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Irrigation Controls Based on Wireless Soil Moisture Technology Assessment: George C. Young Federal Building and U.S. Courthouse, Orlando, FL

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GPG
Green Proving Ground Program

The Green Proving Ground (GPG) program leverages GSA's real estate portfolio to evaluate innovative sustainable building technologies and practices. Findings are used to support the development of GSA performance specifications and inform decision-making within GSA, other federal agencies, and the real estate industry. The program aims to drive innovation in environmental performance in federal buildings and help lead market transformation through deployment of new technologies.

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I. Executive Summary

This report is divided into six sections. The first section provides an executive summary of the major findings of the study. The second section describes the background and opportunity for soil moisture-based irrigation control technology. The third section introduces the new technology, the technical objective, and the demonstration location. The fourth section provides a description of the demonstration facility, the baseline water usage, the configuration of the technology at the demonstration facility, and the system monitoring and study periods for the assessment. The fifth section presents the results of the monitoring activity, documents performance and resulting water savings, describes the challenges experienced during the assessment, and presents the results of a life-cycle cost (LCC) analysis. The final section draws conclusions from the demonstration results and discusses potential applicability for the U.S. General Services Administration (GSA).

A. BACKGROUND

Water used to irrigate the grounds of GSA facilities can be a significant portion of the facility's water usage. According to the U.S. Environmental Protection Agency (EPA), irrigation in commercial office buildings can represent over 20% of the total water consumption of the building.[1] A common technology for controlling irrigation equipment is a timer-based system, which has preset timed schedules that do not automatically respond to current weather conditions. Timer-based systems typically run on a static daily schedule throughout the growing season and are often not adjusted to account for actual environmental conditions. The EPA WaterSense program reports that as much as 50% of the water delivered using conventional timer-based irrigation controllers is wasted due to overwatering.[2]

An alternative to timer-based controllers are smart irrigation controllers that monitor actual conditions to provide the required level of supplemental irrigation to maintain healthy plants. Several research studies show significant savings potential from the use of smart irrigation controllers, generally ranging between 20% and 40% reduction in irrigation.[3] Smart irrigation control technology has the potential to help GSA facilities meet the water related goals of Executive Order 13514, *Federal Leadership in Environmental, Energy, and Economic Performance*.[4] This executive order requires federal agencies to reduce water use and develop sustainability performance plans that put an increasing importance on water management. With rising water rates, investments made in advanced irrigation control systems to improve irrigation efficiency will become more attractive financially to GSA.

There are two main categories of smart irrigation controllers: weather-based and sensor-based. Weather-based (or climate-based) controllers use weather data to determine landscape water requirements. This technology is widely available and performance and savings have been well documented. Sensor-based controllers use on-site sensors, such as soil moisture sensors or rain sensors, to measure specific parameters

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[1] U.S. Environmental Protection Agency. 2012. WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities. http://www.epa.gov/watersense/commercial/bmps.html.

[2] U.S. Environmental Protection Agency. 2013b. WaterSense. WaterSense Labeled Irrigation Controllers. http://www.epa.gov/watersense/products/controltech.html

[3] Dukes, MD. *Water Conservation Potential of Landscape Irrigation Smart Controllers.* American Society of Agricultural and Biological Engineers. ISSN 2151-0032. 2012.

[4] 74 FR 52117. October 8, 2009. Executive Order 13514 of October 5, 2009, *Federal Leadership in Environmental, Energy, and Economic Performance*. Federal Register Vol. 74, No. 194. http://www.gpo.gov/fdsys/pkg/FR-2009-10-08/pdf/E9-24518.pdf#page=1

and use this information to determine whether the landscape requires irrigation and adjust the irrigation schedule accordingly. This report addresses sensor-based irrigation control technology, specifically soil moisture-based irrigation control. Soil moisture sensor-based control systems have been mainly employed in agricultural irrigation to save water and increase crop yield. Because of recent advances in technology, they are now used in residential and commercial properties as well. They have the potential to be more effective than weather-based systems because they can respond to the specific zone's irrigation requirements based on actual soil moisture levels. In fact, a University of Florida study found that in poorly drained soil, soil moisture sensors saved 23% more water than weather-based systems did[5].

B. OVERVIEW OF THE TECHNOLOGY

The technology assessed for this Green Proving Ground (GPG) program demonstration is a wireless soil moisture sensor-based irrigation control system intended for use in large residential and commercial properties. Using a wireless communication network, the control system is designed to gather real-time soil moisture sensor data from predetermined irrigation zones and to use that data to keep soil within those zones at an optimal moisture level. In addition to monitoring and recording data from soil moisture sensors and irrigation flow meters, the system analyzes, presents, and manages data with a web-accessible analytical software package, which enables central management of multiple facilities. According to the manufacturer, typical irrigation water savings experienced when using soil moisture-based controllers range from 20% to 50%, when compared to a conventional timer-based irrigation controller.[6]

Note: the version of the technology assessed in this evaluation was pre-commercial. Product development continued after the completion of this evaluation.

C. STUDY DESIGN AND OBJECTIVES

The soil moisture-based irrigation control technology was installed at the George C. Young Federal Building and U.S. Courthouse (Young Federal Building), in Orlando, Florida. The objective of this project was to monitor the performance of the soil moisture-based irrigation control technology, assess the reduction in irrigation water consumption, and ascertain where this technology might be best deployed.

The landscaped areas of the federal complex comprise a total of 1.1 acres. There are two distinct irrigation control areas, termed "Controller 1" and "Controller 2." There are four general types of landscape at the site: 1) turf; 2) large above-ground planters with ground cover and trees; 3) trees planted in small ground-level planters; 4) ground cover and trees at ground level. There are 23 individual irrigation zones, 10 in the area governed by Controller 1 and 13 in the Controller 2 area.

One soil moisture sensor was buried in each irrigation zone and a wireless communication system was installed to transmit soil moisture content to a controller. The manufacturer installed wireless repeaters at strategic locations to assist in transmitting the signal from the soil moisture sensor to the controllers. GSA installed a flow meter to measure the water flow to the irrigation system. The following data were collected by both control boxes on water events:

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[5] Dukes, Michael D., PhD, PE. *Irrigation Efficiency Research Update—Presentation to the Tampa Bay Water Conservation Coordination Committee, May 2014*

[6] UgMO Technologies. 2013. *The Results: Saving Water Speaks for Itself*. Accessed December 31, 2013 at http://www.ugmo.com/ugmo/results.

- total volume of water
- date and time of watering event
- time duration of watering event
- watering event type (manual or automatic).

The system was designed to automatically send data each day via a network bridge that was located in the office of the facility manager at the site. The bridge would upload data onto the manufacturer's server from which it would be downloaded by Pacific Northwest National Laboratory (PNNL) for analysis.

D. PROJECT RESULTS/FINDINGS

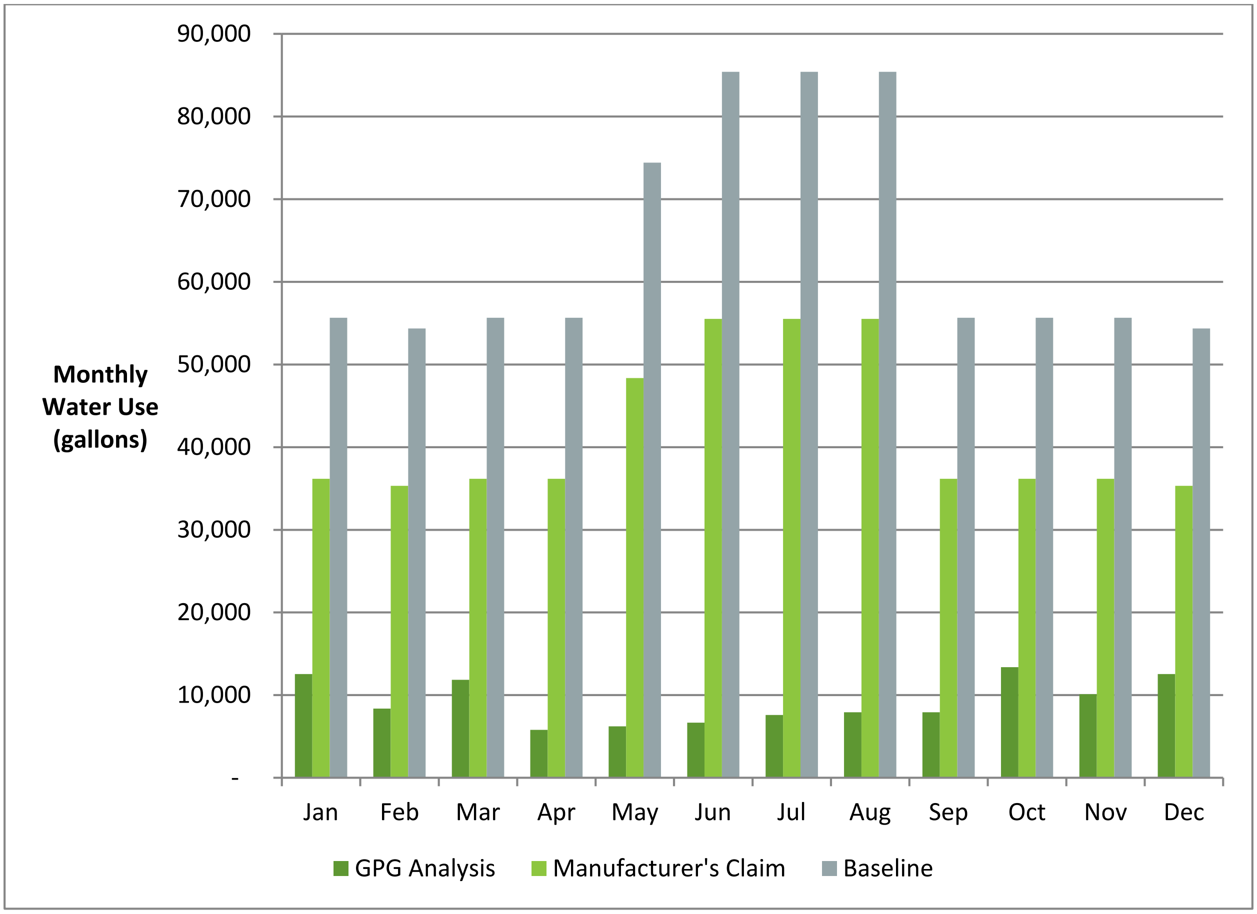
This GPG project had significant challenges, including communication and data transmission problems. Consistent signal failures occurred wherein the soil moisture levels and watering events were not received by the controllers or not recorded by the manufacturer's main server. The heavy concrete construction of the facility and the configuration of the complex impeded the wireless signals. Other communication issues were experienced, such as loss of data logs that were unrecoverable. In addition, very large disparities occurred between the irrigation zones' soil moisture levels and triggered watering events, which may indicate soil moisture sensor errors or problems with the moisture target settings used in the algorithm to trigger watering events. There was evidence of under-watering that may be a result of sensor errors.

Although multiple corrective actions were attempted by the system manufacturer, including the installation of wireless repeaters to restore and improve communication, firmware updates, and controller algorithms corrections, communication failures continued throughout the study. Ultimately very little data was received on Controller 2; and therefore, the analysis and corresponding results regarding water savings potential and economic feasibility presented in this report pertain only to Controller 1.

PNNL developed a baseline water use and analyzed the data collected during the study to estimate savings potential. The baseline water usage was estimated using the schedule of the original timer-based controller and the total measured flow rate of each irrigation zone because irrigation water usage at the facility was not metered before the installation of the soil moisture control system. The annual water usage baseline for Controller 1 totaled 773, 700 gallons (gal).

Data collected on the post-retrofit water usage over the study period was extrapolated to represent a full year of irrigation. The annual water use for Controller 1 was estimated to total 111,000 gal, representing an 85% reduction compared to the baseline. However, because of significant issues with the system's operation during the study, including evidence of under-watering, there is reason to believe that the estimated savings resulting from the analysis is not entirely reliable. Major inconsistencies of the irrigation zones and communication problems may indicate possible systematic malfunctioning of the technology and, therefore, the results of the analysis performed for the GPG project are likely not representative of reasonable savings potential. At the initiation of this evaluation, the manufacturer claimed a conservative estimate of 20%-50% water savings. The comparison between the estimated baseline, GPG analysis results, and the average manufacturer's claim of 35% savings is shown in Figure ES.1. Note that the chart is meant to illustrate that the analysis results during the GPG study are likely not representative of expected savings.

Figure ES.1. Comparison of Annualized Irrigation Water Use



- An economic analysis was performed on the manufacturer’s average reported savings of 35%. Economic parameters used in the analysis include the facility water unit cost of $1.067 per thousand gallons ($/kgal), total system installed cost of $4,500, on-going operational costs of $315 per year, a one-time replacement cost of the soil moisture sensors of $1,300, assuming sensors are replaced every seven years (cost per sensor is $130), and annual data subscription fee of $310 per year.

The Building Life-Cycle Cost (BLCC) analysis tool was used to perform the economic analysis.[7] The scenario using the manufacturer’s reported savings was not LCC-effective with a net present value (NPV) of −$9,200.[8] The poor economic results are due to a combination of very low water unit cost of $1.07/kgal, additional labor requirements to operate the soil moisture-based controls compared to a conventional timer-based system, and data subscription fees through the life of the equipment.

The economic assessment also determined the water rate point at which the technology becomes LCC-effective, *i.e.*, when the savings-to-investment ratio (SIR) is equal to one. An SIR of one shows that the total cost savings is equal to the total capital cost of the project over its life. The break-even water unit cost

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[7] U.S. Department of Energy. 2013. Federal Energy Management Program. Building Life Cycle Cost Programs. Accessed December 30, 2013 at http://www1.eere.energy.gov/femp/information/download_blcc.html.

[8] A meaningful SIR was not produced by BLCC because the present value of the savings was negative.

that produces an SIR of one for the annualized savings achieved from 35% savings is $3.95/kgal. This water unit cost is close to the national average commercial rate of $3.30/kgal reported by the American Water Works Association.[9]

Note: subsequent to this evaluation, two new financing structures became available, a lease and a "savings share." In neither case are there upfront costs. In the savings share, the manufacturer takes a share of the cost savings generated by the technology.

E. CONCLUSIONS

In principle, soil moisture-based irrigation control technology can reduce water usage and increase vegetation health by determining the actual water requirements of specific landscape types and conditions. This technology has been demonstrated in agricultural applications. In the implementation of soil moisture-based irrigation control technology assessed during this GPG demonstration project, however, problems were experienced that compromised the analysis. These problems included communication failures between the controllers and the server and possible sensor errors and algorithm inaccuracies. Also some obstacles incurred were specific to this location, particularly those concerning building layout and construction. The technology assessed was pre-commercial and the manufacturer has made changes to the communication system subsequent to this study. Still, since the data generated during the assessment were unreliable, the only recommendation that can be made at this time is for further study. If another GPG project for soil moisture-based irrigation controls is pursued, GSA should consider the following in connection with deployment:

- Test the wireless signal transmission prior to technology implementation.
- Choose a location with multiple-zone landscape with different irrigation needs for each zone to test the system's response to individual zone irrigation requirements.
- Choose a location that receives intermittent rain through the growing season, which will enable testing of the system's ability to suspend irrigation when rainfall meets the soil moisture requirements.
- Install a dedicated irrigation flow meter that can measure water usage by irrigation zone before and after installation of the soil moisture-based system.
- Analyze zone soil type to understand the general constitution and soil moisture retention so that the control system can be properly programmed.
- Have the manufacturer commission the irrigation system and equipment prior to the installation of the new control system to make sure that all zone irrigation sprinklers are working properly.
- Train grounds maintenance managers on the operation and maintenance of the soil moisture controller, including system programming, adjustments and override mode, so that the system can be monitored and adjusted as appropriate.
- Commission the system components, including sensor performance, periodically throughout the study by grounds maintenance staff.

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[9] American Water Works Association. 2014. *2013 Water and Wastewater Rate Survey*. Denver, CO.

- Monitor the system after installation of the control system by determining whether automatic watering events are triggered by a drop in soil moisture levels to a minimum threshold level.
- Receive training from the vendor on the use of the on-line data system, so that soil moisture and water usage data can be available for system performance monitoring.

Because the results at GPG's Young Federal Building assessment were inconclusive, no recommendation for wide-scale implementation of wireless soil-moisture based irrigation control technology can be made for GSA's portfolio at this time. Until the effectiveness of soil moisture technology is as well documented as weather-based technology, it is recommended that GSA consider integrated weather-based irrigation control instead. For additional information on weather-based control technology, see the GPG evaluation at the Hart-Dole-Inouye Federal Center in Battle Creek, Michigan.[10]

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[10] GPG Findings #18, January 2015, Weather Station for Irrigation Control, http://www.gsa.gov/portal/content/204659

II. Introduction

The U.S. General Services Administration (GSA) is a leader among federal agencies in aggressively pursuing energy- and water-efficiency opportunities for its facilities. GSA's Public Buildings Service has jurisdiction, custody or control over more than 9,600 assets and is responsible for managing an inventory of diverse federal buildings totaling more than 354 million square feet of building stock. This includes approximately 400 buildings listed in or eligible for listing in the National Register of Historic Places, and over 800 buildings that are more than 50 years old. GSA has an abiding interest in examining the technical performance and cost-effectiveness of different energy- and water-efficient technologies in existing building portfolio, as those currently proposed for construction. Given that a large majority of GSA's buildings include office space, identifying appropriate energy- and water-efficient solutions has been a high priority for the GSA. Since the enactment of the Energy Policy Act of 2005 (EPAct 2005) [1] and issuance of Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management (2007)" [2], and Executive Order 13514 [3], "Federal Leadership in Environmental, Energy, and Economic Performance (2009)," other federal agencies are looking to GSA for strategies to meet the energy- and water-related goals laid out by these pieces of legislation and executive orders. Based on the sheer size of the building portfolio, there exists a huge opportunity for potential energy and water savings.

A. PROBLEM STATEMENT

Timer-based irrigation controllers are commonly used to control irrigation systems at GSA facilities. Timer-based controllers have a pre-set timed schedule that is determined by the operator. The irrigation system runs during a set time frame on specific days. Timer-based controllers do not take into account current weather conditions, such as rainfall or soil moisture. A timer-based system typically runs on the same schedule throughout the growing season and is not adjusted to account for actual environmental conditions. The advanced technology available on the market is called a "smart irrigation" controller. This technology irrigates landscape based on actual environmental conditions, providing the amount of supplemental irrigation that is needed by the plants to stay healthy.

B. OPPORTUNITY

The major advantage to smart irrigation controllers is that the technology uses live, local data to determine irrigation schedule. Instead of running the irrigation system on a timed schedule, theoretically the irrigation system is only activated when the plants require water. According to the U.S. Environmental Protection Agency's (EPA's) WaterSense Program[11], as much as 50% of the water delivered using conventional timer-based irrigation controllers is wasted due to overwatering [4]. Several research studies show significant savings potential from proper use of smart irrigation controllers, ranging between 20% and 40% reduction in irrigation [5].

There are two main categories of smart irrigation: weather-based and sensor-based. Weather-based (or climate-based) controllers utilize weather data to calculate evapotranspiration (ET), which represents the level of water loss from the soil due to evaporation and plant transpiration. The ET data is supplied to an irrigation control system, which, in turn, is used to determine the schedule of the irrigation equipment. With

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[11] The WaterSense program is an EPA partnership program that promotes water efficiency through the certification and labeling of water-efficient products. More can be found on WaterSense at: http://www.epa.gov/watersense/

this type of controller, each zone is irrigated based on one ET value. Sensor-based controllers use on-site sensors typically at the zone level, such as soil moisture sensors, to determine whether the specific landscape zone requires irrigation and adjusts the irrigation schedule accordingly. This is an advantage to weather-based controllers because soil-moisture data is provided for individual zones and the irrigation schedule can be fine-tuned accordingly. For example, an irrigation zone that receives more shade than other zones will need less supplemental watering. Zone-level soil moisture sensors will trigger less watering for the shady zone versus the zones that have more sun exposure.

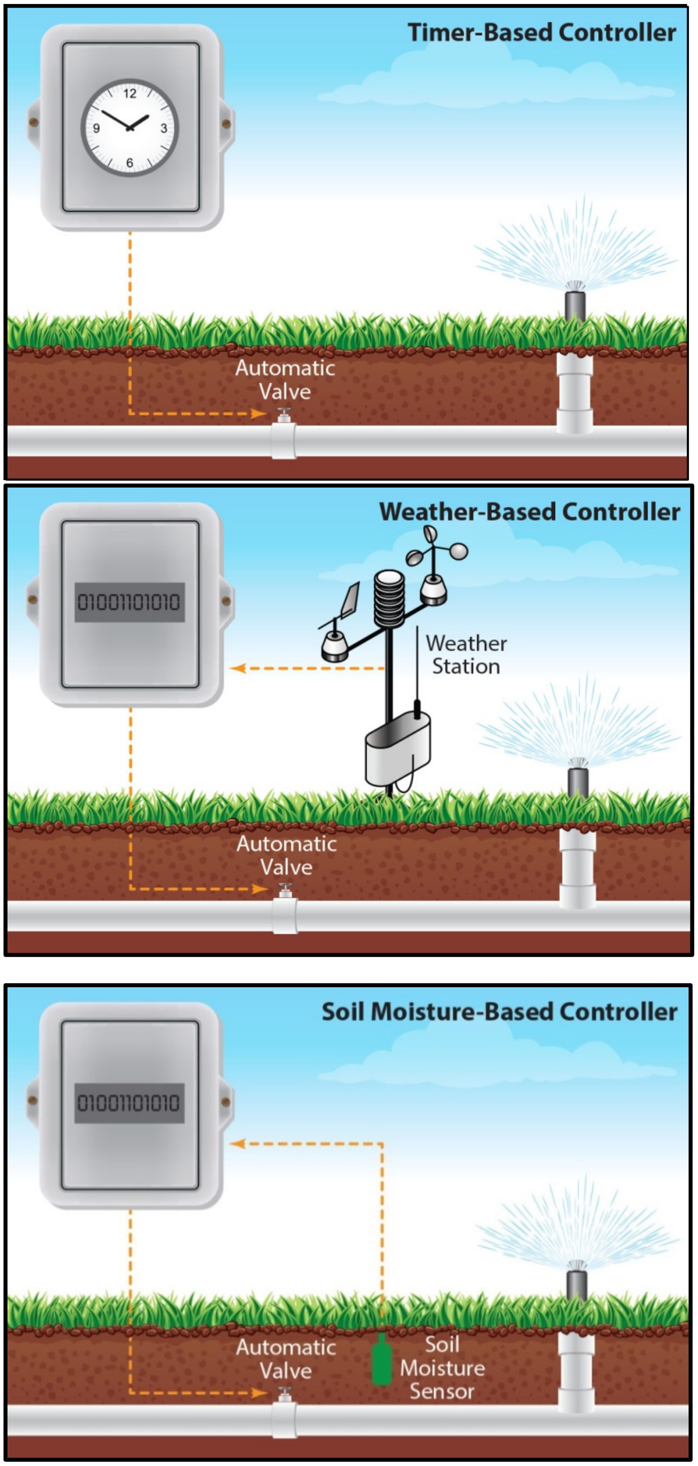
It is common for both types of smart irrigation control technology to be part of a turnkey integrated system supplied by an irrigation control company. These systems typically include sensors or weather data (via either an on-site or nearby weather station) that are integrated into the system, software to determine the irrigation schedule based on actual water needs of the landscape and flow sensors to monitor water use.

Schematics of the timer-based irrigation controller, weather-based controller and soil moisture-based irrigation controller are shown in Figure 1.

Pacific Northwest National Laboratory (PNNL) assessed the water performance of soil moisture-based irrigation control technology at the George C. Young Federal Building and U.S. Courthouse (Young Federal Building) in Orlando, Florida. This technology was chosen to determine whether soil moisture-based irrigation control technology has a potential for significant water reduction, is life-cycle cost (LCC) effective and is appropriate for deployment in GSA facilities.

Soil moisture-based irrigation control technology determines the amount of water needed by each landscape zone based on a measured soil moisture level in the specific zone. Instead of running the irrigation system based on a timed schedule, the irrigation system is only activated if the soil moisture drops below a predetermined threshold for each irrigation zone. In other words, the system only runs when the irrigation zone’s soil dries out to the point where the plants need supplemental water. According to the manufacturer, average irrigation water savings of between 20% and 50% can be achieved, as compared to a conventional timer-based irrigation controller [6].

Figure 1. Schematic of Timer-Based, Weather-Based, and Soil Moisture-Based Irrigation Controllers



III. Methodology

The methodology section is divided into three subsections: first, a detailed description of the technology will be provided; second, the desired technical objectives will be discussed; and finally, the demonstration location will be introduced.

A. TECHNOLOGY DESCRIPTION

The irrigation control technology assessed for this Green Proving Ground (GPG) program demonstration project manages irrigation water by monitoring soil moisture and using the information to control the irrigation system. There are several different applications of soil moisture sensor technology available and a handful of different sensor types. The system under consideration is specifically designed to gather data from buried sensors that monitor soil moisture by measuring the soil's ability to hold an electric charge—its *capacitance*. The more moisture, the greater the capacitance. This information is used to control landscape irrigation. Using real-time soil moisture sensor data on a zone-by-zone basis, the irrigation control system delivers the optimal amount of water. The controller is considered a smart irrigation management system because the system monitors real-time soil conditions and uses this data to adjust irrigation. When compared with weather-based irrigation control systems, which calculates ET based on weather data to determine irrigation needs for the entire landscaped area, this type of controller has a distinct advantage because it responds to zone-specific soil moisture levels to determine the zone watering requirements.

The system uses a wireless communication network to send data from the soil moisture sensors to the controller. The controller monitors and records irrigation data from the soil moisture sensors and water meter, which is web accessible and capable of communicating alerts when atypical water consumption is identified.

The soil moisture-based irrigation control system operates as follows:

- Soil moisture sensors, buried underground in individual irrigation zones, sense the amount of soil moisture, read as a percentage.
- Each irrigation zone's soil moisture level is sent wirelessly to the irrigation control box.
- The irrigation control box is programmed with a minimum soil moisture threshold for each irrigation zone, whereby irrigation is provided to raise the soil moisture to an optimal level for plant health.
- The irrigation control box records the amount of time that the zone is irrigated.
- The control box sends the data to the manufacturer's central server, where it is stored and available to customers with permitted usernames and passwords.

B. TECHNICAL OBJECTIVES

The objectives of this project activity are to monitor the performance of the soil moisture-based irrigation control technology, assess the reduction in irrigation water consumption, document unforeseen impacts on building operations and irrigation system operation, and ascertain whether this new control technology may assist other GSA facilities in reducing water usage. In addition to evaluating the real-world performance, the project's objective includes understanding the potential deployment of this technology to other GSA facilities with potential recommendations on where this technology may be most beneficial, including considerations such as climate, landscape type, water utility rate, and existing system configuration.

C. DEMONSTRATION PROJECT LOCATION

The soil moisture-based irrigation control technology was installed at the Young Federal Building in Orlando, Florida (Figure 2). The courthouse is a six-story, 187,000 square foot (sqft) building that overlooks a landscaped courtyard with 1.1 acres of irrigated landscape. The complex was renovated in 2010 as part of the American Recovery and Reinvestment Act [7], converting the facility to a Leadership in Energy and Environmental Design (LEED) Gold certified building. The renovation project included upgrades to the heating, ventilation, and air conditioning system, rainwater harvesting for cooling tower makeup, plumbing, building controls, sustainable construction products and finish products, daylighting, and drought tolerant turfgrass and native landscaping.

Figure 2. Photograph of the George C. Young Federal Building and U.S. Courthouse

IV. M&V Evaluation Plan

The measurement and verification plan section includes five subsections. The first section provides a detailed description of the demonstration facility, including the landscape type, irrigation zone areas and map. The second subsection provides a description of the baseline irrigation water usage. The third subsection provides the technology specification of the soil moisture-based irrigation control technology at the Young Federal Building. The fourth subsection identifies the system monitoring that was performed for the assessment. Finally, the fifth subsection describes how the study periods for the assessment were determined.

A. FACILITY DESCRIPTION

The landscaped areas of the Young Federal Building comprise a total of 1.1 acres, which constitute the irrigated landscape that was studied for this Green Proving Ground (GPG) project. There are two distinct control zones that are controlled by separate controllers, termed “Controller 1 area” and “Controller 2 area.” There are ten irrigation zones in Controller 1 area and 13 irrigation zones in Controller 2 area. There are four general types of landscape at the site: 1) turf; 2) large above-ground planters with ground cover and trees; 3) trees planted in small ground-level planters; and 4) ground cover and trees at ground level. These landscape types are depicted in Figure 3. Table 1 provides the total area of each irrigation zone and the landscape type. Figure 4 shows a layout of the irrigation zones for both Controllers 1 and 2, along with the locations of the controller boxes.

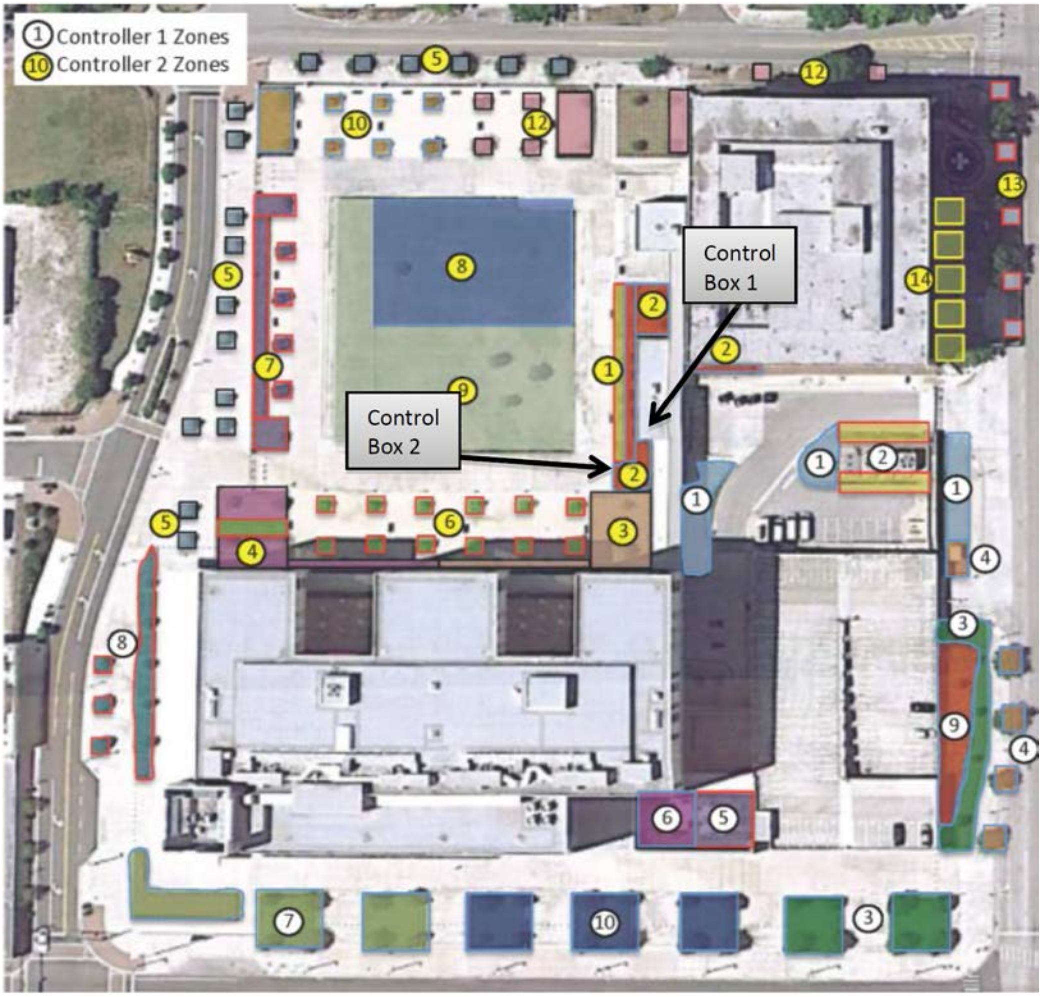
Figure 3. Landscape Types at Young Federal Building

Table 1. Irrigation Zone Descriptions

Controller Area	Irrigation Zone Number	Landscape Area (sqft)	Landscape Type
1	1	2,130	Turf
	2	1,820	Turf
	3	1,080	Ground-level ground cover and trees
	4	1,190	Small planters with trees
	5	600	Ground-level ground cover and trees
	6	2,180	Ground-level ground cover and trees
	7	1,180	Large above-ground planters with ground cover and trees
	8	1,640	Small planters with trees
	9	1,775	Ground-level ground cover and trees
	10	2,080	Large above-ground planters with ground cover and trees
2	1	2,500	Large above-ground planters with ground cover and trees
	2	2,610	Large above-ground planters with ground cover and trees
	3	900	Large above-ground planters with ground cover and trees
	4	2,400	Ground-level ground cover and trees
	5	5,100	Small planters with trees
	6	3,900	Small planters with trees
	7	1,300	Ground-level ground cover
	8	1,910	Turf
	9	4,200	Turf
	10	1,230	Small planters with trees
	12*	1,300	Small planters with trees
	13	650	Small planters with trees
	14	3,400	Small planters with trees
	Total	47,075	

*There is no Zone 11 in Controller Area 2.

Figure 4. Irrigation Zone Map



B. BASELINE IRRIGATION WATER USE

The irrigation water usage at Young Federal Building was not metered before the installation of the soil moisture control system. Therefore, the baseline water usage was estimated using the schedule of the original timer-based controller that was installed prior to the implementation of the soil moisture-based control system and the total measured flow rate of each irrigation zone. The original irrigation system schedule provided by the grounds maintenance manager at the GSA facility was as follows:

- All landscaped bed irrigation zones (landscape types 2-4):
  - winter schedule (last two weeks of September through third week of May): 15 minutes per zone, four days per week
  - summer schedule (last week of May through middle week of September): 15 minutes per zone, six days per week

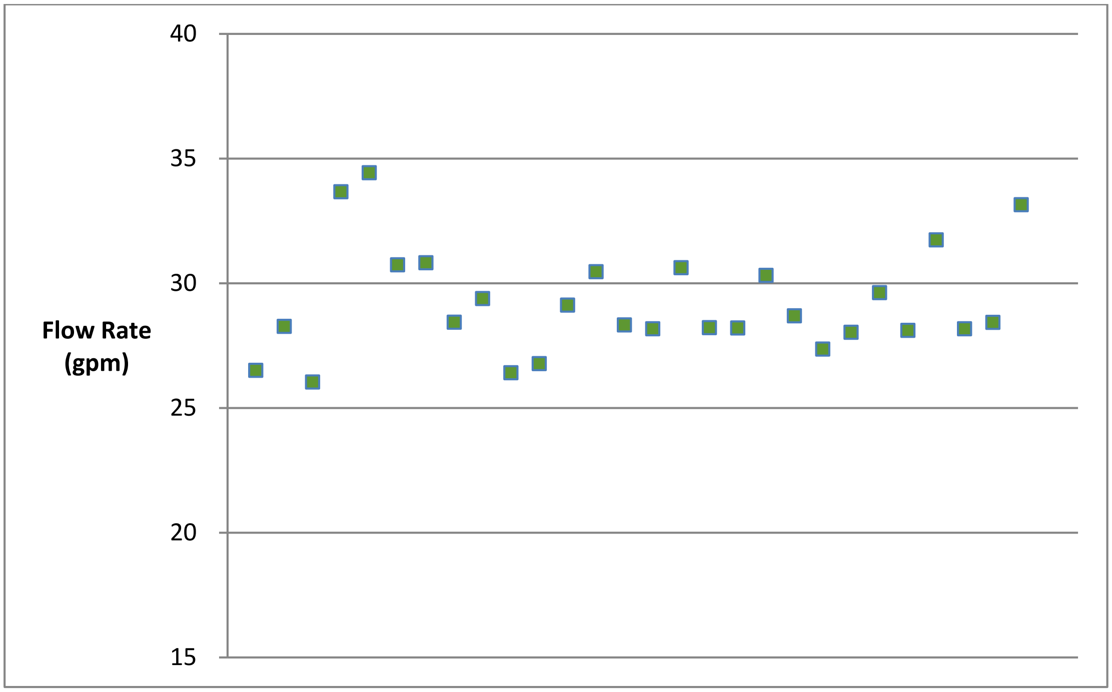
- Turf irrigation zones (landscape type 1):
    - winter schedule: 30 minutes per zone, four days per week
    - summer schedule: 30 minutes per zone Sunday, Monday, Wednesday, and Friday plus 30 minutes additional two times per week.

The baseline water usage was calculated by taking the flow rate of the zone and applying the runtime of the irrigation system based on the schedule provided by the facility. The following simplified equation shows how the baseline was calculated.

$$Baseline\ Volume\ (gal) =$$
$$flow\ rate\ \frac{gal}{min}\ \mathrm{x}\ daily\ run\ time\ \frac{min}{day}\ \mathrm{x}\ weekly\ schedule\ \frac{days}{week}\ \mathrm{x}\ number\ of\ weeks\ \frac{weeks}{baseline\ period}$$

The flow rate of each zone was determined by examining multiple flow rate readings that were recorded during the study. A scatter plot was developed for each zone's flow rates to assess the general trends. Outliers that showed abnormally low or high flow rates were removed from the scatter plots. An example of a scatter plot for Zone 10 on Controller 2 is provided in Figure 5. The scatter plot shows the measured flow rates, measured in gallons per minute (gpm), ranging between 26 and 34 gpm with an average of 29 gpm.

Figure 5. Example of Flow Rate Scatter Plot Used in Baseline Development (Zone 10 on Controller 2)



The average flow rates for each zone are provided in Table 2.

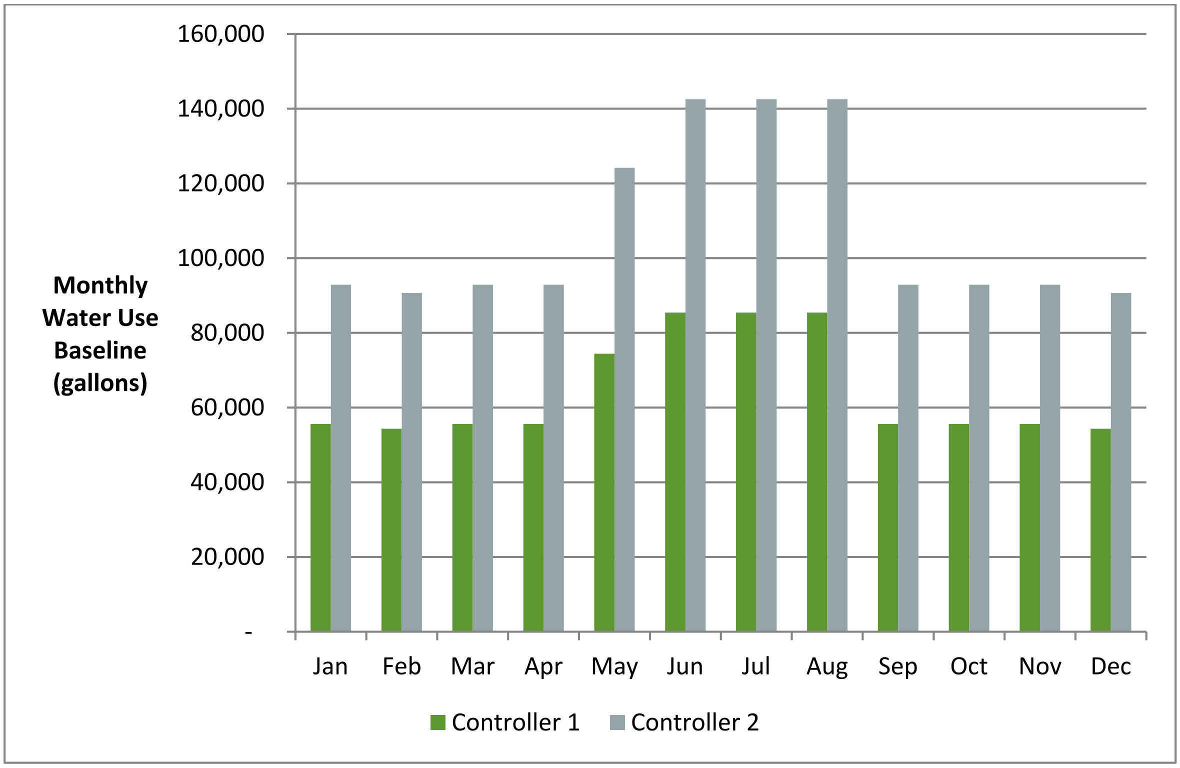
Table 2. Irrigation Zone Flow Rates Used in Baseline Development

Controller Area	Irrigation Zone Number	Irrigation Zone Flow Rate (gpm)	Controller Area	Irrigation Zone Number*	Irrigation Zone Flow Rate (gpm)
1	1	34.0	**2**	1	36.6
	2	24.0		2	30.1
	3	28.0		3	17.8
	4	15.0		4	22.5
	5	12.0		5	26.5
	6	7.4		6	31.6
	7	34.0		7	6.7
	8	17.5		8	21.5
	9	24.5		9	22.1
	10	19.3		10	29.2
				12	27.7
				13	21.1
				14	23.1

*There is no irrigation Zone 11 in Controller 2 area.

Based on these flow rates, the annual water usage baseline for irrigation zones in Controller 1 area is 773,700 gallons (gal). The annual water usage baseline for irrigation zones in Controller 2 area is 1,291,300 gal (Figure 6).

Figure 6. Monthly Water Use Baseline for Controller 1 and Controller 2 Areas



C. TECHNOLOGY SPECIFICATION

The control system was installed at the Young Federal Building in January 2012. The version of the technology assessed in this evaluation was pre-commercial; product development continued after the completion of this evaluation. The system was configured such that all irrigation equipment was controlled with two separate control boxes operating independently of each other. Each of these control boxes had a number of irrigation zones associated with it, and acted as a central hub that collected and controlled the irrigation events that occurred within these zones based on feedback from the soil moisture sensors. One soil moisture sensor was installed in each irrigation zone in Controller Areas 1 and 2 (Figure 7). The soil moisture sensors detect the soil moisture by measuring the conductivity of the soil. The soil moisture level was wirelessly transmitted to the control box for each irrigation area (Figure 8). Wireless signals were not received consistently by the controllers; therefore repeaters were installed at strategic locations to assist in transmitting the signal from the soil moisture sensors to the controllers. A flow meter was installed to measure the water flow to the irrigation system. Data collected by both control boxes on water events consisted of:

- total volume of water
- date of watering event
- time duration of watering event
- watering event type (manual or automatic)

These data logs were sent to a network bridge that was located in the office of the facility manager at the site. The bridge transmitted information to the server, which was available to PNNL for analysis. Communication problems were experienced during the demonstration. It appeared that the soil moisture readings and water usage data were not consistently being transmitted to the bridge and uploaded onto the server. More details on the communication challenges experienced during the demonstration are covered in Section V of this report.

Figure 7. Photos of Soil Moisture Sensors

Figure 8. Photo of Control Box for Controller 1 Area

D. SYSTEM MONITORING

The irrigation system performance was monitored through the manufacturer’s website interface. The irrigation system was configured to post two sets of data logs of the system’s activities each day for each of the controllers. One set of data logs recorded the system’s watering events, differentiating between watering events manually activated by the staff and those triggered automatically by the soil moisture sensors. The duration and water usage for each watering event were recorded for both types of events. The second set of data logs recorded the activity of the soil moisture sensors that were buried in each respective irrigation zone, recording both the measured soil moisture content of the soil (measured as a percentage) and the number of readings received from the sensors by the control box. These data logs were downloaded by PNNL staff and analyzed to verify and evaluate the irrigation system over the course of the study.

System performance was verified by using both sets of data logs to observe the system’s response to soil moisture level in each zone. Staff observed that after soil moisture dropped below a unique threshold for each zone, the system would respond by activating the irrigation system, bringing the soil moisture levels back up to the desired range. Similarly, weather events (rainfall) were observed to create a response in the reported soil moisture levels. System performance was further monitored by tracking the number of readings received by the control boxes from their associated soil moisture sensors in individual zones each day to verify that the system was remaining in contact with each zone’s respective sensor. (Information on zones’ soil moisture profiles is provided in Section V-B of this report.) Taken together, PNNL used the data to determine whether the system was operating correctly, *i.e.*, that the sensors’ observed soil moisture levels were dictating the irrigation system’s watering activities.

E. STUDY PERIODS

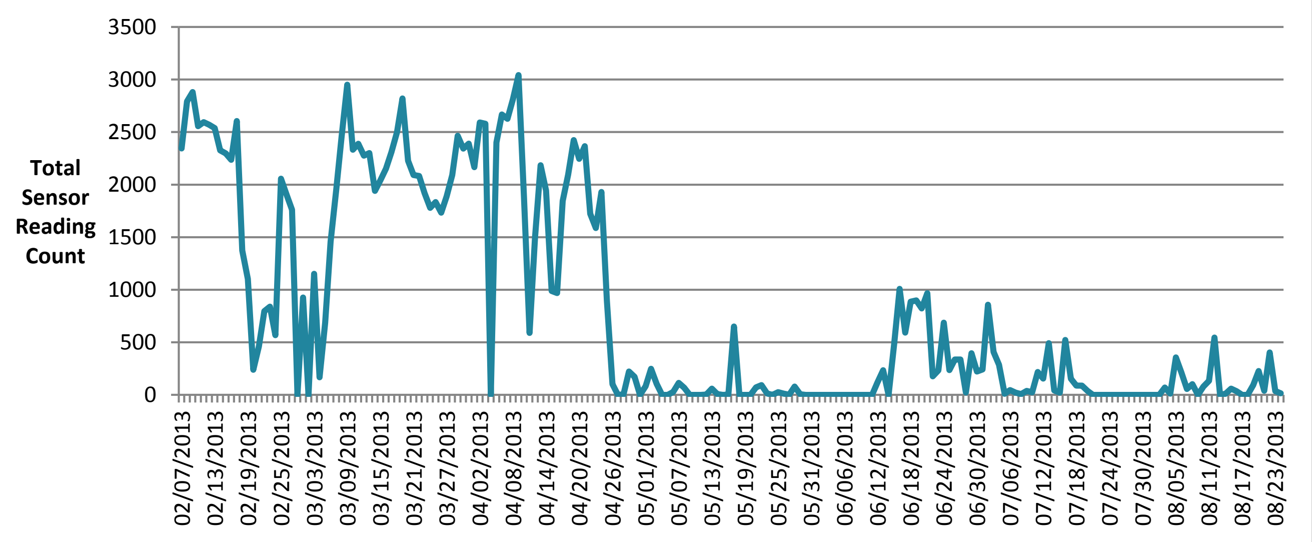
Distinct study periods were selected that represent the time frame in which the controllers were receiving signals consistently from the soil moisture sensors. Throughout the system monitoring performed during the assessment, it appeared that there were varying degrees of technical challenges with connectivity of the soil moisture sensors for each controller, which ultimately resulted in periods in which the system was not responsive to the soil moisture sensors or was functioning but failing to post system data logs. This produced several periods with sizable gaps in the data, spanning days to weeks in length, for which no system logs were available, making it impossible to evaluate the system's performance for these periods. The vendor made significant effort to restore the data during this time, but no long-term solution was found.

Due to these outages, the field study has been divided into several periods of time for which the data were both available and sufficiently robust to support analysis. Controller 1 had three periods for analysis in which soil moisture levels were read by the controller and triggered automatic watering events. Controller 2 had more persistent connectivity issues, which made only one study period possible. The technical challenges underlying these outages are described in detail in Section V.

These periods were selected on the basis that the system continuously recorded at least 50 soil moisture sensor readings per day per zone, a level determined to be sufficient indication that the system had adequate connectivity for the system to upload activity logs to the data server and provide sufficiently detailed data for analysis. Three periods were identified that met these criteria for Controller 1, as shown in Figure 9, where there were consistent sensor counts across all zones:

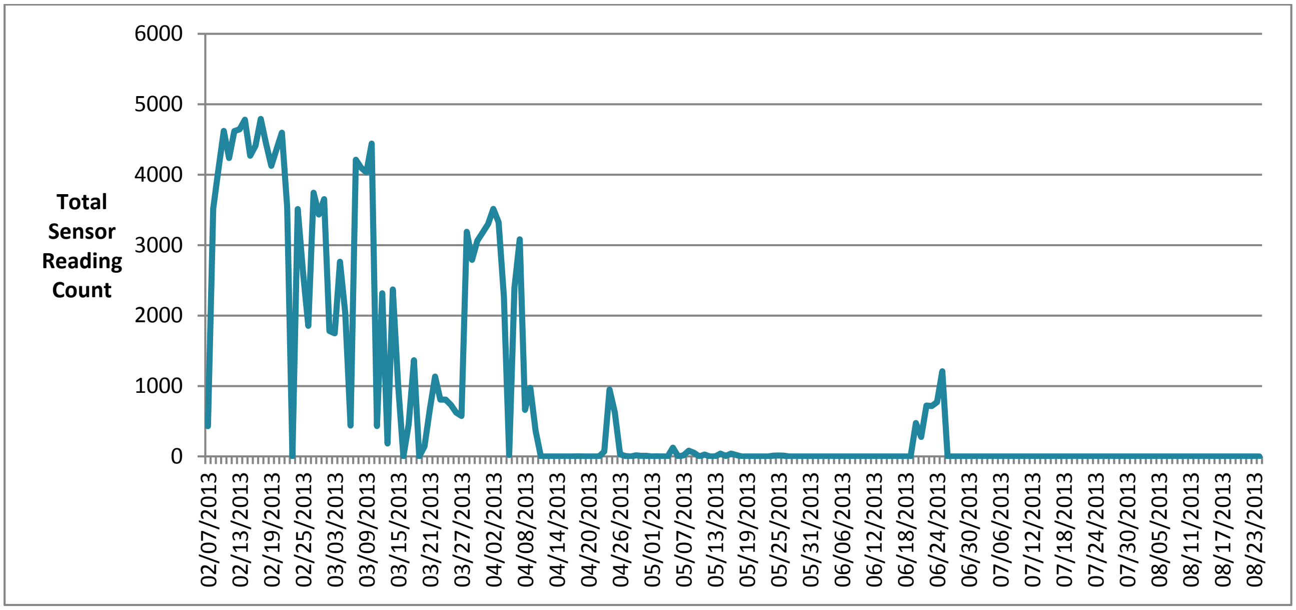
1. February 7th to May 3rd
2. June 16th to July 20th
3. August 5th to August 24th.

Figure 9. Daily Soil Moisture Sensor Reading Counts for Controller 1 Throughout Assessment



The single study period for Controller 2 spans the period from February 7th to April 10th, as shown in Figure 10. The analysis in this report uses only the data collected during these periods, as the data were either unavailable or unusable outside of these periods.

Figure 10. Daily Soil Moisture Sensor Reading Counts for Controller 2 Throughout Assessment



V. Results

The Results section includes six subsections. The first section provides information on weather data collected during the assessment to determine whether data normalization was required for the analysis. The second subsection provides soil moisture profiles for irrigation zones in the Controller 1 area. The third subsection provides water usage of the system and potential savings of the technology. The fourth subsection identifies potential trends in irrigation patterns of Controller 1. The fifth subsection provides the results of the economic analysis. Finally, the sixth subsection describes the technology challenges faced during the assessment.

A. WEATHER NORMALIZATION

Due to the soil moisture-based system's reliance upon soil moisture levels, which were, in turn, impacted by the weather experienced at the site over the course of the study, efforts were made to quantify the impact of annual weather variation on the results. Efforts to normalize system performance against annual weather variation were made by comparing the weather over the course of the study in 2013 against the typical meteorological year (TMY). Unlike an average, TMY data are calculated such that they represent the weather conditions most commonly experienced at a given location, while excluding extreme, but temporary, weather conditions that might be included in a simple average. Weather data for 2013 was collected from the National Oceanic and Atmospheric Administration's National Climate Data Center. TMY weather data were obtained from the National Renewable Energy Laboratory's TMY3 data set [8].

Weather was compared against temperature, relative humidity and precipitation differences at the site—the primary factors affecting soil moisture levels. Daily data for maximum temperature, mean relative humidity, and total precipitation for the study period in 2013 and the same TMY data were plotted against each other and found to largely resemble each other, with regard to both magnitude and time of occurrence.

Temperature, relative humidity and precipitation datasets were also subject to kernel density estimation. Kernel density estimation is a method of representing the distribution of values within a finite dataset (in this case, weather data) that is very similar to histograms. In contrast with histograms, kernel density estimation better represents non-integer values (such as 0.13 inches of rain) that do not fall within the discrete ranges of values for the bins in a histogram, which would result in some values being "lost." The results of the kernel density estimation show that 2013's weather conditions at the site were ultimately found to be nearly identical to TMY conditions. Given the lack of significant weather variation or unusual conditions at the site, it was determined that no additional normalization would be needed to control for extreme or unusual weather conditions affecting system performance. The following series of charts (Figure 11 through Figure 16) provide the comparison of 2013 weather data to TMY data and the results of the kernel density estimation, revealing that 2013 weather closely resembles TMY data.

Figure 11. Daily Maximum Temperature for 2013 Study Period and TMY

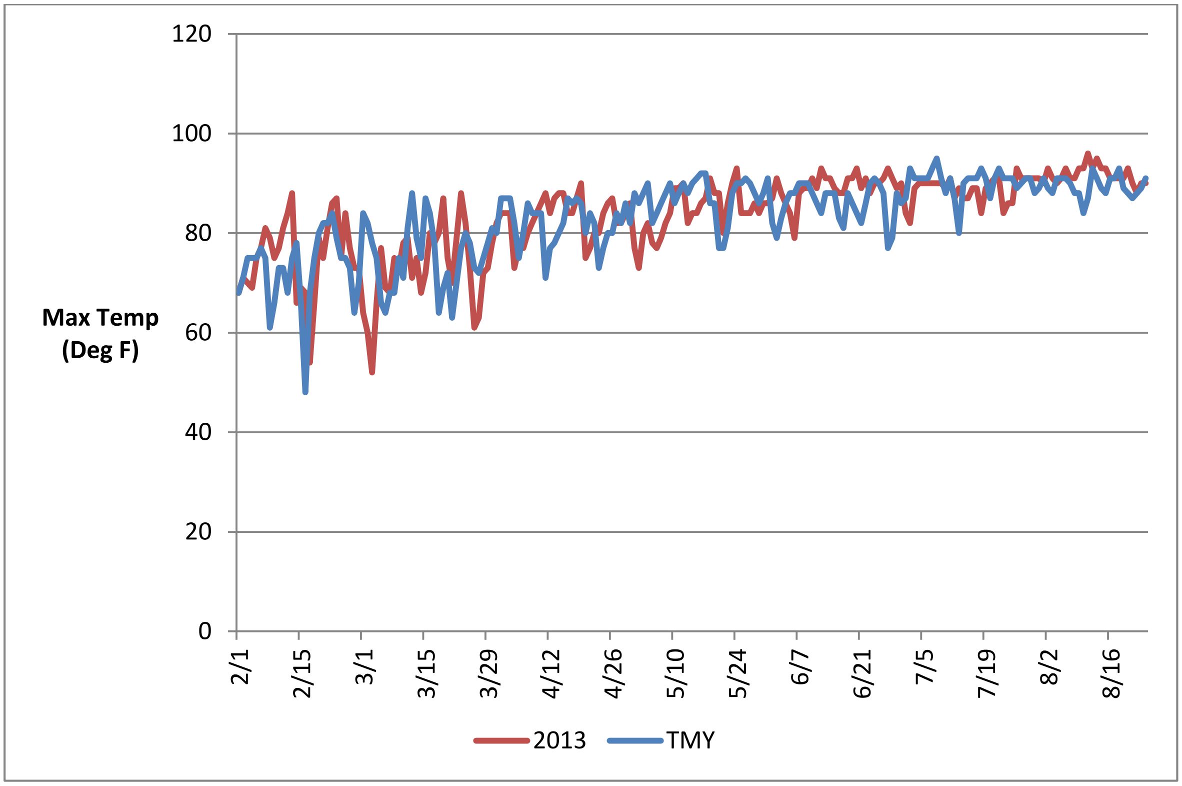
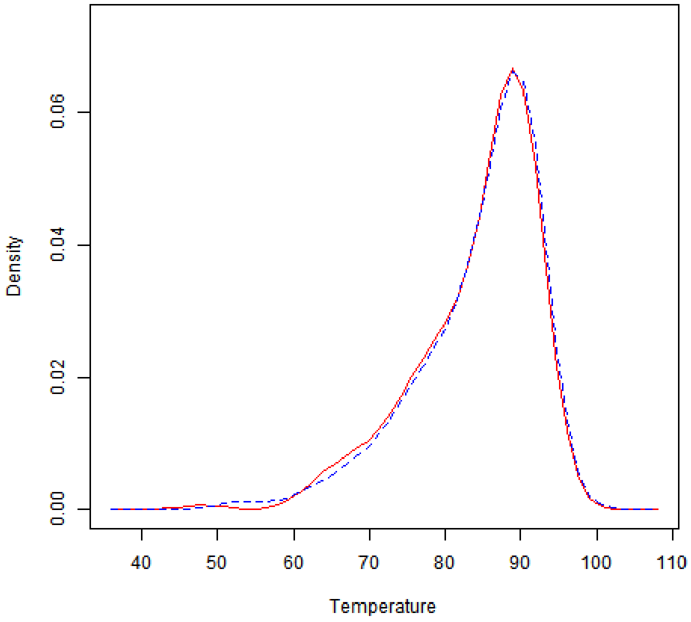


Figure 12. Daily Maximum Temperature Kernel Density Estimation*



*2013 data are represented by the red line while the blue line represents TMY data

Figure 13. Daily Mean Relative Humidity for 2013 Study Period and TMY

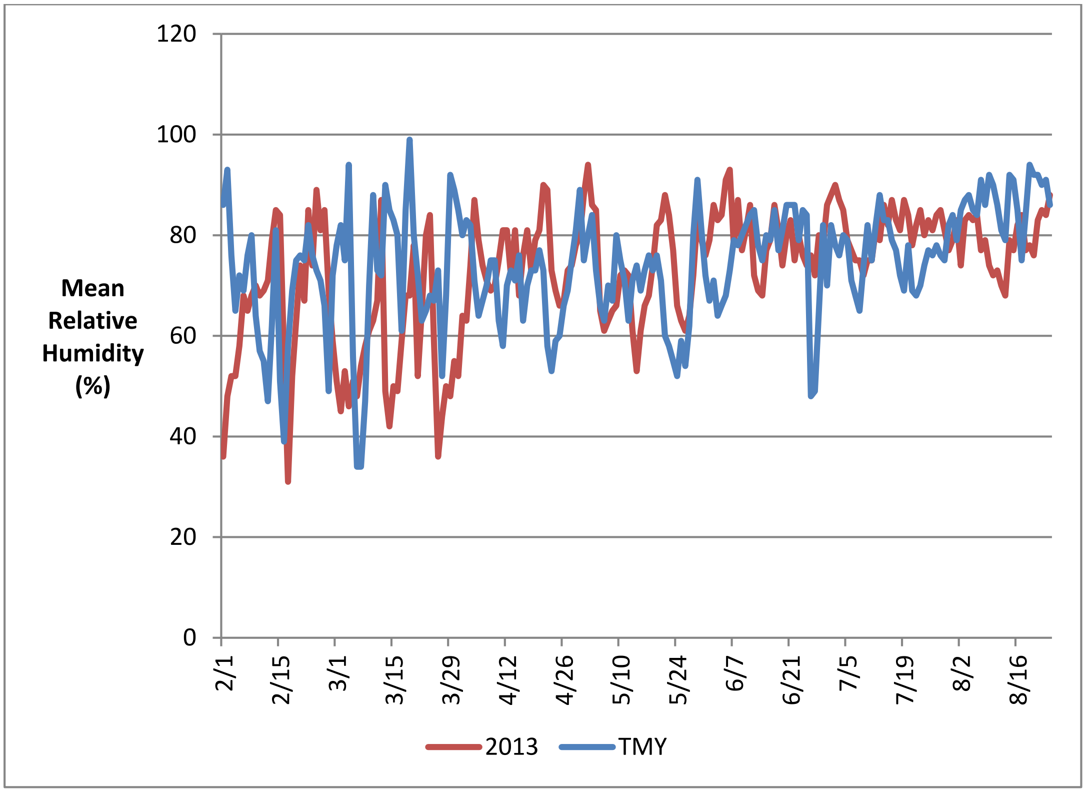
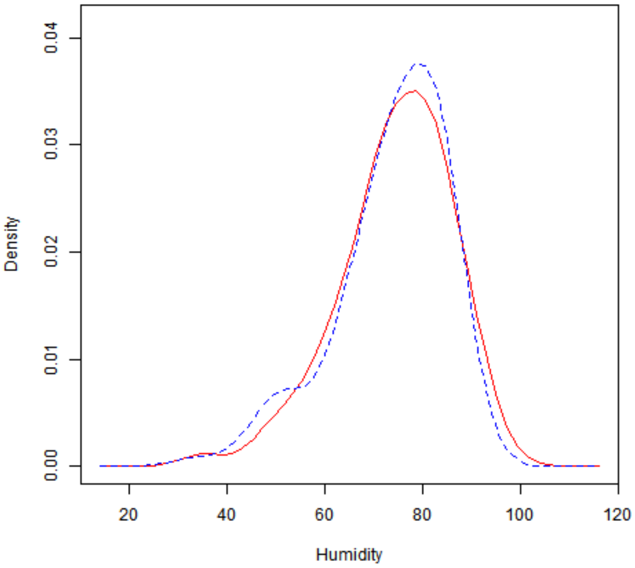


Figure 14. Daily Mean Relative Humidity Kernel Density Estimation*



*2013 data are represented by the red line while the blue line represents TMY data

Figure 15. Daily Total Precipitation for 2013 Study Period and TMY

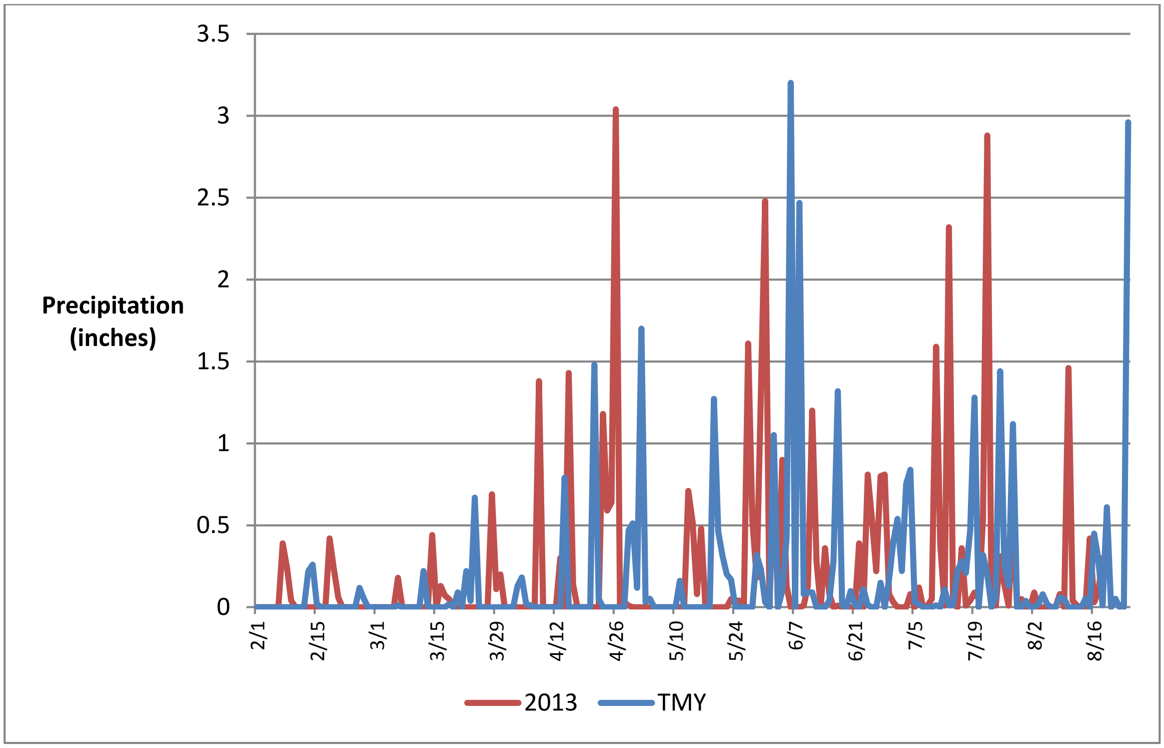
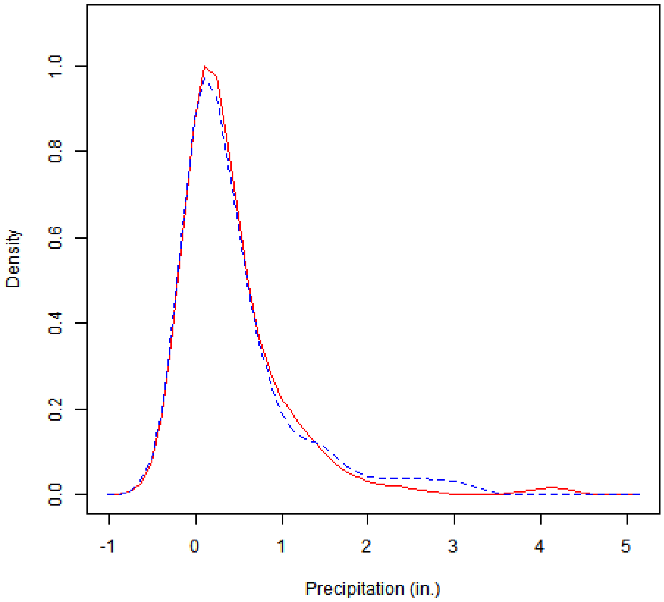


Figure 16. Daily Total Precipitation Kernel Density Estimation*



*2013 data are represented by the red line while the blue line represents TMY data

B. SOIL MOISTURE PROFILES

During the course of the study, soil moisture logs from the sensors were analyzed to determine the functionality of the system and to identify the general trends in soil moisture for individual irrigation zones. Soil moisture levels were sent wirelessly from the soil moisture sensor to the controller, at which point the controller would automatically initiate a watering event. Irrigation would be suspended once the soil moisture once again reached its target level.

Examples of soil moisture profiles for Controller 1, Zones 1, 7, and 10 are given in the charts below in Figure 17, Figure 18, and Figure 19. The charts plot the daily average soil moisture levels (expressed as a percentage) over time during the first study period (January 7 through May 3). The charts also provide vertical lines that denote whether an automatic watering event occurred or whether rain was received on the particular day. These examples show large variations in zone moisture and triggered watering events. Zone 1 had large swings in daily soil moisture with multiple automatic watering events, while Zone 7 had consistently high soil moisture and few watering events. Zone 10 had extremely low soil moisture for the first two months of the study, with many automatic watering events. All of the soil moisture profiles for each irrigation zone in Controller 1 area are provided in Appendix A.

There is no discernible reason for the significant variations between irrigation zones. Zones that have similar exposure and similar plantings do not have similar patterns in automatic watering events and soil moisture levels. For example, Zones 7 and 10 have the same exposure and similar plantings but have extremely different soil moisture levels and triggered watering events (Figure 18 and Figure 19). This inconsistency may have revealed possible soil moisture sensor reading errors, although no sensor failures were determined by the vendor. Section V-E provides additional information on trends that were investigated as part of the analysis.

Figure 17. Daily Average Soil Moisture Profile for Zone 1 on Controller 1 during Study Period 1

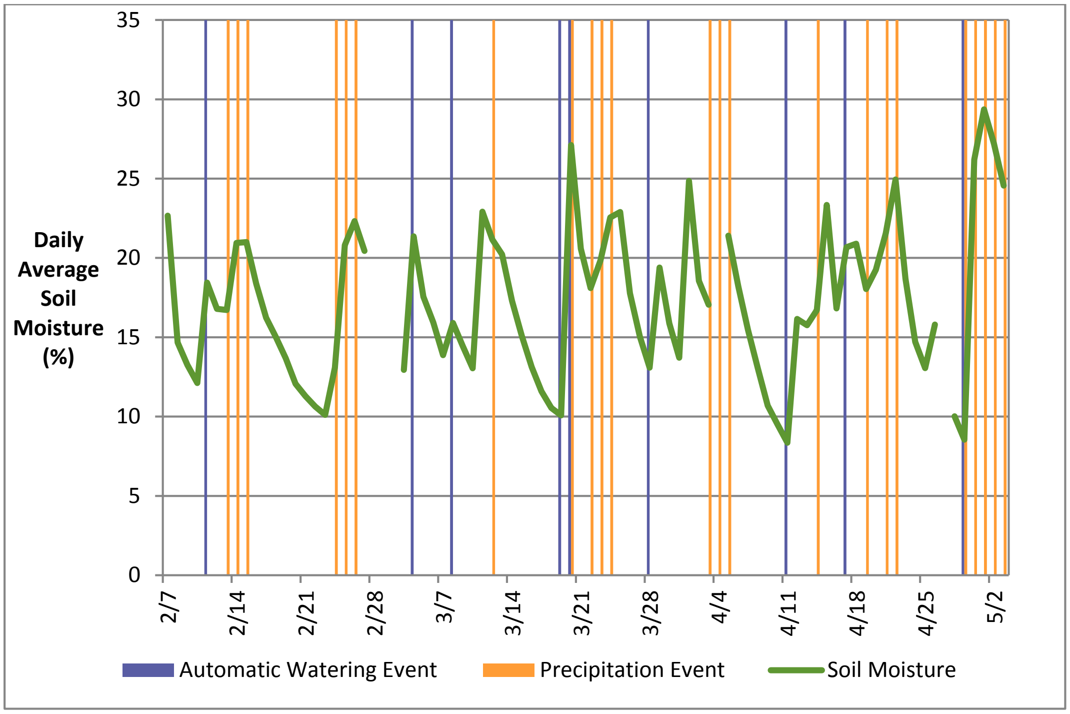


Figure 18. Daily Average Soil Moisture Profile for Zone 7 on Controller 1 during Study Period 1

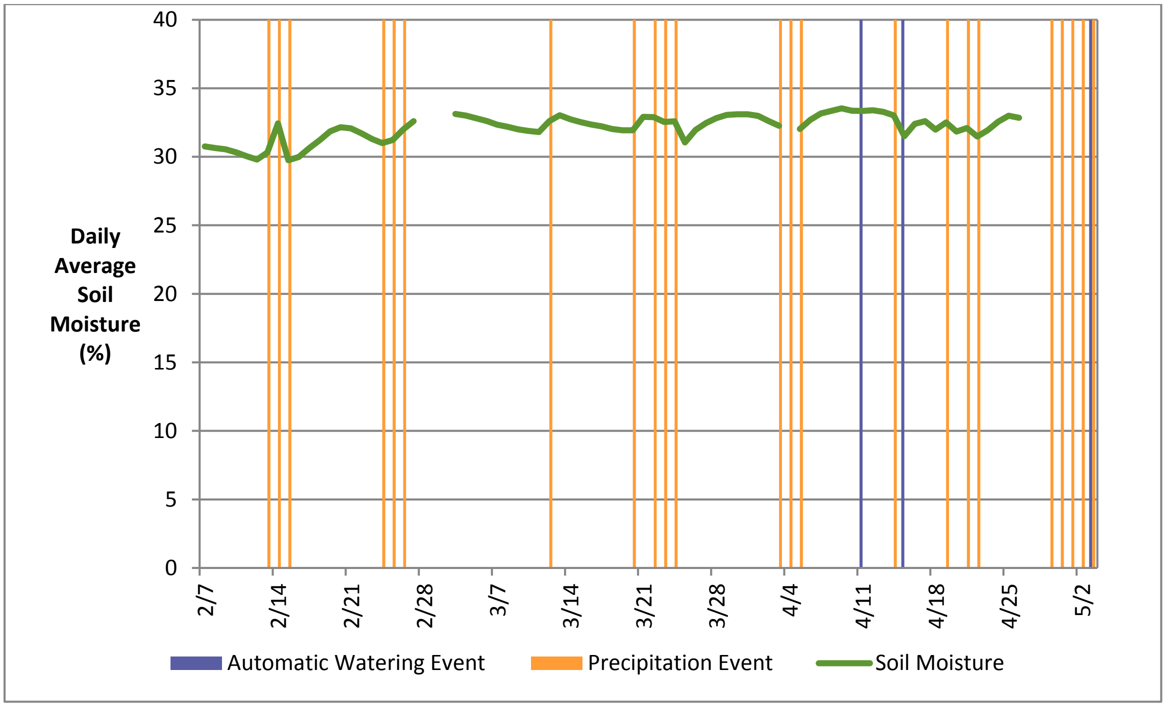
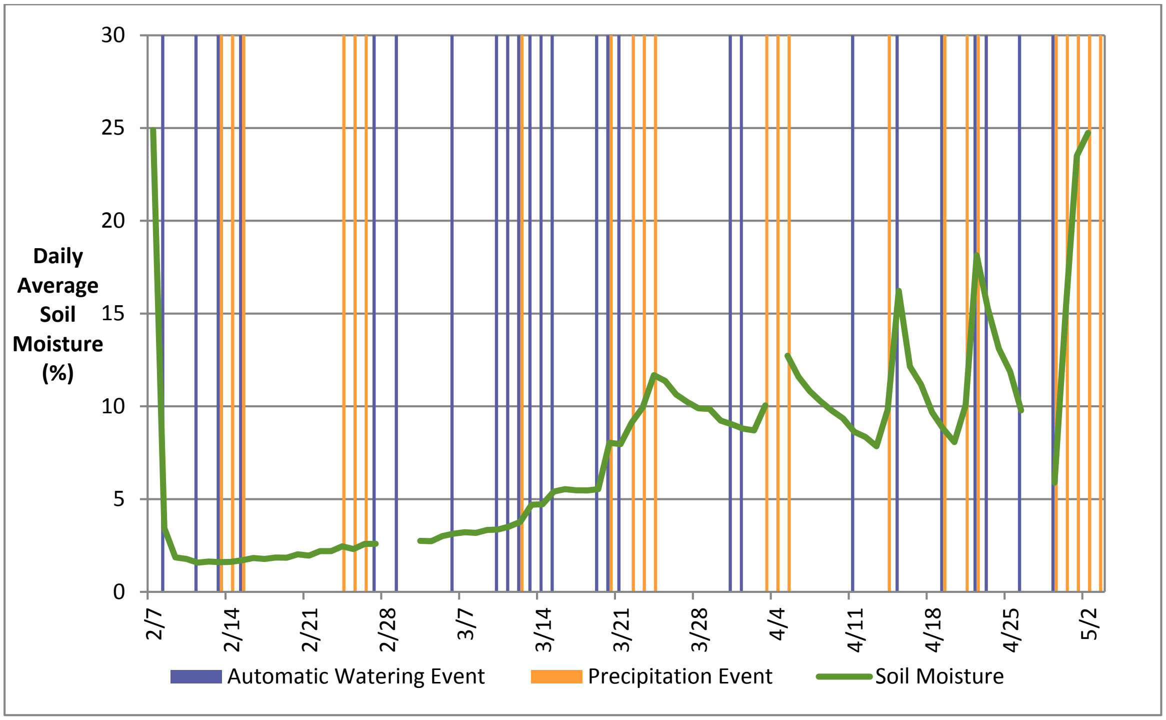


Figure 19. Daily Average Soil Moisture Profile for Zone 10 on Controller 1 during Study Period 1

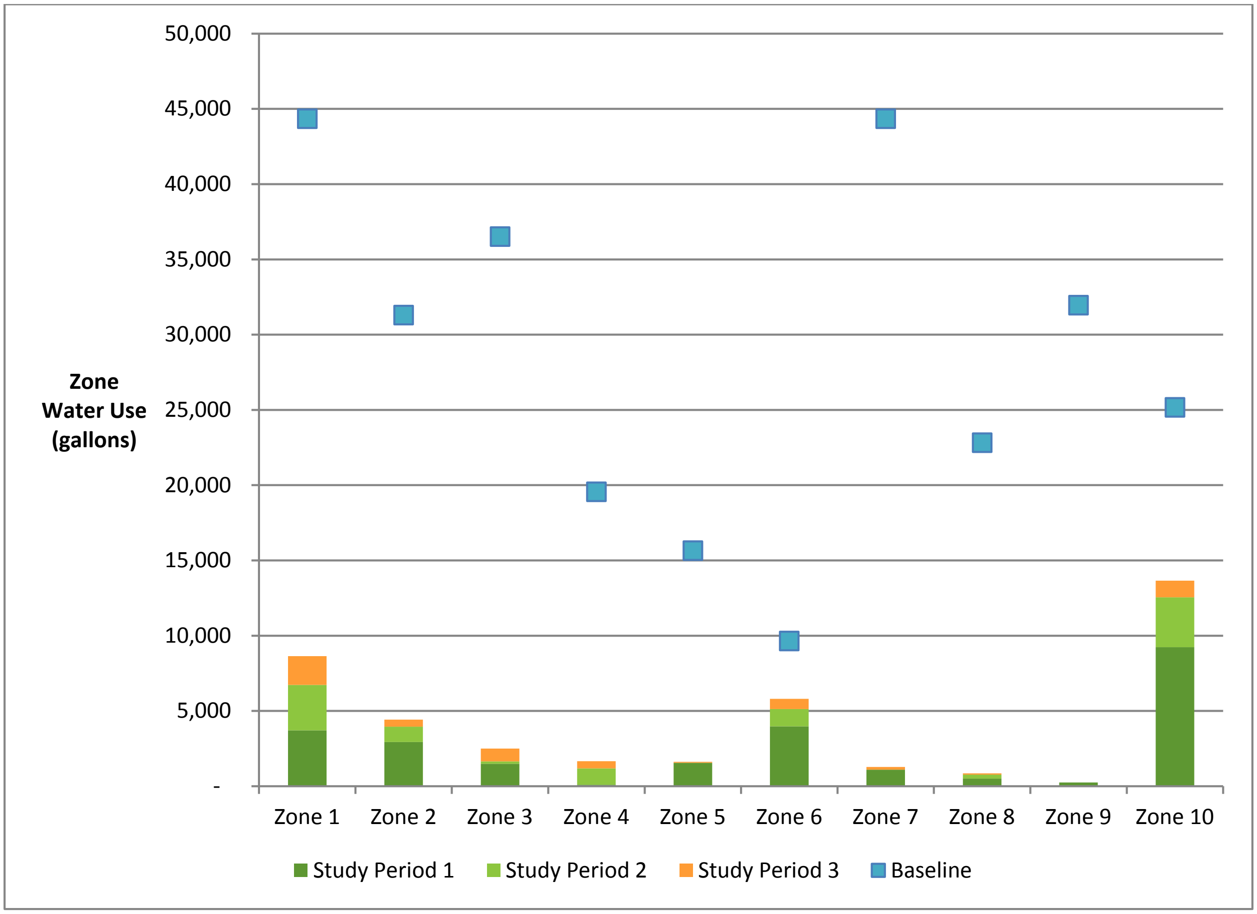


C. WATER USE PERFORMANCE

Water use performance was assessed for zones on Controller 1 during the time periods in which the soil moisture sensors were communicating sufficiently with the controllers (as described in Section IV-E). Water use performance was not assessed for the Controller 2 area because of communication failures during most of the spring and all of the summer months, and, therefore, there was not enough data during these times to properly assess annualized water usage.

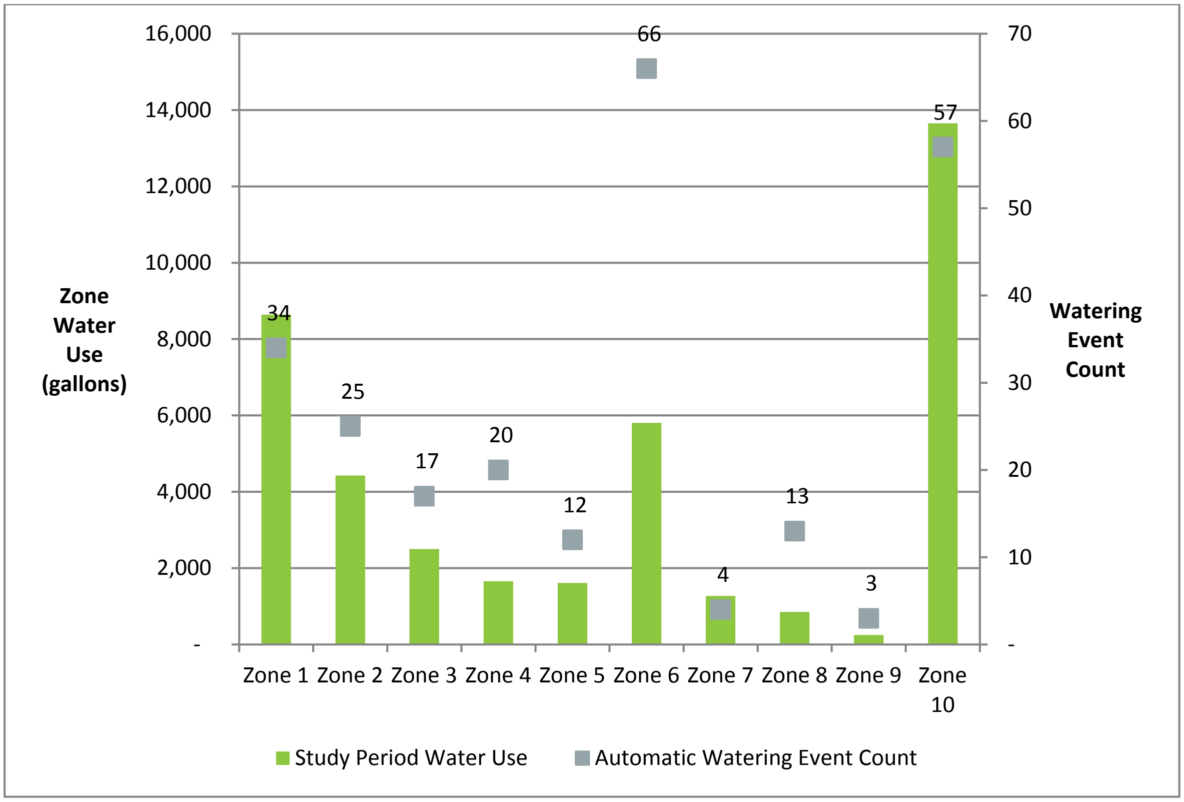
Over the three study periods on Controller 1, there were 251 automatic irrigation events that totaled 40,680 gal. The average runtime of automatic events was 8 minutes, with an average water use per event of 162 gal. Over this same time period, there were 87 manual watering events, using 3,360 gal, with average watering time of 2 minutes and average water use per event of 39 gal; manual watering events were eliminated from the dataset because of their relatively minor impact on water use. The baseline irrigation use for the study periods totaled 281,300 gal based on the original timed schedule (see Section IV-B). The water savings over the study periods was 240,620 gal. The comparison between the baseline and soil moisture-based control system for the study periods is shown in Figure 20.

Figure 20. Zone Water Use Performance over Study Periods on Controller 1 Area



During the study periods, there were a total of 251 automatic watering events. There was a large disparity in the number of watering events between zones, as shown in Figure 21. Zones 6 and 10 had the two largest numbers of watering events, while Zone 9 had the fewest with only three.

Figure 21. Automatic Watering Events and Zone Water Use over the Study Periods

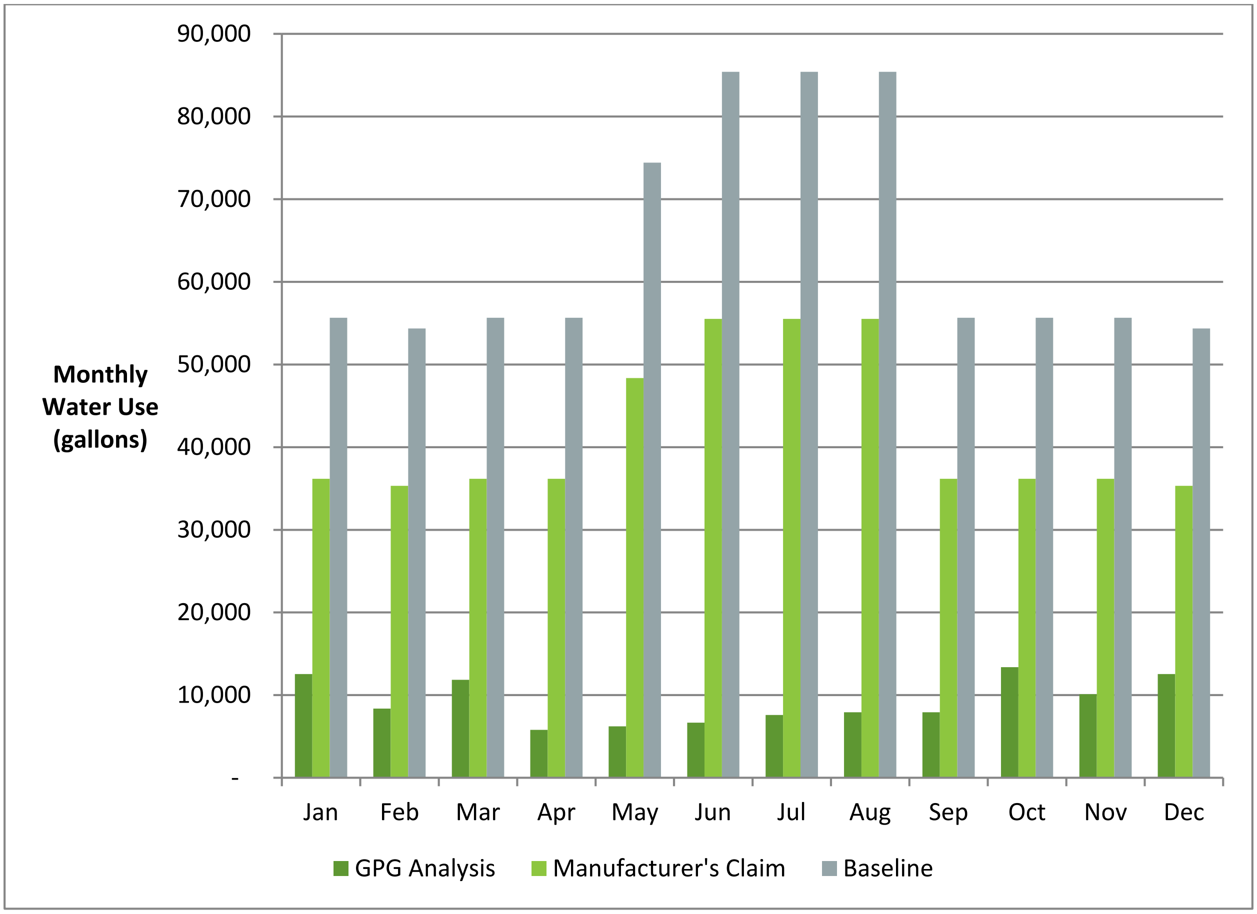


D. ANNUALIZED WATER USE

The water usage over the study periods was extrapolated to represent a full year of irrigation. Typical irrigation patterns that were experienced during the study periods were applied to times during communication failures when no water data were available. The annualized water usage was used to estimate the total potential water reduction for the system and the economic analysis (see Section V-E). When annualized, water reduction for zones on Controller 1 totaled over 662,300 gal, which represents an 85% reduction compared to the baseline. However, because of significant issues with the system's operation during the study including suspended irrigation and evidence of under-watering (Section V-G), there is reason to believe that the estimated savings resulting from the analysis is not entirely reliable. The analysis results may not be representative of reasonable savings potential because the major inconsistencies experienced between irrigation zones reveal possible system malfunction.

The manufacturer claims savings between 20% and 50%, which is much lower than the 85% reduction that was estimated in the study. This manufacturer's savings claim is similar to a field demonstration study of soil moisture-based irrigation controllers performed in Florida by the University of Florida [9]. The theoretical savings based on the manufacturer's average percent savings reduction of 35% is 270,650 gal. The comparison between the estimated baseline, the analysis results and an average manufacturer's claim of 35% savings is shown in Figure 22. It should be noted that the chart's objective is to illustrate the large disparity between the two savings and is not intended to substantiate the manufacturer's savings claim.

Figure 22. Annualized Analysis Results for Controller 1 Area



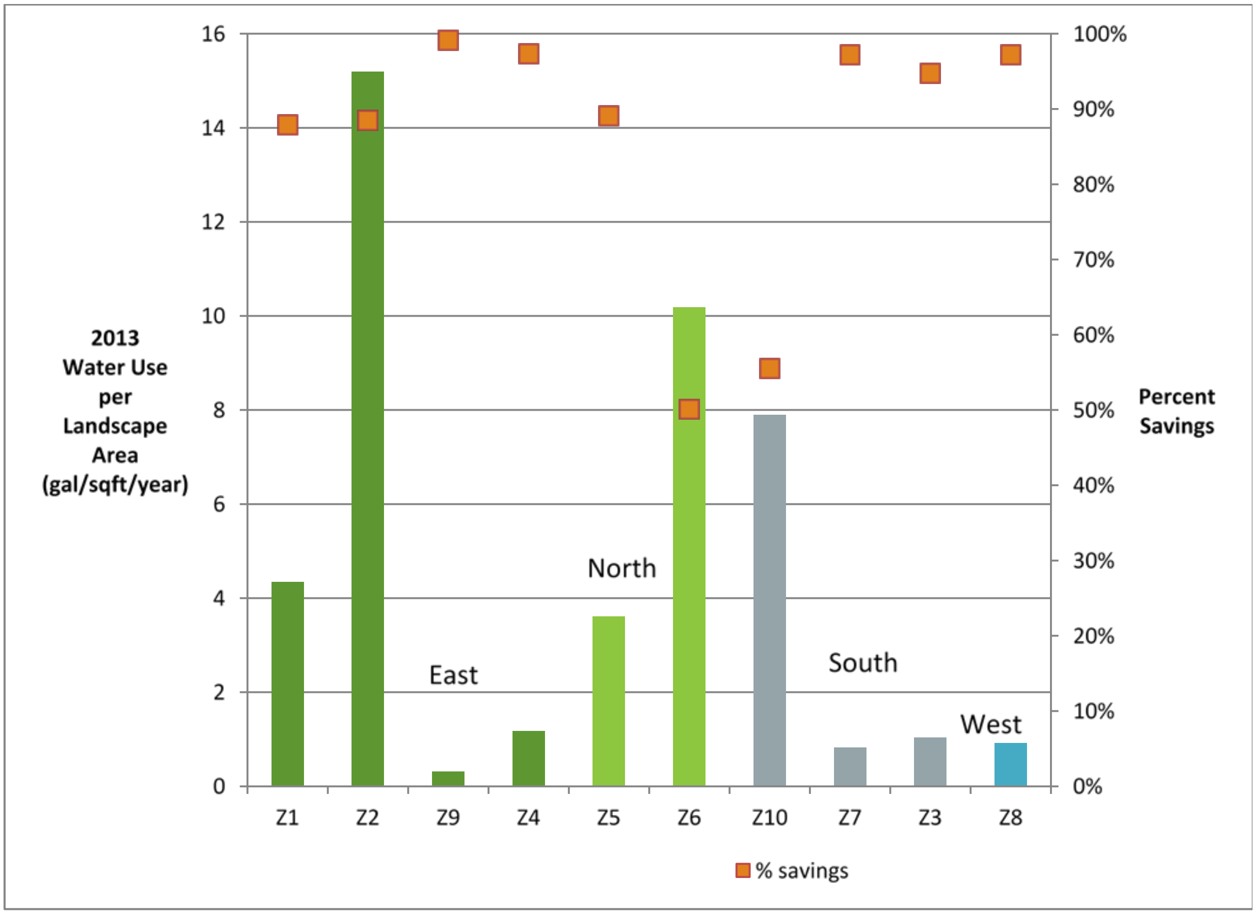
E. POTENTIAL TRENDS IN ZONE WATER USE

The results of the assessment show that not all irrigation zones functioned the same during the study period. Zones 6 and 10 used approximately 50% of the baseline, while the other zones had much larger reductions, averaging a reduction of over 90% compared to the baseline. The reason for the differences in zone irrigation was not readily apparent. Therefore, potential trends were assessed to determine possible impacts on zone water usage. Does the zone’s location have any impact on soil moisture? Does the type of plants in the landscape absorb moisture more quickly and, therefore, cause the soil to dry out more quickly? Zone water usage was compared to the landscape type and the zones’ locations to see whether these parameters potentially impact soil moisture and, ultimately, triggered watering events.

Figure 23 shows water usage per area of landscape, measured in gallons per square feet (gal/sqft) compared to zones’ locations relative to the building (north, east, south, or west) and the percent savings compared to the baseline. Using the amount of water used to irrigate per square foot normalizes the water usage for each zone. Comparing zones’ normalized water usage and relative percent savings to the zones’ locations can help to determine whether the exposure of the zone had any impact on water usage.

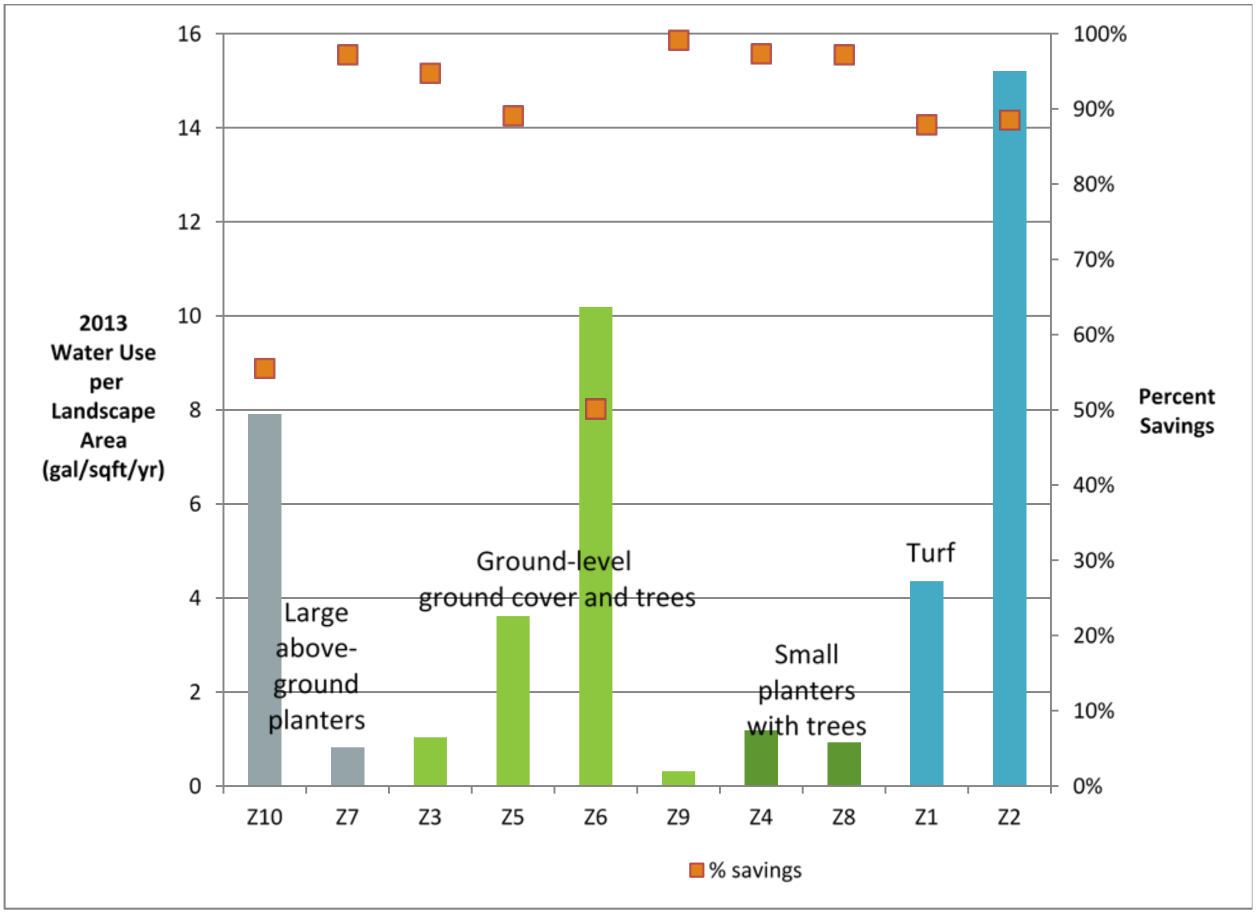
This comparison shows no evident correlation. There are no trends in water usage per area among zones located on the same side of the building (thus having the same type of environmental exposure), as shown in Figure 23.

Figure 23. Controller 1 Zones' Water Use Compared to Zone Location



Additionally, the correlation between the type of landscape and normalized water usage and percent savings was analyzed to see whether the type of plants had an impact on required water usage. No trends are evident in the type of landscape and zone water usage, as revealed in Figure 24. Because no trends were revealed in this analysis, no conclusions can be drawn on trends in zone water use.

Figure 24. Controller 1 Zones' Water Use Compared to Landscape Type



F. ECONOMIC ASSESSMENT

An economic assessment of the actual demonstration project was not possible because realistic savings were not determined due to the issues experienced with the technology over the study period. However, an economic analysis was performed using theoretical water savings. Several research studies show significant savings potential from use of smart irrigation controllers, generally ranging between 20% and 40% reduction in irrigation [5]. These two levels of annual water savings were used in the analysis to represent a range of potential economic results for soil moisture-based irrigation controllers.

Costs associated with the soil moisture irrigation control technology were assessed and an LCC analysis was performed using the Building Life-Cycle Cost (BLCC) analysis tool [10]. The BLCC program was developed by the National Institute of Standards and Technology (NIST).

The economic factors for the control system for Controller 1 are detailed in the following list:

- GSA facility water rate: $1.067 per thousand gallons ($/kgal)
- system cost per zone: $450 (materials and labor)

- total system installed cost: $4,500; cost includes all labor associated with set-up, commissioning, and additional site visits associated with system upkeep
- annualized soil moisture sensor replacement cost: $186; assumes sensors are replaced every seven years; cost per sensor is $130
- annual data subscription fee: $180; $1.50 per zone per month
- annual additional on-going cost to maintain and operate the control system: 45 minutes per month, totaling $315 per year[12]
- life of the soil moisture-based irrigation control system: 15 years
- discount rate: 3%.

Based on the analysis results, the soil moisture irrigation control technology for the Orlando location was not LCC-effective under either savings scenario with negative savings-to-investment-ratio (SIR) and negative net present value (NPV). The poor economics are due to a combination of very inexpensive water, additional labor requirements to operate the soil moisture-based controls compared to a conventional timer-based system, and data subscription fees through the life of the equipment.

The economic assessment also determined for both savings scenarios (20% and 40% savings) the water rate at which the project becomes LCC-effective, *i.e.*, when the SIR is equal to one. An SIR of one shows that the total cost savings is equal to the total capital cost of the project over its life. The breakeven water rate that produces an SIR of one for the 20% savings scenario is $6.23/kgal, whereas the 40% savings scenario breakeven water rate is $3.11/kgal. This water unit cost is close to the national average commercial rate, which is $3.30/kgal, according to a water rate survey performed by American Water Works Association [11].The results of the economic analysis are shown in Table 3.

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[12] Additional labor time for control operation and maintenance was determined by overall assessment of additional time spent through the study period by the grounds maintenance staff.

Table 3. Summary of the Baseline and Post-Installation Economic Assessment

Description	Baseline Timer-Based Irrigation	20% Savings Scenario Post Retrofit with Orlando Water Rate	40% Savings Scenario Post Retrofit with Orlando Water Rate	20% Savings Scenario Post Retrofit with Breakeven Water Rate	40% Savings Scenario Post Retrofit with Breakeven Water Rate
Water consumption (gal/yr)	773,700	618,960	464,220	618,960	464,220
Water rate ($/kgal)	$1.067	$1.067	$1.067	$6.230	$3.110
Installed cost	NA	$4,500	$4,500	$4,500	$4,500
Ongoing costs per year	$0*	$680*	$680*	$680*	$680*
Present Value of Lifetime Water Savings	NA	-$3,950	−$3,030	$5,550	$5,550
Simple payback (years)	NA	NA**	NA**	13	13
Savings-to-investment ratio	NA	NA†	NA†	1.0	1.0
Net present value	NA	−$9,500	−$7,530	$0	$0

*Soil moisture irrigation controls have additional costs compared to timer-based controls: monthly data subscription fee and additional labor to operate and maintain the system.

** Simple payback not reached during 15-year study period

† Meaningful SIR cannot be computed because present value of savings is not positive

Note: subsequent to this evaluation, two new financing structures became available, a lease and a "savings share." In neither case are there upfront costs. In the savings share, the manufacturer takes a share of the cost savings generated by the technology.

G. TECHNOLOGY CHALLENGES

During the study, a number of challenges were encountered that either delayed implementation of the technology or prevented the technology from working as intended in the field, or both. Challenges with the technology included those encountered during the initial startup of the technology, communication issues with the system and its components and data availability to the research team. Many of the startup and data availability issues were typically associated with communication issues between controllers and the data bridge, but there is indication that there were communication problems between the sensors and the controllers.

During installation of the technology, it was discovered that the building's heavy concrete construction impeded the transmission of wireless signals. Therefore, installation of wireless network repeaters was required to make sure the controllers had adequate coverage on the building's network. This process resulted in a delayed start to the study, while suitable locations for these network repeaters were identified and the necessary equipment installed. Early in the study it also was necessary to replace the control box in the Controller 2 area as it was flooded by site irrigation equipment to the extent that it was no longer functional.

Over the course of the study period, additional technical challenges continued to arise with the communication between the controllers and the data bridge located inside the GSA facility that prevented the system from successfully reporting irrigation activities. This was evident in the number of soil moisture sensor readings received by the controllers, showing global reading count for all zones dropping to nearly zero (see Section IV-E). Multiple attempts were made by the technology manufacturer during the study to restore or improve communication between the controllers and the data bridge via firmware updates and fine tuning of the controllers' algorithms. These process improvements did not correct the problem, and no noticeable effect to overall system performance was evident in the system monitoring performed by the research team.

In addition, data on watering events and soil moisture were lost during the study period. Efforts were made by the manufacturer to recover logs but they were ultimately unrecoverable, resulting in periods of time for which no system logs were available and no analysis of system performance was possible. The timing of these outages differed between controller areas, with Controller 1 typically suffering from infrequent outages of a few days to a few weeks at a time before returning to operation. Controller 2, however, consistently failed to communicate with the data bridge for the majority of the study period, and consequently analysis on this controller was not performed by PNNL. (See Section IV-E for more information on system failures.)

Issues also were encountered over the length of the study period with the data server, during which times it was not possible to recover system activity logs. Additionally, past activity would periodically disappear from the server and require restoration via backups by the manufacturer.

There is evidence that there may have been inherent problems with soil moisture sensors due to the inconsistency observed between zones, resulting in inadequate watering. Figure 25 shows a comparison of the turf in Zones 8 and 9 on Controller 2 in late January prior to the start of the study and in late May. The May photo shows that the turf was under stress from possible under-watering during the study. It should be noted, however, that the exact reason for under-watering of zones on Controller 2 is not well understood. It could have been due to sensor communication issues or inherent problems with the irrigation equipment.

Figure 25. Zones 8 and 9 on Controller 2 on January 31, 2013 (left) and May 20, 2013 (right)

VI. Summary Findings and Conclusions

The summary findings and conclusions are discussed below, including information on potential best practices. The barriers to technology adoption are also discussed. Recommendations regarding the future installation and commissioning of the technology are provided as well.

A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITY

In principle, soil moisture-based irrigation control technology can reduce water usage by determining and meeting the actual water requirements of specific landscape types by zone. During this GPG demonstration project, however, significant operational problems were experienced that compromised the analysis of the technology. For this reason, a reliable savings estimate was not determined for the soil moisture-based controls installed at the Young Federal Building.

Over distinct time spans during the assessment, the system had consistent failures in communication during which the soil moisture level and water events were not recorded by the controller or by the main server. Also some obstacles incurred were specific to this location, particularly those concerning building layout and construction. It is not entirely understood whether the soil moisture data was sent properly to the controllers, triggering automatic irrigation events, but this information was simply not transmitted to the server, or whether there was actual lack of watering events because soil moisture data logs were not received by the controllers. There is some evidence that automatic watering events were suspended in the Controller 2 area, because the turf in Zones 8 and 9 became stressed and brown in late May. The analysis also revealed major inconsistencies between irrigation zones' soil moisture levels and triggered watering events that may indicate inaccuracies in the soil moisture sensors or problems with the soil moisture target settings used to trigger watering events. Because of these issues, additional time was spent by GSA grounds maintenance staff to attempt to resolve operational problems.

B. BARRIERS TO ADOPTION

A key barrier to this technology is the complex nature of the system's communication and controls. The grounds maintenance staff at the Orlando site were not able to fine-tune the system easily and had difficulty solving problems because of the system's complicated operation. The control system was not easily monitored and adjusted. The manufacturer made multiple visits to solve issues and to attempt to get the system working properly but ultimately was unable to resolve the issues entirely.

In addition, a key barrier to the implementation of a wireless soil moisture irrigation control system is the transmission of wireless signals sent to the system's controller and network bridge. Most GSA facilities likely have a similar layout as the Young Federal Building, whereby the configuration of the buildings may impede the wireless signals. This problem during the study was never resolved, despite multiple efforts from the manufacturer to correct this problem by installing repeaters and uploading firmware updates to assist the signal transmissions. Subsequent to this study, the manufacturer made changes to the communication system.

C. MARKET POTENTIAL WITHIN THE GSA PORTFOLIO

Based on the results of GPG's Young Federal Building assessment, no recommendation for the implementation of wireless soil-moisture based irrigation control technology can be made for GSA's portfolio at this time. Significant challenges were experienced during the demonstration related to the controls' communication system and potential inaccuracies with the integrated system's software suggesting that the technology was not ready for deployment.

However, at the time of the demonstration this technology was pre-commercial and has undergone modifications subsequent to PNNL's evaluation. In general, soil moisture-based systems have the potential to be more effective than weather-based systems because they can respond to the specific zone's irrigation requirements based on actual soil moisture levels. Because of this potential, soil moisture-based irrigation control technologies may warrant further investigation by GSA.

D. RECOMMENDATIONS FOR FURTHER INVESTIGATION

Because of the issues faced with the general functionality of the control system, there are no recommendations at this time for wide-scale installation, commissioning, training, and change management for wireless soil moisture-based irrigation control systems.

If another GPG project for soil moisture-based irrigation controls is pursued, GSA should consider the following conditions:

- Test the wireless signal transmission prior to technology implementation.
- Choose a location with multiple-zone landscape with different irrigation needs for each zone to test the system's response to individual zone irrigation requirements.
- Choose a location that receives intermittent rain through the growing season, which will enable testing of the system's ability to suspend irrigation when rainfall meets the soil moisture requirements.
- Install a dedicated irrigation flow meter that can measure water usage by irrigation zone before and after installation of the soil moisture-based system.
- Analyze zone soil type to understand the general constitution and soil moisture retention so that the control system can be properly programmed.
- Have the manufacturer commission the irrigation system and equipment prior to the installation of the new control system to make sure that all zone irrigation sprinklers are working properly.
- Train grounds maintenance managers on the operation and maintenance of the soil moisture controller, including system programming, adjustments, and override mode, so that the system can be monitored and adjusted, as appropriate.
- Commission the system components, including sensor performance, periodically throughout the study by grounds maintenance staff.
- Monitor the system after installation of the control system by determining whether automatic watering events are triggered by a drop in soil moisture levels to a minimum threshold level.
- Receive training from the vendor on the use of the online data system, so that soil moisture and water usage data can be available for system performance monitoring.

VII. Appendices

A. INTEGRATED WEATHER-BASED CONTROLLERS

Although this GPG project evaluated wireless soil moisture-based irrigation control technology, GSA may want to consider integrated weather-based irrigation controls as a potential technology for advanced irrigation control. Integrated weather-based irrigation controller technology is readily available on the market with proven savings.. The Department of Energy recommends the use of integrated weather-based controllers in the Federal Energy Management Program's (FEMP's) Best Management Practice on Water-Efficient Irrigation [12]. In addition, EPA published an irrigation best practice that also recommends the use of integrated weather-based irrigation control technology [13]. WaterSense also labels residential integrated weather-based controllers as part of their suite of labeled water-efficient products [4]. Soil moisture sensors are not included in this specification because there is not currently an accepted test protocol for them. The Irrigation Association has developed standardized performance metrics for weather-based controllers through the Smart Water Application Technologies (SWAT) testing protocol that determines system effectiveness. SWAT has also developed a test protocol for soil moisture sensors, and EPA WaterSense will consider developing a specification for this product category once the protocol has been fully reviewed and accepted.

Weather-based systems are generally less complex compared to soil-moisture based systems in terms of the communication and controls. Weather-based systems typically have only one line of communication between the weather station and the controller, which, in turn, is used to set the irrigation schedule for all zones. Conversely, soil-moisture based systems require consistent communication between each zone's moisture sensor and the controller, which inherently increases the likelihood of communication problems.

Table 4 shows a comparison of the benefits of weather-based versus soil moisture-based systems.

Table 4. Comparison of Soil Moisture-Based and Weather-Based Systems

Property	Soil Moisture-Based System	Weather-Based System
EPA WaterSense labeled product		x
Industry accepted performance metrics		x
Live measured data to determine supplemental irrigation	x	
Streamlined communication between data and controller		x
Scheduling control for specific irrigation zones	x	
Integrated data and internal software	x	x
Integrated system flow sensors	x	x

When considering the deployment of integrated weather-based irrigation controllers, GSA should consider the following best practices:

- Procure systems that have been tested in accordance with the Irrigation Association's SWAT testing protocol for weather-based controllers; set a requirement for the irrigation controller to achieve the same performance requirement as the WaterSense program:

  - Achieve an irrigation adequacy of at least 80%, which represents the percentage of water required by the plant that was actually applied to the plant;
  - Prevent irrigation excess of no more than 10%, which represents the amount of water that was applied beyond the requirements of the plant.
- Procure systems that are fully integrated with an on-site weather station or with real-time weather data integrated into the irrigation controller.
- Choose systems with software that automatically calculate system run-time based on ET; software should allow for user input to specify on-site conditions, such as landscape and soil type.
- Install systems that have a rain-delay feature that will automatically interrupt the system during rain events.
- For large facilities with multiple irrigations zones, consider installing a centralized control system with weather data integrated into the system, which allows grounds maintenance staff to have central control over all irrigation zones and equipment.
- Make sure that the weather-based system has a "deficit watering" setting; deficit watering allows for manual adjustment of the controller to irrigate less than the amount that would be required based on ET; this can be vital for areas that are experiencing a drought, where watering restrictions may be in place.
- When selecting and installing integrated weather-based irrigation technology, contract with local irrigation professionals who are specifically trained in this technology.
- Perform commissioning of the system including testing of the controller and weather gauges, to make sure that the weather information is accurately uploaded to the controller and the schedule is adjusting to weather conditions.
- Perform regular calibration of weather sensors and flow sensors to support accurate readings.
- Give priority for adoption of integrated weather-based systems to areas that receive intermittent rain through the growing season because of higher potential water reductions compared to arid areas; irrigation events will be suspended more often because real-time precipitation data will be used to determine irrigation requirements.
- If the integrated system uses wireless connections, special consideration should be made to make sure that wireless signals can be transmitted consistently.

Further information can be found on weather-based irrigation controllers at the following websites:

- FEMP Best Management Practice for Water-Efficient Irrigation: http://energy.gov/eere/femp/articles/best-management-practice-water-efficient-irrigation
- EPA WaterSense At Work on Landscape Irrigation: http://www.epa.gov/watersense/commercial/docs/watersense_at_work/#/160/

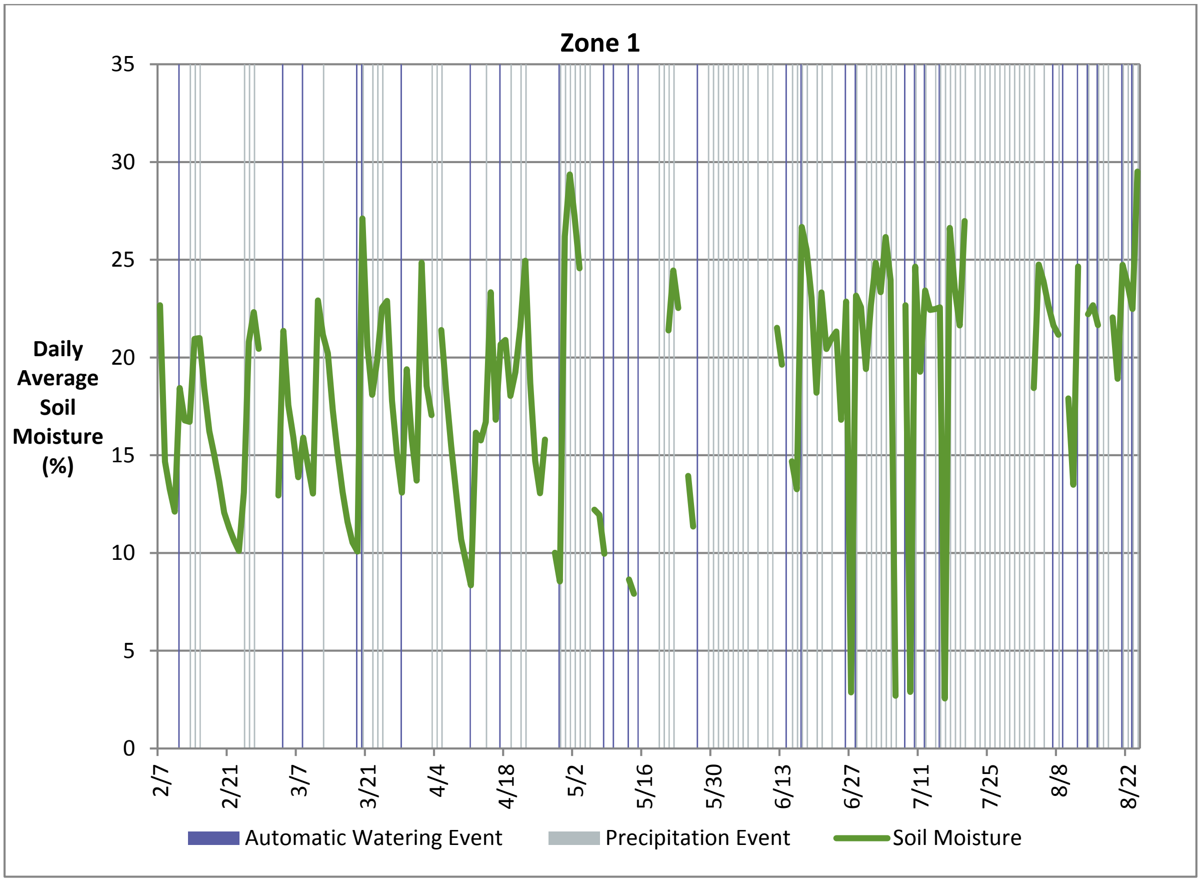
- EPA WaterSense Landscape Irrigation Controllers: http://www.epa.gov/watersense/products/controltech.html

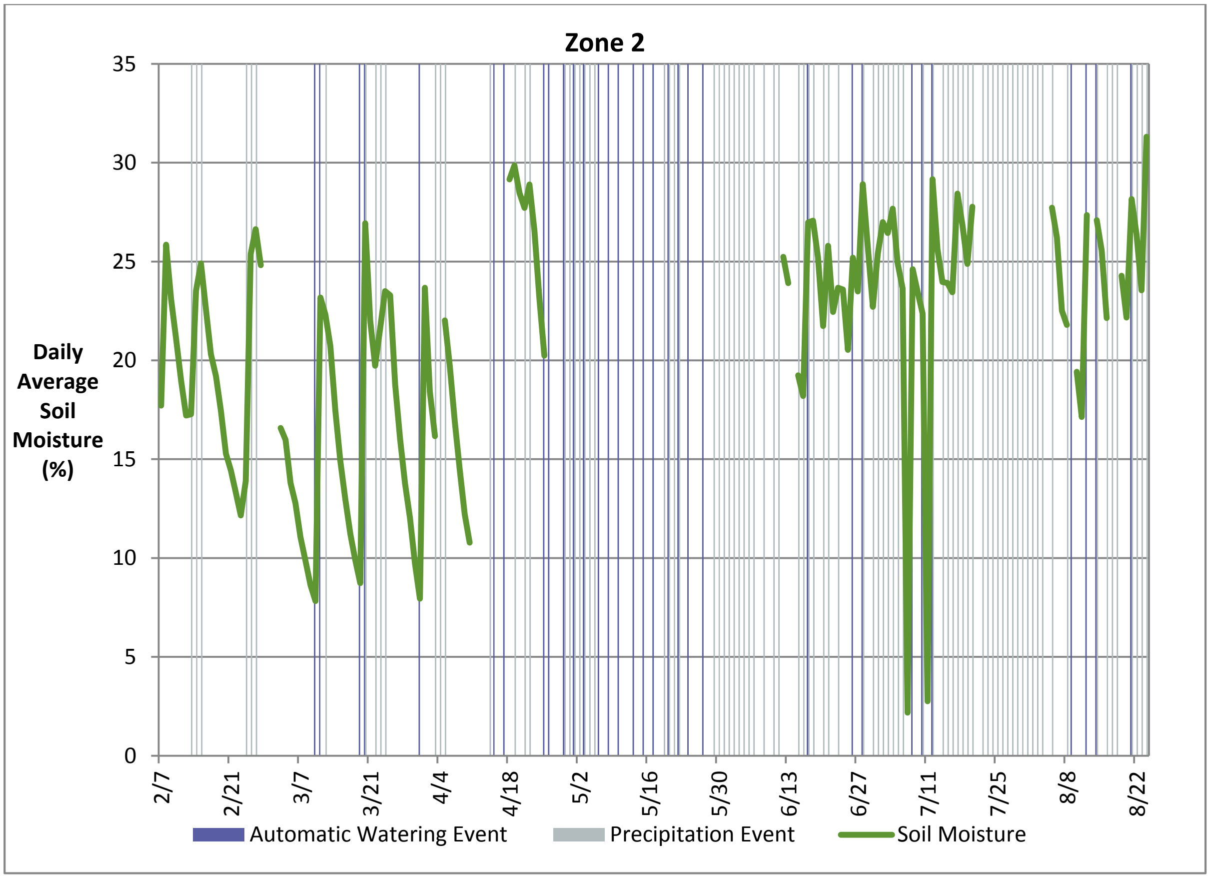
- Irrigation Association SWAT Program: https://www.irrigation.org/SWAT/

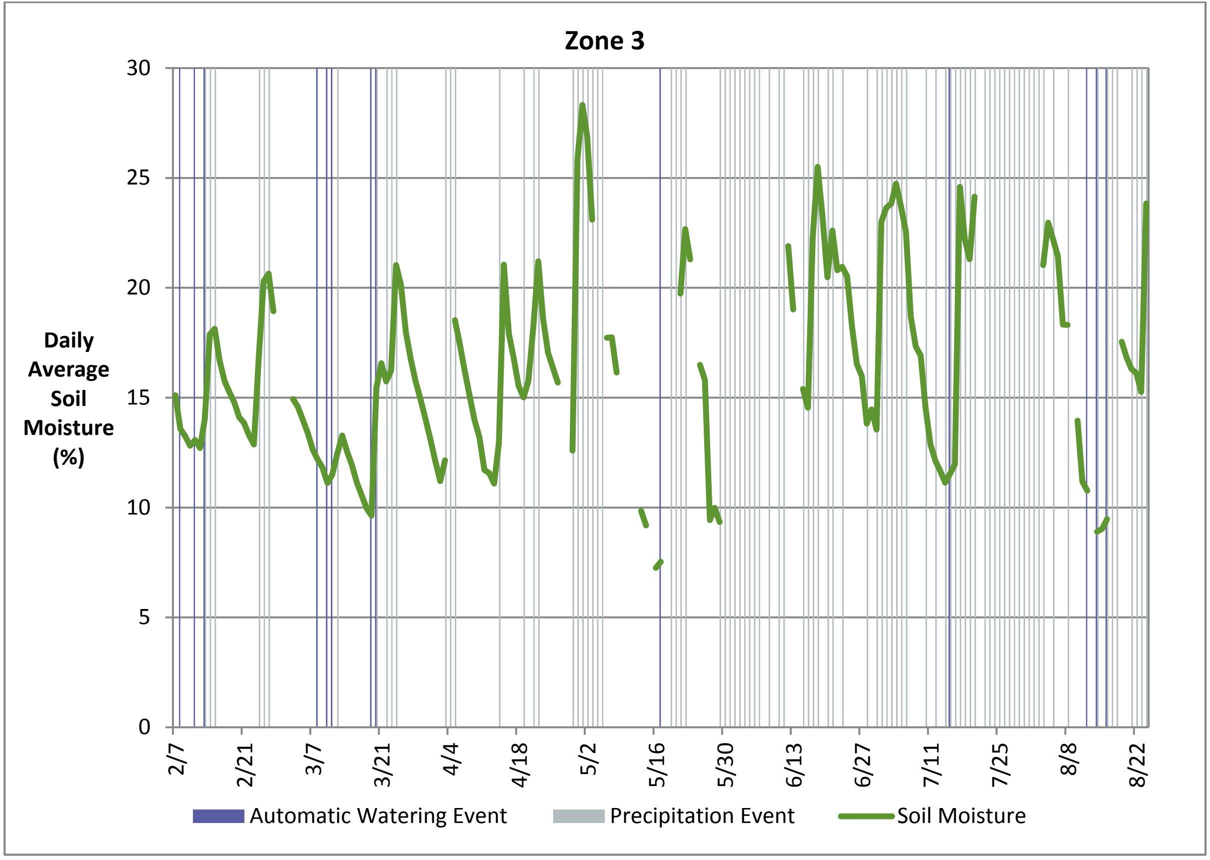
B. IRRIGATION ZONE SOIL MOISTURE PROFILES

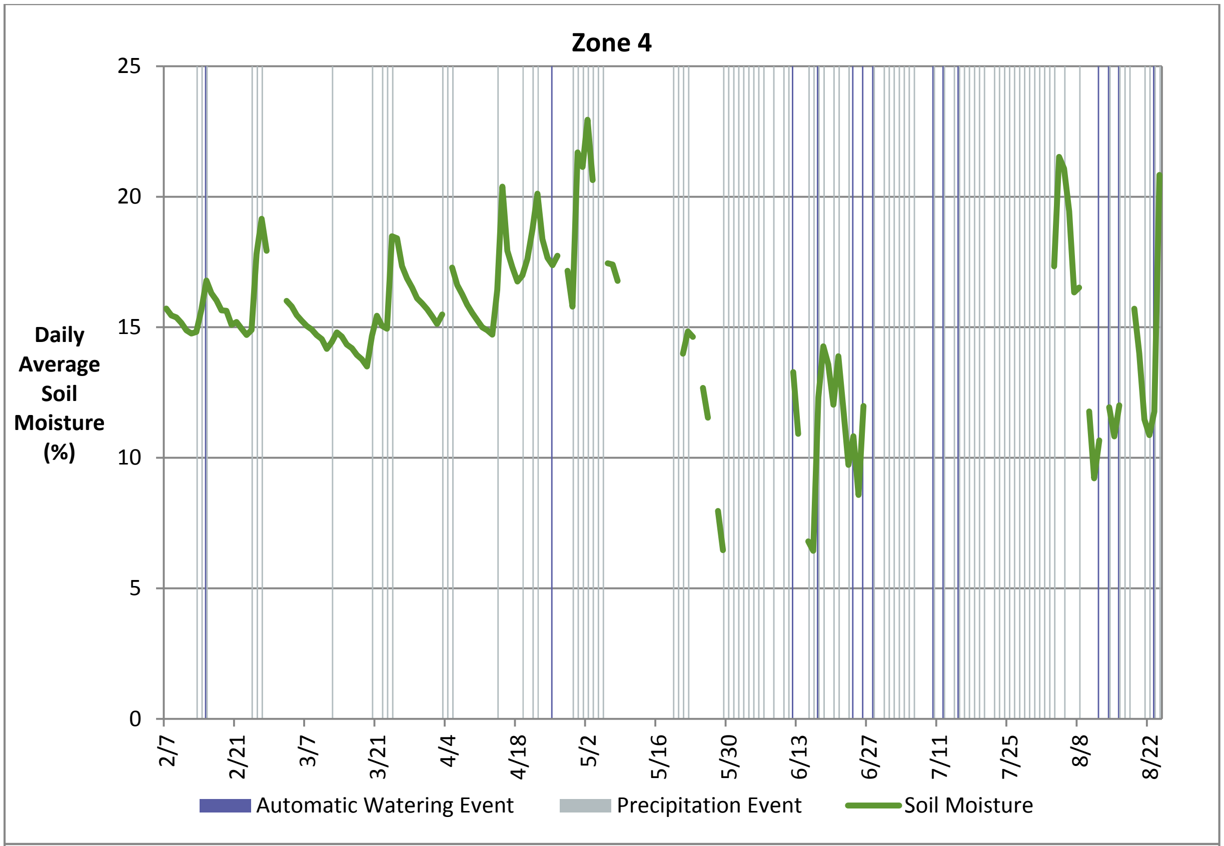
Soil moisture levels were tracked using the sensor logs posted by the system throughout the study. These readings were collected by the sensors buried within each zone at periodic intervals (approximately 15 minutes). Soil moisture level profiles were tracked over the entire course of the study by averaging all readings taken over the course of a day for each individual zone. Precipitation, as well as automatic watering events, is shown on the charts to both make note of system activities and verify that the soil moisture levels are triggering watering events. Note: the lines do not indicate the volume of water delivered to a zone, simply that an automatic watering event of some sort occurred. Gaps in the soil moisture trend line represent days for which no data are available for that zone.

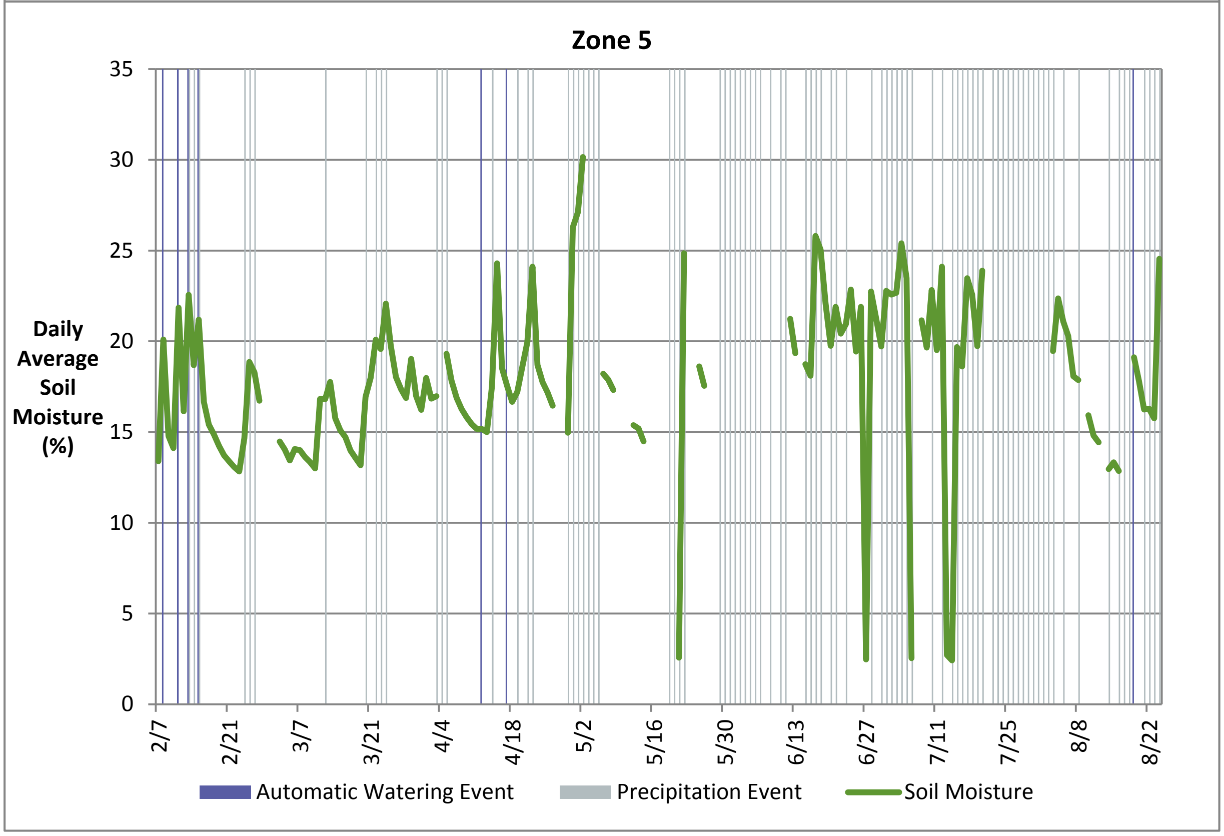
Figure 26. Daily Average Soil Moisture Profiles on Controller 1 Throughout the Study

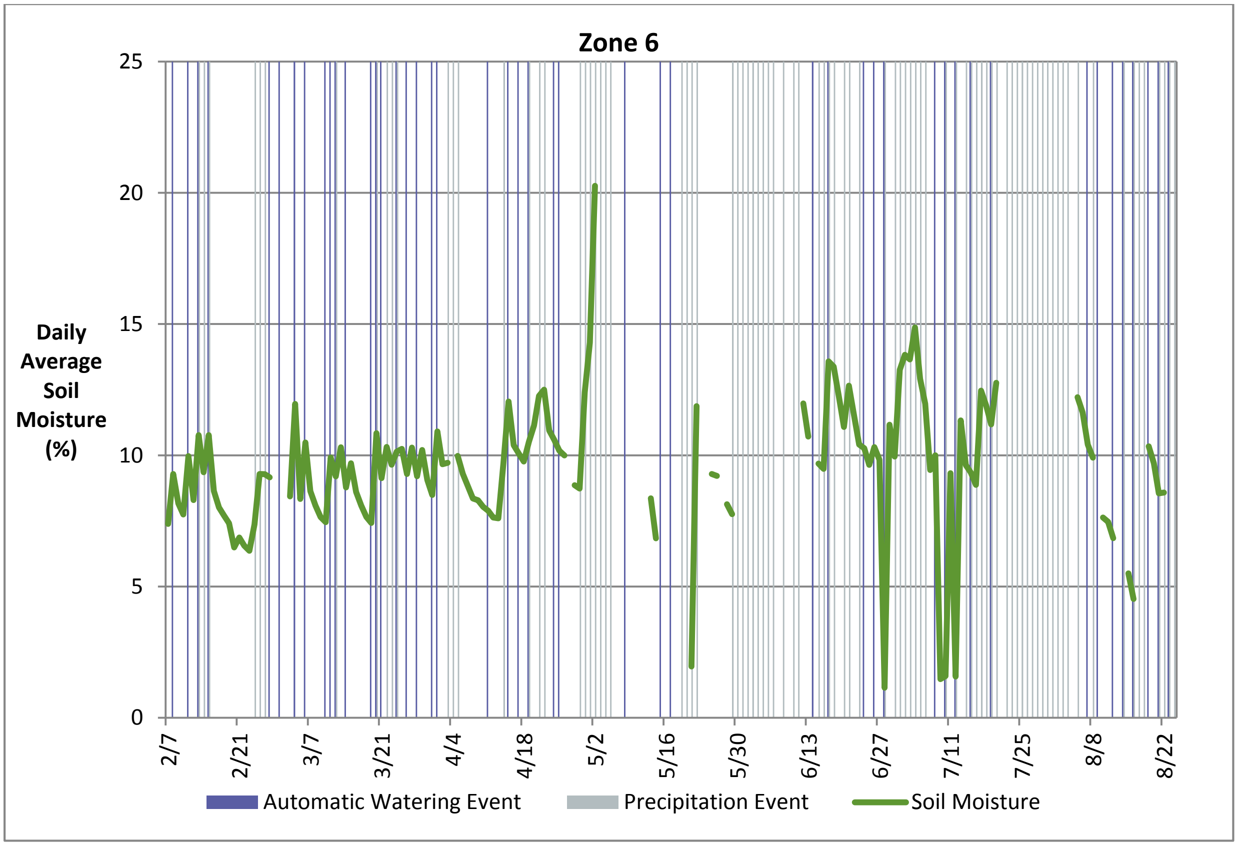


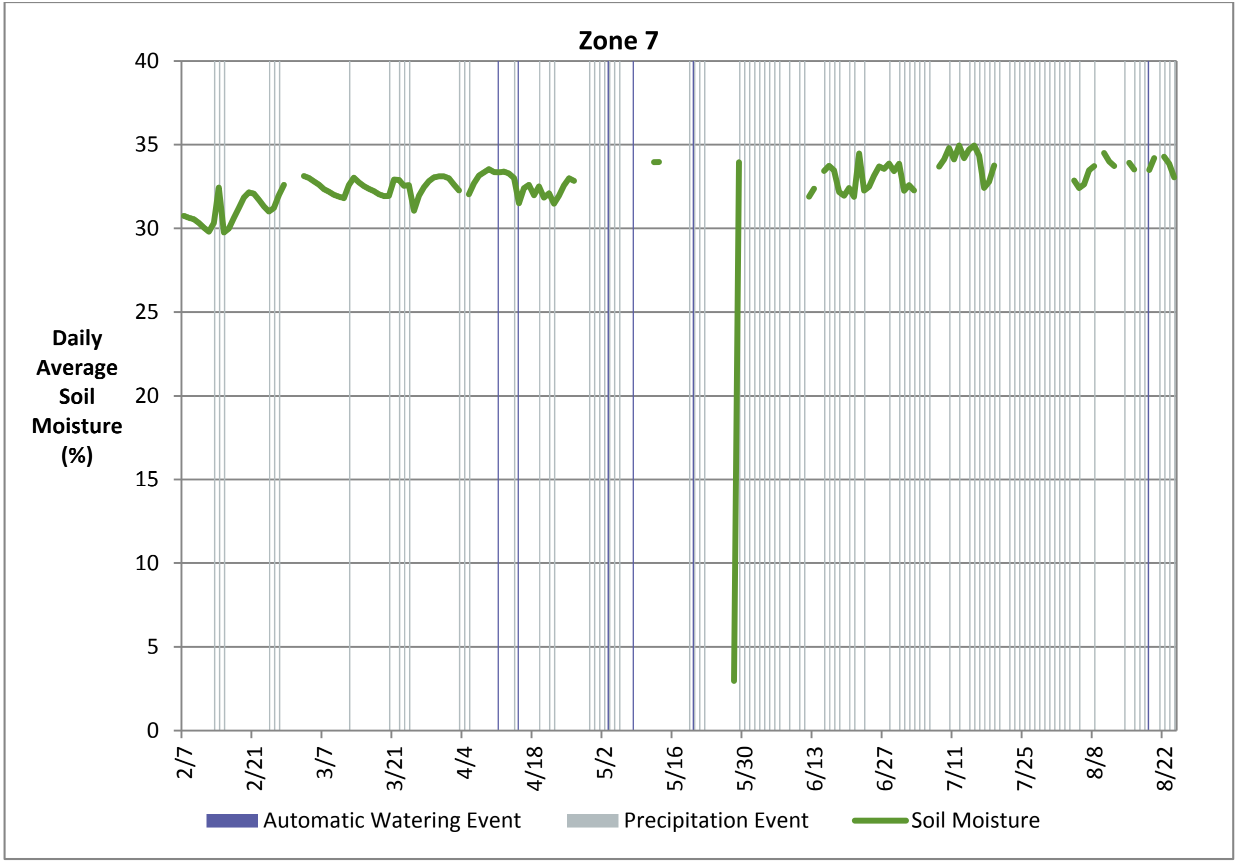

Zone 2
Daily Average Soil Moisture (%)
35
30
25
20
15
10
5
0
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture

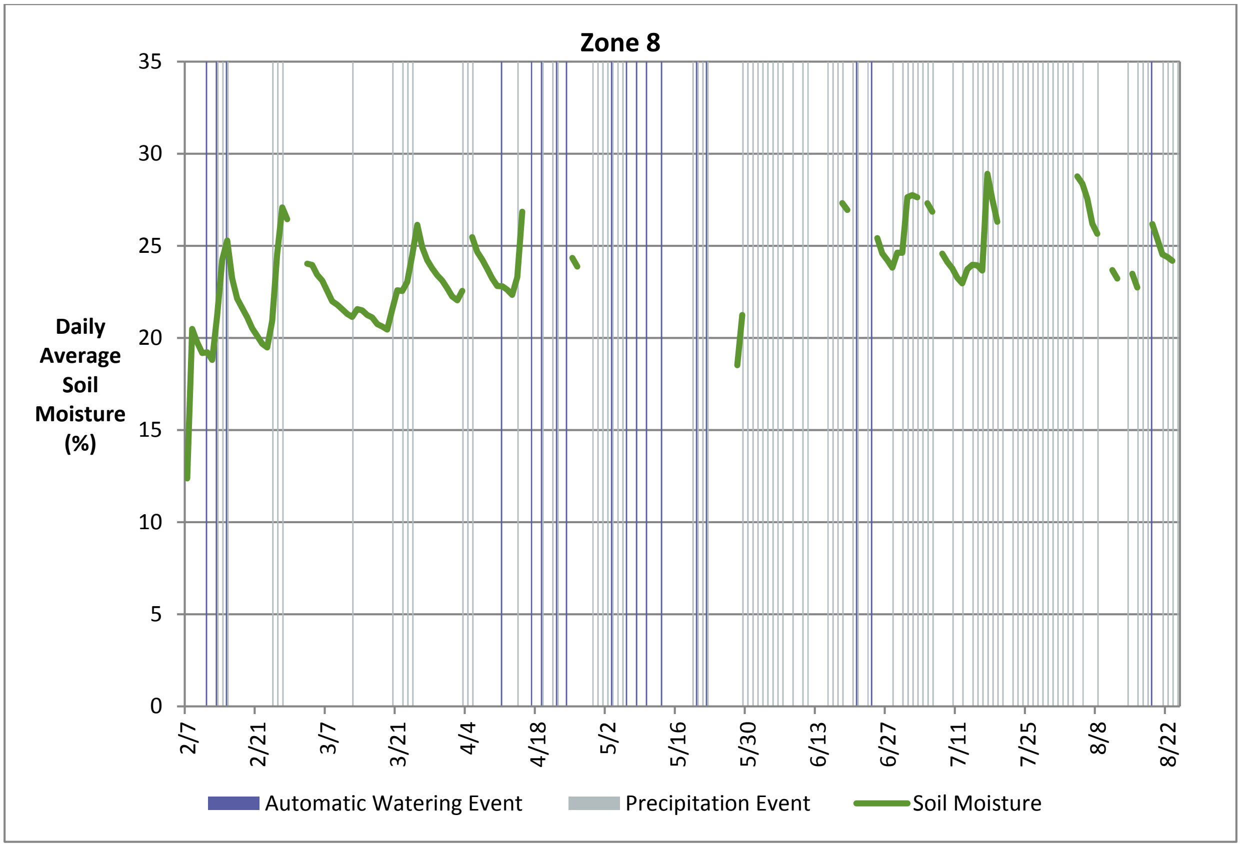

Zone 3
Daily Average Soil Moisture (%)
30
25
20
15
10
5
0
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture

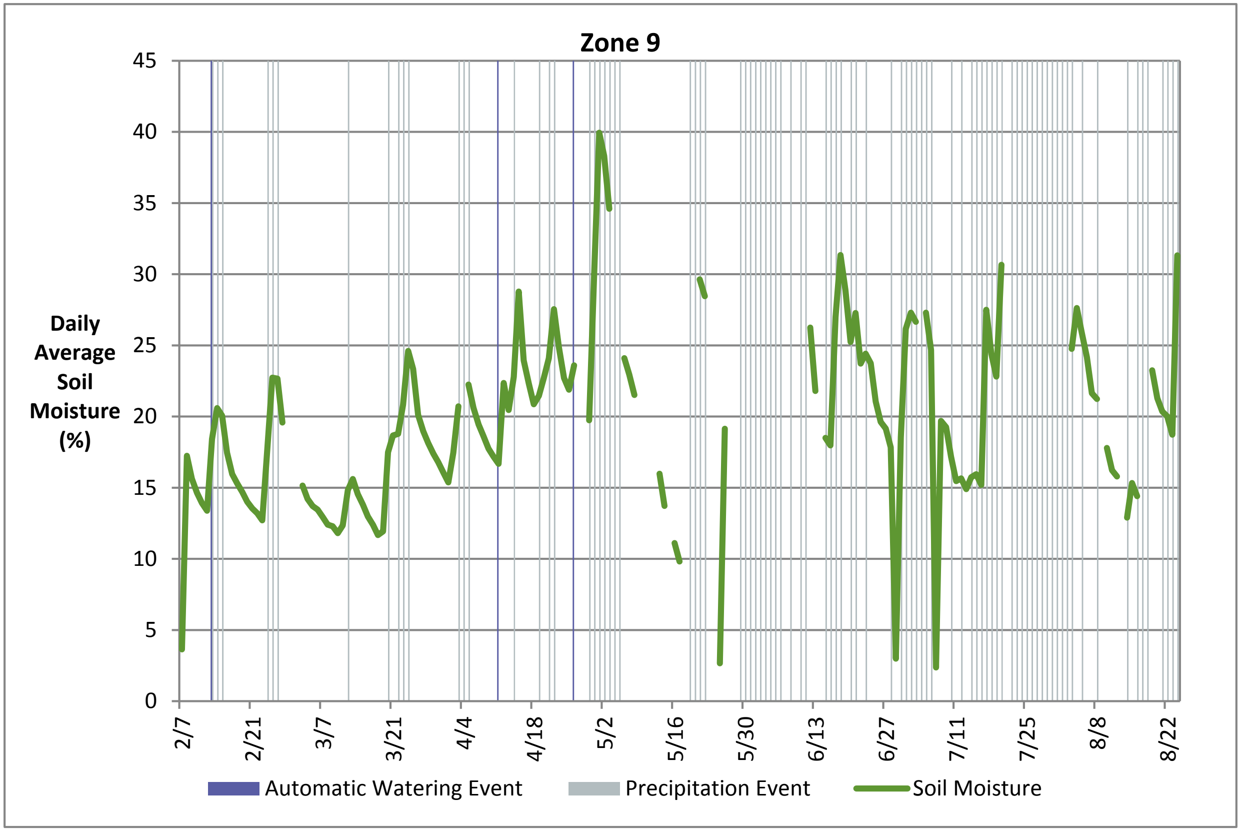

Zone 4
Daily Average Soil Moisture (%)
25
20
15
10
5
0
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture

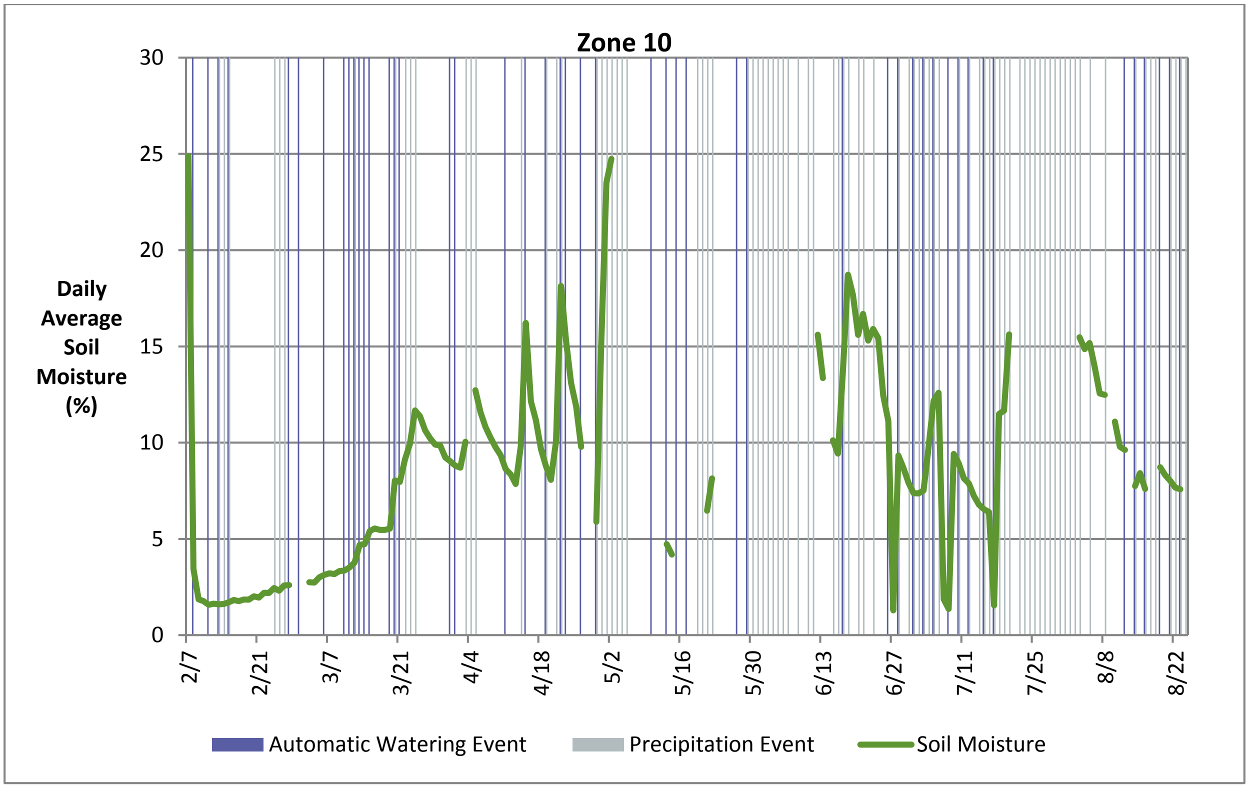

Zone 5
Daily Average Soil Moisture (%)
35
30
25
20
15
10
5
0
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture


Zone 6
Daily Average Soil Moisture (%)
0
5
10
15
20
25
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture


Zone 7
Daily Average Soil Moisture (%)
0
5
10
15
20
25
30
35
40
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture


Zone 8
Daily Average Soil Moisture (%)
35
30
25
20
15
10
5
0
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture


Zone 9
Daily Average Soil Moisture (%)
45
40
35
30
25
20
15
10
5
0
2/7
2/21
3/7
3/21
4/4
4/18
5/2
5/16
5/30
6/13
6/27
7/11
7/25
8/8
8/22
Automatic Watering Event
Precipitation Event
Soil Moisture



C. MANUFACTURER INFORMATION

The irrigation control technology used in this study is specifically designed to manage irrigation water by gathering data from buried sensors that monitor soil moisture and, using that information, to control the irrigation system. Using real-time soil moisture sensor data on a zone-by-zone basis, the irrigation control system applies the optimal amount of water. The controller is considered a smart irrigation management system because the system monitors real-time soil conditions and uses this data to adjust irrigation. A wireless communication network is used to send data from the soil moisture sensors to the controller. The controller monitors and records irrigation data from the soil moisture sensors and water meter. These data are web accessible through a web-enabled system, which is also capable of communicating alerts when atypical water consumption is identified. The technology evaluated was a pre-commercial technology which was what was available at the time of the assessment.

The soil moisture-based irrigation control system operates as follows:

- Soil moisture sensors, buried underground in individual irrigation zones, sense the amount of soil moisture, read as a percentage.
- Each irrigation zone’s soil moisture level is sent wirelessly to the irrigation control box.
- The irrigation control box is programmed with a minimum soil moisture threshold for each irrigation zone, whereby the irrigation is run to raise the soil moisture to an optimal level for plant health.
- The irrigation control box records the amount of time that the zone is irrigated.

- The control box sends the data to the manufacturer's central server, where it is stored and available to customers with permitted usernames and passwords.

D. LIST OF ABBREVIATIONS AND SYMBOLS

The following is a list of abbreviations and symbols used throughout this report.

Term	Description
BLCC	Building Life-Cycle Cost
EPA	U.S. Environmental Protection Agency
EPAct	Energy Policy Act
gal	gallon
gpm	gallons per minute
GPG	Green Proving Ground
GSA	U.S. General Services Administration
kgal	thousand gallons
LCC	life-cycle cost
LEED	Leadership in Energy and Environmental Design
M&V	measurement and verification
NA	not applicable
NIST	National Institute of Standards and Technology
NPV	net present value
PNNL	Pacific Northwest National Laboratory
SIR	savings-to-investment ratio
sqft	square feet
SWAT	Smart Water Application Technologies
TMY	typical meteorological year
TMY3	a third update of TMY data for 1,020 locations based on data from 1991 to 2005
yr	year

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