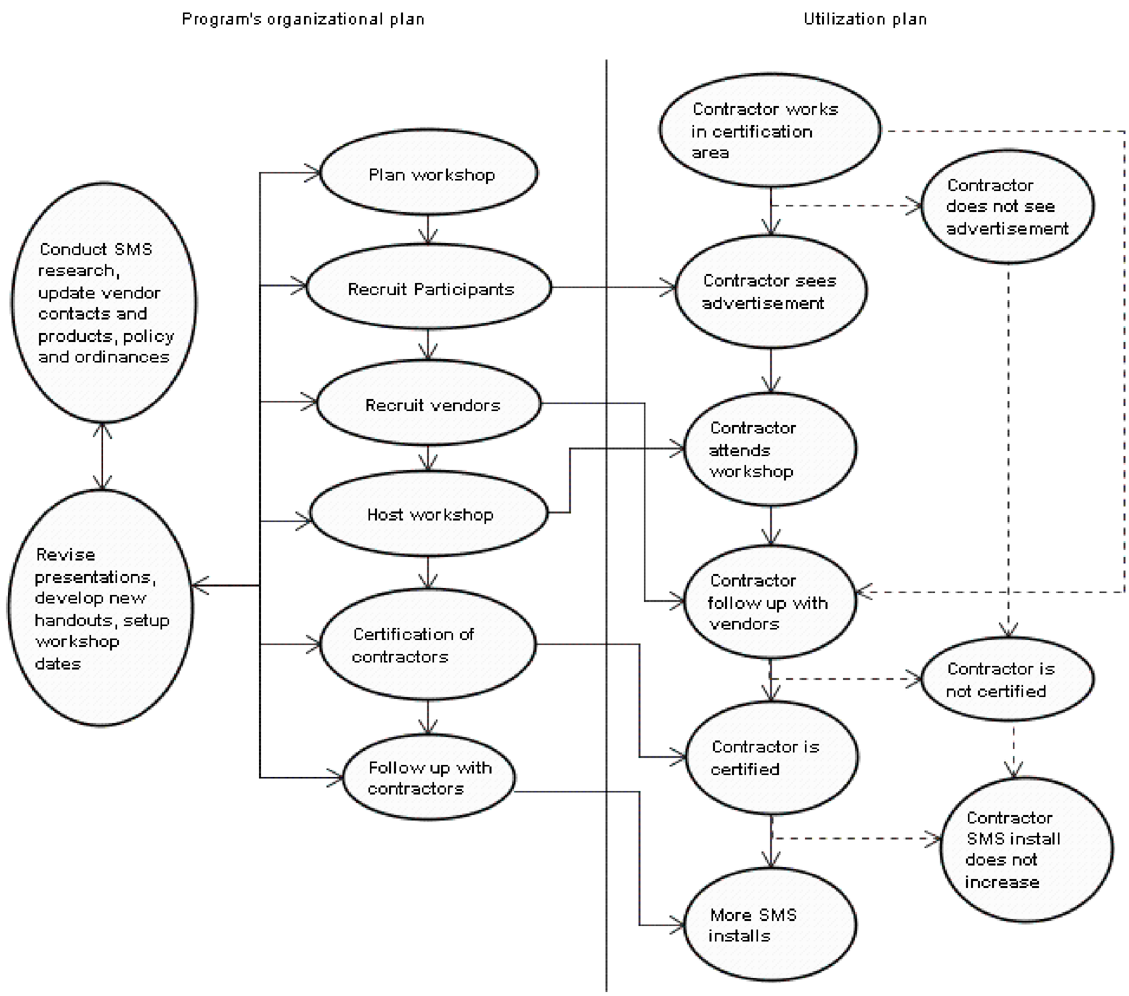

Figure 6. Process theory model for SMS training workshop.

CONCLUSIONS

On average, conservation technology is an effective means for reducing water application by an automatic irrigation system, without compromising the quality of landscapes. However, irrigators who historically irrigated less than the theoretical need have the potential to increase their irrigation application amount when utilizing smart technology. Finally, smart technology is only as smart as the quality of the irrigation system and installation of the technology.

Upon direct comparison of SMS systems to WBICs, the water savings resulting from the SMS technology of these studies was ranged from 4.3% to 43% net water savings, while the WBIC net water savings ranged from -26% to 38%. Although there was variation within the results, within the study conducted during drought conditions with extended dry periods, the devices resulted in 38% and 32% net water savings respectively. While the magnitude of savings is expected to be higher in humid regions, the use of an SMS can also result in water savings resulting from superfluous events (SMS as an irrigation governor).

Efficient irrigation practices cannot only rely on the intelligence of a smart controller. “Even the best, most efficient controller cannot make up for poor irrigation system design, installation, and maintenance…a holistic approach to irrigation systems and landscape design and maintenance is required to achieve the full potential of water savings in the urban irrigation sector” (Mayer et al. 2009). Additionally, the impact of the human behavior is a major factor, “a controller irrigates, a person waters” (Baum Haley 2011).

That said the conservation potential from SMS systems not only positively impacts water savings, but also efficient watering behavior. Research has shown that the potential for water savings from SMS systems used for turf and landscape irrigation is at least, if not greater than, that accepted for WBICs. However, the magnitude of savings may be greater in humid regions where most of the research has taken place. A unique aspect of the use and savings potential of an SMS is the potential for bypassing superfluous events and acting as an irrigation governor.

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