IRRIGATION CONSERVATION TECHNOLOGY EFFECTIVENESS AND BEHAVIOR OF THE DOMESTIC IRRIGATOR

By

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To my grandfather, Henry Frydman, your words gave me drive to begin
To my darling daughter, Lola Eve, your smile from under my desk gave me the motivation to finish

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AMR	Automatic meter reading
ASCE-EWRI	American Society of Civil Engineers Environmental and Water Resources Institute
DU_{lq}	Low-quarter distribution uniformity
EDU	Treatment defined by inclusion of time clock, rain sensor, and educational materials
ET	Evapotranspiration
ET_L	Overall estimated landscape evapotranspiration
ET_O	Reference evapotranspiration for short surfaces
FC	Field capacity
GIS	Graphic Information System
I_{calc}	Calculated net irrigation requirement
I_{gross}	Calculated gross irrigation requirement
IE	Efficiency factor
IUM	Indoor Use Metric
k	Sampling interval
$Kc_{turfgrass}$	Crop coefficient for turfgrass
K_L	Landscape coefficient
L1	Weather station location 1
L2	Weather station location 2
L3	Weather station location 3
L4	Weather station location 4
lpd	Liters per day
MO	Treatment defined by inclusion of time clock only
OCU	Orange County Utilities

PCU	Pinellas County Utilities
RAW	Readily available water
RCW	Reclaimed water
RS	Treatment defined by inclusion of time clock and rain sensor
SJRWMD	St. Johns River Water Management District
SMS	Soil moisture sensor; Treatment defined by inclusion of time clock and soil moisture sensor system
SWB	Soil Water Balance
SWFWMD	Southwest Florida Water Management District
TBW	Tampa Bay Water
TDT	Time Domain Transmissometry
UF-IFAS	University of Florida Institute of Food and Agricultural Sciences
UF-IRB	University of Florida Institutional Review Board
WMD	Water Management District
WWIPP	Water-wise Irrigation Practices and Perceptions

Abstract of Dissertation Presented to the Graduate School
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In order for irrigation water conservation technology to be effective, the equipment must be properly installed and irrigation principles must be understood for correct set-up. There are two aspects that affect the watering efficiency of the “smart” irrigation technology: the technology itself and users interaction with the technology. These technologies include sensor-based irrigation bypass devices as well as weather based controllers. There are fundamental behavioral barriers to irrigation conservation potential when considering the use of “smart” technologies. The behavioral barriers include how to use the equipment, when, and how long to water. Even if these barriers are overcome, a properly set irrigation controller cannot make up for poor irrigation system functionality.

The research presented in this dissertation aims to understand both the effectiveness of irrigation conservation technology and the practices and behavior of the domestic irrigator. These aims are satisfied by meeting the following objectives: (1) Intensively monitor the irrigation water use practices of homes with different levels of irrigation technology and scheduling education. (2) Survey the irrigation practices and

level of community knowledge of water source, conservation technologies, and policy. (3) Identify areas of need for increased public awareness and misunderstanding of irrigation water use principles. (4) Assess an irrigation water conservation campaign where compliance is compared at the household level.

Upon observation of homes with different technology levels, the soil moisture sensor treatment yielded the greatest savings; with 65% less water applied or irrigation than the meter only treatment. In addition to volume of water use, irrigation frequency was determined; again the soil moisture sensor treatment resulted in the lowest number of irrigation events, which were half to a third less than the other study homes. Surveying the irrigation water use practices and level of community knowledge of water source, conservation, technologies, and policy provided the following conclusions: misunderstanding of plant water needs, influence of watering restrictions water source, and property value and size. Efficient irrigation practices cannot only rely on the intelligence of a “smart” controller. The impact of human behavior is a major factor: a controller irrigates, a person waters.

CHAPTER 1
INTRODUCTION

"One of the most fundamental and increasingly important components of land cover change in the U.S. is the monocultural cultivation of the turfgrass yard, whose ecology remains understudied and whose significance continues to grow with the development of each new housing unit on the urban frontier" (Robbins and Birkenholtz 2003).

In the United States, outdoor water use accounts for nearly 60% of the total amount of residential water consumption (Mayer et al. 1999). According the Environmental Protection Agency WaterSense program, the water used to supplement the lawn and landscape is more than 26.5 billion liters per day (lpd), which is enough water to fill 280,000 residential swimming pools. National turfgrass is projected to have 163,800 km^2 ($\pm$ 3,850 km^2) coverage (Milesi et al. 2005), and with the country's urban and built-up area estimated at nearly 60 million acres (Lubowski et al. 2006), the lawn accounts for 40 to 60% of the American urban footprint.

The desire for a dense green lawn often requires irrigation and fertilization, with the perception that both are commonly over applied (Olmsted 2008; Robbins and Birkenholtz 2003). Research has shown that despite frequent rainfall, residential customers in Florida tend to over-irrigate (Haley et al. 2007). While the Water Management Districts (WMD) have implemented allotted irrigation days and times, as well as the requirement of rain shutoff devices, anecdotal evidence suggests that customers may not be following watering regulations and restrictions (Whitcomb 2005). It has also been seen that domestic irrigators do not understand plant water needs related to irrigation (Haley and Dukes 2009). Domestic irrigators rarely choose alternative, low-input methods, because of aesthetic desirability that does not allow for lawn heterogeneity (Bormann et al. 1993), time, effort, and perceived expense for individual households (Templeton et al. 1998).

Objectives

The overall aim of this research is to observe and quantify knowledge and behavior relating to residential irrigation water use and conservation technology. The primary research area was within the Pinellas-Anclote River Basin under the jurisdiction of the Southwest Florida Water Management District (SWFWMD). This area is located in the Southern Water Use Caution Area, meaning the expected water resources demand may be larger than the supply.

In order for conservation technology to be effective, the equipment must be properly installed and irrigation principles must be understood; these study objectives focus on irrigation water use and technology functionality. The specific objectives are outlined below in the order of chapters in this dissertation.

(1) Intensively monitor the irrigation water use practices of homes with different levels of irrigation technology and scheduling education. This objective aims to assess the effect of soil moisture sensor (SMS) controllers, rain sensors, and educational materials for irrigation scheduling on residential irrigation water application of cooperating homes in Southwest Florida.

(2) Survey the irrigation water use practices and level of community knowledge of water source, conservation technologies, and policy. Analysis of the mail-out questionnaire responses will determine public awareness, if local and SWFWMD mandated watering restrictions are followed, and if not, why. Additionally, analysis of total utility water use data will coincide with the surveyed households including non-participants to assess the accuracy of the responses through case study analysis.

(3) Assess an irrigation water conservation campaign where compliance is compared at the household level. Analysis of the campaign will include: a direct correlation identifying the campaign components, which relate to the survey evaluation results.

(4) Identify areas of need for increased public awareness and misunderstanding of irrigation water use principles. Due to the non-normality of the collected data in aim (1), this objective will include an examination on an individual home level to determine water use trends based on measured irrigation water use data and the local weather conditions, utilizing two distinct datasets.

The compilation of these research aims will serve to optimize the management of water and water-related resources through a better understanding of actual residential water use practices to aide in the environmental policy decision-making process. Conclusions will draw together the affect social conditions have on human, the motivation for conservation, and drivers of behavioral change.

Previous surveys in Southwest Florida have looked at homeowner concern relating to water cost (Whitcomb 2005) and participation in Cooperative Extension Service landscape programs (Israel and Hague 2002). As part of the research presented here, the previous data has been reanalyzed and the new questionnaires will expand upon these previous findings to optimize data collection.

This new research will specifically target landscape watering practices, knowledge of water conservation ordinances, motives for water conservation/overuse, and perception of community water conservation/overuse. Water conservation ordinances include watering days and percentage of allowable turfgrass. To investigate technological advances, such as the inclusion of a functioning rain shutoff device or "smart" controller (i.e. soil moisture sensor in this work), it is assumed that an automatic time-based controller operates the irrigation system.

It will also be assumed that the survey respondents will fill out the questionnaires honestly and to the best of their knowledge. Since some of the questions ask about excessive irrigation water use or practices not incompliance with local policy, participants may be reluctant to disclose truthful information. A limitation of this research is that typically homeowners with more water conservative practices have a greater interest in participating. Actual water use statistics will also be performed on a non-respondent sample population to determine if respondents have lower water consumption.

Background

The Lawn

The American lawn is a staple landscape indicative of one's right to the land and earned right to leisure time. This landscape as adopted from pre-romantic British culture developed prior to the 20th century (Jackson 1985). Irrigation equipment was frequently advertised in popular magazines during the Dust Bowl years of the nineteen thirties, to combat drought (DBSC 1937; DBSC 1938). Advertisements targeted the domestic irrigator with promises for a savings in time, money, and increased appearance of their lawn during times of drought with the installation of the in-ground irrigation system (Skinner Irrigation Co. 1930) and in a 1935 United States Department of Agriculture Farmers' Bulletin recommended the installation of permanent in-ground irrigation systems prior to seeded a new lawn (Westover and Enlow 1935). However, since World War II there has been a fundamental change to the ecology of the lawn because of industrialization (Robbins and Birkenholtz 2003), becoming a fundamental part of the environment of the street (Wilkins 1946). Broad reaching periodicals, such as *Better Homes and Gardens*, began encouraging homeowners to cooperate in neighborhood uniformity (Ramsey 1936). *Home Garden* referred to the front lawn as the "Public Area – usually lying between the street and the house…It is the area enjoyed principally by the public and is important chiefly for its effect on community attractiveness" (Robinson 1950).

A well-kept lawn became even more desirable when prompted by Lady Bird Johnson's national beatification program in the mid-nineteen sixties. In addition to calling attention to the aesthetic of roadsides and public spaces, this program urged people to pay attention to their own font lawns. Many municipal authorities began trying to encourage certain lawn color standards. The year-round "velvety green carpet" increased in popularity, especially in retirement and vacation communities, such as Florida (Jenkins 1994).

Although there has been a reduction in lawn size relative to lot size within the U.S. within the last few decades, turfgrass coverage is still forecasted to increase (Robbins and Birkenholtz 2003). The estimated that turfgrass coverage in the U.S. at 163,000 km^2 (±35,850 km^2, Milesi et al. 2005), is three times greater than any other irrigated crop including corn (USDA 2004). In fact, in many parts of the country the current trend is to convert retired farmland into prime real estate (Bormann et al. 1993).

A green lawn is a benefit to the community. Besides the obvious community pride of aesthetics, turfgrass and landscape integrated into the urban setting has been statistically proven to promote mental health, social harmony, and occupational productivity (Beard and Green 1994; Kaplan and Kaplan 1989; Ulrich 1986). Further, physical benefits of turfgrass include, erosion control, heat and noise dissipation, and air pollution control (Beard and Green 1994; Gladon et al. 1993; Johns and Beard 1985). However to maintain an aesthetically desirable lawn, irrigation and fertilization is often required and can be easily over applied. During irrigation system audits conducted as part of various University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) irrigation studies conducted with local WMDs, it was evident that many customers do not irrigate according to the watering restrictions, either intentionally or unknowingly (Dukes and Haley 2009; Haley et al. 2007).

Effect of Irrigation on the Environment

Water use efficiency has become a growing concern at both the local and national level. The water used for residential irrigation can be separated into three unique categories: potable (drinking), domestic well, and reclaimed water. Reclaimed water as an irrigation source is a practical use for treated effluent; however, this source requires additional infrastructure. Therefore this source supplies the smallest sector of irrigators. The most accessible water for the homeowner to use for outdoor purposes is the treated potable water that already supplies drinking water. This is a costly source with water rates steadily increasing due to the considerable amount of energy involved in treatment and delivery. Depending on the aquifer composition, well water may lead to some savings in energy costs, but not a decrease in the depletion of the resource. Decreasing the water table can lead to saltwater intrusion, higher concentrations of natural contaminants (e.g. radon and arsenic), and human pollutants (e.g. fertilizers and pesticides). Regardless of water source, overirrigation can specifically contribute to nonpoint source pollution by increasing runoff containing such pollutants from the suburban landscape.

Water Use in Florida

In 2000, Florida's population was nearly 16 million, which ranked Florida as the fourth most populous state in the U.S. (USCB 2001). In Florida, 88% of the state's population receives their potable water from the public supply. The public supply is that water which is withdrawn by either public or private suppliers and delivered to multiple users. The public supply in Florida is made up of 10% surface water and 90% groundwater withdrawals, ranking it second highest for groundwater withdrawals in the U.S. Over half, 53%, of the total public supply comes from the Floridan aquifer (Marella 1992), which has increasingly been regarded as a limited resource. The public supply is usually treated ground or surface water, which is used for both domestic (indoor and outdoor) and public uses (e.g. firefighting and street washing). This sector of the water supply is critical when ensuring that the total water demand can be met.

The SWFWMD, which is one of five Florida WMDs, accounts for a quarter of the state's overall population, with more than four million inhabitants. Between 1990 and 2000, the population within the District grew by over 640,000 residents, approximately 19%, and is projected to increase another 1.8 million by 2025. The 2000 population for Pinellas County, the primary study area, was 921,482 and is forecasted to be 1,078,600 by 2025, increasing 17% (USCB 2007).

Within the SWFWMD, public water usage accounts for 42% of the total freshwater use, the second largest water use sector after agriculture. According to the SWFWMD

2005 District Management Plan, the projected water demand for the public supply is expected to increase to 841 million lpd (SWFWMD 2005). More than 80% of this water is withdrawn from groundwater sources, mostly from the Floridan aquifer.

Domestic self-supply refers to quantities of potable water withdrawn, via well or pumped from surface water, small enough that a permit is not required from the WMD. Although individual household wells fall under this definition, they are only included when water is used for both indoor and outdoor purposes. When the water is pumped solely for irrigation purposes it is not accounted for in this category (Marella 2004). Recently, some counties (e.g. Pinellas County) have initiated rebate programs for the installation of a shallow well for outdoor water use (PCU 2007a). The contemporary attitude is that the best way to decrease the irrigation demand on the potable water source is to encourage the use of alternative water sources. This avenue has gained support from Florida's Legislature, which has allocated funds to the water management districts for the promotion of alternative water sources for irrigation water.

In the last decade, recreational irrigation has become its own category to be included in the United States Geological Survey statistics of water trends in Florida. Recreational irrigation refers to non-agricultural turf and landscape irrigation. However this category is primarily composed of golf courses, athletic fields, cemeteries, parks, and non-residential lawns (Marella 2004). Again, in this category domestic outdoor use is rarely included. It seems that water use for residential turfgrass and landscape irrigation is slipping through the cracks.

Another desirable non-potable water source for recreational irrigation, including domestic irrigation water use is reclaimed water. The SWFWMD estimates that reclaimed water can offset 33% of the traditional (potable) water source used for residential irrigation. In 2000 there were 80 wastewater treatment plants, within the SWFWMD planning region, which supplied customers with 447 million lpd. By 2010 it is projected that reclaimed water will have the potential to provide 984 million lpd and offset 738 million lpd of potable water demands (Jones et al. 2006).

The domestic per capita use on average for the entire state has increased slightly from 390 lpd in 1995 to 401 lpd in 2000 (Marella 2004). However, the trend of per capita use has been decreasing since a high of 545 lpd in 1980 (Solley et al. 1998). Within the SWFWMD although there has been considerable population growth, the total water consumption has remained fairly constant since the nineteen-nineties. This is a result of an 11% decrease in per capita water use, from 534 to 473 lpd. However, when the per capita water use is normalized for drought or excessively wet seasons, the total public water use has an upward trend. It is expected that as population growth continues, public water use will become the dominant water use sector.

Per capita water use is affected by a number of factors. Improved indoor water fixtures have led to increased efficiencies. Reclaimed water is increasingly used as a substitute water source for irrigation. Drought tolerant landscape designs (e.g. Xeriscape™ or Florida-Friendly Landscaping) and irrigation technology have also led to a reduction in outdoor water consumption. It also must be considered that the method for determining per capita use has changed over the years. Furthermore, population, climate, socioeconomic conditions, water pricing, conservation practices, and alternative supply sources influence the water demand.

Irrigation Conservation Technology

Previous research in Florida has indicated that the use of irrigation technology can decrease irrigation water use without causing turfgrass stress or degradation of appearance (Cardenas-Lailhacar et al. 2010; Davis et al. 2009; Dukes and Haley 2009; Mayer et al. 2009; McCready et al. 2009). Nonetheless, there is reluctance on either the part of the domestic irrigator and/or the irrigation/landscape professional to incorporate such technology.

When the research presented in this dissertation commenced in 2006, it was required for homes with automatic in-ground irrigation systems installed since 1991 to have a functioning rain shut-off device (Florida Statutes, Chapter 373, Section 62). The most simplistic of such devices is an automatic rain sensor for irrigation systems. More advanced technology has also been developed to conserve irrigation water use, which can save significant amounts of water without compromising turfgrass quality, but require more initial homeowner interaction and a higher level of knowledge on the part of the installers. The newer "smart" devices include SMS and weather-based controllers. However, the ordinance has been loosely enforced at best, which has led to many homes, including new construction, neglecting to install such devices.

Effective in late 2010, the Florida Legislature amended the Water Conservation Statute (Florida Statutes, Chapter 373, Section 62) to now states that bypass technology must be operational on any system a licensed contractor works on or installs. Furthermore, local governments are encouraged to impose model ordinances and penalties for contractors who do not comply. Additionally, the statute now specifically includes the use of a SMS control system as a means to reduce over-irrigation.

Nearly all new-homes in Florida are constructed with automatic in-ground irrigation systems. Moreover, recent research in Florida has indicated that homeowners are over-irrigating, by irrigating more than the plant-water needs based on local evapotranspiration (ET) rate and precipitation (Dukes and Haley 2009).

A St. Johns River Water Management District (SJRWMD) residential irrigation efficiency study conducted in Central Florida with 27 participating homes, found that on average, 64% of the total used was for irrigation. In the summer months this percentage increased up to 88%. The study also showed that setting irrigation controllers with respect to historical turfgrass seasonal water needs resulted in a 30% reduction of water use. With the combination of substantial microirrigated landscape planting areas, and irrigation based on historical ET rates, irrigation was reduced on average by 50%. Despite significant savings, all treatments still over-irrigated according to the calculated theoretical estimate. Additionally, during this study it was observed that the homeowners did not have a clear understanding of when and how much to irrigate. (Haley et al. 2007). Thus, better irrigation scheduling practices significantly reduced wasted water while maintaining landscape quality.

Rain sensors are the most common type of senor used in conjunction with automatic irrigation systems. They should be installed in an area unobstructed from rainfall so that after a rain event the sensor causes the system to bypass and prevent unnecessary irrigation. According to UF-IFAS research, systems that incorporate rain sensors used significantly less water than systems without a functioning rain shut-off device. Irrigation reduction as high as 34% has been reported under normal Florida rainfall frequency (Cardenas-Lailhacar et al. 2008); even during dry weather there was still a 13% to 24% savings (Cardenas-Lailhacar et al. 2010) without negatively impacting turfgrass quality. Studies conducted on St Augustinegrass [*Stenotaphrum secundatum*] plots found reductions in irrigation up to 30% when using rain sensors and 53% when using a rain sensor along with customized irrigation scheduling while maintaining good turf quality (McCready et al. 2009).

More advanced irrigation technology resulted in greater water savings. "Smart" irrigation controllers such as SMS controllers offer the opportunity to optimize irrigation based on measured plant demand in the irrigated system. The sensor system can result in the bypass of scheduled irrigation events based on soil moisture content. According to Bermudagrass [*Cynodon dactylon (L.) Pers.*] plot study results in Florida, SMS controlled irrigation represents a technology that could lead to substantial savings in irrigation water use while maintaining acceptable turf quality. During rainy conditions SMS system savings averaged 72% (Cardenas-Lailhacar et al. 2008), and during dry weather conditions savings averaged 54% (Cardenas-Lailhacar et al., 2010). McCready et al. (2009) reported similar magnitude savings on St Augustinegrass during dry conditions. When soil moisture sensor controllers were optimized in terms of setting thresholds and best performing products, irrigation reduction was as high as 60% to 90% under dry and normal rainfall, respectively (McCready et al. 2009; Cardenas-Lailhacar et al, 2008).

Another type of irrigation conservation technology is a weather-based controller (a.k.a. ET controller or climate-based controller). These, devices use an estimation of ET to schedule irrigation and are typically programmed with site and landscape-specific conditions making them more efficient than time-based systems alone (Riley 2005). A recent study in Florida evaluated the ability of weather-based controllers to schedule irrigation by comparing irrigation application to a time clock schedule intended to mimic homeowner irrigation schedules. This study found ET controllers to result in 43% average water savings compared to time-based treatments without a rain sensor while maintaining acceptable turfgrass quality. The ET controllers resulted in about twice the effectiveness for reduction of irrigation compared to standard time-based controllers with rain sensors (Davis et al. 2009).

There are two aspects that affect the functionality of the irrigation system: technology and user interaction with the technology. The irrigation conservation devices listed above are technological components that will all electronically bypass unnecessary irrigation events. The regulations stated by the local WMD have an influence on the use of bypass technology as well as the time and day settings for the automatic irrigation timer. Although within the SWFWMD, twice-weekly irrigation is permitted; certain counties have more stringent water use regulations. During the majority of the data collection period presented here and in accordance with Pinellas County Code 82-2, irrigation within Pinellas County (using potable or well/surface sources) on established lawns and landscapes was only authorized once per week. Watering was also prohibited between the hours of 8:00 am and 6:00 pm. Effective December 2010, twice per week watering was reintroduced and the prohibited hours were lessened to 10:00 am and 4:00 pm. Since March 2009, according to Pinellas County Code 82-3, irrigation of established lawns with reclaimed water (RCW) is only permitted three days per week, as compared to the previous four day per week suggested allowance (PCU 2007b; PCU 2010b).

The tendencies to employ automatic settings (i.e. the “set and forget” mentality) versus manual adjustment (i.e. due to seasonal scheduling) are influenced by water use ordinance and conservation knowledge. Other human factors, such as the inclination to manually override the automatic system (i.e. due to either rainfall events or desire for additional irrigation events), relate to conservation psychology.

Water Conservation Psychology

Social psychological research concerning environmental issues initially focused on the attitudes an individual has towards these topics (Dunlap and Van Liere 1978). In the 1970s, the research shifted to include behaviors relevant to sustainability of natural resources. The interest began with sustainability relating to energy, followed by recycling and then transportation. Most recently water conservation has been added to the list and cost was the initial primary variable of interest (Kurz 2002). Both pro-environmental and anti-environmental reasons influence an individual to act conservatively. Pro-environmental motivation includes concern for family and other people (De Young 1996), cost savings (Oskamp et al. 1991), and concern for environmental welfare (Stern et al. 1993). Anti-environmental incentives include anthropocentric beliefs and the concept of the shared “common supply”. Anthropocentric beliefs are those that refer to nature being there to be consumed or exploited by people (Thompson and Barton 1994). Florida water law follows riparian doctrine, whose philosophy is based on anthropocentric beliefs (Krimsky 2006).

The reference to the “common supply” refers to 1968 article “The Tragedy of the Commons” in which the central theme is the individual’s use of the shared resources (Hardin 1968). Kurz (2002) more recently explains the affect of outdoor water use in relation to the “common supply” as the consumer determining their own environmental affordance of water use behavior based on the extent to which they observe others within their social environment perceiving the same good. Their observance can be either through conversation or observation. For example, if a consumer is initiating irrigation events multiple times during a week, neighbors will also tend to schedule additional events. Likewise, based on the theories of Environmentally Sustainable Behavior, if a consumer became attuned to environmental affordances, or not abusing the common good and complying with local policy, to adjust their own behavior, the consumer will in turn alter the social environment as well through conversation and observation (Kurz 2002; McKenzie-Mohr and Smith 1999).

Of the research that has been conducted proving the effectiveness of technology in reduction of outdoor (lawn and garden) water use, most of these studies have been primarily conducted in controlled settings (i.e. plot or bench studies). It has been found that the reduction in water use for landscape purposes is greater in laboratory data than in the residential arena (Geller et al. 1983). When consumers were unaware of the technology in place, the reduction in water use was more similar to the laboratory tests. This supports the notion that when consumers are aware of technological innovations they may react by using water more laxly (Campbell et al. 2004).

Baumann (1990) established three factors that affect the intensity of water use by residential users. The first two are economically derived; the consumer’s ability to pay and the willingness to pay for water at a given price. The non-economic factor is the consumer’s conservation behavior. This reflects the motivation to employ effort or technological innovations for water conservation. Campbell et al. (2004) has suggested that when looking at the correlation between water use and socio-economic level alone, lower income homeowners may use more water because of limited resources available to fix leaks and install new water saving devices in the home. The common assumption regarding household size is that with a larger house there is greater water consumption. Additionally, higher value homes tend to have more features that consume water than lower value homes. According to the Florida Water Rates Evaluation of Single-Family Homes, completed in 2005, the main concern of homeowners with respect to increased water costs is water used outside the home, specifically for irrigation purposes (Whitcomb 2005).

The household member responsible for paying the bill as well as ownership of the property also affects water consumption. When a home is owned, there is a greater sense of pride for external appearance. When a home is rented and the renter is responsible for the water bill, the renter may choose not to irrigate the landscape in effort to save money. On the contrary, if the renter does not directly pay the water bill, the renter may tend to water more liberally, perceiving the cost of water as free (Campbell et al. 2004).

To increase water conservation, a national sub-metering and allocation billing study found more multi-family dwellings are being converted to billing systems where the water and wastewater charges are paid separately, as opposed to including as part of the total rent. Data suggested that sub-metering irrigation water use would further increase the irrigation water use efficiency and management. Sub-metering on multifamily apartment units and billing based on actual consumption resulted in water savings of 15%. Reduction of irrigation in the winter months resulted in a statistically significant impact on the overall water use ($p<0.001$). The fraction of total property that was irrigated did not have a significant (p=0.150) affect on the total water use. Water billing practices based on the allocation methods (ratio utility billing method) also did not affect water savings (Mayer et al. 2004).

Finally, weather plays a major role in conservation practices as well. During periods of drought, consumers are more willing to employ conservation techniques than during wet years (Baumann 1990). This may be because of increased public awareness stemming from more intense marketing on the part of WMDs and water purveyors. Further, during wet years there is a sense of excess versus a strain on the common supply during drought conditions. This concurs with Hardin's "commons" philosophy discussed above.

Barriers to Irrigation Conservation

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

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

As previously mentioned, irrigation technology have the potential to yield significant water savings, while maintaining adequate health and appearance of landscapes (Cardenas-Lailhacar et al. 2010; Davis et al. 2009; Haley et al. 2007; Mayer et al. 2009; McCready et al. 2009). However, according to survey responses, based on 13 "Smart" Controller programs in California, although programs have yielded success in raising public awareness of irrigation technology, most residential users have "no knowledge of "smart" irrigation control" (Mayer et al. 2009).

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

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

Similar Studies

Many studies have been conducted regarding conservation behavior, attitudes, and practices. However, few have solely considered the topic of domestic outdoor water use, specifically irrigation. An early study conducted by Geller et al. (1983) examined the use of indoor conservation technology on water consumption. The 129 homes in the study were metered for 70 days including an initial observation period to determine baseline use. The aim was to attempt to increase domestic water conservation by including conservation technology, mostly relating to bathroom fixtures, in addition to education and behavior modification efforts. Significant water savings did occur based on the inclusion of technology; however, less than expected based on lab testing.

Water use demographics were closely analyzed in a study conducted in San Antonio, Texas (De Oliver 1999). The target audience of the study included 203 homes selected from census tracts. The variables of interest were income, education, political party affiliation, ethnicity, and home ownership. Residential water use, provided from the local water purveyor, was included in analysis, and this time included both indoor and outdoor consumption. This study found disparities between conservation attitude and water use. However the study conclusions infer the need to alter the questions asked in efforts to gain a better correlation between attitude and use.

In Mexico, Corral-Verdugo et al. (2002) looked at the effect that external perceptions have on domestic water use. The first study included 280 participant answering questionnaires in the cities of Hermosillo and Obregon. Respondents were asked about conservation motives, costs, social observation, campaigns, water restrictions, community interaction, and habits. A structural model was fit showing how motives of conservation and external perceptions affect overall water conservation. It was found that public observation of excessive water use within the community led to water conservation. The second study included 200 participants in the same target area (Corral-Verudgo et al. 2002). This further investigation included anthropocentric beliefs, pro-environmental competency and practices in addition to motives and external perceptions. The results of the structural model showed that pro-environmental competency reduces the desirability to mimic neighbors' non-conservative habits. Actual water use was recorded to report conservation behavior in both studies. However, again no distinction was made between consumption inside and outside the home.

Looking at outdoor water use only, socio-demographic variables were modeled based on 397 single-family homes in Perth, WA, Australia (Syme et al. 2004). Socio-demographic variables included were income, lot size, education, swimming pool, home ownership, garden maintenance level, and automation of irrigation system. This research also included latent attitudinal variables: lifestyle, garden recreation, garden interest, conservation attitude, and social desirability. This investigation found that the attitudinal variables were as important as the socio-demographic variables. The social desirability scale had an effect on conservation attitudes, but not directly on outdoor water use. Conversely, attitudes toward water conservation independently predicted external use. An important interaction that was not included in this study was the use of irrigation conservation technology. The only irrigation technology noted was an automatic timer, which concurred with the literature showing an increase in irrigation application (Mayer et al. 2004; Syme et al. 2004). Lastly, all of the external water use was estimated based on the difference between summer and winter usage, with none of the homes sub-metered for a calculation of actual irrigation water use for model calibration.

Previous studies have found that ET and weather events significantly affect outdoor water use practices (Danielson et al. 1980; Duble 1997; DeOreo et al. 1997). A five year study conducted across 221 communities in Texas found correlation (R^2=0.39) between per capita water use in relation to climate, average water price, and annual income (Griffin and Chang 1989). A more recent two year study conducted in Austin Texas, with 803 participating homes, found residential outdoor water use to correlate (R^2=0.204) with temperature, rainfall, ET, household size, appraised value, lot size, and presence of a pool (Tinkler et al. 2005). Similar results were also reported in a study conducted in Malmo Sweden, where rainfall, household income, household size, age of home, and water prices were modeled (R^2=0.259). In this study rainfall and water price correlated with a reduction in water consumption and increased household income, size, and age were all associated with greater water use (Hanke and Mare 1982).

A large-scale residential end-use water study conducted by the American Water Works Association compiled billing records from 12,000 residences and survey information from 6,000 homes. Results found that the fraction of water used outside the home was on average 58% of total household consumption. However, in warmer climates this fraction increases up to 67%. Other factors that yielded an increase in outdoor water consumption included lot square footage and outdoor water amenities. Homes with pools resulted in twice as much outdoor water use than those without pools (Mayer et al. 1999).

A residential study conducted in Irvine, California, with 40 participating homes, found that the use of “smart” controllers and irrigation schedule postcard reminders could achieve significant savings compared to conservation potential. Here, conservation potential was defined as the difference between actual irrigation water use and theoretical irrigation demand, which considers climate and rainfall. The ET controllers saved 85% of the conservation potential water use savings as compared to homes without “smart” controllers. The treatment with the postcard reminders alone saved 30% (Hunt et al. 2001).

Research Included in this Dissertation

The research findings presented in this dissertation were fundamentally accumulated from three unique irrigation conservation projects. Of which basic methodologies are described here.

The Evaluation of Soil Moisture Sensor On-Demand Irrigation Controllers

The evaluation of SMS on-demand irrigation controllers was funded by the Pinellas-Anclote Basin Board of the SWFWMD, the Florida Department of Agriculture, and the Florida Nursery Growers and Landscape Association. 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 implemented 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 the potable water source. 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 use homes evenly across treatments. Treatment classification was based on the method or technology used for irrigation control as follows:

- Soil moisture sensor system coupled with the existing time-based irrigation controller.
- Rain sensor coupled with the existing time-based irrigation controller.
- Rain sensor coupled with the existing time-based irrigation controller as well as educational materials with time clock run times for a given time of the year based on UF-IFAS recommendations.
- Comparison group without any special control technology in addition to the existing time-based irrigation controller.

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 ET and measured rainfall. Data collection on all of the homes commenced on July 2006 and ended December 2008, with treatments commencing in November 2007 for a total of 26 months.

The objective satisfied in this study section was to intensively monitor the irrigation water use practices of homes with different levels of irrigation technology and scheduling education. Results include cumulative and event-based irrigation water application reduction based on experimental treatment, irrigation practices relative to plant-water needs as determined through a soil water balance, and watering day compliance.

Irrigation Literacy Evaluation

The irrigation literacy evaluation was a cooperative grant between the Communications Department at the SWFWMD and UF-IFAS. The primary objective of this study was to survey the irrigation knowledge by evaluating residents in Pinellas County Florida utilizing an instrument developed by UF-IFAS and reviewed by the SWFWMD. The water-wise practices and perceptions household questionnaire was used to survey irrigation literacy by assessing the knowledge and attitudes of irrigation water use practices and perceptions as they relate to irrigation conservation. In efforts to attain information and opinions from a cross-section of water customers, the survey sample population was divided among three outdoor water sources: potable, reclaimed, and well-water. Address lists were developed from the PCU customer database of customers that had documented requests of: potable variance exemption (a subset of potable customers), reclaimed cross-over inspection, or well installation rebates. Additionally, households that also participated in the irrigation technology study (described above) were sent the survey packet.

Survey packets (n=1090) were mailed following the Multi-wave Method (Dillman 2000). To promote an increased response rate, the survey process included the following mailings: pre-survey letter, survey packet, and reminder postcard.

Analysis of actual water use was collected from utility billing information and irrigation meter data (from a sub-meter off of the utility mainline) where applicable. Utility meter data of both respondents and non-respondents was analyzed for the time period of 5 years prior to project commencement. To measure irrigation needs, billing data was compared to ET and precipitation for the time period. Socio-economic effects and evaluation of demographic data was analyzed utilizing county records and property appraisal information.

By analyzing the irrigation practices, the questionnaire was utilized to determine an irrigation proficiency level. The independent variables included irrigation system type, outdoor water source, ownership and economic profile. Socio-demographic variables included income, lot size, education, swimming pool, homeownership, level of water conservation technology, and automation of irrigation system. Latent attitudinal variables were lifestyle, recreation, landscape interest, conservation attitude, and social desirability towards conservation.

The objective satisfied with this study was the survey of irrigation water use practices and level of community knowledge of water source, conservation technologies, and policy; where areas of need for increased public awareness and misunderstanding of irrigation water use principles were identified.

Water-Wise Practices and Principles Household Campaign

This cooperative grant between the Communications Department at the SWFWMD and UF-IFAS and served as a Phase II to the Irrigation Literacy Evaluation. The primary objectives of this project were to develop a model which further identifies areas of need for increased public awareness and misunderstanding of irrigation water use principles and then create a household campaign implementing these principles following the Social Based Marketing Theory (McKenzie-Mohr and Smith 1999).

Development of the model used with the collected data from the homeowner survey created a framework to establish a scenario plan, which was used to weigh the options between impact and feasibility of an irrigation conservation campaign. From the homeowner survey conclusions, the ideal scenarios were considered to determine the most successful targeted water-wise irrigation education approach.

The target population included a representative sample of homes that reflect the demographic data and which use both potable and alternative water sources in established and new construction neighborhoods. Program participation included: 21 participating homes with potable water and 28 participating homes with RCW in the Pinellas County target area. Additionally, a non-participant comparison group (n=100) was included for water use analysis purposes.

Census data and other available data were used to develop demographic profiles on program participants. To properly evaluate irrigation use water based on utility data, outdoor water was estimated. Water use data was also collected for twelve months following campaign commencement. Potable source participant impact can be measured by comparing water use to non-participants.

For this study the advertisement directed the interested participants to a web survey for the initial questionnaire. As follow-up to the web-survey, the participants were asked a series of questions regarding their landscape layout, irrigation system, irrigation practices, indoor water use, and household demographics. These questions helped to verify existing information gathered on the home from property appraisal parcel information, aerial imagery, and Phase I responses where applicable.

Participants received newsletters either seasonally or monthly based on the frequency the participant selected during the recruitment survey. Each newsletter included a customized irrigation schedule for the month or season as appropriate.

Evaluation of the program was performed with pre and post-tests. Additionally, newsletter click counts and self-reported questionnaire data were evaluated. The irrigation water use of the RCW participants cannot be measured, as these homes are not outfitted with water meters on the RCW line. Therefore, only the newsletter opening rate and self-reported data was collected.

The aim of the project was to facilitate understanding of residents' behavioral change concerning irrigation water use and fulfill the objective of overcoming barriers of irrigation water use conservation.

Additional Projects

Survey data was also collected as part of the "Smart" Irrigation Controller Demonstration and Evaluation in Orange County, Florida. A current project conducted by the UF-IFAS and funded by Orange County Utilities, SJRWMD, South Florida WMD, and the Water Research Foundation. Respondents (n=887) provided information regarding landscape and irrigation practices and knowledge level of irrigation conservation technology. As the web-based survey data was collected during project commencement, follow-up data will not be presented in this dissertation.

Expected Benefits and Results

The ultimate goal of this research is to determine a means to promote knowledge of water conservation relating to residential irrigation by understanding why people over-irrigate. From previous research, it has been shown that there is room for increased efficiency in the residential arena. The culmination of these studies will serve to quantify residential irrigation water use tendencies and water conservation awareness at both the household and community level.

The outcome of the surveyed water use practices and perceptions will create a baseline of the level of community knowledge of water source, conservation technologies, and policy. Using the selected conceptual model with the survey data, areas of need for increased public awareness and misunderstanding of irrigation water use principles will be identified. Through the determined barriers of irrigation water use conservation, a water-wise principles and practices household campaign is expected to reduce outdoor water use.

CHAPTER 2
INTENSIVE MONITORING OF IRRIGATION WATER USE PRACTICES OF HOMES WITH DIFFERENT LEVELS OF IRRITATION TECHNOLOGY AND IRRIGATION SCHEDULING EDUCATION

Background

The Florida climate consists of dry and warm weather during spring and fall, coupled with frequent rain events in summer months (NCDC 2002). With these environmental conditions occurring in areas of predominantly sandy soils that have 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 in 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 (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).

A study conducted with homeowners in Central Florida within the St. Johns River Water Management District (SJRWMD) found that on average, 64% of the water used by the homes went to irrigation. In the summer months this percentage increased up to 88%. The study also showed that setting irrigation controllers with respect to historical turfgrass seasonal water needs resulted in a 30% reduction of water use. With the combination of substantial micro-irrigated landscape planting areas, and irrigation based on historical evapotranspiration rates, the fraction of water use for irrigation purposes was reduced on average by 50%. Despite significant savings, all treatments still over-irrigated according to the calculated theoretical estimate (Haley et al. 2007). Thus, better irrigation scheduling practices significantly reduced wasted water while maintaining landscape quality. “Smart” irrigation controllers such as soil moisture sensor (SMS) controllers offer the opportunity to optimize irrigation based on measured plant demand in the irrigated system.

Controlled vs. Non-controlled Comparison

Of the research that has been conducted proving the effectiveness of technology in reduction of irrigation water application, most of these studies have been primarily conducted in controlled research settings. When attempting to incorporate the recommendations of the research into actual landscapes, savings may not be as significant (Campbell et al. 2004; Geller et al. 1983). When consumers were unaware of the technology in place, the reduction in water use was more similar to the laboratory tests. This supports the notion that when consumers are aware of technological innovations they may react by using water more laxly (Campbell et al. 2004).

Research studies, while resulting in peer-reviewed publications sound statistical analysis, may be not representative of the larger populations involved as irrigation customers of a utility. Therefore, the saving results may not be directly transferable (Dukes 2010). Conversely, larger scale demonstration projects such as the irrigation timer implementation pilot programs in California compare water use before and after installation using accepted statistical practices (Kennedy/Jenks Consultants 2008; Mayer et al. 2009; Hunt et al. 2001). However, with the non-controlled domestic irrigation studies, there is no assurance that the watering practices prior to installation of the devices are indicative of the general population.

According to turfgrass plot study results in Florida, SMS controlled irrigation represents a technology that could lead to substantial savings in irrigation water use while maintaining acceptable turf quality. During rainy conditions SMS system savings averaged 72% (Cardenas-Lailhacar et al. 2008), and during dry weather conditions savings averaged 54% (Cardenas-Lailhacar et al. 2010). McCready et al. (2009) reported similar magnitude savings on St Augustinegrass during dry conditions. When soil moisture sensor controllers were optimized in terms of setting thresholds, irrigation reduction was as high as 60% to 90% under dry and normal rainfall, respectively (McCready et al. 2009; Cardenas-Lailhacar et al. 2008).

In addition to “smart” controllers, rain sensors have been used to significantly reduce irrigation application. Irrigation reduction as high as 34% has been reported under normal Florida rainfall frequency (Cardenas-Lailhacar et al. 2008); even during dry weather there was still a 13 to 24% savings (Cardenas-Lailhacar et al. 2010) without negatively impacting turfgrass quality. Studies conducted on St Augustinegrass plots found reductions in irrigation application while maintaining good turf quality up to 30% when using rain sensors and 53% when using a rain sensor along with customized irrigation scheduling (McCready et al. 2009). More advanced irrigation technology resulted in greater water savings.

The controlled research studies indicate substantial water savings (Cardenas-Lailhacar et al. 2008; Cardenas-Lailhacar et al. 2010: McCready et al. 2009), however “real world” savings in larger pilot scale projects indicate savings typically less than 10% (Kennedy/Jenks Consultants 2008; Mayer et al. 2009). Reasons for the variance between the potential savings suggested from the controlled studies and reduced actual savings in the pilot projects are related to the following deficiencies within the program design of the pilot projects (Dukes 2010):

- Targeting high irrigation users (either a relative or absolute scale)
- Education for contractors and end users

- Timely follow-up to assess water savings

Additionally, much of the controlled research on smart controllers has been conducted in humid regions, such as Florida, where higher potential savings is likely magnified versus arid regions, due to irrigation needed only to supplement rainfall.

Objectives

The objective of this study was to determine if documented irrigation reduction by SMS based irrigation controllers under research conditions could be validated in actual landscapes where homeowners controlled the irrigation system. To do so, irrigation water use was measured and turf quality evaluated 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 (4) homes with minimal intervention during the same data collection period.

Materials and Methods

Participating Homes

The homes included in this research project were located in the City of Palm Harbor, Pinellas County, Florida within the Pinellas Anclote Basin of the Southwest Florida Water Management District (SWFWMD). Residential homes with automatic in-ground irrigation systems using potable water were recruited. 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 of Florida Institute of Food and Agricultural Sciences (UF-IFAS) 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.

Experimental Design

Equipment installation

All cooperating homes had a pre-existing automatic irrigation system and time-based controller. Additionally at each home, a positive displacement irrigation sub-meter was installed as well as supplementary equipment (rain sensor or soil moisture sensor) as needed based on participating home treatment type. This meter allowed direct determination of irrigation use 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). All homeowners ultimately had control of their irrigation controllers, including SMS controllers where installed.

Treatments

The homes were divided into four experimental treatments according to the method or technology used for irrigation control. The four experimental treatments were replicated at least three times in each of four locations for a total of 58 homes in the study group.

The first treatment group had an Acclima TDT RS-500 (Acclima, Inc., Meridian, ID) SMS system set at 10% (volumetric water content) threshold, coupled with the existing timer irrigation controller. Previous experience with time domain transmissometry (TDT) SMS controllers at this volumetric water content threshold resulted in adequate irrigation for Bermudagrass [*Cynodon dactylon (L.) Pers.*] (Cardenas-Lailhacar et al. 2008) and St Augustinegrass [*Stenotaphrum secundatum*] (McCready et al. 2009). The soil moisture sensor was buried in the most demanding area of the landscape in terms of irrigation such as sunny turfgrass to a depth of approximately 8 cm. The SMS system bypassed scheduled irrigation events if the volumetric water content was at 10% or greater at the beginning of an irrigation cycle. The homes in the next two groups had a Mini-click (Hunter Industries, Inc., San Marcos, CA) rain sensor added to the existing timer irrigation controller set to interrupt irrigation after 6 mm of rainfall. One group was also given educational materials (EDU) as described below; the other only had the rain sensor (RS). The comparison group and did not have any control technology other than the existing time clock common to all homes and is referred to hereafter as meter only (MO).

Research personnel programmed the initial SMS controller threshold setting, but the homeowner programmed the irrigation time clock. The threshold setting allows the soil moisture sensor system to only bypass scheduled irrigation events. After the initial adjustment, the SMS controller threshold settings were checked at months 5, 10, and and at the end of the 26 month data collection period. No attempt was made on homes except the EDU group to have homeowners change their existing practices with respect to time clock programming. After the initial intervention, project personnel purposefully limited interaction with all cooperators.

Educational material dissemination

The educational materials included a customized irrigation runtime card and documents explaining outdoor water saving practices developed by UF-IFAS and SWFWMD. The primary component of the educational materials given to the EDU group was the customized irrigation runtime card and documents explaining outdoor water conservation. The runtime card was based on the home's specific irrigation system design, zone layout, and application rates and in accordance with UF-IFAS recommendations (Dukes and Haman 2002). This card provided the homeowner with system runtimes for each season and irrigation zone and was fastened to the irrigation controller. It was hypothesized that the card would make it easier for homeowners to set the correct runtimes on their timer to irrigate a particular irrigation zone, thus leading to irrigation reduction. The laminated card (Figure 2-2) was therefore fastened to the controller box, at the location to directly prompt the intended behavior as suggested by McKenzie-Mohr and Smith (1999).

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 participants was the UF-IFAS publication "Operation of Residential Irrigation Controller" (Dukes and Haman 2002).

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 (Figure 2-2) developed for the unique irrigation system at each participating site.

Cooperator interaction

Contact between the PCU/UF-IFAS personnel and the program 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.

Irrigation System Evaluation and Property Information

Irrigation evaluation

Prior to data collection, an irrigation system evaluation was conducted at each home (Appendix A). During this evaluation any required maintenance resulting from broken heads and/or leaks was noted. Any maintenance that would compromise the irrigation uniformity test was fixed before the testing began. In extreme cases it was recommended that the homeowner fix deficiencies before they could become part of the study. Meter flow rates were 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 calculated according to Equation 2-1. The term uniformity refers to the measure of the variability of applied water over an irrigated area.

$$DU_{lq} = V_{lq} / V_{tot} \qquad \text{Equation 2-1}$$

Where, V_{lq} is the average of the lowest one-fourth of catch-can measurements (ml) and V_{tot} is the 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 assigns a numeric value to quantify system performance.

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 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 SJRWMD, on average the irrigated area was 85% of the non-structural area (Haley et al. 2007). The non-structural land area for each home was determined 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.

Irrigated area

Property information was gathered from the Pinellas County property appraisal public records (www.pcpao.org) for each home included in the analysis. A calculated irrigated area was determined by subtracting the gross structural area and residential extras from the property size. From the Pinellas County public graphic information system (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 2-3). The GIS software was used to determine the aerial estimated irrigated area by calculating the area of each polygon. Actual irrigated areas were also measured at site visits to the participating homes. These measurements were used to verify assumptions in the aerial estimated irrigation area methodology. Details of this technique explored in Chapter 3.

Percentage turf within landscape

From a previous irrigation water use efficiency study, it was concluded that homes with a greater percentage of bedded area and micro-irrigation tended to consume less water use per irrigation cycle because micro-irrigation applies less water per unit area than sprinkler irrigation (Haley and Dukes 2007). In this study, non-turfgrass landscape areas were typically irrigated with sprinklers.

Initially every home was given a visual inspection and rated based on landscape level (Figure 2-4). The landscape levels were qualitatively assigned used to quantify the percentage turfgrass versus bedded areas. Landscape level one is characterized by the turfgrass area greater then bedded landscape area. Landscape level two is characterized by turfgrass and bedded areas approximately equal. Landscape level three is characterized by turfgrass area less then bedded landscape area. During the site visits, it was determined that on average 76%, 74%, 80%, and 79% of the irrigated area was turfgrass for SMS, EDU, RS, and MO homes, respectively, with the remainder referring to the mixed ornamental planting areas.

Weather Data

Four weather stations (Figure 2-5) were setup in Palm Harbor within 4 km of each other, and all had a grass reference surface. Each weather station was within a 1 km radius of the surrounding homes at each of the four location areas (Figure 2-1) and named L1, L2, L3, and L4 respectively. The urban weather stations were fully installed and commenced data collection in July 2006. Three of the four stations are on PCU property. The station at location L4 is on private property.

As common with most urban weather stations, the stations were surrounded by different obstacles and encountered different fetch distances (Figure 2-6 through Figure 2-9). Practical efforts were made to minimize obstructions near the weather stations. In any case, the stations were representative of weather data in urban area.

All four weather stations have the same types of sensors (Figure 2-5). 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. The stations stand approximately 2.4 m tall. The frame is buried 1.2 m in the ground and secured with concrete.

Daily standardized reference evapotranspiration was estimated from weather parameters measured at each weather station. The American Society of Civil Engineers Environmental and Water Resources Institute, ASCE-EWRI (2005) methodology was used as follows:

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{C_n}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

Equation 2-2

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}

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 (2005). In addition to data assessment, routine maintenance was performed to ensure the proper functionality of the weather stations. Technical maintenance includes the evaluation, repair and replacement of equipment, while non-technical site maintenance includes removal of debris from the tipping bucket, cleaning the solar panel, bird prevention, mowing, etc.

Soil Water Balance

Treatment irrigation means were compared to a theoretical irrigation estimate for each location. Evapotranspiration for the landscape was calculated with Equation 2-3 (ASCE-EWRI 2005).

$$ET_L = ETo * K_L \qquad \text{Equation 2-3}$$

Where ET_L is the overall estimated landscape evapotranspiration (mm/d), ET_o is reference evapotranspiration for short surfaces (mm/d) from Equation 2-2, and K_L is landscape coefficient (Equation 2-4).

$$K_L = (Kc_{turfgrass} * A_{turfgrass}) + (Kc_{ornamental} * A_{ornamental}) \qquad \text{Equation 2-4}$$

Where Kc is the crop coefficient for either turfgrass or ornamental plantings and A is the turfgrass or ornamental planting area (%). This theoretical estimation used average turfgrass areas given earlier. The irrigation requirement for the ornamental plant beds was considered to be negligible, since ornamental plant beds require little or no supplemental irrigation once established in Florida (Moore et al 2009; Shober et al. 2009; Wiese et al. 2009; Scheiber et al. 2008). The $Kc_{turfgrass}$ values (Table 2-2) were interpolated between North and South Florida warm season turfgrass values from Jia et al. (2009) as the study location is in between these two regions.

To compare the actual irrigation water applied to the residential landscapes, a theoretical irrigation water requirement was calculated using a daily soil water balance (SWB) as in Equation 2-5 (Dukes 2007).

$$I_{calc} = ET_L - P_{gross} - RO - D \qquad \text{Equation 2-5}$$

Where I_{calc} is the calculated net irrigation requirement (mm/d), P_{gross} is total rainfall (mm/d), D is drainage below the root zone from excess rainfall (mm/d), and RO is surface runoff (mm/d). Effective rainfall (P_e) is the only portion of rainfall beneficial to plants; this excludes precipitation resulting in surface runoff or drainage below the root zone. Effective rainfall was estimated using the soil water content on a day-by-day basis to determine the storage available or rain lost to D or RO.

To determine the amount of irrigation required, drainage, runoff and effective rainfall, the upper and lower boundaries were determined using the soil water holding capacity 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. The rainfall considered effective is only the amount of input until *FC* is reached. Additional rainfall was considered excess and resulted in runoff or drainage. For the sake of minimal plant stress the lower boundary is the readily available water (*RAW*) described by Equation 2-6 (Dukes 2007).

$$RAW = (FC - PWP) * RZ * MAD \qquad \text{Equation 2-6}$$

Where *PWP* is the permanent wilting point, *RZ* is the root zone and *MAD* is the maximum allowable depletion. 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). For St Augustinegrass, the *RZ* was assumed to be 20 cm (Shedd 2008) and *MAD* was assumed to be 0.5 (ASCE-EWRI 2005). It was assumed that once the soil water content exceeded field capacity, drainage and or runoff occurred from excessive rainfall.

Once the soil hydraulic properties were used to define the upper limit of water storage, I_{calc} was determined assuming ideal irrigation conditions such that *D* and *RO* were zero for the theoretical irrigation estimate. Equation 2-7 simplifies as follows to estimate net irrigation requirement.

$$I_{calc} = ET_L - P_e \qquad \text{Equation 2-7}$$

Irrigation, I_{calc}, was simulated when the quantity of soil water at the beginning of the day was at or below the lower boundary, *RAW*. Applied net irrigation was the total necessary to reach the upper boundary, *FC*.

Individual soil water balances were developed for each location and then the calculated irrigation need was averaged. Gross irrigation (I_{gross}) was estimated by dividing I_{calc} by an efficiency factor. An ideal 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. 2008).

Data Collection and Analysis

Water application

The existing utility meters were used to determine total water use that included both indoor and irrigation. A secondary irrigation sub-meter (C700, Elster AMCO Water, Inc., Ocala, FL) was installed on the irrigation main line to isolate irrigation water application. The irrigation water use for the homes was calculated as a depth of water applied (mm) by dividing the volume usage (m^3) by the irrigated area (m^2) of the home and applying appropriate unit conversions. From July 2006 through April 2007, Pinellas County Utilities personnel recorded the weekly elapsed water meter readings manually

(Table 2-1). Beginning in April 2007, dataloggers were attached onto the irrigation meters to collect actual water use frequency and amount. The dataloggers are part of an automatic meter reading (AMR) technology (Firefly AMR System, Datamatic Ltd., Plano, TX) for data collection using a meter interface unit that attaches to the existing irrigation water meter, recording water usage by counting the meter needle sweeps with an optical sensor.

Initially the AMR dataloggers were recording water use at 10 min intervals. However, in December 2007 the AMR logging interval was increased from 10 min to 1 hr. The data collection was previously conducted weekly when the dataloggers were recording water use in a 10 min time interval. With the increase from a 10 min to 1 hr interval, the AMRs were able to hold up to 72 days of hourly data records and therefore could be downloaded less frequently. From December 2007 through the remainder of the data collection period, PCU retrieved the AMR data approximately every 45 days. This change in logging interval did not compromise any data analysis.

Turf quality

Turf quality ratings were collected seasonally as a benchmark measure of minimum acceptability for each treatment regime. Turfgrass areas at the homes were mostly St Augustinegrass. Initial turf quality ratings were taken for each home during the irrigation evaluations, as a baseline standard of comparison for each home and to gauge potential turf quality decline based on irrigation reduction. Turf quality was then evaluated six more times during the monitoring period (Table 2-1). The turf quality assessment is a subjective process following the National Turfgrass Evaluation Procedures (Shearman and Morris 1998) 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 to 9, with 1 being lowest and 9 being highest possible. A rating of 5 is considered minimally acceptable for home landscapes (Figure 2-10). The same person conducted turf quality ratings throughout the study to reduce variability in the ratings based on the subject nature of the evaluation process.

Controlled vs. non-controlled comparison

The resulting water use savings in this study were compared to those results found from similar plot study tests (Table 2-7). The non-controlled settings for irrigation systems incorporating a soil moisture sensor system yielded a 65% savings. Likewise, the controlled setting, with the use of the same soil moisture sensor set at an equivalent threshold, irrigation savings yielded a weighted average of 65%, ranging from 11% to 92% for dry and rainy conditions, respectively (Cardenas-Lailhacar et al. 2010; Cardenas-Lailhacar et al. 2008; McCready et al. 2009).

Although the rain sensor treatment in this study resulted in 14% less irrigation, this difference was not statistically significant. The lack of statistical significance was due to the large amount of variability and non-normality of the irrigation use data. In contrast, the plot studies yielded an average weighted significant savings of 20%, with a range from 7% to 34%, when using rain sensors (Cardenas-Lailhacar et al. 2010; Cardenas-Lailhacar et al. 2008; McCready et al. 2009),

The educational materials in this study were to encourage irrigation scheduling on the part of the participant. This non-controlled treatment yielded a 24% reduction in irrigation application that was not statistically significant. In previous work that was quasi-controlled with educational materials and a rain sensor, irrigation reduction of 30% was reported (Haley et al. 2007).

Statistical analysis

The data across treatment groups and seasons did not maintain a normal distribution; therefore, a Box-Cox transformation procedure was applied such that procedures for normally distributed data could be used. 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, PROC GLIMMIX, 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.

Results

Environmental Conditions

The monthly rainfall totals for the study period are presented in Figure 2-11. 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 (NCDC 2002). During 2008, 33% of the days had rainfall events, resulting in 5 fewer rainfall events than a normal year; the total precipitation was 1,072 mm, 15% lower than normal. A total of 15 of 26 months during the study had less than normal rainfall (Figure 2-11). August through December 2008 was a continuous dry period relative to historical rainfall.

Prior Water Use Analysis

From the PCU utility data of the participants' previous 2 yr 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 2-3). 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).

Irrigated Area Calculation

The GIS aerial images resulted in more accurate estimations of actual irrigated areas compared to the property appraisal data. The average GIS estimated irrigated area error was within 5% of onsite verified irrigated area, with no over or under-estimation greater than 10%. The average irrigated areas for each treatment are listed in Table 2-4. The variability in irrigated area did not affect the statistical analysis.

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 better (Figure 2-12) (IA 2005). Although a third of the homes were lower than “good”, according to previous research 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).

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 runtime cards for the group that received the educational materials. The homes in this study averaged 4 to 6 irrigation zones. Additionally it was commonly observed that the irrigation head types (e.g. rotor and spray) were mixed within single zones. Only 6% of the study homes had pre-existing rain shut-off devices installed and all of these were rain sensors.

Turfgrass Quality

Although, there were cooperating homes that received less than minimally acceptable turf quality ratings (i.e. < 5), 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. Throughout the 26 months of data collection, no significant differences in average site turf quality ratings were detected among homes based on treatment group.

However, there was one season in which treatment related turfgrass stress occurred, and although not statistically different it did appear to affect the effectiveness of the water savings. In April 2008 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 (Figure 2-13). The decline in turf quality and the subsequent increase in irrigation application indicates that the participants left the initial irrigation schedule set as it was at the time of treatment commencement in November 2006 (which was the reduced runtime setting 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 spring of 2008 (Figure 2-13), when the irrigation schedule should have been readjusted back to the lower summer runtimes. Subsequently, the EDU group began irrigating like the RS treatment, the only other treatment with a rain sensor (Table 2-5). Thus, it appears that any type of guidance for homeowner irrigation runtimes 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 at least to some extent in the winter to spring and summer to fall transitions to maintain good turfgrass quality.

Irrigation Application

Irrigation quantity

As part of a concurrent study also within Pinellas County, response from a mail-out survey was received from 272 homes (including 45 of the homes in this study) regarding their irrigation practices (Chapter 3). Sixty-nine percent of these homes reported that they "consider their irrigation practices to be very water conserving" (Haley and Dukes 2008). Furthermore, 33% reported manually adjusting their automatic irrigation system schedule, rather than allowing irrigation control devices to bypass irrigation cycles. However, details such as frequency of adjustment or application amount are unknown.

Irrigation application was significantly influenced by the season of the year, as shown in Table 2-5. The highest water use occurred in the spring months with an average of 56 mm/month applied compared to the other months with an average of 40 mm/month. The spring months had the highest irrigation demand due to the relatively high evaporative conditions and low rainfall. The gross irrigation water requirement in the spring was calculated as 73 mm/month compared to 65 and 48 for the summer and fall, respectively. Although the homes had the highest irrigation in the spring, on average they under-irrigated relative to the gross irrigation requirement calculated here. A similar trend was observed in the summer. The theoretical irrigation requirement estimates well-watered plant needs whereas it is likely that irrigation can be reduced below well-watered levels and still provide good quality or that many homeowners accept some level of quality reduction as a result of reduced irrigation. Winter months required the least irrigation with only 24 mm/month and this was the time period where the homes over-irrigated (40 mm/month applied) relative to the theoretical estimate indicating homeowners did not reduce irrigation in the cooler months as low as might be possible.

Mean cumulative irrigation application for each treatment, over the 26 month data collection period is presented in Figure 2-13. The total cumulative savings were calculated based on the means and compared to the MO treatment. The SMS treatment was the only group of homes with statistically significant savings at the 95% confidence level (Table 2-5); 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 EDU monthly irrigation (36 mm/month) was significantly lower than RS or MO homes at the 90% confidence level but still higher than the SMS homes, indicating that repetitive communication reminding homeowners of time clock adjustment may provide measurable water conservation benefits. 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 spring of 2008 (Figure 2-13). This upward trend is during a time when the irrigation schedule should have been readjusted back to the lower fall runtime. Thus, it appears that the EDU homeowners did not adjust their irrigation according to guidelines provided. The RS treatment likely did not save significant water due to the below normal rainfall conditions.

Water savings were also calculated in terms of volume of water saved relative to the MO treatment. Over the 26 month data collection period, the SMS treatment saved, on average, 992 liters per day, whereas, the other treatments did not result in significant savings.

Irrigation frequency

Irrigation frequency was determined from the AMR data in addition to volume of water applied. Table 2-6 presents the average monthly number of irrigation events by treatment and season. On average the SMS treatment resulted in significantly less irrigation events with 2.3 events/month, compared to RS, and MO homes. The RS and MO treatments both averaged nearly 6 events/month. The EDU homes irrigated a similar number of times per month as the other groups. Four to five 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 2-6). The number of events in the fall increased slightly from the summer requirements (4 to 5 events per month) due to the decrease in rainfall. Thus, the static water restrictions that are typically recommended at 1 or 2 day/week are not adequate year round for optimum plant water demands.

The maximum number of events that occurred in a given month over the 19 full months in which the AMR based data were collected is also presented in Table 2-6. Within all treatments, at least one home irrigated 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 at least one home at some point during the monitoring period. It appears that the SMS systems successfully governed the number of irrigation events that occurred, 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 water content, which can be affected by unnecessary irrigation events as well as rainfall, whereas the rain sensors only bypass actual precipitation events that are detected. In addition, the decreased number of irrigation events by the SMS homes (Table 2-6), which were half to a third of the other study homes, led directly to the cumulative irrigation savings of 65% compared to the homes that were only monitored.

Theoretical Irrigation Requirement

Figure 2-14 through Figure 2-17 shows the calculated irrigation requirement compared to actual irrigation averaged across each treatment group 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 relative to the theoretical estimate, with the SMS treatment expressing the greatest under-irrigation and the EDU applied irrigation most closely to the estimated need.

The SMS treatment group showed little variation throughout the 19 months of irrigation presented in Figure 2-14. However, this treatment did not result in unacceptable turf quality. These homes did apply more irrigation during dry times compared to rainier periods; note the decrease in irrigation during the wet summer months in Figure 2-14. 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 in the winter.

The SMS treatment appears to drastically under-irrigate; however, turf quality was not different than the other treatments that irrigated in greater quantity and frequency. Several reasons are possible for the apparent under-irrigation. As mentioned previously, it is likely that some homes deficit irrigated over some periods of time including the soil moisture sensor controlled homes. McCready et al. (2009) showed that at 7% and 10% volumetric water content threshold on sandy soil similar to this project resulted a reduction in water use while maintaining good St Augustinegrass quality. However, on individual home sites some deficit could have occurred depending on irrigation frequency. The theoretical irrigation estimation is for full water replacement at the optimal time. Without more detailed information of the landscapes and soil water status over time, the theoretical irrigation estimation serves as a relative comparator rather than an absolute predictor. However, the theoretical trends are useful in examining the timing of irrigation rate adjustments by homeowners.

The EDU treatment most closely matched the calculated irrigation requirements trend compared to the other treatments (Figure 2-15). After a gradual increase in water use in mid 2007, throughout 2008 the EDU homes followed the calculated irrigation need trend according to the recommended runtimes for their irrigation controllers. It is clear the irrigation recommendations given to the EDU homes could have been reduced given that turf quality didn't differ across treatment. In addition, the rain sensor on the EDU homes was not as efficient at reducing irrigation application as evidenced by the limited reduction in irrigation on the RS homes. Recent work has shown that reduced irrigation recommendation schedules in Florida can result in similar irrigation savings as a SMS based irrigation controller or evapotranspiration based controller (McCready et al. 2009; Davis et al. 2009)

In both RS and MO homes, over-irrigation occurred during the late fall 2007 through early spring 2008 months (Figure 2-16 through Figure 2-17). These months were particularly dry compared to normal (Figure 2-11). The MO treatment resulted in the greatest over-irrigation, particularly from September 2007 through January 2008 (Figure 2-17). 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, this manual adjustment is not optimal based on landscape water needs.

Plot Study Comparison

The resulting water use savings in this study were compared to those results found from similar plot study tests (Table 2-7). The non-controlled settings for irrigation systems incorporating a soil moisture sensor system yielded a 65% savings. Likewise, the controlled setting, with the use of the same soil moisture sensor set at an equivalent threshold, irrigation savings yielded a weighted average of 65%, ranging from 11% to 92% for dry and rainy conditions, respectively (Cardenas-Lailhacar et al. 2010; Cardenas-Lailhacar et al. 2008; McCready et al. 2009).

Although the rain sensor treatment in this study resulted in 14% less irrigation, this difference was not statistically significant. The lack of statistical significance was due to the large amount of variability and non-normality of the irrigation use data. In contrast, the plot studies yielded an average weighted savings of 20%, with a range from 7% to 34%, when using rain sensors (Cardenas-Lailhacar et al. 2010; Cardenas-Lailhacar et al. 2008; McCready et al. 2009),

The educational materials in this study were to encourage irrigation scheduling on the part of the participant. This non-controlled treatment yielded a 24% reduction in irrigation application that was not statistically significant. In previous work that was quasi-controlled with educational materials and a rain sensor, irrigation reduction of 30% was reported (Haley et al. 2007).

With respect to irrigation frequency, all previous research on this topic has shown that SMS systems result in 2 to 3 times more irrigation reduction compared to RS's (Cardenas-Lailhacar et al. 2008; McCready et al. 2009; Cardenas-Lailhacar et al. 2010). In this study, the decreased number of irrigation events by the SMS treatment homes (Table 2-6), were half to a third of the RS, EDU, and MO homes.

Discussion

The goals of this study were to quantify irrigation water use and to evaluate turf quality differences in residential landscapes between traditional time-based irrigation systems compared to the additional technologies such as a soil moisture sensor controller, rain sensor, and rain sensor along with educational materials advising time clock setting and compare these results to those found from similar plot studies. Of the data collected in this study, the soil moisture sensor treatment was the only treatment with significant irrigation savings, which reduced irrigation 65% relative to the comparison homes. The percent reduction of irrigation water use observed for the SMS treatment concurs with those yielded in controlled plot studies. 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 and irrigation variability among cooperating homes.

Throughout the data collection period, precipitation was 15% 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. Despite lower than normal precipitation during the study, the soil moisture sensor homes bypassed unneeded irrigation events during rainy as well as dry times with intermittent rainfall, with an average of only two 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 four to six 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. 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. In effect, the SMS control systems were able to regulate irrigation more effectively than the mandated day of the week restrictions in place for all homes.

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.

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 UF-IFAS 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 trend may have been due to limited or no adjustment of the time clock. 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 significantly different that the comparison group. Thus, to ensure behavior modification over time, repeat messages and prompts for irrigation schedule changes would be needed.

Table 2-1. Participant contact and/or interaction including equipment installation and routine data collection

Date	Action	Treatment Involvement	Interaction Level
Nov 2005 to May 2006	Irrigation audits, Turf quality ratings	All, letter sent	High
Jan 2006	Notifications of equipment installation	All, letter sent	Medium
Feb 2006 to Jul 2006	Installation of rain sensors	RS and EDU	High
Aug 2006 to Oct 2006	Installation of soil moisture sensor systems	SMS only	High
Jul 2006 to Dec 2008	Meter readings by PCU staff	All	Low
Oct 2006	Turf quality ratings	All	Low
Nov 2006	Check up on SMS	SMS only	High
Nov 2006	Distribution of EDU	EDU only	High
Jan 2007	Turf quality ratings	All	Low
Mar 2007	Check on SMS installation	SMS only	High
Apr 2007	Turf quality ratings	All	Low
Apr 2007	Notification of AMR installation	All, letter sent	Medium
Apr 2007 to May 2007	AMR installation	All	Medium
Aug 2007	Check on SMS programming	SMS only	High
Aug 2007	Turf quality ratings	All	Low
Dec 2007	Turf quality ratings	All	Low
Apr 2008	Turf quality ratings	All	Low
Jun 2008	Survey of water use practices	All, letter sent	Medium
Dec 2008	Check up on SMS	SMS only	High

Table 2-2. Monthly turfgrass crop coefficients for central Florida used for the theoretical irrigation requirement

Month	Crop Coefficient ($Kc_{turfgrass}$)
January	0.45
February	0.45
March	0.65
April	0.80
May	0.90
June	0.75
July	0.70
August	0.70
September	0.75
October	0.70
November	0.60
December	0.45

Table 2-3. Estimated irrigations 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	Mean	Min	Max	Mean	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

Table 2-4. 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: $1m^2 = 10.76\ ft^2$

Table 2-5. Mean monthly irrigation application by treatment and season for all homes and study years (2006-2008)

		I_{actual} Z (mm per month)	N Y (#)	Range (mm per month)	Median (mm per month)	Std Dev (mm per month)	I_{gross} X (mm per month)
Treatment W	SMS	23b V	306	0-317	4	39	41
	EDU	36a	333	0-372	24	47	40
	RS	56a	339	0-775	43	71	43
	MO	64a	330	0-950	41	86	43
Season U	Spring	56a	322	0-950	36	87	73
	Summer	37c	253	0-263	17	49	65
	Fall	45b	339	0-572	26	66	48
	Winter T	40bc	394	0-577	25	51	24

Z Monthly average irrigation applied.
Y N = number of monthly irrigation records in the comparison.
X Average theoretical gross irrigation requirement calculated from the daily soil water balance.
W Treatments are: SMS, time-based controller plus soil moisture sensor system with 10% volumetric water content threshold; RS, time-based controller plus rain sensor at 6 mm threshold; 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 Winter of 2008 consisted of December 2008 and January 2009 only.

Table 2-6. Mean monthly irrigation application by treatment and season for all homes and study years (2006-2008).

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

[Z] Monthly average number of irrigation events applied.
[Y] N = number of monthly AMR datalogged records in the comparison.
[X] Number of irrigation events calculated from the daily soil water balance.
[W] Treatments are: SMS, time-based controller plus soil moisture sensor system with 10% volumetric water content threshold; RS, time-based controller plus rain sensor at 6 mm threshold; 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] Winter of 2008 consisted of December 2008 and January 2009 only.

Table 2-7. Comparison of irrigation water use savings for controlled (plot study) versus non-controlled (cooperating household) settings.

Device	Percent Irrigation Water Use Savings (%)		
	Controlled Setting		Non-controlled Setting
	Mean	Range	
Soil Moisture Sensor	65%[ZYX]	11-92%[ZYX]	65%
Rain Sensor	20%[ZYX]	7-34%[ZYX]	14%
Rain Sensor plus Scheduling	30%[W]	-	24%[V]

[Z] (Cardenas-Lailhacar et al. 2008)
[Y] (McCready et al. 2009)
[X] (Cardenas-Laihacar et al. 2010)
[W] (Haley et al. 2007)
[V] Percentage savings during 12-month period with no contact from program personnel.

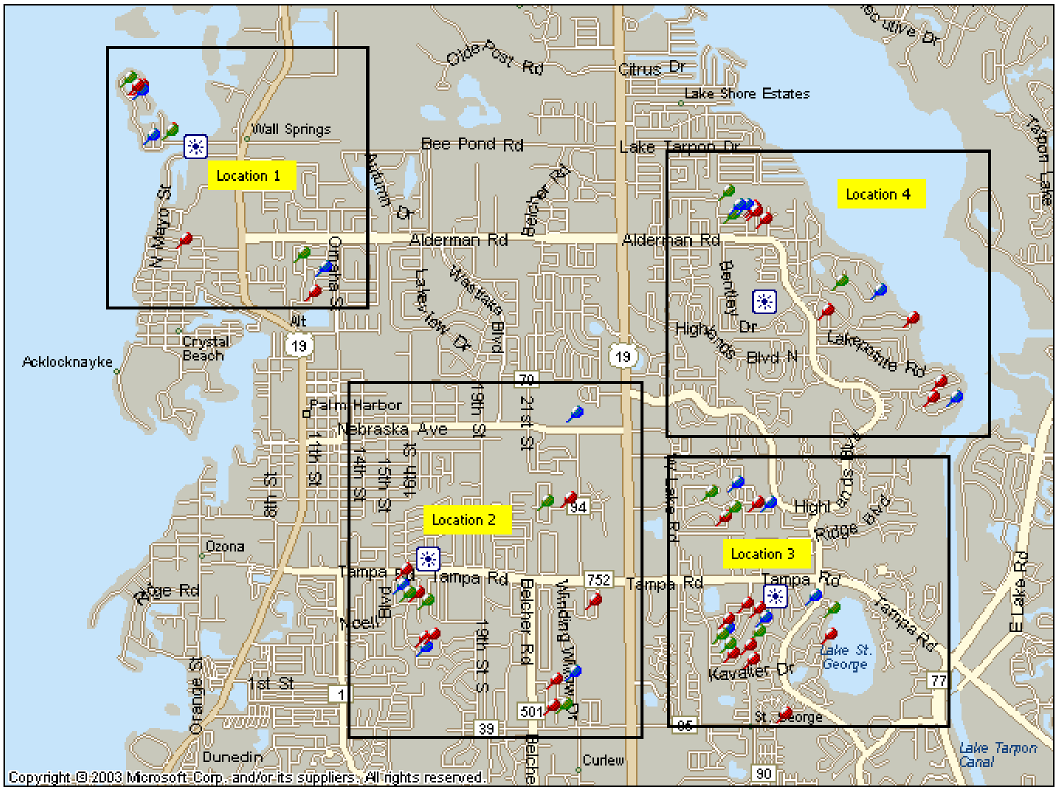

Figure 2-1. Street map of the City of Palm Harbor in Pinellas County Florida with cooperating study homes denoted by pins. The pin color refers to equipment installed at each home: red is flow meter and rain sensor, green is flow meter and soil moisture sensor, and blue is flow meter only. Weather station locations are shown as squares surrounding asterisks.

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.

A

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

For irrigation or project related inquiries:
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mhaley@ifas.ufl.edu
For horticultural inquiries:
Dale Armstrong
at Florida Yards and Neighbors
(727) 582-2108

B

Figure 2-2. Laminated irrigation runtime card distributed to the EDU group of homes. A) Front of card where individual zones specific to a cooperator's irrigation zone application rate (measured during irrigation evaluation) was used to estimate a customized runtime. B) Back of card.

Figure 2-3. Aerial view of residential parcels with red polygons denoting irrigated area. Screen shot courtesy of http://www.gis.pinellas.org.

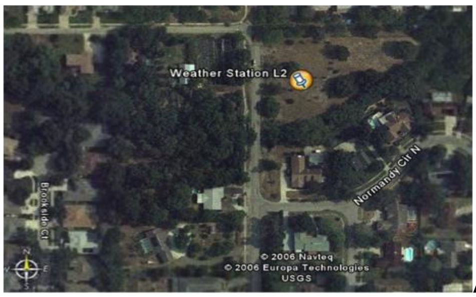
Figure 2-4. Example of Landscape level differences. A) Landscape level one. B) Landscape level two. C) Landscape level three. Photos courtesy of Melissa Baum Haley

Figure 2-5. 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 quantity and duration, (F) datalogger enclosure. Photo courtesy of Melissa Baum Haley.

A


B

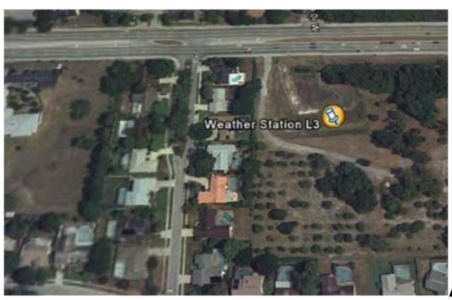
Figure 2-6. Weather station L1 location. A) Areal view; photo courtesy of USGS. B) Location photo; photo courtesy of Melissa Baum Haley.



A


B

Figure 2-7. Weather station L2 location. A) Areal view; photo courtesy of USGS. B) Location photo; photo courtesy of Melissa Baum Haley.



A


B

Figure 2-8. Weather station L3 location. A) Areal view; photo courtesy of USGS. B) Location photo; photo courtesy of Melissa Baum Haley.

A


B

Figure 2-9. Weather station L4 location. A) Areal view; photo courtesy of USGS. B) Location photo; photo courtesy of Melissa Baum Haley.

Figure 2-10. Turf quality examples. A) Above minimum acceptability with a 7 rating. B) Minimum acceptability with a 5 rating. C) Below minimum acceptability with a 2 rating. Photo courtesy of Melissa Baum Haley.

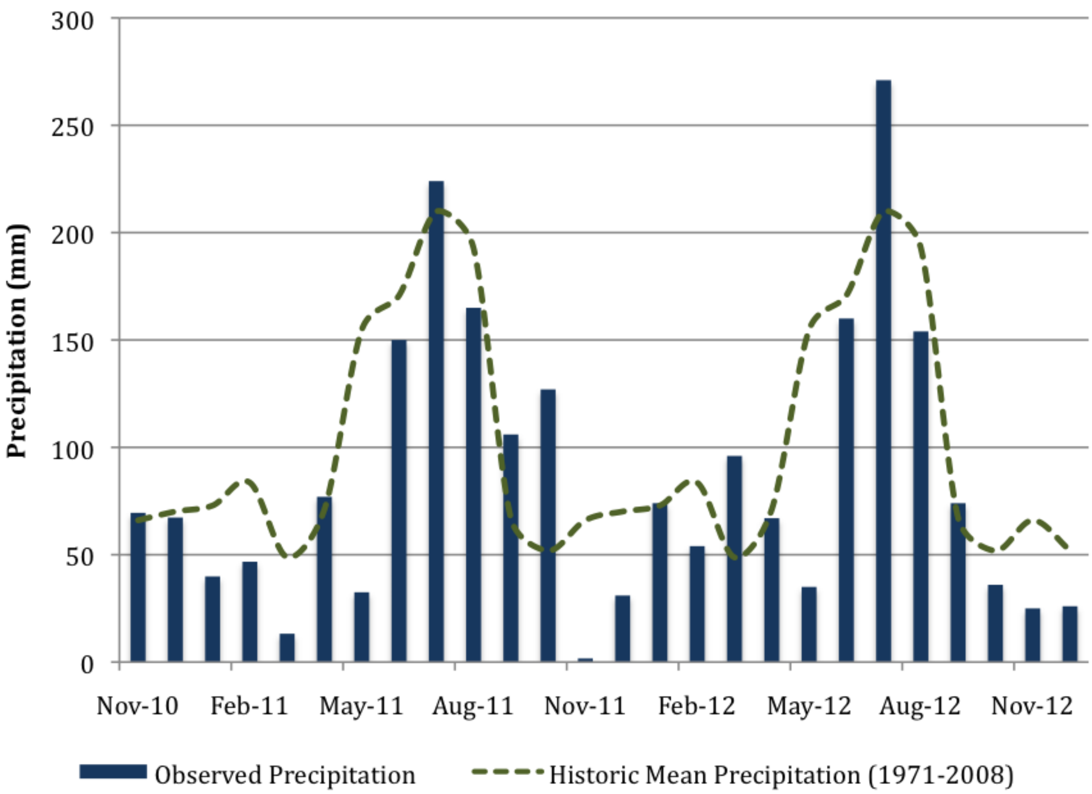


Figure 2-11. Observed monthly rainfall compared to historic rainfall (NCDC 2002) over the study period.

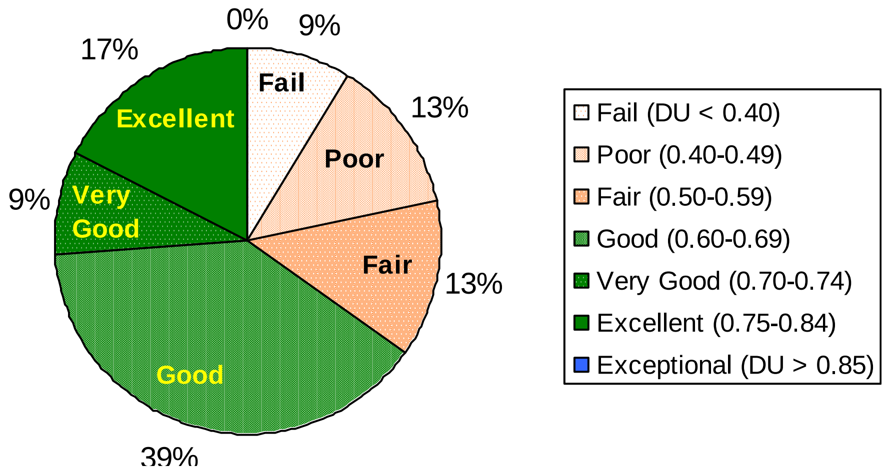


Figure 2-12. Results of irrigation system evaluation uniformity tests compared to Irrigation Association quality ratings (IA 2005).

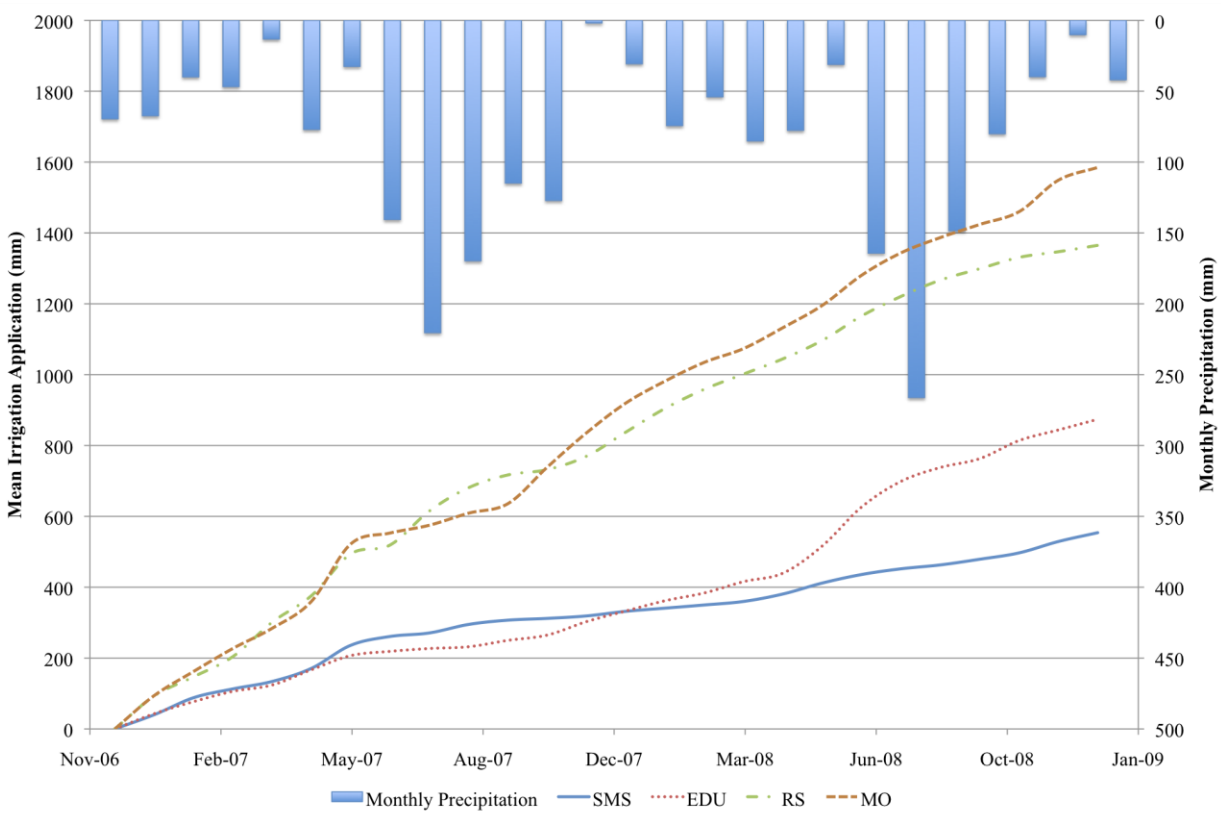


Figure 2-13. Cumulative mean irrigation application over the entire data collection period. Treatments are soil moisture sensor irrigation controller (SMS), seasonal irrigation runtime recommendations plus a rain sensor (EDU), a rain sensor (RS), and timer controlled irrigation system (MO).

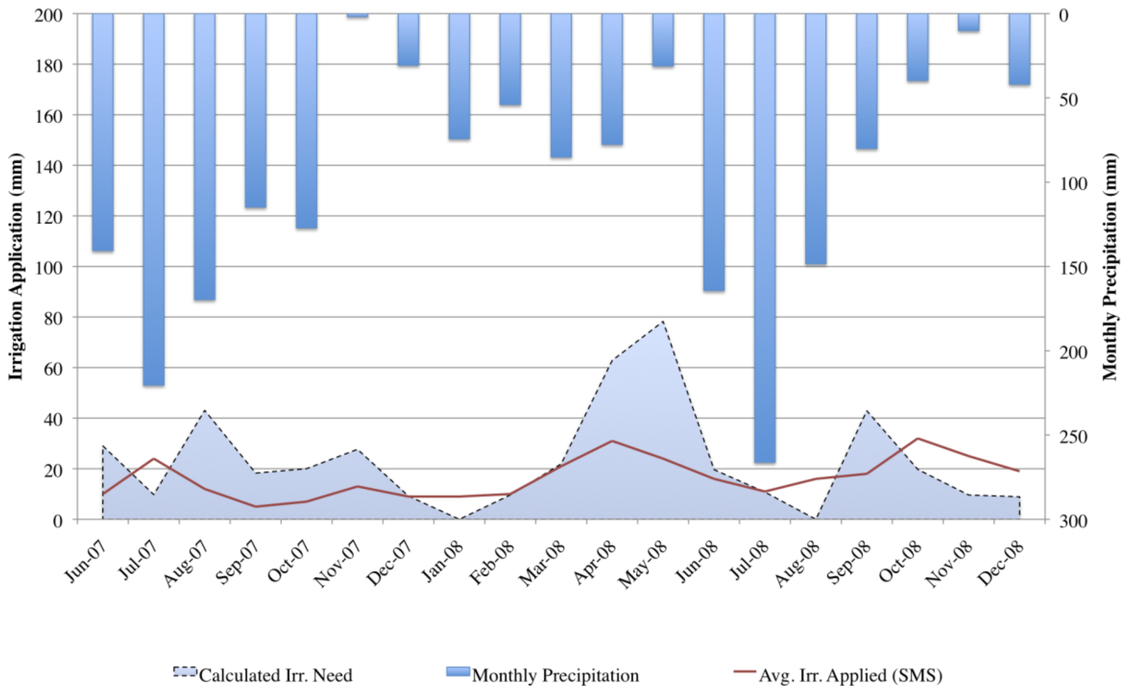


Figure 2-14. Monthly total irrigation application for soil moisture sensor (SMS) system treatment compared to calculated gross irrigation need based on a daily soil water balance model.

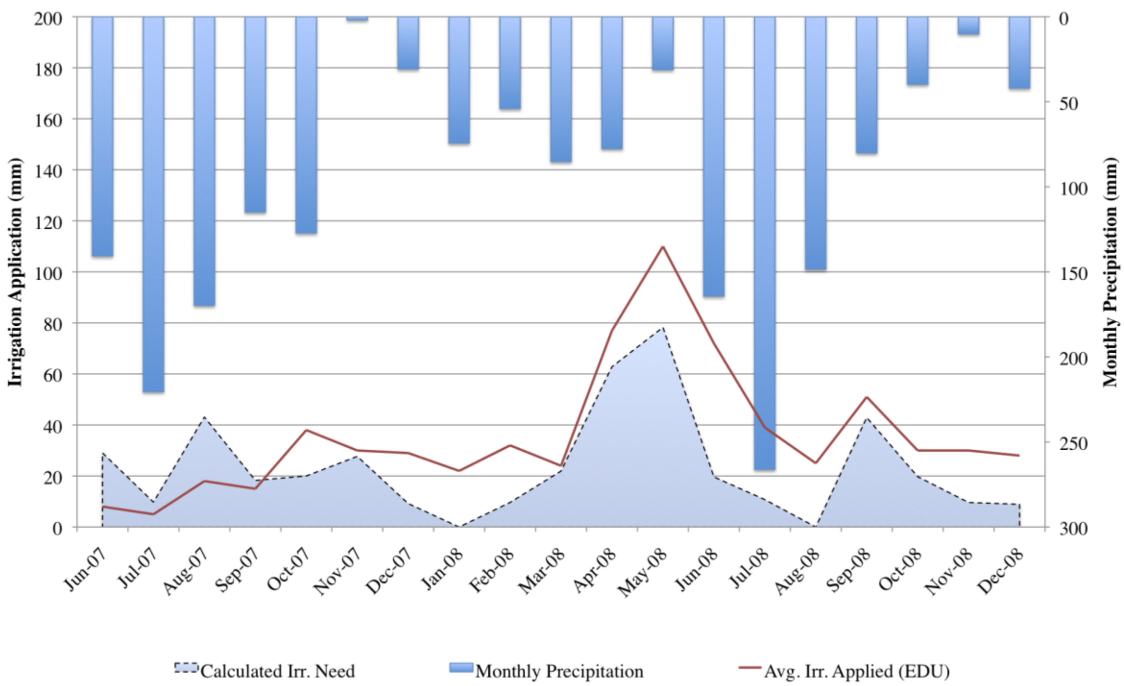


Figure 2-15. Monthly total irrigation application for educational materials (EDU) treatment compared to calculated gross irrigation need based on a daily soil water balance model.

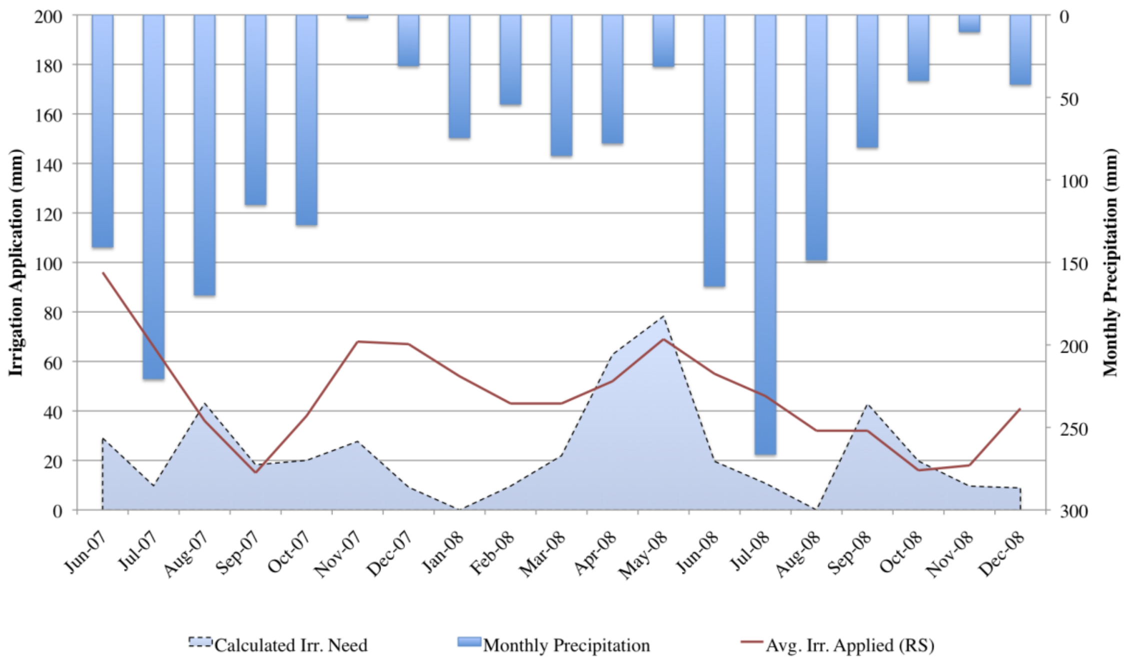


Figure 2-16. Monthly total irrigation application for rain sensor (RS) treatment compared to calculated gross irrigation need based on a daily soil water balance model.

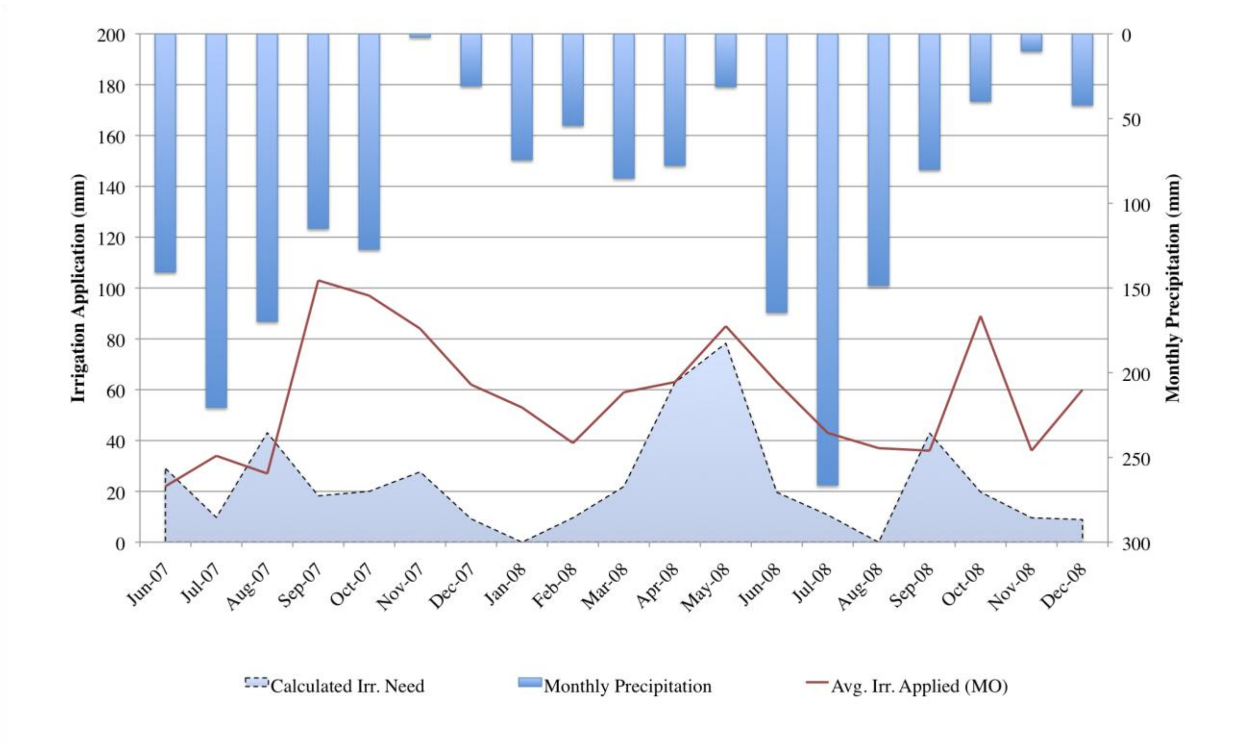


Figure 2-17. Monthly total irrigation application for meter only (MO) treatment compared to calculated gross irrigation need based on a daily soil water balance model.

CHAPTER 3
SURVEY OF IRRIGATION WATER USE PRACTICES AND COMMUNITY KNOWLEDGE

Background

The desire for a lush landscape often requires irrigation and fertilization. Further, many of Florida's residents are not well informed about proper application or the environmental impacts of over application of irrigation and fertilizer (Israel and Knox 2001). Research has shown that residential in-ground automatic irrigation systems can account for over 50% of the customer's total monthly water consumption and that some residential customers in Florida tend to over-irrigate (Haley et al. 2007). Research has also shown that of homeowners and lawn care providers that apply fertilizer applied it more frequently than recommended and did not follow the manufacturer's instructions (Israel et al. 1995).

While Water Management Districts (WMDs) have implemented allotted irrigation days and times, as well as the requirement of rain shut-off devices for newer systems (Florida Statutes, Chapter 373, Section 62), anecdotal evidence suggests that customers may not be following watering regulations and restrictions (Whitcomb 2005). It has also been seen that domestic irrigators do not understand plant water needs related to irrigation. Domestic irrigators rarely choose alternative, water conservative practices, because of the want for aesthetic desirability, which does not allow for lawn heterogeneity (Bormann et al. 1993), time, effort, and perceived expense for individual households (Templeton et al. 1998).

Water use efficiency has become a growing concern on both the local and national level. The water used for residential irrigation can be separated into three unique water categories: potable (drinking) water, domestic well water, and reclaimed water (RCW).

RCW as an irrigation source is a practical use for treated effluent, however this source requires available additional infrastructure. The most accessible water for the homeowner to use for outdoor purposes is the treated potable water line that already supplies water to the residential property. This is a costly source with water rates steadily increasing due to the considerable amount of energy it takes to treat and deliver this water. Depending on the aquifer composition, groundwater from an on-site well may lead to some savings in energy costs, but not a decrease in the depletion of reservoirs and groundwater aquifers. Water table reduction due to over pumping can lead to saltwater intrusion, higher concentrations of natural contaminants (e.g. radon and arsenic), and human pollutants (e.g. fertilizers and pesticides). Over irrigation can specifically contribute to nonpoint source pollution by increasing runoff that can contain pollutants from the suburban landscape.

Previous Work

Previous surveys within the Southwest Florida Water Management District (SWFWMD) have looked at homeowner concern relating to water cost (Whitcomb 2005) and participation in Cooperative Extension Service landscape programs (Israel and Hague 2002). Through previous residential irrigation cooperator studies, conducted by the University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) it was observed that the homeowners did not have a clear understanding of when and how much to irrigate (Haley et al. 2007) and that actual watering days do not necessarily follow local day of the week restrictions (Dukes and Haley 2009).

Residential irrigation research, in Florida, has indicated that the use of technology can decrease irrigation water use without causing plant/turfgrass stress or degradation of appearance (Cardenas-Lailhacar et al. 2010; Davis et al. 2009; Dukes and Haley

2009; Mayer et al. 2009; McCready et al. 2009). Anecdotally, is has been observed that there is reluctance on the part of the domestic irrigator to incorporate this new technology. One such device is an automatic rain shut-off sensor for irrigation systems. At the time of this research, a rain sensor or shut-off device was required for homes with automatic in-ground irrigation systems installed since 1991 (Florida Statutes, Chapter 373, Section 62). However, it is thought that rain sensor installation is not enforced or that these sensors are not maintained. Through the evaluation of water rates for single-family homes in Florida, it was found that 50% of homes with automatic in-ground irrigation systems within SWFWMD do not use rain sensors (Whitcomb 2005). However, from the irrigation evaluations conducted on the SWFWMD study homes in Chapter 2, only 6% of the study homes had pre-existing rain sensors (Dukes and Haley 2009).

There are two aspects that affect the functionality of the irrigation system: technology and user interaction. The technological components include: time clocks, weather-based controllers, soil moisture sensors, and rain sensors, which can electronically bypass unnecessary irrigation events or otherwise modify the irrigation schedule. Local WMD regulations have an influence on the use of bypass technology as well as the time and day settings for the automatic irrigation timer.

Research has been conducted proving the effectiveness of technology in reduction of outdoor (lawn and garden) water use. However, these studies have been primarily conducted in controlled settings. When attempting to incorporate the recommendations of the research into the residential arena savings are not as significant (Campbell et al. 2004; Geller et al. 1983). Controlled research studies, while resulting in peer-reviewed publications sound statistical analysis, may be not representative of the larger populations involved as irrigation customers of a utility. Therefore, the saving results may not be directly transferable (Dukes 2010).

Large scale pilot projects have begun to effectively encourage the use of “smart” timers by the domestic irrigator through rebate and give-a-way programs (Kennedy/Jenks Consultants 2008; Mayer et al. 2009; Hunt et al. 2001). As expected, realized water saving were considerably less than those reported in controlled studies. These demonstration projects compared water use before and after installation using accepted statistical practices However, with the non-controlled domestic irrigation studies, there is no assurance that the watering practices prior to installation of the devices are indicative of the general population (Dukes 2010).

In order to effectively change behavior, factors that contribute to perceived attitude must be considered. Baumann (1990) established three factors that affect the intensity of water use by residential users. The first two are economically derived; the consumer’s ability to pay for and the willingness to pay for water at a given price. The non-economic factor is the consumer’s conservation behavior. This reflects the motivation to employ effort or technological innovations for water conservation. Weather plays a major role in conservation practices as well. During periods of drought, consumers are more willing to employ conservation techniques than during wet years (Baumann 1990). According to the Florida Water Rates Evaluation of Single-Family Homes, completed in 2005, the main concern of homeowners with respect to increased costs is outdoor use (Whitcomb 2005).

Objectives

The objectives of this survey are to quantify the irrigation water use practices and level of community knowledge of water conservation technologies and policy through a mail out questionnaire. Analysis of the mail out questionnaire responses will aim to determine public awareness, if local and SWFWMD mandated watering restrictions are followed, and if not, why. It is hypothesized that factors motivating conservative watering practices include price, source, and watering restriction. Additionally, analysis of actual total water use data will provide evidence for impact due to property size and value.

Materials and Methods

In 2008, an irrigation conservation survey was mailed to residents in Pinellas County Florida. The survey utilized an instrument developed by UF-IFAS and incompliance with the University of Florida Institutional Review Board (UF-IRB) protocol and reviewed by the SWFWMD communications department. The household questionnaire instrument was used to survey knowledge and attitudes about irrigation water use practices and perceptions as they relate to irrigation conservation.

Target Area

The target area was within the Pinellas-Anclote River Basin within the SWFWMD. This area is located in the Southern Water Use Caution Area, meaning the expected water resources demand may be larger than the supply. According to the United States Census Bureau's 2006 estimates, Pinellas County has 924,413 residents, 52.4% female and 47.6% male with an average age of 43 years (USCB 2007). Between 1990 and 2000, the population in this WMD grew by over 640,000 residents, approximately 19%, and is projected to increase another 1.8 million by 2025. The 2000 population for

Pinellas County, the study area county, was 921,482 and is forecasted to be 1,078,600 by 2025, an increase of 17% (SWFWMD 2005).

The survey population includes a representative sample of homes that reflect this demographic data and which use both potable and alternative water sources (RCW and well water). At the time of data collection for this study, the rate for potable water from Pinellas County Utilities was $4.16 per 1,000 gal (3,780 L) and then in October 2008, the rate increased to $4.28 (PCU 2007b). RCW is billed as a flat rate for use.

Sample Design

In efforts to attain information and opinions from a cross-section of water customers, the survey sample population was divided among three outdoor water sources: potable, RCW, and well water. Address lists were developed from the PCU customer database of customers that had documented requests of: potable variance exemption (a subset of potable customers), RCW crossover inspection, or well installation rebates. Additionally households with participation in another UF-IFAS and SWFWMD sensor based irrigation water conservation study (Chapter 2) were included in the sample population.

Once the address lists were compiled, the sample was selected randomly. The systemic sampling approach was employed using Equation 3-1:

$$k = N / n \qquad \text{Equation 3-1}$$

Where, k is the sampling interval, N is the population size, and n is the sample size. Following this technique, every k^{th} customer was selected from the sampling frame.

Mail out Survey

Approximately 1,000 survey packets were mailed following the Multi-wave Method. All participants received the same cover letter, household questionnaire, and incentive option. The initial mail out package included a cover letter, questionnaire, and postage paid addressed return envelope. The survey packages were mailed in three waves and over a course of two months. Follow-up mailings were conducted on returned packages, meaning errors in initial address, to attempt to maintain a sufficient response rate.

Survey Instrument

The household questionnaire was compiled into a four page 6.5 in by 8.5 in bi-fold booklet (Appendix B). The questionnaire was divided into six sections:

1. “Outdoor watering practices”
2. “About your landscape”
3. “Watering habits”
4. “If you have an irrigation system”
5. “Attitudes and actions”
6. “Last bit” (demographics)

Many of the attitudinal questions were presented with Likert scale response options. The Likert scale asks the respondent to rate his/her agreement to statements based on an interval scale. In this questionnaire the scale ranged from “strongly agree” to “strongly disagree” in five even intervals with an additional “don’t know” option.

In addition to the direct questions, the participants were provided a boxed comment area. Each questionnaire was coded to respect the confidentiality of the respondent.

Survey Incentive

As an incentive to complete the questionnaire, all participants were offered either an indoor or outdoor water conservation kit. The indoor kit (Figure 3-1a) included shower and sink water saving faucets as well as aerating nozzles, leak detection tablets, and a hose nozzle. The outdoor kit (Figure 3-1b) included a Mini-click (Hunter Industries, San Marcos, CA) rain sensor and water saving hose nozzle. The kits also included appropriate literature to reinforce the importance of these devices. Both kits were valued at approximately $25.

Assumptions

It is assumed that the survey respondents will fill out the questionnaire honestly. Since some of the questions will be asking about excessive irrigation water use practices or practices not incompliance with local policy, participants may be reluctant to disclose truthful information. A limitation of this study is that typically homeowners with more water conservative practices have a greater interest in participating.

Socio-Economic Analysis

In addition to the survey instrument, actual water use data was obtained for 142 homes in the study area. All of these homes irrigate with water from the public supply. As part of the total sample, a number of the homes participating in the sensor technology irrigation conservation study (Chapter 2) were also included (n=56). 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 gathered from the Pinellas County property appraiser public records.

The non-participant homes (n=86) were neighboring homes to the participating homes from Chapter 2, possessing 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.

Actual water use data analysis

Monthly total water use data, for the potable source homes, was obtained from Tampa Bay Water for a period of 5 years for each residence. The data provided was total monthly household consumption by volume, where both indoor and outdoor use was combined. Irrigation use in units of depth was estimated based on the volume of monthly outdoor water use divided by the estimated irrigated area.

To calculate the monthly outdoor water use, the winter (December, January, and February) water use was analyzed for each parcel to determine the winter minimum usage. For the five years of utility data obtained, winter average, low quartile (lowest 25%), and minimum use were compared. Initially, the minimum winter water use was assumed to be only indoor use; therefore, any use greater than the winter minimum was assumed to be outdoor use. If a monthly use was less than the winter minimum, the outdoor use was estimated as zero for that month. The homes participating in the sensor based irrigation study have sub-meters for their irrigation water use, which were used to verify the winter minimum method. Further analysis on the comparison of these data separation methodologies is discussed in Chapter 5.

Property information

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 (which denotes property value), the property size, total gross living area (i.e. gross structural footprint), and residential extras (e.g. pool, enclosure, patio, shed, etc.).

The irrigated area was determined using this available property information. The irrigated area was calculated by subtracting the gross structural area and residential extras from the property size. From the Pinellas County public geographic information system (GIS) records (www.gis.pinellas.org), the residential parcels are outlined and an aerial layer from Jan/Feb 2006 was overlaid (Figure 3-2). Using the GIS layers, the irrigated areas were outlined with a polygon tool to determine the estimated irrigated area. Actual irrigation area from site visits to homes participating in the irrigation sensor study (Chapter 2) was 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.

Variables of Interest

This survey specifically targets lawn (turfgrass) and landscape (bedded areas) watering practices, knowledge of water conservation ordinances, motives for water conservation/overuse, and perception of community water conservation/overuse. Water conservation ordinances include watering days and percentage of allowable turfgrass. To investigate technological advances, such as the inclusion of a functioning rain shut-off device (e.g. rain sensor, soil moisture sensor, weather-based controller with rain bypass switch), it is assumed that an automatic time-based controller is part of the irrigation system. Socio-demographic variables include income, lot size, education, swimming pool, homeownership, level of water conservation technology, and automation of irrigation system. Latent attitudinal variables will be lifestyle, recreation, landscape interest, conservation attitude, and social desirability towards conservation. The independent variables include irrigation system type, outdoor water source, home ownership and economic profile.

Indexes were developed statistically based on eigenvalue criteria. Indexes serve as a means to group strongly related questions together resulting in a numeric score than can be used for statistical analysis. Three indexes were developed from Likert scale attitudinal questions relating to conservation attitude, conservation knowledge, and personal lawn/landscape interaction.

Questions used in index of conservation attitude:

- When watering with reclaimed water, outdoor water use conservation is not necessary.
- When watering with well water, outdoor water use conservation is not necessary.
- We are all responsible for water conservation in out community.

Questions used in index of conservation knowledge:

- I am not aware of watering restrictions in my area.
- I am aware of lawn appearance requirements in my neighborhood.
- New irrigation systems are required to have shut-off devices.

Questions used in index of personal lawn/landscape interaction:

- I spend a lot of time outside in my lawn/landscape.
- I am very concerned about the appearance of my yard.
- I am familiar with seasonal water needs of my lawn/landscape plants.

Statistical Analysis

Data analysis was performed using SAS software (SAS 2004). Univariate data analysis was used to describe the data set sample with mean, standard deviations, and percentages. The level of measurement was reported as frequency statistics from the survey responses. The bivariate analysis was used for the evaluation of the independent variables and the hypothesis testing between the independent and dependant variables.

Positive and negative correlations were based on Pearson’s correlation coefficient. The multivariate analysis enables assessment of the direct and indirect effects for related variables. An analysis of variance was used to determine main effect differences through general linear model and means comparisons were performed with Duncan’s Multiple Range Test at a 95% confidence level.

The socio-economic data, presented a normal distribution. For this data, statistical analyses were performed using the frequency, Pearson’s correlation, univariate, and general linear model 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.

Results

Response Rates

In three mailing waves, a total of 1090 PCU customers were sent survey packages; 396 potable, 282 well, and 412 RCW (Table 3-1). Of the potable users, 45 respondents were also part of a concurrent irrigation technology study (Chapter 2). The target response rate was at least 384 customers. So long as the response rate was greater than 267, additional mailings were not required. The final response rate was 25%, yielding 272 completed and usable questionnaires, evenly distributed amongst the three water sources.

Survey Incentive

As an incentive to complete the questionnaire, the all participants were offered either an indoor or outdoor water conservation kit (Figure 3-1). Although the incentive was available to every respondent, only 13% requested the kits (Table 3-2).

Demographic Characteristics

The demographic characteristics of the respondents are summarized below. Appendix B provides the exact wording for the demographic questions.

Housing and residency

All 100% of the respondents reside in single-family homes. Additionally, 99% of the respondents own their home. Only 1% of the respondents rent their home. However, 5% of households did not reply to this question. The average length of residence in the current house of the respondents is 13 yrs, with residence times ranging from 0 to 60 yrs.

Eighty percent of the respondents maintain Florida as their primary state of residence, inhabiting the household in question for 9 months or more during the year. Of the respondents that maintain dual residency during the year, 8% live in Florida from 3 months to 9 months of the year, and 12% have their primary residence out of the state, occupying the home for less than 3 months of the year. Seventy-eight percent of the respondents have lived in Florida for more than a decade, with the average length of time residing in the state being 26 yrs.

Demographics

The average age of the respondents at the time of the survey dissemination was 60 yrs. The ages of respondents ranged from 23 to 89 yrs. Twenty-seven respondents did not disclose their age. According to the 2000 U.S. census, the average age for the study area was 43 yrs (USCB 2007).

Sixty-nine percent of the households had from 1 to 4 members within the age range of 21 to 65 yrs. Thirty-seven percent had from 1 to 3 household residents over the age of 66. Of the overall 26% of households that included children, which concurs with the census data for the study area (USCB 2010), 10% had children under the age of 10 yrs and 16% were homes where teenagers were present with ages ranging from 11 to 20 yrs.

The majority of the respondents were college educated, with 64% having completed college or beyond. Of the 81% of respondents who provided household income information, the income ranges were as follows:

- Under $30,000 (7%)
- $30,000 to $49,999 (15%)
- $50,000 to $74,999 (19%)
- $75,000 to $149,999 (39%)
- Over $150,000 (20%)

According to the 2000 U.S. census, the median property value was $124,700 (USCB 2007).

Watering Practices and Irrigation Systems

Watering practices

All together, 91% of the respondents water their lawn/landscape utilizing an automatic irrigation system; which can be broken down to 74% who set to system to run automatically, and 16% who use the system manually. Five percent use a sprinkler head attached to a hose, 3% use a watering can, and 1% responded that no supplemental water is applied to their lawn/landscape.

Of the respondents who irrigate, 84% control the watering practices themselves and in 9% of the households, another household member is in charge of the watering practices. Only 3% of the households relied on a lawn care service provider or irrigation maintenance professional.

Water source

The respondents were evenly distributed amongst water source, with 32% using potable water, 35% using RCW, and 33% as well water users, (Table 3-3). However, given the choice, 64% would rather irrigate with RCW. The want for RCW was almost exclusively from current potable users. Of the potable source respondents, 65% would prefer the opportunity to use RCW and 30% would prefer well water.

Irrigation frequency

PCU customers are supposed to comply with the SWFWMD and more stringent local watering restrictions. According to Pinellas County Code 82-1, homes using county water or wells, lakes, and ponds are allocated one day of irrigation a week for established lawns and landscaping. Irrigation using RCW is on a voluntary schedule (Resolution No. 01-329) permitting up to 4 days of irrigation per week. The mean response for homes receiving RCW was 3.1 times per week.

Table 3-3 presents the irrigation frequency responses. It must be noted that these irrigation frequencies are self-reported. Of the potable users, 75% irrigate once per week, however 12% admit to irrigating beyond the permitted irrigation allowance (including daily). Although 75% of the well water users also reported one irrigation event per week, in this group 24% admitted to irrigating beyond the ordinance allowance.

According to an irrigation requirement simulation determined by the soil water balance in Chapter 2, on average 4 events per month are needed. However, when looking at the average number of events needed each month, based on this soil water balance, the turfgrass may actual require from 2 to 7 events per month. Although on average the study homes appeared to irrigate appropriately according to location watering day restrictions, when considering the range of irrigation event that occurred during a given month, vast over irrigation occurred.

An important step in outdoor water use conservation is proper irrigation scheduling. Most domestic irrigators are not familiar with this term, so the participants were asked a number of questions about their watering habits, presented in Table 3-4. Although 55% reported to adjusting their time clocks seasonally, 31% marked that they did not adjust the time clock throughout the year. Additionally, over half of the respondents schedule irrigation for turfgrass and landscape planting for the same lengths of time regardless of equipment type. This suggests a misunderstanding of irrigation scheduling and plant-water needs.

Based on plant water requirements, landscape and turfgrass should be irrigated differently. However, if a site has mostly one type of irrigated area (predominately turfgrass vs. landscape) it might not make sense to have different watering practices. This would be evident if there was a correlation between responding “no” to watering the lawn and landscape for different lengths of time. However, upon closer observation of the data, there was not a correlation between the type or size of irrigated area and the watering practices of the irrigated area.

The average length of time set for a turfgrass zone during each irrigation cycle was reported as 69 min. The distribution of run time settings of the respondents can be seen in Figure 3-3. UF-IFAS recommendations for irrigation run times were developed for twice weekly irrigation and vary depending on month of year and equipment type. According to these recommendations, for the target area, during the months April through November, turfgrass zones irrigated by gear driven rotary sprinklers should be set for an average of 57 min (ranging from 38 to 75 min depending on month) and fixed spray heads should be set for an average of 19 min (ranging from 13 to 25 min) per irrigation cycle (Dukes and Haman 2002). The run time recommendations given to the sensor study group were developed based on these UF-IFAS recommendations, and tailored to the specific system of each participating home. For 1-day per week irrigation scheduling the rule of thumb is to increase the 2-day per week single cycle run time by 30%.

Landscape characteristics

A series of questions were asked to describe landscape characteristics of the property. A small diagram was provided for the respondent to illustrate the meaning of "lot", "turfgrass", and landscape bed". Table 3-5 details the responses to each of these questions. According to the respondent data, the percentage of the lot that is green space and percentage of the green space that is turfgrass are both normally distributed. More than fifty percent of the respondents utilize a lawn maintenance service.

Irrigation system characteristics

A series of questions were developed to describe the irrigation system (Table 3-6). Of the respondents reporting systems with rain-shut-off devices, the questionnaire included three device type options: rain sensor, soil moisture sensor, and weather-based controller with a rain bypass switch. The only rain shut-off device reported was a rain sensor, corresponding to all 36% of the responses. It is however known that at least 4% of the respondents have soil moisture sensors connected to their system. Additionally, 12% of the respondents didn't know if they had such a device. Therefore the term "rain shut-off" may not be understood to include devices other than rain sensors that automatically bypass irrigation events.

Ninety one percent of the homes report having irrigation timers, and the time clocks were considered to be easily accessible. The primary locations for irrigation time clocks were “in the garage”, which was reported by 72%, and “on an exterior wall of the house”, which 15% of the participants checked. Further, the numbers of zones reported by the participants ranged from 5 to 8 (53%).

Additionally the survey respondents reported on the sprinkler equipment used on at the site, where 58% had mixed zones where there was a combination of both pop-up spray and rotor heads irrigating on the same zone at the same time. This concurred with the observation of equipment during the irrigation evaluations conducted as part of the study presented in Chapter 2 (Dukes and Haley 2009). Lastly, 19% of the sites reported having some sort of low volume irrigation equipment.

Attitudes and Actions

Attitudes regarding watering practices

Overall water price was not the primary motivator for irrigation practices, contrary to the initial hypothesis based on the literature. Cost only became a contributing factor for the potable users, likely due to the volumetric usage pricing associated with this source. The other two sources have either flat rates in the case of RCW or no usage charge with well water. For this sample population, 75% reported water source to be the most influential factor regarding watering practices for either conservative or excessive use.

Of the respondents with irrigation systems, 77% did not consider their personal irrigation practices to be water conserving. Additionally, the poor functionality of their own irrigation system did not diminish their desire to use the system. This was determined by asking the respondent directly “Because my irrigation system functions poorly, I don’t irrigate.”

The respondents did however, express room for improvement, with 66% aware of the availability of local conservation programs, 53% trusting the reliability of a rain sensor, and 68% expressing interest in installing more advanced technology such as a soil moisture sensor. Further, 75% understand the importance of a rain shut-off device, finding them very important for water conservation.

Eighty-seven percent of the participants are aware of watering restrictions in their area. Concurrently, 57% often observe their neighbors over-irrigating.

With regards to irrigation scheduling, although 5% stated no understanding of plant water needs at all, 77% did report familiarity with seasonal water needs of their lawn and landscape plants. Further, 70% reported that they decrease their irrigation in the winter months.

Attitudes regarding landscapes

The participants were asked to rank statements which best describe their attitude toward their present landscape, the top three results were, in order of priority:

- I am reasonably content with my present landscape and am not considering any changes.
- I would like to learn more about landscape water use before deciding what, if any, actions to take.
- I would like to consider changes but don’t have the money.

The results showed no trend in reaction to the water needs of native plants. Inferring that the respondents were unaware of the drought-tolerant traits of native plants as compared to non-native plants. When looking at the correlation of the Likert scale questions, the responses were evenly distributed across the Likert scale.

Seventy-seven percent reported that the neighborhood or association has lawn appearance requirements and 92% of the respondents are very concerned personally about the appearance of their yard. Further, the respondents did not have a negative impression of the appearance of native plants in the landscape beds.

Attitudes regarding conservation

Only 25% of the respondents have previously participated in an outdoor water use conservation program. While 90% reported having appliances or devices that are intended for water savings inside the home, while a mere 3% reported having water saving devices outside the home, and 7% reported having no water saving devices at all. Similarly, 92% reported having appliances or devices intended for energy savings versus the 8% that reported having no such devices, but 91% of the respondents were aware of the interaction between water use and energy use.

Seventy-eight percent feel that their personal conservation practices affect the overall water supply, and 98% reported that everyone is responsible for water conservation jointly within the community. However, when asked directly, the respondents did not state that environmental concern had any effect on irrigation practices. This resulted in a disconnect between reported attitude and behavior, suggesting a socially desirable bias.

As previously stated, 75% responded that water source affected their watering practices. Further, 70% reported that when watering with RCW, outdoor water conservation is not necessary; and 86% reported that conservation is not necessary when using well water. Finally, the participants were asked to rate their opinion of the effectiveness of water conservation ordinances, practices, and programs. The results are illustrated in Figure 3-4. The participants rated rain shut-off devises as the most effective conservation method, followed by the use of native plants and watering restrictions.

Index development

The index for conservation knowledge was correlated with education level ($r = 0.60$, $p = 0.01$). There was also a moderate correlation ($r = -0.42$, $p = 0.02$) between the conservation knowledge index and the statement that the “homeowner would like to consider changes but [does not] have the money.” The strongest correlation ($r = -0.87$, $p < 0.01$) existed between the conservation attitudinal index and the statement that the homeowner would “prefer more lawn (turfgrass) and would like to increase the lawn area of [their] yard.” This means that a higher conservation attitude score by the respondent would be associated with the understanding that a larger turfgrass yards may require more water. Further, there were only weak correlations between the personal lawn/landscape interaction and the attitudinal preferences about the present landscape and the desire to make changes.

Socio-Economic Analysis

Estimated irrigation water use (potable water source only) was analyzed considering socio-economic parameters, primarily focusing on property value and size.

Property information

The GIS aerial images proved to be more accurate estimations of actual irrigated areas than the property appraisal data (Figure 3-5). To determine the accuracy of the GIS measurement method, the true irrigated area was measured on-site at homes in the participant group from Chapter 2. The GIS aerial areas yielded an average error within 5%, with no over or under-estimation greater than 10%. Although 35% of the irrigated areas calculated from the parcel information were also within 5% of the GIS aerial estimated areas, the error ranged from 49% under-estimation to 180% over-estimation. 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. Additionally, the property appraisal information rarely includes 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, were there are obviously non-irrigated areas. The parcel lines can also cause discrepancy; within GIS the boundaries do not always coincide with the actual parcel size, sometimes including lakes or natural areas adjacent to the property. Possible irrigated areas beyond the total property size and 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 aerial estimated irrigated calculations.

Actual water use

Irrigation use (depth) was estimated based on the monthly volume of water used outside normalized for the aerial estimated irrigated area. For the five years of utility data obtained, winter average, low quartile (lowest 25%), and minimum use were compared to the actual irrigation water use from the participating homes that had sub-meters for irrigation water consumption. The average actual monthly average use for the time period was 51 mm/month (25 m^3/month). Using the average winter use, the monthly average consumption resulted in 23 mm/month, a 54% error. The low quartile outcome was 38 mm/month, which is a 25% difference form the actual value. The minimum winter water use over the billing period resulted in 56 mm/month average use which was the lowest error at 9%.

Irrigation water use analysis

From the correlation analysis, 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 ($r = 0.85$, $p < 0.0001$) and a (log) negative correlation between irrigated area and water application depth ($r = -0.89$, $p < 0.0001$); note Figures 3-6 and 3-7 respectively. This trend is most evident when looking at the homes without pools (Table 3-7). There was a significant difference ($p < 0.001$) between the water use in homes with and without a pool.

The homes with pools used on average 25 mm more water per month, which concurs with the literature (Mayer et al. 1999). Upon further investigation, the presence of a pool can be considered a conditional relationship, where the impact is greater for one group than for another when other factors are included. This could be caused by a combination of two factors. First, the pool may consume a notable fraction of the average monthly consumption, and the monthly use should be offset accordingly. Additionally, external factors may need to be considered. For example, people who reside in homes with pools may tend to spend more time outdoors, consequently having a stronger motivation for increased landscape aesthetics.

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 3-7). The interaction of a having pool can also be seen here, nearly all homes valued above $500,000 have a pool. The positive correlation ($r = 0.85$, $p < 0.0001$) between property value and irrigation application depth suggests socioeconomic level affects conservation behavior (Figure 3-6), likely because cost is less of a primary motivation. It should be noted that an low outlier within the $700,000 to $900,000 property value range was removed. From the analysis of property value and outdoor water application, it can also be observed that the homes ranging from $900,000 to $1,500,000 used the most water for outdoor use ($p < 0.0001$). This trend concurs with the literature, suggesting that sensitivity to water cost results in reduction of use (Whitcomb 2005). For homes participating in the PCU study (Chapter 2) the trend between increased water applications with increased property value is less apparent as the water use for the sites with the property value ranging from $100,000 to $700,000 are all the same statistically (Table 3-8).

Conversely, the smaller the irrigated area, the more water was applied (Figure 3-7). It is also interesting to note that the homes with smaller irrigated areas all have property values ranging from $100,000 to $500,000. The increase in negative correlation ($r = -0.76$, $p < 0.0001$) 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 outdoor 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 or felt as an excessive economic stress.

Of the 142 homes included in this analysis, 56 were also part of an irrigation conservation study since 2006 (homes from Chapter 2). In Table 3-8, it can be observed that the homes associated with the Chapter 2 study applied more irrigation on average, 60 mm per month, versus 51 mm per month for the non-participant group ($p<0.001$). The increased outdoor 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. However, since the commencement of that study there was a significant ($p<0.001$) reduction, from 64 to 53 mm per month of average outdoor water application for participating homes due to treatment effects in that study.

Discussion

This chapter presents the analysis of the irrigation water use practices and perceptions survey, distributed summer 2008. A significant result observed was the misunderstanding of terminology of bypass devices. When asked about rain shut-off devices, 36% respondents reported having a rain shut-off device. All of these were reported to be rain sensors. However, it was known, from actual observation that at least 4% of the respondents have functioning soil moisture sensors attached to their system. This concurs with the notion that the term “rain shut-off” is confusing to domestic irrigators. Further, Florida Statute, Chapter 373, Section 62, which required irrigation systems to have “rain sensor devices”, proved to be even more misleading. Since then, the wording of Florida Statute, Chapter 373, Section 62 has changes due to Senate Bill 494, to more clearly define the meaning of sensors and the specific inclusion on soil moisture sensors.

The two questions with the highest rate of response for the answer option “don’t know”, were 1) the presence of a rain sensor and 2) irrigation schedule. These questions resulted in proportion of 12% and 13% “don’t know” responses, which disproportionally higher than that response for any other question.

The significant difference between water source and how often the respondent admits to watering their lawn/landscapes agrees with the watering day restrictions within Pinellas County. However, it should be noted that although the potable respondents reported once per week irrigation, previous research in the target area has observed greater irrigation frequencies for some potable users. This is evidence of bias within the survey data.

There were also significant differences observed between the number of irrigation events per week and automation of the system. Homes that allow the rain shut-off device to bypass irrigation following rain events reported less weekly irrigation events occurring. A homeowner may attempt to be more conservative by manually operating the time clock schedule in response to rainy weather; however, these homes also seem to have their timers set to higher frequencies. Additionally, homes without irrigation time clocks reported less frequent irrigation than those homes with automatic systems, this concurs with previous findings about residential end use by the American Water Works Association (Mayer et al. 1999).

The average length of time set per irrigation cycle for a single turfgrass zone was 69 min, and ranged from 20 to 120 minutes. Based on the application rates of standard pop-up spray heads a runtime of approximately 25 min in the spring/summer months is sufficient for the plants needs. Therefore, turfgrass zones that include spray heads are significantly over irrigated with the reported average runtimes.

A higher water use knowledge level was positively correlated with the educational level of the respondent. Furthermore, an increased knowledge index score was correlated with the attitudinal factor of money affecting the desire to change the landscape. Thus, homeowners are aware of the expected costs for changes to the lawn/landscape when adding or removing turfgrass or conservation technology devices. These concepts where investigated further in Chapter 5.

Interestingly, an increased conservation attitude was positively correlated with increased turfgrass area. What this result could imply regarding the homeowners' attitude toward alternative water sources is that they do not require irrigation conservation practices, and in turn provide the additional water needed for an increased turfgrass lawn area.

There were no obvious correlations between the personal lawn/landscape interaction, which is the index that attempts to quantify the level of time spent in the lawn/landscape, and any of the attitudinal choices about the present landscape, which express the homeowner's satisfaction or desire to make changes. It would have been expected for this index to have a more defined opinion clearly observable.

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 based on the actual water use analysis in this study were economic level, displayed in the form of property value, and irrigated area. The property value analysis showed that the highest value range ($900,000-$1,500,000) used the most water even when normalized for irrigated area. Overall there was a trend of increased water application with increased property value. Conversely, the smaller the irrigated area, the more water was applied. 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.

The ultimate goal of this research is to determine a means to promote knowledge of water conservation related to residential irrigation by understanding why people over irrigate. To best determine the avenues to promote behavioral change leading to measured water conservation in landscape irrigation the following significant barriers and benefits were identified. The misunderstanding of plant water needs and seasonal scheduling relates to watering practices. Confusion related to terminology in reference to rain shut-off device could impact the effectiveness of legislature requiring such devices, further there is concern relating to the perception of rain shut-off device reliability. Additional factors that influence perception of watering behavior include the influence of water source, property value, or property size. However, there is expressed room for improvement and interest in learning.

Table 3-1. Response rate of mail out questionnaire

	Mail out total (n)	Response rate (n)	(%)
Overall	1090	272	25
Potable	396	87	32
Reclaimed	282	94	35
Well	412	91	33

Table 3-2. Distribution of requested incentive packages

	Mail out total	Response rate (n)	
	(n)	Outdoor kit	Indoor kit
Overall	34	20	14
Potable	14	7	7
Reclaimed	15	12	3
Well	5	1	4

Table 3-3. Distribution of reported irrigation frequency

	Overall %	Potable %	Reclaimed %	Well %
Never/rarely	5	12	3	1
Once per week	56	75	16	75
Twice per week	27	10	46	23
Three to four times per week	13	1	34	1
Nearly every day	1	1	1	0

Table 3-4. Distribution of reported irrigation scheduling practices

Characteristic	Response option	Distribution (%)
Do you adjust your watering schedule during the year?		
	Monthly	14%
	Seasonally	55%
	Not really	31%
Do you water your lawn (turfgrass) and landscape (bedded area) for different lengths of time?		
	Yes	44%
	No	53%
	Don’t know	3%

Table 3-5. Distribution of reported landscape characteristics

Characteristic	Response option	Distribution (%)
Percentage of lot that is lawn/landscape		
	0-25%	10%
	26-50%	38%
	51-75%	36%
	Over 75%	16%
Percentage of landscape that is turfgrass		
	0-25%	21%
	26-50%	37%
	51-75%	31%
	Over 75%	11%
Has a lawn maintenance service		
	Yes	52%
	No	11%
Has additional water features on property		
	Yes	64%
	If yes, Swimming pool	46%
	No	36%

Table 3-6. Distribution of reported irrigation system characteristics

Characteristic	Response option	Distribution (%)
Has mixed zones (spray and rotor)		
	Yes	58%
	No	38%
	Don't Know	5%
Number of zones		
	0-4	37%
	5-8	53%
	9 or more	6%
	Don't know	4%
Use of low volume irrigation		
	Yes	19%
	If yes, Micro-irrigation	38%
	If yes, Drip tubing	40%
	If yes, Bubblers	21%
	No	66%
	Don't Know	7%
Use of rain shut-off device		
	Yes	36%
	If yes, connected and functioning	66%
	If yes, not connected or functioning	21%
	If yes, don't know	12%
	Turns off system manually	31%
	No	21%
	Don't Know	12%

Table 3-7. Average outdoor water application depth per month for homes with and without pools for the time period of 2002-2007.

Category		Overall Use$_{avg}$ (mm)	Overall No. of homes	With Pool Use$_{avg}$ (mm)	With Pool No. of homes	Without Pool Use$_{avg}$ (mm)	Without Pool No. of homes
Property Value Range	\$100K - \$300K	45 d[Z]	66	58 c	32	33 b	34
	\$300K - \$500K	57 c	54	61 c	43	41 a	11
	\$500K - \$700K	62 c	7	62 c	7	-	0
	\$700K - \$900K	86 b	8	85 b	7	-	1
	\$900K - \$1.5M	102 a	7	102 a	6	-	1
Aerial Est. Irrigated Area Range (m^2)	90 – 280	93 a	7	108 a	5	59 a	2
	280 – 465	59 b	31	72 b	19	41 b	12
	465 – 650	48 c	60	56 c	38	34 bc	22
	650 - 850	50 c	31	61 c	21	27 c	10
	> 850	53 c	13	58 c	12	8d	1
Average		54	40	63[Y]		35[Y]	
Total			142		95		47

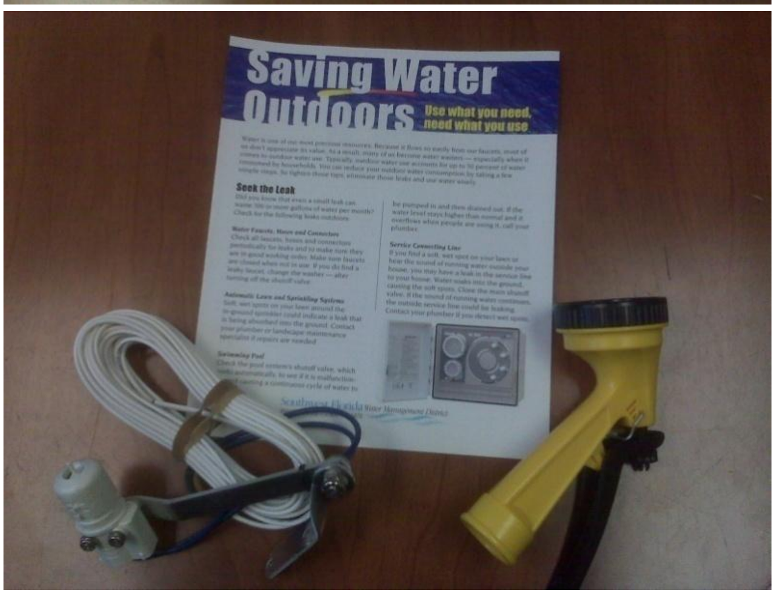
[Z] Numbers followed by different letters, within each column, are statistically different at the 95% confidence level.
[Y] Means comparison between homes with and without pools shows these averages to be significantly different.

Table 3-8. Average outdoor water application depth per month for PCU study participants and non-participants for the time period of 2002-2007.

Category		PCU study Participants Actual Use$_{avg}$ (mm)	PCU study Participants No.	Non-participant comparison Estimated Use$_{avg}$ (mm)	Non-participant comparison No.
Property Value Range	\$100K - \$300K	54c[Z]	25	38 d	41
	\$300K - \$500K	55c	21	58 c	33
	\$500K - \$700K	56c	4	69 b	3
	\$700K - \$900K	86b	3	86 a	5
	\$900K - \$1.5M	119a	3	86 a	4
Aerial Est. Irrigated Area Range (m^2)	90 – 280	143a	3	50 b	4
	280 – 465	56b	13	62 a	18
	465 – 650	51b	22	45 b	38
	650 - 850	56b	10	47 b	21
	> 850	58b	8	34 c	5
Average		60[Y]		51[Y]	
Total			56		86

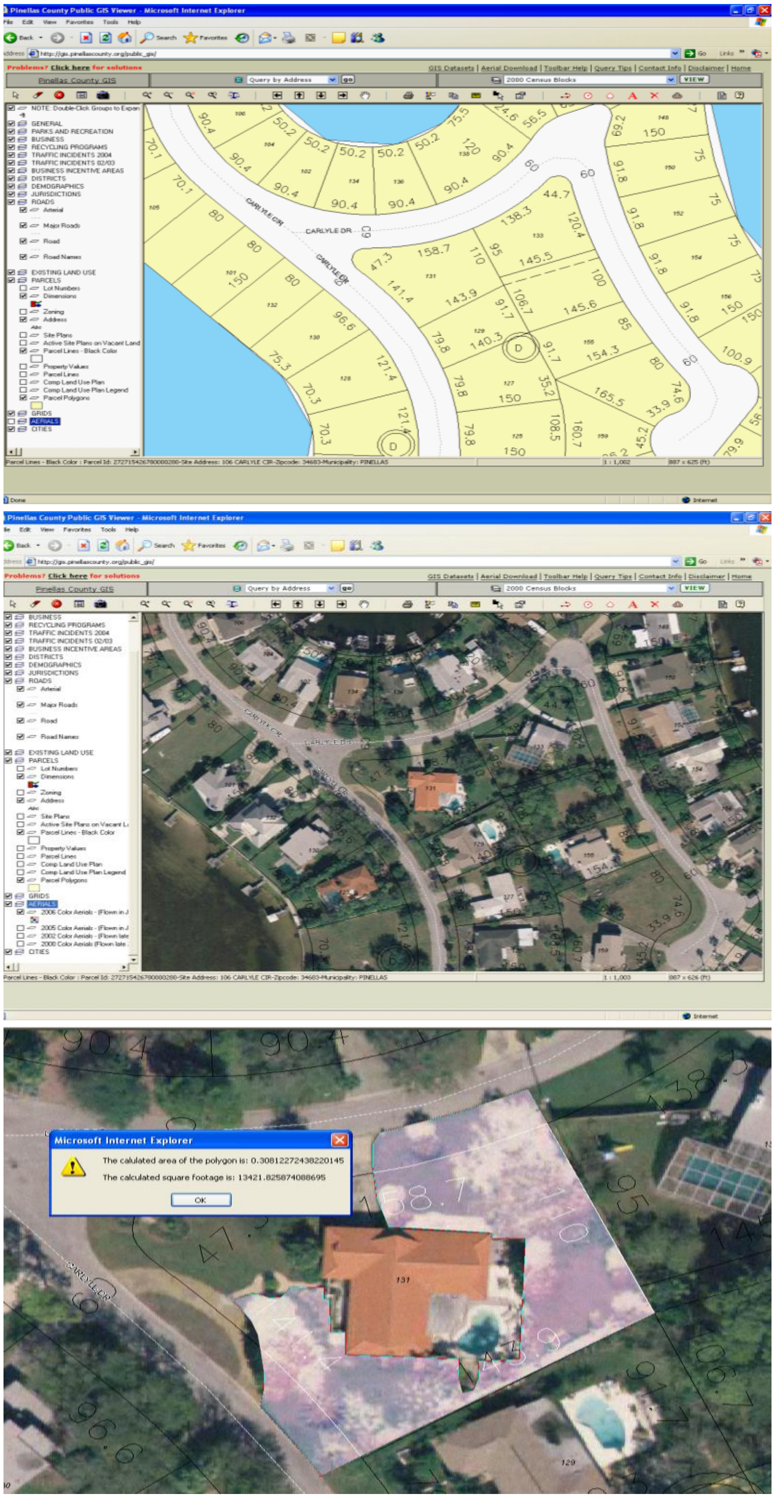
[Z] Numbers followed by different letters, within each column, are statistically different at the 95% confidence level.
[Y] Means comparison between PCU study participant and non-participant homes shows these averages to be significantly different.

A



B

Figure 3-1. Survey incentive kit options. A) Indoor water conservation kit components. B) Outdoor water conservation kit components. Photo courtesy of Melissa Baum Haley.



A
B
C

Figure 3-2. Property information data collected from Pinellas County public GIS server. A) Parcel map. B) Parcel map with areal imagery overlay. C) Calculated area using polygon tool. Screen shots courtesy of http://www.gis.pinellas.org.

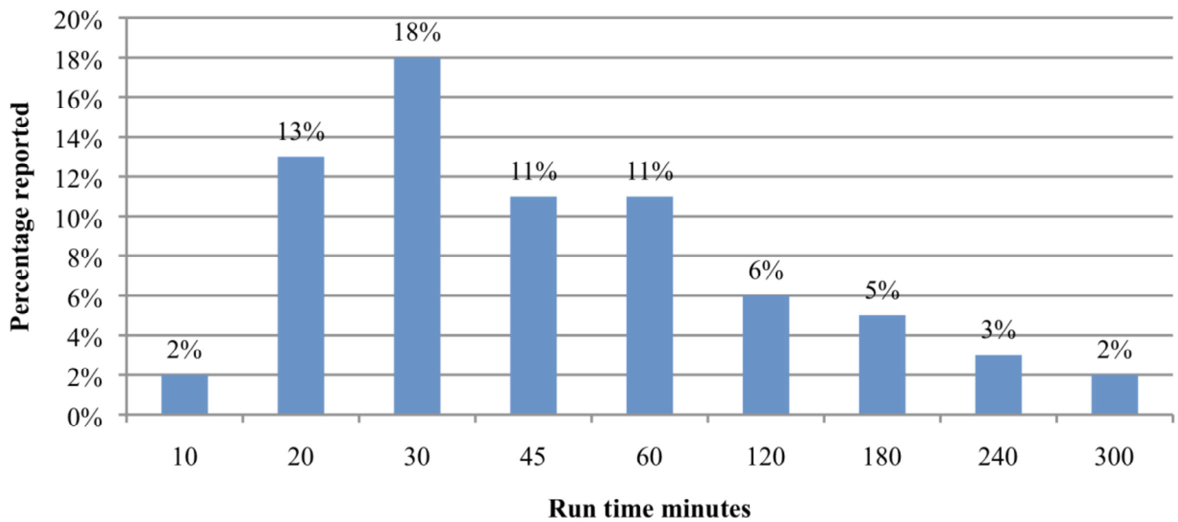


Figure 3-3. Survey respondent reported irrigation controller run time settings for turfgrass irrigation

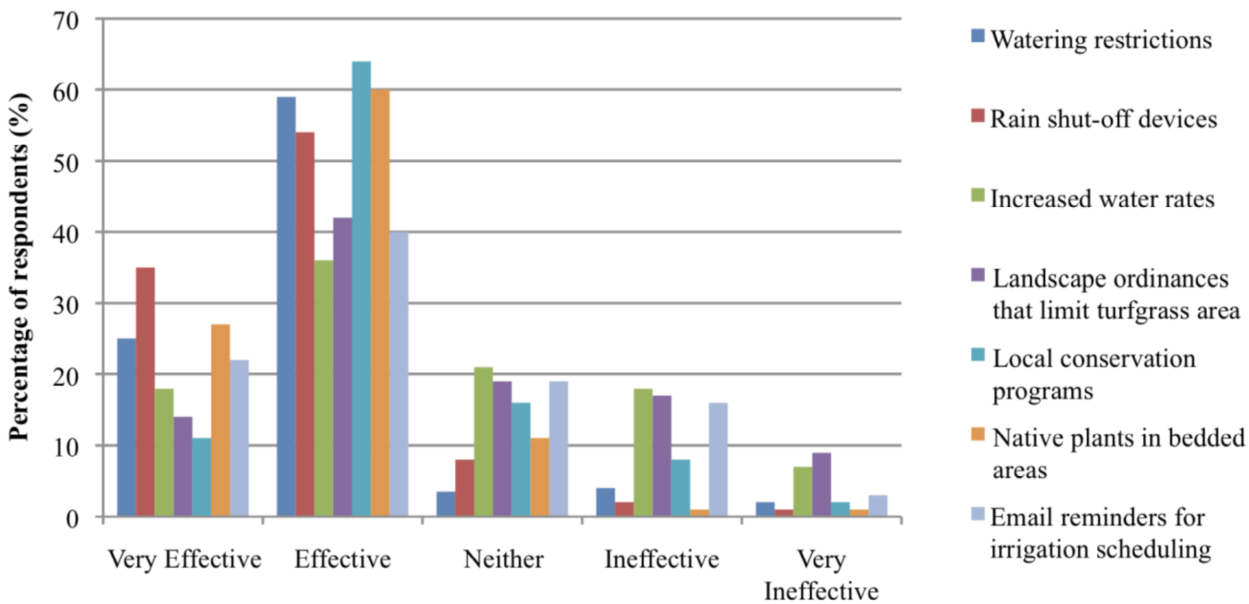


Figure 3-4. Survey respondent opinion of effectiveness of various water conservation methods

A

B

Figure 3-5. Example of variation between parcel map and areal imagery when determining irrigated area. A) Certain commonly irrigated areas are not included in the parcel. B) Sometimes non-irrigated areas are included in the parcel such as adjacent “natural areas” and waterways. Screen shots courtesy of http://www.gis.pinellas.org.

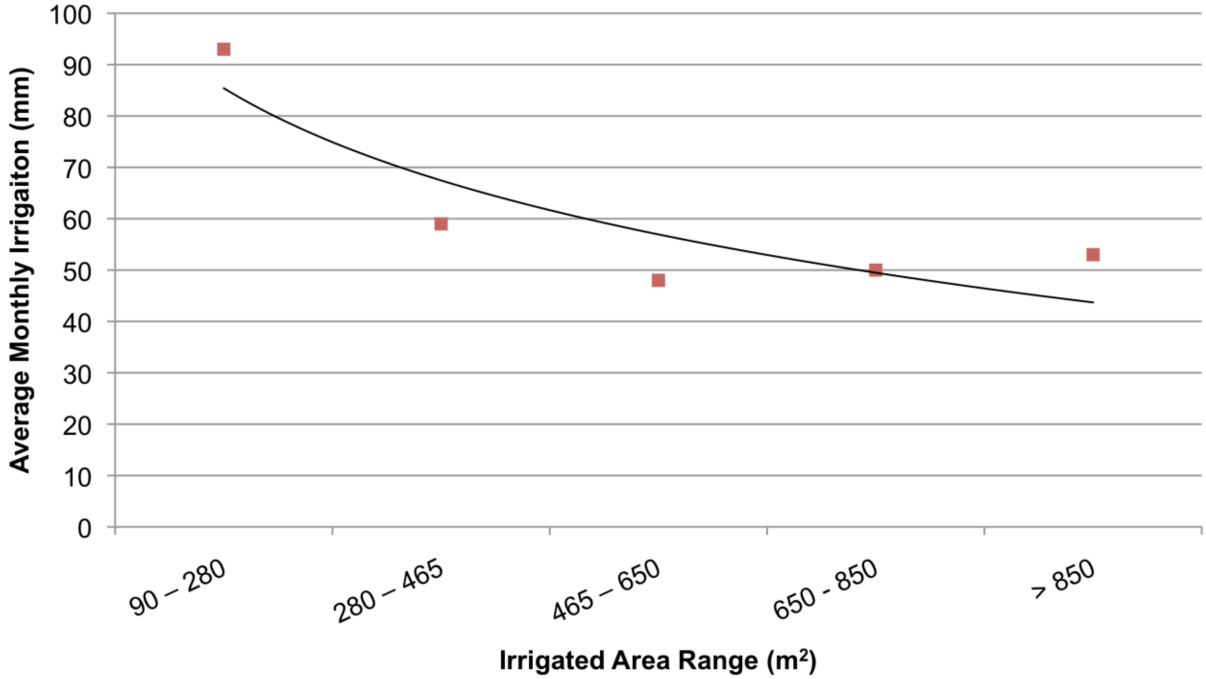


Figure 3-6. Correlation between property value and average monthly irrigation (n = 142).

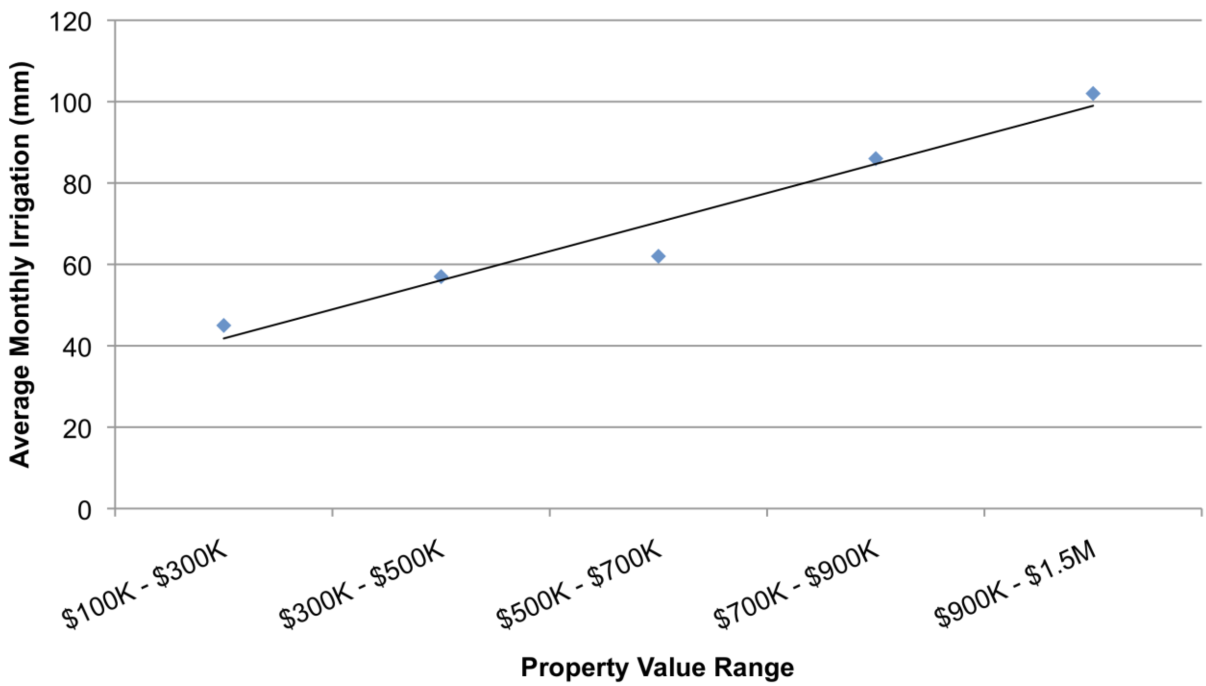


Figure 3-7. Correlation between irrigated area and average monthly irrigation (n = 142).

CHAPTER 4
IRRIGATION WATER CONSERVATION CAMPAIGN

Background

This irrigation water conservation campaign was developed as a Phase II of the Water-wise Irrigation Practices and Perceptions (WWIPP) survey described in Chapter 3. The Phase I investigated outdoor water-use practices and perceptions of single-family homes, through a mail-out questionnaire booklet. The Phase I survey targeted lawn and garden practices, environmental skill, knowledge of ordinances, motives for conservation/use, and perception of community conservation/use of the typical household. The goal of Phase I was to investigate and document user knowledge of residential outdoor water used for irrigation compared to actual use data. The quantification of this information will help to identify areas in need of increased public awareness. Areas of concern include misunderstandings of outdoor water use principles, irrigation scheduling, and the integration of technological devices such as rain sensors, soil moisture sensors, and weather-based controllers.

Phase II included an examination and review of various models based on social-psychological theories of behavior and change, the study of how social conditions affect human actions. The ideal model selection for consumer behavior attempts to capture both internal and external dimensions of pro-environmental behavior. An example of an internal influence can be irrigation scheduling knowledge, while and external factor can be homeowner association deeds. The motivation for conservation and drivers of behavioral change can be more easily understood using conceptual models. More specifically, models can demonstrate social and psychological influences of the typical homeowner as well as pro-environmental consumer behavior. A model used with the collected data in Phase I can help to develop suggestions that can be incorporated to implement change in outdoor water use behavior for irrigation conservation.

According to the conclusions drawn from the household survey, significant barriers and benefits were identified (Dukes and Haley 2009). There was an overall misunderstanding of plant water needs and seasonal scheduling of irrigation systems. Further, there was confusion as to the terminology in reference to rain shut-off devices versus rain sensors. Respondents expressed room for improvement and interest in learning, suggesting a sense of reliability of rain shut-off device functionality, and conservation behavior relating to water source. Finally, there was influence of property value or property size on irrigation water use.

Scenario Planning

The development of a scenario plan can be used to weigh the options between impact and feasibility of an irrigation conservation campaign. The purpose of scenario planning is to develop a set of unpredictable interventions with plausible alternative social, technical, economic, environmental, educational, political or aesthetic trends as key driving forces. From the Phase I survey conclusions, the ideal scenarios determine the most successful targeted water-wise irrigation education approach in Phase II with application in the development and implementation of a campaign to stress irrigation conservation practices, as determined to be under-employed from Phase I. The identification of key drivers, and using storylines to “wind tunnel” strategic options will help to identify effective components of the campaign models.

Figure 4-1 presents the influences of community, technological, political, and water purveyors on irrigation water use. There are some common and divergent views within the clusters illustrated. The overall theme encourages irrigation water use conservation.

However, for many of the new technological devices to function most effectively the system should be set to run outside the irrigation day regulations. “Smart” controllers (such as soil moisture sensor systems or weather-based controllers) monitor and use information about site conditions. They are able to reduce irrigation water use by applying the right amount of water based on those factors when installed and scheduled correctly. Essentially, these irrigation controllers receive feedback from the irrigated system and schedule or adjust irrigation duration and/or frequency accordingly. Policy states that all systems must have some type of rain shut-off device (Florida Statutes, Chapter 373, Section 62), but there is little enforcement of this ordinance by local entities. The local utilities have steadily increased water costs over the last five years; they have also encouraged the use of alternative sources (PCU 2010a). Different irrigation water sources (e.g. reclaimed) are given different watering restrictions, which can be confusing within the community (PCU 2010b). Further, alternative sources are given cost incentives that may encourage overuse, such as non-metered flat rates.

From the internal influences that stem from the community/policy/technology/utility cluster diagram in Figure 4-1, Figure 4-2 presents possible water conservation activities within quadrants suggesting high or low impact and the predictability of outcome based on the perceived benefits and barriers.

Scenario plan story lines

As part of creating the Scenario Plan, story line possibilities are developed. Based on potential for irrigation effectiveness presented above, the four story lines explored are:

- Scenario 1 – Rain sensor incentive/citation
- Scenario 2 – Irrigation scheduling incentive/citation

- Scenario 3 – “Smart” choices
- Scenario 4 – Alternative action

The rain sensor incentive/citation scenario would aim to increase community awareness of the rain sensor ordinance. In this scenario the participant would be given information regarding rain shut-off device functionality and requirement in the form of a fact sheet. The participant will also be informed of the possibility of a fine; if the rain sensor ordinance is not complied with, a citation could be issued by local utilities. As a positive offering on the part of the program, a free rain sensor along with installation instructions and window decal will be offered as an incentive for program participation. In this scenario other more technologically advanced devices (e.g. “smart” controllers) would also satisfy the aim. The key drivers in this scenario include: technology innovation, growing environmental awareness, and policy intervention.

The irrigation scheduling incentive/citation scenario would aim to increase community awareness of watering day restrictions and seasonal irrigation scheduling. In this scenario the participant would be given information regarding (1) day of week restriction based on house number and water source and (2) seasonal irrigation scheduling guidelines in the form of a fact sheets and/or website link. The participant would also be informed of the possibility of a fine; if the day of week restriction is not complied with, a citation could be issued by local utilities. As a positive offering on the part of the program, a personalized laminated irrigation system run time card will be created as incentive for program participation. In this scenario other more technologically advanced devices (e.g. “smart” controllers) if set properly would also satisfy the aim. Here, the key drivers include: technology innovation, growing environmental awareness, and policy intervention.

The third scenario story line, “smart” choices, offers variance to watering restriction based on the use of “smart” irrigation technology. If a “smart” controller is installed and certified as set properly, the home may be exempt from irrigation day regulations, based on increased technology. In this scenario the participant would be given information regarding “smart” controller functionality in the form of a fact sheet. These homes have the possibility of using less water because of the increased technology during wet years. However, during dry years, it is possible, that the controller could allow for additional irrigation events. Furthermore, previous irrigation habits must be considered. This scenario story line would be considered beyond WWIPP scope as it is a policy suggestion that outside of the currently ordinance. However, research has shown water savings with the use of “smart” irrigation technology coupled with such a variance (Davis et al. 2009). A consequence of this scenario is that a neighbor might notice the off day irrigation events without the knowledge that the house is utilizing a “smart” controller. This neighbor may then possibly irrigate on off days as well. The key drivers: of this scenario are: technology innovation, growing environmental awareness, decreased policy intervention.

The final scenario story line, alternative action, would require homes within an alternative water source availability area to be required to use that alternative water sources (e.g. reclaimed, shallow well, or surface water) for irrigation. This scenario would require less enforcement and policy intervention, since all homes in a neighborhood would have similar watering days and times of day based on source type. However, this scenario is also beyond the WWIPP scope as it would mandate infrastructure on the part of the homeowner. This scenario would also prevent neighbors from being influenced to irrigate on off days or hours based on source allowances. A consequence would be that a homeowner may irrigate more than previously with alternative water source because environmental awareness may become skewed by lower water costs. There could be a change in the aquifer recharge cycle or a drain on the reclaimed storage, which would lead to new problems with water demand for the public supply. The key drivers in this scenario include: decreased environmental awareness, decreased policy intervention.

Some wildcards that must be taken into consideration for these scenarios could be (1) irrigation days could be severely restricted, making the technology less effective, (2) all homes could be plumbed for reclaimed water, (3) extreme drought, or (4) excessively wet years.

Wind tunnel strategic options

A wind tunnel matrix for the four trial scenarios is illustrated in Table 4-1. From this matrix, it can be observed which scenarios might be most feasible for implementation. The rain sensor and irrigation scheduling scenarios would be the most conducive to the scope of the WWIPP participant Phase, based on the number of cells with (+) symbols in Table 4-1. Previous research has indicated that the inexpensive technology and seasonal irrigation scheduling both promote irrigation water conservation. These scenarios are in compliance with the current jurisdiction and both can be implemented using the principals of Community Based Social Marketing. The Alternative Action and “Smart” Choices scenarios both have impractical aspects of implementation, note cells with (-) symbols in Table 4-1.

Community Based Social Marketing

Community-based social marketing goes beyond the scope of public awareness to identify and overcome barriers in efforts to create long lasting changes in behavior, increasing impact and predicting outcome. This technique has been effective in promoting sustainable behavior (McKenzie-Mohr and Smith 1999). When trying to create a more sustainable practice of residential automatic irrigation behavior, two feasible options, with favorable impact, are to encourage the installation of rain sensor and/or practice irrigation scheduling.

Irrigation scheduling refers to setting the runtimes of the irrigation time clock based on when and how much to water. This is derived from factors such as soil type, root zone depth and local weather conditions. According to University of Florida research in conjunction with the St. Johns River Water Management District, setting residential irrigation controllers with respect to historical turfgrass seasonal water needs resulted in a 30% reduction of water use (Haley et al. 2007). During this study as well as Phase I (the WWIPP survey) it was observed that the homeowners did not have a clear understanding of when and how much to irrigate (Haley et al. 2007; Dukes and Haley 2009). A useful tool that has been developed to aid the homeowner in properly setting their irrigation time clock, based on seasonal plant water needs, is the Urban Irrigation Scheduler, which is located on the Florida Automated Weather Network Website (http://fawn.ifas.ufl.edu/tools/ urban_irrigation/).

Following the steps of community-based social marketing, a program aimed at encouraging irrigation scheduling is outlined below. The first step is to understand the behavior better, which can be accomplished with the behavior matrix presented in Table 4-2.

Using enforcement to “regulate” a behavior is not always helpful. For example, within the Southwest Florida Water Management District (SWFWMD) irrigation is only permitted certain days. Therefore a common misconception on the part of the homeowner, when irrigating less frequently, is to set longer cycle lengths during their given watering day. According to University of Florida research in conjunction with the SWFWMD, it was found that homeowners often deviate from the watering day restrictions (Dukes and Haley 2009).

Promotion of economic self-interest in relation to irrigation water use can also provide little impact. According to Phase I results, there was a trend of increased water application with increased property value. Conversely, the smaller the irrigated area, the more water applied when normalized with respect to application depth. A primary cause for the increased use in both homes of higher property value or smaller irrigated area is likely due to the minimal impact water cost has on excessive use (Dukes and Haley 2009).

Both internal and external barriers can hinder the success of the program. For this example, internal barriers may include a lack of knowledge regarding: plant water needs, irrigation time clock functionality, and available resources (i.e. Urban Irrigation Scheduler). External barriers may include: willingness, policy change, other irrigation technology, climactic conditions, and influence by homeowner’s association, neighbors, or landscape professional. One way to remove an external barrier is to educate the landscape professionals and/or homeowner associations.

The following steps help promote an effective program: written commitments, prompts, messaging, and incentives. Written commitments are more successful than oral commitments. Signing a pledge can be added into the program as an initial step, it will actively involve the participant and help them view themselves as environmentally concerned.

Prompts such as a self-explanatory laminated runtime card to be attached near the irrigation time clock or other location temporally and spatially close to the behavior. Additional prompts could include seasonal telephone, mail, or email reminders to change their irrigation runtime. For a more wide range program media reminders could also be utilized such as television, radio, and newsprint.

A standard pattern of behavior can be created through report cards issued to program participants. Based on their utility water use data, the outdoor use can be determined. A report card style indicator, for landscape water management, has been found to be very effective in engaging conservation behavior. Messages, mottos, or slogans are most effective when to the point. It can be a printed window decal, refrigerator magnet, or hose nozzle. The message is to set your irrigation clock based on seasonal plant water needs. The slogan could be “Set by Season, be Water Wise”.

In this program, incentives will be non-monetary and related to the desired behavior. The primary incentive will be the irrigation evaluation and subsequent individualized runtime card. This will be beneficial for both educational and monitoring purposes. As budget permits, homes will receive an outdoor water conservation kit similar to that from Phase I (Figure 4-3), which includes a rain sensor, water saving hose nozzle, and appropriate literature to reinforce the importance of these devices.

A program evaluation is the best way to determine both the impact of the program and how well the program itself was facilitated. The evaluation should include multiple time steps of data collection as well as comparison with a control group.

If the rain sensor incentive were included in Phase II, as mentioned in the rain sensor scenario, the participant would also be provided with installation instructions and window decal (Figure 4-3). Additionally, during the irrigation evaluation interview, any home noted as having a rain shut-off device would also receive the decal. The biggest reasons rain shut-off device ordinances are currently ignored are due to lack of awareness and lack of enforcement. The window decals could raise awareness and eventually ease enforcement. The rain shut-off decal can act as a prompt to encourage irrigation water conservation awareness, involving homeowners to view themselves as environmentally concerned.

Model Development

The ideal selection of a model based on social-psychological theories of behavior and change will try to capture both internal and external dimensions of pro-environmental behavior. An example of an internal influence can be irrigation scheduling knowledge, while and external factor can be watering day restrictions. The motivation for conservation and drivers of behavioral change can be understood more clearly using conceptual models. More specifically, models can demonstrate social and psychological influences of the typical homeowner as well as pro-environmental consumer behavior. A model used with the collected data in Phase I can help to develop suggestions that can be incorporated to implement change in outdoor water use behavior for irrigation conservation.

Methods

Model Development

A logic model visually displays the progression of actions and outcomes that describe what an evaluation hopes to accomplish, Figure 4-4. There are five main components: inputs, outputs, outcomes, assumptions, and external factors. The logic model and subsequent impact theory model, Figure 4-5, along with the process theory model, Figure 4-6, address an educational program that would help homeowners appropriately set their irrigation time clocks to manage their landscape. According to Rossi et al. (2004), the logic model is a familiar depiction of program theory because it lays out the rational path from program services to participant outcomes. Additionally, the logic model will make it easy to identify appropriate future evaluation questions and can be further refined into the corresponding domains (Israel 2001). A logic model can be used as the basis for the future evaluation design and can be developed with stakeholders to represent a harmonious view, clarifying evaluation questions to determine relevant and important program impacts. As an added benefit to an evaluator, the logic model may bring to light issues that stakeholders may have otherwise neglected to notice. The models developed here are based off of established Florida Yards and Neighborhoods theory models (Israel 2001).

Participant Program Plan

Program activities can be observed in detail with the process theory model, Figure 4-6, which began with solicitation of participants in the target area following the IRB protocol. Once contact was been made with the participants, the homes were given an irrigation system evaluation interview (Appendix C). This interview established their current irrigation habits and baseline information regarding their irrigation system and lawn/landscape. Homes were contacted at monthly/seasonal intervals encouraging the reprogramming of their irrigation time clock. Additionally, utility data will be obtained from Tampa Bay Water (TBW) online database. This data was used to monitor the proposed outcome, reduction of water use, and as a feedback loop.

The previous utility data, up to 60 months where available, was obtained for all participating homes, including the 12 months following the commencement of the campaign. To determine the effectiveness of the campaign on irrigation water use conservation, an equal number of non-participant households of similar value and parcel size were randomly selected as a control group for comparative analysis (Israel and Hague 2002).

Participant solicitation

The program was initially solicited via mail-out advertisement or personal communication. As part of the campaign advertisement and in compliance with UF-IRB regulations, address information was collected. For this study the advertisement directed the interested participant to a web survey as an initial criteria questionnaire. The chosen participants will then be contacted by telephone by University of Florida research personnel.

Contact list

The primary contact list contained 250 addresses, advertising of the program was sent in multi-waves to reach at least 100 households. Address lists were ascertained from the Pinellas County Utilities (PCU) customer service database. Initial contact has been made with these homes during Phase I. The water source is known for all homes. Although further data analysis was conducted on homes to identify a subset of higher water users the contact list was expanded due to poor response rate.

IRB documentation

Following IRB submission requirements, this research study was granted IRB protocol exemption (#2009-U-0386) based on interaction level of participants in accordance with 45 CFR 46.

Irrigation evaluation interview

As follow-up to the web-survey the researcher, via telephone or other preferred method of communication if noted, contacted participating homes. At this time the participant were asked a series of questions regarding their landscape layout, irrigation system, irrigation practices, indoor water use, and household demographics. These questions helped to verify existing information gathered on the home from property appraisal parcel information, aerial imagery, and Phase I responses if applicable.

Newsletter Correspondence

The newsletter distribution was either seasonally or monthly based on the frequency the participant selected during the recruitment survey. Current frequency distribution includes: monthly newsletters (n=34) and seasonal newsletters (n=15).

In the case of the monthly newsletter (Appendix D), each participant was always given a runtime schedule for the month. It was not noted if the schedule grid is the same as a previous month, the goal was for grid to prompt the homeowner into a habit of checking their clock regularly. Typically, there was at least mild variation in runtimes even from month to month.

In the case of seasonally scheduling, there were always obvious changes to be made compared to the previous schedule. Aside from the runtime matrix, the seasonal newsletter was the same as the monthly newsletter for the first month of each season (e.g. March = spring, June = summer, September = fall, December = winter).

The reclaimed water (RCW) participants received the newsletters with a slightly different scheduling matrix due to the variation in watering days and billing. Instead of runtimes listed by zones, the run times were only listed by equipment type (spray head versus rotor head).

Irrigation schedules were provided for participants based on their unique irrigation system and landscape. The Urban Irrigation Scheduler on the Florida Automated Weather Network website (http://fawn.ifas.ufl.edu/tools/urban_irrigation/) and EDIS Document AE-220 (http://edis.ifas.ufl.edu/AE220) were used to standardize recommendations based on equipment type. These documents suggest irrigation run times based on two-day-per-week watering restrictions. However, since potable and well source irrigation is limited to one-day-per-week in the study area, the two-day-per-week runtimes (following the 80% replacement recommendation) was increased by 30%. Homes irrigating with reclaimed water were permitted three-days-per-week of irrigation, however in this case the recommended runtimes remained the two-day-per-week runtimes, as this provides adequate irrigation.

Program Evaluation

The program evaluation, conducted to measure the program outcomes, was conducted during October 2010, at the latter section of the newsletter distribution and data collection period. This evaluation supplied information that will aide in program improvement if the District were to extend or expand the program (Appendix E). However, since outcomes are affected by events and experiences that are independent of a program, the changes in the levels of outcomes may not always be directly interpreted as program effects.

Water Use Data

Potable source participant impact can be measured by comparing water use to non-participants. The water use of the potable source participants was utility data where indoor and outdoor use was separated to determine the irrigation use estimates. Utility water use data was collected from the single main meter for billing purposes and acquired from the TBW GovNet online database, Figure 4-7. This data combines both indoor and outdoor water consumption and the irrigation use was estimated as a fraction of the total use following appropriate methodology and assumptions. The data separation techniques most reliable for this program considers the minimum month method and/or the metric referred to as the indoor use metric, IUM (Dziegielewski and Kiefer, 2009). Where the lower of the two methods was considered the actual indoor usage.

The most widely employed technique for indoor and outdoor utility data water use separation is the seasonal versus non-seasonal use metric using the minimum month method (Dziegielewski and Kiefer, 2009; Vickers, 2001). This method uses the underlying assumption that residential water demand fluctuates over time due to weather variability, consequently allowing for seasonal and non-seasonal components of water use to be detected. The seasonal water use, also known as the weather sensitive water use, is considered nearly all water used outside the home. Furthermore, the seasonal use varies based on the months of the year. In contrast, non-seasonal water use refers to water use that is assumed to be constant throughout the year and typically embodies the indoor use.

The minimum month method was developed around the basic assumption that during the month of the lowest water consumption, seasonal or outdoor water use equals zero. Thus, the non-seasonal or indoor water use was assumed to be constant. Indoor water use (IU) is the volume of the single lowest month, $V_{Min\text{-}M}$ (Dziegielewski and Kiefer, 2009).

$$IU = Q_{Min\text{-}M} \qquad \text{Equation 4-1}$$

Where:

IU = indoor (non-seasonal) volumetric water use per month
$Q_{Min\text{-}M}$ = minimum monthly volumetric water use per month

The outdoor water use for each month in a given year can be calculated as the difference between the total water use and the indoor use.

$$OU = Q_{Tot} - IU \qquad \text{Equation 4-2}$$

Where:

OU = outdoor (seasonal) volumetric water use per month
Q_{Tot} = monthly volumetric water use per month

The second, and more detailed, approach considers the per capita water use based on the number of occupants that reside in the household. This metric is referred to as the indoor use metric or IUM_c (Dziegielewski and Kiefer, 2009), where the subscript c denotes per capita use. Where household occupancy data was not readily available, the indoor use metric IUM_a was used, where the subscript a denotes account (also referred to as household). In this case, estimates are used for the average number of persons per household.

$$IUM_c = U * M \qquad \text{Equation 4-3}$$

$$IUM_a = IUM_c * N_a \qquad \text{Equation 4-4}$$

Where:

IUM_c = per capita indoor volumetric water usage per person
U = average frequency of events (e.g. toilet flushing, clothes washing, showering, bathing, faucet use, dishwashing, etc.) per person
M = average volumetric use per event

IUM_a = average household indoor volumetric use per account
N_a = average number of persons in household

The coinciding outdoor usage metric (OUM_a) is the difference between the average annual rate and the indoor usage metric.

$$OUM_a = Q_{Annual} - IUM_a \qquad \text{Equation 4-5}$$

Where:

OUM_a = average household volumetric outdoor usage per account per month
Q_{Annual} = average household volumetric annual usage per account per month
IUM_a = average household volumetric indoor usage per account per month

This technique requires certain assumptions to be made regarding household characteristics. The indoor and outdoor usage metrics (IUM_a and OUM_a) were calculated with actual characteristics self-reported by the households in the participant data set.

Water use data analysis is presented for the entire study period for both potable participants (n=21) and non-participants (n=100) Additionally, newsletter click counts and self-reported questionnaire data were evaluated. However, the outdoor water use of the RCW participants cannot be measured, as these homes are not outfitted with water meters on the RCW line. Therefore, only the newsletter opening rate and self-reported data can be collected. The RCW participants (n=28) are not included in the response rate count because they were routed to the WWIPP program online survey from their response to another SWFWMD RCW project advertisement.

Irrigated Area Estimation

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, the property size, total gross living area (i.e. gross structural footprint), and residential extras (e.g. pool, enclosure, patio, shed, etc.).

The irrigated area was determined using this available property information. The irrigated area was calculated by subtracting the gross structural area and residential extras from the property size. From the Pinellas County public geographic information system (GIS) records (www.gis.pinellas.org), the residential parcels are outlined and an aerial layer from Jan/Feb 2006 was overlaid (Figure 4-8). Using the GIS layers, the irrigated areas were outlined with a polygon tool to determine the estimated irrigated area. The aerial estimated irrigated area was then compared to the calculated irrigated area from the property appraisal information.

The irrigated area was used to convert the billing data, provided in gallons of water used per month, into a normalized depth of water applied at each home.

$$I_{applied} = CF * OU / IA \qquad \text{Equation 4-6}$$

Where:

$I_{applied}$ = depth of water use applied across the irrigated area (mm/month)
OU = volume of outdoor water use (liter)
IA = irrigated area (m^2)
CF = conversion factor

Theoretical Irrigation Requirement

Actual monthly irrigation estimated means were compared to theoretical irrigation estimate. Where, the evapotranspiration for the landscape, ET_L was calculated using

Equations 2-3 and 2-4, where the landscape coefficient assumed an average turfgrass area of 75%, which is appropriate for the study area (Dukes and Haley 2009). Otherwise, the soil water balance procedure remained the same as that detailed in Chapter 2 (Equations 2-5 to 2-7) and produced a theoretical irrigation water requirement. The actual irrigation water estimate ($I_{applied}$) applied to the residential landscapes was compared to the theoretical irrigation water requirement (I_{calc}). Additionally, a water use ratio can be calculated by the equation:

$$Water\ Use\ Ratio = I_{applied} / I_{calc} \qquad \text{Equation 4-7}$$

Where:

$I_{applied}$ = depth of water use applied across the irrigated area (mm/month)
I_{calc} = theoretical gross depth of irrigation needed (mm/month)

Data Analysis

Data analysis was performed using SAS software (SAS 2004). Univariate data analysis was used to describe the data set sample with mean, standard deviations, and percentages. The level of measurement was reported as frequency statistics from the survey responses. The bivariate analysis was used for the evaluation of the independent variables and the hypothesis testing between the independent and dependent variables.

Positive and negative correlations were based on Pearson's correlation coefficient. The multivariate analysis enables assessment of the direct and indirect effects for related variables. An analysis of variance was used to determine main effect differences through general linear model and means comparisons were performed with Duncan's Multiple Range Test at a 95% confidence level.

Results

Model Development

The major outcomes of the participant program, with respect to the input investments and output activities are identified in Figure 4-4. From this model the assumptions and external factors can be identified. For the homeowner irrigation scheduling program, relevant assumptions include: homeowner willingness to interact with irrigation time clock, their want to be in compliance with policy, and a want to conserve water. The External factors that may influence participation were identified as: willingness to participate, influence by homeowner's association or neighbors, policy change, other irrigation technology, and climactic conditions. These assumptions and external factors needed consideration upon development of the experimental design and program evaluation. Figure 4-5 elaborates on the impact of the Phase II participant program. The primary long-term outcome is to reduce irrigation water consumption and therefore reduce the groundwater demand. According to this model, homeowners are encouraged to practice irrigation scheduling which will reduce over watering and increase watering restriction/ordinance compliance. The feedback loop acknowledges the continued follow-up with the participants at various intervals over the 12-month program period. The impact model in Figure 4-5 also shows how the external factor, outlined in Figure 4-4, may hinder the programs desired outcomes. The selection of participants may have an effect based on the demographic and property attribute, as well as the preexisting practices, knowledge, and skill. The impact model also displays how the external factors can cause positive results that do not stem from the program directly. For example, if a homeowner installs a "smart" controller the same outcomes could be observed.

The process theory model, Figure 4-6, provides even more detailed insight by breaking the model into: “who”, “how”, “what”, and “what-if”. The program organizational half of the model refers to “who” and “how”. Here the roles and responsibilities of the researcher are drawn out following a sequential order, form development, to solicitation, to continued monitoring, and finally evaluation. The service utilization half of the model shows the “what” and “what-if” scenarios. In this case, what the homeowner should do as a program participant and how the same outcome could or could not occur if any step was removed. The objective of the service utilization plan was to come up with a sufficient plan that will initiate the sequence of outcomes specified in the logic and impact theory models, Figures 4-4 and 4-5.

Program Participation

Current program participation included: 21 participating homes with potable water and 28 participating homes with RCW in the Pinellas County target area. Additionally, a non-participant comparison group (n=100) was included for water use analysis purposes.

Response rate

WWIPP Phase I yielded a 25% response rate (Haley and Dukes 2008). In anticipation of a similar or grater response rate, initially 100 advertising letters was projected as sufficient in the WWIPP Phase II scope of work. As the response to the advertising letters yielded less than desired rate the contact list increased from 100 to 250, of these 244 ended up being viable addresses, yielding a final response rate of 8.6% with 21 respondents to the advertising letters.

Click rate

The newsletter click count averaged 91% per newsletter issue. This high level of response concurs with the expressed interest and consequential motivation of the participant group. Conversely, the because the group of program participants was motivated, this result may be more likely to overstate the benefits of the program, if extended to a wider audience such as the entire District, in light of the low overall coverage rate (n=49).

Evaluation Results

The evaluation design was considered to be non-randomized partial coverage because only a small section of the target audience (domestic irrigators within the SWFWMD jurisdiction) was reached with the program. The evaluation looked at attitudinally-based questions from the primary and follow-up questionnaires as well as compared perception and knowledge questions of the participants with non-participants responses from WWIPP Phase I. Response rate of the program evaluation questionnaire was 92% (n=45).

Attitudinal questions

As part of the program evaluation, all participants were asked to self-report (n=45) their expected use of knowledge gained from the program. The expected uses are presented in Table 4-3. The primary objective of the program was to promote the use irrigation scheduling. From the self-reported expected behavior change, 93% of participants plan continued fulfillment this objective aim using either monthly or seasonal adjustments. In WWIPP Phase I only 69% of the participants actually fulfilled this aim based on self-reported data.

Knowledge score was calculated from the response to questions on preliminary and follow-up surveys regarding a broad spectrum of the landscape and irrigation system characteristics discussed in the subject matter of the program newsletters (Figure 4-9). Initially these questions were only part of the preliminary RCW survey, but were provided to all program participants in the follow-up questionnaire. The knowledge score was tallied and ranges from 0 to 70. The original question formats were presented as measures using a point Likert scale on the survey instrument. The answer options ranged from 5 to 1, rating level of familiarity with each characteristic, where 5 represents the highest level of knowledge.

Based on the follow-up survey responses, there was a gain in knowledge by the program participants for all characteristics listed in Figure 4-9 aside from: plant root depths, where the follow-up survey yielded less understanding; and soil type, where the responses remained approximately equivalent. Greatest increases in knowledge score were reported for the irrigation system characteristics regarding zone locations and sprinkler head types.

Both irrigation zone locations and sprinkler head types were an integral part of the irrigation evaluation interview. The participant was asked to record this information in efforts to obtain the proper run time recommendations for their "unique" system. The exercise yielded a positive principle in increased learning and retention. Therefore, the program did promote active learning with interactive information provided regarding water conservation research results (Kyam, 2000). Furthermore, by incorporating hands-on interaction with the irrigation system, cognitive learning was enhanced (Korwin and Jones, 1990).

Participants were asked to rate their level of familiarity to certain lawn and landscape characteristics, Figure 4-10. The level of familiarity was a self reported-rating from 5 to 1, where 5 represents the highest level of knowledge from preliminary survey responses and the RCW group only. The opinions of the effectiveness of water conservation ordinances, practices, and programs are illustrated in Figure 4-11.

Satisfaction

The satisfaction level of the participants of WWIPP Phase II was measured using a point Likert scale, with answer options ranging from very satisfied (5) to very dissatisfied (1). Figure 4-12 presents the average satisfaction score for the overall program newsletters, ease of understanding, accuracy, and relevancy. The overall satisfaction score of the program was 4.7.

Water Use Analysis

To determine any effect on irrigation water use by the participant homes during the study period, the estimated outdoor use was compared to: a non-participant group during the same period, a theoretical irrigation need, and the estimation of outdoor water use for the participant group prior to the study, shown in Table 4-4 and Figures 4-13 thru 4-15. A reliable method of observation of program impact is to observe the water use over the same period of time by two separate groups; in this case, comparison during the study period for the participant group versus a similar group of non-participants. Significant differences between the participant group, the non-participant group and theoretical need at the 90% confidence interval ($p = 0.03$). The monthly average irrigation water use for the participant group (0.23 mm/month, Table 4-4) was significantly different than the non-participant group (29 mm/month) resulting a 20% less use (Figure 4-13).

Additionally, from the graphs of Figures 4-14 and 4-15, it is apparent that the theoretical irrigation need was greater than the estimated irrigation applied by both the participant and non-participant groups for the majority of the 2010 study period. In fact, both the non-participant and participant use were statstically lower than the theoretical irrigation need (Figure 4-13). Therefore, during these months, all groups resulted in some under-irrigation relative to the theoretical estimate. Overall the ratio of estimated irrigation application to theoretical irrigation need during the study period was 0.6. This water use trend is consistent with similar water use analysis in the same area (Dukes and Haley 2009).

The water use of the potable participant group was compared to itself at two time intervals: the average of up to 60 months prior to and the 12 month period following the commencement of the program. A correlation existed between a decrease in water use and an increase in knowledge score calculated from the program evaluation. A higher water use knowledge score was negatively correlated with the change in water use of the participating household. However, the water savings of the participant group compared to itself at the two time periods were not significant when observing the water use.

Discussion

The WWIPP Phase II program was developed in response to primary conclusions drawn during WWIPP Phase I (Chapter 3). The “misunderstanding of irrigation scheduling and seasonal plant water needs” is addressed in each newsletter by providing suggested seasonally appropriate run times. The WWIPP Phase I respondents exhibited “interest in improving conservative water habits”, each newsletter provides information and tips on increasing efficient irrigation.

Long term WWIPP Phase II success will be measured by a change in first attitude and second behavior. Initial attitude changes were quantified by the preliminary and follow-up questionnaire self-reported data. Actual behavioral would result in a measurable decrease in irrigation water use. The goal of the evaluation was to determine the success of the program, areas of improvement, and steps the District would need to take in order to implement the campaign on a larger scale.

The WWIPP Phase II program aimed to capture irrigation water use savings by educating homeowners on irrigation principles through monthly/seasonally newsletters that focused on principles of irrigation scheduling. The participation in the study showed a decrease in potable irrigation water use compared to a non-participant group and a correlation existed between an increase in knowledge and decrease in water use over time.

Evident by a low water use ratio, the sample population of both participants and non-participants are water conservative. This may either stem in part from effective measures by SWFWMD or the local utilities. Additionally, the participant households have displayed interest in outdoor water reduction by program interest and are enticed by non-monetary incentives. Populations such as these would be candidates for community prompts such as the rain shut-off device decal.

This program could serve as a pilot test for a larger conservation campaign. If the WWIPP Phase II program were to be implemented on a larger scale, the following steps should be taken.

1. Advertising
    a. Solicit program participation to a wider audience
    b. Sign-up form link located on SWFWMD or Utilities websites

    c. Mail outs included in utility bill stuffers
2. Target high water users or neighborhoods with known over irrigation practices
3. Monetary incentive for participant to increase participation would broaden appeal
    a. Requires cooperative effort with Utilities
4. Data collection – would be beneficial to have this data directly available
    a. Parcel information
    b. Aerial imagery
    c. Household size (number of people) verification
    d. Water use data (potable homes)
5. Surveys
    a. Create a single recruitment survey that will auto generate the newsletter frequency distribution (monthly vs. seasonally)
    b. Auto generate follow-up emails or instruments based on number on months participant is active in the program
6. Newsletters
    a. Provide monthly or seasonal run times by zones based on equipment type
    b. Ideally the run time matrix lists minutes per zone for each zone at a participating home. However on a larger scale this matrix would require more advanced programming and greater involvement by program administration.
    c. Alternatively run times can be listed based on equipment type only. Similar to that of the RCW newsletters in the WWIPP Phase II or the FAWN Urban Irrigation Scheduler

The following points of improvement were identified as part of the program evaluation. These points should be addressed if the program were expanded into or implemented on a larger scale on the future. The primary aims would be to increase participant count to further test the impact and feasibility of the program. As well as target general populations as subsets of a larger area that are known to have high water use.

To a lesser degree additional areas of improvement would include the consideration of variations to run times matrix for future larger scale implementation. The selection of participants may have an effect based on the demographic and property attribute, as well as the preexisting practices, knowledge, and skill. The impact of external factors should be addressed; these can cause positive results that do not necessarily stem from the program directly. For example, if a homeowner installs a "smart" controller the same outcomes could be observed. Finally, if implementing on a larger scale over a multiple years, it may be beneficial to have at least a total of 24 newsletters (2 versions per month) that can be cycled through.

Table 4-1. Wind tunnel matrix for the four trial scenarios

Current plans, actions, or law	Scenario plan 1 Rain sensor incentive/ citation	2 Irrigation scheduling incentive/ citation	3 "Smart" choices	4 Alternative action
Current/Previous Technology Testing in Florida	+	+	++	- -
Community Based Social Marketing	++	++	+	+
Ordinance/Restrictions Compliance	++	++	- -	+
WWIPP Participant Program Scope	++	++	-	-

Table 4-2. Matrix of perceptions for irrigation behaviors

Behavior Type	Behavior	Perceived Benefits	Perceived Barriers
New	Irrigation scheduling	In touch w/ water use ↓ Water use Saves money Good for environment ↓ Weeds in lawn	↑ Effort Misunderstanding ↓ Turf quality
Competing	"Set & Forget"	No time or effort Lawn won't suffer ↑ Turf quality	↑ Water = ↑ Cost Not in touch
Competing	Manually irrigate	In touch w/ water use ↓ Water use Saves money Good for environment	↑ Effort May not know when to
Competing	Does not irrigate	No time or effort ↓ Water use Saves money Good for environment	↓ Turf quality ↑ Weeds in lawn

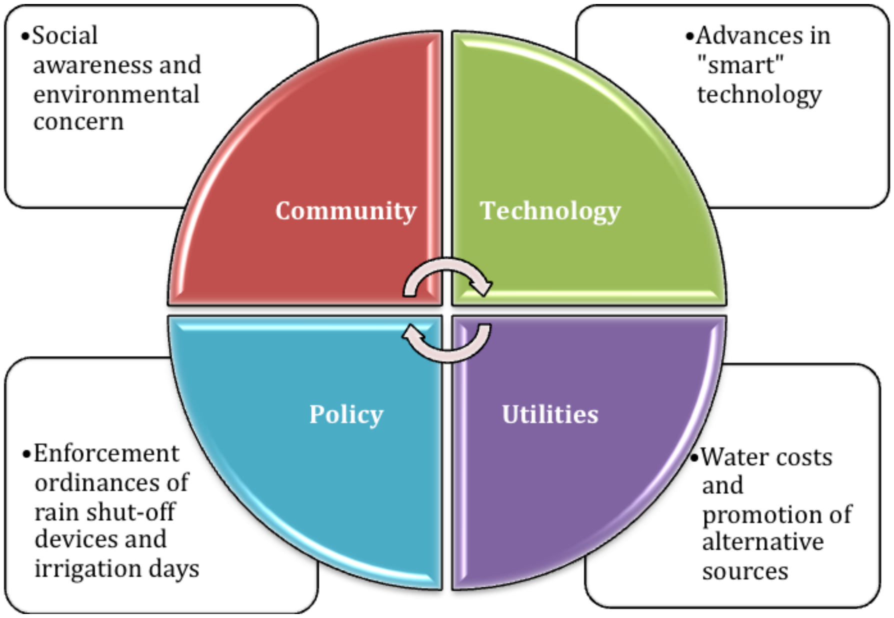
Table 4-3. Response percentages for continued use of evaluation objectives

Aim description	Phase I (n=251)	Phase II (n=45)
How often do plan to continue your watering schedule adjustment during year?		
Monthly	14%	20%
Seasonally	55%	73%
Neither	31%	6%
Do you water your lawn (turfgrass) and landscape (bedded area) for different lengths of time? To the best of the systems ability.		
Yes	44%	90%
No	53%	8%
Don't know	3%	2%

Table 4-4. Comparison of estimated irrigation application by month and season.

	Participants During Study (n=21)	Participants Prior to Study (n=21)	Non-participants (n=100)	Theoretical Need
Estimated Irrigation Applied (mm/month)				
Jan	17	20	23	12
Feb	14	17	20	20
Mar	24	26	28	30
Apr	22	25	30	49
May	30	35	42	64
Jun	27	31	37	45
Jul	26	27	29	51
Aug	30	30	30	24
Sep	28	31	34	44
Oct	19	21	25	45
Nov	25	27	29	23
Dec	15	17	21	16
Estimated Irrigation Applied (mm/month by season)				
Winter	17	20	23	12
Spring	14	17	20	20
Summer	24	26	28	30
Fall	22	25	30	49
Estimated Irrigation Applied (mm/month)				
Monthly Average	23	23 c[Z]	29 b	35 a
Estimated Irrigation Applied (mm/year)				
Annual Total	278	306[Y]	349[Y]	422

[Z] Numbers followed by different letters, within each column, are statistically different at the 90% confidence level.
[Y] Means comparison between PCU study participant and non-participant homes shows these averages to be significantly different.



External influences (scenario options):
Enforce rain shut-off ordinance
↑ Population
↑ Water demand
Technology shift

Internal influences (current activities):
Rain shut-off device required
Irrigation day restrictions
Potable water cost increase
Low cost for alternative sources
↑ # of homes with irrigation systems

Figure 4-1. Cluster diagram of community, technological, political, and water purveyor influences.

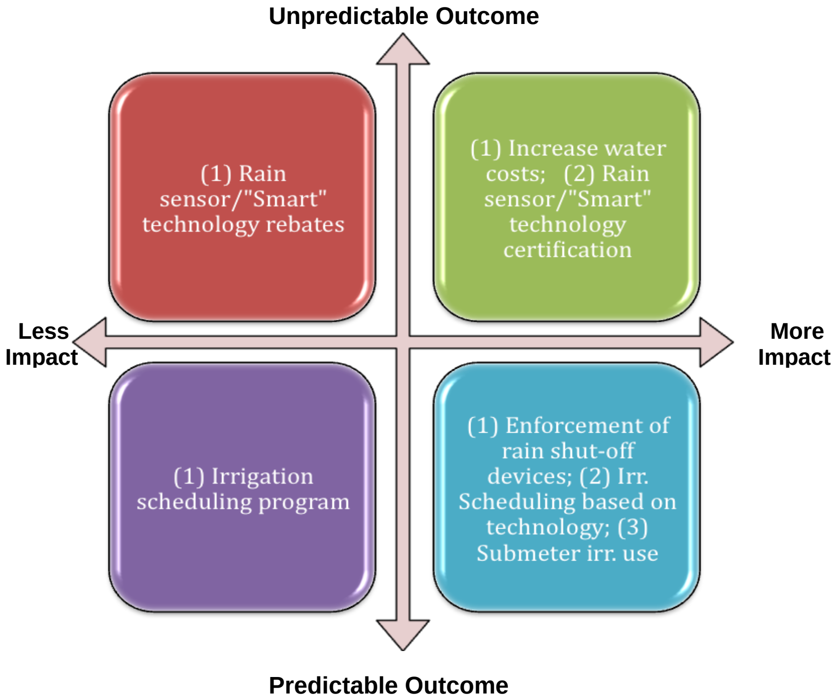


Figure 4-2. Impact versus outcome diagram of possible irrigation water conservation activities.

Figure 4-3. Rain shut-off device window decal. Illustration courtesy of Melissa Baum Haley.

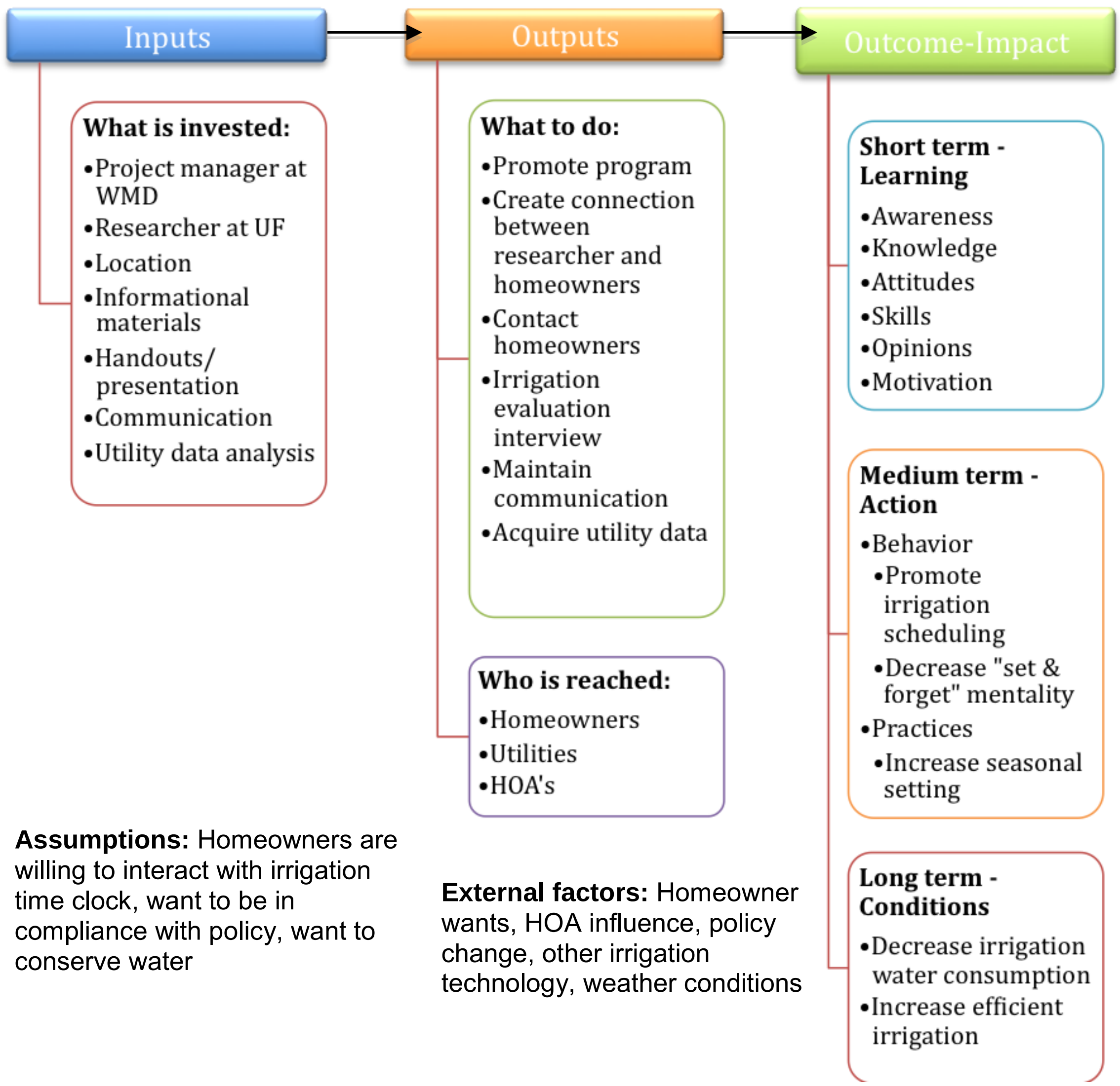


Figure 4-4. Logic model for household irrigation scheduling program.

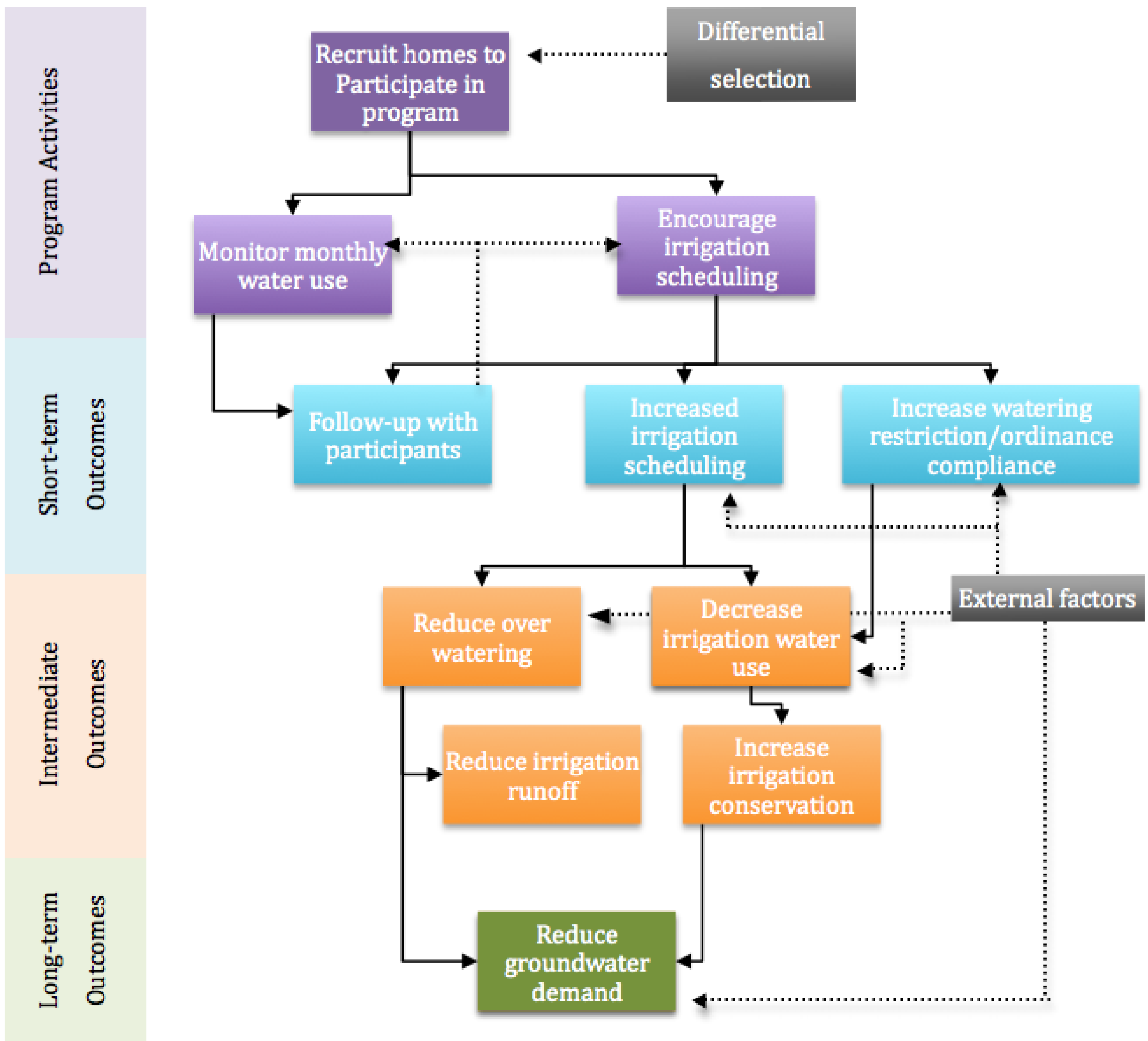


Figure 4-5. Impact theory model for homeowner irrigation scheduling program.

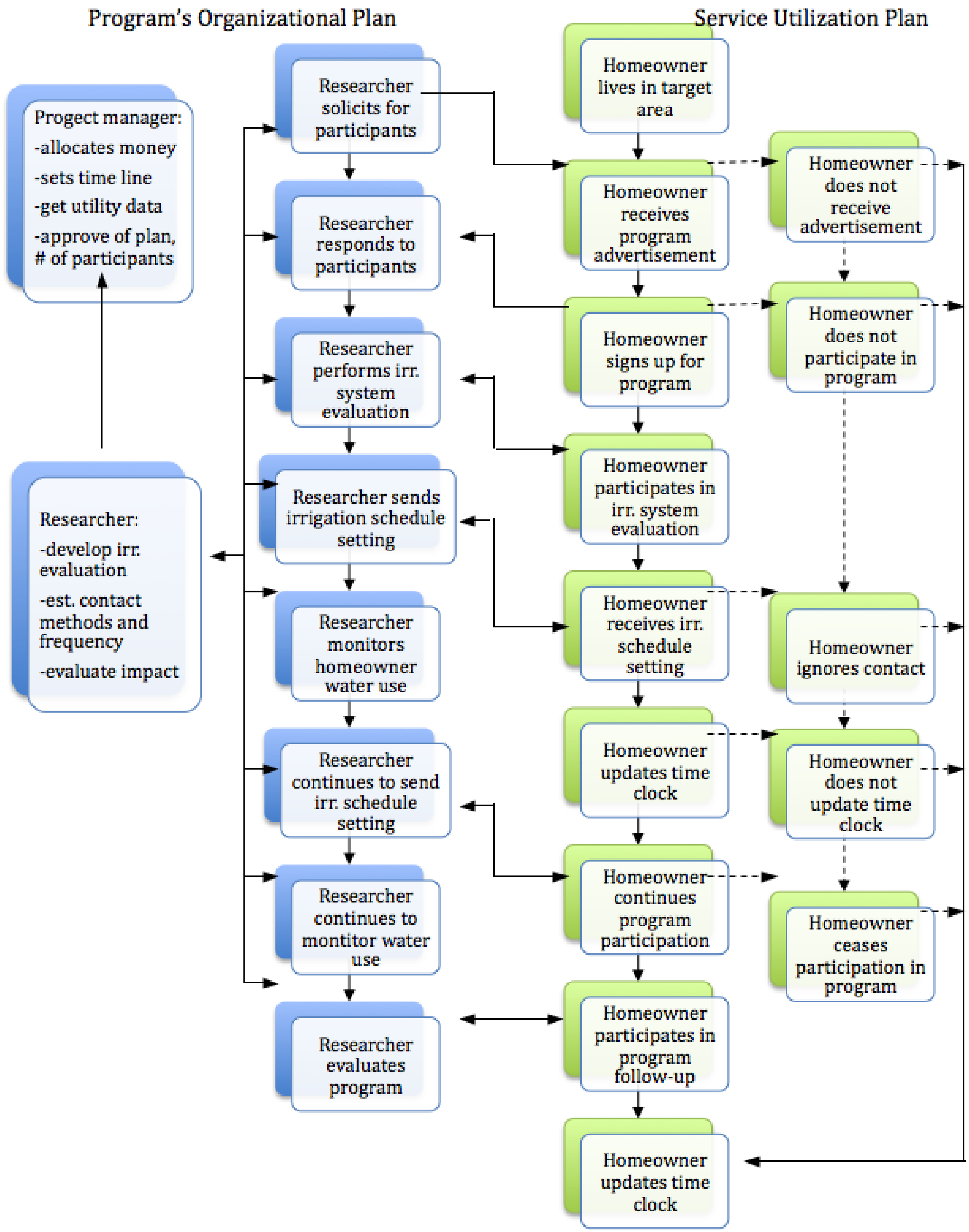
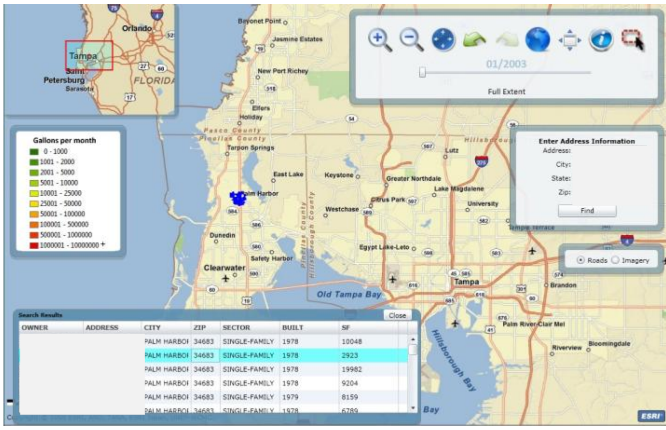
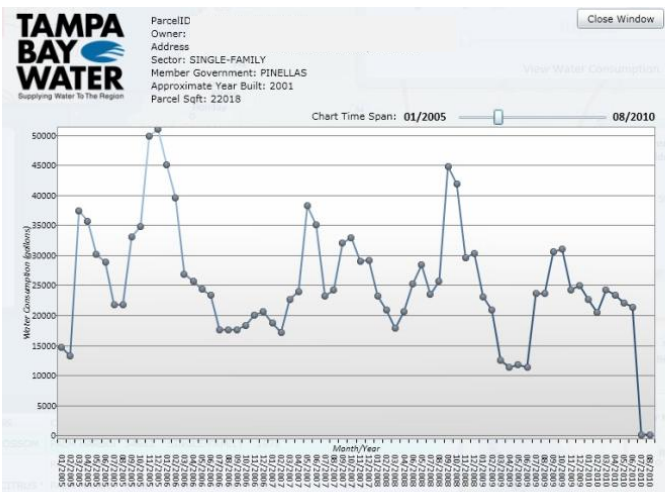


Figure 4-6. Process theory for household irrigation scheduling program.



A



B

Figure 4-7. Screen shots from the Tampa Bay Water GovNet online water use database. A) Default map showing parcel selection tool icons. B) Parcel water consumption report display. Screen shots courtesy of http://govnet.tampabaywater.org.

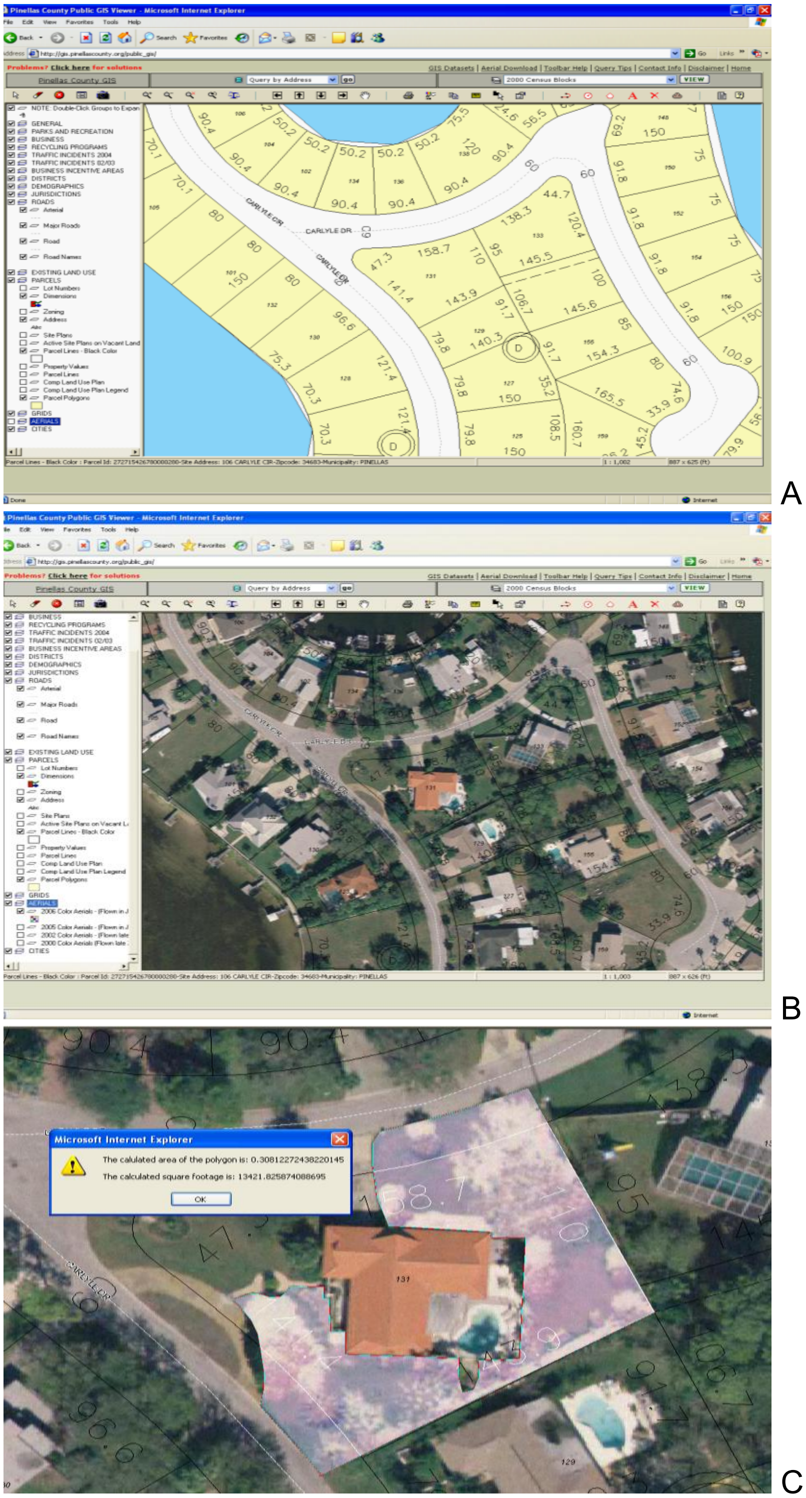


Figure 4-8. Property information data collected from Pinellas County public GIS server. A) Parcel map. B) Parcel map with areal imagery overlay. C) Calculated area using polygon tool. Screen shots courtesy of http://www.gis.pinellas.org.

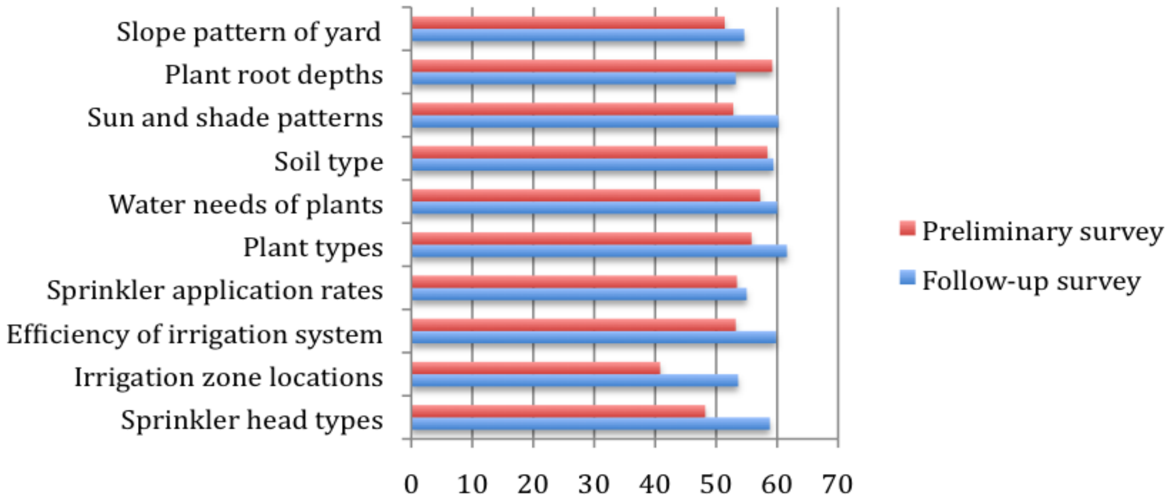


Figure 4-9. Knowledge scores from preliminary (RCW group only, n=28) and follow-up (all participants, n=45) surveys for landscape and irrigation system characteristics.

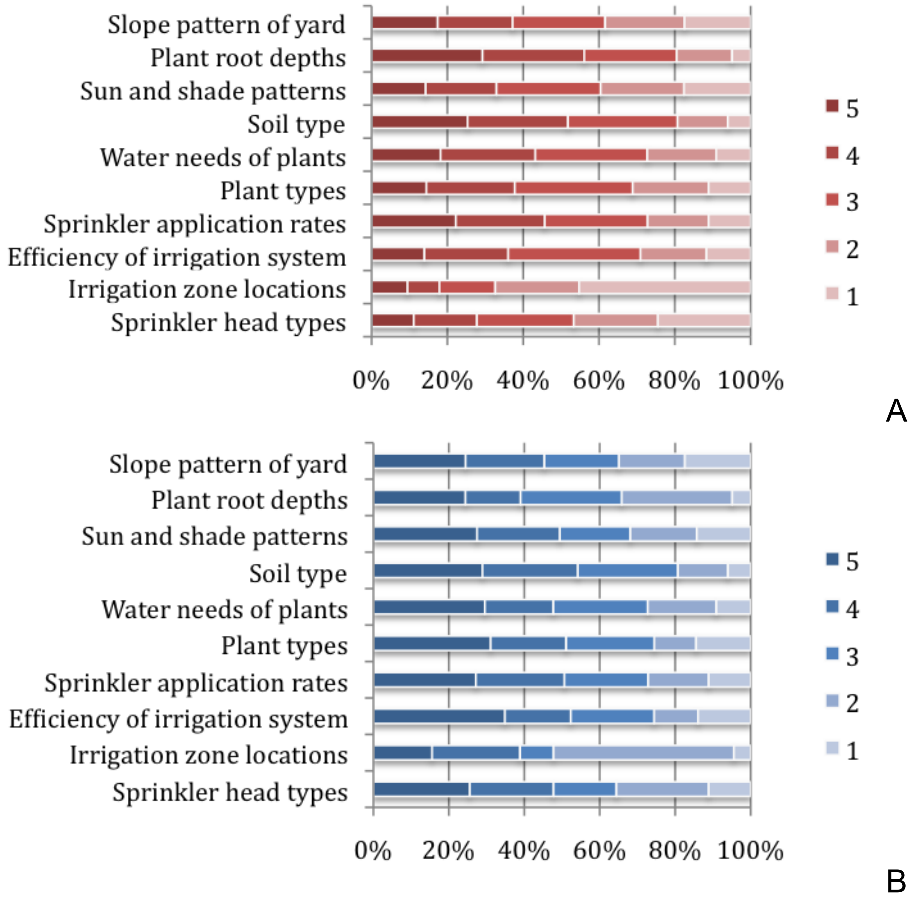


Figure 4-10. Level of familiarity of lawn and landscape characteristics rated from 5 to 1, where 5 represents the highest level of knowledge from (A) preliminary survey responses, RCW group only (n=28); (B) follow-up survey responses for all participants (n=45).

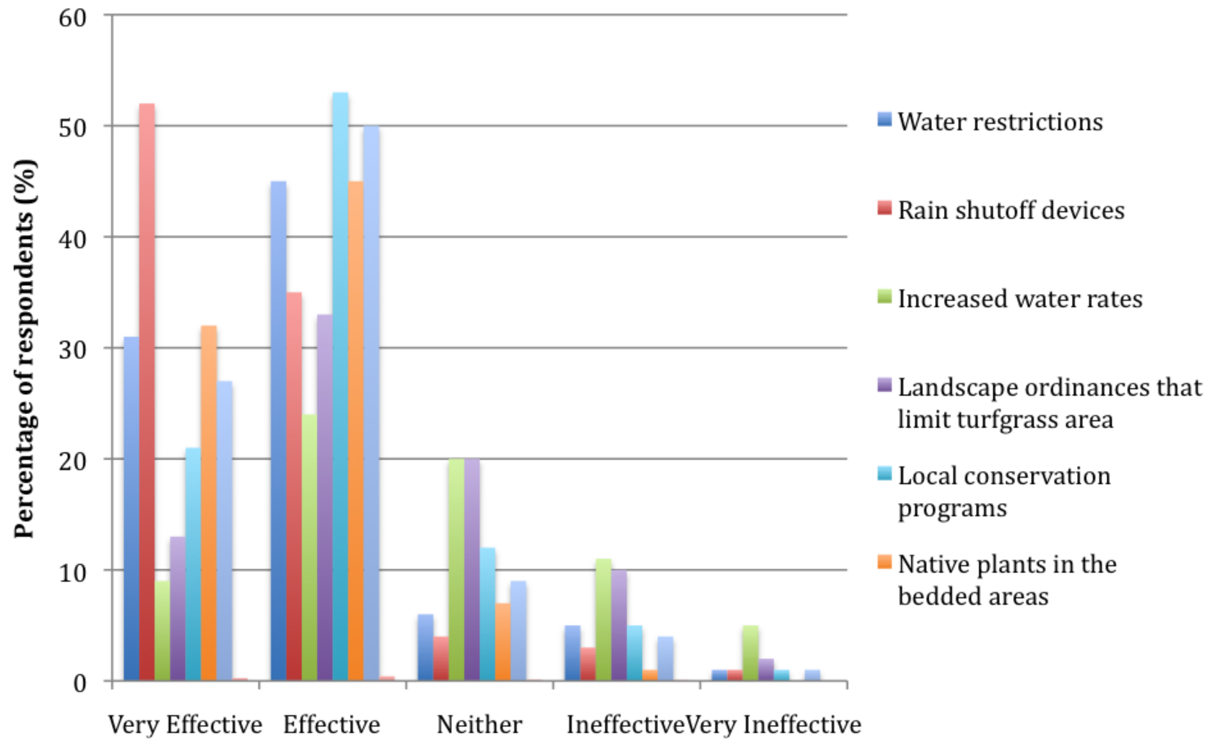


Figure 4-11. WWIPP Phase II respondent opinion of effectiveness of various water conservation methods (n=45)

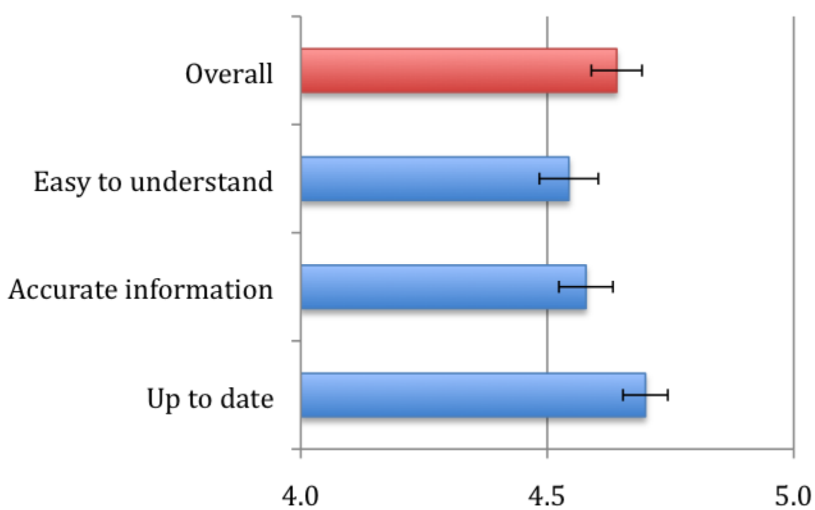


Figure 4-12. WWIPP Phase II program satisfaction scores with standard error bars (n=45)

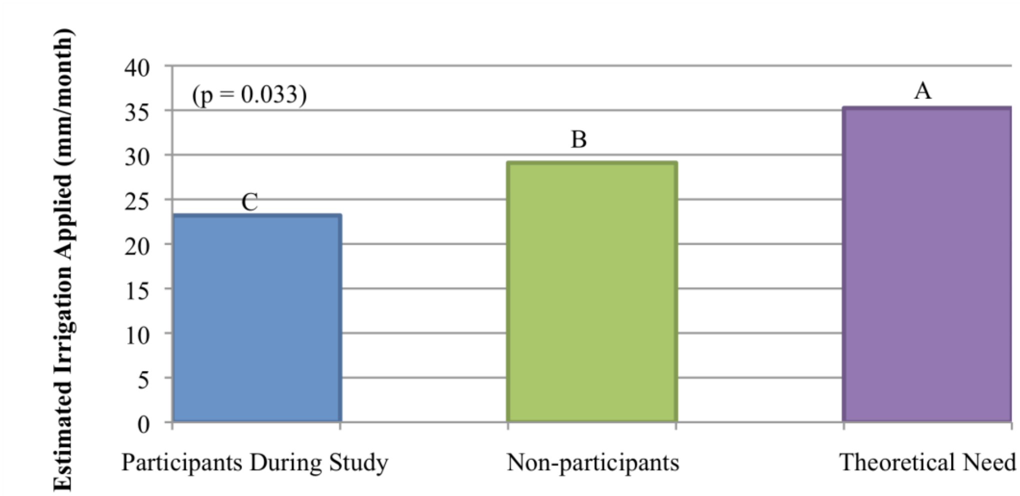


Figure 4-13. Comparison of irrigation water use during the 2010 study period. Upper case letters denote significant differences at the 95% confidence level based on Duncan's Multiple Range Test.

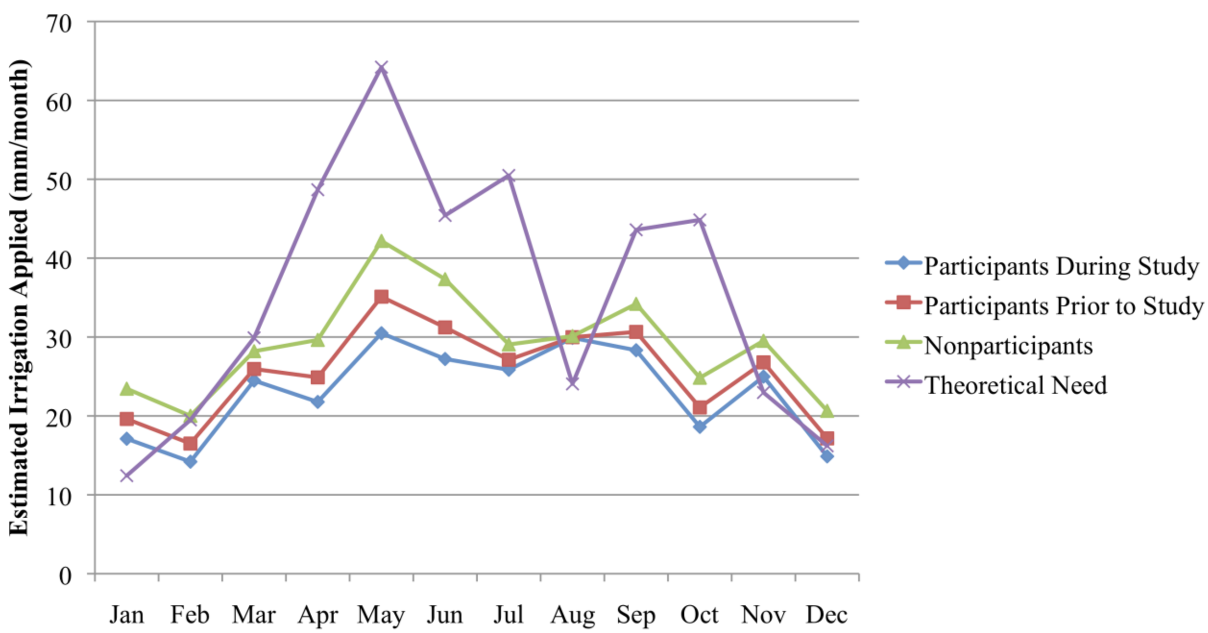


Figure 4-14. Comparison of estimated irrigation applied monthly.

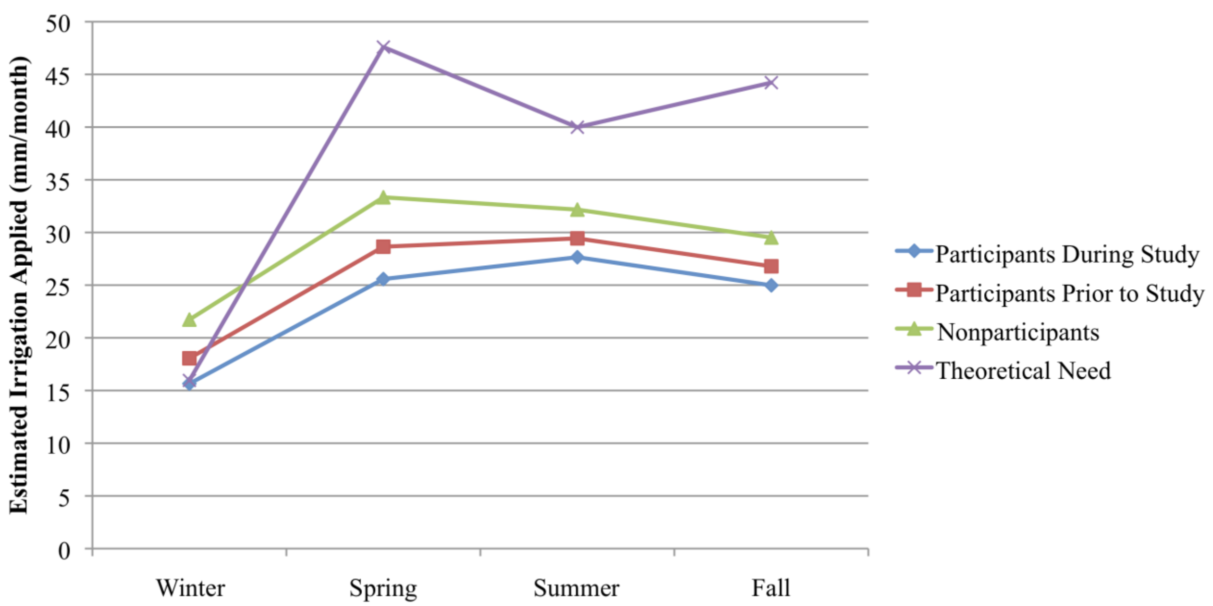


Figure 4-15. Comparison of estimated irrigation applied per season.

CHAPTER 5
IDENTIFY AREAS OF NEED FOR INCREASED PUBLIC AWARENESS OF IRRIGATION PRINCIPLES

Background

It is often thought that domestic irrigators typically set their irrigation time clocks and do not adjust in response to changing climatic demands or rainfall. Informally this practice is referred to as the “set it and forget it”. Approximately 50% of the Florida residential landscapes with in-ground irrigation systems have time clocks that have programmed run times that are too long or operating too frequently or both (Olmsted 2008).

Homes with in-ground sprinkler systems have been shown to use over 40% more water than those that do not have an in-ground system (Mayer et al. 1999). It has also been documented that residential irrigation results in a substantial amount of wasted water with homeowners in parts of the state applying two to three times plant water requirements (Haley et al. 2007).

Sensor-Based Conservation Technology

As of 2010 all homes with automatic in-ground irrigation systems are required to have a functioning rain shut-off device (Florida Statutes, Chapter 373, Section 62). The most simplistic of the sensor-based technologies with conservation potential is an automatic rain sensor for irrigation systems. More advanced technology has also been developed to conserve irrigation water use, which can save significant amounts of water without compromising turfgrass quality, but requires more initial homeowner interaction and a higher level of knowledge on the part of the installers. The newer “smart” devices include SMS and weather-based controllers. However, the ordinance has been loosely enforced at best, which has led to many homes, including new construction, neglecting to install rainfall shut-off devices.

Rain sensors are the most common type of senor used in conjunction with automatic irrigation systems. They should be installed in an area unobstructed from rainfall so that after a rain event the sensor causes the system to bypass and prevent unnecessary irrigation. According to UF-IFAS research, systems that incorporate rain sensors used significantly less water than systems without a functioning rain shut-off device. Although the rain sensor treatment in Chapter 2 resulted in a 14% less irrigation, this difference was not statistically significant compared to the treatment without a sensor. The lack of statistical significance was due to the large amount of variability and non-normality of the irrigation use data. In contrast, plot studies yielded an average weighted significant savings of 20%, with a range from 7% to 34%, when using rain sensors (Cardenas-Lailhacar et al. 2010; Cardenas-Lailhacar et al. 2008; McCready et al. 2009),

More advanced irrigation technology resulted in greater water savings. “Smart” irrigation controllers such as SMS controllers offer the opportunity to optimize irrigation based on measured plant demand in the irrigated system. The sensor system can result in the bypass of scheduled irrigation events based on soil moisture content. In a non-controlled setting, irrigation systems incorporating a soil moisture sensor system yielded a 65% savings (Chapter 2). Likewise, in a controlled setting, with the use of the same soil moisture sensor set at an equivalent threshold, irrigation savings yielded a weighted average of 65%, ranging from 11% to 92% for dry and rainy conditions, respectively (Cardenas-Lailhacar et al. 2010; Cardenas-Lailhacar et al. 2008; McCready et al. 2009).

Another type of “smart” controller is the weather-based controller (a.k.a. evapotranspiration (ET) controller or climate-based controller). These, devices use an estimation of ET to schedule irrigation and are typically programmed with site and landscape-specific conditions making them more efficient than time-based systems alone (Riley 2005). However, these devices require site-specific parameter input knowledge for proper installation and setup.

Aspects of Functionality

There are two aspects that affect the functionality of the irrigation system: technology and user interaction with the technology. The irrigation conservation devices listed above are technological components that can alter when irrigation events occur or length of those events. Local Water Management District (WMD) regulations have an influence on the use of bypass technology as well as the time and day settings for the automatic irrigation time clock. Additionally, weather and climactic awareness influence irrigation habits. During periods of drought, consumers are more willing to employ conservation techniques than during wet years (Baumann 1990). This may be because of increased public awareness stemming from more intense marketing on the part of WMDs and water purveyors.

Objectives

Water use and watering behavior was examined on individual homes to determine and document water use trends based on actual irrigation water use data and the local weather conditions, with known water restrictions. The objective of this chapter is to identify areas of need for increased public awareness and misunderstanding of irrigation principles.

Materials and Methods

To assess the individual level of irrigation water use trends, two data sources were examined: 1) water use data collected as part of a greater irrigation study in southwest Florida and 2) survey data as part of a greater irrigation study conducted in central Florida.

Study Design

The study design of the research presented in this chapter follows case study methodology. Case study research allows the researcher to capture and describe the complexity of a real-world event, in this case irrigation practices (Yin 2009). Providing a holistic approach will most effectively allow for in-depth analysis combining describing the behavior associated with irrigation technology.

Data Sources

Two distinct data sources were used to develop a more comprehensive understanding of irrigation practices and perceptions. The data sets come from homes residing in two different potable water service areas and under the jurisdiction of different WMDs. This means there were variations in the external influences (i.e. weather conditions or policy change) affecting watering practice behavior. Therefore, commonalities between the data sets will strengthen conclusions and the ability for such generalizations to be transferable, at least across central and southwest Florida.

The water use data was selected based on the robustness of this data set, due to the availability of dual meter data, known sensor-based technology level, irrigated area and percentage turfgrass of each site, as well as local precipitation and evapotranspiration. Conversely, the survey data was explicitly selected over the survey data presented in Chapter 3 because of the nature of instrument’s design. The survey instrument utilized in this Chapter was administered as a more cognitive interview, conducted via online instrument or telephone as requested, prompting for and accommodating considerable open-ended comment responses.

Participating Homes

The participants included in these research projects were all single-family residential irrigators with automatic in-ground irrigation systems using potable water. The participants were either located in Pinellas County, Florida within the Pinellas Anclotte Basin of the Southwest Florida Water Management District (SWFWMD) or Orange County, Florida within the St. Johns River Water Management District (SJRWMD) watershed.

Initial participant recruitment of both studies consisted of an advertisement in the corresponding service area customer water bill: Pinellas County Utilities (PCU) or Orange County Utilities (OCU).

Water Use Data

The water use data is based on PCU study homes (Chapter 2), where approximately 200 customers responded to the initial advertisement by telephone communication. The interested participants were then invited to local workshops. The final count of qualified participants was 59 homes. Qualification criteria were based on proximity to weather station locations and baseline turf quality and landscape level ratings. A secondary irrigation meter and meter reading device was installed at each home (Chapter 2). For this analysis, weekly irrigation water use and weather was collected and analyzed for 73 weeks at the 59 sites.

Water use ratio

Weekly total water use was evaluated by two methods: (1) actual water use (I_{actual}) measured at each site, and (2) theoretical need (I_{gross}) based on a daily soil water balance (SWB) model. Four unique categories were considered:

- Irrigation was applied at the site and irrigation was needed based on the SWB. Therefore, $I_{actual} > 0$ and $I_{gross} > 0$.
- Irrigation was applied at the site, but irrigation was not needed based on the SWB. Therefore, $I_{actual} > 0$ and $I_{gross} = 0$.
- Irrigation was not applied at the site, but irrigation was needed based on the SWB. Therefore, $I_{actual} = 0$ and $I_{gross} > 0$.
- Irrigation was not applied at the site and irrigation was not needed based on the SWB. Therefore, $I_{actual} = 0$ and $I_{gross} = 0$.

The I_{gross} represents the calculated gross irrigation requirement (I_{gross}). Gross irrigation was determined by dividing the net irrigation requirement from the SWB model, I_{calc} (Chapter 2, Equation 2-7), by an efficiency factor (IE). The IE is greater than low quarter distribution uniformity (DU_{lq}) alone, as it takes the lateral movement of water in the soil into account and is calculated with the following equation (IAEF, 2010):

$$IE = 0.4 + (0.6 \times DU_{lq}) \qquad \text{Equation 5-1}$$

The DU_{lq} was calculated by performing a catch-can test at the site as part of the irrigation audit described in Chapter 2 and presented as a decimal.

From the water use categories listed above, a ratio of water use can be calculated from the equation:

$$Water\ Use\ Ratio = I_{actual} / I_{gross} \qquad \text{Equation 5-2}$$

Where, I_{actual} is the sum of the weekly water use applied (mm) at each house and I_{gross} is the sum of the weekly gross irrigation requirement calculated by the SWB for that house.

The water use ratios quantify over or under irrigation and calculated in the cases were the inequalities $I_{actual} > 0$ and $I_{gross} > 0$ are both satisfied. A value over 1.00 represents the fraction of irrigation applied beyond the SWB requirement. Likewise, a value lower than 1.00 represents the fraction of water applied less than the needed.

Due to the extreme non-normality of the data set, the ratio is only calculated for first category listed above, and not when $I_{gross} = 0$. The introduction of the categories elevated some of the strong kurtosis of the dataset, allowing better observation of the actual irrigation behavior.

Irrigation conservation level

Homes used in this analysis are grouped based on irrigation conservation level in the form or sensor based technology and educational materials. Where homes fell into one of four treatment groups (Chapter 2 has detailed methodology of these treatments):

- SMS: soil moisture sensor system, coupled with the time clock irrigation controller.
- EDU: current irrigation system with an added mini-click rain sensor as well as educational materials with time clock run times for a given time of the year based on UF-IFAS recommendations.
- RS: a mini-click 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.

The list above presents the treatment groups from greatest to least "conservation potential" based on sensor based technology and educational materials.

Survey Data

Survey administration

A survey instrument (Appendix F) was distributed to 795 potential OCU household participants via email correspondence. Although the questionnaire was developed as an online instrument, the participants were provided the option for a hard copy version or telephone interview. The initial advertisement was followed by two additional reminder emails to non-respondents, after one, three, and five weeks of elapsed non-response.

Survey instrument

The survey instrument was developed by UF-IFAS and in compliance with the University of Florida Institutional Review Board protocol and reviewed by OCU. This survey was developed following the PCU survey in Chapter 3, elaborating upon the areas of greatest interest based on the conclusions and points of deficiency. The instrument prompted for and accommodated considerable open-ended comment responses, acting as an interactive cognitive interview. In addition to questions relating to watering practices and familiarity/trust regarding irrigation technology, a series of questions relating specifically to the functionality and appropriate use of irrigation conservation technology was asked to each participant. After each of these more technical functionality questions, the participant was provided with the correct answer and a brief explanation of the concept. These technical questions were used to gage the knowledge of the participant group. Benchmark knowledge scores were calculated based on factor analysis criteria.

Index development

An index was developed by combining the responses to questions relating to time clock interaction level, system and site characteristics, and irrigation conservation knowledge; this index was coined the “domestic irrigator index”. Conceptually, this index concurs with the water savings findings from Kennedy/Jenks (2008) of domestic irrigators of self-installed controllers, where the ability to self-install would require a high level index score.

The interaction level with the time clock was measured on a 5 point Likert-scale with the question “please rate how often you currently interact with (i.e. check or adjust) your irrigation time clock”. The parameter input score was developed based on the 5 point Likert scale responses of familiarity to the following system and site characteristics:

- Amount of sun and shade around the yard
- Number of zones
- Sprinkler head type within a zone
- Plant type (i.e. turfgrass or bedded area)
- Soil type (i.e. sand or clay)

The knowledge score was calculated as the number of correct answers to the following irrigation system scheduling, conservation technology functionality, and installation questions:

- Which of the following factors need not be considered when programming the run time for each zone on your irrigation system (a.k.a. irrigation scheduling)?
- Which of the following locations would be an ideal spot to install a rain sensor?
- When might a soil moisture sensor system bypass an irrigation event?
- An ET controller (a.k.a. weather based controller) is an irrigation controller that __________ (mark the best answer)
- Where are rain shutoff devices (i.e. rain sensors or soil moisture sensors) required by law in Florida?

Statistical Analysis

Analysis of data began with the use of questioning. Questions were used to generate ideas or ways of looking at the data. The questions aided in triangulation of data because the stimulus for a question sometimes occurred in the data source while the answer to that question appeared in a different data source.

Due to the nature of variables included in the analysis presented in this chapter, a number of different techniques were employed based on the criterion and independent variable scales and markedly non-normality of the actual water use. Where the criterion (a.k.a. dependent variable) and the independent variable was a nominal scale, the chi-square test of independence was used to determine if there was a significant relationship between variables. To determine correlation between variables where ordinal scales are included, the Spearman correlation coefficient is used in lieu of Pearson's correlation coefficient. Spearman correlations are also appropriate for non-normal interval and ratio level variables. Additionally, multivariate analysis was used as an assessment of the direct and indirect effects for related variables. For this data, statistical analyses were performed using univariate, and general linear model, GLM procedures of the SAS software (SAS 2004). An analysis of variance was used to determine main effect differences through PROC GLM and means comparisons were performed with Duncan's Multiple Range Test at a 95% confidence level.

The comments provided by participants served as an integral part of the survey data. These comments were coded and categorized following qualitative research data analysis procedures to develop appropriate themes (Corbin and Strauss 2008). Analysis of survey data included microanalysis of coding procedures of the open-ended comment data began with open-ended coding. This requires the data to be broken into discrete parts before being more closely examined. The open-ended coded was followed with axial coding. The data was then grouped by emerging categories and themes. However it should be noted, with such data analysis the methodology is somewhat recursive. The emerging themes were derived to identify conceptually congruent statements for each domain. Through factor analysis, the latent factors that are responsible for the covariation in the data set are identified (Hatcher 1994). The factor analysis procedure followed uses square multiple correlations as prior communality estimates.

Results

Water Use Data

The water use data analysis consisted of a 73 week period from fall 2007 through winter 2009 on the PCU homes. The calculated I_{gross} for each site incorporated the system specific IE. Overall the IE had an average value of 76%. The average was slightly lower than the standard efficiency assumption value of 80% for typical systems in Florida (Dukes et al. 2008), used as part of the SWB in Chapter 2 (Haley and Dukes 2011). However the individual IE values in this analysis ranged from 57% to 91% with a standard deviation of 9%.

The water use habits of the PCU homes were broken into four irrigation categories (Figure 5-1). The scenario where irrigation was neither applied nor needed, $I_{actual} = 0$ and $I_{gross} = 0$, occurred 36% of the time, followed by irrigation applied but not needed, $I_{actual} > 0$ and $I_{gross} = 0$, occurring 26% of the time, then applied and needed, $I_{actual} > 0$ and $I_{gross} > 0$, at 21%. The least common scenario was when irrigation was not applied but needed, $I_{actual} = 0$ and $I_{gross} > 0$, 19% of the time. Additionally, there is an interaction between season and treatment when looking at the water use category ($p = 0.03$, Table 5-1). However this interaction is not significant for water use ratio ($p = 0.08$, Table 5-2).

Role of weather

Correlations existed between the water use categories and weekly landscape evaporation rate (ET_L) and effective rainfall. Where, either a rise in ET_L or rainfall frequency resulted in a shift in irrigation trends. There was a moderate positive correlation between a rise in weekly landscape evapotranspiration rate (ET_L) and irrigation use ($r = 0.52$, $p < 0.0001$). There was also a negative correlation between effective rainfall and irrigation use ($r = -0.38$, $p < 0.0001$). With an increase in effective rainfall, there is a decrease in irrigation use. The correlation was stronger with effective rainfall rather than overall precipitation. A domestic irrigator cannot fully realize to what extent precipitation is effective without considering the factors of soil water characteristics. However, the effectiveness of rainfall with respect to rainfall characteristics (i.e. amount, frequency and intensity) and crop response (i.e. turfgrass growth) is observable and can relate to the irrigation behavior (Dastane 1978).

Variations due to change in weather pattern can be characterized by season of the year. Season is defined as: spring, March, April, May; summer, June, July, August; fall, September, October November; winter, December, January, February. Where, season reflects the combination of ET_L, precipitation, and time of year, and can act as a statistical index, accounting for 77% of the variability (Cronbach's $\alpha = 0.8$, eigenvalue = 2.3). Weekly I_{gross} varies by season ($p < 0.001$), where weekly supplemental irrigation, I_{calc}, is needed most during the spring months, followed by fall, summer, then winter, with a significant difference between need for each season.

There was also a significant difference between the irrigation applied ($p = 0.002$) at the sites, I_{actual}, number of unneeded events ($p = 0.009$) by season (Tables 5-2 and 5-

3). As evident by water use ratios in Table 5-2, the homeowners tended to over-irrigate 1.5 to 2 times all but the spring months. Likewise, unnecessary events occurred most often during winter and summer months.

Irrigation technology

There was also correlations between the water use categories and treatment, where sensor-based "conservation potential" resulted in a shift toward more efficient irrigation trends, χ^2 (9) = 627, $p < 0.0001$. Sensor-based irrigation "conservation potential" realized through this analysis is presented in Table 5-1. Homes with soil moisture sensors, the treatment with the highest "conservation potential" were the dominant treatment group (39%) of the category where weekly irrigation was neither required nor applied, $I_{actual} = 0$ and $I_{gross} = 0$.

For any given week where irrigation was applied at the site but irrigation was not needed based on the SWB model, $I_{actual} > 0$ and $I_{gross} = 0$, yields the percent of unnecessary events either not bypassed or inappropriately scheduled. In this scenario, the "conservation potential" of the SMS treatment is again realized, whereby the SMS treatment resulted in the significantly lowest number of unnecessary events, particularly during the winter, (Tables 5-1; Figure 5-2) as well as the lowest average irrigation applied per week, ($p = 0.0001$), Table 5-3.

It should be noted that Figure 5-2 only displays irrigation application for the scenario where irrigation was applied but not required based on the theoretical need ($I_{actual} > 0$ and $I_{gross} = 0$). During the spring months, $I_{gross} > 0$, therefore the irrigation application is not represented in Figure 5-2. Alternatively, Figure 5-3 illustrates the water use ratio where both $I_{actual} > 0$ and $I_{gross} > 0$.

When irrigation was applied and needed, $I_{actual} > 0$ and $I_{gross} > 0$, the water use ratio was also significantly lower for the SMS treatment, where this was the only treatment where I_{actual} was less than I_{gross} (Table 5-2; Figure 5-3), consequently suggesting under-irrigation based on I_{gross}. However, more importantly providing some evidence towards the effectiveness of the SMS system on conservative watering practices.

The effectiveness of only a rain sensor is less evident (Figures 5-2 and 5-3). From Table 5-2, although the water use ratio suggests over-irrigation compared to I_{gross}, the irrigation applied is significantly lower ($p < 0.001$) than that found at the homes with no type of bypass sensor installed denoting the lowest "conservation potential". In many instances, for the water use categories where irrigation was applied at the site but irrigation was not needed, or not applied and needed, the RS and MO treatments did not differ (Tables 5-1 and 5-3). The water use trends between the homes with rain sensors versus no sensor is statistically ($p < 0.001$) apparent with the EDU treatment (Table 5-3) where the rain sensor was coupled with a run-time card when considering the cases where irrigation was not applied and not needed. However, the average applied irrigation during unnecessary events was significantly lower ($p < 0.0001$) for the rain sensor treatments than for the MO treatment (Table 5-3; Figure 5-2). These observations tend to agree with plot study findings that if the irrigation schedule is appropriately set, the rain sensor will bypass as needed (Cardenas-Lailhacar et al. 2010; Cardenas-Lailhacar et al. 2008; McCready et al. 2009); although, the response of these homes is not as strong as with the plot studies likely due to varying control of the irrigation system by homeowners.

Watering restrictions

Watering day/time restrictions are established to effectively modify irrigation practices. Figures 5-4 though 5-5 display examples of the I_{actual} for four individual homes during a 70-day period. These graphs demonstrate the effectiveness of the sensor functionality as well as the effectiveness or reluctance towards watering day restrictions. Figure 5-4 depicts a MO home that is not in compliance with the once per week watering restriction as where Figure 5-5 depicts a MO home that is in compliance with the local watering restriction. Both of the MO homes depicted in Figures 5-4 and 5-5 show consistent irrigation application over the time period regardless of precipitation. On average, the MO treatment applied more unnecessary events than any other treatment with the greatest occurrences during the fall months (Table 5-1).

A home with a functioning rain sensor is illustrated in Figure 5-6. It can be seen that although this particular home is not in compliance with the 1-day per week watering restriction, the sensor is effectively reducing irrigation events. Finally, Figure 5-7 presents the water use frequency of a home with a soil moisture sensor. During times of consistent rainfall (Figure 5-6, mid-June through July 2008), no supplemental irrigation was applied at the example SMS home. Comparing the effectiveness of the sensor technologies in Figures 5-6 and 5-7, in periods of moderate rainfall (May 2008), the SMS appears to be more efficiently bypassing irrigation event versus the rain sensor, which concurs with the average trends in Figures 5-2 and 5-3. Although a site with a sensor may not be in compliance with the 1-day per week watering restriction, the utilization of the sensor does act a governor, particularly with a device such as a soil moisture sensor with an adequately set threshold (Haley and Dukes 2011).

Survey Data

The OCU survey yielded a 62% response rate (n = 490) and from this, qualitative analysis of self-reported data was performed. The analysis presented is broken down into (1) interaction with irrigation and landscape and (2) irrigation knowledge assessment.

Interaction with irrigation and landscape

Respondents were provided the opportunity to describe their interaction level. The mean response to the 5 point Likert scale was 3.1, with a standard deviation of 1.3. These comments inferred trends for interaction prompts. The most common optional comment referred to the need to manually adjust the irrigation controller due to precipitation events (25%). Other prompts included adjustments to the watering schedule based on day light savings (12%) followed by seasonal change (8%). Other comments included the need to interact with the timer based on changes to watering restrictions (8%), solely based on observation (8%), and following a power outage (7%). A small percentage of the respondents (5%), evaluate the system performance 3 to 4 times per year. Additionally there were two categories that suggested reasons why the participant does not interact with the controller: limited by irrigation system equipment (5%) and limited by timer setting ability (3%).

Major changes to the lawn/landscape included turfgrass resodding (57%), replanting within the bedded areas (21%), and planting or trimming of trees (11%). Additionally, 11% of the comments noted a desire to make changes with a limitation due to current weather. While the majority of the repairs performed to the irrigation system were to the heads (74%), 18% commented specifically on effort to reduce overspray or increase the distribution uniformity of the system. Other changes to the system included modification to the controller (18%), general maintenance (6%), and valve repair (3%).

Irrigation knowledge assessment

Familiarity with irrigation technology and concepts are primary parameters when assessing the participants' knowledge and trust of device functionality, Table 5-4. The participants surveyed here responded similarly to previously surveyed single-family homes within Florida (Haley and Dukes 2009). The most commonly known irrigation conservation device was the rain sensor (85%), followed by soil moisture sensors (20%). The low level of familiarity with ET controllers (7%) makes sense, as these are the newest product to emerge within the local market. Finally, 15% were unfamiliar with any type of irrigation conservation technology. The participants were also asked about their familiarity with common input parameters needed for advanced "smart" irrigation technology: number of zones (90%, n = 404), amount of sun and shade around yard (73%, n = 353), irrigation sprinkler type within a zone (56%, n = 253), plant type within a zone (52%, n = 235), and soil type (40%, n = 178). The response to the input parameter questions resulted in an input parameter score ranging from 1 to 5, with an overall mean score of 3.2 and a standard deviation of 0.9.

When asked which of these technologies they would trust to appropriately bypass unnecessary irrigation events, both rain sensors and soil moisture sensors yielded a level of trust by more than half of the participants, Table 5-4. Survey participants were also given the opportunity to comment on their reasoning for trust, or lack of trust, regarding irrigation technology providing justification for the following themes. The dominant motives for distrust were lack of familiarity with "smart" irrigation technologies followed by questioning of the functionality of rain sensors. An interesting theme that arose was the inclination towards the use of soil moisture sensor systems over the other devices listed. Lastly, there was a theme relating to the proper installation. When directly asked whom the participants would trust to install or set the technology, irrigation contractors were the most trusted followed by UF-IFAS Extension or Florida Yards and Neighborhoods personnel. Less than 20% of the respondents would trust themselves to properly setup or install the technology correctly. These response percentages are illustrated in Figure 5-8. A weak, albeit significant, correlation existed between trust and familiarity with “smart” technology, but not rain sensors. The correlation increases to $r = 0.44$ ($p < 0.0001$) when there is trust for one of the “smart” devices there will be trust for the other.

As part of the pre-test questionnaire, the participants were asked direct irrigation scheduling and technology function knowledge questions. These questions combine to yield a knowledge score. The percentages correct for each of the knowledge questions are displayed in Table 5-5. The knowledge score was ranged from 0 to 5, with the overall mean of 3.0 and a standard deviation of 1.5. The question relating to irrigation law specifically focused on when rain shut-off devices are required. The most common answer (30%) was an incorrect option stating that irrigation shut-off devices are not required on irrigation systems within Florida. The most common response for all of the other questions was the correct answer and a moderate significant correlation exists between the overall knowledge score and system input parameter knowledge score, where $r = 0.55$ ($p < 0.001$). Further, characterization of the domestic irrigator can be measured by combining the interaction level time clock, knowledge score, and parameter score estimated overall domestic irrigator index, accounting for 53% of the variability (Cronbach's α = 0.7, eigenvalue = 1.6).

The latent factors that are responsible for the covariation in the data were categorized by three unique factors. The participants can be characterized into two opposing groups, those with technological trust vs. then hands-on irrigator. The first factor represents the irrigation conservation technology trust through a comprehension level. The factor was loaded by rain sensor, soil moisture sensor, and ET controller familiarity, trust, and knowledge responses. This factor accounts for 34% of the common variance. When asked what the most common motivation was for the use of efficient irrigation technology, 65% of the respondents reported "to save water", and 30% reported "to save money". Only 1% of respondents were motivated by the time saving aspect of the devices.

The second factor represents the hands-on participant, where the latent variables responsible include satisfaction with landscape/irrigation, level of interaction with the time clock, and influence of season and weather. This factor accounts for another 32% of the common variance. The third factor, which resulted in the remaining 26% of the common variance, represents the non-weather related external influence on irrigation behavior. This factor is comprised of the influence resulting from watering restrictions, policy/social aspects, observation of neighbors, and homeowners associations. The self-reported influence ratings, from external parameters on watering practices, are displayed in Figure 5-9.

Discussion

The water use habits of the PCU homes were broken into four irrigation categories. The most frequent scenario was irrigation neither applied nor needed, where the SMS treatment made up the highest proportion of this category. This would suggest that the SMS devices were effectively bypassing unnecessary or superfluous irrigation events. This result is further supported by the correlation between sensor-based “conservation potential” and water use trend, meaning sensor-based conservation potential not only positively impacts water savings, but also efficient watering behavior.

The next most common category was irrigation applied but not needed, suggesting inappropriate irrigation timing relative to actual weather patterns and an over-irrigation resulting from unnecessary events. In this scenario the MO treatment applied more unnecessary events than any other treatment with the greatest occurrences during the fall months. On the opposite end of the “conservation potential” spectrum, the SMS treatment applied the least unneeded irrigation, particularly during the winter. However, the SMS treatment did result in under-irrigation relative to the theoretical baseline. Although the theoretical baseline assumes full soil water replacement, acceptable landscape quality can be maintained over a wide range of moisture conditions (McCready et al. 2009). The least common scenario observed through the PCU water data was when irrigation was not applied but needed, inferring missed irrigation events.

The correlations existing between water use categories weekly ET_L, and effective rainfall, can be characterized by the weather factor and season, where either a rise in ET_L or rainfall frequency, resulted in a shift in irrigation trends. For example, a rise in ET_L yielded the tendency for increased irrigation application, regardless of irrigation need. This concurred with the trends reported from the OCU survey data. Conversely, winter weather impacted irrigation watering practices in both data sets. In these cases there was a reduction in ET_L, but also during this time there is often a change in turfgrass appearance, when warm season turfgrass will wan in color due to the affects of dormancy. During the winter months, the water use ratio was significantly the highest with homes applying nearly twice as much irrigation as needed. Winter was also noted in the OCU survey responses as a dominant influence on increased watering practices. The correlation between effective rainfall rather than overall rainfall suggested that the characteristics of rainfall amount, frequency, intensity, and turfgrass response are more influential on domestic irrigation behavior than simply the presence of rainfall alone.

From the survey data, there is a positive correlation between knowledge score and parameter score. These two scores, along with the self-reported time clock interaction level can be used to numerically characterize the domestic irrigator index.

The most incorrectly answered knowledge question was regarding the rain shut-off device requirement. Of the input parameter knowledge questions, plant type within a zone and soil type were the least known, where 50% or less of the responses stated knowledge of these parameters, and the response rate of these questions was less than 50% of the participants.

Homeowners typically adjust irrigation timers due to watering day/time restrictions. This theme agrees with the OCU survey responses and open-ended comments regarding influential factors on watering practices. Further, the domestic irrigator can be characterized into two groups, those with technological trust vs. the hands-on irrigator. The PCU water use data also shows influence of watering day/time restrictions, but more so how the “conservation potential” of the sensor-based technologies can help to govern unnecessary events.

Two barriers should be noted from the themes which emerged from the survey data: (1) there is concern over watering day/time allowances where participants commented that the lawn/landscape requires more water than permitted by restrictions and (2) concern towards rain sensor functionality. The watering restriction concern agrees with the self-reported data of influential factors on watering practices. The concern toward rain sensor functionality is related to the distrust towards technology.

Table 5-1. Distribution of irrigation event categories for each treatment by season, where significant differences are presented for each category row.

Water Use Category[Z]	Treatment[Y] Percentage of Events (%)			
	SMS	EDU	RS	MO
	Season[X]: Spring			
Irrigation applied and needed ($I_{actual} > 0$, $I_{gross} > 0$)	18 c[W]	26 b	29 a	27 a
Irrigation applied but not needed ($I_{actual} > 0$, $I_{gross} = 0$)	19 b	32 a	26 a	24 a
Irrigation not applied but needed ($I_{actual} = 0$, $I_{gross} > 0$)	31 a	27 b	23 bc	19 c
Irrigation neither applied or needed ($I_{actual} = 0$, $I_{gross} = 0$)	37 a	30 b	19 c	15 c
	Season: Summer			
Irrigation applied and needed ($I_{actual} > 0$, $I_{gross} > 0$)	13 c	23 b	40 a	25 b
Irrigation applied but not needed ($I_{actual} > 0$, $I_{gross} = 0$)	21 c	23 b	30 a	26 b
Irrigation not applied but needed ($I_{actual} = 0$, $I_{gross} > 0$)	20 b	17 b	31 a	33 a
Irrigation neither applied or needed ($I_{actual} = 0$, $I_{gross} = 0$)	34 a	27 b	16 d	22 c
	Season: Fall			
Irrigation applied and needed ($I_{actual} > 0$, $I_{gross} > 0$)	20 b	18 b	33 a	29 a
Irrigation applied but not needed ($I_{actual} > 0$, $I_{gross} = 0$)	19 c	23 bc	29 ab	30 a
Irrigation not applied but needed ($I_{actual} = 0$, $I_{gross} > 0$)	27 a	28 a	23 b	22 b
Irrigation neither applied or needed ($I_{actual} = 0$, $I_{gross} = 0$)	26 a	27 a	25 b	22 b
	Season: Winter			
Irrigation applied and needed ($I_{actual} > 0$, $I_{gross} > 0$)	19 b	21 b	38 a	22 b
Irrigation applied but not needed ($I_{actual} > 0$, $I_{gross} = 0$)	15 c	25 b	35 a	25 b
Irrigation not applied but needed ($I_{actual} = 0$, $I_{gross} > 0$)	32 a	21 b	21 b	26 a
Irrigation neither applied or needed ($I_{actual} = 0$, $I_{gross} = 0$)	30 a	30 a	20 b	20 c

[Z] Category based on actual water use (I_{actual}) at site and theoretical need (I_{gross}) based on the SWB.
[Y] Treatments are: SMS, time-based controller plus soil moisture sensor system with 10% volumetric water content threshold; RS, time-based controller plus rain sensor at 6 mm threshold; MO, time-based controller only; EDU, time-based controller plus rain sensor and educational materials.
[X] Season defined as: spring, March, April, May; summer, June, July, August; fall, September, October November; winter, December, January, February
[W] Numbers followed by different letters are statistically different at the 95% confidence level.

Table 5-2. Average weekly water use by season and treatment for the 73-week time period from fall 2007 through winter 2009. Where irrigation applied and water use ratio is presented when $I_{actual} > 0$ and $I_{gross} > 0$). Significant differences are presented in each column.

		Average Weekly Irrigation		Water Use Ratio[Z]
		I_{gross} (mm)	I_{actual} (mm)	I_{gross} / I_{actual}
Season[Y]	Spring	17 a[X]	16 bc	1.01 c
	Summer	13 b	17 ab	1.40 b
	Fall	10 c	17 a	1.82 a
	Winter	9 d	15 c	1.91 a
Treatment[W]	SMS	14 a	11 c	0.76 c
	EDU	14 a	16 b	1.35 b
	RS	13 b	17 b	1.45 b
	MO	13 b	19 a	1.69 a

[Z] Water use ratio equals actual water use (I_{actual}) at site divided by theoretical need (I_{gross}) from SWB, where $I_{actual} > 0$ and $I_{gross} > 0$.
[Y] Season defined as: spring, March, April, May; summer, June, July, August; fall, September, October November; winter, December, January, February.
[X] Numbers followed by different letters are statistically different at the 95% confidence level.
[W] Treatments are: SMS, time-based controller plus soil moisture sensor system with 10% volumetric water content threshold; RS, time-based controller plus rain sensor at 6 mm threshold; MO, time-based controller only; EDU, time-based controller plus rain sensor and educational materials.

Table 5-3. Average weekly water use for unnecessary events by season and treatment for the 73-week time period from fall 2007 through winter 2009. Where unnecessary irrigation is presented where $I_{actual} > 0$ and $I_{gross} = 0$. Significant differences are presented in each column.

		Unnecessary Weekly Irrigation[Z]	
		I_{actual} (mm)	Percentage of Events (%)
Season[Y]	Spring	14 c[X]	12 d
	Summer	16 ab	29 b
	Fall	17 a	16 c
	Winter	15 bc	42 a
Treatment[W]	SMS	11 d	18 c
	EDU	14 b	24 b
	RS	16 b	30 a
	MO	19 a	28 a

[Z] Unnecessary irrigation occurs at a site when $I_{actual} > 0$ and $I_{gross} = 0$.
[Y] Season defined as: spring, March, April, May; summer, June, July, August; fall, September, October November; winter, December, January, February.
[X] Numbers followed by different letters are statistically different at the 95% confidence level.
[W] Treatments are: SMS, time-based controller plus soil moisture sensor system with 10% volumetric water content threshold; RS, time-based controller plus rain sensor at 6 mm threshold; MO, time-based controller only; EDU, time-based controller plus rain sensor and educational materials.

Table 5-4. Distribution of responses to irrigation technology familiarity and trust questions.

Device	Familiarity (%)	(n)	Trust (%)	(n)
Rain sensor	86	388	57	257
Soil moisture sensor	20	92	52	235
ET controller (a.k.a. weather-based controller)	7	31	36	161
None	15	67	13	57

Table 5-5. Distribution of correct responses to irrigation technology knowledge questions.

Subject	Correct Response (%)	(n)
Irrigation scheduling	72	328
Rain shut-off device requirement	25	136
Rain sensor installation	87	395
Soil moisture sensor functionality	91	413
ET controller functionality	81	365

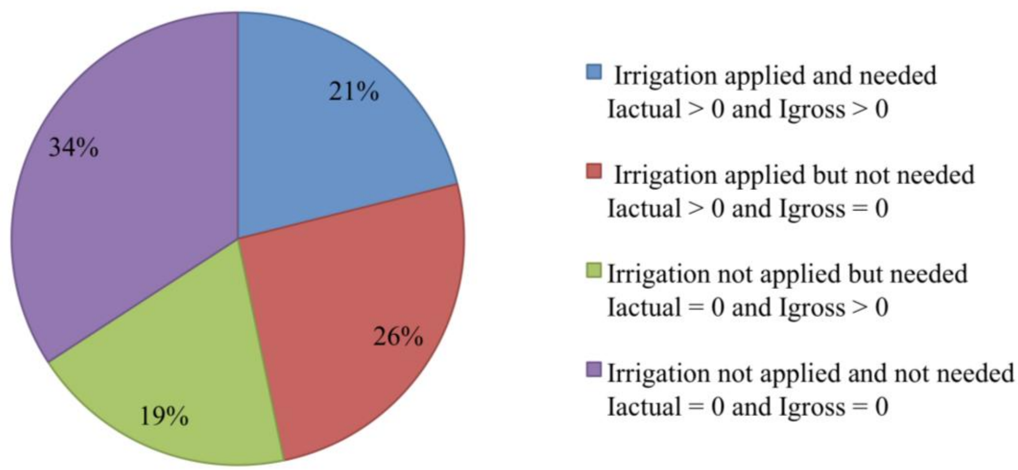
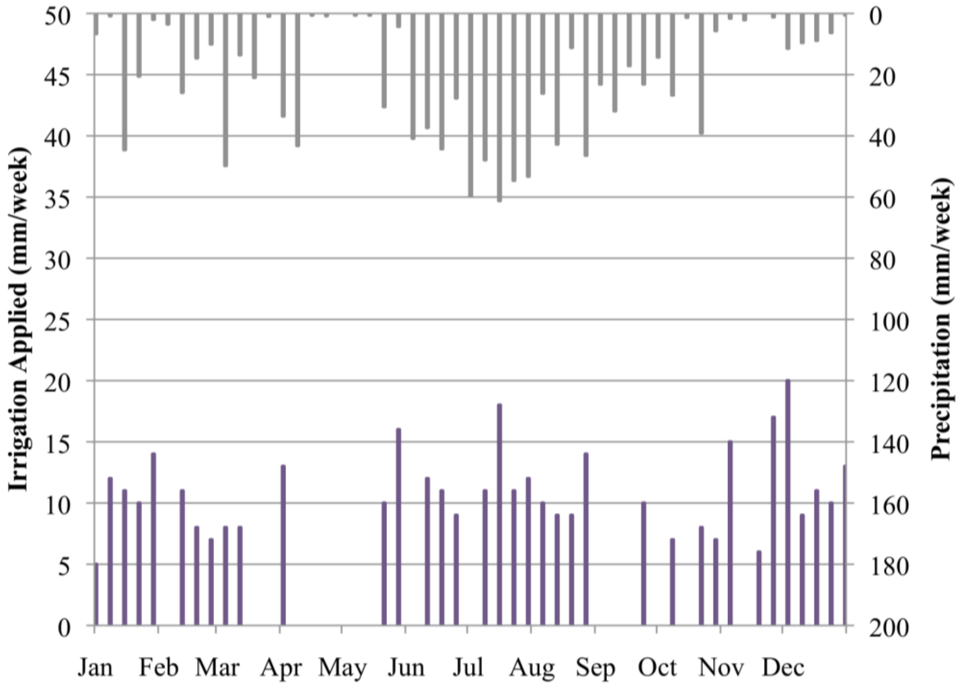
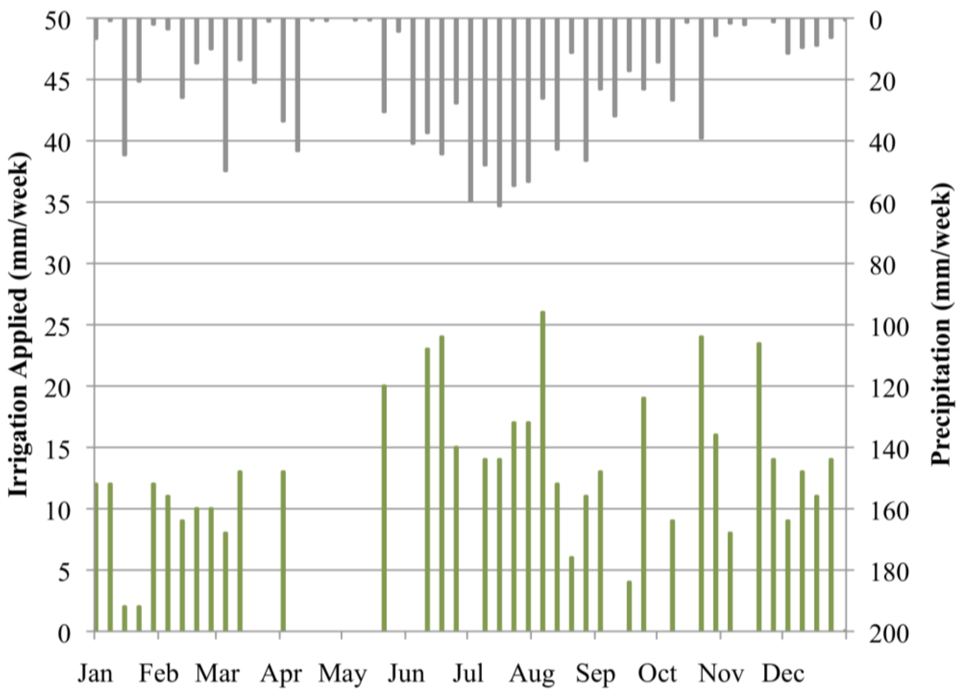


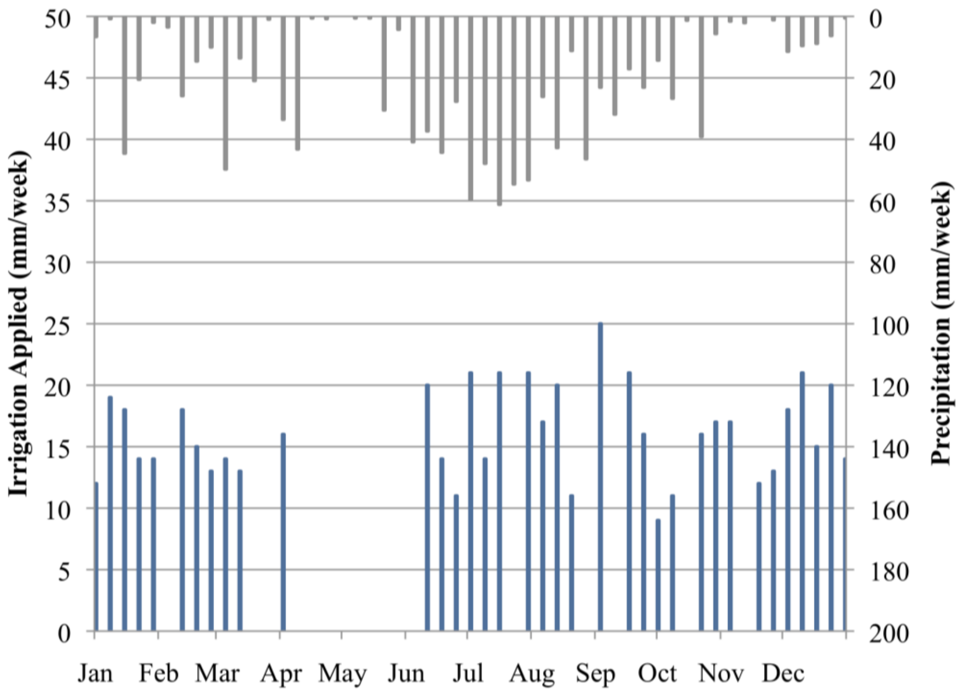
Figure 5-1. Distribution of sites within each water use category during the 73 weeks of data analysis of the PCU homes.


Irrigation Applied (mm/week)
Precipitation (mm/week)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

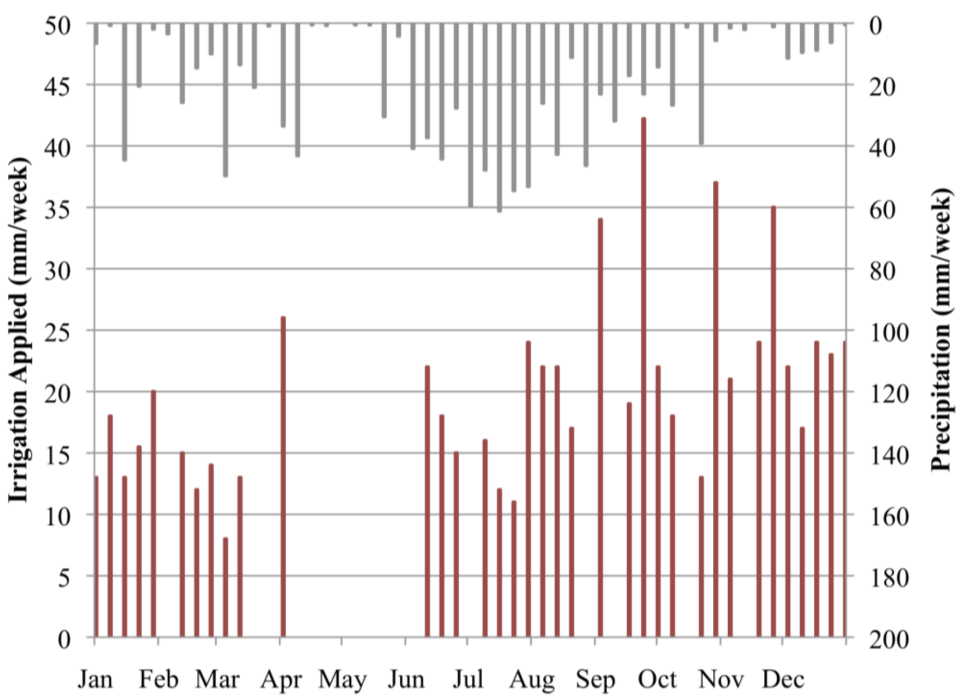
(A)


Irrigation Applied (mm/week)
Precipitation (mm/week)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

(B)

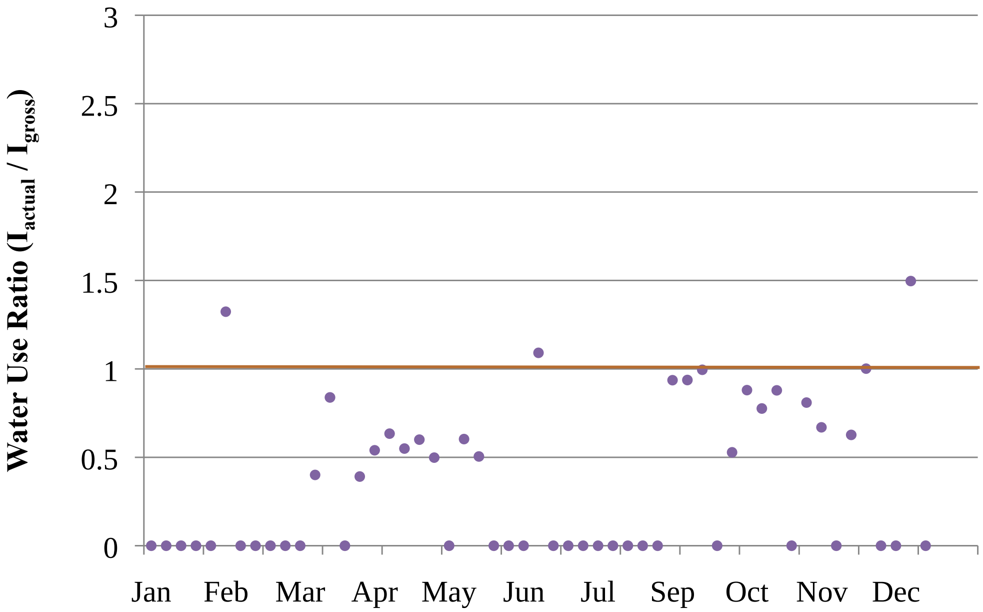


(C)

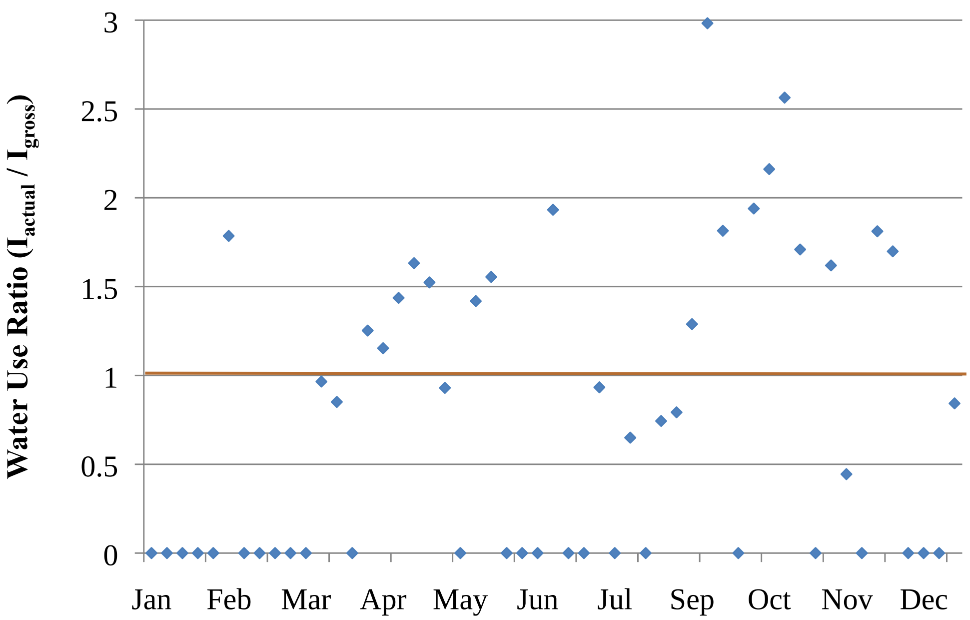


(D)

Figure 5-2. Water use for the category where irrigation was applied but not needed, $I_{actual} > 0$ and $I_{gross} = 0$, by treatment over across the months of the year. (A) SMS, time-based controller plus soil moisture sensor system with 10% volumetric water content threshold; (B) EDU, time-based controller plus rain sensor and educational materials; (C) RS, time-based controller plus rain sensor at 6 mm threshold; (D) MO, time-based controller only.


Water Use Ratio (I_{actual} / I_{gross})
3
2.5
2
1.5
1
0.5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Sep
Oct
Nov
Dec

(A)


Water Use Ratio (I_{actual} / I_{gross})
3
2.5
2
1.5
1
0.5
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Sep
Oct
Nov
Dec

(B)

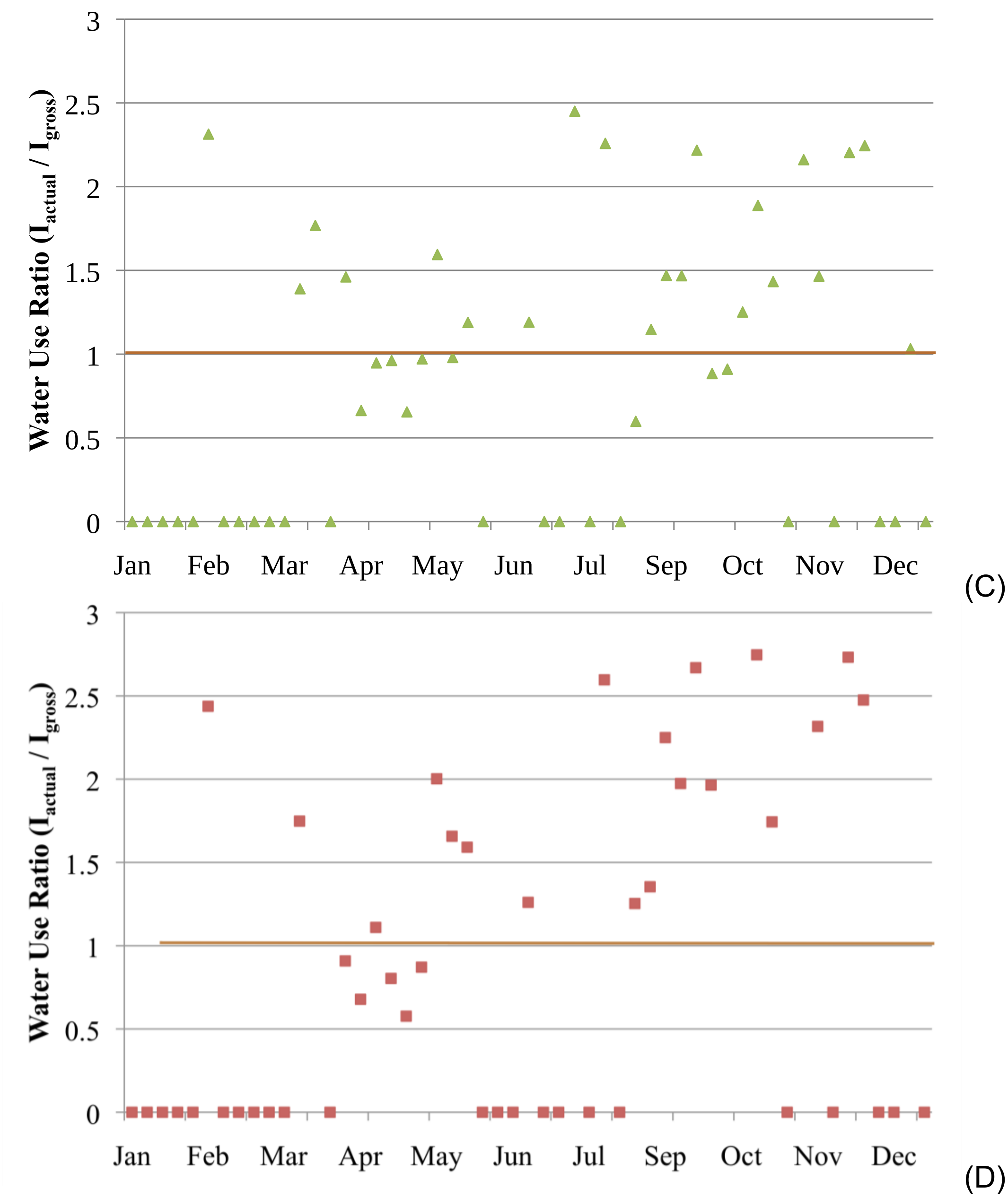


Figure 5-3. Water use ratio where $I_{actual} > 0$ and $I_{gross} > 0$ by treatment across the months of the year, where when $I_{actual} = I_{gross}$, the water use ratio = 1. (A) SMS, time-based controller plus soil moisture sensor system with 10% volumetric water content threshold; (B) EDU, time-based controller plus rain sensor and educational materials; (C) RS, time-based controller plus rain sensor at 6 mm threshold; (D) MO, time-based controller only.

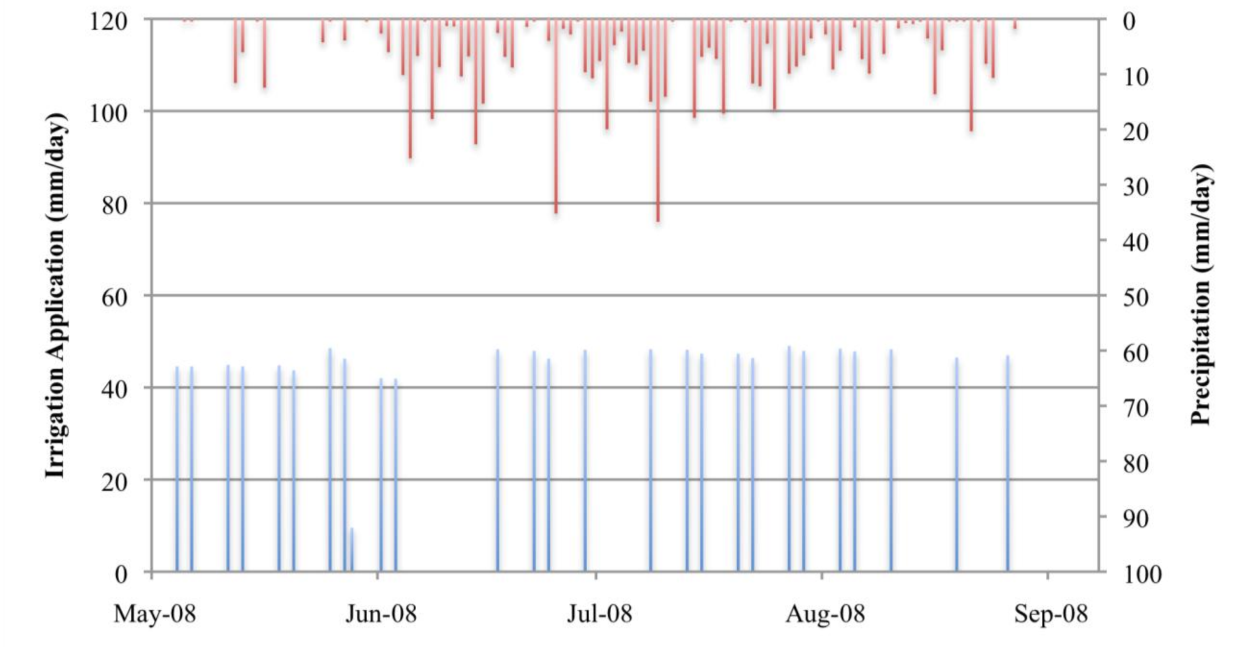


Figure 5-4. Irrigation frequency of a home not in compliance with the 1-day per week restriction. Blue columns denote irrigation application (mm/day). Red columns denote precipitation (mm/day).

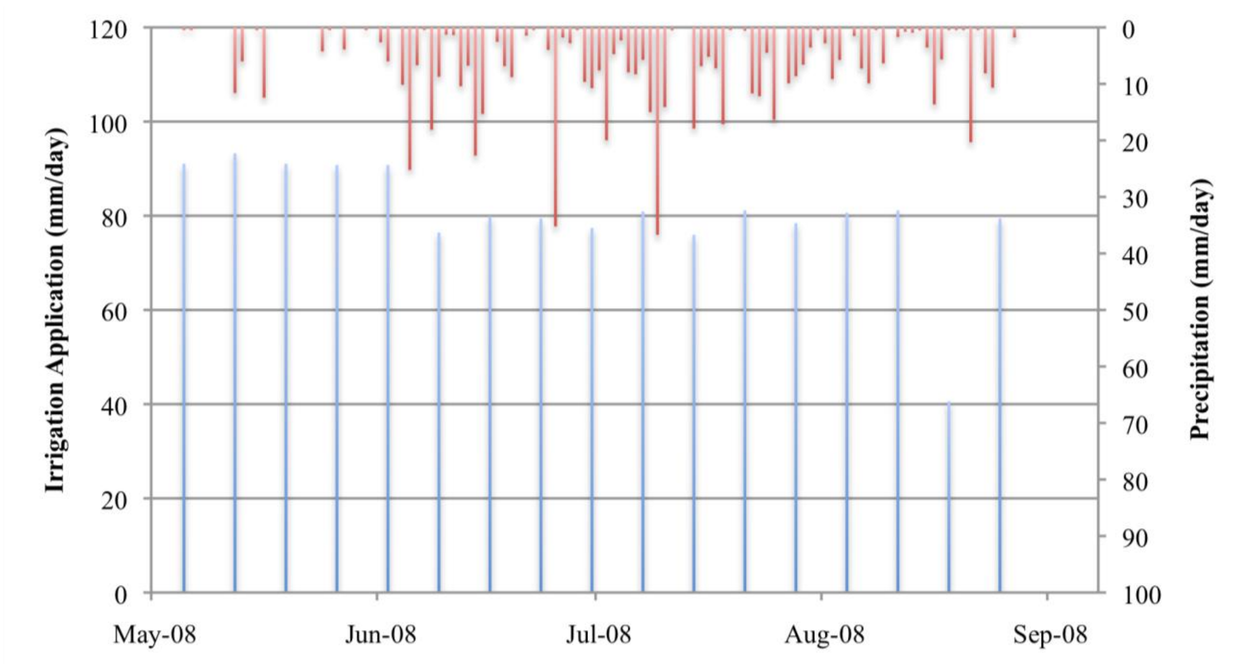


Figure 5-5. Irrigation frequency of a home in compliance with the 1-day per week restriction. Blue columns denote irrigation application (mm/day). Red columns denote precipitation (mm/day).

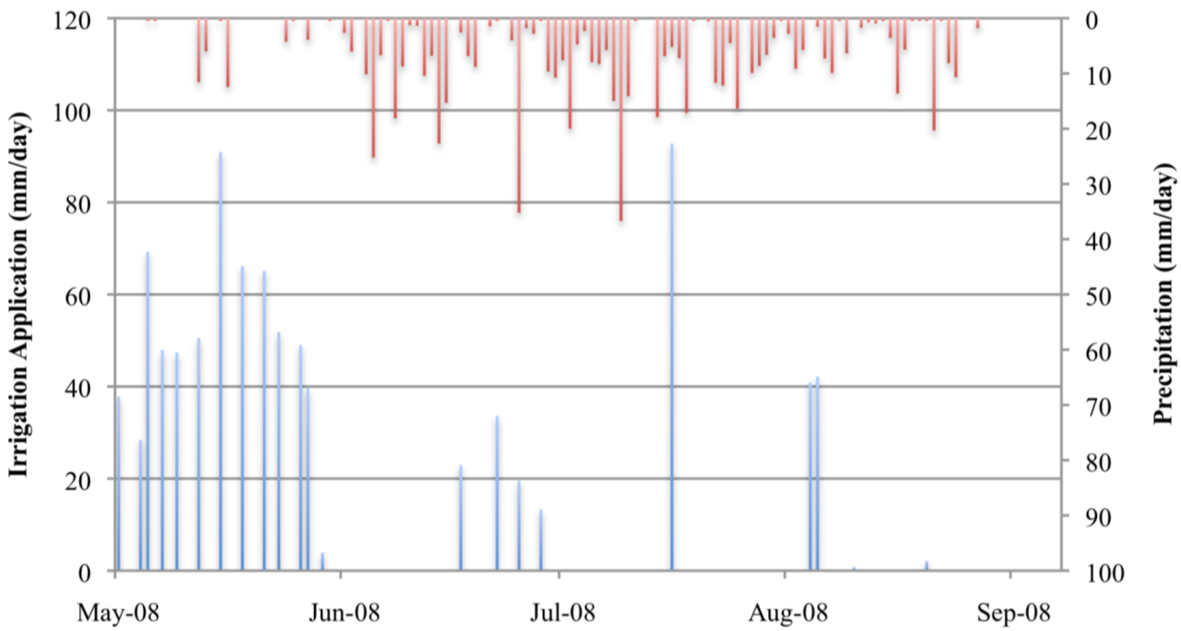


Figure 5-6. Irrigation frequency of a home with a rain sensor. Blue columns denote irrigation application (mm/day). Red columns denote precipitation (mm/day).

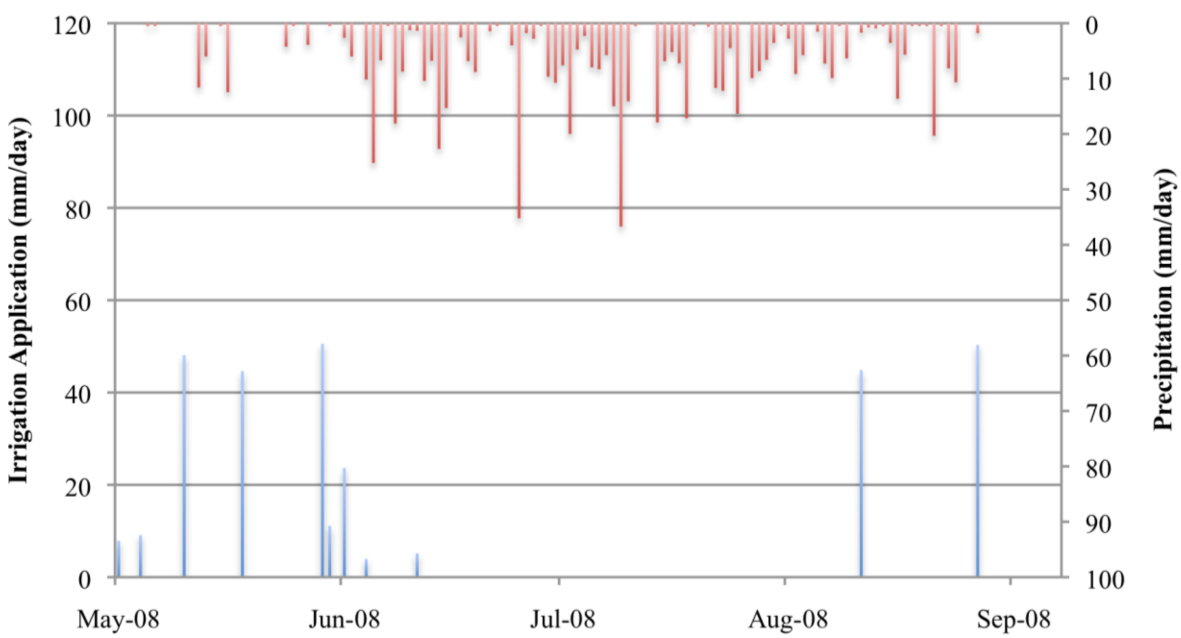


Figure 5-7. Irrigation frequency of a home with a soil moisture sensor. Blue columns denote irrigation application (mm/day). Red columns denote precipitation (mm/day).

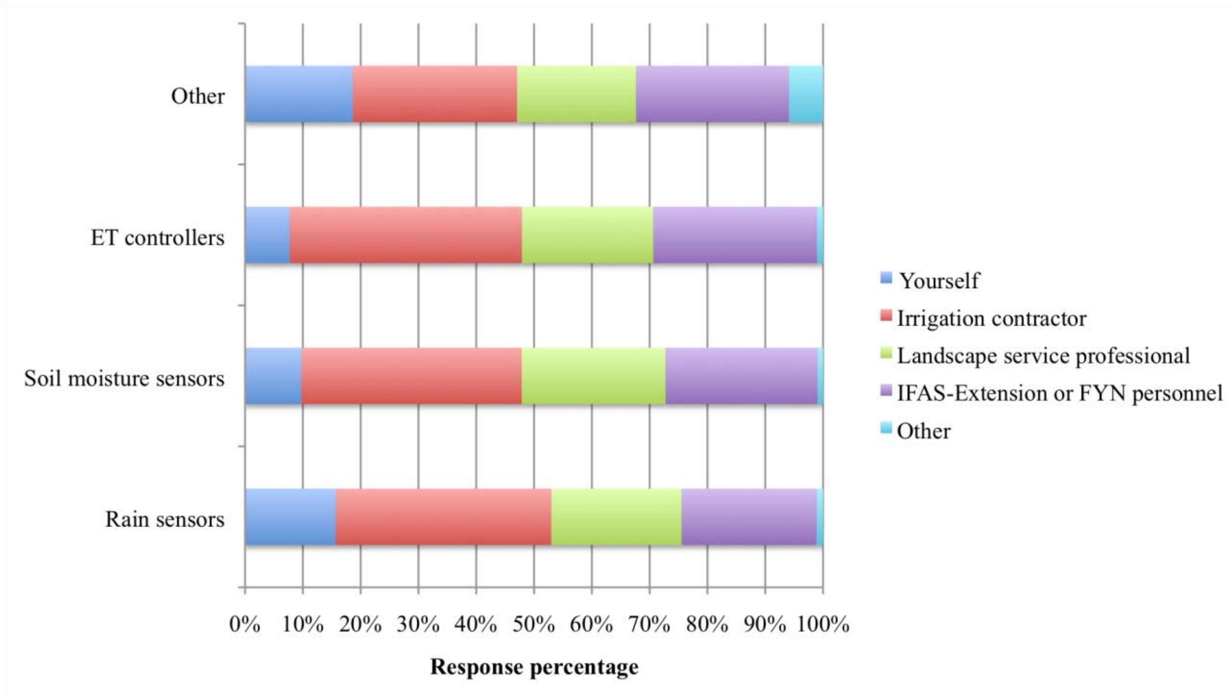


Figure 5-8. Self-reported response of persons trusted to install or set irrigation technology from OCU survey data.

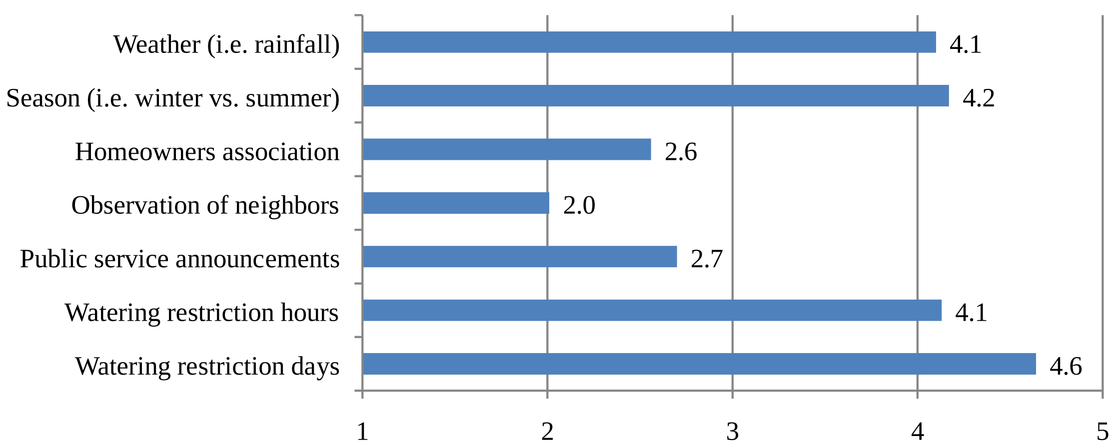


Figure 5-9. Self-reported external parameters that influence watering practices from OCU survey data on a 5 point Likert scale, with mean scores for each parameter labeled.

CHAPTER 6
CONCLUSIONS

This work began with a quote focusing on the turfgrass footprint within the United States: “One of the most fundamental and increasingly important components of land cover change in the U.S. is the monocultural cultivation of the turfgrass yard, whose ecology remains understudied and whose significance continues to grow with the development of each new housing unit on the urban frontier” (Robbins and Birkenholtz 2003).

A common thought in the landscape water conservation arena is to eliminate turfgrass a means to save water. Research relating to irrigation water use practices and perceptions will still be relevant even in light of the growing trend to limit turfgrass areas for the residential home. In response, the waste of water results from improper watering practices and poor landscape designs, rather than any one major group of landscape plant materials, such as turfgrass (Beard and Green 1994). Consequently the removal of turfgrass is not the answer. Even homes with no lawn may still have an irrigation system for the landscape. Regardless of size, personal green space provides the resident a sense of privacy and ownership (Beard and Green 1994).

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

Summary of Objectives

The overall aim of this research was to observe and quantify knowledge and behavior relating to residential irrigation water use and conservation technology. In order for conservation technology to be effective, the equipment must be properly installed [research assumed this and even fixed systems prior to treatment] and irrigation principles must be understood; the study objectives focus on irrigation water use and technology functionality.

Monitor Irrigation Technology

The primary objective of the project presented in Chapter 2 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 (RS), RS plus educational materials (EDU), and time-based irrigation controllers without an additional sensor (MO).

The SMS treatment yielded the greatest savings; with 65% less water applied (554 mm) for irrigation than the MO treatment (1,585 mm) at the 95% confidence level. These results were similar to what was found in the earlier plot study, where during wet conditions SMS system savings averaged 72%, and during dry weather conditions savings averaged 28% to 54%. Although the EDU treatment initially had a trend of reduced irrigation, over the 26-month study period, the total irrigation savings was 45% (at the 90% confidence interval) with 864 mm applied. Lastly, although there was a 14% reduction in irrigation application for the RS treatment versus the MO treatment, the results were not statistically significant. Plot studies also yielded non-significant savings for RS treatments versus MO treatments during similar dry conditions (Cardenas-Lailhacar et al. 2010).

Survey of Irrigation Practices

The objectives of the study presented in Chapter 3 were to quantify irrigation practices and level of community knowledge of water conservation technologies through a mail-out survey questionnaire.

Upon asking a series of questions regarding watering practices, 12% of potable customers and 24% of well water users reported irrigating more often than permitted, where 1-day per week irrigation was permitted for potable and well water users. Only 1% of the reclaimed users reported irrigating more often than permitted; however, it should be noted at the time of the data collection, reclaimed users were permitted up to four days of irrigation per week. Overall, the reported average length of time set per irrigation cycle for a single turfgrass zone was 69 minutes, ranging from 20 to 120 minutes. According to University of Florida Institute of Food and Agricultural Sciences recommendations for the Central Florida area, during the months April through November, turfgrass zones irrigated by gear driven rotary sprinklers should be set for an average of 57 min (ranging from 38 to 75 min depending on month) and fixed spray heads should be set for an average of 19 min (ranging from 13 to 25 min) per irrigation cycle. Although 55% reported adjusting their watering schedule seasonally, 31% admitted that they do not adjust their irrigation run times based on seasonal plant water needs.

It was observed that there was a correlation between irrigation knowledge and education level ($r = 0.60$, $p = 0.01$). There was also a moderate correlation ($r = -0.42$, $p = 0.02$) between the knowledge index and the statement that the "homeowner would like to consider changes but [does not] have the money." The strongest correlation existed between the conservation attitudinal index and the statement that the homeowner would "prefer more lawn (turfgrass) and would like to increase the lawn area of [their] yard" ($r = -0.87$, $p < 0.01$). Where, a higher conservation attitude score by the respondents was associated with the understanding that larger turfgrass yard may require more water. A key finding was the misunderstanding about rain shut-off devices.

Irrigation Scheduling Education Campaign

The objective of the campaign presented in Chapter 4 aimed to capture irrigation water use savings by educating homeowners on irrigation principles through monthly/seasonal newsletters that focused on principles of irrigation scheduling.

To determine any effect on irrigation water use by the participant homes during the study period, the estimated outdoor use was compared to a non-participant group and the theoretical irrigation need during the same period. Potable water savings were significant when comparing the estimated irrigation application of the participant group to the nonparticipant group and the theoretical need during the study period at the 90% confidence interval. Additionally, a significant correlation existed between the increase in knowledge and decrease in water use over time. Evident by the low water use ratio, 0.6, the sample population of both participants and non-participants are water conservative.

Based on the campaign participation follow-up survey responses, there was a gain in knowledge by the program participants for all characteristics aside from plant root depths (where the follow-up survey yielded less understanding) and soil type (where the responses remained approximately equivalent). Greatest increases in knowledge score were reported for the irrigation system characteristics regarding zone locations and sprinkler head types.

Both irrigation zone locations and sprinkler head types were an integral part of the irrigation evaluation interview. Participants were asked to record this information in an effort to obtain the proper run time recommendations for their “unique” systems. According to Korwin and Jones (1990), such exercises promote active learning by incorporating hands-on interaction, suggesting that cognitive learning relating to irrigation principles can be enhanced.

Misunderstanding of Irrigation Principles

The objective of the analysis presented in Chapter 5 aimed to identify areas of need for increased public awareness and misunderstandings of irrigation principles.

The domestic irrigation water use habits were broken into four irrigation categories: (1) irrigation applied and needed, (2) irrigation applied and not needed, (3) irrigation not applied but needed, and (4) irrigation neither applied nor needed (representing the most common scenario at 34%). The category where irrigation was applied but not needed, infers misunderstanding of irrigation principles, suggesting inappropriate irrigation timing relative to actual weather patterns and an over-irrigation resulting from unnecessary events. Homes fell into this category 26% of the time, with the MO treatment applying more unnecessary events than any other group. On the opposite end of the “conservation potential” spectrum, the SMS treatment applied the least unneeded irrigation.

From the survey data, there was a significant positive correlation between knowledge score and system parameter score ($r = 0.55$, $p < 0.001$). The knowledge score was established from the correct answers to questions relating to irrigation scheduling, conservation technology functionality, and installation. The system parameter score was developed from Likert-scale familiarity level with site and system characteristics. These two scores, along with the self-reported time-clock interaction level can be used to numerically characterize the domestic irrigator index. The most incorrectly answered knowledge question was regarding the rain shut-off device requirement. Of the input parameter knowledge questions, plant type within a zone and soil type were the least known, where 50% or less of the responses stated knowledge of these parameters.

Summary of Trends

This research combined extensive data on irrigation water use by the single-family homes in addition to data on behavioral aspects of residential irrigation habits. Three primary factors that affect the intensity of water use by residential users have been established (Baumann 1990). The first two are economically derived; the consumer's ability to pay for and the willingness to pay for water at a given price. However, few people elect to change behavior in their homes in response to economic appeals alone (McKenzie-Mohr and Smith 1999). The non-economic factor is the consumer's conservation behavior. This reflects the motivation to employ effort or technological innovations for water conservation. Additionally weather and climactic awareness influence irrigation habits (Baumann 1990). The measured trends based on these factors include the effects of irrigation frequency, property value and size, technology effectiveness and reluctance, and climactic variability.

Irrigation Frequency

During the period of data collection presented in this body of work, according to Pinellas County Code 82-1, homes using county water or wells, lakes, and ponds are allocated one day of irrigation a week for established lawns and landscaping. From the Chapter 3 questionnaire self reported data, 75% of the potable water users irrigated once per week and 10% irrigate 2 days per week. Interestingly, 1% of the respondents admitted to 3 to 4 times per week and 1% also admitted to irrigating nearly everyday.

Over the total study period in Chapter 2, on average the soil moisture sensor treatment resulted in 2 events per month, with a range from 0 to 11 events per month. While the EDU treatment averaged 4 events, ranging from 0 to 20 events per month. The RS and MO treatments both yielded means of 5 events per month, with ranges from 0 to 22 and 29 events per month respectively. Four to five events per month would comply with the one-day per week watering restriction for the study area. According to the irrigation requirements simulation based on the soil water balance, on average 4 events per month were needed. However, 2 to 7 events per week were simulated as being required depending on season of the year. Although on average the study homes appeared to irrigate appropriately according to local watering day restrictions, when considering the range of irrigation events that occurred during a given month, over-irrigation occurred.

Watering Day Restrictions

According to the self-reported questionnaire data in Chapter 5, homeowners typically adjusted their irrigation timers due to watering day/time restrictions. From the Chapter 5 survey data, the domestic irrigator can be characterized into two groups, those with technological trust vs. the hands-on irrigator. The water use data from Chapters 2 and 5 also showed influence of watering day/time restrictions, but more so how the “conservation potential” of the sensor-based technologies can help to govern unnecessary events.

The primary expected motivation for watering restriction compliance is economic self-interest. Noncompliance with watering day restrictions can result in a fiscal penalty. However, there are a few barriers to this approach. Enforcement of watering-day restriction non-compliance requires both monitoring and monetary compensation. There is often minimal enforcement due to a lack of adequate monitoring (Whitcomb 2006). Reduced watering day restrictions are more effective on water use reduction, where one-day per week restrictions result in greatest behavior modification (Silva et al. 2010). Using force of law to regulate or control behavior is not always helpful. For example when homeowners fear only a limited window of opportunity, they may irrigate more than needed during that window (McKenzie-Mohr and Smith 1999).

Property Value and Size

The positive correlation between property value and irrigation application depth ($r = 0.85$, $p < 0.0001$) suggests socioeconomic level affects conservation behavior, likely because cost is less of a primary motivation. Homes ranging from $900,000 to $1,500,000 applied the most irrigation, 102 mm/month ($p < 0.001$) and homes valued less than $700,000 used 47 mm/month on average. This trend concurs with the literature, suggesting that sensitivity to water cost results in reduction of use (Whitcomb 2005). Homes with a higher property value can be equated to an increased socio-economic level, where the cost of water has less of an impact.

Conversely, the smaller the property, the more irrigation was applied, described by a (log) negative correlation ($r = -0.89$, $p < 0.0001$). Homes with an estimated irrigated area range of 90 to 280 m^2 used 93 mm/month. Where homes with 465 m^2 or above used 49 mm/month on average. Homes with smaller irrigated areas all had lower property values, ranging from $100,000 to $500,000. The increase in water application with the decrease in irrigated area could be due to a misunderstanding of irrigation scheduling principles and the over-design of irrigation systems (e.g. too many heads per hydrozone), or a desire for neighborhood continuity in terms of landscape appearance (i.e. knowledge vs. motivation). 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 or felt as an excessive economic stress.

Irrigation Conservation Technology Effectiveness

Research in Florida has indicated that the use of technology can decrease irrigation water use without causing plant/turfgrass stress or degradation of appearance, and can therefore, be a useful tool in domestic water savings. It has also been found from the literature that the reduction in water use for landscape purposes is greater in laboratory data than in the residential arena (Geller et al. 1983).

Rain sensors are the most common type of senor used in conjunction with automatic irrigation systems. This sensor works as a bypass switch, triggered by a precipitation event. A soil moisture sensor also results in the bypass of scheduled irrigation events, however based on soil moisture content, which can be affected by either rainfall or prior irrigation events. Therefore, a SMS results in the highest level of “conservation potential”.

The most frequent water use category scenario in Chapter 5 was when irrigation was neither applied nor needed, where the SMS treatment made up the highest proportion of this category, suggesting that the device was effectively bypassing unnecessary or superfluous irrigation events. This result is further supported by a significant difference ($p = 0.001$) between sensor-based “conservation potential” and water use category. Where sensor-based conservation potential not only positively impacts water savings, but also efficient watering behavior.

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

Irrigation Conservation Technology Reluctance

Reluctance on either the part of the domestic irrigator and/or the irrigation/landscape professional to incorporate the conservation technology exists. Florida Statue 373 is often ignored. The rain sensor is an inexpensive device (typically less than $100 installed) and commonly neglected in irrigation systems. The more advanced technology requires more initial homeowner interaction and a higher level of knowledge on the part of the installers. The newer “smart” devices have been gaining public awareness in the industry; these include soil moisture sensors and weather-based controllers (ranging from $300 to upwards of $500 installed).

In the homeowner questionnaire in Chapter 3, the participants were questioned about rain shut-off devices and given three device type options: rain sensor, soil moisture sensor, and weather-based controller with a rain bypass switch. Only 36% of the respondents reported systems with a rain-shut off device. Further, the only rain shut-off device reported was a rain sensor, corresponding to all 36% of the responses. However, at least 4% of the respondents had soil moisture sensors connected to their system. Therefore the term “rain shut-off” may not be understood to include devices other than rain sensors that automatically bypass irrigation events.

The U.S. Environmental Protection Agency has developed the WaterSense as a benchmark rating and labeling program on water saving devices. Effective “smart” irrigation technology is expected to gain mainstream attention through this program. Additionally, Water Management Districts are able to use the rating criteria as justification for rebate programs.

Climactic Variability

Effect of precipitation

Weather plays a major role in conservation practices as well. During periods of drought, consumers are more willing to employ conservation techniques than during wet years (Baumann 1990). This may be because of increased public awareness stemming from more intense marketing on the part of the Water Management Districts and water purveyors. Further, during wet years there is a sense of excess vs. a strain on the common supply during drought conditions. This concurs with Hardin’s philosophy of a sense of a “common” resource (Hardin 1968).

The data collected in this study revealed that the cooperating homes had relatively low water use characteristics. From the response to the mail-out survey regarding irrigating practices, Chapter 3, 69% of the homes reported that they “consider their irrigation practices to be very water conserving”. Furthermore, 33% of the participants in the Chapter 2 study report manually adjusting their automatic irrigation system schedule, rather than allowing irrigation control devices to bypass irrigation cycles.

From Chapter 2, in 2007 even though the cumulative precipitation, at 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 was 1,072 mm, 15% lower than normal. From the actual water use data, during 2007, the homes used on average 51 mm/month. While during the wetter of the two total years of data collection, the homes used on average 40 mm/month. The correlation between effective rainfall ($r = -0.38$, $p < 0.001$) rather than daily rainfall ($r = -0.18$, $p < 0.001$) suggested that the characteristics of rainfall amount, frequency, intensity, and turfgrass response are more influential on domestic irrigation behavior than simply the presence of rainfall alone.

Effect of season

Irrigation application is also influenced by the season of the year. The spring months have the highest irrigation demand due to the relatively high evaporative demand as well as low rainfall. 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 (Chapter 2). This trend coincided with the highest period of irrigation water requirements and occurred despite uniform day of the week water restrictions throughout the year.

The velvety green turfgrass lawn is desirable year-round, particularly within retirement and vacation areas, such as Florida. The green lawn represents the quintessential sign for a true escape from winter (Jenkins 1994). Winter weather impacted irrigation watering practices in both data sets of Chapter 5. In these cases there was a reduction in evapotranspiration, but also during this time there is often a change in turfgrass appearance, when warm season turfgrass will wan in color due to the affects of dormancy. During the winter months, the water use ratio was significantly the highest with homes applying nearly twice as much irrigation as needed. Winter was also noted in the Chapter 5 survey responses as a dominant influence on increased watering practices.

Water Source

Previous studies of domestic irrigation with potable water have found price to be a primary motivator for irrigation practices (Whitcomb 1999). For the sample sets in this body of work, price was only a factor for potable users. Seventy-five percent of all users (Chapter 3) responded that source was the major influence affecting their irrigation practices. The most desired water source was reclaimed water for irrigation purposes, even though the responses were evenly distributed across the three sources (potable, well and reclaimed). Of the potable source respondents, 65% would prefer the opportunity to use reclaimed water and 30% would prefer a well. This can be viewed as an environmentally socially desirable response. It also might reflect preference for a water source with less restricted use.

Understanding the attitudes towards water source is also important. There must be a positive perception by the community to warrant the water use. Signs are often posted in public spaces where irrigation water is from alternative sources. Older signs highlighted the safety concerns of drinking reclaimed water. The new movement is to emphasize groundwater savings in effort to promote conservation acceptance relating to irrigation water source. In efforts to further modify the attitude of the public about the benefits of alternative water sources the terminology is shifting from “reclaimed” to “recycled” water.

Significant Barriers and Benefits

The three fundamental behavioral barriers to irrigation conservation potential when considering the use of "smart" technologies are: (1) how to use the equipment, (2) when and how long to schedule irrigation, and (3) system uniformity (Mayer et al. 2009). The first two barriers are behavioral while the third barrier is non-behavioral. Again suggesting the need for a holistic approach, incorporating both technology and the domestic irrigator to realize true irrigation conservation potential. Consideration must be made in understanding the behavioral aspects of the domestic irrigator.

From the data analyzed in Chapter 2 and 3, there was (1) an overall misunderstanding of plant water needs and seasonal scheduling of irrigation systems and (2) confusion with terminology in reference to rain shut-off devices versus rain sensors. Of barriers noted from the themes, which emerged from the Chapter 4 and 5 survey data, there was (1) concern over watering day/time allowances where participants commented that the lawn/landscape requires more water than permitted by restrictions and (2) concern towards rain sensor functionality. The watering restriction concern agrees with the Chapter 3 data of influential factors on watering practices. The concern toward rain sensor functionality is related to overall distrust or reluctance towards technology mentioned above. Thus, these barriers or themes are likely to vary in importance for different market segments (e.g. technology trusters).

There were influences from property value and area irrigated, suggesting an increase or decrease respectively for irrigation water use. Of the system uniformity non-behavioral barrier, the typical standard for irrigation system efficiency is 80% (IAEF 2010), however the sample data set in Chapters 5 resulted in an average system efficiency of 72%, with a range from 57% to 91%.

Limitations to the studies include the relatively focused study areas within Southwest and Central Florida. Additionally, the experimental designs only targeted single-family residential sites.

A benefit observed in the body of work is the participants' expressed room for improvement and interest in learning, suggesting a sense of reliability of rain shut-off device functionality, and conservation behavior relating to water source. This, along with the fact that the respondents believe they are already efficient water users concurs with the literature, where conservative domestic irrigators believe they are conservative regardless of actual water use (Silva et al. 2010).

Irrigation conservation efforts must effectively educate the domestic irrigator about: (1) what constitutes efficient use, (2) the conservation potential of sensor-based irrigation technology, and (3) how their own watering practices and site specific irrigation system fit into the spectrum of efficiency levels.

APPENDIX A
ON-SITE IRRIGATION EVALUATION TEMPLATE

Irrigation System Evaluation

Name: ______________________ Date: ________

Address: ______________________

Zone	**Type**	**Orig. Time (min)**	**Run Time (min)**	**Meter Initial (gal)**	**Meter Final (gal)**	**No. of Heads and Nozzle Pattern**	**Location**	**Turf Quality (1-9)**
1	S R							
2	S R							
3	S R							
4	S R							
5	S R							
6	S R							
7	S R							
8	S R							

Irrigation Day _____

Start Time _________

Rain Sensor? Y N

Uniformity Test

Zone(s): _________

Time: _________

Can No.	TDRpre	TDRpost	Volume
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			
16			
17			
18			
19			
20			
21			
22			
23			
24			

Reference Sketch

Catch-Can Layout

Comments: ______________________

APPENDIX B
WATER-WISE IRRIGATION PRACTICES AND PERCEPTIONS HOUSEHOLD SURVEY INSTRUMENT

Outdoor Water Use Practices & Perceptions

Household Questionnaire

UF | UNIVERSITY of FLORIDA

Please use a **ball point pen** to complete this survey regarding your outdoor water use practices and perceptions. Upon completion, please return in the preaddressed, stamped envelope provided. Thanks!

Outdoor watering practices

1. How do you water your lawn/landscape?
   - ☐ Automatic irrigation system, which is set
   - ☐ Automatic irrigation system, used manually
   - ☐ Sprinkler head with hose attachment, which is moved around yard
   - ☐ Hose or watering can
   - ☐ I do not apply water to my lawn/landscape

2. On average, how often is your lawn/landscape watered?
   - ☐ Only when it rains
   - ☐ Never/Rarely
   - ☐ Once per week
   - ☐ Twice per week
   - ☐ Three to four times per week
   - ☐ Nearly every day

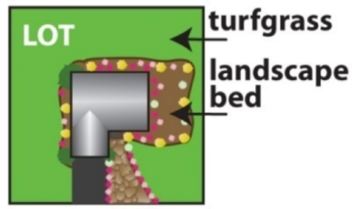
3. Who is in charge of watering your lawn/landscape?
   - ☐ I am
   - ☐ Other member of household
   - ☐ Lawn care service provider
   - ☐ Irrigation maintenance professional
   - ☐ Other: ______________________

4. Where does the water used in your lawn/landscape come from?
   - ☐ Rainwater only
   - ☐ Municipal/City/County water (not reclaimed)
   - ☐ Reclaimed water
   - ☐ Well or surface water
   - ☐ Rain barrels
   - ☐ Don't know
   - ☐ Other: _________________

5. Given the choice, which water source would you prefer for outdoor water use?
   - ☐ Municipal water
   - ☐ Reclaimed water
   - ☐ Well or Surface water
   - ☐ Don't care

About your landscape

1. About what percentage of your **lot** is turfgrass and landscape?
   - ☐ 0% – 25%
   - ☐ 26% – 50%
   - ☐ 51% – 75%
   - ☐ Over 75%



2. About what percentage of your **landscape** is turfgrass?
   - ☐ 0% - 25%
   - ☐ 26% - 50%
   - ☐ 51% - 75%
   - ☐ 76% - 100%

3. Do you pay a company to maintain your lawn/landscape?
   - ☐ Yes ☐ No

4. Does your home have outdoor water features?
   - ☐ No
   - Yes
     - ☐ Swimming pool
     - ☐ Hot tub
     - ☐ Fountain
     - ☐ Pond
     - Other: ____________

Watering habits

1. Do you adjust your watering schedule throughout the year?
   - ☐ Monthly ☐ Seasonally ☐ Not really
2. Does your system have ***both*** spray and rotary sprinkler heads within the same zone?
   - ☐ Yes ☐ No ☐ Don't know
3. Do you water your lawn (turfgrass) and landscape (bedded area) for different lengths of time?
   - ☐ Yes ☐ No ☐ Don't know
4. How long do you typically water your lawn (turfgrass) each time you water?
   - ☐ _____ hours ☐ _____ minutes ☐ Don't know

If you have an irrigation system *(If not, proceed to next section.)*

1. Do you use any of the following low-volume irrigation equipment?
   - Yes
     - ☐ Micro-irrigation
     - ☐ Drip tubing
     - ☐ Bubblers
     - Other: ______________
   - ☐ No
   - ☐ Don't know

2. If you have an irrigation timer, where is it located?
   - ☐ Attached to hose bib or faucet
   - ☐ In the garage
   - ☐ Inside of house
   - ☐ Exterior wall of house
   - ☐ Don't know where it is
   - ☐ Don't have one

3. If you have an irrigation timer, is it easily accessible?
   - ☐ Yes
   - ☐ Somewhat
   - ☐ No
   - ☐ Don't know

4. Do you have a rain shut-off device attached to your watering system?
   - Yes
     - ☐ Rain sensor
     - ☐ Soil moisture sensor
     - ☐ Weather-based controller (with a rain bypass switch)
     - ☐ Other: _______________
   - ☐ No
   - ☐ No, but I turn the irrigation timer off manually when it rains
   - ☐ Don't know

5. If you have a rain shutoff device, is it connected and functioning?
   - ☐ Yes
   - ☐ No
   - ☐ Don't know

6. How many zones does your system have?
   - ☐ 0–4
   - ☐ 5–8
   - ☐ 9 or more
   - ☐ Don't know

Please rate your agreement to the following statements:

	Strongly Agree	Agree	Neither	Disagree	Strongly Disagree	Don't Know
7. Water costs don't affect my irrigation practices.	☐	☐	☐	☐	☐	☐
8. I would install a soil moisture sensor on an irrigation system.	☐	☐	☐	☐	☐	☐
9. I consider my irrigation practices to be very water conserving.	☐	☐	☐	☐	☐	☐
10. Local conservation programs are readily available.	☐	☐	☐	☐	☐	☐
11. Rain sensors are reliable.	☐	☐	☐	☐	☐	☐

Attitudes and actions

1. Please mark the top three statements that best describe your attitude toward your home's present landscape (in order of priority, 1 through 3).
   - ___ I am reasonably content with my present landscape and am not considering any changes.
   - ___ I prefer less lawn (turfgrass) and would like to remove some of it.
   - ___ I prefer more lawn (turfgrass) and would like to increase the lawn area of my yard.
   - ___ I would like to learn more about landscape water use before deciding what, if any, actions I take.
   - ___ I don't think my neighbors (and/or Homeowners Association) would accept the changes I would like to make.
   - ___ I would like to consider changes but don't have the ***time***.
   - ___ I would like to consider changes but don't have the ***money***.
   - ___ Other: ____

2. Have you ever participated in an outdoor water use conservation program?
   ☐ Yes ☐ No ☐ Don't know

3. Does your house have any of the following appliances or devices that are intended for water savings?
   ☐ No

   Yes (check all that apply)

Already there	I/we installed		Already there	I/we installed	
☐	☐	Low-flow faucet or showerhead	☐	☐	Micro-irrigation
☐	☐	Low-flow toilet	☐	☐	Drip irrigation
☐	☐	Water-efficient dishwasher	☐	☐	Rain sensor
☐	☐	Water-efficient washing machine	☐	☐	Soil moisture sensor
☐	☐	Tankless water heater	☐	☐	Weather-based (ET) controller
☐	☐	Rain Barrel	☐	☐	Other:____________

4. Does your house have any appliances or devices intended for energy savings?
   ☐ No

   Yes (check all that apply)

Already there	I/we installed	
☐	☐	Compact fluorescent light bulbs
☐	☐	Energy-saving power strips
☐	☐	High-efficiency clothes dryer
☐	☐	High-efficiency air conditioner
☐	☐	Tankless water heater
☐	☐	Solar water heater
☐	☐	Solar panels
☐	☐	Other:

Please rate your agreement to the following statements:	Strongly Agree	Agree	Neither	Disagree	Strongly Disagree	Don't Know
5. Native plants don't need to be watered once established.	☐	☐	☐	☐	☐	☐
6. I do not feel my conservation of water affects the overall supply.	☐	☐	☐	☐	☐	☐
7. Because my irrigation system functions poorly, I don't irrigate.	☐	☐	☐	☐	☐	☐
8. I don't irrigate because of environmental concern.	☐	☐	☐	☐	☐	☐
9. My water source influences my outdoor water use practices.	☐	☐	☐	☐	☐	☐
10. When watering with reclaimed water, outdoor water use conservation is not necessary.	☐	☐	☐	☐	☐	☐
11. I spend a lot of time outside in my lawn/landscape.	☐	☐	☐	☐	☐	☐
12. I am very concerned about the appearance of my yard.	☐	☐	☐	☐	☐	☐
13. I am familiar with seasonal water needs of my lawn/landscape plants.	☐	☐	☐	☐	☐	☐
14. I am not aware of watering restrictions in my area.	☐	☐	☐	☐	☐	☐
15. I am aware of lawn appearance requirements in my neighborhood.	☐	☐	☐	☐	☐	☐
16. I think a rain shut-off device is very important.	☐	☐	☐	☐	☐	☐
17. Conservative outdoor water-use practices save money on my water bill.	☐	☐	☐	☐	☐	☐
18. I often observe my neighbors overirrigating.	☐	☐	☐	☐	☐	☐
19. When watering with well water, outdoor water use conservation is not necessary.	☐	☐	☐	☐	☐	☐
20. When it does not rain regularly, I tend to water my lawn a little extra.	☐	☐	☐	☐	☐	☐
21. I water less in the winter months.	☐	☐	☐	☐	☐	☐
22. Native plants in the landscape tend to look un-maintained.	☐	☐	☐	☐	☐	☐
23. New irrigation systems are required to have rain shutoff devices.	☐	☐	☐	☐	☐	☐
24. Water conservation is a contribution to energy savings.	☐	☐	☐	☐	☐	☐
25. We are all responsible for water conservation in our community.	☐	☐	☐	☐	☐	☐

In your opinion, how effective are (or would be) each of the following to increase water conservation:

	Very Effective	Effective	Neither	Ineffective	Very Ineffective	Don't Know
26. Watering restrictions	☐	☐	☐	☐	☐	☐
27. Rain shut-off devices	☐	☐	☐	☐	☐	☐
28. Increased water rates	☐	☐	☐	☐	☐	☐
29. Landscape ordinances that limit turfgrass area	☐	☐	☐	☐	☐	☐
30. Local conservation programs	☐	☐	☐	☐	☐	☐
31. Irrigation scheduling based on water needs of plants	☐	☐	☐	☐	☐	☐
32. Using native plants in the bedded areas	☐	☐	☐	☐	☐	☐
33. Email reminders of when to change the irrigation timer and suggested run times would help increase irrigation efficiency	☐	☐	☐	☐	☐	☐

Last bit…

1. Do you own or rent your home?

   ☐Own ☐ Rent

2. How many years have you lived in your current home?

   _______ years

3. How many years have you lived in Florida?

   _______ years

4. How many months out of the year are you in Florida?

   ______ months

5. Including yourself, how many members in your household are in each age group?

   _______ under 10
   _______ 11 – 20
   _______ 21 – 65
   _______ 66 or older

6. What is your age?_____ years

7. What is the highest level of education you have completed?

   ☐ Some high school
   ☐ Complete high school
   ☐ Some college
   ☐ Completed college
   ☐ Advanced degree

8. Please indicate the income range that most closely approximates your total household income.

   ☐ Under $30,000
   ☐ $30,000 – $49,999
   ☐ $50,000 – $74,999
   ☐ $75,000– $149,999
   ☐ Over $150,000

Is there anything we have overlooked? Please enter your comments in the space provided below.

Thank you very much for your time!

We really appreciate your completion of this questionnaire.
Please send the survey back
as soon as possible.

If you have misplaced the preaddressed, stamped envelope, please send it to the address below.

Agricultural & Biological Engineering

Attn. Melissa B. Haley
Frazier Rogers Hall
P.O. Box 110570
Gainesville, FL 32611-0570

Phone (352) 392-1864 ext 263
Fax (352) 392-4092

Survey No.________

APPENDIX C
NEWSLETTER CAMPAIGN IRRIGATION EVALUATION INTERVIEW QUESTIONNAIRE

Irrigation Evaluation Interview

1. Irrigation System Evaluation Interview

Thank you for participating in the Irrigation Water Conservation program conducted by the IrriGator Research Team of Agricultural & Biological Engineering Dept at the University of Florida/IFAS.

Answers to the following questions regarding your irrigation system and practices, will enable us to create an individualized irrigation system schedule for your house.

If you do not know the information asked in any of the questions, that is absolutely fine. Just move on and answer what you know to the best of your ability.

If you need to step away from the computer you can complete the survey again by going to https://irrigation.ifas.ufl.edu/sign-up.shtml

Then just re-enter your name and house number and pick up where you left off.

*** 1. For record keeping, please provide**

last name

house number

Irrigation Evaluation Interview

2. Current irrigation schedule

To answer the following questions, you may need to look at your irrigation time clock.

1. What day(s) of the week do you run your irrigation system?

☐ Sun ☐ Mon ☐ Tue ☐ Wed ☐ Thu ☐ Fri ☐ Sat

2. When do you manually bypass the irrigation system from running?

	Always	Regularly	Sometimes	Rarely	Never
When do you manually bypass the irrigation system from running?	○	○	○	○	○
(Always, Regularly, Sometimes, Rarely, Never)	○	○	○	○	○
a) Typically allow the system to run automatically	○	○	○	○	○
b) Manually initiate irrigation events	○	○	○	○	○
c) Turn off the system after a large rain event	○	○	○	○	○
d) Adjust the run times monthly	○	○	○	○	○
e) Adjust the run times seasonally	○	○	○	○	○
f) Turn off the system for more than one month of the year	○	○	○	○	○

Other (please specify)

3. How long is the irrigation system set to run for each zone? Please provide your answer in number of minutes.

Zone 1

Zone 2

Zone 3

Zone 4

Zone 6

Zone 7

Zone 8

Zone 9

Zone 10

Zone 11

Zone 12

Irrigation Evaluation Interview

3. About the irrigation system

To answer this question, you may need to observe your irrigation system running. This can be done by manually turning on the system.

1. About the irrigation system zones

	Sprinkler type	What it waters
Zone 1		
Zone 2		
Zone 3		
Zone 4		
Zone 5		
Zone 6		
Zone 7		
Zone 8		
Zone 9		
Zone 10		
Zone 11		
Zone 12		

Other (please specify)

Irrigation Evaluation Interview

4. Water conservation devices

1. Water conservation devices

	Yes	No	Don't know
a) Does your irrigation system have a rain sensor?	◯	◯	◯
--- Is the rain sensor functioning?	◯	◯	◯
--- Is the rain sensor located underneath a tree canopy or roof overhang?	◯	◯	◯
b) Does your system have a soil moisture sensor?	◯	◯	◯
c) Is your controller a weather-based (or ET) controller?	◯	◯	◯

Irrigation Evaluation Interview

5. Water use

1. What is your water source?

- ◯ Potable (regular Pinellas County Utility water)
- ◯ Reclaimed
- ◯ Well or Surface
- ◯ Don't know

2. Please comment on any changes to the following as they may affect your water use.

a) Connect to reclaimed water source	
b) Install a well or surface water pump	
c) Major changes to your lawn/landscape	
d) Major changes to a pool or other outdoor water feature	

3. Are you a year-round (12-month) resident at this address?

- ◯ Yes
- ◯ No

Irrigation Evaluation Interview

6. Services/Maintenance

1. What professional services have you used for your lawn, landscape, or irrigation system (mark all that apply)?

- [ ] Chemical application (fertilizer, pesticides, etc.)
- [ ] Landscape service
- [ ] Irrigation contractor
- [ ] IFAS/Extension or FYN (Florida Yards and Neighborhoods)

2. How often do you perform general maintenance on your irrigation system?

- ○ At least once per year
- ○ Every other year
- ○ At least once in the last 5 years
- ○ Never
- ○ Don't know

Other (please specify)

Irrigation Evaluation Interview

7. Thank you!

Thank you for completing the irrigation system evaluation interview. This information will be utilized to create unique irrigation system recommendations.

If we have any questions based on your answers, we will contact you through your preferred method of communication.

You will receive your irrigation recommendations at the communication frequency you initially requested.

Feel free to contact me with any questions by phone at (352) 871-3523 or email at mbhaley@ufl.edu. Your participation in this Irrigation Water Conservation program is greatly appreciated!

Melissa Baum Haley
Irrigation Practices Researcher
University of Florida - IFAS
Dept of Agricultural and Biological Engineering

APPENDIX D
EXAMPLE IRRIGATION SCHEDULER HOUSEHOLD NEWSLETTERS

UF-IFAS IrriGator Newsletter **January**

U.F. IrriGator Irrigation Scheduler Newsletter

Welcome to the U.F. Irri*Gator* Irrigation Scheduler Newsletter. These monthly newsletters are a reminder to update your irrigation schedule. All it takes is a minute at your time clock, and your lawn will thank you for it. Remember, irrigation scheduling is key when it comes to efficient water use. **Just changing the run times on your time clock can help reduce irrigation water use by 30%.**

Did you know?

The typical homeowner uses up to 50% of a homes total water consumption for irrigation, and often over-irrigating?

January time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	5
2	Rotor	Back left	10
3	Rotor	Back right	10
4	Spray	Side right	5
5	Rotor	Front	10
6	Spray	Front beds	5

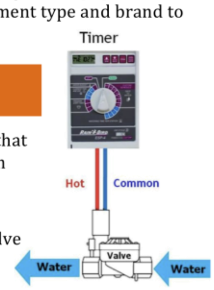
* Sprinkler type refers to the predominant head type for the zone.

Get to know your sprinkler time clock

The first step to effective irrigation scheduling is getting to know your sprinkler time clock as irrigation system. Can you answer the following questions?

1. **Where is time clock located? Is it easily accessible?**
2. **Do you know how to adjust the run times, start times, and watering days?** Check out the following video tutorial to learn more: http://abe.ufl.edu/mdukes/Controllers/video-irrigation-controllers.shtml
3. **What areas of the yard are watered with each zone?** Acquaint yourself with the irrigation zones. Typically, grass and landscape plantings should be watered for different lengths of time and should therefore be on different zones.
4. **What sprinkler types are used to water different areas?** Acquaint yourself with the irrigation equipment. Remember, when replacing broken heads, it is important to keep consistence with equipment type and brand to maintain matched precipitation rates and maintain system uniformity of distribution.

How it works



A standard irrigation time clock stores your irrigation schedule and runs the irrigation based on that schedule. You use the time clock to program specific run times, in minutes, for each zone based on day of the week. You can also set the time clock to automatically "turn-on" at specific start times. Some newer time clocks also have a percent adjust feature.

When the time clock want to "turn-on" the irrigation system, a signal will be sent to a solenoid valve allowing the valve to open and water to enter the system.

Want to learn more?

Further reading that will help you understand how your irrigation system and controllers are set up include *Irrigation System Controllers* http://edis.ifas.ufl.edu/AE077, *Using the Irrigation Controller for a Better Lawn on Less Water* http://edis.ifas.ufl.edu/EP235, and *Selection and Use of Water Meters for Irrigation Water Measurement* http://edis.ifas.ufl.edu/AE106.

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U.F. IrriGator Irrigation Scheduler Newsletter

Why do we irrigate? Plants need water. Irrigation is used to supply plants with water when there is either not enough rainfall, or the rainfall doesn't occur at the right time. The goal of efficient irrigation water use is to apply only that water lost through evapotranspiration that is not already replaced by rainfall.

This month's newsletter is dedicated to the fundamental concept behind the need for irrigation scheduling, evapotranspiration.

February time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	10
2	Rotor	Back left	15
3	Rotor	Back right	15
4	Spray	Side right	10
5	Rotor	Front	15
6	Spray	Front beds	10

* Sprinkler type refers to the predominant head type for the zone.

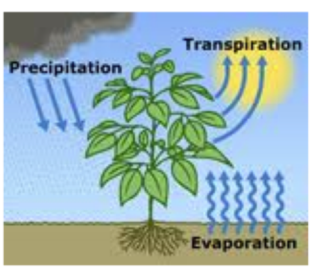
Where can I find my local evapotranspiration rates?

The Florida Automated Weather Network is a great website tool to accesses weather data across Florida. In addition to listing the ET for your area, FAWN also has an Urban Irrigation Scheduler.

[Check it out at http://fawn.ifas.ufl.edu](http://fawn.ifas.ufl.edu)

Understanding ET

At the center of irrigation scheduling is ***EVAPOTRANSPIRATION***, also referred to as ET. Evapotranspiration is the amount of water lost through evaporation or transpiration (water used by plants). Since it is very difficult to actually separate evaporation and transpiration mathematically, these two terms are combined.



Evapotranspiration considers a number of factors, such as wind, humidity, temperature, and solar radiation. All of these characteristics of weather vary throughout the year and from season to season. As do the water requirements of a plant. Of course, every plant uses water differently, and so each plant has a specific value (called a "crop coefficient") that represents the amount of water the plant might need relative to its seasonal growing stage. A plant's specific evapotranspiration rate will either be increased or decreased based on crop coefficient.

With the amount of a plant specific evapotranspiration rate changing from week to week, month to month, and season to season, it becomes clear why your irrigation schedule needs to vary as well. How much water needs to be replaces is not static.

Thanks for reading

Spring is approaching and there will be big changes in the weather and plant water needs with this new season.

This newsletter is a reminder to update your irrigation schedule. All it takes is a minute at your time clock, and your lawn will thank you for it. Remember, irrigation scheduling is key when it comes to efficient water use. **Just changing the run times on your time clock can help reduce irrigation water use by 30%**.

Interested in a specific topic? Drop is a line for future newsletter content suggestions. And as always, if you ever have any questions please feel free to email us at irrigation@ufl.edu.

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U.F. IrriGator Irrigation Scheduler Newsletter

Water conservation has become a major concern for Florida as the demand for water increases. The average residential irrigation cycle consumes several thousand gallons of water during each irrigation event. This month newsletter focuses on the importance of irrigation water conservation.

March time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

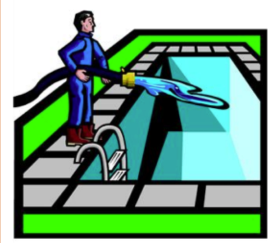
This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	15
2	Rotor	Back left	35
3	Rotor	Back right	15
4	Spray	Side right	35
5	Rotor	Front	15
6	Spray	Front beds	35

* Sprinkler type refers to the predominant head type for the zone.

Did you know?

According to the U.S. Environmental Protection Agency, the national volume of water used to for watering the lawn and landscape is more than 7 billion gallons per day, which is enough to fill 280,000 residential swimming pools.



A little history

The common lawn sprinkler dates back to the 1870s.
Residential irrigation began being frequently advertised in magazines by the 1930s, in which homeowners were promised savings in time, money, and an increased appearance of their lawn during times of drought with the installation of a permanent in-ground irrigation system. Now almost all newly constructed homes include an in-ground irrigation system with an automatic sprinkler timer.

Why irrigation conservation matters

Although Florida has what is considered a humid climate (meaning the average annual precipitation rate is greater than the evapotranspiration rate), spring, fall, and winter are normally dry months with little rainfall. Overall, the average annual rainfall in Florida is approximately 52 inches with most of rainfall occurring in the summer months (June through August). The spring months (March through May) are typically the hottest and driest.

This region is also characterized by sandy soils with a low water-holding capacity; therefore, storage of water in the plants root zone within the soil is minimal. These characteristics (dry and hot spring weather and sporadic large rain events in the summer, coupled with the low water-holding capacity of the soil) make irrigation necessary for the high-quality landscapes desired by homeowners.

Residential water use will continue to increase with increased population in the state. According to the U.S. Census Bureau, Florida has the largest net gain in population with an inflow of approximately 1,100 people per day and is fourth in overall population. New home construction has increased to accommodate such a large influx of people. Florida ranked first in the construction of single-family residential homes, totaling 209,162 homes in 2005, and most new homes included in-ground automatic irrigation systems.

As urban areas grow throughout the country, limited water resources will be stretched to fulfill urban, agricultural, recreational, and other needs.

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U.F. IrriGator Irrigation Scheduler Newsletter

If you have a 5,000 square-foot yard and use an in-ground sprinkler system, you may be spending $5 to $25 every time you irrigate. Overwatering the lawn and landscape is a common mistake many homeowners make. Keep in mind that, like most homeowners using public water, you are charged twice for the water you use—once for fresh water coming in, and a second time for the estimated wastewater that you discharge.

This month's newsletter is dedicated to saving money and water!

Did you know?

Iron stains on this fence are the result of an irrigation radius that is too large for the area.

Replacing the sprinkler heads with nozzles with smaller radii would reduce this staining and keep the fence from needing constant re-painting.

April time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	20
2	Rotor	Back left	40
3	Rotor	Back right	40
4	Spray	Side right	20
5	Rotor	Front	40
6	Spray	Front beds	20

* Sprinkler type refers to the predominant head type for the zone.

Know your spray heads

VS.

There is a new sprinkler on the block and it is packing a punch in terms of water savings. Chances are that you have seen flooded sidewalks or runoff streaming down the curb from excessive irrigation. The rotating nozzle (shown on the right) can use 20% less water than a conventional spray head (shown on the left), when properly directed. Multi-trajectory, rotating streams apply water more slowly and uniformly. The uniform distribution of irrigation will encouraging healthy plant growth and reduce the need for increasing runtimes as a result of dry spots.

Ways to save water outdoors

Follow these simple steps for the potential to save thousands of gallons of water!

- Water in the early morning, before 8 a.m., to reduce evaporation and interference from the wind – can save 25 gallons per day.
- Check sprinkler system for leaks, overspray and broken sprinkler heads – can save 500 gallons per month.
- Turn off hoses run when not in use and use a water-saving hose nozzle instead – can save up to 7,500 gallons per year.
- Install a "smart" sprinkler controller – can save 40 gallons per irrigation cycle.
- Place organic mulch throughout garden to reduce evaporation, even soil temperatures and inhibit weed growth - can save hundreds of gallons per year.
- Replace thirsty plants with Florida Friendly drought-resistant varieties - saves hundreds of gallons each year per plant.

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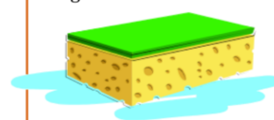
U.F. IrriGator Irrigation Scheduler Newsletter

This month's newsletter is dedicated to the ***soil moisture sensor system***, also referred to as SMS. The soil moisture sensor system utilizes a sensor buried within the root zone of the lawn. These systems also have a controller to identify a specified wetness threshold. The best thing about these systems is that can be added onto most existing time clocks. ***Soil moisture sensor systems have the potential to save over 70% during normal Florida rainy conditions, and even more approximately 50% during dry times.***

Did you know?

The root zone of your lawn is like a sponge filled with water…pouring more in will not keep it full any longer.



Only the water applied to the lawn until the irrigated area reaches field capacity is beneficial.

Any additional water applied will result in runoff or deep percolation.

May time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

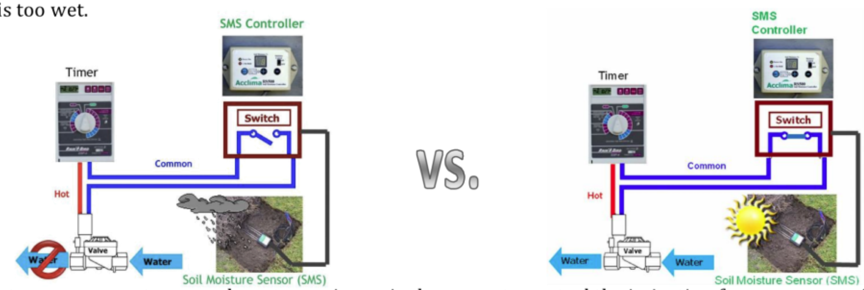
Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	25
2	Rotor	Back left	45
3	Rotor	Back right	45
4	Spray	Side right	45
5	Rotor	Front	45
6	Spray	Front beds	25

* Sprinkler type refers to the predominant head type for the zone.

How a soil moisture sensor works with your irrigation system

Bypass type soil moisture controllers are designed to allow or bypass a scheduled event from an automatic irrigation system timer if the soil water content is below or above a certain threshold. This threshold is defined and set by the user. The sensor buried within the turfgrass or landscape root zone checks the soil water content.

Soil moisture sensor systems only **bypass** the scheduled irrigation cycle time if the soil is above the set threshold, when the soil is too wet.



Soil moisture sensor systems can be set up using a single sensor to control the irrigation for many zones (where an irrigation zone is defined by a solenoid valve) or multiple sensors. In the case of one sensor for several zones, the zone that is normally the driest, or most in need of irrigation, is selected for placement of the sensor in order to ensure adequate irrigation in all zones.

Want to learn more?

Check out this video tutorial about SMS systems (http://abe.ufl.edu/mdukes/controllers/video-soil-moisture-controllers.shtml). Further reading that will help you understand more about soil moisture sensor systems, *Smart Irrigation Controllers: How Do Soil Moisture Sensor (SMS) Irrigation Controllers Work?* (http://edis.ifas.ufl.edu/ae437) and *What Makes an Irrigation Controller Smart?* (http://www.edis.ifas.ufl.edu/ae442). Details on soil moisture sensor controller installation and programming can be found in the Field Guide to Soil Moisture Sensor Use in Florida (http://www.sjrwmd.com/floridawaterstar/pdfs/SMS_field_guide.pdf).

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U.F. IrriGator Irrigation Scheduler Newsletter

This month's newsletter is dedicated to the ***weather-based irrigation controller***, also referred to as an ET controller. These are more than just time clocks; they are irrigation scheduling devices that use the principles of the soil water balance to schedule irrigation amounts and timing. ***Weather based irrigation controllers are about twice as effective in the reduction of unnecessary irrigation compared to standard time-based controllers with rain sensors.***

June time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	25
2	Rotor	Back left	50
3	Rotor	Back right	50
4	Spray	Side right	25
5	Rotor	Front	50
6	Spray	Front beds	25

* Sprinkler type refers to the predominant head type for the zone.

Did you know?

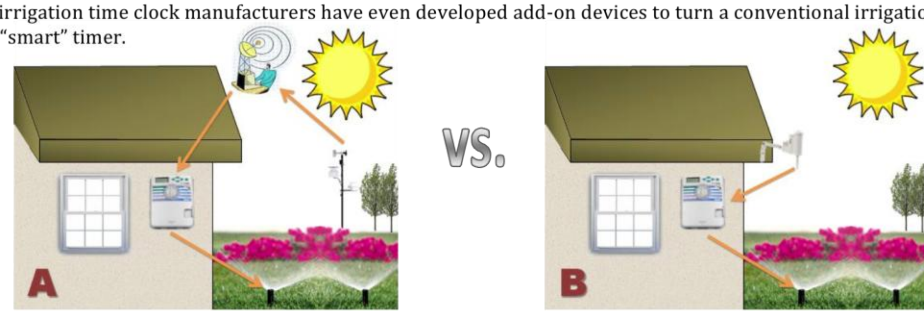
The U.S. Environmental Protection Agency has developed the WaterSense program to certify and label devices that are water efficient.

In the coming year, you will start to see the WaterSense program label on approved irrigation devices such as weather based irrigation controllers.

How a weather based irrigation controller works

A weather based irrigation controller determines how much irrigation to apply based on weather conditions such as temperature and humidity. The weather data is either sent to the controller as part of a subscription service or collected on site with a mini weather station. There are two types of systems: signal-based and sensor-based.

A signal-based systems use wired (phone) or wireless (cellular or paging) communication to receive weather data. The sensor-based systems are stand-alone controllers with onsite measurement devices to calculate irrigation need based on the local weather conditions. Onsite sensors could include: temperature, solar radiation, or even a full weather station. Some irrigation time clock manufacturers have even developed add-on devices to turn a conventional irrigation timer into a "smart" timer.



Want to learn more?

Check out this video tutorial on weather based irrigation controllers (http://abe.ufl.edu/mdukes/controllers/video-weather-based-controllers.shtml). Programming recommendations for several controllers in Florida conditions can be found in *Programming Guidelines for Evapotranspiration-Based Irrigation Controllers* (http://edis.ifas.ufl.edu/AE445). General information on ET controllers and other smart irrigation technologies can be found in *What Makes an Irrigation Controller Smart* (http://edis.ifas.ufl.edu/AE442).

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U.F. IrriGator Irrigation Scheduler Newsletter

JULY SMART IRRIGATION MONTH

Most homeowners overwater their yard, unintentionally wasting money every time the hose is taken out or the sprinklers are turned on. To raise awareness of the benefits of efficient watering practices, the Irrigation Association has named July Smart Irrigation Month.

Using an automated irrigation system is one of the best ways to keep your lawn and landscape beautiful and healthy, while minimizing water waste. Make time this summer to be sure you're getting the most out of your irrigation system, while keeping utility bills low and helping to protect the environment.

July time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	30
2	Rotor	Back left	55
3	Rotor	Back right	55
4	Spray	Side right	30
5	Rotor	Front	55
6	Spray	Front beds	30

* Sprinkler type refers to the predominant head type for the zone.

What types of controllers are "Smart"?

Weather-based irrigation controllers

Soil moisture sensor systems

Video of the month

The Smart Water Application Technology Research Area, at the Plant Science Research Education Unit of the Turfgrass Research Facility in Citra, FL, is highlighted in this presentation discussing soil-moisture sensors, evapotranspiration controllers and rain shut-off devices.

Click here to view the video
(http://vfd.ifas.ufl.edu/turfgrass/smart_water_application.shtml)

All about "smart" irrigation systems

The new generation of "smart" irrigation systems monitor weather, soil conditions, evaporation and plant water use and automatically adjust your watering schedule.

The secret to smart systems is the controller. Smart controllers use weather and/or site data to determine when and how long to water. Then, sprinklers apply just enough water at exactly the right time in each zone of your yard.

Save water. Smart systems automatically suspend watering during rain, freezing or high wind conditions. Careful scheduling minimizes evaporation and encourages water to soak in, reducing the total amount of water needed. Preventing overwatering actually keeps plants healthier by encouraging stronger roots and discouraging weeds, disease and fungus growth.

Save money. Smart systems can reduce your annual water bill by as much as 30% by preventing water waste.

Save time. Once your site data is programmed into the smart system, the controller adjusts the watering schedule based upon weather conditions and soil moisture without manual intervention.

Add convenience. Smart controllers adapt to seasonal weather changes without requiring reprogramming. And their "set and forget" technology is perfect for complying with any local watering restrictions, as well as for frequent travelers and vacation or second homes.

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U.F. IrriGator Irrigation Scheduler Newsletter

Hope you are having a great summer. As always, this newsletter is a reminder to update your irrigation schedule. All it takes is a minute at your time clock, your lawn with thank you for it.

Remember, irrigation scheduling is key when it comes to efficient water use. Just changing the settings on your clock can help reduce irrigation water use by 30%.

August time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	25
2	Rotor	Back left	50
3	Rotor	Back right	50
4	Spray	Side right	25
5	Rotor	Front	50
6	Spray	Front beds	25
* Sprinkler type refers to the predominant head type for the zone.			

Did you know?

During the hot summer months it is important to maintain sufficient irrigation for your lawn. However, more is not always better.

Did you know that Dollar Weed (a.k.a Pennywort) can result from too much irrigation.

Video of the month

Are you familiar with how your irrigation time clock works? To learn more about using your irrigation controller or time clock, follow the link to watch a short video.

Click here to view controller setting video
(http://abe.ufl.edu/mdukes/Controllers/video-irrigation-controllers.shtml)

In the news

You may have heard about changes to your watering restrictions. It is true, the Southwest Florida Water Management District has amended the watering ordinances in certain counties.

Click here to read more
(http://www.swfwmd.state.fl.us/conservation/restrictions/swfwmd.php)

Inform yourself about the state of irrigation watering restrictions for Pinellas County.

Click here to view the PCU watering rules
(http://www.pinellascounty.org/utilities/water-restrict.htm)

Thanks for reading

Coming up... Know how your lawn reacts with each season.

Interested in a specific topic? Drop us a line and we will include in an upcoming newsletter. And as always, if you ever have any questions, please feel free to email us at irrigation@ufl.edu.

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U.F. IrriGator Irrigation Scheduler Newsletter

Did you ever think about what happens to those scheduled irrigation events after it rains? There are a number of rain shutoff devices that can help bypass these unnecessary irrigation events. The newsletter this month is dedicated to the rain sensor.

A recent study found that using a rain sensor along with setting your time clock can result in more than a 50% water savings!

September time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** events per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	20
2	Rotor	Back left	35
3	Rotor	Back right	20
4	Spray	Side right	35
5	Rotor	Front	35
6	Spray	Front beds	20

* Sprinkler type refers to the predominant head type for the zone.

Did you know?

With all this talk about rain sensors, it is important to know if your rain sensor is in the right location.

Rain sensors should be installed in a location without obstruction from rainfall.

Q. Can you identify what is wrong with the location of this rain sensor?

A. It should NOT be under the eave of the roof.

Video of the month

Using a rain sensor can help reduce unnecessary irrigation events. A rain sensor is an inexpensive add-on rain shutoff device that can be incorporated into your irrigation system. Rain sensors will cause the irrigation system to bypass scheduled irrigation events after a specific amount of rainfall has occurred.

To learn more about rain sensors, follow the link to watch a short video.
Click here to view the rain sensor video
(http://abe.ufl.edu/mdukes/controllers/video-rain-sensors.shtml)

In the news

Florida is one of a handful of states that has a statute specifically dedicated to rain shutoff devices. You may have heard that this statute was recently modified. Now all irrigation systems are required to have some type of rain shutoff device.

Learn more about types of rain shutoff devices.

Click here to read more about rain shutoff devices
(http://edis.ifas.ufl.edu/ae221)
Click here to see the Florida statute

Thanks for reading

Autumn is approaching and there will be big changes in the weather and plant water needs with this new season.

This newsletter is a reminder to update your irrigation schedule. All it takes is a minute at your time clock, and your lawn will thank you for it. Remember, irrigation scheduling is key when it comes to efficient water use. **Just changing the settings on your time clock can help reduce irrigation water use by 30%.**

Interested in a specific topic? Drop us a line and we will include in an upcoming newsletter. And as always, if you ever have any questions, please feel free to email me at irrigation@ufl.edu.

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U.F. IrriGator Irrigation Scheduler Newsletter

When is the last time you observed your irrigation system running? Observing your irrigation system in action can help you save water by improving both the irrigation system efficiency and uniformity. This month's newsletter will help you learn more about the difference between these two terms: efficient irrigation vs. uniform irrigation.

October time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **1** event per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	20
2	Rotor	Back left	40
3	Rotor	Back right	40
4	Spray	Side right	20
5	Rotor	Front	40
6	Spray	Front beds	20

* Sprinkler type refers to the predominant head type for the zone.

Did you know?

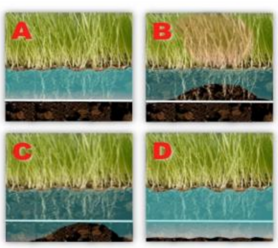
Good uniformity combined with proper scheduling will result in reduced pest and weed invasion and less "dry spots."

Use tuna cans distributed on your lawn to measure your irrigation system's application rate and uniformity.

Efficiency vs. Uniformity

The terms *efficiency* and *uniformity* are often confused when discussing irrigation. It is a common mistake to use them synonymously. ***Efficiency*** refers to how much of the water applied to the plants is finally used by them, while ***uniformity*** refers to how evenly the water is applied to the plants. Uniformity is increased with proper head-to-head coverage. Although a system can have sufficiently good uniformity, this does not mean that the irrigation event will necessarily be efficient.

The following illustrations depict four irrigation water application scenarios in the soil within and below the root zone of the plants. Can you tell the difference between the efficient and uniform irrigation?



(A) The irrigation water applied is both uniform and efficient (the goal).
(B) While efficient in terms of conservative water use, the irrigation was not uniform. Underwatering areas in the root zone will result in plant quality decline (leading to pest and weed invasion, or "dry spots").
(C) Nonuniform and inefficient due to over watering some areas.
(D) Uniform but inefficient due to overwatering, resulting in drainage below the root zone (which, with time, can result in plant loss as well as the transport of excess nutrients, fertilizers and pesticides that harm the environment).

Helpful links and further reading

System evaluations (or audits) can be performed by a state Mobile Irrigation Lab (http://fawn.ifas.ufl.edu/focus/topic.php/mobile_irrigation) or by the homeowner. If you are interested in performing your own system evaluation a good place to start will be with "How to Calibrate Your Sprinkler System" (http://edis.ifas.ufl.edu/LH026).

For a more in-depth discussion of the concept, see "Understanding the Concepts of Uniformity and Efficiency in Irrigation" (http://edis.ifas.ufl.edu/AE364) and "Lawn Sprinkler Selection and Layout for Uniform Water Application" (http://edis.ifas.ufl.edu/AE084).

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U.F. IrriGator Irrigation Scheduler Newsletter

We all want to water more wisely. This month consider your efficient irrigation capability. Try to implement some of the suggestions from the efficient irrigation checklist below while trying to avoid the six most common irrigation errors.

November time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **1** event per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	15
2	Rotor	Back left	35
3	Rotor	Back right	35
4	Spray	Side right	15
5	Rotor	Front	35
6	Spray	Front beds	15

Did you know?

Florida uses 8.2 billion gallons of water per day.

Of that, residential irrigation accounts for 1 billion gallons of water per day.

Checklist for efficient irrigation

Increasing the efficiency of your irrigation system can be accomplished easily by following this checklist for efficient irrigation.

- ✓ Perform regular maintenance by turning on all irrigation zones. Check for leaks and that all irrigation heads are operating properly.
- ✓ Adjust irrigation zones/sprinklers to avoid spraying buildings, driveways, streets and sidewalks. In addition, be certain that plants or structures do not interfere with irrigation spray patterns.
- ✓ Make sure there is a functioning rain shutoff device placed in an unobstructed location.
- ✓ Separate the irrigation system into multiple zones to water only those areas that need it.
- ✓ Use your programmable timer to irrigate different areas of the landscape for different lengths of time.
- ✓ Use micro-irrigation in ornamental planting areas. Micro-irrigation applies water more efficiently by dispensing water slowly near the base of the plant, reducing runoff and evaporation.

For a more in-depth discussion of the concept, see "Energy Efficient Homes: The Irrigation System" (http://edis.ifas.ufl.edu/FCS3274).

The 6 most common irrigation errors

1. **Broken or misdirected sprinklers**.
2. **Sprinkler spray pattern obstructed by plant parts or grass blades**. These include branches, trunks or leaves that can cause the spray pattern to be uneven.
3. **Mixed sprinkler types**. For example, when stationary shrub spray heads and rotating turf sprinklers are used in the same irrigation zone, the shrubs usually end up being overwatered.
4. **Unmatched precipitation rates**. The flow rate (amount of water applied per minute) of a sprinkler with a quarter-circle spray pattern should be ½ the amount of the same type of sprinkler with half-circle coverage, and a ¼ of the flow rate of a full-circle sprinkler.
5. **Improperly spaced sprinklers**. Space the lawn sprinklers so the water from one sprinkler head just reaches the adjacent sprinkler head(s), ensuring full coverage.
6. **Irrigation scheduled incorrectly**. Irrigation controllers are often set to run too frequently or for too long per irrigation event.

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U.F. IrriGator Irrigation Scheduler Newsletter

As we approach winter, consider reducing your irrigation. During these colder months, your lawn and landscape require less water to replace that lost to evapotranspiration.

December time clock settings

Below are the run times for your time clock. This recommended irrigation schedule has been developed specifically for your irrigation system, based on information from the questionnaire you completed.

This irrigation schedule is based on **2** event per week.

Zone	Sprinkler*	Area	Run time (minutes)
1	Spray	Side left	5
2	Rotor	Back left	10
3	Rotor	Back right	10
4	Spray	Side right	5
5	Rotor	Front	10
6	Spray	Front beds	5

* Sprinkler type refers to the predominant head type for the zone.

Did you know?

In 2005, Floridians paid an average of $15 per month for their household water charge. Compare that to the average monthly expenses of $49 for cable and $59 for soda and other drinks.

In the news

Water Shortage Declared for Southwest Florida. In a signal that watering restrictions may be coming in the next few months, the Southwest Florida Water Management District's governing board declared a water shortage today. The shortage declaration, which goes into effect on Dec. 1, is meant to alert local governments and the public to developing drought conditions. It does not bring additional watering restrictions. The water district is urging residents to check their irrigation systems to make sure they do not leak and that timers and rain sensors work properly. An estimated 50% of fresh water suitable for drinking is doused on landscaping in many parts of Southwest Florida.

[Source: Florida Trend Magazine]

What is dormant grass?

Warm season grasses, such as St. Augustinegrass, actively grow in the warmer months of the year. They also may go dormant during the winter months. Dormant warm season grasses will either keep the green color or the foliage may freeze, fading in color. Although some of the foliage may freeze, the turfgrass lawn itself is not dead and will regrow once warmer conditions return. This is referred to as greenup.

Turfgrass may enter a state of dormancy for differing lengths of time depending on the genetics of the variety and overall health of the lawn. Dormant grass is simply in a state of reduced water usage where the plant focuses resources on the roots. In central and southwest Florida, the turfgrass most commonly exhibit a reduction in growth and metabolism, rather than true dormancy.

Click here to read more about "Low Temperature Damage to Turf" (http://edis.ifas.ufl.edu/lh067)

APPENDIX E
NEWSLETTER CAMPAIGN PROGRAM EVALUATION QUESTIONNAIRE

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Institute of Food and Agricultural Sciences

Example Participant Survey

Survey ID No. ☐☐☐☐

Thank you for your interest in irrigation water conservation as a participant in the IrriGator Irrigation Scheduler Newsletter program. We would like to ask you a few questions regarding your irrigation practices and the Irrigation Scheduler Newsletters. Your response is beneficial to the success of this water conservation research.

1. **How often do plan to adjust your watering schedule during the coming year?**

   ☐ Monthly
   ☐ Seasonally
   ☐ Neither
   ☐ Other: ____________________

2. **Do you water your lawn (turfgrass) and landscape (bedded area) for different lengths of time? (*To the best of the systems ability.*)**

   ☐ Yes ☐ No ☐ Don't know

3. **How satisfied are you with your current irrigation practices?**

   ☐ *Very satisfied* ☐ *Somewhat satisfied* ☐ *Neither* ☐ *Somewhat dissatisfied* ☐ *Very dissatisfied*

4. **How satisfied are you with your current landscape appearance?**

   ☐ *Very satisfied* ☐ *Somewhat satisfied* ☐ *Neither* ☐ *Somewhat dissatisfied* ☐ *Very dissatisfied*

5. **Please rate your familiarity with the following characteristics of your irrigation system from 5 to 1 (where 5 represents the highest level of familiarity):**

	5	4	3	2	1
Sprinkler head types	☐	☐	☐	☐	☐
Irrigation zone locations	☐	☐	☐	☐	☐
Efficiency of irrigation system	☐	☐	☐	☐	☐
Sprinkler application rates	☐	☐	☐	☐	☐
Local conservation programs	☐	☐	☐	☐	☐

6. **Please rate your familiarity with the following characteristics of your landscape/yard from 5 to 1 (where 5 represents the highest level of familiarity):**

	5	4	3	2	1
Plant types	☐	☐	☐	☐	☐
Water needs of plants	☐	☐	☐	☐	☐
Soil type	☐	☐	☐	☐	☐
Sun and shade pattern	☐	☐	☐	☐	☐
Plant root depths	☐	☐	☐	☐	☐
Slope pattern of yard	☐	☐	☐	☐	☐

7. **In your opinion, how effective are each of the following for increasing water conservation:**

	Very effective	Effective	Neither	Ineffective	Very ineffective	Don't know
Water restrictions	☐	☐	☐	☐	☐	☐
Rain shutoff devices	☐	☐	☐	☐	☐	☐
Increased water rates	☐	☐	☐	☐	☐	☐
Landscape ordinances that limit turfgrass area	☐	☐	☐	☐	☐	☐
Local conservation programs	☐	☐	☐	☐	☐	☐
Using native plants in the bedded areas	☐	☐	☐	☐	☐	☐
Irrigation scheduling based on water needs of plants	☐	☐	☐	☐	☐	☐
Email reminders of when to change the irrigation timer and suggested run times would help increase irrigation efficiency	☐	☐	☐	☐	☐	☐

8. **Please rate your satisfaction with the IrriGator Irrigation Scheduler Newsletters?**

	Very satisfied	Satisfied	Neither	Dissatisfied	Very dissatisfied	Don't know
Easy to understand	☐	☐	☐	☐	☐	☐
Accurate information	☐	☐	☐	☐	☐	☐
Up to date	☐	☐	☐	☐	☐	☐
Overall	☐	☐	☐	☐	☐	☐

Thank you for your participation!

APPENDIX F
OCU SURVEY INSTRUMENT

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Participant Survey

ID# ________

Thank you for your interest in irrigation water conservation. Based on your response to the initial online questionnaire, you have been selected as a household of interest in this study. Therefore, we would like ask you to please complete this survey regarding your experiences with irrigation technology.

Changes to your landscape, irrigation system, and watering schedule

1. **Please rate how often you currently interact with (i.e. check or adjust) your irrigation time clock by marking the number which best describes your interaction.**

   ☐ Never
   ☐ Set & Forget
   ☐ Minimally interactive
   ☐ Moderately interactive
   ☐ Very interactive

   Comments (optional): ____

2. **In the past 6 months, have you made changes to your lawn/landscape or pool area?**

☐	☐	☐	☐
Major changes	*Minor changes*	*No changes*	*Don't' know*

3. **In the past 6 months, have you made changes to your irrigation system?**

☐	☐	☐	☐
Major changes	*Minor changes*	*No changes*	*Don't' know*

   Comments (optional): ____

4. **In the past 6 months, have you (or someone else) performed maintenance on the irrigation system?**

   ☐ Yes
   ☐ No
   ☐ Don't know

   Comments (optional): ____

5. **In the past 6 months, have you adjusted your watering schedule?**

   ☐ Monthly
   ☐ Based on seasonal change
   ☐ Not really
   ☐ Other

   If other, please specify: ____

Your irrigation practices

6. **How satisfied are you with your current irrigation practices?**

☐	☐	☐	☐	☐
Very satisfied	*Somewhat satisfied*	*Neither*	*Somewhat dissatisfied*	*Very dissatisfied*

6a. Why are you dissatisfied? ____

Your landscape appearance

7. **How satisfied are you with your current landscape appearance?**

☐ *Very satisfied* ☐ *Somewhat satisfied* ☐ *Neither* ☐ *Somewhat dissatisfied* ☐ *Very dissatisfied*

7a. Why are you dissatisfied? ____

Your opinion about watering practices

8. **How much influence do the following factors have on your watering practices? Rate on a scale from 1 to 5 (with 5 representing the highest level of influence).**

	No Influence 1	2	3	4	A Lot of Influence 5
Watering restriction ***days***	☐	☐	☐	☐	☐
Watering restriction ***hours***	☐	☐	☐	☐	☐
Public service announcements (Radio, TV)	☐	☐	☐	☐	☐
Observation of neighbors	☐	☐	☐	☐	☐
Homeowners association	☐	☐	☐	☐	☐
Season (i.e. winter vs. summer)	☐	☐	☐	☐	☐
Weather (i.e. rainfall)	☐	☐	☐	☐	☐

About irrigation technology

9. **Are you familiar with any of the following types of irrigation technology? Mark all that apply.**

☐ Rain sensors
☐ Soil moisture sensors
☐ ET controllers (a.k.a. weather-based sensors)
☐ No
☐ Other

If other, please specify: ____

10. **Do you have a rain shutoff or bypass device attached to your irrigation system (i.e. rain sensor or soil moisture sensor, etc.)?**

☐ Yes ☐ No ☐ Don't know

Comments (optional): ____

11. **In your opinion, what is the most common motivation for the use of irrigation technology (i.e. rain sensors, soil moisture sensors, or ET controllers) (select one):**

____ To save money
____ To save time
____ To save water
____ General interest in new technology
____ Other: _________________

Rain sensors and soil moisture sensors are used to bypass unnecessary irrigation events whereas ET controllers calculate the amount of time the irrigation system should run based on weather data and conditions.

12. **Which of the following technologies do you trust to appropriately bypass unnecessary irrigation events (select all that apply)?**

☐ Rain sensors
☐ Soil moisture sensors
☐ ET controllers
☐ ET controllers with a rain switch
☐ None
☐ Other

If other, please specify: ____

13. **Which of the following are you familiar with at your home (mark all that apply):**

☐ Amount of sun and shade around the yard
☐ Number of zones
☐ Sprinkler head type within a zone
☐ Plant type (i.e. turfgrass or bedded area)
☐ Soil Type (i.e. sand or clay)

14. **In your opinion, whom of the following would you trust to install or set the following irrigation technology correctly?**

	Rain sensors	Soil moisture sensor systems	ET Controllers	Other: ________
Yourself	☐	☐	☐	☐
Irrigation contractor	☐	☐	☐	☐
Landscape service professional	☐	☐	☐	☐
IFAS-Extension or FYN (Florida Yards and Neighborhoods) personnel	☐	☐	☐	☐
Other	☐	☐	☐	☐

If other, please specify: ____

How irrigation technology works

We would now like to ask you a few specific questions regarding how irrigation technology works. Please answer to the best of your knowledge.

15. **Which of the following factors need NOT be considered when programming the run time for each zone on your irrigation system (a.k.a. irrigation scheduling):**

☐ Soil type
☐ Root zone depth
☐ Local weather conditions
☐ Property size

16. **Which of the following locations would be an ideal spot to install a rain sensor?**

☐ On the edge of the roof line, without obstruction from rainfall
☐ On the side of the house, under the eave of the roof
☐ On a fence post, below a tree canopy
☐ Anywhere is o.k.
☐ Don't know

17. **When might a soil moisture sensor system bypass an irrigation event (mark the best answer)?**

- ☐ At the scheduled irrigation cycle time if the soil is wet
- ☐ At the scheduled irrigation cycle time if the soil is dry
- ☐ Never

18. **An ET controller is an irrigation controller that (mark the best answer):**

- ☐ Applies irrigation based on how many minutes you program into it
- ☐ Applies irrigation based on weather information and conditions like temperature and humidity
- ☐ Applies irrigation based on how wet or dry the soil is
- ☐ Don't know

19. **Where are rain shutoff devices required by law in Florida?**

- ☐ Only in districts with watering restrictions
- ☐ On all newly installed irrigation systems
- ☐ On all irrigation systems
- ☐ They are not required by law
- ☐ Don't know

The University of Florida and Orange County Utilities would like to thank you for your participation in this survey! Thank you again!

If there is anything else you would like for us to now about your opinions regarding watering practices or irrigation technology, please feel free to comment.

Answers to responses for questions 16-19 and 21:

16. When programming the run time for each zone on your irrigation system (a.k.a. irrigation scheduling) a factor that need not be considered is: Property size. Although a larger lawn may consume a greater amount of water during the total irrigation event, each zone runtime is set no differently than that for a smaller yard. Factors that are important to irrigation scheduling are: soil type, root zone depth, and local weather conditions

17. Rain sensors should be installed on the edge of the roof line, without obstruction from rainfall. If there is a roof eave or tree canopy obstructing the rain sensor catchment, the device will not function properly.

18. Soil moisture sensor systems only bypass the scheduled irrigation cycle time if the soil is **above** the set threshold, when the soil is too wet.

19. An ET controller determines how much irrigation to apply based on weather conditions such as temperature and humidity. The weather data is either sent to the controller as part of a subscription service or collected on site with a mini weather station.

21. According to Senate Bill 494, rain shutoff devices are required on all irrigation systems in Florida.

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BIOGRAPHICAL SKETCH

Melissa Baum Haley was awarded her Bachelor of Science degree in 2002 and Master of Engineering degree in 2005 from the University of Florida in agricultural and biological engineering, focusing on land and water resources. Her master's work analyzed effects of irrigation efficiency on water use for homes in North Central Florida within the St. Johns River Water Management District.

With the acceptance of this dissertation, she graduated with her Doctor of Philosophy degree from the Agricultural and Biological Engineering Department through the College of Agriculture and Life Sciences, studying the interaction between the technical and social aspects of residential irrigation water-use conservation. Melissa has worked on various projects with the Southwest Florida Water Management District (SWFWMD), in efforts to reduce residential irrigation water application by incorporating sensor based controllers and educational materials. She also wrote two cooperative grants with the SWFWMD Communications Department to quantify water conservation practices, perceptions, and effective behavioral change.

Melissa's research lends itself to a great deal of public interaction. She often works with residential program participants and survey respondents, as well as utility personnel, Extension Faculty, FYN and Master Gardener groups. Upon obtaining her doctoral degree, she would like to use the knowledge gained through academic research in conservation behavior to shape policy by working with governmental and non-governmental agencies, and local water purveyors for the implementation of more practical water use strategies that change and affect both human and natural systems.

The time Melissa spent at the University of Florida will forever shape her view of research and academia. She was ever fortunate to have a superb mentor in Dr. Michael

Dukes, and his quest for excellence will remain woven through her professional aspirations.

Melissa now lives in Southern California with her husband, Patrick, and daughter, Lola. As of February 2011, she has been employed as a water use efficiency programs specialist at Municipal Water District of Orange County.