



Prepared for the General Services Administration  
By the Pacific Northwest National Laboratory



December 2014

# Assessment of Weather Station Used for Irrigation Control: Hart-Dole-Inouye Federal Center, Battle Creek, MI

KL McMordie Stoughton

RS Butner



The Green Proving Ground 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.

---

## DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Pacific Northwest National Laboratory (PNNL), nor Battelle Memorial Institute, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or PNNL, or Battelle Memorial Institute. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Pacific Northwest National Laboratory, or Battelle Memorial Institute. The work described in this report was funded by the U.S. General Services Administration under Contract No. PX0013875. PNNL is a multi-disciplinary research laboratory operated for the U.S. Department of Energy by Battelle Memorial Institute under contract number DE-AC05-76RL01830.

## NO ENDORSEMENTS

Any hyperlink to any website or any reference to any third party website, entity, product, or service is provided only as a convenience and does not imply an endorsement or verification by PNNL of such website, entity, product, or service. Any access, use or engagement of, or other dealings with such website, entity, product, or service shall be solely at the user's own risk.

## ACKNOWLEDGEMENTS

United States General Services Administration's Green Proving Ground National Program Team: Kevin Powell, Erika Larsen, Michael Hobson, Christine Wu, and David Gray

United States General Services Administration Region 5: Mark Hurley and Michael Virgilio

United States General Services Administration Hart-Dole-Inouye Federal Center: Dan Ahlberg, Dan Bartley, and grounds maintenance staff

Tenfold Information Design: Andrea Silvestri

Pacific Northwest National Laboratory: Susan Arey, Nathan Bauman, John Hail, Mike Parker, Steven Parker, Lorena Ruiz, Jennifer Williamson, Maura Zimmerschied, and Matt Wilburn.

For more information contact:

Kevin Powell  
Program Manager, Green Proving Ground  
Office of the Chief Greening Officer  
U.S. General Services Administration  
50 United Nations Plaza  
San Francisco, CA 94102-4912  
Email: kevin.powell@gsa.gov

# Table of Contents

I. Executive Summary.....	3
II. Introduction .....	11
A. Problem Statement .....	11
B. Opportunity.....	11
III. Methodology.....	14
A. Technology Description.....	14
B. Technical Objectives.....	15
IV. Measurement and Verification .....	16
A. Facility Description .....	16
B. Landscaped Areas .....	17
C. Baseline Irrigation Water Use .....	19
D. Technology Specification .....	21
E. System Monitoring .....	22
F. BAS Programming .....	24
G. Study Period .....	26
V. Results.....	27
A. Evapotranspiration Data .....	27
B. Theoretical Water Savings Potential .....	28
C. Economic Indicators fOR Weather-Based Control Technology .....	29
VI. Summary Findings and Conclusions.....	36
A. Overall Technology Assessment at Demonstration Facility .....	36
B. Barriers.....	38
C. Best Practices .....	38
VII. Appendices.....	40
A. Manufacturer Information .....	40
B. Evapotranspiration Information.....	42
C. List of Abbreviations and Symbols .....	44
D. References.....	45

## 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 weather-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, presents a qualitative discussion on potential water savings, and economic indicators for weather-based technology. The final section draws conclusions from the demonstration results and applicability for the U.S. General Services Administration (GSA).

### BACKGROUND

Water used to irrigate 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.<sup>1</sup> A common technology for controlling irrigation equipment is a timer-based system. Timer-based controllers have a preset timed schedule that does not take into account current weather conditions. A timer-based system typically runs on the same schedule throughout the growing season and is often not adjusted to account for actual environmental conditions. According to the EPA WaterSense program, as much as 50% of the water delivered using conventional timer-based irrigation controllers is wasted due to overwatering.<sup>2</sup>

There are smart irrigation controllers on the market that irrigate landscape based on actual conditions, providing the amount of supplemental irrigation that is needed by the plants to stay healthy. Several research studies show significant savings potential from proper use of smart irrigation controllers, generally ranging between 20% and 40% reduction in irrigation.<sup>3</sup> Using weather-based irrigation control technology has the potential to help GSA facilities meet the water reduction goals of Executive Order 13514.<sup>4</sup>

There are two main categories of smart irrigation controllers: weather-based and sensor-based. Weather-based (or climate-based) controllers use real-time weather data to determine landscape water requirements. Sensor-based controllers use on-site sensors, such as soil moisture sensors, to determine whether the landscape requires supplemental irrigation and adjust the irrigation schedule accordingly. This report only addresses weather-based irrigation control technology.

<sup>1</sup> U.S. Environmental Protection Agency. 2012. WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities. [http://www.epa.gov/watersense/commercial/docs/watersense\\_at\\_work/#/160/](http://www.epa.gov/watersense/commercial/docs/watersense_at_work/#/160/).

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

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

<sup>4</sup> 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>.

## OVERVIEW OF THE TECHNOLOGY

Weather-based irrigation control technology determines the amount of water needed by the landscape based on the current weather conditions. Weather data is provided by either an on-site weather station located at the facility or a nearby weather station. This data is used 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. Most weather-based irrigation controllers are integrated systems. The system evaluated here takes a novel approach to landscape irrigation by ceding control to the facility's Building Automation System (BAS).

- **Integrated system:** The irrigation controller is part of a turnkey system, typically supplied by an irrigation control company, with integrated weather data (via either an on-site or nearby weather station), software to determine the irrigation schedule based on actual water needs of the landscape, and flow sensors to monitor water use.
- **Building Automation System -interconnected system:** Irrigation equipment is controlled by a facility's BAS, whereby weather data is interconnected to the BAS via an on-site stand-alone weather station. The BAS is programmed to set the irrigation schedule based on ET, calculated by the weather station.

This Green Proving Ground (GPG) program project assessed a BAS-interconnected system that used a stand-alone weather station in conjunction with the facility's existing BAS at the Hart-Dole-Inouye Federal Center in Battle Creek, Michigan. The weather station was designed to provide data for commercial irrigation and agricultural irrigation scheduling. The weather station included weather sensors that measure real-time conditions, such as wind, temperature, relative humidity, solar radiation, and precipitation. Software was included in the weather station that calculated ET based on the monitored weather conditions, measured in inches of water required by the landscape to stay healthy. The weather station was required to be interconnected with the BAS and programmed by GSA facility staff to schedule the irrigation equipment.

## STUDY DESIGN AND OBJECTIVES

The objectives of this project were to assess the performance of the BAS-interconnected system that used the weather station and its integration into the facility's existing BAS to control the irrigation system based on ET, determine the potential reduction in irrigation water consumption, and ascertain whether this technology may assist other GSA facilities in reducing water usage. This BAS-interconnected configuration was chosen for the GPG project because the weather station offered a high quality, scientific-grade, stand-alone weather station.

In addition, interconnecting into the facility's BAS offers a centralized data management feature, allowing facility staff to monitor irrigation schedule and water use through the existing BAS platform. The BAS has the potential to be used as a diagnostic tool to monitor problems in the irrigation system such as leaks. The project also included tying advanced flow meters into GSA's web-enabled advanced metering system, creating a streamlined data management approach. GSA's advanced metering system tracks interval data across multiple facilities for different utilities, such as electricity, water, and natural gas. Connecting irrigation water meters into this system potentially may help to expand GSA's "smart building initiative," which has the goal to integrate major building systems on a common network and share information to

enhance building operation<sup>5</sup>. The objective of the assessment ultimately tried to determine if interconnecting a weather-based irrigation system to an existing BAS offers water and cost savings and advantages in data management.

The landscaped areas of the Hart-Dole-Inouye Federal Center comprise of a total of 3.2 acres, which primarily have Kentucky bluegrass turf and large trees (Figure ES.1). There are five irrigation zones that are controlled by the facility's BAS (noted as 1E, 2S, 2N, 2BS, and 2BN). The weather station was installed on the south side of the facility in an open field that is exposed to the general weather conditions. The weather station measured weather data in 15 minute intervals. The weather and ET data were transmitted to the facility's existing BAS via a hard wired connection, where data were collected, stored, and used to determine the irrigation schedule.

**Figure ES.1. Landscape at Hart-Dole-Inouye Federal Center**



The irrigation zones' water use was monitored by two flow meters. Zones were connected to GSA's integrated web-enabled advanced metering system and data were provided to Pacific Northwest National Laboratory (PNNL). For the purposes of this report, irrigation Zones 2N, 2BS, and 2BN are called "Meter Area 1" and irrigation Zones 1E and 2S are called "Meter Area 2." The study period for this assessment was from August 21, 2013, to September 26, 2013, which was shorter than planned because the BAS was not programmed to adjust the irrigation schedule based on ET until August 21<sup>st</sup>. In addition, the meter for two of the irrigation zones was not installed and connected to the advanced metering system until September 2.

<sup>5</sup> Information on GSA's Smart Building Initiative can be found at: <http://www.gsa.gov/portal/content/103965>

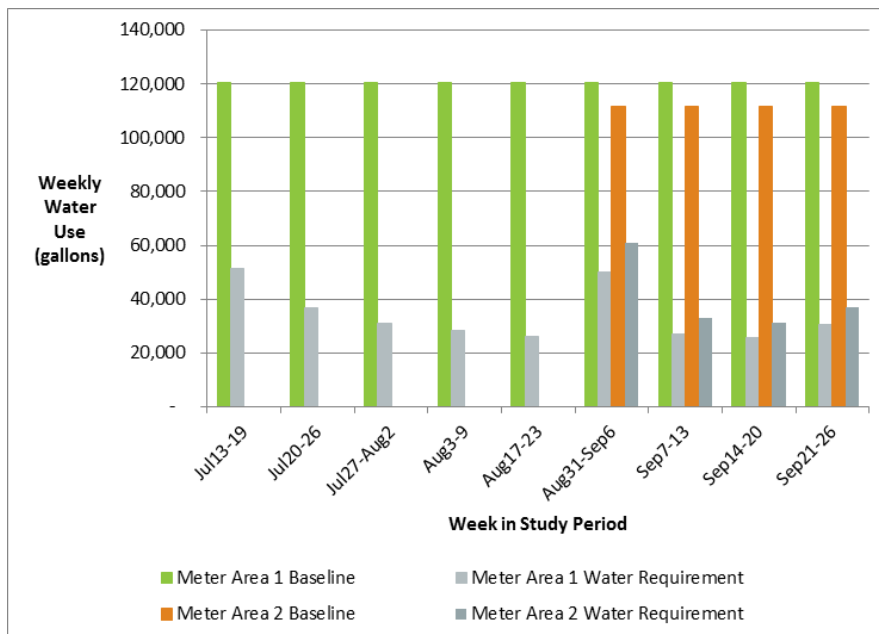
## PROJECT RESULTS/FINDINGS

The programming of the BAS to set the irrigation schedule was challenging. The manufacturer of the weather station did not provide technical support because BAS programming was outside of the manufacturer’s expertise and technical assistance. Ultimately, the BAS was not programmed properly to accurately adjust runtime under all conditions. In addition, the rain sensor was not properly maintained during the study period and was over-recording precipitation, which, in turn, caused the system to underwater the landscape at certain times during the study.

Because of the shortened study period and inaccurate irrigation scheduling, it was not possible to perform the originally planned analysis to determine system savings and cost-effectiveness. Therefore, the research team developed an alternative analysis to determine potential savings by estimating the theoretical irrigation demand that would have been applied to the landscape with proper scheduling. This was done by calculating the required supplemental water for each irrigation zone based on the ET and precipitation data that were collected during the study period. Actual supplemental irrigation requirements of each zone were determined by subtracting the weekly precipitation received at the site from the total weekly ET calculated by the weather station, which totaled 1.4 million gallons (Mgal) over the irrigation season. A calculated baseline of 4.1 Mgal per year was developed based on the timer-based system. The potential savings in annual water use is thus 2.7 Mgal, or 66%.

Figure ES.2 shows the calculated baseline for Meter Area 1 and Meter Area 2 over the weeks of the study period. This was estimated by multiplying the flow rate of each zone, measured in gallons per minute, and by the weekly minutes of runtime of the each zone’s irrigation schedule prior to the installation of the weather station. Figure ES.2 also shows the theoretical weekly water use for Meter Area 1 and Meter Area 2 calculated from actual ET and precipitation data, as described above. The difference between the baseline and estimated water requirement on the chart reveals the potential savings.

**Figure ES.2. Comparison of Weekly Baseline to Theoretical Water Requirements Based on ET**





The study's planned standard economic analysis was not performed because the post-retrofit water usage data was not sufficient to annualize the results. Without a credible annualized estimate, the cost savings expected from the technology could not be calculated. The assessment team therefore developed an alternative economic analysis to provide useful guidance on the economic viability of Battle Creek's BAS-interconnected system and integrated weather-based systems. This analysis was completed by conducting a life-cycle cost (LCC) analysis for three scenarios, as follows:

**Scenario 1 - Battle Creek BAS-interconnected system:** This scenario used the actual costs of the Battle Creek project, the theoretical savings of 66%, and the site's water unit cost of \$5.00 per thousand gallons (kgal).

**Scenario 2 - Large-sized facility with integrated weather-based system:** A series of LCC analyses were performed on a hypothetical integrated weather-based controller for a large facility with a 4 Mgal annual water use baseline (an irrigation demand similar to the Battle Creek facility) with a savings of 20% to 40%, variable water rates from \$3/kgal to \$8/kgal in \$1/kgal increments, and variable installed costs from 10,000 to \$30,000 in \$5,000 increments.

**Scenario 3 - Medium-sized facility with integrated weather-based system:** This scenario uses the same variables as Scenario 2 for a medium-sized facility approximately half the size of the Battle Creek facility with an annual irrigation baseline of 2 Mgal.

The LCC analyses determined the LCC-effectiveness of the three scenarios by establishing when the savings-to-investment ratio (SIR) is equal to one. The LCC analysis for the Battle Creek BAS-interconnected system (Scenario 1) resulted in an SIR of 7.7, which reveals that using ET to determine irrigation scheduling has the potential to be LCC-effective for the Battle Creek facility if the system is properly programmed.

The analysis revealed the "breakeven" water rates and installed costs for Scenarios 2 and 3, which is the cost at which the system should become LCC-effective with water savings ranging between 20% and 40%, which is the expected range of savings for integrated weather-based controllers.<sup>6</sup> The intent of Scenarios 2 and 3 is to simply provide GSA facilities with the general level of savings required to achieve an LCC-effective project at a specific water rate and installed cost. This analysis reveals that a large GSA facility (Scenario 2) can expect to have an LCC-effective project of an integrated weather-based system with a water rate of \$2.87/kgal at an installed cost of \$15,000, assuming a low-end water savings of 20%. The breakeven installed cost is \$21,300 at a water rate of \$3.00/kgal, assuming the low-end water savings of 20%. A medium-sized facility (Scenario 3) can expect to have an LCC-effective project with a water rate of \$4.72/kgal at an installed cost of \$20,000 and a breakeven installed cost of \$31,200 at \$8.00/kgal, assuming 20% savings. The SIR results are shown in Table ES.1, Table ES.2, and Table ES.3.

<sup>6</sup> Dukes, MD. *Water Conservation Potential of Landscape Irrigation Smart Controllers*. American Society of Agricultural and Biological Engineers. ISSN 2151-0032. 2012.

**Table ES.1. Economic Results for Scenarios 2 and 3 with Varying Water Rates**

Water Rate	SIR <sup>a</sup>	Simple Payback (years) <sup>a</sup>	SIR <sup>b</sup>	Simple Payback (years) <sup>b</sup>
\$3/kgal	1.1 – 2.6	4.9 – 11.8	0.4 – 1.4	8.8 – 30.0
\$4/kgal	1.6 – 3.5	3.5 – 8.0	0.8 – 2.1	6.0 – 16.7
\$5/kgal	2.1 – 4.5	2.7 – 6.1	1.1 – 2.7	4.6 – 11.5
\$6/kgal	2.6 – 5.5	2.3 – 4.9	1.4 – 3.4	3.7 – 8.8
\$7/kgal	3.1 – 6.5	1.9 – 4.1	1.8 – 4.1	3.1 – 7.1
\$8/kgal	3.6 – 7.5	1.7 – 3.5	2.1 – 4.7	2.6 – 6.0
Breakeven Water Rate	Low end savings: \$2.87/kgal	High end savings: \$1.43/kgal	Low end savings: \$4.72/kgal	High end savings: \$2.36/kgal

<sup>a</sup> Scenario 2 (installed cost of \$20,000) - Large Facility with Integrated System with 20% to 40% Savings

<sup>b</sup> Scenario 3 (installed cost of \$15,000) - Medium Facility with Integrated System with 20% to 40% Savings

**Table ES.2. Economic Results for Scenarios 2 and 3 with Varying Installed Cost and \$3/kgal Water Rate**

Installed Cost	SIR <sup>a</sup>	Simple Payback (years) <sup>a</sup>	SIR <sup>b</sup>	Simple Payback (years) <sup>b</sup>
\$10,000	2.1 – 5.1	2.4 – 5.9	0.7 – 2.1	5.9 – 20.0
\$15,000	1.4 – 3.4	3.7 – 8.8	0.4 – 1.4	8.8 – 30.0
\$20,000	1.1 – 2.6	4.9 – 11.8	0.3 – 1.1	11.8 – 40.0
\$25,000	0.9 – 2.0	6.1 – 14.7	0.3 – 0.9	14.7 – 50.0
\$30,000	0.7 – 1.7	7.3 – 17.7	0.2 – 0.7	17.7 – 60.0
Breakeven Installed Cost	Low end savings: \$21,300	High end savings: \$51,000	Low end savings: \$6,500	High end savings: \$21,300

<sup>a</sup> Scenario 2 - Large Facility with Integrated System with 20% to 40% Savings

<sup>b</sup> Scenario 3 - Medium Facility with Integrated System with 20% to 40% Savings

**Table ES.3. Economic Results for Scenarios 2 and 3 with Varying Installed Cost and \$8/kgal Water Rate**

Installed Cost	SIR <sup>a</sup>	Simple Payback (years) <sup>a</sup>	SIR <sup>b</sup>	Simple Payback (years) <sup>b</sup>
\$10,000	7.1 – 15.0	0.8 – 1.8	3.1 – 7.1	1.8 – 4.0
\$15,000	4.7 – 10.0	1.2 – 2.6	2.1 – 4.7	2.6 – 6.0
\$20,000	3.5 – 7.5	1.7 – 3.5	1.6 – 3.5	3.5 – 8.0
\$25,000	2.8 – 6.0	2.1 – 4.4	1.3 – 2.8	4.4 – 10.0
\$30,000	5.0 – 2.4	2.5 – 5.3	1.0 – 2.4	5.3 – 12.0
Breakeven Installed Cost	Low end savings: \$70,800	High end savings: \$150,000	Low end savings: \$31,200	High end savings: \$70,800

<sup>a</sup> Scenario 2 - Large Facility with Integrated System with 20% to 40% Savings

<sup>b</sup> Scenario 3 - Medium Facility with Integrated System with 20% to 40% Savings

## CONCLUSIONS

In general, weather-based irrigation controls offer a considerable improvement compared to timer-based controls, which can lead to significant water and monetary savings. However, the BAS-interconnected system at the Battle Creek facility was challenging to install, program, and commission. A possible solution is to develop a standardized programming protocol for a BAS-interconnected system, which potentially could be replicated at GSA facilities. This protocol, however, was not developed during the course of this study and the research team was unable to determine if a standardized protocol is replicable at other GSA facilities. GSA facility and regional staff continue to improve the BAS programming and better commission the system with the objective to achieve a properly functioning system. GSA should leverage the current work being performed at Battle Creek as the system functioning improves to understand the potential benefits of a BAS-interconnected weather-based control technology.

An alternative technology option to the BAS-interconnected controller is an integrated weather-based system, which is a turnkey product that provides all of the crucial elements required for both determining ET and controlling the irrigation equipment. An integrated weather-based system has internal software that determines the runtime of the irrigation equipment, requiring minimal programming by site staff. Because of these features, the integrated system will likely be more easily deployed at other GSA facilities.

GSA should consider the deployment of integrated weather-based systems. These systems are readily available on the market from a variety of irrigation control companies and are recommended by the Department of Energy Federal Energy Management Program's Best Management Practice on Water-Efficient Irrigation.<sup>7</sup> In addition, the EPA published an irrigation best practice that also recommends the use of integrated weather-based irrigation control technology.<sup>8</sup> 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 Smart Water Application Technologies (SWAT) testing protocol for weather-based controllers.
- 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 calculates system runtime based on ET; software should allow for user input to specify specific 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.

<sup>7</sup> U.S. Department of Energy Federal Energy Management Program. 2013. Best Management Practice: Water-Efficient Irrigation. [http://www1.eere.energy.gov/femp/program/waterefficiency\\_bmp5.html](http://www1.eere.energy.gov/femp/program/waterefficiency_bmp5.html).

<sup>8</sup> U.S. Environmental Protection Agency. 2012. WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities. [http://www.epa.gov/watersense/commercial/docs/watersense\\_at\\_work/#/160/](http://www.epa.gov/watersense/commercial/docs/watersense_at_work/#/160/).

- For large facilities with multiple irrigation zones, consider installing a centralized control system with weather data integrated into the system that 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, which allows for manual adjustment of the controller to reduce irrigation below the required 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 data 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 as a result of real-time precipitation data being 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.

## 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 federally owned and leased assets and is responsible for managing an inventory of diverse federal buildings totaling more than 354 million square feet. GSA has an abiding interest in examining the technical performance and cost-effectiveness of different energy- and water-efficient technologies in its existing building portfolio, as well as those currently proposed for construction. Given that a large majority of the GSA's buildings include landscaping, identifying appropriate water-efficient irrigation solutions has been a high priority for GSA. Since the enactment of the Energy Policy Act of 2005 [1] and issuance of Executive Order 13423, "Strengthening Federal Environmental, Energy, and Transportation Management (2007)," [2] and Executive Order 13514, "Federal Leadership in Environmental, Energy, and Economic Performance (2009)," [3] other federal agencies are looking to GSA for strategies for meeting the water-related goals laid out by this statute and these executive orders. Specifically, agencies are required to reduce the potable water use intensity (measured in gallons per square foot of facility space) 2% per year through Fiscal Year 2020, based on a baseline year in Fiscal Year 2007. Based on the sheer size of the building portfolio, there exists a large opportunity for potential water savings.

### A. PROBLEM STATEMENT

Timer-based irrigation controllers are commonly used to control irrigation systems at GSA facilities. Timer-based controllers have a preset timed schedule that is determined by the operator. The irrigation system runs during a set time frame on specific days, agnostic to current weather conditions, such as rainfall. A timer-based system typically runs on the same schedule throughout the growing season and is not adjusted to account for precipitation or other weather conditions. Timer-based controllers can be very wasteful because the irrigation system will operate under any conditions, rain or shine. There are smart irrigation controllers on the market that irrigate landscape based on actual conditions, providing the amount of supplemental irrigation that is needed by the plants.

### B. OPPORTUNITY

The major advantage of smart irrigation controllers is that the technology uses live, local data to determine the irrigation schedule. Instead of running the irrigation system on a timed schedule, the irrigation system is only activated when the plants require water. According to the U.S. Environmental Protection Agency's (EPA) WaterSense Program,<sup>1</sup> 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 use weather data to determine landscape water requirements. Sensor-based

---

<sup>1</sup> The WaterSense program is an EPA partnership program that promotes water efficiency through the certification and labeling of water-efficient products. More information can be found on WaterSense at: <http://www.epa.gov/watersense/>

controllers use on-site sensors, such as soil moisture sensors, to determine whether the landscape requires irrigation and adjusts the irrigation schedule accordingly.

This Green Proving Ground (GPG) program project only addresses weather-based irrigation control technology. Weather-based irrigation control technology determines the amount of water needed by the landscape based on the current weather conditions, such as precipitation, solar radiation, temperature, relative humidity, and wind speed. Weather data is provided by either an on-site weather station located at the facility or a nearby weather station. This data is used 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, sets the schedule of the irrigation equipment based on the ET data. (Section VII-C provides more information on ET and how it is calculated.)

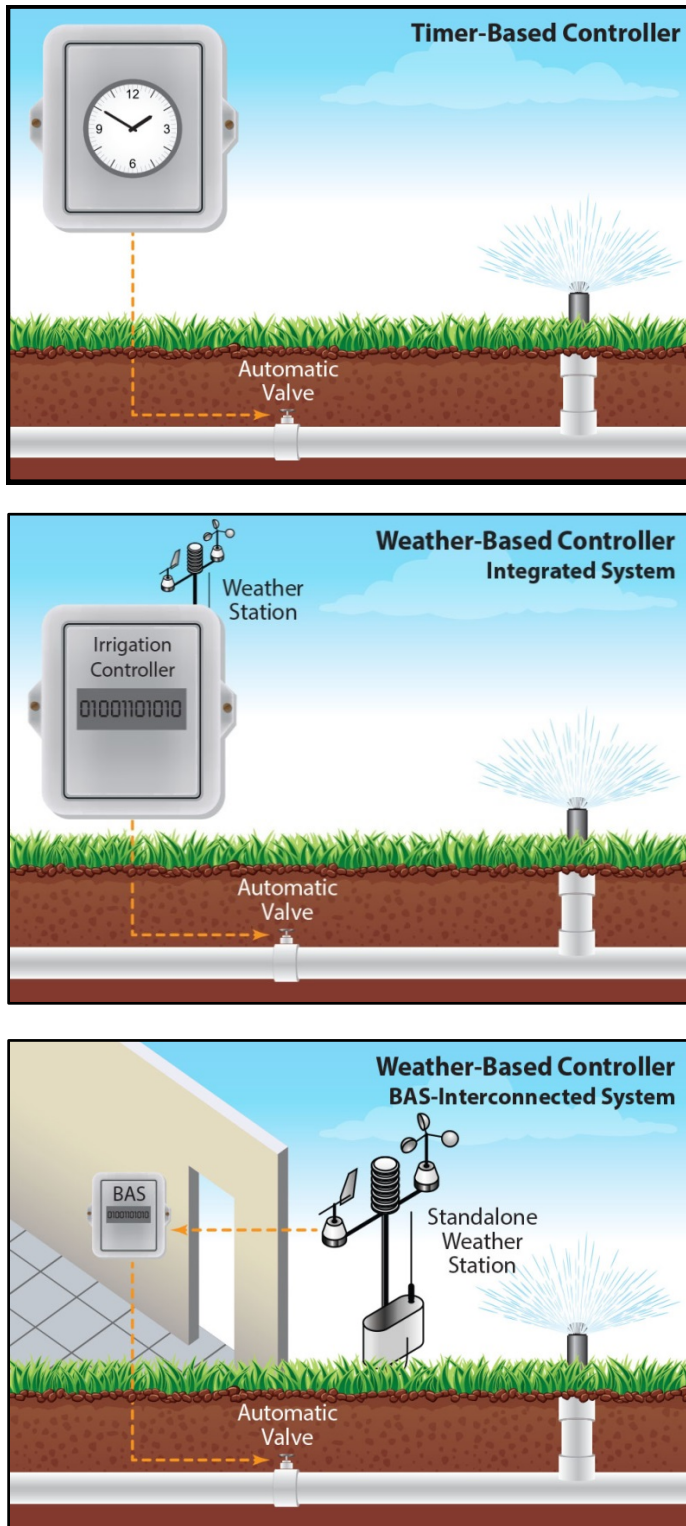
There are two main configurations for a weather-based irrigation control system:

- **Integrated system:** The irrigation controller is part of a turnkey system, typically supplied by an irrigation control company, with integrated weather data (via either an on-site or nearby weather station), software to determine the irrigation schedule based on actual water needs of the landscape, and flow sensors to monitor water use. The integrated system is the most common type of weather-based control system.
- **Building Automation System -Interconnected System:** Irrigation equipment is controlled by a facility's building automation system (BAS), whereby weather data is interconnected to the BAS via an on-site stand-alone weather station. The BAS is programmed to determine the irrigation schedule based on ET, calculated by the weather station.

Schematics of a timer-based irrigation controller and the two types of weather-based irrigation control systems are shown in Figure 1. (More details on how weather-based control technology functions are provided in Section III.A.)

For this GPG project, Pacific Northwest National Laboratory (PNNL) assessed a BAS-interconnected system that used a stand-alone, on-site weather station in conjunction with the facility's existing BAS at the Hart-Dole-Inouye Federal Center in Battle Creek, Michigan. This configuration was chosen for the GPG project because the weather station offered a high quality, scientific-grade, stand-alone weather station, which may prove to be more robust than typical weather stations used in integrated systems.

Figure 1. Schematics of Timer-Based and Weather-Based Irrigation Controllers



### III. Methodology

The methodology section is divided into two subsections: first, a detailed description of the technology is provided and second, the desired technical objectives are discussed.

#### A. TECHNOLOGY DESCRIPTION

The stand-alone weather station was installed at Hart-Dole-Inouye Federal Center (Figure 2). The weather station is designed to provide data for commercial irrigation and agricultural irrigation scheduling. The station calculates ET, which is the level of water loss due to evaporation and plant transpiration from the soil. The station includes the following weather sensors:

- wind sensor
- solar radiation sensor
- air temperature probe
- relative humidity probe
- rain gauge.

Software is included in the weather station that calculates ET based on the monitored weather conditions and the type of landscape at the location. ET is measured in inches of water required by the landscape to stay healthy. Section VII-C provides information on how ET is calculated. The weather station was connected via a hardwire connection to the facility's BAS.

**Figure 2. Weather Monitoring Station**





In contrast, an integrated weather-based controller incorporates components provided turnkey by the manufacturer. Typical features of these systems include:

- integrated weather sensors that measure precipitation and other weather factors or automatic transmission of weather data from a nearby weather station;
- a controller with multi-zone scheduling and monitoring that allows for customized scheduling;
- hydraulic monitoring to detect pressure changes in the system that can alert staff of system leaks or valve failures; and
- integrated software that calculates ET and adjusts irrigation schedule automatically and offers centralized control.

## **B. TECHNICAL OBJECTIVES**

The objectives of this project are to assess the performance of the BAS-interconnected system that used the weather station and its integration into the facility's existing BAS to control the irrigation system based on ET, determine the potential reduction in irrigation water consumption, and ascertain whether this technology may assist other GSA facilities in reducing water usage. This BAS-interconnected configuration was chosen for the GPG project because the weather station offered a high quality, scientific-grade, stand-alone weather station.

In addition, interconnecting into the facility's BAS offers a centralized data management feature, allowing building operators to collect and interpret water data via the existing BAS platform. The BAS offers a diagnostic tool to monitor potential operational problems in the irrigation system, such as system leaks. The project included tying advanced flow meters into the GSA's web-enabled advanced metering system, creating a streamlined data management approach. GSA's advanced metering system tracks interval data across GSA's inventory of facilities for different utilities, such as electricity, water, and natural gas. Connecting irrigation water meters into this system potentially may help to expand GSA's "smart building initiative," which has the goal to integrate major building systems on a common network and share information to enhance building operation<sup>2</sup>. Ultimately, the objective of the assessment is to determine if interconnecting a standalone weather station to an existing BAS offers water and cost savings and advantages in data management.

<sup>2</sup> Information on GSA's Smart Building Initiative can be found at: <http://www.gsa.gov/portal/content/103965>

## IV. Measurement and Verification

The measurement and verification plan section includes six 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 use. The third subsection provides the technology specification for the weather station at the Federal Center. The fourth subsection identifies the system monitoring that was performed for the assessment. The fifth subsection describes the programming required for irrigation scheduling. Finally, the sixth subsection describes the study period for the assessment.

### A. FACILITY DESCRIPTION

The GPG project was performed at Hart-Dole-Inouye Federal Center. The complex includes 21 buildings and sits on 24 acres. The main facility, referred to as “Building 1,” is a 15-story building (Figure 3). Building 1 was added to the original building, referred to as “Building 2.” Building 2 is a historic building, dating back to 1902 [6].

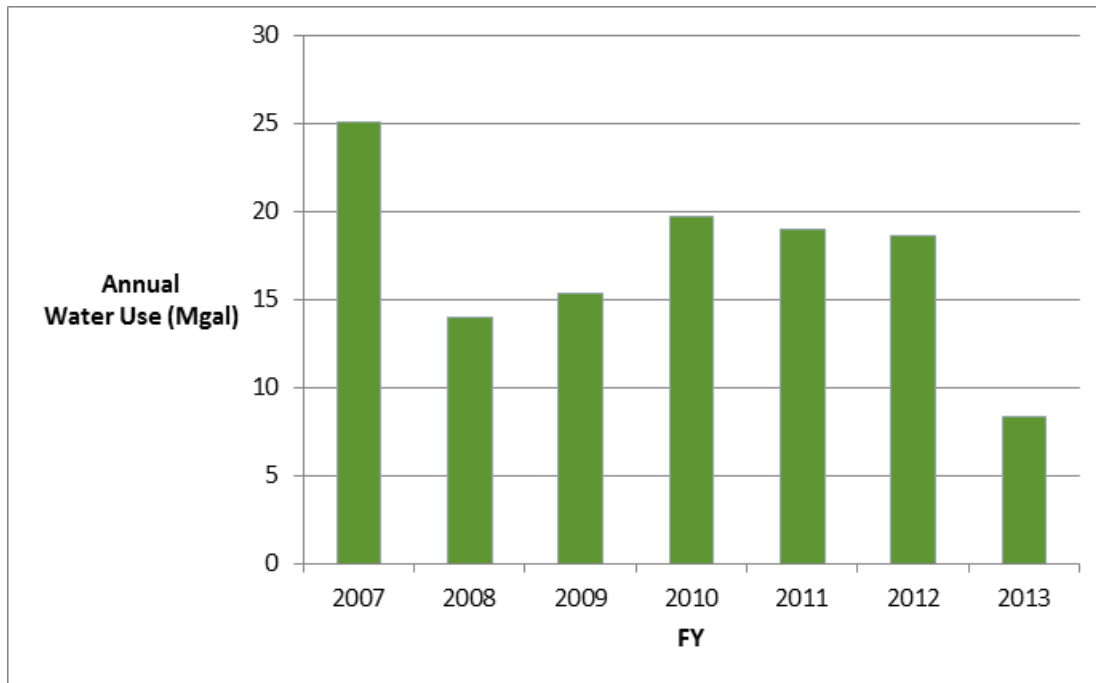
**Figure 3. Photograph of the Hart-Dole-Inouye Federal Center.**



Source: <http://www.panoramio.com/photo/3711952>

In fiscal year (FY) 2014, the facility won a Federal Energy and Water Management Award from the Department of Energy’s Federal Energy Management Program (FEMP). The award was given to the facility for reducing water by 55% in one year from FY 2012 to FY 2013. These reductions were accomplished by directing rainwater through drains on two roofs to an abandoned 125,000 gallon cistern to serve both cooling tower make-up water and manual irrigation, closing off several irrigation lines that were no longer necessary, and reducing irrigation water use associated with the BAS-interconnected weather station. Figure 4 shows annual water use from FY 2007 through FY 2013, revealing the large water reduction in FY 2013.

**Figure 4. Annual Water Use from 2007 through 2013.**



#### **B. LANDSCAPED AREAS**

The landscaped areas of the Hart-Dole-Inouye Federal Center comprise a total of 3.2 acres. The landscape in these zones consists primarily of Kentucky bluegrass turf with large trees (Figure 5). There are five irrigation

zones that are controlled by the facility’s BAS, denoted as 1E, 2S, 2N, 2BS, and 2BN. Table 1 provides the area for each irrigation zone and Figure 6 provides the irrigation zone map.

**Figure 5. Landscape at Hart-Dole-Inouye Federal Center**



**Table 1. Irrigation Zone Areas**

Irrigation Zone Number	Landscape Area (square feet/acres)
1E	42,950 / 1.0
2S	18,070 / 0.4
2N	33,810 / 0.8
2BN	11,970 / 0.3
2BS	30,950 / 0.7
Total	137,750 / 3.2

Figure 6. Irrigation Zone Map



### C. BASELINE IRRIGATION WATER USE

The original timer schedule of the irrigation system was provided by the grounds maintenance manager at the GSA facility, provided in Table 2. The original timer schedule was in operation every day of the week during the irrigation season, which is typically from May or June through September or October, depending on irrigation needs in late spring and early autumn. The baseline water usage using the original timer schedule was estimated by taking the flow rate of the zone, measured in gallons per minute (gpm), and applying the minutes of runtime from the timer schedule. The following simplified equation shows how the baseline was calculated.

$$\text{flow rate} \frac{\text{gal}}{\text{min}} \times \text{daily run time} \frac{\text{min}}{\text{day}} \times \text{weekly schedule} \frac{\text{days}}{\text{week}} \times \text{number of weeks} \frac{\text{weeks}}{\text{irrigation season}} = \text{Baseline Volume (gal)}$$

The flow rate for each zone was provided by the Hart-Dole-Inouye facility manager; it was measured by the irrigation meters (described in Section IV-D). The zone flow rate is dependent on the number of sprinkler heads installed in the zone. Zones 2S and 2BN had significantly more sprinkler heads per landscape area than the other irrigation zones. Zones 2S and 2BN are the principal landscaped areas for the facility; therefore, the irrigation design included additional sprinkler heads to supply more water to keep the grass lush.

Based on these flow rates, the annual water usage baseline for irrigation zones is estimated to be between 3.7 and 4.6 million gallons (Mgal) per year, based on an irrigation season of 16 to 20 weeks, averaging 4.2 Mgal per year. Typically, irrigation is suspended in late September and the system is winterized in October. The baseline monthly water use totaled 928,200 gallons. Data on zone schedule, flow rate, relative flow rate per landscape area, and baseline water consumption are shown in Table 2.

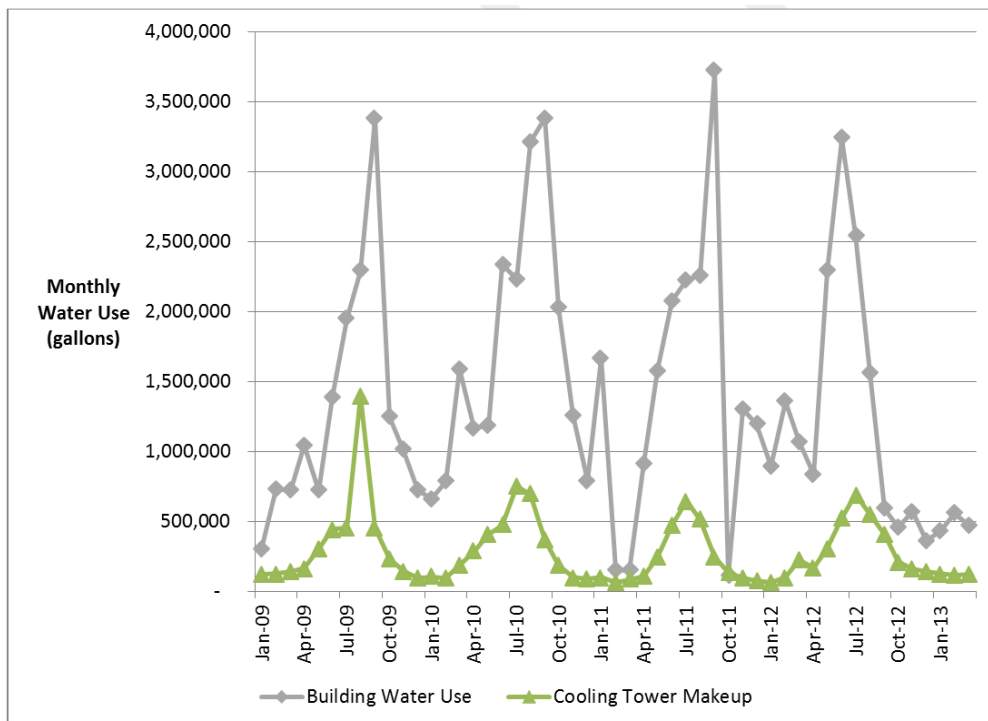
**Table 2. Irrigation Zone Schedule, Flow Rates, and Baseline Water Use**

Irrigation Zone Number	Original Timer Schedule (minutes per day)	Weekly Schedule (days per week)	Zone Flow Rate (gpm)	Flow per Area (gpm per 1000 sqft)	Baseline Water Use (1000 gallons)
1E	120	7	92.0	2.1	1,391
2S	60	7	82.0	4.5	344
2N	60	7	45.5	1.3	617
2BN	120	7	49.0	4.1	741
2BS	120	7	71.5	2.3	1,081
<b>Total</b>					<b>4,177</b>

**FACILITY WATER USAGE DATA**

PNNL was provided data on total water usage for the facility and on metered cooling tower makeup water, which were used to verify the baseline irrigation water usage estimated from the timer-based schedule. The building-level water usage data from 2009 through 2012 show a significant spike in water use typically between May through October. The cooling tower makeup water reflects this general seasonal pattern as well, as shown in Figure 7. The other contributor to the summer peak in water use is irrigation. Irrigation can be estimated by taking the difference between the facility’s total water usage and cooling tower makeup water during the peak period, taking into account the indoor water usage. The facility’s indoor water usage was estimated from the average water consumed during the winter months (non-peak period). Between 2009 and 2012, it is estimated that 4.5 Mgal was used per year in irrigation on average. This substantiates the baseline calculated from the timer-based schedule, which averaged approximately 4.1 Mgal annually.

**Figure 7. Building Water Use and Cooling Tower Makeup from 2009 through 2012**



#### D. TECHNOLOGY SPECIFICATION

The weather station was installed at Hart-Dole-Inouye Federal Center (Figure 8). The weather station is a scientific-grade weather station providing weather data, including precipitation, solar radiation, temperature, relative humidity, and wind speed. The weather station has internal software that uses this weather data to calculate ET (see section VII-C). It should be noted that integration into irrigation controllers is not an inherent function of the weather station.

The weather station was installed on the south side of the building in an open field that is exposed to the general weather conditions of the facility. The GSA staff installed the equipment without support from the manufacturer. The weather station measured temperature, relative humidity, solar radiation, and precipitation at 15-minute intervals. The weather station was hard wired to the facility's BAS, where data was collected and stored. ET is calculated every 15 minutes, and then sent to the BAS. The BAS was programmed to calculate the runtime of the irrigation equipment based on the ET that was determined by the weather station. As described in detail in section IV-E, programming the BAS to determine the runtime correctly based on ET was challenging.

**Figure 8. Weather Station at Hart-Dole-Inouye Federal Center**

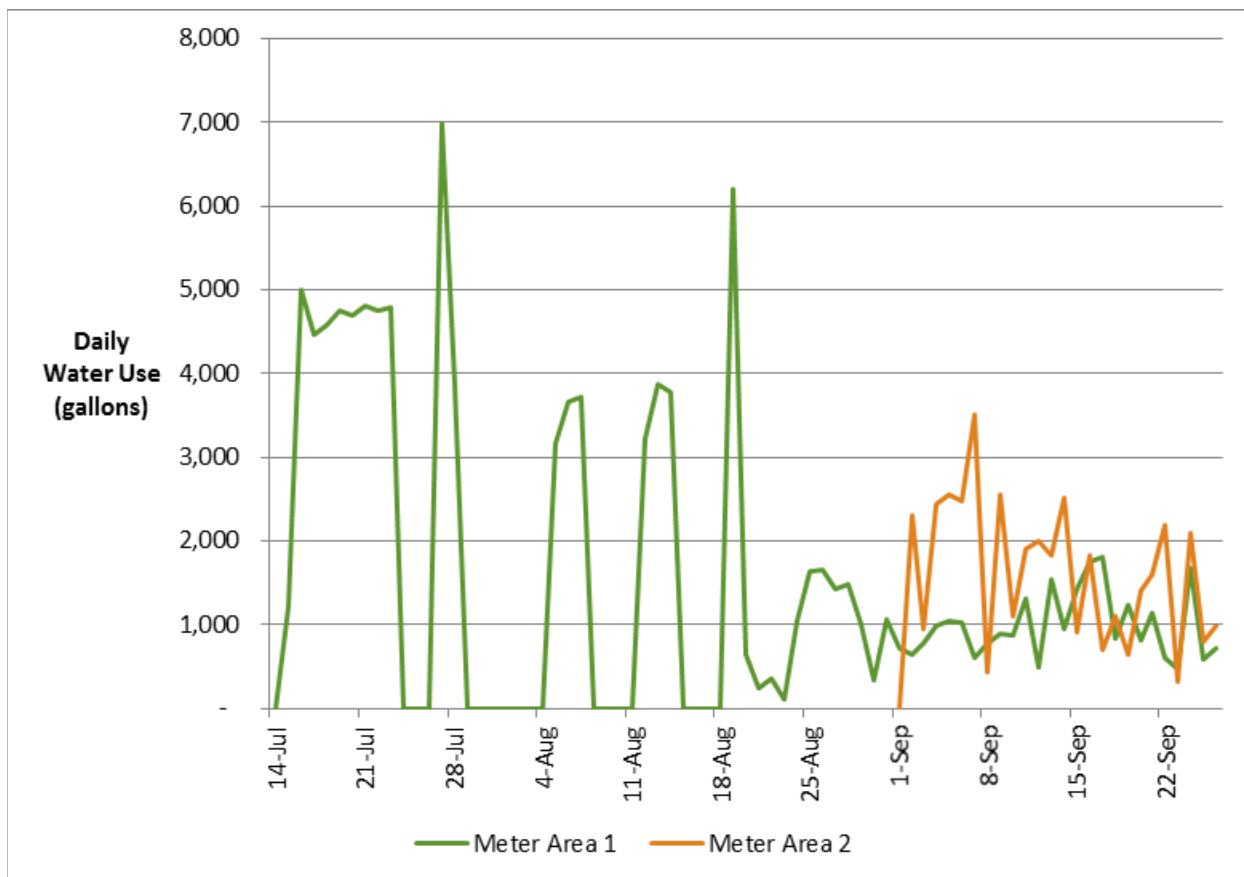


### E. SYSTEM MONITORING

The irrigation zones' water use was monitored by two flow meters. One meter measured water use in Zones 2N, 2BS, and 2BN, while another meter monitored water use in Zones 1E and 2S. For the purposes of this report, irrigation Zones 2N, 2BS, and 2BN are called "Meter Area 1" and irrigation Zones 1E and 2S are called "Meter Area 2."

Both meters were connected to GSA's integrated web-enabled advanced metering management system. The advanced metering system collects and stores interval data from facility meters across GSA's inventory. Data were provided to PNPL in weekly emails. Daily water data for Meter Area 1 were provided from May 2012 through September 2013. However, the water meter for Meter Area 2 was not installed until September 2, 2013, so minimal water data were collected on these zones. It should be noted that a temporary meter was installed on Zones 1E and 2S at the beginning of the technology assessment, but a data logger was not installed on the meter and, therefore, daily water usage data were not collected nor provided to PNPL. Daily water data during the project assessment in 2013 from the advanced metering system are shown in Figure 9.

**Figure 9. Advanced Metering System Irrigation Water-Use Data**





## WEATHER DATA

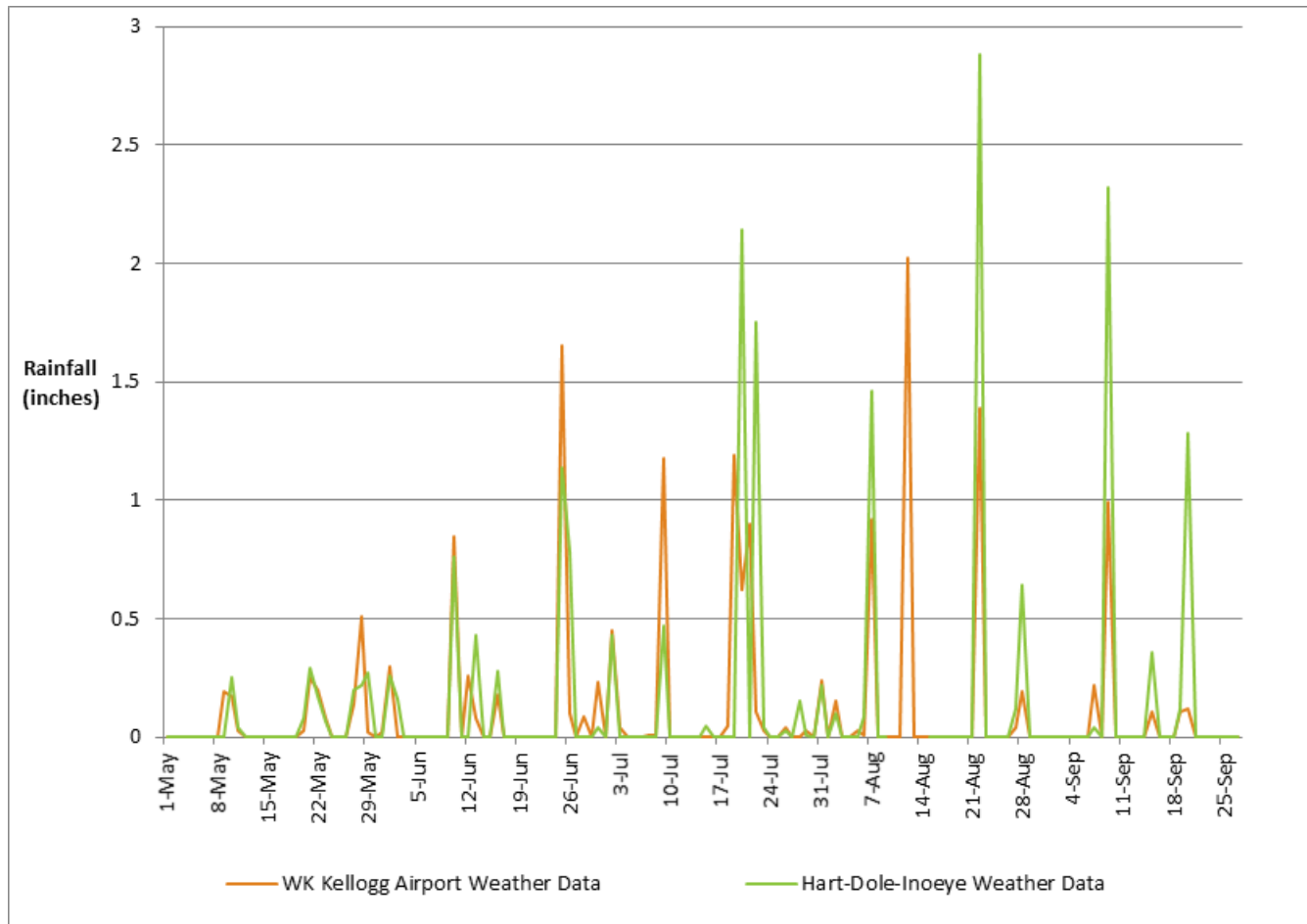
Weather data for the study period were collected from the weather station that was installed at the Hart-Dole-Inouye Federal Center. This weather station collected temperature, solar radiation, precipitation, and relative humidity, in addition to calculating the ET.

Weather data were provided to PNNL by staff at the GSA facility. In addition, precipitation data for 2012 and 2013 were collected from a nearby weather station at Battle Creek's W. K. Kellogg Airport for comparison against the on-site weather station's results to verify the readings [7]. The local airport is 3.5 miles from the Hart-Dole-Inouye Federal Center. Large differences in weather patterns between the Federal Center and airport should be minimal because of the homogeneous nature of the topography of Battle Creek. Comparing 2012 and 2013 daily rainfall data from the nearby airport, the volume of precipitation at the Battle Creek facility in the later spring and early summer of 2013 was greater than the previous year, which, consequently, delayed the start of the normal irrigation season. During May through June 2012, the airport received 1.8 inches. During this same time period in 2013, 5.4 inches were received.

Daily rainfall data from the weather station at the GSA facility were compared to the rainfall data from the nearby airport. From May to September 2013, the on-site weather station reported 20% more rain than the airport's weather station. There are some rain events in mid-July through September 2013 where it appears that the on-site weather station may have been over-recording precipitation. For example, on August 22, 2013, rainfall data collected at the Hart-Dole-Inouye Federal Center indicated a total rainfall of nearly 3 inches, while the airport's weather station measured a daily rainfall total of 1.4 inches (Figure 10). Differences in measured precipitation are expected between weather stations because even subtle changes in topography can influence weather. But the consistently high recordings of the on-site weather station during major storm events in mid- to late summer paired with the magnitude of the difference from the W. K. Kellogg Airport's weather station indicates inaccurate measurement by the rain sensor. Inaccurate measurement of the rain sensor was verified by GSA facility staff. The rain sensor required weekly cleaning, which was not being performed during the study period, and, therefore, caused over-recording of the sensor.

**Figure 10. Comparison of Daily Precipitation Data from the On-Site Weather Station and the W. K.**

## Kellogg Airport Weather Station for May through September 2013



### F. BAS PROGRAMMING

The Hart-Dole-Inouye Federal Center was responsible for programming the existing BAS to irrigate the facility grounds based on the ET data from the weather station. GSA received no programming support from the weather station manufacturer. The manufacturer specializes in scientific monitoring equipment. The weather station simply measures weather conditions and uses this information to calculate ET. The weather station was not designed specifically for irrigation control through the BAS at the Hart-Dole-Inouye Federal Center.

Conceptually, irrigation runtime is set to the amount of water needed by the landscape based on ET requirements, taking into account the rainfall received over the same time frame. Weather-based irrigation scheduling should determine irrigation needs over a time frame of several days to a week that considers recent weather conditions. For example, a large rain event can provide adequate water to a landscape that can likely decrease the need for irrigation over the next several days.

To calculate the correct runtime, each zone's irrigation system precipitation rate was determined. Precipitation rate is the amount of water distributed by the irrigation system over time for the given landscape area, measured in inches per hour. The precipitation rate of each zone was calculated by

converting the zone’s flow rate in gpm to inches per hour. This was accomplished by first converting gpm to cubic inches per hour and then applying the zone’s area to calculate the inches of water applied to the zone over time, as shown in the following formula:

$$\text{Zone Precipitation Rate (inches per hour)} = \text{zone flow rate} \frac{\text{gal}}{\text{min}} \times 231 \frac{\text{cubic inches}}{\text{gal}} \times 60 \frac{\text{min}}{\text{hour}} \div \text{zone area (square feet)} \div 144 \frac{\text{square inches}}{\text{square feet}}$$

Using this formula, the precipitation rate for each zone was calculated; results are presented in Table 3. The considerable range between zones’ precipitation rates is a result of the differences between zones’ flow rates, as described in section IV-B.

**Table 3. Zone Precipitation Rate**

Irrigation Zone Number	Precipitation Rate (inches per hour)
1E	0.21
2S	0.44
2N	0.13
2BN	0.39
2BS	0.22

The precipitation rate was then used to calculate the irrigation runtime for each zone, using the following formula:

$$\text{Irrigation Zone Runtime (hours)} = (ET \text{ (inches)} - \text{Rainfall (inches)}) \div \text{Precipitation Rate} \left( \frac{\text{inches}}{\text{hour}} \right)$$

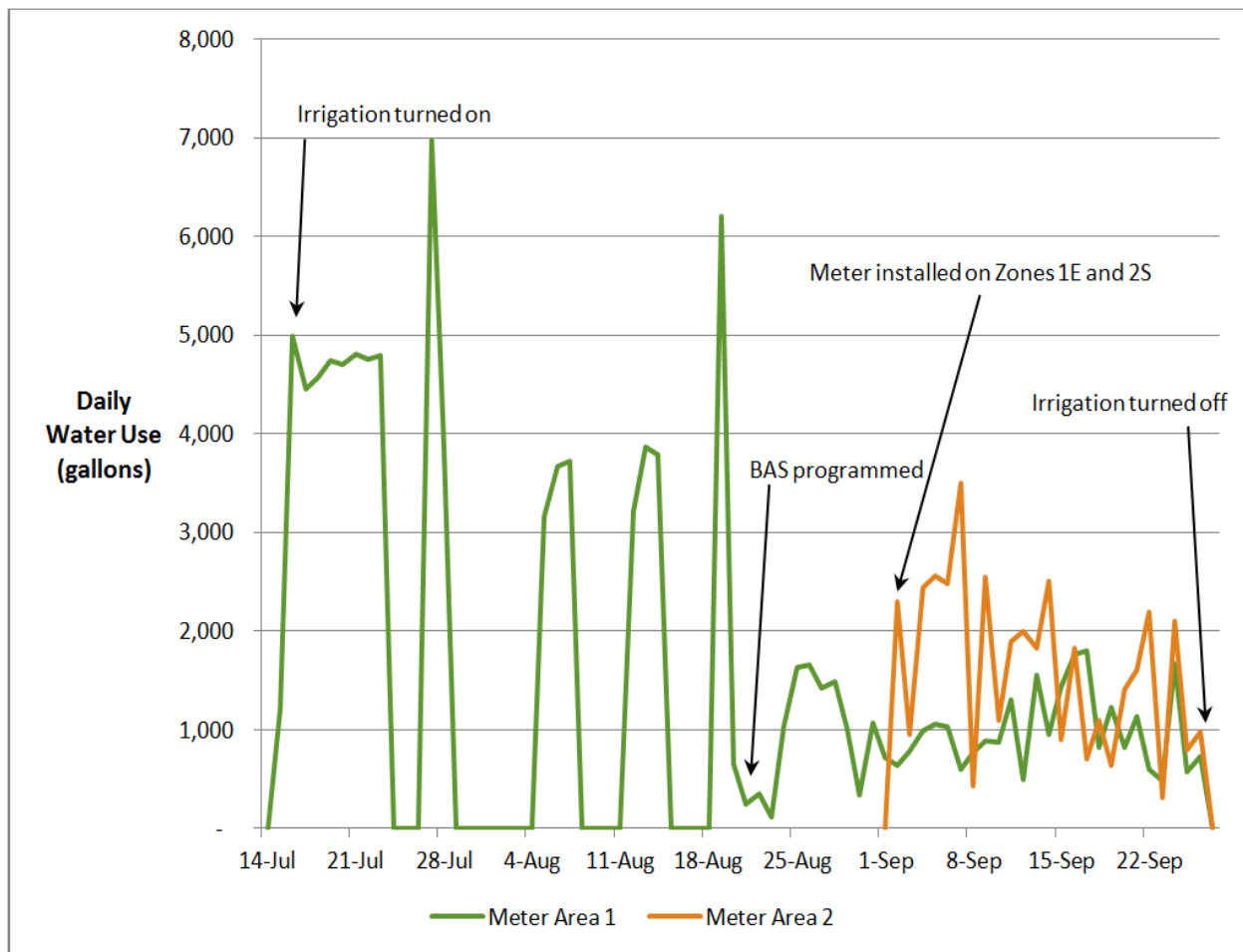
This formula takes into account the amount of water needed by the landscape, the amount of rainfall received and the amount of water that can be applied by the irrigation equipment over time. An algorithm was developed by GSA in an attempt to translate this basic conceptual formula into the programming protocol of the BAS. The BAS was programmed on August 21, 2013. Before this time frame, the BAS was not irrigating using ET data and was manually set by the grounds maintenance staff.

The programming of the BAS was challenging. It took several iterations to complete the program. There was no standardized program available; therefore, the program was developed from scratch. Taking into consideration the many responsibilities of the facility, there was not adequate time to develop the irrigation programming. Ultimately, the BAS program did not function properly, and irrigation equipment runtime did not adjust accurately under all weather conditions. Specifically, the BAS program did not include an algorithm to suspend irrigation when rainfall exceeded ET. In other words, when no supplemental irrigation was required because rain provided enough water to the plants, the BAS continued to irrigate each zone. Therefore, a standardized BAS program protocol was not developed, which was one of the objectives of this GPG project. Therefore, the research team was not able to determine the ease at which it could be replicated at other GSA facilities.

### G. STUDY PERIOD

The study period for this assessment was from August 21, 2013, to September 26, 2013. The study period was shorter than anticipated for several reasons. The irrigation system was not turned on until July 15, 2013, because of an unusually rainy spring and early summer at Battle Creek. Note between July 15 and August 20, the original timed schedule was not used and the irrigation system was operated manually by the grounds maintenance staff. The BAS was programmed August 21, 2013, to establish irrigation runtime based on ET calculated by the weather station. There was a significant reduction in daily irrigation after the BAS was programmed. The meter for Zones 1E and 2S was installed and connected to the advanced metering system on September 2, 2013. The system was completely turned off on September 27, 2013, because it was the end of the irrigation season and the system was winterized. These key events are shown in the water-use data in Figure 11.

**Figure 11. Key Events during Study Period**



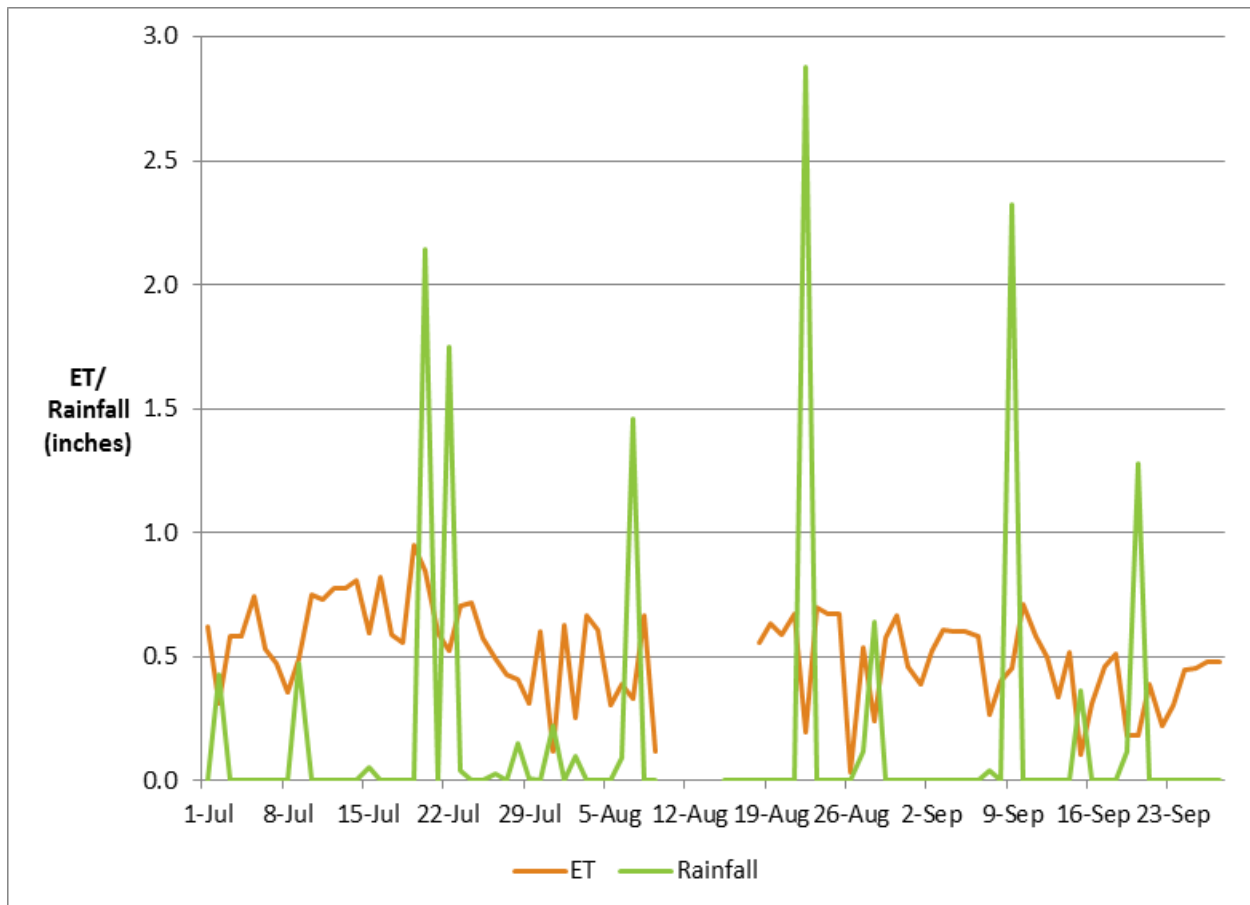
## V. Results

The results section includes three subsections. The first section provides information on ET data that were calculated by the weather station. The second subsection provides water use of the system and a qualitative discussion on potential savings of the technology. The third subsection identifies potential economic indicators for weather-based irrigation control technology.

### A. EVAPOTRANSPIRATION DATA

ET data received from the on-site weather station located at the Battle Creek site indicated that throughout the study period ET rates were positive, though varying depending upon the weather. The total required ET and rainfall data received throughout the study period are shown in Figure 12. When rainfall exceeds ET, this indicates that no supplemental irrigation is needed for that particular day. Note that ET data from the on-site weather station were not provided to PNNL for the week of August 10 – 16, and, therefore, there is a gap in data during this week.

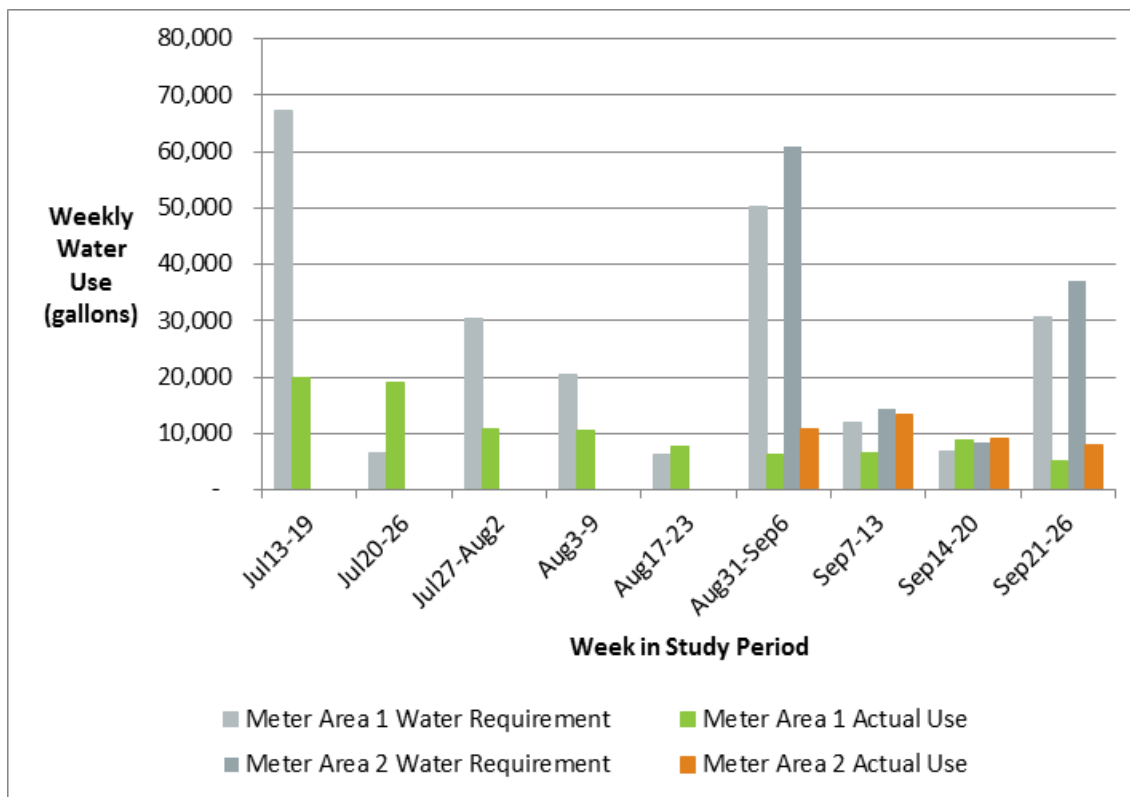
Figure 12. ET and Rainfall through Study Period



The supplemental irrigation requirement for the Federal Center was determined by subtracting total ET from rainfall received over the same time period. The supplemental ET was summed weekly and then compared to the irrigation applied to Meter Area 1 and Meter Area 2. Weekly supplemental ET was

converted to total gallons of water required for each landscape area by dividing supplemental ET by the zones' precipitation rate and multiplying by flow rate (Figure 13). Comparing weekly water requirements to actual water usage reveals that the irrigation schedule did not consistently provide enough irrigation. It appears the irrigation runtimes were not long enough to meet the supplemental ET five weeks out of a total of nine. For example, during the week of August 31, ET totaled nearly 4 inches and very little rain was received by the site, resulting in a total water requirement of 111 thousand gallons (kgal) of supplemental irrigation during that week. However, only 17 kgal was applied. This highlights the fact that the BAS program for scheduling the irrigation equipment was not working properly.

**Figure 13. Comparison of Weekly Water Use to Water Requirement**



### B. THEORETICAL WATER SAVINGS POTENTIAL

Because of the truncated study period due to the late irrigation start, delayed and improper BAS programming, as well as suspected calibration issues with the weather station, a robust analysis of savings potential was not possible. With only approximately 5 weeks of irrigation data on Meter Area 1 and 3.5 weeks of data on Meter Area 2, there were not enough data to develop a realistic understanding of water use after the installation of the weather station.

Even though a robust analysis could not be performed, the research team approximated a theoretical amount of irrigation water that would have been supplied to the grounds if the BAS had been properly programmed. This was accomplished by comparing the weekly amount of required supplemental irrigation

(ET minus precipitation<sup>3</sup>) to the weekly baseline, as described in section IV.B (Figure 14). This savings was extrapolated over the irrigation season. The theoretical amount of irrigation that would have been supplied to the landscape to meet ET would have totaled 1.4 Mgal. With an irrigation baseline of 4.1 Mgal per year, the estimated water savings is 2.8 Mgal annually and resulting in a water reduction of 66%.

**Figure 14. Comparison of Weekly Baseline to Theoretical Water Requirements Based on ET**



### C. ECONOMIC INDICATORS FOR WEATHER-BASED CONTROL TECHNOLOGY

Similar to the water savings analysis, a thorough economic analysis was not appropriate for this assessment because the post-retrofit water usage cannot be annualized. Annual water usage data is required to estimate the cost savings expected from the technology.

However, a life-cycle cost (LCC) analysis was performed on weather-based controllers for three scenarios to attempt to draw basic conclusions on the cost-effectiveness of BAS-interconnected systems versus integrated weather-based systems. (See section II.B for a description of these systems.) Scenarios chosen

<sup>3</sup> Precipitation data from the W.K. Kellogg weather station was used to estimate supplemental ET requirements, since the precipitation data from the on-site weather station was suspect, as described in section IV-D [6].

include the Battle Creek demonstration site with the BAS-interconnected system along with two hypothetical facilities with integrated weather-based controllers. The three scenarios are described below.

**Scenario 1 - Battle Creek BAS-interconnected system:** An LCC analysis was performed on the actual costs incurred for the installation of the stand-alone weather station at Battle Creek with the theoretical savings of 66% that was estimated in the analysis (see section V.B)

**Scenario 2 - Large-sized facility with integrated weather-based system:** A series of LCC analyses were performed on an integrated weather-based controller for large facility similar in size to the Battle Creek facility.

**Scenario 3 - Medium-sized facility with integrated weather-based system:** A series of LCC analyses were performed on an integrated weather-based controller for a medium-sized facility approximately half the size of the Battle Creek facility.

Table 4 provides information on the installation costs, baseline water use, water savings, operation and maintenance (O&M) costs, and water rates that were used in the economic analysis for each scenario. Further information on the economic parameters is provided in the text below the table.

**Table 4. Economic Analysis Parameters for Each Scenario**

Scenario	Total Installation Cost	Annual Baseline Water Use (Mgal)	Annual Water Savings (Mgal)	Water Rate (\$/kgal)	Annual O&M Costs
Scenario 1. Battle Creek BAS-interconnected system	\$21,000	4.1	2.7	\$5.00	\$700
Scenario 2. Large facility with integrated system	\$10,000 – \$30,000	4.0	1.6 and 0.8	\$3.00 – \$8.00	\$700
Scenario 3. Medium facility with integrated system	\$10,000 – \$30,000	2.0	0.8 and 0.4	\$3.00 – \$8.00	\$700

**Total Installation Cost:**

**Scenario 1:** The breakout of costs for the Battle Creek BAS-interconnected system is as follows:<sup>4</sup>

- weather station: \$6,500
- installation of weather station (includes labor and miscellaneous materials): \$14,500

**Scenarios 2 and 3:** The costs for the large- and medium-sized facilities include materials and labor for installation of a commercial-grade centralized weather-based irrigation controller, including flow sensors,

<sup>4</sup> Technology and installation costs were provided to PNNL by Mark Hurley, Building Service Specialist, GSA Great Lakes Region, on May 13, 2013. Costs incurred for the stand-alone weather station are considered fairly typical for this type of application.



weather gauges and integrated software. The range in installed costs is based on previous system development costs for similar systems assessed by PNNL. The costs for the large- and medium-sized facilities are not directly proportional to their sizes because both systems required the same flow sensor technology, weather gauges and centralized controller.

### **Annual Baseline Water Use**

**Scenario 1:** The annual baseline for the Battle Creek BAS-interconnected system is the water used during a normal irrigation season based on the original timer-based schedule of 4.1 Mgal/yr (see section IV-B).

**Scenarios 2 and 3:** The annual baselines for the large- and medium-sized facilities were 4.0 and 2.0 Mgal/yr, respectively, and were selected to represent the hypothetical range of irrigation water use at GSA facilities.

### **Annual Water Savings**

**Scenario 1:** The annual water savings for the Battle Creek BAS-interconnected system is the theoretical savings of 66% that was estimated in the analysis (see Section V-B).

**Scenarios 2 and 3:** Two levels of annual water savings of 20% and 40% were selected for Scenarios 2 and 3 to represent a range of savings potential for integrated weather-based irrigation controllers based on research results of smart irrigation controller studies [5].

### **Water Rates**

**Scenario 1:** The water rate for the Battle Creek BAS-interconnected system is the actual water rate incurred by the Hart-Dole-Inouye Federal Center in 2013 of \$5/kgal.

**Scenarios 2 and 3:** A range of water unit costs of \$3.00 to \$8.00/kgal were used in the LCC analyses for both Scenarios 2 and 3 to represent the general range of expected water rates at GSA locations. These water rates were used to determine the rate at which the integrated weather-based systems become LCC-effective. The LCC-effectiveness was identified by determining when the savings-to-investment ratio (SIR) is equal to one. An SIR of 1 indicates that the total cost savings is equal to the total capital cost of the project over its life.

### **Annual O&M Costs**

**Scenarios 1, 2, and 3:** Additional ongoing maintenance costs to operate the weather station and program the BAS were assumed to be \$100 per month for 7 months out of the year.<sup>5</sup> These same O&M costs were used in Scenarios 2 and 3, assuming that similar system checks will be required on an integrated weather-based system.

<sup>5</sup> Additional labor time for control operation and maintenance was determined by overall assessment of additional time spent through the study period by the facility staff; typical GSA labor rate for grounds maintenance was provided to PNNL by Mark Hurley, Building Service Specialist, GSA Great Lakes Region, on May 13, 2013.

## Other Economic Parameters

The other economic parameters used in the LCC analyses for all scenarios are the following:

- system life of 15 years; and
- discount rate: 3%.

## LCC ANALYSIS RESULTS

The results of the LCC analyses determined the SIR and simple payback for each scenario. The LCC analysis for the Battle Creek BAS-interconnected system (Scenario 1) resulted in an SIR of 7.7, net present value of \$140,960, and simple payback of 1.6 years. This reveals that using ET to determine irrigation scheduling has the potential to be LCC-effective for the Battle Creek facility, but the results should not be used as a key conclusion of economic viability for the technology assessed for this GPG project because the LCC analysis is based on theoretical savings and not on actual data collected during the demonstration due to the lack of robust data.

The objective of the LCC analyses for the integrated weather-based controllers in Scenarios 2 and 3 was to determine at which water rate and installed cost these scenarios become LCC-effective (*i.e.*, SIR of 1 or greater), termed the “breakeven point.” The SIR results for varying water rates in Scenarios 2 and 3 are shown in Table 5, which shows the breakeven water rates, range of expected SIRs, and simple payback for water savings ranging between 20% (low end) and 40% (high end). This savings range was chosen based on research results of smart irrigation controller studies [5]. The intent of Scenarios 2 and 3 was to simply provide GSA a range of possible LCC-effectiveness at different water rates for integrated systems. These results are shown in Figure 15. Figure 15 can help GSA facilities determine the general level of savings that is required to achieve an LCC-effective project at a specific water rate. For example, a large-sized GSA facility (Scenario 2) with a water rate of \$3.00/kgal (blue dotted line in Figure 15) can expect to have an LCC-effective project with low-end water savings of 20% reduction from the baseline of 4 Mgal/yr. A medium-sized facility (Scenario 3) with a 2 Mgal/yr baseline can expect to have an LCC-effective project with a water rate of \$5/kgal with 20% savings (red dotted line in Figure 15).

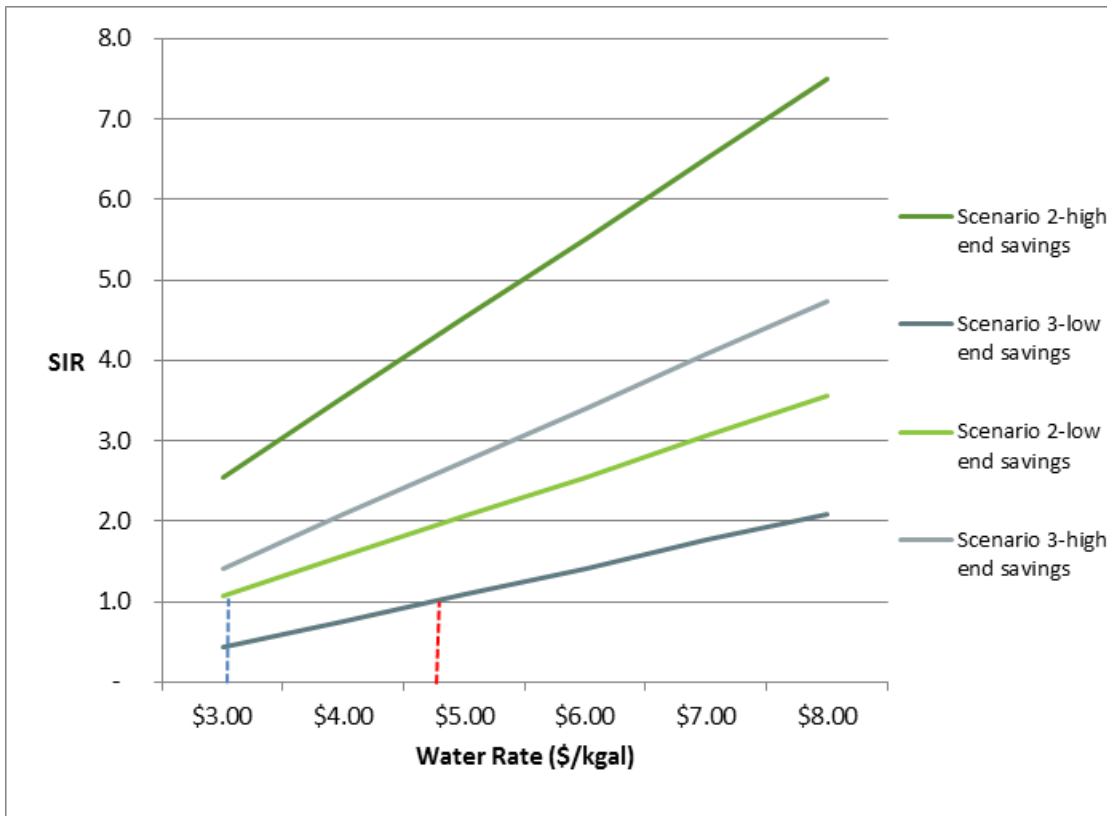
**Table 5. Economic Results for Scenarios 2 and 3 with Varying Water Rates**

Water Rate	SIR <sup>a</sup>	Simple Payback (years) <sup>a</sup>	SIR <sup>b</sup>	Simple Payback (years) <sup>b</sup>
\$3/kgal	1.1 – 2.6	4.9 – 11.8	0.4 – 1.4	8.8 – 30.0
\$4/kgal	1.6 – 3.5	3.5 – 8.0	0.8 – 2.1	6.0 – 16.7
\$5/kgal	2.1 – 4.5	2.7 – 6.1	1.1 – 2.7	4.6 – 11.5
\$6/kgal	2.6 – 5.5	2.3 – 4.9	1.4 – 3.4	3.7 – 8.8
\$7/kgal	3.1 – 6.5	1.9 – 4.1	1.8 – 4.1	3.1 – 7.1
\$8/kgal	3.6 – 7.5	1.7 – 3.5	2.1 – 4.7	2.6 – 6.0
Breakeven Water Rate	Low end savings \$2.87/kgal	High end savings: \$1.43/kgal	Low end savings: \$4.72/kgal	High end savings: \$2.36/kgal

<sup>a</sup> Scenario 2 (installed cost of \$20,000) - Large Facility with Integrated System with 20% to 40% Savings

<sup>b</sup> Scenario 3 (installed cost of \$15,000) - Medium Facility with Integrated System with 20% to 40% Savings

Figure 15. LCC-Effectiveness of Integrated Weather-Based Irrigation Systems with Varying Water Rates



An economic analysis was also performed to determine the installed cost at which the project becomes LCC-effective. The following parameters were used in the analysis for Scenarios 2 and 3: A range of total installed costs from \$10,000 to \$30,000 with \$5,000 increments; water rates of \$5/kgal and \$3/kgal; and low end (20%) versus high end (40%) savings. The results are shown in Table 6 and Table 7 and Figure 16 and Figure 17. These data can be used to determine general range of installed costs that will produce LCC-effective projects. For example, an installed cost of \$20,000 for the low end savings of 20% with a water rate of \$3/kgal achieves an SIR of 1.1 and simple payback of 11.8 years. Anything over \$20,000 for this case would likely not be cost-effective (blue dotted line in Figure 16).

**Table 6. Economic Results for Scenarios 2 and 3 with Varying Installed Cost and \$3/kgal Water Rate**

Installed Cost	SIR <sup>a</sup>	Simple Payback (years) <sup>a</sup>	SIR <sup>b</sup>	Simple Payback (years) <sup>b</sup>
\$10,000	2.1 – 5.1	2.4 – 5.9	0.7 – 2.1	5.9 – 20.0
\$15,000	1.4 – 3.4	3.7 – 8.8	0.4 – 1.4	8.8 – 30.0
\$20,000	1.1 – 2.6	4.9 – 11.8	0.3 – 1.1	11.8 – 40.0
\$25,000	0.9 – 2.0	6.1 – 14.7	0.3 – 0.9	14.7 – 50.0
\$30,000	0.7 – 1.7	7.3 – 17.7	0.2 – 0.7	17.7 – 60.0
Breakeven Installed Cost	Low end savings: \$21,300	High end savings: \$51,000	Low end savings: \$6,500	High end savings: \$21,300

<sup>a</sup> Scenario 2 - Large Facility with Integrated System with 20% to 40% Savings

<sup>b</sup> Scenario 3 - Medium Facility with Integrated System with 20% to 40% Savings

**Table 7. Economic Results for Scenarios 2 and 3 with Varying Installed Cost and \$8/kgal Water Rate**

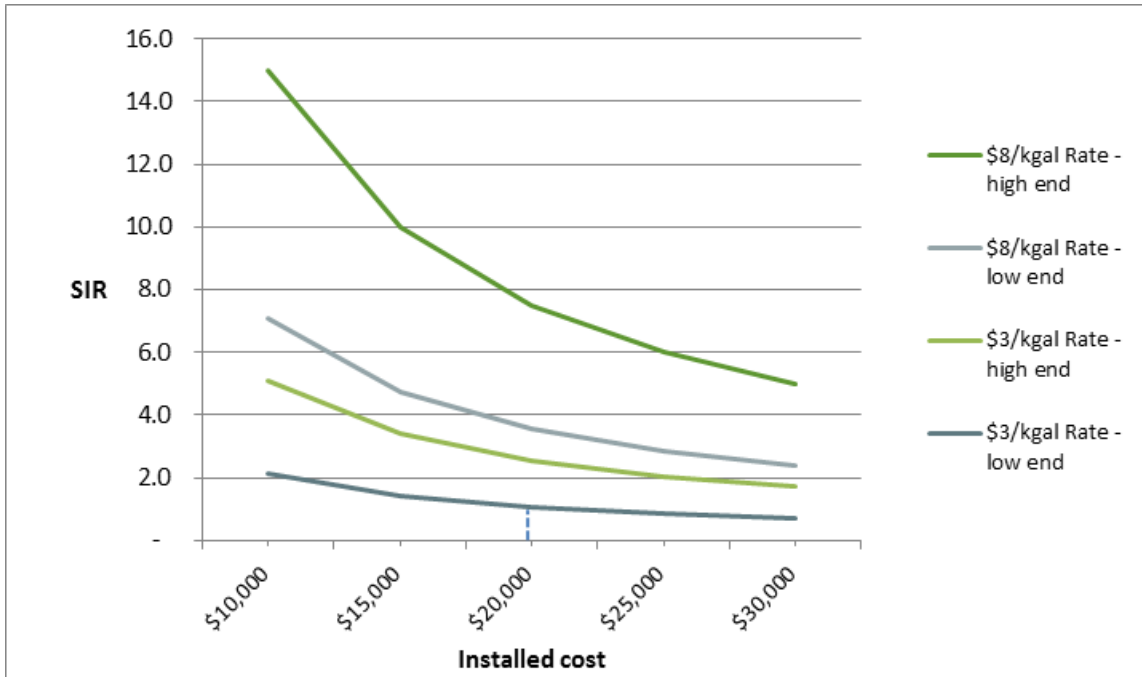
Installed Cost	SIR <sup>a</sup>	Simple Payback (years) <sup>a</sup>	SIR <sup>b</sup>	Simple Payback (years) <sup>b</sup>
\$10,000	7.1 – 15.0	0.8 – 1.8	3.1 – 7.1	1.8 – 4.0
\$15,000	4.7 – 10.0	1.2 – 2.6	2.1 – 4.7	2.6 – 6.0
\$20,000	3.5 – 7.5	1.7 – 3.5	1.6 – 3.5	3.5 – 8.0
\$25,000	2.8 – 6.0	2.1 – 4.4	1.3 – 2.8	4.4 – 10.0
\$30,000	5.0 – 2.4	2.5 – 5.3	1.0 – 2.4	5.3 – 12.0
Breakeven Installed Cost	Low end savings: \$70,800	High end savings: \$150,000	Low end savings: \$31,200	High end savings: \$70,800

<sup>a</sup> Scenario 2 - Large Facility with Integrated System with 20% to 40% Savings

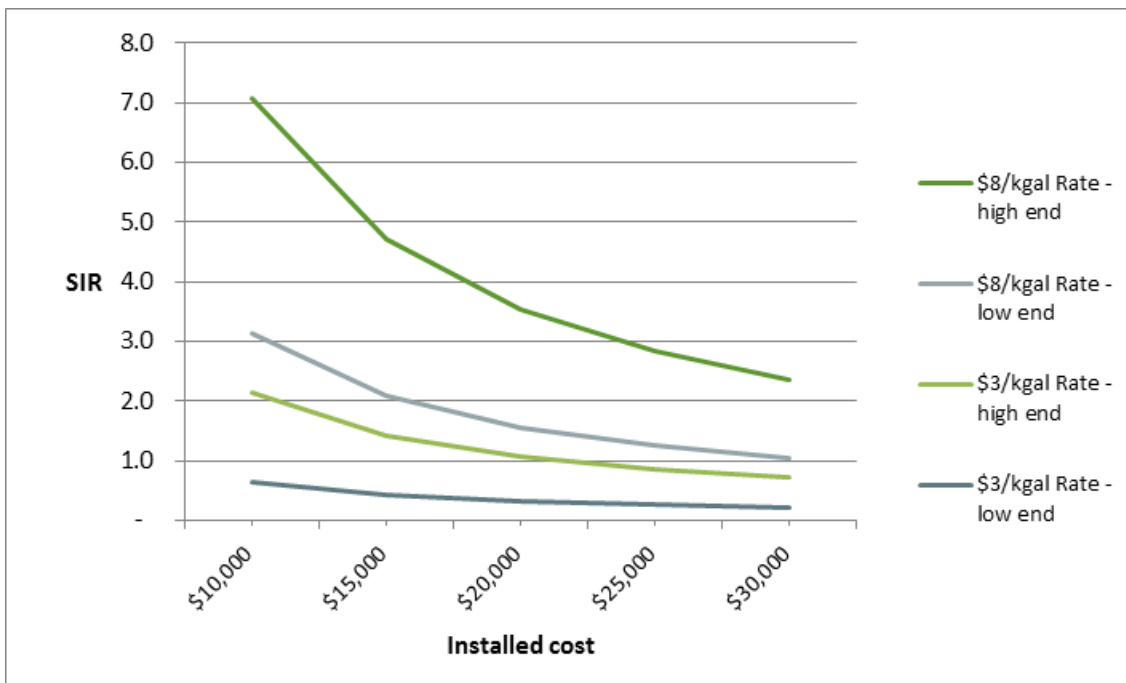
<sup>b</sup> Scenario 3 - Medium Facility with Integrated System with 20% to 40% Savings

**Figure 16. Scenario 2 LCC-Effectiveness of Integrated Weather-Based Irrigation Systems with Varying**

**Installed Cost**



**Figure 17. Scenario 3 LCC-Effectiveness of Integrated Weather-Based Irrigation Systems with Varying Installed Cost**



## VI. Summary Findings and Conclusions

The overall summary of findings in this section includes a qualitative discussion on the barriers to the specific technology installed at the Hart-Dole-Inouye Federal Center and best practices that GSA should consider with weather-based irrigation control technology.

### A. OVERALL TECHNOLOGY ASSESSMENT AT DEMONSTRATION FACILITY

A BAS-interconnected configuration was chosen for the Battle Creek location. The stand-alone weather station offered high quality, scientific-grade weather data. In addition, interconnecting into the facility's BAS and GSA's advanced metering system offered a centralized data management feature, allowing facility staff potentially to monitor irrigation schedule and water use through the existing BAS platform. This type of configuration is less common than integrated weather-based systems at GSA facilities, and evaluating it was worthwhile to determine whether using a stand-alone weather station interconnected with a BAS would provide advantages to a turnkey integrated weather-based system.

The intent of the GPG project was to evaluate water savings, cost-effectiveness, acceptance of the system by facility staff, ease of operation of a BAS-interconnected system, data management benefits, and potential for replication at other GSA facilities. Because the study period was truncated as a result of the late irrigation start and delayed and improper BAS programming, a robust analysis of savings potential was not possible. The small dataset did not contain enough data to develop a realistic understanding of water use after the installation of the BAS-interconnected stand-alone weather station. The programming of the BAS was ultimately not developed properly and accurate runtimes were not established. In addition, the rain sensor was not properly maintained during the study period and was over-recording precipitation, which, in turn, caused the system to underwater the landscape at certain times during the study. Therefore, the water use during the study period is not a true reflection of an irrigation schedule based on ET.

Due to the lack of data, an analysis was performed to determine theoretical savings at the Battle Creek facility, comparing the baseline water use of the timer-based controller to the amount of supplemental ET required by the landscape as determined by the stand-alone weather station. The results of this analysis showed a 66% reduction in irrigation water use. Therefore, this assessment broadly determined that using ET rates as a means of scheduling irrigation has the potential for considerable water savings.

In addition to determining the theoretical savings of the Battle Creek facility, PNNL performed an LCC analysis of integrated weather-based systems with the objective to understand potential economic benefits. The analysis findings show that integrated weather-based systems are generally LCC-effective at a water rate of \$1.40/kgal or higher and an installed cost of \$20,000 or less for a GSA facility that uses 4 Mgal annually in irrigation water. For facilities with 2 Mgal/yr in irrigation, a water rate of \$2.50/kgal or higher and installed cost of \$16,000 or less produce an LCC-effective project.

In general, weather-based irrigation controls offer a considerable improvement compared to timer-based controls, which can lead to significant water and monetary savings. In addition, the research team concluded that integrated weather-based systems are preferable to BAS-interconnected systems. It was found through this GPG project that the BAS-interconnected system is challenging to install, program and commission. It should be noted that, potentially, a standardized algorithm could be developed, which, in turn, could be utilized by at other GSA facilities' BAS. This would help alleviate the challenges faced at the Battle Creek

location. However, a standardized BAS program protocol was not developed as part of this GPG project and, therefore, the research team was not able to determine the ease at which it could be replicated at other GSA facilities.

An integrated weather-based system is a turnkey product that provides all of the crucial elements required for both determining ET and controlling the irrigation equipment. An integrated weather-based system has internal software that determines the runtime of the irrigation equipment, requiring minimal programming by site staff. These features make an integrated system more easily deployable at other GSA facilities. Table 8 shows a summary of the benefits and limitations of these two types of systems.

**Table 8. Benefits and Limitations of BAS-interconnected Systems versus Integrated Systems**

	Weather-Based BAS-interconnected System	Weather-Based Integrated System
<b>Benefits:</b>		
Significant water savings potential	x	x
Integrated weather data and internal software		x
Integrated into GSA’s advanced metering system	x	
Integrated system flow sensors		x
Easily deployed at GSA facilities		x
<b>Limitations:</b>		
BAS programming requirement	x	
Commissioning requirement	x	x
System integration requirement	x	
Ongoing O&M requirement	x	x

Integrated weather-based systems are readily available on the market from a variety of irrigation control companies. Several research studies show significant savings potential from proper use of integrated weather-based irrigation controllers, generally ranging between 20% and 40% reduction in irrigation [5]. The Department of Energy recommends the use of integrated weather-based controllers in the FEMP’s Best Management Practice on Water-Efficient Irrigation [8]. In addition, EPA published an irrigation best practice that also recommends the use of integrated weather-based irrigation control technology [9]. WaterSense also labels residential integrated weather-based controllers as part of its suite of labeled water-efficient products [4].

In addition, the Irrigation Association has developed the Smart Water Application Technologies (SWAT) program to promote the use of water efficient irrigation control technology. The mainstay of the SWAT program is testing of weather-based irrigation controllers. The SWAT testing protocol provides a standardized method to determine performance of these products [10].

WaterSense requires that residential weather-based controllers applying for WaterSense labeling are tested in accordance with the SWAT testing protocol and achieve minimum performance levels determined by the SWAT testing protocol. Performance requirements include achieving an irrigation adequacy of at least 80%, which represents the percentage of water required by the plant that is actually applied to the plant. In

addition, WaterSense labeled controllers must have irrigation excess of no more than 10%, which represents the amount of surplus irrigation water that is applied beyond the requirements of the plant [11].

Further information can be found on these programs 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/](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. BARRIERS**

Overall, the assessment revealed that a BAS-interconnected system with a stand-alone weather station involves significant barriers. The weather station was required to be tied to the facility BAS. This proved to be challenging. The programming of the BAS to calculate runtime for each irrigation zone based on ET was not straightforward. Even with several iterations on the programming algorithms, the BAS program ultimately was never correct. This was probably because of three main factors:

- The weather station was not designed to perform as an irrigation controller; the weather station only collected weather data and calculated ET.
- There was no support provided by the technology manufacturer to program the BAS because its role as an irrigation controller for this project was outside the scope of the manufacturer's technical services.
- There was inadequate time to understand the BAS programming protocols and the relationship between irrigation runtime and ET.

Also, the weather station was not properly commissioned, which may have led to suspect weather data. Ultimately, the challenges faced at the demonstration location to tie the weather station into the existing BAS will likely be challenging at any GSA location. GSA facility and regional staff continue to improve the BAS programming and better commission the system with the objective to achieve a properly functioning system. GSA should leverage the current work being performed at Battle Creek as the system functioning improves to understand the potential benefits of a BAS-interconnected weather-based control technology.

## **C. BEST PRACTICES**

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 of the WaterSense program:
  - an irrigation adequacy of at least 80%, which represents the percentage of water required by the plant that was actually applied to the plant; and
  - 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 runtime based on ET; software should allow for user input to specify specific 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 data is accurately uploaded to the controller and the schedule is adjusting to weather conditions.
- Perform regular calibration of weather sensors and flow sensors to facilitate 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 as a result of real-time precipitation data being used to determine irrigation requirement.
- If the integrated system uses wireless connections, special consideration should be made to ensure that wireless signals can be transmitted consistently.

## VII. Appendices

### A. MANUFACTURER INFORMATION

The Campbell Scientific ET107 Evapotranspiration Monitoring Station was installed at Hart-Dole-Inouye Federal Center (Figure 18). The weather station is designed to provide data for commercial irrigation and agricultural irrigation scheduling. The station calculates ET using the Penman-Monteith equation. See section VII-C for information on this calculation.

The ET107 ET station consists of meteorological sensors, an aluminum 3-meter pole, and an environmental enclosure that houses a wiring panel, and a sealed rechargeable battery. Meteorological sensors included with the ET107 are as follows<sup>6</sup>:

- CS305-ET Solar Radiation Sensor: measures total sun and sky solar radiation using a silicon photocell. The spectral range is 300 to 1000 nanometers, which encompasses most of the shortwave radiation that reaches the earth's surface.
- HMP60-ETS Air Temperature and Relative Humidity Probe: The HMP60 uses a capacitive relative humidity chip, which is field-replaceable that can eliminate the downtime typically required for the recalibration process. The probe includes a radiation shield, which is a six-plate naturally aspirated shield with a louvered construction that allows air to pass freely through the shield, thereby keeping the probe at or near ambient temperature. It is a double-plated shield that can help reduce the likelihood of nesting insects.
- TE525-ET Tipping Bucket Rain Gauge: The tipping bucket has a 6" orifice and measures rainfall in 0.01 inch increments and funnels precipitation into a bucket mechanism that tips when filled to a calibrated level.
- 034B-ETM Wind Set: This sensor combines a 3-cup anemometer and vane, constructed out of lightweight aluminum and is designed for continuous long-term operation.

Software is included in the weather station that calculates ET based on the monitored weather conditions and the type of landscape at the location.

<sup>6</sup> Specifications for the Campbell Scientific ET107 Evapotranspiration Monitoring Station were obtained from: <http://www.campbellsci.com/et107-specifications>

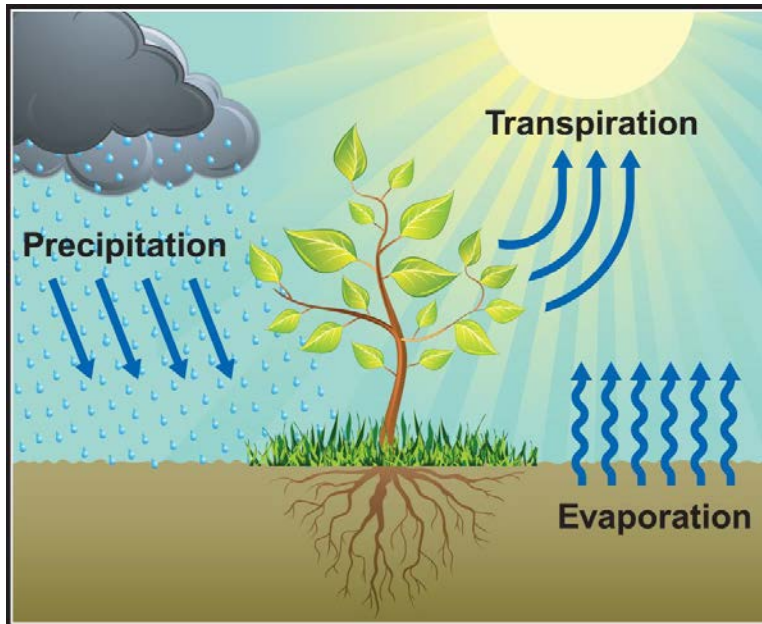
Figure 18. Campbell Scientific ET107 Evapotranspiration Monitoring Station



## B. EVAPOTRANSPIRATION INFORMATION

Evapotranspiration (ET) is the total amount of evaporation from the soil and transpiration from the plant to the atmosphere, which represents the total amount of moisture lost from the plant (Figure 19). Transpiration is the movement of water through the plant and evaporation through the plant's surface components, such as leaves, stems and flowers.

Figure 19. Evapotranspiration Diagram



ET is commonly used to determine the amount of supplemental water that is needed to keep a plant healthy. ET is calculated for a reference crop, typically alfalfa grass. The reference crop ET, denoted as  $ET_o$ , provides a standard ET value to which all other plants' ET can be based on. This is accomplished by applying a crop coefficient to the reference ET. For example, a cool season turfgrass, such as Kentucky bluegrass, has a crop coefficient of 0.8. This essentially means that Kentucky bluegrass needs 80% of the water that is required by the reference crop.

The weather station installed at the Battle Creek facility uses the Penman-Monteith equation to calculate reference ET, represented in the following equation.<sup>7</sup>

$$ET_o = \left[ 0.408\Delta(Rn - G) + \gamma \left( \frac{900}{T + 273} \right) u(VPD) \right] \div [\Delta + \gamma(1 + 0.34u)]$$

Where:

<sup>7</sup> Food and Agriculture Organization of the United Nations. Natural Resources Management and Environment Department. *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. Rome, Italy. 1998. Accessed on March 10, 2014, at: <http://www.fao.org/docrep/X0490E/X0490E00.htm>

$E_{To}$  is the daily reference crop ET measured (mm/day)

$T$  is the mean of the maximum and minimum air temperatures recorded for the day ( $^{\circ}\text{C}$ )

$VPD$  is the vapor pressure deficit, which is the actual vapor pressures subtracted from the saturated vapor pressure (kPa)

$u$  is the wind speed measured by the weather station (m/second)

$R_n$  is the net radiation at the plant's surface ( $\text{MJm}^{-2}\text{d}^{-1}$ )

$G$  is the soil heat flux density ( $\text{MJm}^{-2}\text{d}^{-1}$ )

$\Delta$  is the slope vapor pressure curve ( $\text{kPa}^{\circ}\text{C}^{-1}$ )

$\gamma$  is the psychrometric constant ( $\text{kPa}^{\circ}\text{C}^{-1}$ )

The Battle Creek facility turf is Kentucky bluegrass. Therefore, a crop coefficient of 0.8 is applied to the reference crop ET, calculated by the weather station. This ET value is then subtracted from the total precipitation received over the same timeframe to determine the amount of supplemental irrigation required by the landscape.

### C. LIST OF ABBREVIATIONS AND SYMBOLS

Term	Description
BAS	building automation system
EPA	Environmental Protection Agency
ET	evapotranspiration
FEMP	Federal Energy Management Program
FY	fiscal year
GPG	Green Proving Ground
gpm	gallons per minute
GSA	U.S. General Services Administration
kgal	thousand gallons
LCC	life-cycle cost
M&V	measurement and verification
Mgal	million gallons
O&M	operations and maintenance
PNNL	Pacific Northwest National Laboratory
SIR	savings-to-investment ratio
sqft	square feet
SWAT	Smart Water Application Technologies

#### D. REFERENCES

- [1] Energy Policy Act of 2005. 2005. 42 USC 15801 et seq. Public Law No. 109-58, as amended.
- [2] 72 FR 3919. January 26, 2007. Executive Order 13423 of January 24, 2007, Strengthening Federal Environmental, Energy, and Transportation Management. Federal Register Vol. 74, No. 17. Accessed December 31, 2013 at <http://www.gpo.gov/fdsys/pkg/FR-2007-01-26/pdf/07-374.pdf>.
- [3] 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. Accessed December 30, 2013 at <http://energy.gov/eere/femp/executive-order-13514>
- [4] U.S. Environmental Protection Agency. 2013. WaterSense. WaterSense Labeled Irrigation Controllers. Accessed December 30, 2013 at <http://www.epa.gov/watersense/products/controltech.html>.
- [5] Dukes, MD. 2012. *Water Conservation Potential of Landscape Irrigation Smart Controllers*. American Society of Agricultural and Biological Engineers. ISSN 2151-0032.
- [6] U.S. General Services Administration. 2013. Hart-Dole-Inouye Federal Center, Building 2, Battle Creek, MI. Accessed January 8, 2014 at <http://www.gsa.gov/portal/ext/html/site/hb/category/25431/actionParameter/exploreByBuilding/buildingId/787>.
- [7] National Oceanic and Atmospheric Administration National Climatic Data Center. 2013. Precipitation Data for Battle Creek, Michigan. Accessed October, 2013 at <http://www.ncdc.noaa.gov/>.
- [8] U.S. Department of Energy Federal Energy Management Program. 2013. Best Management Practice: Water-Efficient Irrigation. Accessed December 10, 2013 at [http://www1.eere.energy.gov/femp/program/waterefficiency\\_bmp5.html](http://www1.eere.energy.gov/femp/program/waterefficiency_bmp5.html).
- [9] U.S. Environmental Protection Agency. 2012. WaterSense at Work: Best Management Practices for Commercial and Institutional Facilities. Accessed December 10, 2013 at [http://www.epa.gov/watersense/commercial/docs/watersense\\_at\\_work/#/160/](http://www.epa.gov/watersense/commercial/docs/watersense_at_work/#/160/).
- [10] Irrigation Association. 2014. Smart Water Application Technologies Testing Protocol for Climate-Based Irrigation Controllers. Accessed February 25, 2014 at <https://www.irrigation.org/SWAT>
- [11] U.S. Environmental Protection Agency. 2011. *WaterSense Specification for Weather-Based Irrigation Controllers Version 1.0*. Washington DC.