Evaluation of Soil Moisture-Based On-Demand Irrigation Controllers, Phase II

Final Report

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Southwest Florida Water Management District

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Acknowledgments and Disclaimer

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Media Summary

Soil moisture sensor (SMS) irrigation control systems have been shown to reduce irrigation relative to representative homeowner irrigation amounts in plot scale studies. The SMS system can improve irrigation efficiency, promote water conservation, and reduce the environmental impacts of over irrigation.

A three-year research project, funded by the Southwest Florida Water Management District (SWFWMD), to evaluate irrigation conservation technology on cooperating homes, including SMS-based irrigation systems was recently completed. These SMS systems were compared to irrigation systems on homes incorporating rain sensors, and educational materials. These irrigation control intervention activities and technologies were compared to time-based irrigation schedules implemented by participants with minimal intervention. All of these strategies were implemented on cooperating homes in Pinellas County.

Dr. Michael D. Dukes, Mrs. Melissa Baum Haley, and Dr. Grady Miller conducted the research. The research provided data on how much water can be saved by SMS-based irrigation systems when used in landscape irrigation. The SMS homes were the only group with statistically significant savings; 65% less irrigation applied compared to homes that were only monitored. Although the educational material homes initially showed savings, later in the study their irrigation use increased. Incorporating a rain sensor did not result in significantly lower irrigation amounts compared to homes without rain sensors, in part likely due to the dry conditions during the study.

Agencies involved in addition to SWFWMD staff included: Pinellas County Utilities, Pinellas County Extension, Florida Yards & Neighborhoods, Florida Nursery Growers and Landscape Association, Florida Irrigation Society, Tampa Bay Water, Florida Department of Agriculture and Consumer Services, and the City of St. Petersburg. In addition to primary funding by SWFWMD, both the Florida Department of Agriculture and Consumer Services and the Florida Nursery Growers and Landscape Association contributed funds toward the project. The following list acknowledges the individuals that provided guidance and input throughout the project: Kathy Scott, Melissa Musicaro, Jay Yingling, Lois Sorenson, Robert Peacock, James Spratt, Dave Bracciano, Dale Armstrong, Hugh Gramling, Gail Huff, Ralph Craig, and Christine Claus.

Executive Summary

The primary objective of this project was to determine if an automatic irrigation system in the residential environment, when receiving feedback from a soil moisture sensor system (sensor and proprietary controller; SMS systems), could reduce irrigation water application while maintaining acceptable turfgrass quality. These SMS systems were compared to irrigation systems incorporating rain sensors, educational materials, and time-based irrigation controllers with schedules set by participants. All of these strategies were implemented on cooperating homes in Pinellas County.

Fifty-nine homes voluntarily cooperated throughout the study, each with an automatic in-ground irrigation system, utilizing potable water. Homes were categorized into four unique experimental treatments at each of four locations within the study area. Historical water use was analyzed to distribute high and low irrigation users evenly across treatments. Treatment classification refers to the method or technology used for irrigation control as follows:

- SMS - soil moisture sensor system, coupled with the time clock irrigation controller.
- RS – an expanding disk rain sensor coupled with the time clock irrigation controller.
- MO - comparison group and without any special control technology other than the existing time clock common to all homes.
- EDU - current irrigation system with an expanding disk rain sensor as well as educational materials with time clock run times for a given time of the year based on Institute of Food and Agricultural Sciences (IFAS) recommendations.

Meters were installed at each house on the irrigation main line to measure irrigation water use. Additionally, weather stations were installed for each location to estimate theoretical irrigation need. Estimated irrigation need was determined using a daily soil water balance based on calculated turfgrass evapotranspiration and measured rainfall. Data collection on all of the homes commenced in July 2006 and ended December 2008, with treatments commencing in November 2007 for a total of 26 months. During this period the rainfall was 17% less (1,043 mm) than historical (1,259 mm). Using a soil water balance, the calculated gross irrigation requirement averaged 54 mm per month, with a range of 31-95 mm per month, and 4 irrigation events per month, with a range of 2-7 events per month.

The total cumulative savings were calculated compared to the meter only treatment. The SMS treatment was the only group with statistically significant savings, with 65% less water applied (554 mm) for irrigation than the MO treatment (1,584 mm). Although the EDU treatment initially showed savings, over the 26-month study period this trend did not persist. Lastly, the RS treatment did not result in a significant reduction in irrigation, likely due to dry conditions during the study. The

SMS savings were similar to what was found in Phase I, the plot study. During wet conditions SMS system savings averaged 72%, and during dry weather conditions savings averaged 28 to 54%. However, the Phase I rain-sensor treatment resulted in 34% less water applied than the without-rain-sensor treatment during wet weather conditions, which was a significant savings.

After the EDU group's gradual increase in water use in mid 2007, throughout 2008 the EDU homes followed the theoretical irrigation need trend similar to RS only homes. Initially it was hypothesized that the EDU group did not adjust their timers, after the commencement of the treatment in Nov 2006, until the turf showed signs of stress the following spring. The upward trend beginning in 2007 was during a time when the irrigation schedule should have been readjusted back to the lower fall runtime, which also concurs with the hypothesis of minimal timer adjustment.

In addition to volume of water use, irrigation frequency was determined from automatic meter reading (AMR) device data. The SMS treatment resulted in the lowest number of irrigation events, which were half to a third less than the other study homes. This result indicates that the SMS irrigation controllers bypassed irrigation events resulting in significant irrigation savings. The MO, RS, and EDU homes each had at least one home that had 20 or more irrigation events a month over the study time frame. The SMS systems appeared to have limited the number of irrigation events, where the maximum number of monthly events was 11 versus the 29 events of the MO treatment. This trend occurred despite 1 day per week water restrictions since January 2007. Thus, the SMS systems act as "irrigation regulators" and limited unnecessary irrigation regardless of homeowner controller programming.

All homes in the study applied more water in the spring months compared to other times of the year. Average irrigation during these months was 56 mm/month compared to 41 mm/month the rest of the year. This trend coincided with the highest period of irrigation water requirements.

Throughout the 26 months from the commencement of treatments establishment, no significant differences in average turf quality ratings were detected among homes based on treatment group. Thus, even during the relatively dry study period, reducing water application through the use of SMS irrigation controllers did not reduce turfgrass quality. Other landscape plant material quality was not measured; however, cooperating homeowners did not indicate any negative quality aspects due to irrigation reduction.

1. Introduction

1.1. Background

This document serves as the final report for the project entitled "Evaluation of Soil Moisture Based On-demand Irrigation Controllers", with Southwest Florida Water management District (SWFWMD) Project Number B-187 and University of Florida Project Number 00055546. This project was officially started in March 2005 when the fully executed contract was sent to the University of Florida and ended December 2009 with this final report.

1.2. Justification

The Florida climate consists of dry and warm weather in spring and fall, coupled with frequent rain events in summer months (NOAA 2003). With these environmental conditions occurring in areas of mostly sandy soil, which has a low water holding capacity, irrigation is often used to supplement rainfall to maintain high quality landscapes. Therefore, automatic in-ground irrigation is common in Florida. Of all new home construction within the United States, more than 15% occurred in Florida from 2005-2006 (USCB 2007). Further, the majority of new homes are sold with automatic in-ground irrigation systems already in place(TBW 2005; Whitcomb 2005). Homes with automatic irrigation systems have been reported to have higher water use compared to manual irrigation or hose-end sprinklers (Mayer et al. 1999).

According to Phase I results of this project, soil moisture sensor system controlled irrigation represents a technology that could lead to substantial savings in irrigation water use while maintaining acceptable turf quality, even during dry weather conditions (Dukes et al. 2008). The project described here (Phase II) expands the testing of this technology with existing residential irrigation systems as agreed upon between the District and the University, validating the plot study results of Phase I.

1.3. Objectives

The objectives of this study were to quantify irrigation water use and to evaluate turf quality differences between: 1) a time-based irrigation system with a soil moisture sensor system, 2) a time-based irrigation system with a rain sensor, and 3) a time-based irrigation system with rain sensor as well as distributed educational materials. All of these experimental treatments consisted of technology or irrigation scheduling intervention and were compared to homes with minimal intervention during the project.

2. Materials and Methods

2.1. Participant Recruitment

The homes included in this research project were located in the City of Palm Harbor, Pinellas County, Florida within the Pinellas Anclotte Basin of SWFWMD. Initial participant recruitment consisted of an advertisement enclosed in Pinellas County Utilities (PCU) customer water bills. Approximately 200 customers responded to the advertisement by telephone communication with either PCU or University personnel. The interested participants were then invited to workshops held in Palm Harbor. The workshops were meant to educate the participants on the project protocol and served as a form of informed consent for participation.

By November 2005, 59 residential cooperators, with automatic in-ground irrigation systems using potable water, were recruited. The site locations were divided into four quadrants, based on distance from the coast and natural groupings of homes and labeled as follows: Northwest quadrant (Location 1), Southwest quadrant (Location 2), Southeast quadrant (Location 3), Northeast quadrant (Location 4), as shown in Figure 2.1.

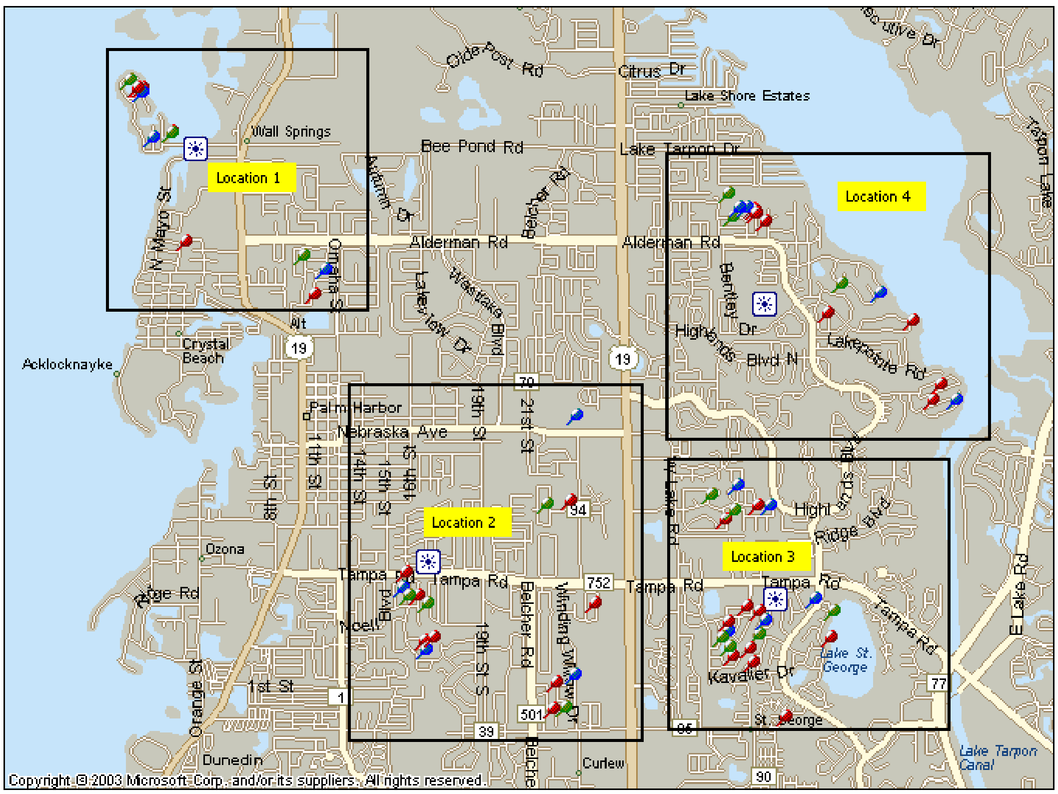

Figure 2.1. Street map of the City of Palm Harbor in Pinellas County Florida with cooperating study homes denoted by pins. The pin color refers to equipment installed at each home: red is flow meter and rain sensor, green is flow meter and soil moisture sensor, and blue is flow meter only. Weather station locations are shown as squares surrounding asterisks.

2.2. Experimental Design

2.2.1. Equipment Installation

All cooperating homes had a pre-existing automatic irrigation system and time-based controller. An irrigation contractor was hired by the University to install all supplementary equipment (rain sensor or soil moisture sensor) as necessary based on participating home treatment type. Additionally at each home, a positive displacement irrigation sub-meter was installed. This meter allowed direct determination of irrigation usage exclusive of indoor use. The equipment installation timeline is listed in Table 2.1. The meters were installed in straight pipe runs where possible to ensure meter accuracy (Baum et al. 2003).

2.2.2. Treatments

The homes were divided into four experimental treatments. Treatment classification refers to the method or technology used for irrigation control.

- Treatment one, T1, homes had an Acclima TDT RS-500 soil moisture sensor system (SMS) set at a 10% (volumetric water content) threshold, coupled with the timer-based irrigation controller.
- Treatment two, T2, homes had an expanding disk (Hunter Mini-Click) rain sensor (RS) added to the timer-based irrigation controller.
- Treatment three, T3, homes were a comparison group and did not have any control technology other than the existing time clock common to all homes. This treatment is referred to hereafter as meter only (MO).
- Treatment four, T4, homes had an expanding disk (Hunter Mini-Click) rain sensor added to the timer-based irrigation system as well as educational materials (EDU).

Research personnel programmed the SMS controller threshold setting, but the homeowner programmed the irrigation time clock. Only in the T4 (EDU) group was an attempt made to explicitly encourage homeowners to set their irrigation timers according to recommended settings after the initial treatment implementation. It is important to note that the MO homes did not have rain sensors.

2.2.3. Educational Material Dissemination

The educational materials included a customized irrigation run time card and documents explaining outdoor water saving practices developed by UF-IFAS and SWFWMD . The run time card is based on the home's specific system design, zone layout, and application rates. This card provides the homeowner with system run times for each season. The laminated card was fastened to the controller box (Figures 2.2 and 2.3). It was hypothesized that the card would make it easy for homeowners to set the correct time on their timer to irrigate a particular irrigation zone.

Additionally, the educational materials included a SWFWMD developed document "Saving Water Outdoors; Use what you need, need what you use." This is a six-page booklet informing users on leak detection, outdoor irrigation, lawn care and principles of Florida-Friendly landscaping. In reference to irrigation, the document briefly explains when and how to irrigate, information about rain sensor functionality, and irrigation methods.

The most technical document given to the participant was the UF-IFAS publication "Operation of Residential Irrigation Controller". This article explains the setting of irrigation controller runtimes based on application rate. At the end of the document, there are a series of tables suggesting runtimes by month. This document was provided as a supplement to the personalized runtime card developed for the participating site's unique irrigation system. Copies of these additional educational materials can be found in Appendix A.

Irrigation Runtimes in Minutes

Use the following table to set your irrigation system for seasonal water use. The zone runtimes have been calculated for your system based on once day per week irrigation. These are guidelines and set to help you conserve water, you can water more or less if you notice inadequate water application in the landscape. Please call the University with any major changes to the suggested runtimes so we may update our records or your water practices.

Season	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
Winter (Dec., Jan., Feb.)						
Spring (Mar., Apr.)						
Summer (May, Jun., Jul., Aug.)						
Fall (Sep., Oct., Nov.)						

Your Zone Locations and sprinkler types:

Zone 1 – Micro-irrigation by house.
Zone 2 – Left side, mostly rotor heads.
Zone 3 – Right side, rotor heads.
Zone 4 – Sidewalk strip, spray heads.
Zone 5 – Front micro-irrigation.
Zone 6 – Back yard, spray heads.

Figure 2.2. Front of laminated irrigation runtime card distributed to the educational group of homes (T4).Individual zones specific to a cooperator's irrigation zone application rate (measured during irrigation evaluation) was used to estimate a customized runtime.

The System Rain Sensor

The rain sensor is set to bypass the irrigation system if there has been greater than ¼ inch of rainfall. If the sensor bypasses the system, your turfgrass will NOT suffer. Additional irrigation will not be absorbed into the root zone at this time. Irrigation is not necessary is the rain sensor is activated. You do not need to turn off your controller; it will automatically bypass the signal sent from the controller to the irrigation valves.

The Irrigation Flow Meter

You may have noticed the new meter installed. This meter measures the amount of water used by the irrigation system only. The utility water meter measures the total water use from your home, both inside and outside use. This meter will be read monthly by an employee of Pinellas County Utilities, it will not affect your water bill. You are welcome to read it yourself as well.

Questions or Concerns

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Figure 2.3. Back of laminated irrigation runtime card distributed to the educational group of homes (T4).

2.2.4. Contact/Interaction

Contact between the PCU/University personnel and the Phase II participants after all of the experimental treatments were installed and functional was limited as much as possible. Participants were encouraged to maintain irrigation practices, as they would do if not part of the study. The timeline of contact or observed interaction is listed in Table 2.1.

Table 2.1. Participant contact and/or interaction including equipment installation and routine data collection.

Date	*Action*	*Treatment Involvement*	*Interaction Level*
11/2005- 5/2006	Irrigation audits, Turf quality ratings	All, letter sent	High
1/2006	Notifications of equipment installation	All, letter sent	Medium
2/2006-7/2006	Installation of RS	T2 and T4	High
8/2006-10/2006	Installation of SMS	T1 only	High
7/2006- 12/2008	Commencement of meter readings by PCU staff	All	Low
10/2006	Turf quality ratings	All	Low
11/2006	Check up on SMS	T1 only	High
11/2006	Distribution of EDU	T4 only	High
1/2007	Turf quality ratings	All	Low
3/2007	Check on SMS installation	T1 only	High
4/2007	Turf quality ratings	All	Low
4/2007	Notification of AMR installation	All, letter sent	Medium
4/2007-5/2007	Installation of AMRs	All	Medium
8/2007	Check on SMS programming	T1 only	High
8/2007	Turf quality ratings	All	Low
12/2007	Turf quality ratings	All	Low
4/2008	Turf quality ratings	All	Low
6/2008	Survey of water use practices	All, letter sent	Medium
12/2008	Check up on SMS	T1 only	High

2.2.5. Weather Stations

Four weather stations were setup in Palm Harbor. The stations were relatively close to each other, within 4 km, and all had a grass reference surface (Figure 2.1). Each weather station was within a 1 km radius of the surrounding homes for the given location. As common with most urban weather stations, the stations were surrounded by different obstacles and encountered different fetch distances (Figures 2.4-2.11). All practical efforts were made to minimize obstructions near the weather stations. In any case, the stations were representative of weather data in urban area.

Figure 2.4. Weather station L1 location.

Figure 2.5. Weather station L1 photo.

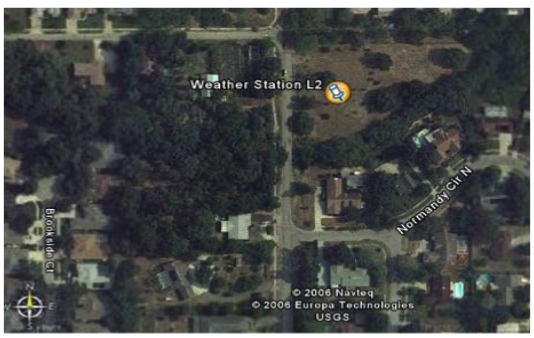

Figure 2.6.Weather station L2 location.

Figure 2.7. Weather station L2 photo.

Figure 2.8.Weather station L3 location.

Figure 2.9. Weather station L3 photo.

Figure 2.10.Weather station L4 location.

Figure 2.11. Weather station L4 photo.

The urban weather stations were installed and commenced data collection in July 2006. The stations stand approximately 2.4 m. The frame is buried 1.2 m in the ground and secured with concrete. Three of the four stations are on PCU property. The station at location L4 is on private property.

All four weather stations have the same types of sensors (Figure 2.12). Solar radiation was measured by a LI200X LI-COR silicon pyranometer (Campbell Sci. Inc., Logan, UT); wind speed and wind direction by a WS425 ultrasonic wind sensor (Vaisala Inc., Woburn, MA); and temperature and relative humidity by HMP45C temperature and humidity probe (Vaisala Inc., Woburn, MA). All data were recorded by a CR10X datalogger (Campbell Sci. Inc., Logan, UT). The output parameter was 15 min average values.

Daily evapotranspiration was estimated from weather parameters measured at each weather station. This data were used to calculate the standardized reference evapotranspiration rate on a daily basis, following the ASCE-EWRI (Allen et al. 2005) methodology:

$$ET_o = \frac{0.408\,\Delta (R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + C_d u_2)}$$ Equation. 2.1

where: ET_o = reference evapotranspiration for short surfaces (mm d^{-1})

R_n = calculated net radiation at the crop surface (MJ m^{-2} d^{-1})

G = soil heat flux density at the soil surface (MJ m^{-2} d^{-1})

T = mean daily or hourly air temperature at 1.5 to 2.5-m height (°C)

u_2 = mean daily or hourly wind speed at 2-m height (m s^{-1})

e_s = saturation vapor pressure at 1.5 to 2.5-m height (kPa), calculated for daily time steps as the average of saturation vapor pressure at maximum and minimum air temperature

e_a = mean actual vapor pressure at 1.5 to 2.5-m height (kPa)

Δ = slope of the saturation vapor pressure-temperature curve (kPa $°C^{-1}$)

γ = psychrometric constant (kPa $°C^{-1}$)

C_n = numerator constant that changes with reference type and calculation time step (K mm s^3 Mg-1 d^{-1})

C_d = denominator constant that changes with reference type and calculation time step (s m^{-1})
Units for the 0.408 coefficient are m^2 mm MJ^{-1}.

For the soil water balance comparisons described in the next section daily ET_o was calculated at each location. Crop coefficient evapotranspiration for daily turfgrass water use was calculated with the following equation (Allen et al. 2005):

$$ET_c = ET_o * K_c$$ **Equation. 2.2**

where: ET_C = crop evapotranspiration (mm d^{-1})
ET_O = reference evapotranspiration for short surfaces (mm d^{-1})
K_c = crop coefficient

The crop coefficients recommended for warm season turfgrass in South Florida range from 0.71 in January to 0.99 in May (Jia et al. 2009).

Since the calculated evapotranspiration relies on the quality of the weather data, integrity and quality assurance of these data were assessed as recommended by ASCE-EWRI (Allen et al. 2005). In addition to data assessment, routine maintenance was performed to ensure the proper functionality of the weather station. Technical maintenance includes the evaluation, repair and replacement of equipment, while non-technical site maintenance includes removal of debris from tipping bucket, cleaning solar panel, bird prevention, mowing, etc.

Figure 2.12. Anatomy of a weather station: (A) solar radiation sensor, (B) solar panel to power the station, (C) relative humidity sensor, (D) sonic anemometer to measure wind speed and direction, (E) tipping bucket to determine rainfall amount and duration, (F) datalogger enclosure.

2.3. Soil Water Balance

To compare the actual irrigation water applied of the residential landscapes, a theoretical irrigation water requirement was calculated using a daily soil water balance (SWB) (Dukes 2007):

$$\Delta S = I_{calc} + P_e - ET_c - D - RO \qquad \text{Equation. 2.3}$$

where: ΔS = change in soil water storage within the root zone (mm d^{-1})
I_{calc}= calculated net irrigation requirement (mm d^{-1})
P_e= effective rainfall (mm d^{-1})
ET_c= calculated ET (mm d^{-1})
D = drainage below the root zone from excess irrigation (mm d^{-1})
RO = surface runoff (mm d^{-1})

To determine the amount of irrigation, drainage, and effective rainfall, the upper and lower boundaries were determined using the hydraulic properties of the soil. The upper boundary is referred to as field capacity (FC), and is the amount of water the soil can hold after gravitational drainage. For the sake of minimal turfgrass stress the lower boundary is the readily available water (RAW).

$$WHC = FC - PWP \qquad \text{Equation. 2.4}$$

$$AW = WHC * RZ \qquad \text{Equation. 2.5}$$

$$RAW = AW * MAD \qquad \text{Equation. 2.6}$$

where: WHC = water holding capacity based on soil properties (mm^3 mm^{-3})
FC = field capacity of soil, upper boundary of the SWB (mm^3 mm^{-3})
PWP = permanent wilting point (mm^3 mm^{-3})
AW = available water (mm^3 mm^{-3})
RZ = root zone (mm)
RAW = readily available water, lower boundary of the SWB (mm)
MAD = maximum allowable depletion, assumed to be 0.5 for St. Augustinegrass.

Once the soil hydraulic properties are used to define upper limit of water storage and then to estimate drainage or runoff, Equation 2.3 can be rearranged to solve for I_{calc} assuming ΔS is minimal between irrigation cycles. Based on the soil survey data for the soil series Astatula and urban land for Pinellas County, the FC was taken as 11% and PWP as 4%, resulting in a 7% available water content, which is appropriate for the area (Lewis et al. 2006).

The change in soil water storage within the root zone, ΔS, is then calculated following on a daily basis. Irrigation, I_{calc}, is needed when the amount of soil water at the beginning of the day is at or below the lower boundary, RAW. Applied net irrigation is the amount necessary to reach the upper boundary, FC. Likewise, only the rainfall considered effective is the amount of input until FC is reached. Additional rainfall was considered excess and results in runoff or drainage. To determine the theoretical soil water balance, individual soil water balances were developed for each location and then the calculated irrigation need was averaged.

The gross irrigation requirement mimics irrigation under actual irrigation system conditions considering allowable irrigation inefficiencies. An acceptable irrigation efficiency factor of 80% was used in this project to simulate ideal irrigation based on uniformity potential of irrigation systems in Florida (Dukes et al., 2006). Therefore a gross irrigation amount needed by the homes was determined by the SWB as 25% more than the net irrigation calculated.

2.4. System Evaluations

Irrigation system evaluations were conducted at each home included in Phase II. The evaluation was used as a method of quantifying the irrigation system performance. During this evaluation any required maintenance resulting from broken heads and/or leaks was noted. Any maintenance that would compromise the uniformity test was fixed before the testing began. In extreme cases it was recommended that the homeowner would fix deficiencies before they could become part of the study.

Meter data was used to determine the application rate (depth/time) for each zone on all of the irrigation systems. This information was later utilized when creating the runtime cards for the EDU treatment.

An estimation of system low-quarter distribution uniformity (DU_{lq}) was calculated by performing a catch-can test following the Mobile Irrigation Lab Handbook guidelines for Florida (Mickler 1996). Uniformity of water distribution measures the relative application depth over a given area and is described by Equation 2.7. The term uniformity refers to the measure of the variability of applied water over an irrigated area.

$$DU_{lq} = V_{lq} / V_{tot} \qquad \text{Equation. 2.7}$$

where: V_{lq}= average of the lowest one-fourth of catch-can measurements, mL
V_{tot}= average depth of application over all catch can measurements, mL

To distinguish between a measure of uniformity and efficiency, DU_{lq} is expressed as a decimal as suggested by Burt et al. (1997). This concept can assign a numeric value to quantify how well a system is performing.

2.5. Historical Water Use

Cooperating home historical water use was examined to establish treatments across low to high water users to minimize the possibility of water use bias in a given treatment. Residential potable water use (indoor plus irrigation) data were analyzed based on the previous two years of billing data for each home. Bimonthly potable water meter billing data was provided by PCU. To estimate the bimonthly irrigation water use, the indoor water use was subtracted from the total water use, by assuming that indoor water use was the minimum bimonthly consumption over the two-year period. The irrigation water use in volume was then divided by 85% of the non-structural land area to determine the irrigation application per given time period. In a previous study conducted with St. Johns River Water Management District (SJRWMD), on average the irrigated area was 85% of the non-structural area (Haley and Dukes 2007a). The non-structural land area for each home was calculated from county parcel records.

Once the bimonthly irrigation water use was estimated, each home was then categorized into an irrigation tendency classification. These classifications were based on quartiles where the low quartile was "low", two next quartiles (2 and 3) were "medium" and the upper quartile was classified as "high" irrigation users. Homes from each of these water use tendencies were then assigned approximately evenly across the four treatments to minimize any water use trends impact on treatment effects from inherent tendencies of individual users.

2.6. Irrigated Area

Property information was gathered from the Pinellas County property appraisal public records (www.pcpao.org) for each home included in the analysis. These records included information on the comparable sales from 2005-2006 (property value), the property size, total gross living area (i.e. gross structural footprint), and residential extras (e.g. pool, enclosure, patio, shed, etc.). A calculated irrigated area was determined by subtracting the gross structural area and residential extras from the property size. From the Pinellas County public GIS records (www.gis.pinellas.org), the residential parcels are outlined and an aerial layer from Jan/Feb 2006 was overlaid. Using GIS image layers, the irrigated areas were outlined with a polygon measurement tool (note the red polygons in Figure 2.13). The GIS software was used to determine the aerial estimated irrigated area by calculating the area of each polygon. Actual irrigated areas were measured at site visits to homes participating in Phase II. These measurements were used to verify assumptions in the aerial estimated irrigation area methodology. The aerial estimated irrigated area was then compared to the calculated irrigated area from the property appraisal information.

Figure 2.13. Aerial view of residential parcels with red polygons denoting irrigated area.

2.7. Landscape Level

Initially every home was given a visual inspection and rated based on landscape level (Figures 2.14 through 2.16). The landscape levels were qualitatively assigned based on the percentage turfgrass versus bedded areas. From a previous irrigation water use efficiency study, it was concluded that homes with a greater percentage of bedded area and microirrigation tended to consume less water use per irrigation cycle because microirrigation applies less water per unit area than sprinkler irrigation(Haley and Dukes 2007b). In this study, non-turfgrass landscape areas were typically irrigated with sprinklers.

- (LL1) Turfgrass comprises greater area then bedded landscape area
- (LL2) Turfgrass and bedded areas approximately equal
- (LL3) Turfgrass comprises less area then bedded landscape area

Figure 2.14. Example of landscape level one, LL1.

Figure 2.15 Example of landscape level LL2.

Figure 2.16.Example of landscape level three, LL3.

2.8. Data Collection

2.8.1. Water Application

Household water consumption, both total and water used for irrigation was recorded by flow meter readings. The irrigation water use for the homes was calculated as a depth of water applied (mm or inches) by dividing the volume usage (m^3 or gal) by the irrigated area (m^2 or ft^2) of the home.

From July 2006 through April 2007, PCU personnel recorded the weekly elapsed water meter readings manually. Beginning in April 2007, dataloggers were attached on the irrigation meters to collect actual water use in 10 min time intervals. The dataloggers are part of an automatic meter reading /recording (AMR) technology for data collection using a meter interface unit (MIU) which attaches to the existing irrigation water meter. The MIUs were installed on the majority of the homes during late April 2007 by the AMR Company Datamatic, Inc. University personnel installed the additional MIU's during May 2007 after installation training by Datamatic, Inc.

By December 2007 the AMR logging interval was increased from 10 min to 1 hr. The data collection was previously conducted weekly and the data-loggers were recording water use in a 10 min time interval. With the increase from a 10 min to 1 hr interval, the AMRs can hold 72 days of hourly data records and therefore may be downloaded less frequently. This change in logging interval did not compromise any data analysis.

2.8.2. Turfgrass Quality

Turf quality ratings can be used as a method to quantify the overall appearance of the turfgrass area as well as a measure of functional use and aesthetics. Initial turf quality ratings were taken for each home during the irrigation evaluations, as a baseline standard of comparison for each home. The assessment of turfgrass is a subjective process following the National Turfgrass Evaluation Procedures (NTEP) (Shearman and Morris 1998). This assessment is based on visual estimates such as color, stand density, leaf texture, uniformity, disease, pests, weeds, thatch accumulation, drought stress, traffic, and quality. The rating scale is from 1-9, with 1 being lowest and 9 being highest possible. A rating of 5 is considered minimally acceptable (see Figures 2.17 through 2.19). Turf quality was rated at each house seasonally throughout the duration of the study (see Table 2.1 for schedule).

Figure 2.17. Turf quality example; above minimum acceptability with a 7 rating.

Figure 2.18. Turf quality example; minimum acceptability with a 5 rating.

Figure 2.19. Turf quality example; below minimal acceptability with a 2 rating.

2.8.3. Socio-economic Analysis

To determine the effects of socio-economic level on water use, information regarding property value, house size, house age, and the presence of a pool, was all gathered from the Pinellas County property appraiser public records. This information as well as utility water data was obtained for 56 of the Phase II homes as well as 86 non-participant homes. The non-participant homes were neighboring homes to the Phase II participating homes where there were similar irrigated areas, landscape levels, and turf quality. It was not known whether all of the non-participating homes utilized an automatic irrigation system. However, based on visual observation of turf quality the use of irrigation was assumed.

Monthly total water use data was also obtained from Tampa Bay Water for a period of 5 years for each residence. Irrigation use was estimated based on the volume of monthly water use outside and the aerial estimated irrigated area as described previously. If a monthly use was less than the winter minimum (described in section 2.6), the outdoor use was estimated as zero for that month.

2.8.4. Statistical Analysis

The four experimental treatments were replicated at least three times in each of four locations for a minimum of 48 sites. Treatments had three or more replications for a total of 58 homes in the study group.

The data across treatment groups and seasons did not maintain a normal distribution. The data were therefore transformed using the Box-Cox transformation procedure in order to perform valid statistical analysis. The Box-Cox method is a family of power transformations, which transforms non-normally distributed data into a set of data that has approximately normal distribution by reducing the difference in variances (Littell et al. 2006). The water use data were transformed with a fourth root and the irrigation event data were transformed with a square root. A generalized linear mixed model (GLIMMIX) procedure was then used in the SAS software to determine statistical differences across treatment and season groups (SAS 2004). Once means differences were determined, statistical difference indicators were applied to the raw means.

The socio-economic data, were represented by a normal distribution. For these data, statistical analyses were performed using the frequency, Pearson's correlation, univariate, and general linear model (GLM) procedures of the SAS software (SAS 2004). Analysis of variance was used to determine treatment differences and Duncan's Multiple Range Test was used to identify mean differences.

3. Results

3.1. Environmental Conditions

The monthly rainfall amounts for the study period are presented in Figure 3.1. In 2007 even though the cumulative precipitation, 1,014 mm, was 19% less than the historical records, there were the same number of rainfall events, 34% of the days (NOAA 2003). During 2008, 33% of the days had rainfall events, resulting in 5 fewer rainfall events than a normal year; the total precipitation amount was 1,072 mm, 15% lower than normal. A total of 15 of 26 months during the study had less than normal rainfall (Figure 3.1). August through December 2008 was a continuous dry period relative to historical rainfall amounts.

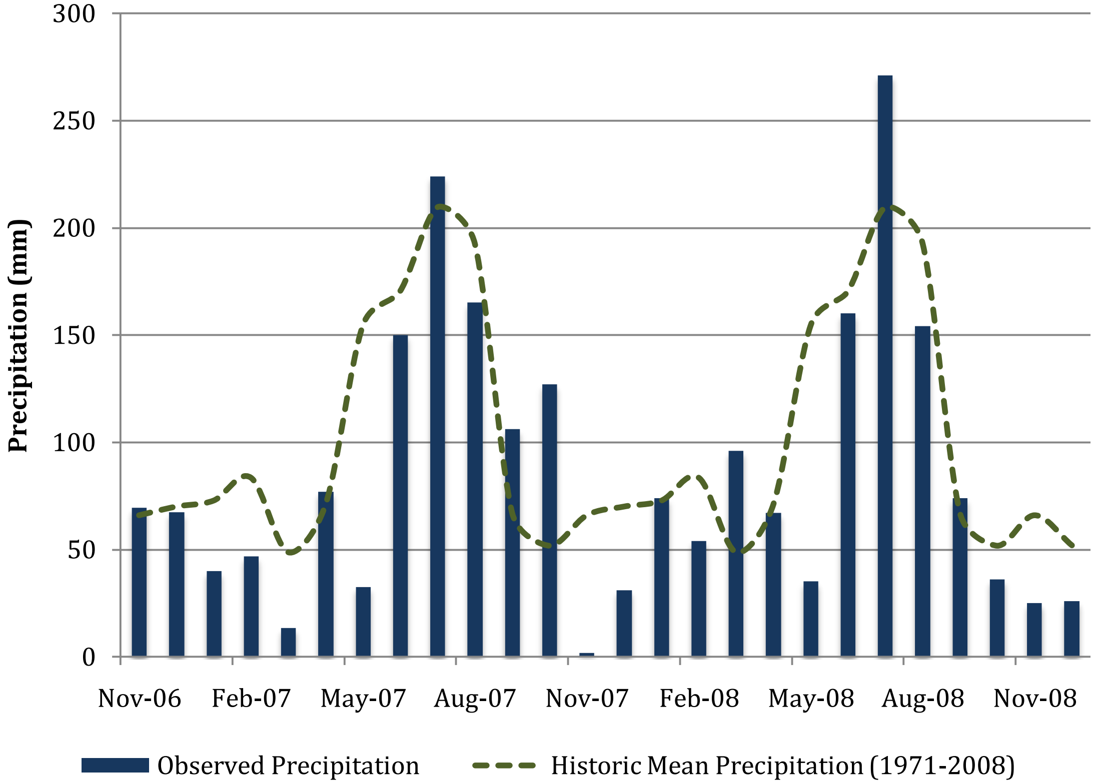

Figure 3.1. Observed monthly rainfall compared to historic rainfall (NOAA 2003) over the study period.

3.2. Prior Water Use Analysis

From the PCU utility data of the participants' previous 2 year water usage, 26% of the homes were relatively low irrigation water users and had an average irrigation water application of 30 mm (5 kgal, where 1 kgal = 1,000 gal) per month. Medium water users accounted for 48% of the homes and consumed an average of 62 mm (10 kgal) of water for irrigation water use monthly. The high water users had an average of 134 mm (19.5 kgal) of water per month for irrigation water use and comprised the upper 26% of the sample (Table 3.1). The estimated irrigation use of these homes was considerably less than homes monitored in the Central Florida region that had irrigation application ranging from 80-140 mm per month (Haley et al. 2007).

Table 3.1.Estimated water use statistics two years prior to the study beginning, used for treatment determination.

	Estimated Irrigation Water Application Depth (mm/30d)			Estimated Irrigation Water Volume Usage (gal/30d)		
Quartile	Average	Min.	Max.	Average	Min.	Max.
Low	30	20	36	5,029	1,875	9,000
Medium	62	40	87	9,999	4,281	17,063
High	134	92	214	19,517	6,719	33,000

* Conversion: 1 inch = 25.4 mm

3.3. Irrigated Area Calculation

The GIS aerial images resulted in more accurate estimations of actual irrigated areas compared to the property appraisal data. The average irrigated area error was within 5%, with no over or under-estimation greater than 10%. Although 35% of the calculated irrigated areas (for property appraiser data) were also within 5% of the actual estimated areas, the error ranged from -49% to 180% (Haley and Dukes, 2007b). Sources of error can be found for both methods of determining irrigation area. The property appraisal information may include enclosures, patios, and pools. However, it is not clearly defined whether the pool/patio is housed within the enclosure or additional area. Furthermore, the property appraisal information rarely denotes the areas comprised by driveways, child playgrounds, and sheds. When looking at the property size, from the public records, the parcel may consist of two lots or a fenced portion, with obviously non-irrigated areas. Possible irrigated areas beyond the total property size that are not included in the recorded parcel area are: easements, walkways, and buffer zones. These areas, which are irrigated and considered part of the actual irrigated area, were included in the actual irrigated area calculations. Most of these areas were easily identified from the GIS measurement, increasing the accuracy of this method. The actual average irrigated areas for each treatment are listed in Table 3.2. The variability in irrigated area did not affect the statistical analysis.

Table 3.2. Average irrigated areas for each of the treatments.

Treatment	Irrigated Area (m^2)				Irrigated Area (ft^2)			
	Mean	Med	Min	Max	Mean	Med	Min	Max
SMS	494	481	188	800	5,318	5,176	2,018	8,605
RS	676	550	362	1,764	7,279	5,919	3,899	18,976
MO	662	610	272	1,187	7,118	6,559	2,929	12,773
EDU	568	562	259	998	6,113	6,042	2,788	10,736

* Conversion: $1m^2 = 10.76\ ft^2$

3.4. Irrigation System Evaluations

The average DU_{lq} of the homes in this study was 0.62, with a range from 0.32 to 0.85. Following the Irrigation Association overall system quality ratings, related to distribution uniformity, 65% the homes in this study can be classified as “good” or higher (Figure 3.2) (IA 2005). Although a third of the homes were lower than “good”, based on previous research study lower uniformities do not necessarily mean poor landscape quality since uniformity of soil moisture is relatively insensitive to catch can DU_{lq} values above 0.4 (Dukes et al. 2006) and nearly all homes had values higher than 0.40. At this level of catch can uniformity the soil moisture uniformity can be approximated as 0.80.

Compared to a Central Florida study, following a similar uniformity methodology, the average DU_{lq} of the homes was 0.58, with a range from 0.42 to 0.82 (Baum et al. 2005).

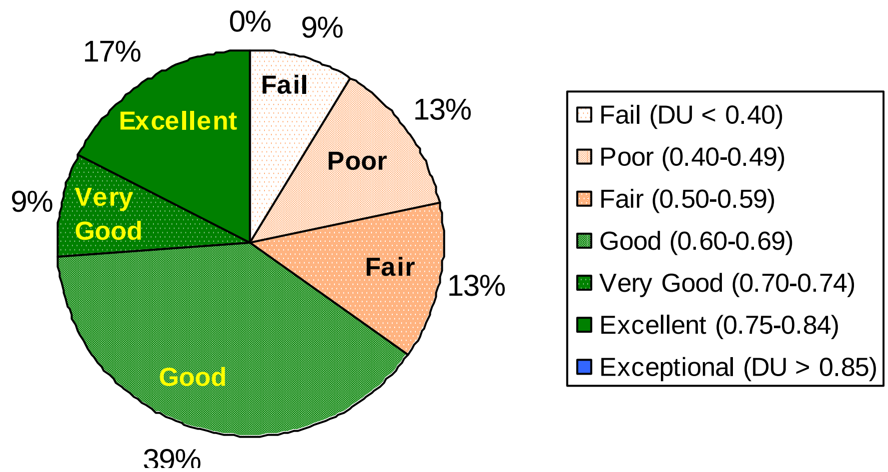

Figure 3.2. Results of irrigation system evaluation uniformity tests based on IA system quality ratings (IA 2005).

As part of the irrigation system evaluation, the number, location, irrigation equipment, and plant type irrigated for each zone was denoted. This information was used in developing the irrigation run cards for the group that received the educational materials. The homes in this study averaged 4-6 irrigation zones. Additionally it was commonly observed that the irrigation head types (e.g. rotor and spray) were mixed within single zones.

3.5. Irrigation Application

3.5.1. Water Application

Over the course of the study, it was observed that the cooperating homes had relatively low water use characteristics compared to other regions in Florida. As part of a concurrent study (SWFWMD funded) in Pinellas County, a response from a mail-out survey was received from 272 homes (including 45 Phase II homes) regarding their irrigation practices. Sixty-nine percent of the Phase II homes reported that they "consider their irrigation practices to be very water conserving" (Haley and Dukes 2008). Furthermore, 33% report manually adjusting their automatic irrigation system schedule, rather than allowing irrigation control devices to bypass irrigation cycles. However, details such as frequency of adjustment are unknown.

Irrigation application was significantly influenced by the season of the year, as shown in Table 3.3. The highest water use occurred in the spring months with an average of 56 mm/month applied compared to the other months with 40 mm/month ($p<0.0001$). The spring months had the highest irrigation demand due to the relatively high evaporative demand and low rainfall. The gross irrigation water requirement in the spring was calculated as 95 mm/month compared to 84 and 62 for the summer and fall respectively. While winter months required the least irrigation with only 31 mm/month.

Table 3.3 presents the irrigation application for each treatment for the study years 2006 through 2008. Overall, the SMS treatment used significantly less irrigation (23 mm/month) compared to the MO RS, and EDU treatments at (51 mm/month). The other irrigation control technologies/strategies used similar amounts, ranging from of 36 to 64 mm/month (Table 3.3). Thus, even though the fall months were dry and resulted in increased irrigation in all treatments (Figure 3.1), the SMS control systems resulted in significant savings during the rainy summer months as well as intermittent rain in the fall.

Mean and median cumulative irrigation application for each treatment, over the 26-month data collection period is presented in Figures 3.3 and 3.4. These figures show the irrigation depth applied by each treatment group, where the recorded volumes were normalized over the irrigated areas. The median values are displayed in Figure 3.4 because the data are not normally distributed.

The total cumulative savings were calculated based on the means and compared to the meter only treatment. The SMS treatment was the only group of homes with statistically significant savings; with 65% less water applied (554 mm) for irrigation than the MO treatment (1,585 mm). Although the EDU treatment initially showed substantial savings, over the 26-month study period the trend did not persist. The RS treatment likely did not save significant water due to the below normal rainfall conditions.

These results were similar to what was found in Phase I, the plot study. During frequent rainfall conditions, SMS based control savings averaged 72% and during dry weather conditions, savings averaged 28 to 54% (Dukes et al. 2008). The Phase I rain-sensor treatment resulted in significant savings of 34% compared to a timer only during wet weather conditions.

Initially it appeared that the EDU treatment was as effective as the SMS treatment. In Table 3.3, it can be noted that although the EDU treatment was lower than the RS and MO treatments, the difference was not statistically significant. Over time the EDU treatment acted similarly to the RS treatment. A steady increase in the consumptive use of the EDU treatment can be observed beginning in the fall of 2007 (Figure 3.3). This upward trend is during a time when the irrigation schedule should have been readjusted back to the lower fall runtime. Thus, EDU homeowners did not adjust their irrigation according to guidelines provided.

Water savings were also calculated in terms of gallons of water saved relative to the MO treatment. Over the 26-month data collection period, the SMS treatment saved, on average, 262 gallons per day, whereas, the other treatments did not result in significant savings. It should be noted that this savings is not adjusted for irrigated area like the values calculated from the irrigation depths in Table 3.3.

Table 3.3. Mean monthly irrigation application by treatment and season for all homes and study years (2006-2008).

		I_{actual}[Z] (mm[W]/month)	N[Y] (#)	Range (mm/month)	Median (mm/month)	Std Dev (mm/month)	CV (%)	I_{calc}[X] (mm/month)
Treatment[V]	SMS	23b[U]	306	0-317	4	39	170	
	RS	56a	339	0-775	43	71	127	
	MO	64a	330	0-950	41	86	134	54
	EDU	36a	333	0-372	24	47	131	
Season[T]	Spring	56a[S]	322	0-950	36	87	155	95
	Summer	37b	253	0-263	17	49	132	84
	Fall	45bc	339	0-572	26	66	147	62
	Winter[R]	40c	394	0-577	25	51	128	31

[Z] Monthly average irrigation applied.

[Y] N = number of observations in the comparison.

[X] Average irrigation application calculated from the SWB.

[W] Conversion: 1 inch = 25.4 mm

[V] Treatments are: SMS, time-based controller plus soil moisture sensor system; RS, time-based controller plus rain sensor; MO, time-based controller only; EDU, time-based controller plus rain sensor and educational materials.

[U] Numbers followed by different letters are statistically different at the 95% confidence level.

[T] Seasons defined as: spring, March, April, May; summer, June, July, August; fall, September, October, November; winter, December, January, February.

[S] AMRs installed during late Spring 2007.

[R] Winter of 2008 consisted of December 2008 and January 2009 only.

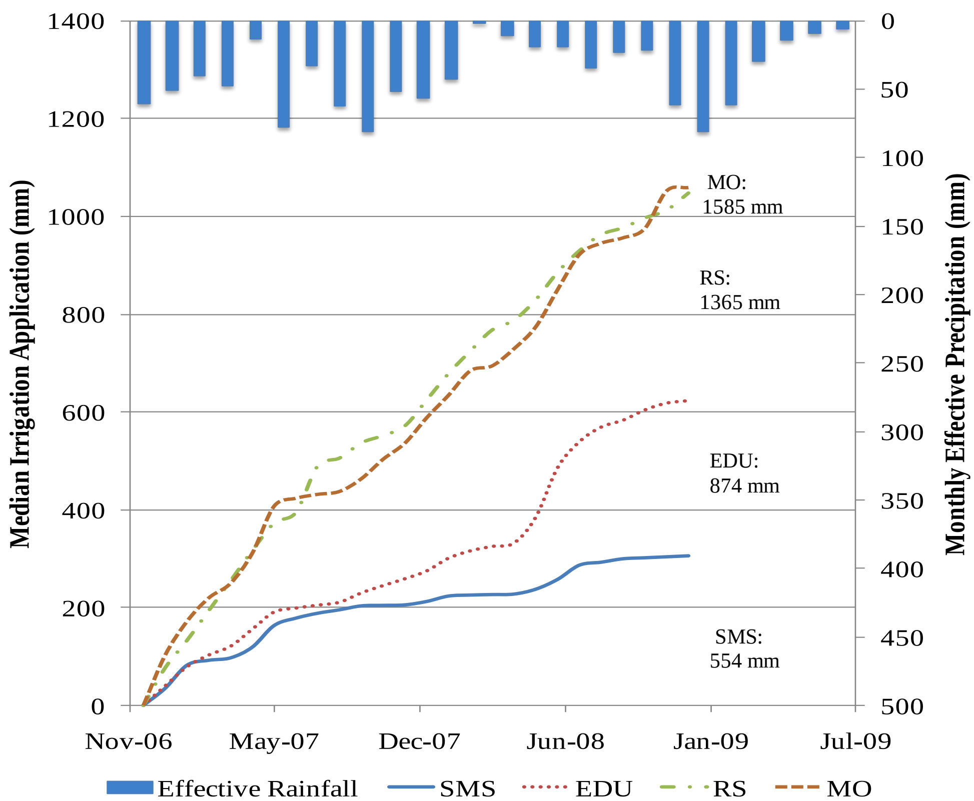

Figure 3.3. Cumulative mean irrigation application over the entire data collection period.

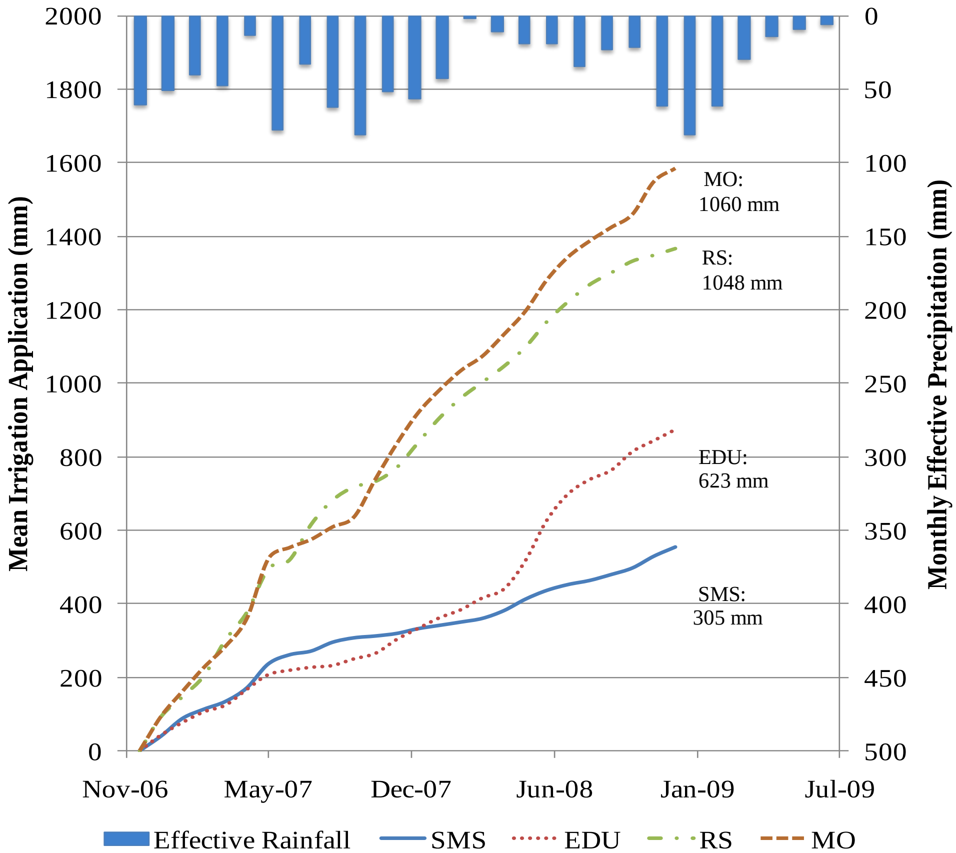

Figure 3.4. Cumulative median irrigation application over the entire data collection period.

3.5.2. Irrigation Frequency

Irrigation frequency was determined from the AMR data in addition to volume of water use. Table 3.4 presents the average monthly number of irrigation events by treatment and season. On average the SMS treatment resulted in the least number of irrigation events with 2.3 events/month. The EDU group averaged 4.5 events/month which was similar to the SMS group. The RS and MO treatments both averaged approximately 6 events/month, which was similar to the 4.5 events/month of the EDU group. Four events per month would agree with the one-day per week watering restriction for the study area. According to the irrigation requirements simulation, on average 4 events per month are needed. However, when looking at the average number of events needed each month by season, based on the SWB the range is from 2 events per month in the winter to 7 events per month in the spring.

Table 3.4 also displays the number of events per season. Over the range of 1.5 years, that data was collected with AMRs, the irrigation requirement simulation suggests that one irrigation event per week (i.e. 4 events per month) is enough to satisfy the theoretical demand. However, the irrigation need within the year can vary as a function of rainfall and climatic demand. For example, in the winter two events per month were needed based on the simulation, while the number of irrigation events peaked in the spring at 7 per month and then decreased to 3-5 per month needed in the summer. The number of events in the fall increased slightly from the summer requirements (4-5 events per month) due to the decrease in rainfall.

The maximum number of events that occurred in a given month over the 19 full months in which the data was collected via AMR technology is also presented in Table 3.4. Within all treatments, at least one home had scheduled irrigation events that were outside of the watering restriction guidelines at some point during this data collection period. However, all but the SMS group resulted in nearly one event per day for one homes at some point during the monitoring period.

It appears that the SMS systems govern the number of irrigation events that occur, where the maximum number of monthly events was 11 versus the 24 events on average of the other treatments. The SMS system bypass technology works based on the soil moisture level, which can be affected by unnecessary irrigation events as well as rainfall, whereas the rain sensors only bypass actual precipitation events that are detected. Therefore, the decreased number of irrigation events by the SMS homes (Table 3.4) which were half to a third of the other study homes lead directly to the cumulative irrigation savings as high as 65% compared to the homes that were only monitored.

Table 3.4. Number of irrigation events per month, for the AMR irrigation meter data from study homes during the collection period June 2007 – Jan 2009.

		I_{actual}[Z] (#[X]/month)	N[Y] (#)	Range (#/month)	Median (#/month)	Std Dev (#/month)	CV (%)	I_{calc}[X] (#/month)
Treatment[V]	SMS	2.3b[U]	191	0-11	1	3.4	1.4	
	RS	5.7a	203	0-22	4	7.1	1.2	4
	MO	6.0a	182	0-29	4	7.8	1.3	
	EDU	4.5ab	196	0-20	3	6.3	1.4	
Season[T]	Spring	6.6a[S]	160	0-29	5	7.4	1.1	7
	Summer	4.3b	177	0-26	2	6.4	1.5	4
	Fall	3.8b	202	0-29	2	5.8	1.5	5
	Winter[R]	4.2b	233	0-29	3	6.4	1.5	2

Note: Uppercase superscript letters indicate footnotes.
[Z] Monthly average number of irrigation events applied.
[Y] N = number of observations in the comparison.
[X] Number of irrigation events calculated from the SWB.
[X] Conversion: 1 inch = 25.4 mm
[W] Treatments are: SMS, time-based controller plus soil moisture sensor system; RS, time-based controller plus rain sensor; MO, time-based controller only; EDU, time-based controller plus rain sensor and educational materials.
[V] Numbers followed by different letters are statistically different at the 95% confidence level.
[U] Seasons defined as: spring, March, April, May; summer, June, July, August; fall, September, October, November; winter, December, January, February.
[T] AMRs installed during late Spring 2007.
[S] Winter of 2008 consisted of December 2008 and January 2009 only.

3.6. Theoretical Irrigation Requirement

Figures 3.5-3.8 show the calculated irrigation requirement compared to actual irrigation averaged across each treatment group as well as the median use across each treatment. From these graphs, it is apparent that the irrigation requirement was highest during spring through early summer 2008. During these months, all treatments resulted in some under-irrigation; with the SMS treatment expressing the greatest under-irrigation and the EDU applying the amount of irrigation that most closely meets the estimated need.

The SMS treatment group showed little variation throughout the 19 months of irrigation presented in Figure 3.5. However, this treatment did not result in detrimental turf quality (see section, 3.7). These homes did apply more irrigation during dry times compared to rainier periods; however, it appears that even during relatively dry periods irrigation was limited due to sporadic rainfall or the fact that plant demand did not deplete soil moisture to the point that irrigation was required, such as might occur in the winter.

Figures 3.6 and 3.7 illustrate the irrigation water use of the RS and MO treatments, respectively. In both of these groups, over irrigation occurred during the late fall 2007 through early spring 2008 months. These months were particularly dry compared to normal (Figure 3.1). The MO treatment resulted in the greatest amount of over-irrigation, particularly from September 2007 through January 2008

(Figure 3.7). It is apparent that the homeowners in both the RS and MO groups adjust their irrigation time clocks in response to changing climatic demands, generally lowering the irrigation amount in the fall and winter. However, it is clear from both groups that the adjustment is not optimal. The rain sensor addition in this project did not result in significant savings, in contrast to results reported by Cardenas-Lailhacar et al. (2008) during a rainy period where significant savings (34%) were reported.

Overall, the actual water application from the EDU treatment closely matches the calculated irrigation requirements, with the smallest areas of over and under irrigation, Figure 3.8. After a gradual increase in water use in mid 2007, throughout 2008 the EDU homes followed the calculated irrigation need trend. Initially it was hypothesized that the EDU group did not adjust their timers, after the commencement of the treatment in Nov 2006, until the turf showed signs of stress the following spring (see section 3.7). However, Figure 3.8 suggests that once the homes finally began adjusting their time clocks, during the winter months of 2008, they may have followed the recommended irrigation schedule. Despite this fact, it has been shown that historical irrigation recommendations can result in over-irrigation since the historical schedules do not match real-time requirements (Haley et al., 2007). In addition, the rain sensor on the EDU homes was not as efficient at reducing irrigation application since the SMS homes had 4.5 times more irrigation savings compared to the RS homes.

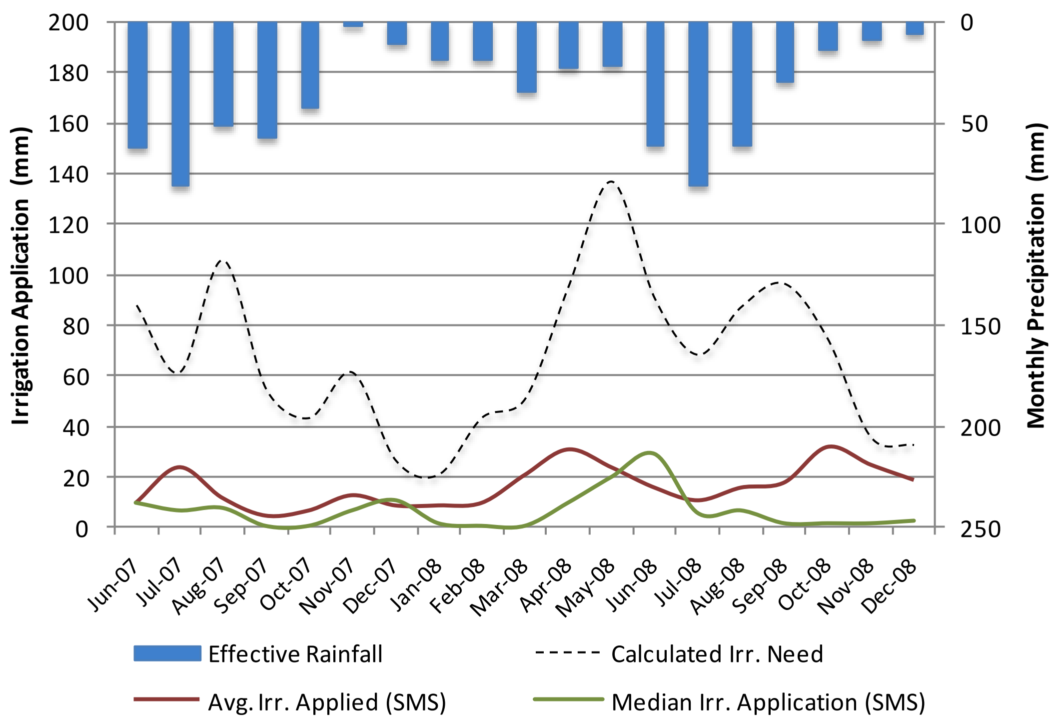

Figure 3.5. Irrigation application for soil moisture sensor (SMS) system treatment compared to calculated gross irrigation need based on rainfall daily soil water balance model.

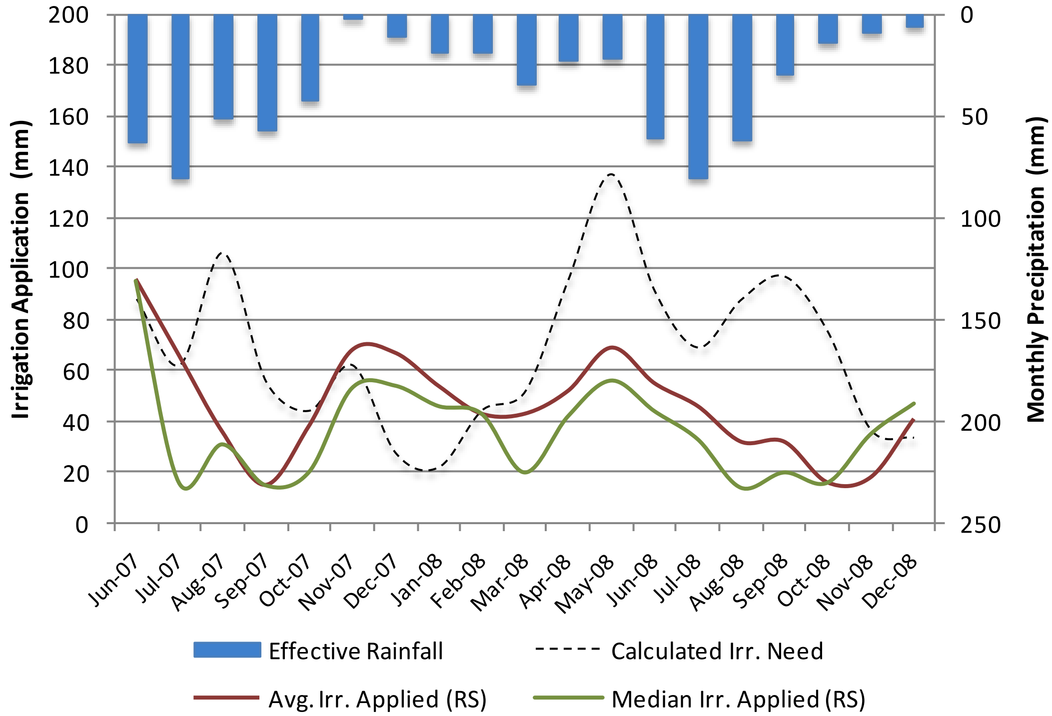

Figure 3.6. Irrigation application rain sensor (RS) treatment compared to calculated gross irrigation need based on rainfall daily soil water balance model.

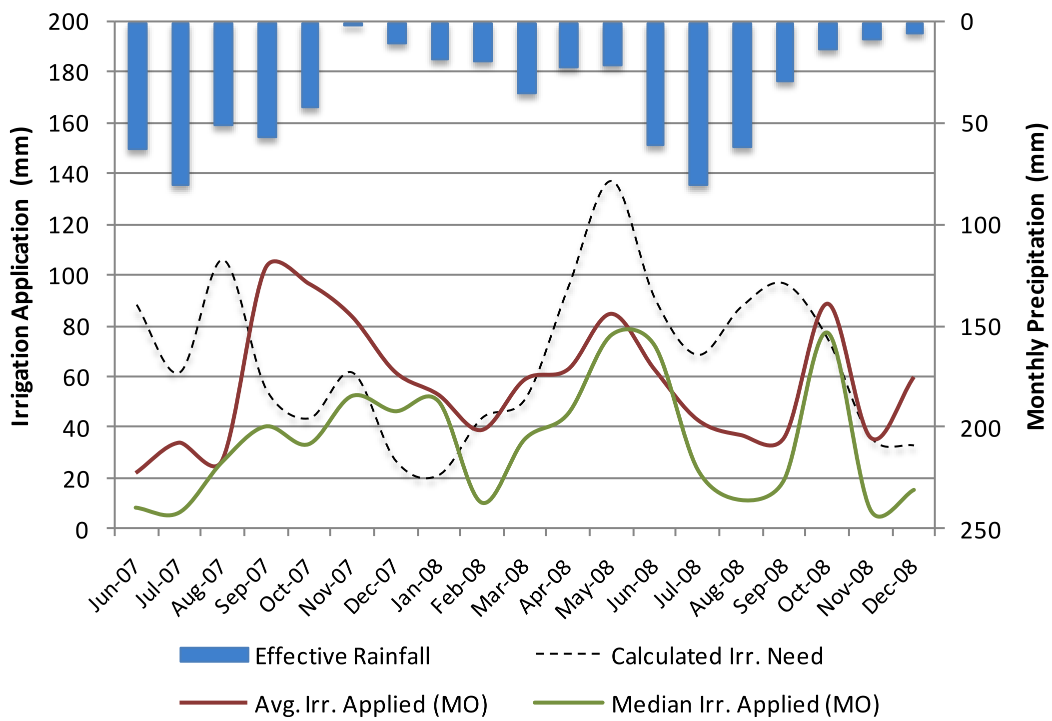

Figure 3.7. Irrigation application for meter only (MO) treatment compared to calculated gross irrigation need based on rainfall daily soil water balance model.

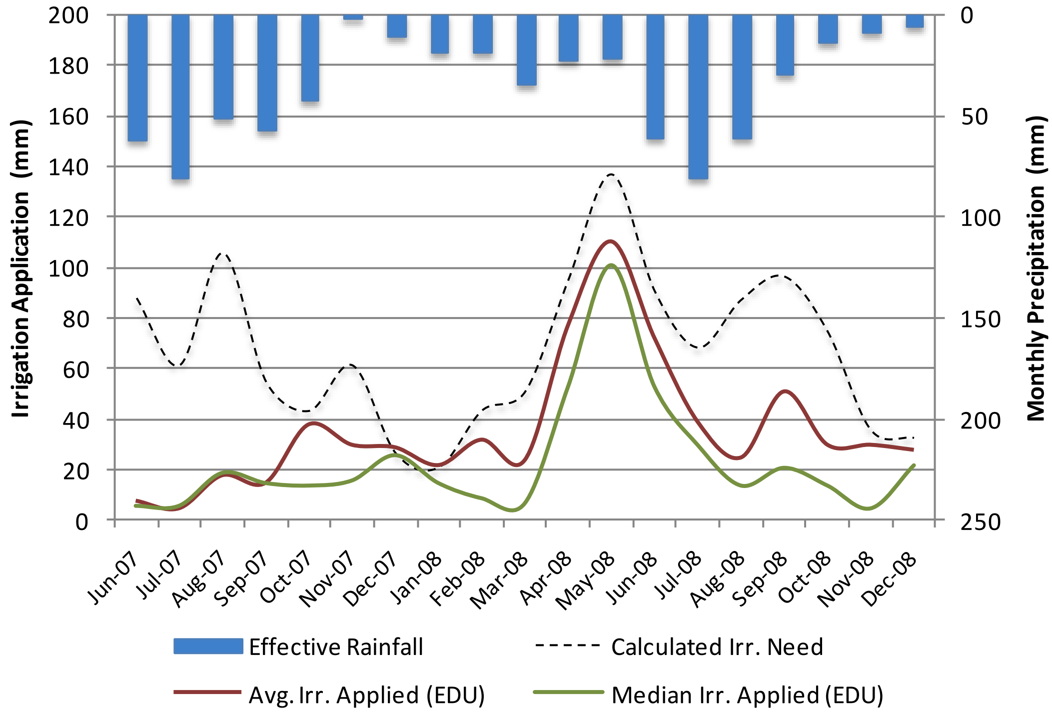

Figure 3.8. Irrigation application for educational materials (EDU) treatment compared to calculated gross irrigation need based on rainfall daily soil water balance model.

3.7. Turfgrass Quality

Initial turf quality ratings were taken during the irrigation system evaluations. These ratings were used as a baseline to gauge potential turf quality decline based on irrigation reduction. Turf quality was evaluated six more times during the data collection period. Although, there were homes that received less than minimally acceptable turf quality ratings, there was no significant correlation of these homes with the treatment designations. Overall the average turfgrass quality rating improved over the course of this study. Turf quality ranged from 3 to 8 over the entire study period. Photographic examples of turf quality for the study homes are shown in Figures 3.9 through 3.14.

Throughout the 26 months of data collection, no significant differences in average site turf quality ratings were detected among homes based on treatment group. There was, however, a significant relationship between turf quality ratings and location ($p<0.001$), which was correlated with socio-economic level ($r = 0.73$), where quality increased with property value. There still was not a significant difference between treatments when controlling for location.

However, there was one season in which treatment related turfgrass stress, although not statistically different did appear to affect the effectiveness of the water savings. In April 2007 the turf quality rating showed signs of water stress in the EDU group. This observation may have been the reason that the irrigation on these homes subsequently increased (Figures 3.3 and 3.4). The decline in turf quality and the subsequent increase in irrigation application concurs with the hypothesis that the participant left the initial irrigation schedule set as it was at the time of treatment commencement in November 2006 (which was the reduced runtimes for winter months) and remained reduced, until there was noticeable need for an increase in irrigation application, especially because of the low rainfall during spring 2008. After this point, there was a steady increase in the consumptive use of the EDU treatment; most noticeable after fall of 2008 (Figures 3.3 and 3.4), when the irrigation schedule should have been readjusted back to the lower fall runtimes. Subsequently, the EDU group began irrigating like the RS treatment, the only other treatment with a rain sensor (Table 3.3). Thus, it appears that any type of guidance for homeowner irrigation run times will need to be repeated perhaps during key periods such as fall to winter or spring to summer transitions where irrigation can typically be reduced substantially. On the other hand, irrigation needs to be increased in the winter to spring and summer to fall transitions to maintain good turfgrass quality.

Figure 3.9. Participant home turf quality rating of 3.

Figure 3.10. Participant home turf quality rating of 4.

Figure 3.11. Participant home turf quality rating of 5.

Figure 3.12. Participant home turf quality rating of 6.

Figure 3.13. Participant home turf quality rating of 7.

Figure 3.14. Participant home turf quality rating of 8.

3.8. Socio-economic Effects

From the correlation analysis of study participants as well as the neighboring non-participant homes, there were associations between irrigation application depths with property value, house size, presence of a pool, and aerial estimated irrigated area. Overall, there was a positive correlation between property value and irrigation application depth (r = 0.66) and a negative correlation between irrigated area and water application depth (r = 0.85). This trend is most evident when looking at the homes without pools ($p<0.001$).

Property values were categorized in to five profiles: $100,000 to $300,000, $300,000 to $500,000, $500,000 to $700,000, $700,000 to $900,000, and $900,000 to $1,500,000 (Table 3.5). The positive correlation between property value and irrigation application depth suggests socioeconomic level affects conservation behavior, likely because cost is less of a primary motivation. From the analysis of property value and irrigation water application, it can also be observed that the homes ranging from $900,000 to $1,500,000 had the largest irrigation depths ($p<0.001$). This trend has been shown in the literature, suggesting that sensitivity to water cost results in reduction of use (Whitcomb 2005) For homes participating in this study, the trend between increased water applications with increased property value is most apparent. For the total sample, the same trend exists, aside from the $700,000 to $900,000 range (Table 3.5).

The smaller the property, the more (depth of) water was applied, described by a negative correlation. It is also interesting to note that the homes with smaller irrigated areas all have property values ranging from $100,000 to $500,000. The increase in negative correlation between irrigated area and water application could be due to a misunderstanding of irrigation scheduling principles and the over-design of irrigation systems (e.g. too many heads per hydrozone). Moreover, high consumption of irrigation water use is typically flagged by excessive volume use, not taking area into consideration. Therefore, over irrigation in smaller irrigated areas are rarely flagged by local purveyors because the volumetric usage is not excessive even though that amount normalized for irrigated area may be much higher than plant needs.

Of the 142 homes included in the socio-economic analysis, 56 were Phase II participants. In Table 3.5, it can be observed that the homes associated with the irrigation study applied more irrigation on average, 56 mm per month, versus 48 mm per month for the non-participant group ($p<0.001$). The increased irrigation water use for participating homes might be attributed to consistent use of an automatic irrigation system, as it was one of the criteria for participation in the sensor based irrigation water conservation program. However, since the commencement of that study there has been a significant ($p<0.001$) reduction, from 63 to 53 mm per month of average irrigation water application during 2006-2007 for participating homes possibly due to treatment effects of the study.

Table 3.5. Socio-economic characteristics and average irrigation water application depth per month for 2002-2007.

		Overall		***Participants***	
		Use_{avg} (mm*)	No.	Use_{avg} (mm)	No.
Property Value Range	$100K - $300K	41 c*	66	51 c	25
	$300K - $500K	53 b	54	51 c	21
	$500K - $700K	58 b	7	53 c	4
	$700K - $900K	38 c	8	81 b	3
	$900K - $1.5M	102 a	7	119 a	3
Aerial Est. Irr. Area Range (ft^2)	1000-3000	84 a	7	137 a	3
	3000-5000	56 b	31	51 bc	13
	5000-7000	46 c	60	48 c	22
	7000-9000	46 c	31	53 bc	10
	> 9000	43 c	13	56 b	8
	Average	48		56	
	Total		142		56

* Conversion: 1 inch = 25.4 mm
** Lower case letters denote significant differences at the 95% confidence level based on Duncan's Multiple Range Test.

4. Summary and Conclusions

The goal of Phase II was to quantify irrigation water use and to evaluate turf quality differences between the time-based irrigation system compared to treatments with a soil moisture sensor and controller, rain sensor, and rain sensor along with educational materials advising time clock setting. To determine the treatment effects, average monthly irrigation was compared to the meter only treatment. The soil moisture sensor treatment was the only treatment with significant irrigation savings, which reduced irrigation 65% relative to the comparison homes. Although the educational materials treatment initially showed savings similar to soil moisture sensor controllers, over the 26 months monitoring, this initial savings did not persist. Lastly, the rain sensor treatment did not have significantly different irrigation relative to the comparison group, likely due to dry conditions during the study. Use of an SMS controller could result in a reduction of water consumption of 262 gallons per day compared to homes with no sensor.

Throughout the data collection period, precipitation was 17% less (1,043 mm) than historical (1,259 mm). A total of 15 of 26 months during the study had less than normal rainfall. August through December 2008 was a continuous dry period. In light of the less than normal precipitation, the soil moisture sensor homes bypassed unneeded irrigation events during rainy as well as dry times with intermittent rainfall, with an average of only 2 irrigation events per month. All other treatments had at least one home with more than 20 irrigation events over the course of a month, with a mean of 4-5 events per month. Thus, the soil moisture sensor systems limited the number of irrigation events, where the maximum number of monthly events was 11 versus the 29 events of the meter only treatment. Further, the number of irrigation events by the SMS homes that were half to a third less than the other study homes. Therefore, the soil moisture sensor system controllers can act as a "regulator" for irrigation time clock programming that does not correspond to changing weather conditions.

Over the course of the study, it was hypothesized that the cooperating homes had lower water use characteristics than expected. As part of a concurrent study in Pinellas County, the study cooperating homes were sent a mail-out survey regarding their irrigating practices. Based on their reported responses that they admit to manually adjusting their automatic irrigation system functionality, rather than allowing the devices to bypass event based on "smart" technology. It was clear from monitoring data that most homes had irrigation time clock adjustments in response to seasonal demands; however, adjustments were not optimized for climatic demand, resulting in over-irrigation in many cases.

The rain sensor plus educational materials treatment provides some insight into the reliability of effective behavior modification. The commencement of the educational materials initially included University personnel setting the irrigation time clock along with the homeowner. The treatment was established during the fall/winter 2006 season, resulting in minimum runtime settings. The treatment remained on a path of limited water use, initially paralleling the savings of the soil moisture sensor treatment. However, this is likely due to the reluctance on the part of the participants to update the time clock. Once the treatment began to show signs of stress, the water use steadily increased until the rain sensor plus educational materials paralleled the rain sensor without educational materials and ultimately the monthly average irrigation of this group was not different that the comparison group. Thus, to ensure behavior modification over time, repeat messages will be needed.

When comparing the actual irrigation application with the calculated gross irrigation need, the actual water application from the educational materials plus rain sensor treatment most closely parallels the calculated irrigation requirements.

Although all of treatments resulting in some under-irrigation during spring 2008, the meter only treatment resulted in the greatest over-irrigation, particularly from September 2007 through January 2008. Although the soil moisture sensor treatment consistently under irrigated as compared to the soil water balance, water savings in this study did not significantly reduce turf quality.

A pro-environmental behavior such as water conservation can stem from reluctance to over-use irrigation water based on cost. Two barriers to this conservation behavior, observed in this study were economic level, displayed in the form of property value, and irrigated area. Overall there was a trend of increased water application depth with increased property value. Conversely, the smaller the irrigated area, the more depth of water was applied potentially resulting in irrigation beyond plant needs. A primary cause for the increased use in both homes of higher property value or smaller irrigated area is likely due to minimal impact water cost for excessive use.

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Technology Transfer

During this study, as a result of initial data collection and analysis, numerous presentations, papers, and extension activities were developed.

Presentations were given at:

- UF/IFAS Extension In-service trainings, 2007-2009
- SMS Training workshops in cooperation with UF Program for Resource Efficient Communities, 2007-2009
- Florida Turfgrass Association conference, 2007
- Irrigation Association, Annual Irrigation Show, 2006-2007
- UF Water Institute Symposium, 2008
- FL Section American Society of Agricultural and Biological Engineers, 2006
- American Society of Agricultural and Biological Engineers, 2007

Publications include:

- M.B. Haley, M.D. Dukes, G.L. Miller. 2006. Evaluation of Sensor Based Residential Irrigation Water Application. Paper Number: 06021, FASABE Annual Conference and Trade Show, 1-3 June, Jupiter, FL.
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- M.B. Haley and M.D. Dukes. 2007. Residential Irrigation Water Application Influenced by Socio-economic Parameters. Irrigation Association Annual Show, Dec. 9-11 CD-ROM. Irrigation Association. Falls Church, VA.

List of Abbreviations

AMR	Automatic meter reader/recorder
DU	Distribution uniformity
DU_{lq}	Low-quarter distribution uniformity
EDU	Educational materials, or T4
ET	Evapotranspiration
IFAS	Institute of Food and Agricultural Science
LL	Landscape level
MIU	Meter interface unit
MO	Meter only treatment, T3
PCU	Pinellas County Utilities
RS	Rain sensor, or T2
SMS	Soil moisture sensor system, or T1
SWB	Soil water balance
SWFWMD	Southwest Florida Water Management District
TMT	Treatment
T1	Treatment 1: time clock + SMS
T2	Treatment 2: time clock + RS
T3	Treatment 3: time clock
T4	Treatment 4: time clock + RS + EDU
UF	University of Florida

Appendix A - Educational Materials

Saving Water Outdoors

Use what you need, need what you use

Water is one of our most precious resources. Because it flows so easily from our faucets, most of us don't appreciate its value. As a result, many of us become water wasters — especially when it comes to outdoor water use. Typically, outdoor water use accounts for up to 50 percent of water consumed by households. You can reduce your outdoor water consumption by taking a few simple steps. So tighten those taps, eliminate those leaks and use water wisely.

Seek the Leak

Did you know that even a small leak can waste 300 or more gallons of water per month? Check for the following leaks outdoors:

Water Faucets, Hoses and Connectors
Check all faucets, hoses and connectors periodically for leaks and to make sure they are in good working order. Make sure faucets are closed when not in use. If you do find a leaky faucet, change the washer — after turning off the shutoff valve.

Automatic Lawn and Sprinkling Systems
Soft, wet spots on your lawn around the in-ground sprinkler could indicate a leak that is being absorbed into the ground. Contact your plumber or landscape maintenance specialist if repairs are needed.

Swimming Pool
Check the pool system's shutoff valve, which works automatically, to see if it is malfunctioning and causing a continuous cycle of water to be pumped in and then drained out. If the water level stays higher than normal and it overflows when people are using it, call your plumber.

Service Connecting Line
If you find a soft, wet spot on your lawn or hear the sound of running water outside your house, you may have a leak in the service line to your house. Water soaks into the ground, causing the soft spots. Close the main shutoff valve. If the sound of running water continues, the outside service line could be leaking. Contact your plumber if you detect wet spots.

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Outdoor irrigation

Irrigation

How often should I water?

Know and follow your local watering restrictions, but don't water just because it's your day. The basic principle of lawn and garden watering is not to overwater. The time to irrigate will vary depending on your soil type and your location in the state.

Irrigate your lawn when it shows signs of stress from lack of water. Pay attention to signs of stressed grass, such as a bluish-gray color, lingering tire tracks or footprints, and leaf blades that are folded in half lengthwise. Also, you can determine if your lawn needs water by measuring soil moisture.

Sophisticated soil moisture sensors will turn on your automatic irrigation system when water is needed. The more basic soil moisture sensors turn off your system when water is adequate. Reliable soil moisture sensor technology is currently available in irrigation supply stores.

What time of day should I water?

Evaporation loss can be 60 percent higher during the day, so water during the cool, early morning hours to minimize water loss by evaporation and to discourage disease. Avoid watering on windy days.

How long should I water?

Apply moderate amounts of water to create a healthy, drought- and stress-tolerant lawn. For most Florida soils, an average of one-half to three-quarters of an inch of water per application is enough to replenish the grass. Saturate the root zone, then let soil dry to encourage healthy, deep root growth.

To determine how long you should run your sprinkler, place five to seven empty straight-edged cans (about the size of an average tuna can) at different distances away from the sprinkler. Run the sprinkler for 15 minutes and measure the amount of water collected in each can. Calculate an average water depth and determine how long it will take to apply one-half to three-quarters of an inch of water.

If you have an automatic sprinkler system, be sure it is equipped with a working rain shutoff device, which overrides the system when enough rain has fallen. It automatically resets the system when the turf requires more water. Rain shutoff devices are required by Florida law on all automatic sprinkler systems installed since 1991. Check regularly to ensure the device is working properly and that the corresponding switch in the control box is set at "on."

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Irrigation Methods

Drip irrigation is the most efficient method of watering for non-turf areas such as bedded plants, trees or shrubs. Drip systems minimize or eliminate evaporation, impede weed growth, and may help prevent grass diseases caused by underwatering or overwatering.

Soaker hoses are an inexpensive alternative to drip irrigation. Soil moisture should be monitored to determine when enough water has been applied.

If using a hose and sprinkler, place the sprinkler in the area that is driest. Allow the sprinkler to run the proper length of time to apply one-half to three-quarters of an inch of water. When that area is complete, move the sprinkler to another dry area. Place the sprinkler so that its water spray will overlap the area previously watered. Adjust the hose or sprinkler until it waters just the grass or shrubs, not paved areas.

Inground irrigation systems can be automatic or manual, or a combination. The automatic system can provide an efficient method of irrigating lawns because controllers turn the system off after a predetermined amount of time, so a measured amount of water is applied. Learn how to operate your system. Check timing devices regularly to make sure they are operating properly. Watch for broken or misdirected sprinklers.

Use the appropriate sprinkler head for the irrigated area. Install sprinklers that are the most water-efficient for each use. Rotors or spray heads are good for turf areas, but shouldn't be used in the same zone. For even distribution, flow rates must be consistent throughout the zone.

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Lawn care

Fertilization

Apply fertilizers sparingly, using those that contain slow-release, water-insoluble forms of nitrogen. Fertilizer applications depend on such factors as grass species, soil type and permeability, and your location in the state. To save water and to avoid thatch buildup, disease and excessive growth, follow these University of Florida-recommended practices:

- Fertilize in moderation. More is not necessarily better. Read and follow all fertilizer label instructions.
- For Bahiagrass, apply 2 to 3 pounds of nitrogen per 1,000 square feet per year in the northern part of Florida, and 2 to 4 pounds per 1,000 square feet in the central and southern areas of Florida. For St. Augustinegrass, annual nitrogen needs range from 2 to 4 pounds in the north, 2 to 5 pounds in the central area and 4 to 6 pounds in the south. For specifics in your area, contact your local county Extension service.
- Fertilize only during the growing season. Allow a month between autumn application and the time of freeze, if possible, allowing new growth to harden off and become less vulnerable to frost.
- Feed in the spring with a complete micronutrient fertilizer.
- Use a 1:1 ratio of nitrogen to potassium (first and last numbers on the bag). Test for phosphorus; apply only if lacking. Florida soil is naturally high in phosphorus, so ideal fertilizer is 15-0-15; if not available, use 16-4-8.
- Use pesticides only when needed and just on affected areas.

- Do not apply fertilizer when more than 1 inch of rainfall is predicted in the next 48 hours. Leaching and runoff of nutrient-contaminated water may occur.

Mowing

Cut your grass at the highest recommended height for your turf species, or the highest setting on your lawn mower. Mow regularly, cutting no more than one-third of the grass length to encourage grass roots to grow deeper and grass blades to hold moisture.

Keep mower blades sharp. Dull blades tear grass, opening it to disease, and cause it to appear tan and ragged. Leave short grass clippings where they fall, reducing the lawn's need for water and fertilizer. Remove thick patches of clippings so that the clippings will not kill the grass underneath.

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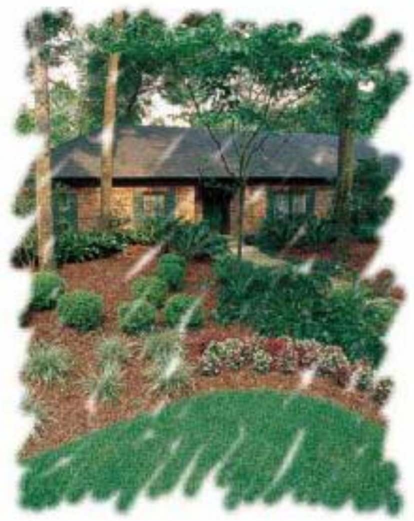
The 9 Principles of Florida-Friendly Landscaping are:



Right Plant, Right Place — Plants selected to suit a specific site will require minimal amounts of water, fertilizer and pesticides.

Water Efficiently — Irrigate only when your lawn and landscape need water. Efficient watering is the key to a healthy Florida yard and conservation of limited resources.

Fertilize Appropriately — Less is often best. Overuse of fertilizers can be hazardous to your yard and the environment.

Mulch — Maintaining a 3-inch layer of mulch will help retain soil moisture, prevent erosion and suppress weeds.

Attract Wildlife — Plants in your yard that provide food, water and shelter will attract Florida's diverse wildlife.

Manage Yard Pests Responsibly — Unwise use of pesticides can harm people, pets, beneficial organisms and the environment.

Recycle — Grass clippings and leaves provide nutrients to the soil and reduce waste disposal when reused on the landscape.

Reduce Stormwater Runoff — Water running off your landscape can carry pollutants, such as gasoline, debris, fertilizer, pesticides and even soil, that can adversely impact water quality. Reduction of this runoff will help prevent non-point source pollution.

Protect the Waterfront — Waterfront property, whether on a river, stream, pond, bay or beach, is very fragile and should be carefully protected to maintain freshwater and marine ecosystems.

These principles were established by the University of Florida's Institute of Food and Agricultural Sciences for the Florida Yards & Neighborhoods Program.

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- Do not leave sprinklers unattended. Use a kitchen timer to remind yourself to turn sprinklers off.
- Water slowly to reduce runoff and to allow deep penetration.
- Observe the watering schedule for your address.
- Dig out water-loving weeds and cultivate soil often.
- Use a rain barrel to collect rainwater. Rainwater is free and is better for your plants because it doesn't contain hard minerals.
- Do not hose down your driveway or sidewalk. Use a broom to clean leaves and other debris from these areas.

- Use a shutoff nozzle on your hose that can be adjusted down to a fine spray so that water flows only as needed. When finished, turn it off at the spigot instead of at the nozzle to avoid leaks. A garden hose without a shutoff nozzle can pour out 530 gallons of water in an hour.
- Avoid purchasing recreational water toys that require a constant stream of water.
- Consider using a commercial car wash that recycles water. If you wash your own car, park on the grass, use a bucket of soapy water and use a hose with a shutoff nozzle.
- Avoid the installation of ornamental water features (such as fountains) unless the water is recycled.
- If you have a swimming pool, consider a new water-saving pool filter.
- Cover your spa or pool to reduce evaporation.

For more information, call the Southwest Florida Water Management District at 1-800-423-1476, ext. 4757, or visit our web site at *WaterMatters.org*

This information will be made available in accessible formats upon request. Please contact the Communications Department at (352) 796-7211 or 1-800-423-1476 (FL only), ext. 4757; TDD only at 1-800-231-6103 (FL only).

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CIR1421

UF UNIVERSITY of FLORIDA IFAS

Operation of Residential Irrigation Controllers[1]

Michael D. Dukes and Dorota Z. Haman[2]

Introduction

Automatic landscape irrigation systems have become quite common in Florida in recent years. Electronic irrigation controllers are used to control these systems; however, it is not always obvious how to program these controllers to apply the desired amount of irrigation water.

Irrigation Controllers

The document "Irrigation System Controllers" (IFAS Publication SS-AGE-22; on the Web at:http://edis.ifas.ufl.edu/AE077) discusses various types of typical irrigation controllers in detail. In general, commercially available controllers are mechanical, electromechanical, electronic, or computer based. Electronic controllers are commonly installed in residential and small commercial landscape irrigation systems. We will discuss the general operation common to most residential irrigation controllers. For details specific to a given controller the reader should refer to the owner's manual.

Electronic Controller Operation

Generally, electronic controllers allow flexible scheduling of irrigation systems (Figure 1).

Figure 1. Typical residential irrigation controller.

Some scheduling options provided by controllers are:

Days of the week

1. This document is CIR1421, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date July 2002. Reviewed December 2005. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.
2. Michael D. Dukes, assistant professor; Dorota Z. Haman, associate professor; Agricultural and Biological Engineering Department, Institute of Food and Agricultural Sciences, University of Florida, Gainesville.

The appearance of trade names in this publication does not imply endorsement of any product by the authors or by the Institute for Food and Agricultural Sciences at the University of Florida.

Controllers may be set for irrigation every day, every second day, every third day, etc. Typical controllers will allow for selection of certain days of the week in a "custom" option or frequency, such as "every 2 days," for setting frequency of irrigation. The "custom" option is the one normally used during times of water restrictions, when irrigation is limited to one or two days each week.

Run time

The amount of time that each zone runs may be set from several minutes to several hours. Generally run time should be less than 60 minutes for Florida's sandy soils. The exact time depends on system application rate which can be determined as discussed in the next section. Irrigating longer will lead to movement of water below the root zone, which wastes water.

Percent

Most controllers have percentage settings so that the relative time may be adjusted. For example, if the controller is set to run 60 minutes per cycle the controller may be set to water at 75%. This will result in 60 minutes * 0.75 = 45 minute run time. Likewise, the run times in the other zones will be reduced to 75% of the zone time setting. This is helpful in Florida when the summer rains begin and irrigation can be cut back. However, no less than 1/2" of water should be applied in any one application (see Watering Your Florida Lawn, http://edis.ifas.ufl.edu/LH025). Deep, infrequent watering promotes deeper root growth, compared to shallow, infrequent watering.

Program

Controllers usually have the capacity to run multiple programs. For example, on program "A", the controller may be set to water six rotor zones for 60 minutes twice each week. If new plants are planted in a landscape bed, they may need more frequent watering to become established. In this case, program "B" can be used to water that zone every day of the week.

Application Rates

The application rate is an amount of water applied over an area, such as a yard with landscape plants and turfgrass, in a given amount of time. Usually this is expressed as inches per hour (in/hr) and implies an even application of water. The application rate of an individual irrigation zone must be known to properly set the irrigation controller.

There are several ways to find the application rate of an irrigation zone. It may be:

1. given by the designer or contractor,
2. calculated from system and or sprinkler specifications,
3. calculated based on measurements of flow from a water meter, or
4. measured directly by placing catch containers in the irrigated zone of interest.

1. Application rate given by the designer or contractor.

Although application rates of each individual zone should be calculated by the designer, in practice this is rare.

2. Application rate calculated from system or sprinkler specifications.

Application rate may be calculated from the system specifications according to the total area method (Equation 1) or from the sprinkler specifications assuming they are all alike according to the sprinkler spacing method (Equation 2). Actual application rates may not match calculated rates due to misadjusted sprinklers, wind drift, pressure problems, etc. For these reasons, it is preferred that the actual application rate be verified by measurement as described in the sections 3 and 4.

Total area method:

$$AR = \frac{96.3 \times GPM}{AREA} \quad [1]$$

where:

AR = application rate (in/hr)

GPM = system or zone flow rate (gpm)

AREA = total or zone irrigated area (ft^2)

Sprinkler spacing method:

$$AR = \frac{96.3 \ x \ GPM}{ROW \ x \ COL} \qquad [2]$$

where:

AR = application rate (in/hr)

GPM = individual nozzle flow rate (gpm)

ROW = spacing of sprinkler rows (ft)

COL = spacing of sprinklers within the rows (ft)

3. Application rate calculated based on measurements of flow from a water meter.

The application rate for each irrigation zone can be determined from flow meter records. If a separate irrigation meter is not installed (which is typical on most homes), the utility meter must be used for this method. To use the utility meter, conduct the test when water is not being used in the home. If a separate irrigation meter is available, household water use does not have to be considered for the test. If a well is used to supply the irrigation system, then a meter must be installed after the pump to use this method.

Example - The meter reading prior to irrigation of a single zone was 1895750 gallons and after irrigation the meter reading was 1900600 gallons. The amount of water used during the irrigation cycle was 1900600-1897750 = 2850 gallons. The irrigation time for the zone was 2.5 hours (2.5 hours * 60 = 150 minutes). The irrigated area is approximately square and was known to be approximately 6750 ft^2. Now the average application rate for the irrigated zone can be calculated by Equation 3.

$$AR = \frac{96.3 \ x \ GAL}{AREA \ x \ TIME} \qquad [3]$$

where:

AR = application rate (in/hr)

GAL = total volume of water measured by the flow meter (gal)

AREA = irrigated area (ft^2)

TIME = total time of irrigation cycle (min)

According to Equation 3:

$$AR = \frac{96.3 \ x \ 2850}{6750 \ x \ 150} = 0.27 \text{ in/hr}$$

Although this method is relatively easy, unless it is performed for each zone it will not give the accurate representation of individual zones that is needed to set the controller. For example, rotors (see Figure 2) typically have application rates of 0.25-1.0 in/hr, while spray heads (see Figure 3) have application rates of 0.75-1.5 in/hr. Therefore, these equipment types should be tested separately.

Figure 2. Gear-driven rotor irrigation head.

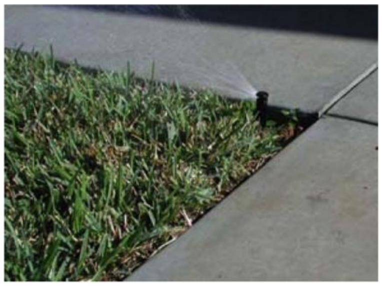

Figure 3. Fixed spray irrigation head.

4. Application rate measured directly using catch containers.

Application rate can be measured directly by placing several containers in a given irrigation zone during an irrigation event (see How to Calibrate Your Sprinkler System, http://edis.ifas.ufl.edu/LH026). This is similar to testing the system uniformity (see Lawn Sprinkler Selection and Layout for Uniform Water Application, http://edis.ifas.ufl.edu/AE084). Essentially, the containers must be the same shape and size. Old coffee cans are one example of a good container for this purpose. The rim of the can should be above the turf and the cans should be level. At least six cans per zone should be used and they should be distributed randomly. Next, run the irrigation system over a normal cycle. Then you can calculate the application rate according to the following example.

Example - One irrigation zone is to be tested. Several catch cans are positioned throughout the zone such that overlap from other zones does not contribute to those cans. Average depth of water measured in the cans was 1.25 inches after an irrigation run of 45 minutes.

$$AR = \frac{DEPTH}{TIME / 60} \qquad [4]$$

where:

AR = application rate (in/hr)

DEPTH = average depth in catch cans for any one zone (in)

TIME = run time of irrigation zone tested (min)

According to Equation 4,

$$AR = \frac{1.25}{45 / 60} = 1.67 \text{ in/hr}$$

Setting the Time on Irrigation Controllers

Once the application rate is known, then the irrigation controller can be set for a desired irrigation depth according to Equation 5 with the parameters defined as in Equation 4.

$$TIME = \frac{60 \times DEPTH}{AR} \qquad [5]$$

Table 1 gives the calculated times according to Equation 5 based on desired application amount or depth and the application rate of the individual zone or system.

Seasonal Setting of Irrigation Controllers

The objective of irrigation is to replenish the water in the plant roots to avoid excessive plant stress. For landscape plants, especially turf, where the objective is to maintain the appearance and not to produce the highest amount of biomass, it is usually sufficient to aim for 60 - 100% replacement of water in the root zone.

Augustin (see "Water Requirements of Florida Turfgrasses", IFAS Publication BUL 200, on the Web at: http://edis.ifas.ufl.edu/EP024) calculated the net irrigation requirement of turfgrass for several geographical areas and based on effective rainfall. Effective rainfall takes into account the low water-holding capacity of Florida's soils (see Watering Your Florida Lawn, http://edis.ifas.ufl.edu/LH025 and Turf Irrigation for the Home, http://edis.ifas.ufl.edu/AE144). Net irrigation requirement is the amount of irrigation water that must be delivered to the crop. This does not consider irrigation losses such as pipeline leakage, wind drift, non-uniform application, etc.

Tables 2-9 present a suggested irrigation controller time setting assuming two irrigation events per week, and an irrigation system efficiency of 60% for application rates of 0.50, 0.75, 1.00, 1.25, and 1.50 in/hr, respectively. Three regions are represented in Tables 2-9, north (Gainesville), central (Orlando), and south (Miami). In addition, three levels of replacement are presented. It is desirable to irrigate at the lowest possible level of replacement without an acceptable degradation in turf or landscape quality. Two irrigation events per week were assumed since this is a common practice due to water restrictions. Any irrigation time exceeding 60 minutes should be split into two applications at least four hours apart with the time in between applications during the day when the plants will use the water (i.e., morning and afternoon). If the measured or calculated application rate does not exactly correspond to those given in the table, use the closest rate. For example, a homeowner measures an application rate of 0.6 in/hr. The table with the 0.5 in/hr application rate (Table 3) would be used.

Setting Microirrigation Zones

Microirrigation zones are sometime called "drip" or "trickle" irrigation and are becoming popular for landscape beds due to their ease of use and low use of water. There are several types of microirrigation emitters (see Figures 4, 5, 6, 7). More information on those emitters and how they are defined can be found in "Retrofitting a traditional in-ground sprinkler irrigation system for microirrigation of landscape plants" (IFAS Publication ABE324; on the Web at: http://edis.ifas.ufl.edu/AE222). Typically microirrigation does not wet the entire root zone; therefore, the application rate concept does not apply. These emitters have various emission rates, usually in gallons per hour. General guidelines on how many gallons are required for landscape plants can be found in "Fertilization and Irrigation Needs for Florida Lawns and Landscapes" (IFAS Publication ENH860; on the Web at: http://edis.ifas.ufl.edu/EP110). Once the gallons required are known, then the irrigation controller may be set according to Equation 6, assuming one emitter per plant. Since application depth may be difficult to calculate, microirrigation zones should be set initially for one-hour run time, two times each week. These zones can be reduced 15 minutes each cycle every week until plants show stress.

$$\text{TIME} = \frac{\text{GAL}}{\text{GPH} / 60} \quad [6]$$

where:

TIME = microirrigation run time (min)

GAL = volume of irrigation water required for a plant (gal)

GPH = emission rate of a drip emitter (gph)

References

Turf Irrigation for the Home (IFAS Publication Circular 829; on the Web at: http://edis.ifas.ufl.edu/AE144)

Turf Irrigation With a Hose and Sprinkler (IFAS Publication AE265; on the Web at: http://edis.ifas.ufl.edu/WI015)

Reduced Irrigation of St. Augustinegrass Turfgrass in the Tampa Bay Area (IFAS Publication AE264; on the Web at: http://edis.ifas.ufl.edu/WI014)

Fertilization and Irrigation Needs for Florida Lawns (IFAS Publication ENH860; on the Web at: http://edis.ifas.ufl.edu/EP110)

Coping with Drought in the Landscape (IFAS Publication ENH70; on the Web at: http://edis.ifas.ufl.edu/MG026)

How to Calibrate Your Sprinkler System (IFAS Publication ENH61; on the Web at: http://edis.ifas.ufl.edu/LH026)

Watering Your Florida Lawn (IFAS Publication ENH9; on the Web at: http://edis.ifas.ufl.edu/LH025)

Water Requirements of Florida Turfgrasses (IFAS Publication Bulletin 200; on the Web at: http://edis.ifas.ufl.edu/EP024)

Irrigation of Lawns and Gardens (IFAS Publication Circular 825; on the Web at: http://edis.ifas.ufl.edu/WI003)

Lawn Sprinkler Selection and Layout for Uniform Water Application (IFAS Publication Bulletin 230; on the Web at: http://edis.ifas.ufl.edu/AE084)

Irrigation System Controllers (IFAS Publication SS-AGE-22; on the Web at: http://edis.ifas.ufl.edu/AE077)

Retrofitting a Traditional In-ground Irrigation Sprinkler System for Microirrigation (IFAS Publication ABE324; on the Web at: http://edis.ifas.ufl.edu/AE222)

Abbreviations

in -- inches

gal -- gallons

hr -- hour

gpm -- gallons per minute

gph -- gallons per hour

min -- minutes

ft -- feet

ft^2 -- square feet

Figure 4. Individual drip emitters.

Figure 5. Drip tube or tape.

Figure 6. Bubbler.

Figure 7. Microjet or microspray.

Table 1. Irrigation zone run time (min) for a given application rate and a desired application depth.

Application rate (in/hr)	Desired Application Amount (in)			
	0.25	0.50	0.75	1.00
0.00	0	0	0	0
0.25	60	120	180	240
0.50	30	60	90	120
0.75	20	40	60	80
1.00	15	30	45	60
1.25	12	24	36	48
1.50	10	20	30	40
1.75	9	17	26	34
2.00	8	15	23	30

Table 2. Irrigation controller run time for each of two irrigation events per week at an application rate of 0.25 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent Replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	2	0	23	31	38	57	76	94
Feb	0	2	0	17	22	28	61	80	100
Mar	10	14	17	34	46	57	85	113	141
Apr	59	79	99	81	108	134	91	121	151
May	100	134	167	128	171	214	83	110	138
Jun	90	120	150	100	133	167	75	100	126
Jul	84	112	140	97	130	162	117	156	195
Aug	77	103	129	127	169	211	129	172	215
Sep	98	131	164	95	127	159	77	102	128
Oct	64	86	107	86	115	143	31	41	51
Nov	40	54	67	64	85	106	80	106	133
Dec	16	21	26	32	43	54	71	94	118

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.

Table 3. Irrigation controller run time for each of two irrigation events per week at an application rate of 0.50 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	0	0	12	15	19	28	38	47
Feb	0	0	0	0	11	14	30	40	50
Mar	0	0	0	17	23	28	42	56	70
Apr	30	40	49	40	54	67	45	60	76
May	50	67	84	64	85	107	41	55	69

Table 3. Irrigation controller run time for each of two irrigation events per week at an application rate of 0.50 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

Jun	45	60	75	50	67	83	38	50	63
Jul	42	56	70	49	65	81	59	78	98
Aug	39	51	64	63	85	106	64	86	107
Sep	49	66	82	48	64	80	38	51	64
Oct	32	43	54	43	57	72	15	20	26
Nov	20	27	34	32	43	53	40	53	67
Dec	0	10	13	16	21	27	35	47	59

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.

Table 4. Irrigation controller run time for each of two irrigation events per week at an application rate of 0.75 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	0	0	0	10	13	19	25	31
Feb	0	0	0	0	0	0	20	27	33
Mar	0	0	0	11	15	19	28	38	47
Apr	20	26	33	27	36	45	30	40	50
May	33	45	56	43	57	71	28	37	46
Jun	30	40	50	33	44	56	25	33	42
Jul	28	37	47	32	43	54	39	52	65
Aug	26	34	43	42	56	70	43	57	72
Sep	33	44	55	32	42	53	26	34	43
Oct	21	29	36	29	38	48	10	14	17
Nov	13	18	22	21	28	35	27	35	44
Dec	0	0	0	11	14	18	24	31	39

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.

Table 5. Irrigation controller run time for each of two irrigation events per week at an application rate of 1.00 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	0	0	0	0	0	14	19	24
Feb	0	0	0	0	0	0	15	20	25
Mar	0	0	0	0	11	14	21	28	35
Apr	15	20	25	20	27	34	23	30	38
May	25	33	42	32	43	53	21	28	34
Jun	22	30	37	25	33	42	19	25	31
Jul	21	28	35	24	32	41	29	39	49
Aug	19	26	32	32	42	53	32	43	54
Sep	25	33	41	24	32	40	19	26	32

Table 5. Irrigation controller run time for each of two irrigation events per week at an application rate of 1.00 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

Oct	16	21	27	21	29	36	0	10	13
Nov	10	13	17	16	21	27	20	27	33
Dec	0	0	0	0	11	13	18	24	29

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.

Table 6. Irrigation controller run time for each of two irrigation events per week at an application rate of 1.25 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	0	0	0	0	0	11	15	19
Feb	0	0	0	0	0	0	12	16	20
Mar	0	0	0	0	0	11	17	23	28
Apr	12	16	20	16	22	27	18	24	30
May	20	27	33	26	34	43	17	22	28
Jun	18	24	30	20	27	33	15	20	25
Jul	17	22	28	19	26	32	23	31	39
Aug	15	21	26	25	34	42	26	34	43
Sep	20	26	33	19	25	32	15	20	26
Oct	13	17	21	17	23	29	0	0	10
Nov	0	11	13	13	17	21	16	21	27
Dec	0	0	0	0	0	11	14	19	24

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.

Table 7. Irrigation controller run time for each of two irrigation events per week at an application rate of 1.50 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	0	0	0	0	0	0	13	16
Feb	0	0	0	0	0	0	0	13	17
Mar	0	0	0	0	0	0	14	19	23
Apr	0	13	16	13	18	22	15	20	25
May	17	22	28	21	28	36	14	18	23
Jun	15	20	25	17	22	28	13	17	21
Jul	14	19	23	16	22	27	20	26	33
Aug	13	17	21	21	28	35	21	29	36
Sep	16	22	27	16	21	27	13	17	21
Oct	11	14	18	14	19	24	0	0	0
Nov	0	0	11	11	14	18	13	18	22
Dec	0	0	0	0	0	0	12	16	20

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.

Table 8. Irrigation controller run time for each of two irrigation events per week at an application rate of 1.75 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent Replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	0	0	0	0	0	0	11	13
Feb	0	0	0	0	0	0	0	11	14
Mar	0	0	0	0	0	0	12	16	20
Apr	0	11	14	12	15	19	13	17	22
May	14	19	24	18	23	31	12	16	20
Jun	13	17	21	14	19	24	11	14	18
Jul	12	16	20	14	19	23	17	22	28
Aug	11	15	18	18	23	30	18	25	31
Sep	14	19	23	14	18	23	11	15	18
Oct	0	12	15	12	16	20	0	0	0
Nov	0	0	0	0	12	15	11	15	19
Dec	0	0	0	0	0	0	10	13	17

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.

Table 9. Irrigation controller run time for each of two irrigation events per week at an application rate of 2.00 in/hr, assuming system efficiency of 60%, and considering effective rainfall*.

	North Florida			Central Florida			South Florida		
	Percent Replacement								
	60%	80%	100%	60%	80%	100%	60%	80%	100%
Jan	0	0	0	0	0	0	0	0	12
Feb	0	0	0	0	0	0	0	0	12
Mar	0	0	0	0	0	0	11	14	18
Apr	0	0	12	10	13	17	11	15	19
May	13	17	21	16	21	27	10	14	17
Jun	11	15	19	12	17	21	0	13	16
Jul	10	14	17	12	16	20	15	20	24
Aug	0	13	16	16	21	26	16	21	27
Sep	12	16	20	12	16	20	0	13	16
Oct	0	11	13	11	14	18	0	0	0
Nov	0	0	0	0	11	13	0	13	17
Dec	0	0	0	0	0	0	0	12	15

*If the controller only allows 15 incremental changes, use the increment closest to the numbers in the table.