RESIDENTIAL IRRIGATION AND RESPONSES TO CONSERVATION MEASURES IN FLORIDA

By

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To my greatest accomplishments,
Ian Bay, Callum Berkshire, and Delaney Wren

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AD	Allowable depletion
AWHC	Available water holding capacity
COT	City of Tampa
DOR	Department of Revenue
ET	Evapotranspiration
ET_C	Crop evapotranspiration
ET_o	Reference evapotranspiration
FFL	Florida-Friendly Landscaping
FYN	Florida Yards and Neighborhoods
HCU	Hillsborough County Utilities
I_{app}	Irrigation applied
ID	Identification number
I_{req}	Irrigation required
IWR_{net}	Net irrigation water applied since the start of the previous day's irrigation window
gpad	Gallons per account per day
gpcd	Gallons per capita per day
GIR	Gross irrigation required
Kc	Crop coefficient
K_L	Landscape coefficient
MAD	Maximum allowable depletion
MGD	Million gallons per day
NPR	New Port Richey
NTEP	National Turfgrass Evaluation Program
NWH	Northwest Hillsborough County

OCU	Orange County Utilities
PAS	Pasco County
PAW	Plant available water
PF	Plant factor
PIN	Pinellas County
PWR	Plant water requirement since the start of the previous day's irrigation window
Re	Effective rainfall since the start of the previous day's irrigation window
RZ	Root zone depth
SCH	South Central Hillsborough County
$SMB_{current}$	Current soil moisture balance
$SMB_{previous}$	Soil moisture balance level at the start of the previous day's irrigation window
SMS	Soil moisture sensor
STP	St. Petersburg
SWFWMD	Southwest Florida Water Management District
TBW	Tampa Bay Water
TIR	Theoretical irrigation required

Abstract of Dissertation Presented to the Graduate School
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The historical irrigation demand of single family residential potable water customers without access to reuse in southwest and central Florida was estimated using approximately twelve years of monthly water billing records for customers in seven member government service areas of Tampa Bay Water and in Orange County Utilities. The majority of customers under irrigated as compared to the estimated gross irrigation required. Sixty seven percent of customers irrigated less than 1 inch per month and 84 percent used less than the gross irrigation requirement (GIR). The methodology outlined to stratify customers into irrigating groups is reproducible by utilities that maintain monthly billing records and have access to parcel records.

The observed impact of two conservation strategies, Florida Friendly Landscaping (FFL) and irrigation water restrictions, were estimated using the monthly billing records coupled with Florida Friendly Landscaping recognition lists and water restriction ordinances. Irrigation savings when considering all Florida Friendly Landscaping recognized homes was 50 percent, and irrigation savings when considering high quality Florida Friendly Landscapes and comparison homes was 76 percent.

Long term water restrictions that reduced allowable irrigation from two days to one day per week were successful in reducing irrigation demand. Annual irrigation demand decreased 13 percent, while annual irrigation required increased 3 percent under the more stringent restrictions. High irrigators reduced their irrigation demand 20 percent under the more stringent conditions, indicating that those who irrigated most had the most potential for conservation.

Predicted irrigation changes in Hillsborough County Utilities and Orange County Utilities were estimated using the monthly billing records coupled with field studies of three water conservation tools, FFL, soil moisture sensors, and evapotranspiration controllers. Targeted implementation of conservation tools such as FFL, soil moisture sensor controllers (SMS), and evapotranspiration (ET) controllers could decrease irrigation demand for the targeted customers without impacting those who have historically used minimal irrigation. As utilities increase their understanding of customers current irrigation behavior through analysis of water billing records, the most effective conservation measures can be selected and water conservation can be maximized.

CHAPTER 1
INTRODUCTION

Organization of Dissertation

The goal of this doctoral research was to investigate historical irrigation demand of single-family residential potable water customers without access to reuse in southwest and central Florida and to estimate irrigation changes (both observed and predicted) in response to several conservation measures. Chapter 2 evaluates the effectiveness of Florida-Friendly Landscapes to conserve residential irrigation and was published in the Journal of Irrigation Drainage and Engineering. Chapter 3 explores using customer water billing data to characterize residential irrigation demand and was published in the Journal of the American Water Works Association. Chapter 4 evaluates the use of long-term water restrictions to reduce residential irrigation and will be submitted to the Journal of the American Water Works Association. Chapter 5 contrasts residential irrigation in two utilities and predicts the water savings of Florida-Friendly Landscaping, soil moisture sensors, and evapotranspiration controllers. Lastly, the Conclusions chapter summarizes the research chapters and their importance in understanding residential irrigation conservation.

Residential Irrigation

An improved understanding of baseline residential irrigation practices is essential to promote irrigation conservation, thereby reducing demand on high-quality drinking water supplies. In Florida as in many other parts of the country, irrigation is often used to maintain residential landscapes and can be a substantial component of a home’s total potable water use. For example, DeOreo et al. (2016) estimated that irrigation accounts for 50% of total residential potable water use in the United States. However, existing residential irrigation estimates tend to be very general, are often based on "best guesses", and usually do not account for customer, spatial, or temporal variations within a utility. By developing scientifically-based irrigation estimates that capture the patterns of the broader population and evaluating the actual irrigation savings of Florida Friendly Landscaping, water restrictions, and smart irrigation technologies, utilities and governments will have the knowledge and tools to better manage their water resources and to effectively educate their customers.

Methods for estimating customer irrigation include: installing dedicated irrigation meters, performing customer surveys, analyzing monthly billing records, and using continuous monitoring. Dedicated irrigation meters provide the most accurate data, but are generally cost prohibitive and may have the unintended effect of increasing irrigation by making a water bill cheaper due to avoiding wastewater fees (Tiger et al. 2011). Surveys have been used to document landscape habits and can be used in conjunction with billing records or continuous monitoring (Mayer et al. 1999, Law et al. 2004, Whitcomb 2005, DeOreo et al. 2016). Survey respondents, however, may provide inaccurate answers or survey results may be misleading (Silva et al. 2010).

Continuous monitoring without concurrent surveys can be used to determine irrigation without solicitation of the water customers, which minimizes influencing the homeowner's water use habits. Automatic meter recording (AMR) devices have been used to monitor utility potable water meters at a high frequency approximating continuous monitoring (Mayer et al. 1999, Gato-Trinidad et al. 2011, Haley & Dukes 2012, DeOreo et al. 2016). The Residential End Users of Water Study provides a comprehensive analysis of both indoor and outdoor single-family residential water use

(Mayer et al. 1999). The original 1999 study first analyzed the historic monthly water billing records from approximately 12,000 customers (residences) in fourteen North American cities. Next, surveys were sent to 1,000 customers per location, with approximately 6,000 completed surveys were returned. The surveys provided household-level information, including the number of residents, the number and types of water-using appliances or fixtures in a residence, water use habits, and landscape area. Approximately 1,200 homes that had water use similar to the utility as a whole were selected for monitoring. Monitoring was conducted for two weeks in the summer and two weeks in the winter in each of the twelve cities. Flow rates were recorded every ten seconds and disaggregated using Trace Wizard software. The data collection was frequent enough to distinguish between residential water uses such as hand washing, toilet flushing, dishwashing and irrigating. Analysis with Trace Wizard was an iterative process, with a user specifying a flow rate for each water-using appliance or fixture. Across all study sites, average indoor use was 69.3 gallons per capita day (gpcd) and average outdoor use was 100.8 gpcd.

The updated Residential End Users of Water Study was expanded to 23,749 homes in twenty-three North American utilities for monthly billing data and 762 homes in nine utilities for AMR data (DeOreo et al. 2016). Indoor water use decreased from 69.3 to 58.6 gpcd (15%). The update also included a more detailed outdoor water use analysis than the previous report. The monitored outdoor water use (the majority of which is assumed to be irrigation) for 838 homes was compared to the theoretical irrigation required (TIR, similar to GIR). The TIRs were based on the measured irrigated areas and groundcover types at each of the 838 homes. Seventy-two percent of these homes were classified as low/deficit irrigators (irrigation demand was 70% or less than TIR), 16% were target irrigators (irrigation demand was 70-130% of TIR), and 13% were excess irrigators (irrigation demand was greater than 130% TIR).

Several similar studies have been performed using continuous monitoring to observe irrigation and total water use. Gato-Trinidad et al. (2011) followed the same methodology as the REUWS except that data was collected at five second intervals to determine irrigation use in Melbourne, Australia. Two additional studies characterized water use of homes in California and new homes nation-wide. Results are presented in Table 1-1.

The Analysis of Water Use in New Single-Family Homes (DeOreo 2011) studied homes in nine utilities in the United States. The study of single family homes built since 2001 showed the differences in water usage of “standard new” homes (those built to meet the 1992 Energy Policy Act) and “high-efficiency new” homes (those that exceed the requirements of the Policy Act and met the draft of the WaterSense New Home specification). These new homes were also compared to those in the Mayer et al. (1999) study, which were all built before 1996. Initial data collection was similar to Mayer et al. (1999); historical billing records were studied and customers were mailed surveys. However, local builders were also contacted to help identify the high-efficiency new homes, site visits of the majority of monitored houses were performed, and additional data such as aerial photographs and property appraiser records were obtained. All standard new and high-efficiency new homes were monitored for two weeks, and data was disaggregated using Trace Wizard. The observed indoor water use was 44.2 gpcd for standard new and 35.6 gpcd for high efficiency new. A previous study of EPA retrofits was referenced as having an observed indoor water use of 30.0 gpcd.

Because many landscapes for the high efficiency new homes had not been installed before the monitoring period, outdoor water use was only calculated for the 235 homes in the standard new group. Only one of the 235 standard new homes appeared to be a non-irrigator, and the distribution of all irrigators was log normal. Irrigation was reported in units of inches and was converted to volumes. The calculated irrigation used (demand) was compared to the net evapotranspiration, which is a main component of the irrigation required and defined as the reference evapotranspiration (ET_o) minus the effective rainfall. On average, two of the seven utilities in the study applied less than net ET_o and five applied less than ET_o. Both of the under-irrigating locations, Tampa and St. Johns River Water Management District, are located in Florida. Within these two locations, approximately 80% of homes were considered under irrigators.

Annual irrigation as a percent of total potable water use, as a volume, and, when available, as a depth for various cities is presented in Table 1-1. All studies except the Heatherwood study, which used monthly billing records, used AMR monitoring for several weeks in the summer and winter. Several utilities (Denver, Eugene, Las Virgenes, Phoenix, Scottsdale, and Tampa) participated in two studies performed at different times. While the results were similar for Phoenix, Scottsdale, and Tampa, but were vastly different for Las Virgenes and Eugene. In Denver, the annual irrigation volume was different, but the percentage of total water used for irrigation stayed the same. In Florida, annual irrigation for Tampa, Toho, and the St. Johns River Water

Management District are well below the mean and median of the values in Table 1-1. However, the highest reported percentage of total water used for irrigation is in the St. Johns River Water Management District.

In an analysis of monthly water billing records, customers in five North Carolina utilities were determined to be irrigating based on comparing summertime to wintertime peaking factors and comparing the behavior of homes with irrigation meters (known irrigators) to those without. Approximately 4 to 12% of all customers were identified as irrigators (Boyle et al. 2011). Additionally, Tiger and Boyle (2012) compared the irrigation patterns of customers with irrigation meters to customers without irrigation meters in twelve North Carolina utilities. Based on similarities in their usage patterns and assuming that irrigators must have an average household water use greater than 10,000 gal/month for May through October, it was determined that between 2 to 17% of customers (depending on utility) that did not have access to reuse were irrigators. The authors noted that the criteria for identifying irrigators was strict and that, most likely, more customers than reported were irrigating. Volumetric water use of irrigators was not reported. The method for determining irrigators that was used in North Carolina is not applicable in Florida where irrigation may occur year-round (Mayer et al. 1999). A more appropriate method for Florida is to estimate irrigation from billing records by subtracting estimated indoor water use from total water use, where indoor use is based on estimated per capita use (Mayer et al. 1999).

Landscape Coefficients for Irrigation Requirements

Irrigation requirements are calculated using a soil water balance. Reference evapotranspiration (ET_o) is an important component of the soil water balance and is defined as the evapotranspiration rate from a uniform surface of dense, actively growing vegetation of a given height and surface resistance that is well-watered and uniform for a minimum area of 100 meters in all directions (Irrigation Association 2005). For comparison to residential landscapes (which are traditionally turf-dominated), a short crop with an approximate height of 0.12 meters is used for calculating ET_o. Evapotranspiration for many plant species have been experimentally determined and can be expressed as a percentage of ET_o using the equation $K_C = ET_C / ET_o$, where K_C is the crop coefficient and ET_C is the crop evapotranspiration.

Crop coefficients have been documented for turfgrasses to a greater extent than other landscape plants. Warm season turfgrass crop coefficients differ in value depending on the study site and methods, but have generally been shown to be between 0.6 and 0.8 (Kneebone & Pepper 1982, Costello et al. 2000). Allen et al. (1998) recommended K_C of 0.80 to 0.85 for warm season grasses and 0.90 to 0.95 for cool season grasses. Jia et al. (2009) reported that monthly K_C values for bahiagrass ranged from 0.29 to 1.01, with higher values in the active growing season and lower values in the winter. The study noted that cloudy conditions, frequent rainfall, and high relative humidity may limit turfgrass evapotranspiration, thus reducing K_C. Brown et al. (2001) developed crop coefficients for use with desert turf systems. The K_C of bermudagrass in summer was 0.78 to 0.83 and the K_C of ryegrass in winter was 0.78 to 0.90.

The K_C of an entire residential landscape, also expressed as K_L, is difficult to quantify because the assumptions on which ET_o is based are not valid. Residential landscapes are not grown to maximize yield, are not uniform, and may incorporate water conservation. Landscapes can be extremely diverse in their composition, and factors such as plant density, geographic location, microclimates, and time of year can influence the K_C for each species.

There are several examples of how factors such as diversity or available water impact K_C or K_L. Using a K_C based on well-watered conditions may overestimate plant water use and not capture drought tolerance. McGroary et al. (2011) noted that even though bahiagrass used more water than St. Augustinegrass under well-watered conditions, bahiagrass was able to survive water deficit conditions better than St. Augustine. Carrow (1995) calculated K_C values for seven of the most commonly used turfgrasses under drought conditions in Georgia and observed K_C values 40-60% lower than those reported for the same genotype from arid and semi-arid regions under non-limited soil moisture, indicating that K_C values can be lower under drought conditions. In a similar study by Huang et al. (1997), the most commonly used turfgrasses were tested for drought tolerance, with zoysiagrass demonstrating the least drought tolerance.

Adjustments to the evapotranspiration equation have been proposed to capture the importance of aesthetics and drought tolerance in landscape plants. St. Hilaire et al. (2008) suggested using an adjustment factor (Plant Factor, abbreviated PF) rather than a landscape coefficient that considers that the soil is not consistently well-watered. Smeal et al. (2010) recommended using a species coefficient and including the canopy area to estimate plant water needs in order to compensate for variability in plant spacing, varietal differences and plant vigor. The Landscape Coefficient Method (Costello et al. 2000) recommends incorporating plant species, vegetation density, and microclimates into one landscape coefficient value.

Plant factors for over ninety species were developed by Smeal et al. (2010) by irrigating plots at 0.2, 0.4. 0.8, and 1.0 times ET_o minus precipitation and incorporating the plant canopy into an equation for PF. A PF (or K_L) of 0.3 for xeric landscapes in the intermountain western US was recommended, but noted that PF varied significantly between species.

Studies of drought tolerance have indicated that supplemental irrigation is rarely required for landscape ornamentals. Scheiber et al. (2008) evaluated the effect of irrigation rate on canopy size of ten of the most common native shrubs and ten of the most common exotic shrubs used in residential landscapes in Florida. Aesthetically, irrigated and non-irrigated plants were similar, indicating that the irrigation of native or exotic ornamental shrubs may not be necessary. Wiese et al. (2009) reported that two shrub species survived and grew on natural rainfall alone once established. Supplemental irrigation was only needed when there was no measurable rainfall for thirty consecutive days.

White et al. (2004) developed a landscape coefficient for a landscape that consisted of a mature walnut tree, crape myrtles, St. Augustinegrass, dwarf yaupon, and rose bushes during summer months in Texas. Irrigation was applied based on visual assessments (plant wilt and leaf rolling of turf), and a K_L of 0.70 was recommended. Pannkuk (2010) had similar results when developing K_L for single- and mixed-species landscapes and recommended a K_L of 0.5 to 0.7 for southern Texas. The K_L of St. Augustinegrass did not differ significantly from other individual or mixed species treatments. Native grasses appeared to be opportunistic water users.

The Water Use Classification of Landscape Species (WUCOLS) manual provides a comprehensive list of recommended species coefficients for use in California (Costello et al. 2000). The manual provides guidelines on the general water use of species and includes considerations of plant species, vegetation density, and microclimates in the calculation of a landscape coefficient. Each landscape plant is assigned three coefficients (species, density, and microclimate) that correspond to categories of high, moderate, low, and, for the species coefficient only, very low. Although developed for California, the landscape coefficients have also been used to estimate irrigation requirements for residential urban landscapes in New Mexico (Al-Kofahi et al. 2012). The interactive web-based tool allows a homeowner to determine their expected irrigation requirement under one of three levels of specificity.

Conservation Measures

Florida- Friendly Landscaping

The Florida-Friendly Landscaping (FFL) program promotes environmentally sustainable practices through nine principles such as water and fertilize efficiently, reduce storm water runoff, and protect the waterfront (UF/IFAS 2009a). The residential component of FFL is Florida Yards and Neighborhoods (FYN), and homes are recognized as FFL (or FYN) by passing a landscape evaluation. Prescribed methods to conserve water include such practices as: grouping plants with similar water needs, reducing irrigation in the summer and winter, and maintaining an automatic rain shutoff device for a sprinkler system (UF/IFAS 2009b). Homes in the FFL program are generally characterized by greater plant diversity (more ornamental plants) and less turfgrass. The FFL program has a broader environmental scope than Xeriscape, a widely accepted and proven method for reducing irrigation under most applications. Irrigation savings of Xeriscapes has ranged from 0 to 76%.

Xeriscape used 31% less water in Austin, Texas (Gregg et al. 1994). Landscapes of residential water users were evaluated using “drive-by’s” to identify xeric features, the presence of irrigation systems, and geographic location. The traditional landscapes were defined as having St. Augustinegrass, whereas Xeriscapes had buffalo grass or no turf. The monthly billing records for 6,015 of the evaluated landscapes were isolated and compared to determine differences in water consumption. Xeriscapes used approximately 175 gpd less than traditional landscapes.

Xeriscaping resulted in an irrigation savings of 18 to 63% in the Denver, Colorado area (Medina and Gumper 2004). The four-year study compared Xeriscapes and traditional landscapes installed at homes with similar property (i.e., new construction or existing) and landscape features (i.e., soils or presence of mature trees). There were seven study areas, each with the two landscape treatments (traditional and Xeriscape) and approximately 30 replications. Irrigation for most landscapes was estimated using monthly billing records and subtracting the estimated indoor water use based on winter average usage. One of the seven study areas received dedicated irrigation meters. All volumetric irrigation estimates were converted to a volume per unit area using estimates of landscape area determined from field evaluations. Six of the seven treatment groups had statistically significant irrigation savings over the course of the study, although Xeriscapes for two treatment groups used more irrigation than the traditional landscapes during a drought year. Median monthly irrigation use for all groups ranged from 1.77 to 2.86 gal/sq ft (2.84 to 4.59 inches) for traditional landscapes and 0.85 to 1.9 gal/sq ft (1.36 to 3.05 inches) for Xeriscapes.

In a similar study in Fargo, North Dakota Medina and Lee (2006) observed that Xeriscaping conserved irrigation for new construction homes but not for retrofits of existing landscapes. The study hypothesized that existing traditional landscapes were already low or non-irrigators and therefore converting to a different landscape could not provide savings. Median monthly irrigation use for all groups ranged from 0.07 to 0.54 gal/sq ft (0.11 to 0.87 inches) for traditional landscapes and 0.15 to 0.38 gal/sq ft (0.24 to 0.61 inches) for Xeriscapes.

The Xeriscape Conversion Study estimated that Xeriscaping reduced annual irrigation by 76% and total water use by 30% for residential homes in member utilities of the Southern Nevada Water Authority (Sovocool et al. 2006). Customers who agreed to participate in the study (and therefore knew that they would be monitored) were classified as having either Xeriscapes or turf landscapes. These groups were monitored for five years using their existing main meter and an additional irrigation submeter. Because of the configuration of some irrigation systems, it was possible that the submeter did not capture all irrigation occurring on the landscape, but irrigated areas were calculated and the volumetric irrigation data was assumed to be applied to only the calculated area. Only customers that had monitored areas that were completely turf were included in the turf group. The groups consisted of 1,550 and 107 customers for the Xeriscape and turf groups, respectively. The Xeriscaped homes demonstrated consistently lower water use, including during landscape establishment. The study included a third control group who were not aware that their monthly total water use was monitored. A negligible difference in monthly total water use of turf and control groups was observed, indicating that being aware of monitoring did not affect water use. Additionally, a comparison of the pre- and post-retrofit total water use of the Xeriscape group and the control group indicated that the Xeriscape homeowners had historically been lower water users.

Although the landscapes studied by Rosenberg et al. (2009) were not strictly classified as “Xeriscapes”, they were located in an arid environment. The three demonstration landscapes were located in Salt Lake City, Utah and consisted of a traditional landscape with cool-season turfgrass and some perennials, a perennial landscape with a smaller area of cool-season turfgrass, and a woodland landscape that had only trees, shrubs, and perennials. Based on irrigation data recorded by maintenance staff from 2001 to 2007, the perennial landscape used 33% less water and the woodlands landscape used 70% less water than the traditional landscape.

Devitt et al. (2008) attributed 81% of residential outdoor water use to the total turfgrass area at mixed landscape sites. As turfgrass area increased, residential outdoor water use increased. The study of satellite-based ET irrigation controllers in the arid southwest investigated the irrigation use of cool season grass (tall fescue) and desert plants.

The conservation potential of FFL and Xeriscaping may differ because of inherent program and climatic differences: Xeriscape focuses primarily on water savings, is designed for arid climates, often has a maximum turfgrass allowance, and seeks to reduce the amount of higher-water requiring cool season turfgrasses rather than the warm season turfgrasses that are predominately used in Florida. Because of these differences, the irrigation savings of FFL must be investigated independently and not extrapolated from Xeriscape irrigation savings. Quantified irrigation savings of FFL has been limited to anecdotal reports in extension newsletters and has not been published in peer-reviewed literature. For example, a townhome subdivision reported reducing irrigation by 60% by adopting FFL principles (UF/IFAS 2011).

Water Restrictions

Water restrictions are often a standard water conservation tool for utilities, especially in the southeast and southwest where water resources are particularly limited and there have been prolonged droughts. Water restrictions take various forms throughout the United States. Most residential ordinances ban irrigating during the hottest daytime hours (when irrigation water can be lost to evaporation before it has a chance to be used by plants) and limit homes to specific watering days. Some restrictions are voluntary while others are mandatory. Many have exceptions for newly planted landscapes or hand watering.

One of the earliest documented cases of water restrictions occurred in Las Vegas, Nevada (Jones & Cahlan 1975). Water was often wasted egregiously and with severe consequences. Las Vegas first adopted restrictions in 1934 and limited irrigation for several short stretches (usually banning daytime watering for a few days at a time) from 1947 to 1959. Las Vegas took their ordinances seriously: the city hired a “water cop” in 1936 to look for wasteful water use practices and irrigation violation penalties were a $50 fine or 25 days in jail for each offense. Despite their ban on wasteful water use, irrigation was so high that the water pressure dropped critically low on July 19, 1949. Parts of the city at higher elevations were without water, including the second floor of the Las Vegas Hospital. Temporarily banning lawn irrigation between 9 a.m. and

5 p.m. alleviated the worst of the problems, but a group of citizens responded with a petition that the water company be required to provide them with unlimited water so they could continue their all day, every day lawn irrigation. Another water crisis occurred in June 21, 1954 after a well pump broke, reducing the amount of water supplied at the same time water demand spiked. Residents were asked to cut back on their water use and irrigation was banned. Water cops were sent out in the 117 degree heat to patrol streets, and several homeowners suspected of violating the water restrictions were arrested.

A complete literature review of water restrictions in the United States with documented changes in water use is presented in Chapter 4. Utilities throughout the country have adopted water restrictions, with the majority of those experiencing at least a minimal conservation results.

Smart Irrigation Technologies

Both Soil Moisture Sensors (SMS) and Evapotranspiration (ET) controllers are smart technologies that adjust or override irrigation based on weather or soil conditions. Soil moisture sensors bypass manually scheduled irrigation events when the measured soil moisture is greater than a user-specified threshold. Soil water balance evapotranspiration controllers typically use weather data (either historical or real-time) and user-selected program settings to describe the landscape characteristics (i.e., soil type, soil, sun exposure). The ET controller then determines the irrigation schedule instead of using manually selected days and runtimes. Both SMS and ET controllers are used in conjunction with automatic, in-ground sprinkler systems. The technologies differ in that, without user interference (e.g., a homeowner adjusting their irrigation settings), SMSs can only decrease irrigation whereas ET controllers can increase or decrease irrigation. Results of previous SMS and ET plot and field studies are summarized in Chapter 5.

Table 1-1. Summary of residential irrigation study results

Location	% Total potable water for irrigation	Annual irrigation (kgal/home)	Annual irrigation (inches)	Sample size (number of households)	Reference
Florida					
Tampa	35%	30.5		99	Mayer et al. 1999
Tampa		64	22	~50	DeOreo 2011
St. Johns River Water Management District	81%	21		~50	DeOreo 2011
Toho Water Authority	36%	33.1	19.1	95	DeOreo et al. 2016
Southeast					
Clayton County, Georgia	31%	19.2	3.7	103	DeOreo et al. 2016
California					
Davis Water Department	60%	261		60	DeOreo et al. 2011
East Bay Municipal Utility District	44%	129		120	DeOreo et al. 2011
Sonoma County Water Agency	45%	132		60	DeOreo et al. 2011
Redwood City	36%	101		60	DeOreo et al. 2011
San Diego	53%	166		60	DeOreo et al. 2011
Irvine Ranch Water District	56%	227		120	DeOreo et al. 2011
Los Angeles Department of Water and Power	57%	238		120	DeOreo et al. 2011
Las Virgenes Municipal Water District	79%	851		60	DeOreo et al. 2011
Las Virgenes Municipal Water District	75%	213.2		100	Mayer et al. 1999
San Diego County	54%	217		60	DeOreo et al. 2011
Northern California Sites	46%	125		360	DeOreo et al. 2011

Table 1-1. Continued

Location	% Total potable water for irrigation	Annual irrigation (kgal/home)	Annual irrigation (inches)	Sample size (number of households)	Reference
Southern California Sites	60%	340		420	DeOreo et al. 2011
Walnut Valley Water District	60%	114.8		99	Mayer et al. 1999
San Diego	64%	99.3		100	Mayer et al. 1999
Roseville		149	82	~50	DeOreo 2011
Lompoc	41%	43.5		100	Mayer et al. 1999
Southwest					
Tempe, Arizona	61%	100.3		40	Mayer et al. 1999
Scottsdale, Arizona	72%	156.5		59	Mayer et al. 1999
Scottsdale, Arizona	65%	120.4	77.1	111	DeOreo et al. 2016
Phoenix, Arizona	70%	161.9		100	Mayer et al. 1999
Phoenix, Arizona		117	70	~50	DeOreo 2011
Las Vegas, Nevada		118	101	~50	DeOreo 2011
San Antonio, Texas	55%	62	14.7	98	DeOreo et al. 2016
Colorado					
Denver	63%	104.7		99	Mayer et al. 1999
Denver	62%	77	27.2	95	DeOreo et al. 2016
Aurora		91	45	~50	DeOreo 2011
Boulder	58%	73.6		100	Mayer et al. 1999
Heatherwood, Boulder	47%	77		228	DeOreo et al. 1996
Fort Collins	50%	55.9	12.9	88	DeOreo et al. 2016
Pacific Northwest					
Seattle, Washington	29%	21.7		99	Mayer et al. 1999
Eugene, Oregon	43%	48.8		98	Mayer et al. 1999

Table 1-1. Continued

Location	% Total potable water for irrigation	Annual irrigation (kgal/home)	Annual irrigation (inches)	Sample size (number of households)	Reference
Eugene, Oregon		95	38	~50	DeOreo 2011
Canada					
Waterloo, Ontario	10%	7.8		37	Mayer et al. 1999
Cambridge, Ontario	10%	7.8		58	Mayer et al. 1999
Other					
All New Home Study		130	56		DeOreo 2011
Melbourne, Australia		0 summer, 20.8 winter		80	Gato-Trinidad et al. 2011
All REUWS	59%	84.6	17	1188	Mayer et al. 1999
All REUWS-Version 2	50%	50.5	24.9	838	DeOreo et al. 2016

CHAPTER 2
IRRIGATION CONSERVATION OF FLORIDA-FRIENDLY LANDSCAPING BASED ON WATER BILLING DATA*

Chapter Abstract

Supplemental irrigation is often required to maintain residential landscapes in Florida, but existing and projected water shortages have led to an increased focus on reducing the amount of publically supplied potable water used for irrigation. Florida-Friendly Landscaping™ (FFL) has been promoted as a method to reduce irrigation, but the actual water savings has not been previously quantified. Analysis of monthly combined (indoor and outdoor) potable water billing records and parcel data for 125 (FLL and 736 traditionally landscaped comparison homes in southwest Florida indicated that FFL homes used 50% less irrigation. Irrigation savings increased to 76% when considering only good examples of FFL and comparison landscapes with high-quality turfgrass. The FFL customers reduced their irrigation use (279 mm/yr) after their landscapes became recognized (202 mm/yr). Prior to recognition, these customers were already using less irrigation than their neighbors (279 mm/yr vs. 464 mm/yr, respectively), indicating that those most concerned with water use were more likely to choose a Florida-Friendly Landscape. The results of this study demonstrate the ability of alternative landscapes in a hot, humid climate to conserve potable water used for irrigation; however, mechanisms for irrigation reduction in these landscapes are still unknown.

* Reproduced with permission from Boyer, M. J., Dukes, M. D., Young, L. J., & Wang, S. (2014). Irrigation conservation of Florida-Friendly Landscaping based on water billing data. Journal of Irrigation and Drainage Engineering, 140(12), 04014037.

Chapter Introduction

In Florida as in many other parts of the country, irrigation is often used to maintain residential landscapes and can be a substantial component of a single family home’s total potable water use. For example, Mayer et al. (1999) estimated that irrigation accounted for 59% of total residential potable water use in North America, Haley et al. (2007) found that irrigation accounted for 64% (peaking to 88% in the summer months) of total residential potable water use in central Florida, and Romero and Dukes (2013) estimated that 32-63% of total residential potable water use in central Florida can be attributed to irrigation, despite average rainfall of 1,340 mm/year. Available rainfall and plant water needs often do not coincide, resulting in the need for supplemental irrigation. Additionally, Florida soils tend to be sandy, and the low water holding capacity of the sandy soil influences the need for irrigation. For example, 84% of the land area included in this study had sandy soils, and the mean volumetric available water capacity was 6%. Despite the theoretical irrigation requirements due to Florida’s environment, some residents over-irrigate (Haley et al., 2007; Romero & Dukes, 2013). However, over half of Florida by area currently has or is projected to have within the next twenty years critical water supply problems (Florida Department of Environmental Protection, 2011). Landscapes that are designed and maintained in order to reduce irrigation may have the potential to reduce stress on the region’s finite water resources.

The Florida-Friendly Landscaping™ (FFL) program is promoted as a water conservation method (Florida statute 373.185, 2012), but the actual water savings, if any, have not been quantified. The FFL program promotes environmentally sustainable practices through nine principles: 1) right plant, right place; 2) water efficiently; 3) fertilize appropriately; 4) mulch; 5) attract wildlife; 6) manage yard pests responsibly; 7) recycle; 8) reduce stormwater runoff; and 9) protect the waterfront (UF-IFAS, 2009). The residential component of FFL is Florida Yards and Neighborhoods (FYN), and homes are recognized as FFL by passing a landscape evaluation performed by a county extension agent. The landscape evaluation is based on a checklist of required and optional practices (UF-IFAS, 2010b). Optional practices are grouped by FFL principles and homeowners receive points for practices implemented. Recognition is granted if a homeowner follows all required practices (such as having at least five species of plants) and collects a minimum number of points from optional practices (such maintaining separate irrigation zones for turf and ornamental landscape plants). Other optional practices designed to conserve water include: grouping plants with similar water needs, reducing irrigation in the summer and winter, and maintaining an automatic rain shutoff device for a sprinkler system (UF-IFAS, 2009). Homes in the FFL program are generally characterized by greater plant diversity (more ornamental plants) and less turfgrass, although there is no maximum turfgrass coverage limitation. Several other states have landscaping programs that are based on FFL, such as Carolina Yards (Clemson University, 2013), Louisiana Friendly Landscaping (LSU AgCenter Research and Extension, 2013), and Tennessee Yards and Neighborhoods (University of Tennessee Institute of Agriculture, 2013). The Environmental Protection Agency's WaterSense program is similar to FFL in that it encourages appropriate landscape design to conserve water. WaterSense requires the use of a water budget tool that calculates the potential reduction in irrigation from a baseline cool-season turfgrass landscape to a mixed-plant landscape (US EPA, 2013).

The FFL program has a broader environmental scope than Xeriscape, a widely accepted and generally proven method for reducing irrigation. In Las Vegas, Nevada, Xeriscaping reduced annual irrigation by 76% per unit area and total water use by 30% (Sovocool et al., 2006). Study participants were classified as having either Xeriscapes or turf landscapes and were monitored for five years using their existing main water meter and an additional irrigation submeter. Xeric landscapes generally contained desert-adapted plants and crushed rock mulch, and turfgrass landscapes generally had cool-season grass and used in-ground irrigation systems. Irrigation systems for the xeric landscapes varied, but xeric landscapes with drip systems used significantly less irrigation than xeric landscapes that had bubblers, microsprays, or mixed systems (Sovocool & Morgan, 2005). As a whole, the Xeriscaped homes demonstrated consistently lower water use, including during landscape establishment (Sovocool et al., 2006). Xeriscaping has also resulted in an irrigation savings of 18 to 63% in the Denver, Colorado area and 31% in Austin, TX (Gregg et al., 1994; Medina & Grumper, 2004). However, the conservation potential of FFL and Xeriscaping may differ because of inherent program and climatic differences: Xeriscape focuses primarily on water savings, is designed for arid climates, may have a maximum turfgrass allowance, and is often based on reducing the amount of higher-water requiring cool season turfgrasses whereas warm season turfgrasses are predominately used in Florida. Because of the differences between FFL and Xeriscaping as well as climatic differences, the irrigation savings of FFL must be investigated independently and not extrapolated from documented Xeriscape irrigation savings.

Documented irrigation savings of FFL has been limited to self-reported data collected by county extension agents and have not been published in peer-reviewed literature. Several extension newsletters have highlighted FFL projects, such as a townhome subdivision that reported reducing irrigation by 60% by adopting FFL principles and a condominium community that reported reducing irrigation by over 50% by installing low volume irrigation (UF-IFAS, 2010a; UF-IFAS, 2011).

The goal of this project was to quantify the irrigation use of FFL recognized single family homes and their traditionally-landscaped comparison neighbors (COMP). The primary objective was to determine if the estimated irrigation demand of all FFL homes identified in municipal water billing records was significantly different than comparison homes. The secondary objective was to explore how factors such as landscape quality, irrigation use before becoming FFL-recognized, and weather influenced changes in estimated irrigation use.

Materials and Methods

Customer Identification

Data analysis focused on three counties in the Southwest Florida Water Management District (SWFWMD): Hillsborough, Pasco, and Pinellas. Lists of FFL-recognized homes were provided by county extension agents and generally included at least the home's address and FFL recognition date. Recognition dates ranged from 1996-2007 in Hillsborough and Pasco Counties and from 1995-2011 in Pinellas County. There were a total of 397 FFL-recognized homes in the three counties. Data that did not include the recognition date were excluded from analysis.

Tampa Bay Water (TBW), a regional water supply authority, provided monthly potable water billing records for the seven member-government service areas within

Hillsborough, Pasco, and Pinellas counties: Pasco County, New Port Richey, Pinellas County, St. Petersburg, Northwest Hillsborough County, City of Tampa, and South Central Hillsborough County. Monthly billing data for over one million unique customers were provided for the approximate dates of 1998-2010, with the time period varying slightly for each service area. Because a home may have been occupied by more than one group of residents during the approximately 12 year period, a location may have had multiple unique customers. This analysis investigates the overall behavior of a group (FFL or traditionally landscaped homes) and not an individual location. Water billing data contained total potable water use (indoor and outdoor combined) for single-family residential customers. Monthly water meter readings were adjusted by TBW so that each monthly billing record accurately reflected the number of days in the month. In addition, TBW provided parcel data that included parcel identification numbers (parcel IDs), addresses and the parcel and built areas. Customers with separate irrigation meters or with access to reclaimed water were excluded from analysis. Customers with less than six observations, any negative consumption readings, and duplicate observations were deleted.

All data sets were imported into SAS 9.2 (SAS Institute, Cary NC), and the billing and parcel data for each service area were merged, yielding over 44 million monthly customer records for the entire TBW area. The parcel IDs for the FFL homes were obtained from searching county property appraiser records (Hillsborough County Property Appraiser, 2013; Pasco County Property Appraiser, 2013; Pinellas County Property Appraiser, 2013). Addresses were not used to search the water billing data for matches to the list of FFL-recognized homes because an address could often be written in different ways (e.g., 100 S. Main St., 100 Main St. S., 100 S. Main Street), whereas the parcel IDs could be easily formatted to be consistent between the FFL lists and the TBW billing records. Of the 397 FFL homes in the county extension list, 160 were identified in the TBW billing and parcel data. Of those, 125 had sufficient water and parcel data to include in the analysis (e.g., if there was no estimate of the irrigated area, a home was excluded). A home may not have been found in the TBW data if it was located within a municipality that purchased bulk water from TBW (and thus TBW only had aggregate water consumption for that municipality), it was a townhome or other non-single-family residential unit, it had a private potable well used for drinking water, it had access to reclaimed water, or if there was an error in the address provided.

Site visits of all FFL homes identified in the TBW billing records were conducted September 3-14, 2012. The condition of the FFL yard was evaluated and nearby homes with acceptable turf quality to use as comparisons were identified. Photographs were taken to document all FFL and COMP homes. All homes were evaluated from the public right-of-way and there was no contact with homeowners or residents. For all properties included in this analysis, satellite images from property appraiser websites were also available. The landscape visible from the right-of-way was consistent with the overall landscape visible in the satellite image. The FFL homes were evaluated based on aesthetics and plant diversity of the visible landscape. FFL homes were classified as good examples of FFL (Figure 2-1), well-maintained landscapes that did not appear to exhibit FFL principles (i.e., turf-dominated, Figure 2-2), and poorly maintained landscapes (e.g., poorly maintained turf or dead plants, Figure 2-3). For comparison homes, turfgrass quality evaluations were made using the National Turfgrass Evaluation

Program procedures (Shearman & Morris, 1998) by an experienced evaluator who evaluated all homes. Ratings of turfgrass quality were based on density, color, and the presence of weeds and were on a scale of 1 (dead) to 9 (perfect). The minimum acceptable turf quality for this analysis was 6, and an example of a minimally acceptable comparison home is shown in Figure 2-4. Nearby homes (COMPs) were chosen to be representative of the landscape characteristics of each neighborhood. Up to 10 comparison homes were identified during the site visits. Some neighborhoods did not have sufficient comparison homes, either due to the poor quality of landscapes near the FFL home, the small size of the neighborhood, the prevalence of non-single family residential properties, or other factors. Eighty-seven percent of FFL homes in this analysis had at least five comparison homes. Approximately 20 of the FFL homes were geographically clustered near at least one other FFL and therefore used the same comparison homes. Using the addresses of the comparison neighbors, parcel IDs were obtained from county property appraiser websites following the same procedure of parcel identification as the FFLs. These parcel IDs were then used to identify the comparison homes in the TBW billing data.

All data collected from the site visits, including an assigned unique house number, an assigned neighborhood number, landscape type (FFL or COMP), address, whether a home was a good example of FFL or the turf quality rating (depending on landscape type), and parcel IDs were imported into SAS and merged with the list of FFL-recognized homes. The combined dataset included the recognition date for each FFL and, for each comparison, the earliest recognition date of a FFL in the comparison home's neighborhood. The FFL recognition dates were assigned to COMPs so that water billing records of both FFL and respective COMPs after a FFL became recognized could be isolated.

Irrigation Demand

Irrigation was estimated by subtracting the estimated indoor water use from the billing record total water use. Three commonly used methods of estimating indoor water use from combined data are minimum month, winter average, and per capita. The minimum month method assumes that the monthly indoor water use is equal to the minimum monthly billing record in a year and that there is no outdoor water use in this minimum month. Similarly, the winter average method assumes that monthly indoor use is equal to the average of the billing records for December, January and February and that there is no outdoor water use in the winter. Romero & Dukes (2011) concluded that irrigation estimates based on the minimum month method were 23% lower than actual metered irrigation because the minimum month may include irrigation. Because irrigation may occur year-round in southwest Florida, neither the minimum month nor the winter average method is applicable. Therefore, the per capita indoor use estimate was deemed most appropriate.

The estimated irrigation demand expressed as a depth was obtained by dividing the estimated volumetric outdoor water use by the estimated irrigated area. All outdoor water use was assumed to be due to irrigation and other outdoor uses (e.g., filling swimming pools or washing cars) were ignored. The estimated indoor water use was calculated using an average per capita indoor use of 265 liters/capita/day, based on the Mayer et al. 1999 estimate of 69.3 gallons/capita/day), the average household size for each member government service areas (2.31 in Pasco County, 2.12 in New Port Richey, 2.16 in Pinellas County, 2.17 in St. Petersburg, 2.54 in Northwest Hillsborough

County, 2.38 in City of Tampa, and 2.64 in South Central Hillsborough County, as given by the Southwest Florida Water Management District (2011). The estimated irrigated area was the estimated green space area provided in the parcel datasets and was defined as the parcel area minus the sum of the building area and any taxable extra features such as patios. No adjustments for additional pervious or impervious areas were made because reductions for impervious areas, such as driveways, and additions for pervious areas, such as the irrigated area in the right-of-way (i.e., outside the parcel boundary, but maintained by the homeowner), generally offset each other. Calculations assumed that the same irrigation rate was applied over the entire landscape.

If a monthly billing record for an FFL home was missing, none of its comparison homes were included for that month. Because the recognition dates varied from 1995 to 2011, the number of records pre- and post- recognition for each FFL home and its comparison neighbors varied. Of 108,294 total monthly records, 47,906 were pre-recognition and 60,388 were post-recognition of the FFL home itself or, for comparison homes, the first FFL-recognized home in a neighborhood.

Gross Irrigation Requirement

The monthly gross irrigation required (GIR) for each FFL and comparison customer was calculated based on site-specific weather and soil conditions and general plant water needs using a daily soil water balance. The daily soil water balance, also referred to as a soil moisture balance, was used to track water inputs such as rainfall into the soil and outputs such as evapotranspiration in order to determine supplemental irrigation requirements. The daily soil water balance was calculated as follows (Irrigation Association, 2005):

$$SMB_{current} = SMBprevious - PWR + R_e + IWR_{net} , \qquad (2\text{-}1)$$

where $SMB_{current}$ is the current soil moisture balance level (mm), $SMB_{previous}$ is the soil moisture balance level (mm) at the start of the previous day's irrigation window, PWR is the plant water requirement (mm) since the start of the previous day's irrigation window, Re is effective rainfall (mm) since the start of the previous day's irrigation window, and IWR_{net} is the net irrigation water applied (mm) since the start of the previous day's irrigation window. The daily plant water requirement is defined as the daily reference evapotranspiration (mm) multiplied by a landscape coefficient:

$$PWR = ET_o \times K_L. \tag{2-2}$$

Allowable depletion of soil moisture is expressed as:

$$AD = PAW \times (MAD/100) = (AWHC \times RZ) \times (MAD/100), \tag{2-3}$$

where AD is the allowable depletion (mm), PAW is plant available water (mm), MAD is the management allowable depletion (%), AWHC is the available water holding capacity (mm water per mm soil), and RZ is the root zone depth (mm). If the $SMB_{current}$ exceeds the AD, then rainfall or irrigation has occurred in excess of field capacity. The excess water will either be lost to runoff or deep percolation, and $SMB_{current}$ will then equal AD:

$$\text{If } (SMB_{current} > AD) \text{ then } SMB_{current} = AD). \tag{2-4}$$

For the analysis presented in this paper, irrigation is assumed to be required when the SMBcurrent falls below zero and irrigation will occur until SMBcurrent = AD:

$$\text{If } (SMB_{current} < 0) \text{ then } IWR_{net} = AD). \tag{2-5}$$

To obtain the daily GIR, IWR_{net} was divided by an assumed system efficiency of 80% (based on Davis & Dukes, 2010). Daily GIRs were then summed by month to yield monthly GIR. Soil water balances were calculated for each customer over the time period of 1998-2010.

Site-specific weather and soil data were used in the monthly GIR calculations for each FFL and comparison customer. Daily evapotranspiration and rainfall data on a 2-km grid were obtained from USGS (2013) and SWFWMD, with each grid square referred to as a pixel or grid-cell number. A GIS shapefile for the 2-km pixel grid was also provided by SWFWMD. Soil data were obtained from the USDA's Soil Data Mart (Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture, 2013). Soil data was available by county and included soil types, AWHC, and GIS shapefiles of soil polygons.

The PWR assumed that each landscape consisted of 79% turfgrass and 21% ornamental plant beds based on landscape characteristics of homes in Pinellas County, Florida reported by Haley and Dukes (2012). The GIR is intended to be a baseline that reflects the typical irrigation requirements of comparison landscapes. Warm season turfgrass crop coefficients (used as K_L in the soil moisture balance), which varied from 0.45 to 0.75 depending upon the time of year, were used (Jia, et al., 2009). The water requirement for the ornamental plant beds areas was assumed to be zero because typical ornamentals in Florida have been shown to not require irrigation after establishment while maintaining acceptable quality (Moore et al., 2009; Scheiber et al., 2008; Shober et al., 2009; Wiese et al., 2009). The AWHC could vary by customer. Turfgrass was assumed to have a 30 cm root zone. It was assumed that MAD=70% (based on Cathey et al., 2011).

Calculations were performed using ArcGIS 10 Desktop (Environmental Systems Research Institute, Redlands CA), SAS, and R 2.13.2 (www.r-project.org) to yield a monthly GIR for each FFL and comparison customer. Separate files were developed in GIS for each county due to the large size of the parcel datafiles. Parcel shapefiles were obtained from the Florida Department of Revenue (Florida Department of Revenue, 2011). Water customer parcel lists were generated in SAS from TBW parcel data files. All variables except parcel ID were deleted. The parcel lists were exported from SAS as text files and imported into GIS. For each member-government service area, the parcel shapefile and water customer parcel list text file were joined by parcel ID in GIS and only matching records were displayed. These matching records yielded a polygon for each identified water customer in the service area. The joined layer was exported to create a permanent layer. The exported layer was intersected with the pixel grid to determine a pixel number for each customer parcel. The intersect operation yielded every pixel-parcel combination, and the area of each pixel-parcel polygon was added to the attribute table in GIS. The attribute tables were exported from GIS and imported into SAS, and the largest pixel-parcel area for each customer parcel was retained.

Following the same procedure as for the pixel-parcel lists, the AWHC for each parcel was assigned. The soil characteristic used was the available water storage in the first 25 cm of soil as a weighted average. The pixel-parcel and soil-parcel lists were merged in SAS by parcel ID. The parcel ID variable was dropped and duplicate rows of data were deleted, yielding one list of all pixel-soil combinations for each member-government service area. The purpose of this step was to compress the data to minimize the number of soil water balances to be calculated.

All daily weather data were imported into SAS. Since the separate ET_o and rainfall data files used the same grid system, the data were combined to yield one dataset of daily weather data (ET_o and rainfall) by pixel. The pixel-soil dataset and weather-pixel datasets were merged to yield one dataset that included all daily weather data for each pixel and soil type. The turfgrass coefficients (K_L) were added to SAS and the appropriate K_L based on the month was selected during the soil water balance calculations. Landscape coefficients K_L were: 0.45 (January, February), 0.65 (March), 0.8 (April), 0.9 (May), 0.75 (June), 0.7 (July, August), 0.75 (Spetember), 0.7 (October), 0.6 (November) and 0.45 (December) (Jia, et al., 2009). Daily soil water balances were calculated for all pixel-soil combinations using the equations outlined above. The daily calculations were performed in R because R is more efficient than SAS for iterative calculations and an R program could be submitted to the University of Florida's High Performance Computing Center. Daily GIRs were summed to yield monthly GIRs, which was then exported from R and imported into SAS. For each monthly customer billing record, the monthly GIR that corresponded to the customer's parcel pixel-soil combination was appended to the data row.

Irrigation Ratio

One method of characterizing whether too much or too little irrigation is applied is to compare the calculated irrigation applied (demand) to the calculated irrigation required. This ratio, I_{app}/I_{req}, can indicate whether a customer is sufficiently irrigating ($I_{app}/I_{req} = 1$), under-irrigating ($I_{app}/I_{req} < 1$), or over-irrigating ($I_{app}/I_{req} > 1$). This ratio was calculated for each monthly billing record for each customer using the calculated estimated irrigation demand as the irrigation applied and the calculated theoretical GIR as the irrigation required. In addition to using the ratio to identify customers that tend to over- or under-irrigate, the irrigation ratios also provide some control for weather variations. For example, some time periods may have had higher rainfall (and therefore lower evapotranspiration), resulting in lower irrigation required regardless of landscape type. Since weather parameters are used to calculate the irrigation required, the influence of weather on irrigation demands is removed by converting irrigation demands to ratios. After all customers had been assigned irrigation ratios, the records of FFL and comparison homes were isolated using their parcel IDs. If a customer's parcel was not included in the Florida Department of Revenue's parcel GIS shapefiles, then no GIRs or irrigation ratios were calculated.

Modeling Irrigation Savings

All comparisons of irrigation use of FFL and COMP homes were modeled using SAS. The irrigation depths and ratios were not normally distributed and often had a value of zero, so the data were transformed by taking the natural log of the sum of the response variable (i.e., depth or ratio) and one. The data were then fit to a generalized linear mixed model (proc glimmix). Random effects were used to account for variation due to groups of homes located in geographic clusters (neighborhoods) and the homes within each neighborhood. The independent variable of interest was the fixed effect of the landscape type, either FFL or COMP.

Results and Discussion

Reduction in Irrigation When Considering All FFLs and COMPs

A substantial portion, 59% of FFL and 50% of comparison homes, had monthly irrigation estimates of zero, meaning that a large portion of customers are not regularly irrigating. For both FFLs and comparisons, the means exceeded the medians in all months, indicating that there are a smaller number of high irrigators. The median FFL irrigation depth was zero for eleven months out of the year, whereas the median comparison irrigation depth was zero for one month out of the year, indicating that FFL homes are irrigating less than their non-FFL neighbors.

All monthly irrigation demand estimates for FFL and comparison homes were modeled in SAS and mean monthly irrigation demands were plotted (Figure 2-5). The analysis is based on 125 FFL and 736 comparison homes. Graphically, the irrigation demand for both landscape types show the seasonal irrigation patterns that are consistent with Florida’s dry springs, wet late summers, and mild winters. The FFL homes show a consistent trend of using less irrigation than comparisons. Although the monthly standard deviations are large, the 95% confidence interval (shown as the error bars in Figure 2-5) is small due to the large sample size. Florida Friendly Landscaped homes irrigated significantly ($P<0.0001$) less than comparison homes, 18 mm/month versus 37 mm/month.

FFL homes most likely have a smaller percentage of turf area or sprinkler irrigated area and a larger percentage of ornamental beds. It is possible that FFL customers are irrigating turfgrass at rates that are similar to the COMP rates, but the FFL customers apply less over the entire landscape because of the smaller turfgrass area. Less sprinkler irrigated area in favor of unirrigated area or microirrigation would lead to lower irrigation due to lower instantaneous application rates. Unfortunately, the scope of this project did not allow us to contact homeowners to determine these mechanisms.

Although the estimated irrigation rates of the FFLs and comparison homes were lower than expected, the results are realistic. In a study of single-family residential irrigation in Pinellas County, the control treatment (monitored only) applied a mean monthly irrigation rate of 64 mm/month and the soil moisture sensor treatment applied a mean monthly irrigation rate of 23 mm/month (Haley & Dukes, 2012). Turfgrass quality was generally acceptable, and the calculated irrigation was based on measured turfgrass areas only. In contrast, the irrigation rates of this study were assumed to be applied to the entire greenspace (i.e., potential irrigated area that contained landscaped beds and, when applicable, turfgrass). Adjusted for the entire greenspace and assuming that landscaped areas were not receiving appreciable irrigation, the control treatment and soil moisture sensor treatments of the Haley and Dukes study applied approximately 51 mm/month and 17 mm/month, respectively. Additionally, homes with in-ground irrigation systems use 35% more irrigation than those without in-ground systems (Mayer et al., 1999). All homes monitored by Haley and Dukes used in-ground irrigation systems, whereas there was no information on whether a home in this study used an in-ground system. Additional discrepancies may be due to the high number of monthly irrigation readings of zero and sources of error, such as the number of people in the household. In both studies, customers appear to irrigate at different frequencies throughout the year. For example, a customer may irrigate once a week in the spring (or approximately four times a month), then not irrigate in the winter.

Compared to other parts of Florida, customers in southwest Florida tend to have low irrigation demands. Estimated irrigation demand in Tampa, located in southwest Florida, was approximately half of that in Orlando, located in central Florida (Romero & Dukes, 2013). Higher irrigation rates were observed in central Florida, where the calculated mean irrigation rate applied over the entire landscape was 74 mm/month and

149 mm/month for landscapes with 31% and 74% average turfgrass cover, respectively (Haley et al., 2007).

Reduction in Irrigation When Considering Good Examples of FFLs and High-Quality COMPs

The impact of the landscape quality on irrigation savings was explored next. In order to maximize irrigation savings, a utility may target customers with higher-quality landscapes who are more likely to consistently irrigate for conversion to FFL rather than those customers with landscapes where it is apparent from the turf quality that little, if any, irrigation is applied. For this analysis, COMPs with a turf quality rating of eight (the highest rating assigned to homes in this study) were included in order to capture customers that may be higher water users. For homes that are targeted for conversion, a utility may also expect that FFLs be aesthetically pleasing and well-maintained. Under the FFL program, there is no requirement for a landscape to be re-evaluated once it is recognized as FFL, although some county extension agents do perform annual site visits of recognized landscapes. However, once a landscape is recognized as a FFL, there is generally no record that the homeowner continues to follow FFL practices. Because of this, the site visits were used to identify those homes that maintained FFL principles. Homes categorized as good examples of FFL (Figure 2-1) were included in this analysis. Good examples of FFLs had diverse plantings (e.g., a mix of trees, shrubs, groundcovers, and turfgrass), were well maintained (e.g., no major weed problems or dead plants), and matched the aesthetics of the neighborhood. Only neighborhoods that had both good examples of FFL and high-quality COMPs (Figure 2-6) were included. Thirty-five FFL and 103 COMP homes met this criterion.

Compared to the overall analysis with all FFL and COMP sites, the high quality FFL irrigation observations are, on average, 37% lower and the COMP irrigation values 25% higher (Figure 2-7). For the comparison homes, it is intuitive that the amount of irrigation applied to maintain a higher quality turfgrass lawn would be higher. For the FFL homes, it is possible that good examples of FFL irrigate less than all FFL-recognized homes because the FFL-recognized turf-dominated homes (assumed to have sprinkler irrigation), which were included in the initial analysis of all FFL homes but not included as an example of a “good” FFL, are higher water users. Florida Friendly Landscaped homes irrigated 12 mm/month and COMP homes irrigated 49 mm/month. Based on these results, customers with good examples of FFL use 76% less irrigation than comparison customers with high-quality turf. The model indicated that irrigation differences were statistically significant ($P<0.0001$). The reduction in irrigation is most likely due to a combination of better irrigation practices (e.g., not over-watering turfgrass) and less turfgrass area. For COMP homes, if an average irrigation rate of 49 mm/month applied to only the assumed turfgrass area of 79% and no irrigation is applied to ornamentals, the turfgrass application rate would be 62 mm/month. If it is also assumed that FFLs irrigate turfgrass at similar rates, the FFLs would consist of 19% turfgrass and 81% ornamentals to yield a landscape-average application rate of 12 mm/month.

Reduction in Irrigation When Customers Become FFL-Recognized

Understanding the type of customers that chose to convert their landscapes to FFLs can help when predicting the future conservation potential of additional homeowners converting to FFLs. The irrigation behavior pre- and post-recognition was compared to evaluate whether FFL customers were already low water uses (i.e., conservation-minded), or if the reduction in irrigation use could be attributed solely to the recognition process (Figure 2-8). Because the water billing records obtained began in 1998, any FFL homes recognized prior to 1998 were excluded. All homes had at least one observation pre- and post-recognition. The average pre-recognition irrigation rate was 23 mm/month, and the average post-recognition irrigation rate was 17 mm/month, a reduction of 28% that was statistically significant ($P < 0.0001$). The reduction in irrigation rates of comparison homes during the same time period was just 2% (from 39 to 38 mm/month). Since the FFLs exhibit a greater reduction in irrigation rates than the comparisons, there is evidence that the FFL recognition process is responsible for the reduction in irrigation use.

Reduction in Irrigation Ratio When Considering All FFLs and COMPs

The water use of FFL and comparison homes expressed as an irrigation ratio was used to analyze the irrigation habits for both landscapes in the context of plant water needs and account for effects due to varying weather (Figure 2-9). All mean monthly irrigation ratios for FFLs and eight mean monthly irrigation ratios for COMPs are less than one, meaning that customers with both landscapes tend to under-irrigate under the assumptions of well-watered turf, estimates of the irrigated area are inaccurate, or both. The pattern of the monthly irrigation ratios graphed differs from the pattern of monthly irrigation depths (Figure 2-5, Figure 2-7, and Figure 2-8), with the lowest ratios and highest depths occurring in the spring months. This behavior indicates that many customers may have a “set it and forget it” mentality and do not adjust their irrigation systems based on the seasonal variations in plant water requirements. The average monthly irrigation ratio was 0.44 for FFLs and 0.90 for COMPs, for a FFL reduction of 51%. The numerator of the ratio (irrigation demand) assumes that irrigation is applied to the entire landscape whereas the denominator of the ratio (irrigation required) assumes that irrigation is applied to only the assumed turfgrass area of a standard (COMP) landscape. When using the same area (the estimated greenspace area) for the numerator and denominator in the ratio, the average monthly irrigation ratio was 0.35 for FFLs and 0.71 for comparisons. Additionally, if it is assumed that both FFLs and COMPs maintain their turfgrass areas similarly (i.e., have the same irrigation ratio for turfgrass areas) and that COMP landscapes are 79% turfgrass, the turfgrass irrigation ratio would be 1.14 (slightly over-irrigating) and FFL landscapes would consist of 39% turfgrass.

Chapter Conclusions

Florida-Friendly Landscaping™ can result in a substantial irrigation savings for single-family residential customers irrigating with potable water as compared to their traditionally landscaped neighbors. The irrigation savings was estimated from up to twelve years of monthly combined (indoor and outdoor) potable water billing records and parcel data for 125 FFL and 736 traditionally landscaped comparison homes (COMPs). When considering all FFL-recognized homes, irrigation savings was 50%. However, utilities may be able to realize a 76% irrigation reduction by targeting homeowners with high-quality turfgrass (indicative of higher irrigation use) for conversion to FFL and by encouraging homeowners to maintain their FFL landscapes practices post-recognition. The FFL customers reduced their irrigation use after their landscapes became FFL-recognized. Prior to recognition, these customers were already using less irrigation than their neighbors, indicating that those most concerned with water use were the ones that adopted FFL practices. The results of this study demonstrate the ability of alternative landscapes in a hot, humid climate to conserve potable water used for irrigation. These results are complementary to previous studies that have documented irrigation savings of Xeriscapes in arid climates. However, specific reasons for irrigation reductions by FFL homes are not known. Future work should determine if these reductions are due to irrigation system composition, management or both.

Figure 2-1. Example of a good FFL. Site characterized by well-maintained, diverse plantings (trees, shrubs, and groundcovers) and aesthetics that matched the neighborhood. If turfgrass was present, turfgrass was well maintained (turf quality 6 or greater) and did not dominate the landscape. Classification as "good FFL" was subjective. Photo courtesy of Michael Gutierrez. 2011.

Figure 2-2. Example of a FFL-recognized landscape that was well-maintained but did not exhibit FFL principles. The landscape was dominated by turfgrass and did not exhibit plant diversity. Photo courtesy of Michael Gutierrez. 2011.

Figure 2-3. Example of a FFL recognized landscape that was poorly maintained. Landscape was characterized by weeds and insufficient plantings. If turfgrass was present, turf quality was less than 6. Photo courtesy of Michael Gutierrez. 2011.

Figure 2-4. Example of a comparison landscape classified minimally acceptable (turf quality rating= 6). Photo courtesy of Michael Gutierrez. 2011.

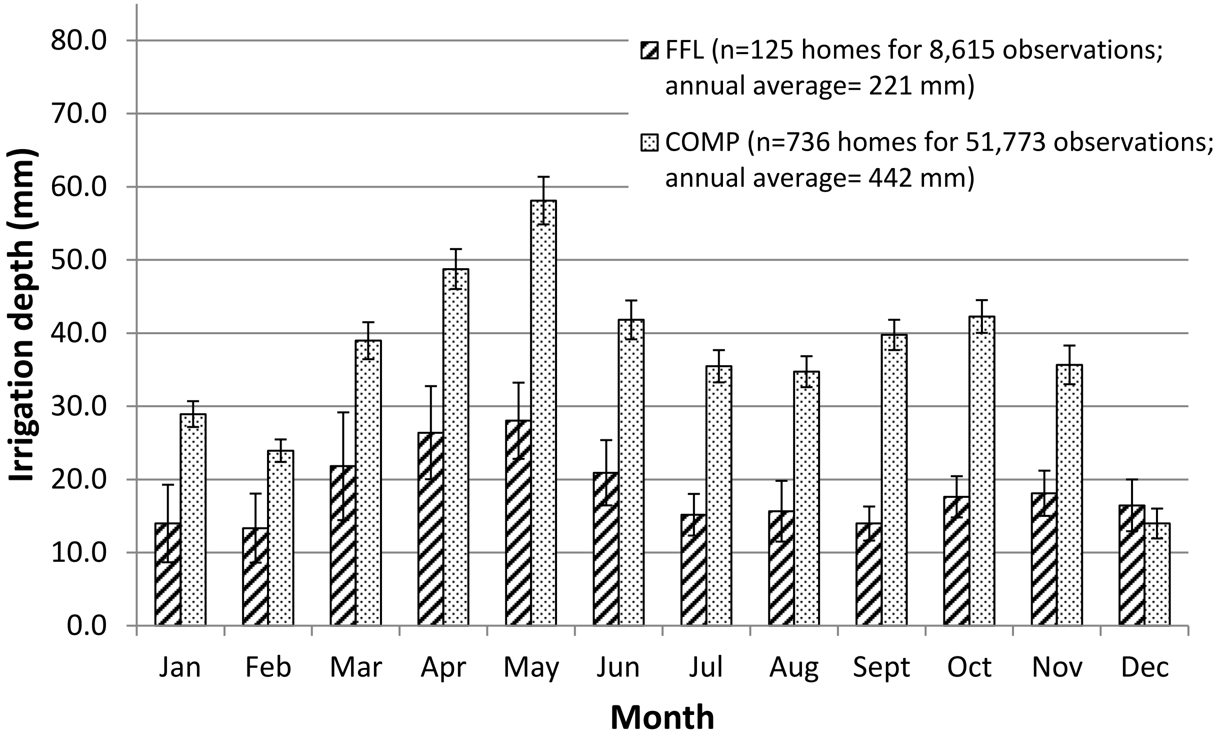

Figure 2-5. Mean monthly estimated irrigation applied of all FFL and COMP homes. Error bars indicate 95% confidence interval.

Figure 2-6. Example of a comparison landscape classified as high-quality (turf quality rating= 8 or higher). Photo courtesy of Michael Gutierrez. 2011.

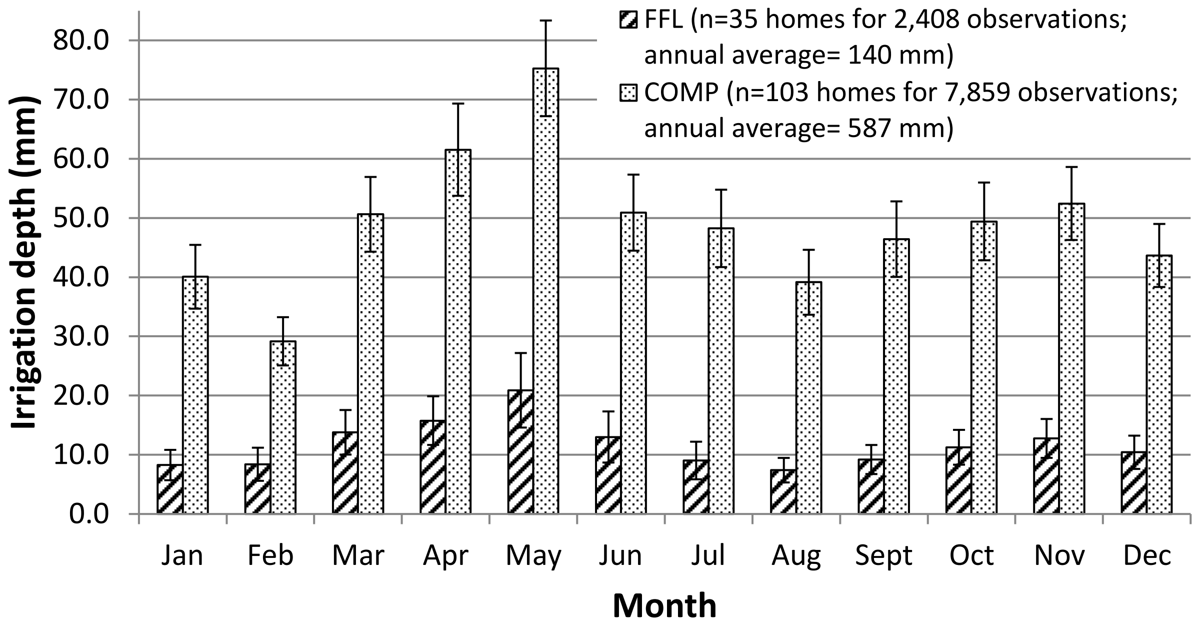

Figure 2-7. Mean monthly estimated irrigation applied of good examples of FFL and high quality COMP homes. Error bars indicate 95% confidence interval.

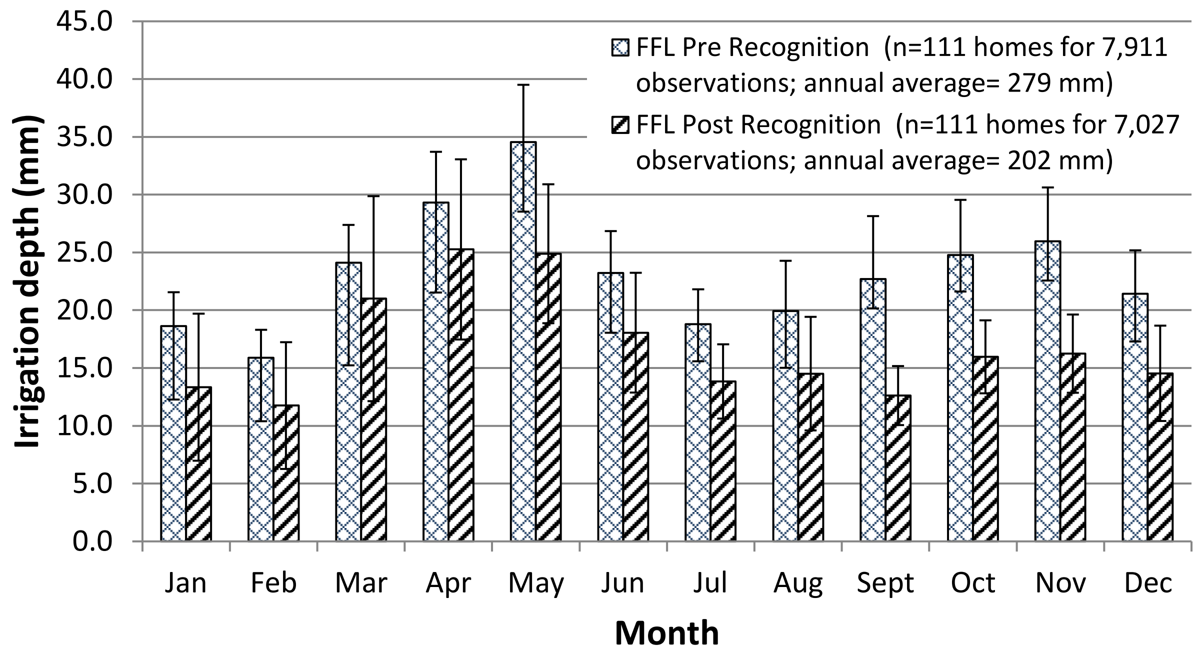

Figure 2-8. Mean monthly estimated irrigation applied of all FFL homes pre- and post-recognition. Error bars indicate 95% confidence interval.

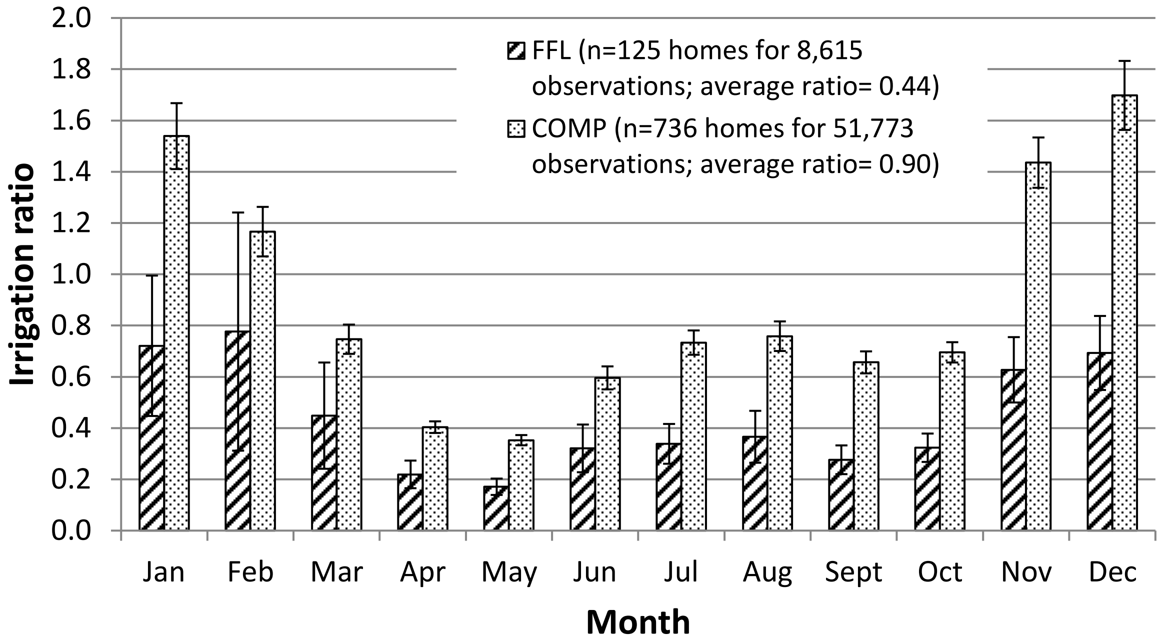

Figure 2-9. Mean monthly irrigation ratio of all FFL and COMP homes. Irrigation ratio is defined as irrigation demand calculated from water billing records divided by theoretical irrigation required calculated from soil-water balance. Error bars indicate 95% confidence interval.

CHAPTER 3
MINING FOR WATER: USING BILLING DATA TO CHARACTERIZE RESIDENTIAL IRRIGATION DEMAND[*]

Chapter Abstract

Understanding current residential irrigation behaviors is essential for selecting the most effective conservation measures and determining which customers should be targeted for conservation. This study stratified single family residential customers without access to reuse water into irrigating groups. Irrigation demands were calculated using monthly combined (indoor and outdoor) water billing and parcel records for over 165,000 customers in southwest Florida over approximately twelve years. Gross irrigation required was calculated using parcel and high-resolution site data. Seven and a half percent of customers used no irrigation over the study period, 67% of customers used 1 inch/month or less, and 84% used less than the average monthly gross irrigation required of 2.2 inch/month. Eighty-five percent of customers were classified as occasional irrigators whereas only 2% were classified as high irrigators. With such low estimated irrigation demands, this study reinforces the importance of selecting conservation methods so as to not inadvertently increase irrigation.

Chapter Introduction

With a growing population, continued development, and customer preferences for high-quality landscapes all contributing to the water resources strain in Florida, utilities and water managers often rely on water conservation programs to dampen—and potentially reverse—the increasing residential potable water demand for irrigation.

[*] Reproduced with permission from Boyer, M. J., Dukes, M. D., Young, L. J., & Wang, C. (2016). Mining for Water: Using Billing Data to Characterize Residential Irrigation Demand. Journal-American Water Works Association, 108(11), E585-E597.

Florida utilities withdraw an estimated 1.4 billion gallons of freshwater per day to satisfy the thirst of publicly supplied residential water users. Florida’s public water supply accounts for 35% of the freshwater use in the state, second only to agriculture at 40% (Marella 2010). Evaluating current irrigation behaviors is essential for selecting the most effective conservation measures, determining which customers should be targeted for conservation, and quantifying actual water savings. Studies often focus on high water users, but understanding which customers irrigate less than the theoretical irrigation requirement also known as the gross irrigation requirement (GIR) is just as important as identifying the high users: eliminating excess irrigation without increasing irrigation for customers that are below the GIR is essential for achieving irrigation conservation without compromising quality of life (DeOreo & Mayer 2012).

Water billing data, even without dedicated irrigation meters, can provide insights into customer irrigation behavior. Dedicated irrigation meters provide the most accurate data, but are generally cost prohibitive and may have the unintended consequence of increasing irrigation by making a water bill cheaper due to avoided wastewater fees (Tiger et al. 2011). In the absence of dedicated irrigation meters, previous studies have used monthly water billing records over long durations, high frequency meter readings over short durations, direct customer surveys, and remote sensing to elucidate irrigation habits. The most comprehensive residential water use study, Mayer et al. (1999), used three of these methods: monthly billing records, high frequency meter readings (every 10 seconds) for two, two-week monitoring periods for each customer, and mailed customer surveys for 1,188 single family residential water customers in twelve North American cities to determine the indoor and outdoor water use habits of customers.

Because of the limited duration of the high frequency monitoring and the potential for high variability in irrigation behavior throughout the year, the study used the high frequency readings to determine indoor use. Irrigation was estimated as the billed monthly total water use minus the estimated indoor water use. Mean outdoor water use across all study locations was 100.8 gallons per capita per day (gpcd), 59% of total water use. An update to the report was published while this paper was under review. The update's analysis was expanded to 23,749 homes in twenty-three North American utilities (DeOreo et al. 2016). Indoor water use decreased from 69.3 to 58.6 gpcd (15%). The update also included a more detailed outdoor water use analysis than the previous report. The monitored outdoor water use (the majority of which is assumed to be irrigation) for 838 homes was compared to the theoretical irrigation required (TIR, similar to GIR). The TIRs were based on the measured irrigated areas and groundcover types at each of the 838 homes. Seventy-two percent of these homes were classified as low/deficit irrigators (irrigation demand was 70% or less than TIR), 16% were target irrigators (irrigation demand was 70-130% of TIR), and 13% were excess irrigators (irrigation demand was greater than 130% TIR).

Several studies similar to Mayer et al. (1999) have been performed using high frequency monitoring to observe irrigation and total water use (Gato-Trinidad et al. 2011, DeOreo et al. 2011, DeOreo 2011). Despite differences in volumetric irrigation, homes in the California study (DeOreo et al. 2011) and the new home study (DeOreo 2011) reported very similar average irrigation application as a depth (57 inch/year and 56 inch/year, respectively). However, there was considerable spatial variation for the seven monitored new home locations throughout the United States, where Tampa, Florida irrigated 22 inch/year (DeOreo 2011).

In two studies in North Carolina, approximately 4 to 17% of customers in twelve utilities were classified as irrigating based on comparison of the water billing records of homes with irrigation meters (known irrigators) to those without (Boyle et al. 2011, Tiger et al. 2011). The authors noted that the criteria for identifying irrigators was strict and that, most likely, more customers were irrigating than they reported.

With the help of dual water meters for a subset of the study area, Friedman et al. 2013 used monthly water billing records to estimate irrigation demand of individual customers in Gainesville, Florida (n=1,402 customers with dual meters and n= 29,501 customers with combined meters). Irrigation use of the combined meter group was estimated using their total billing records and the estimated indoor water use. Indoor water use was calculated using the minimum month method (Romero and Dukes 2015) and was comparable to the indoor use of the dual metered customers. Mean irrigation for all customers (combined and dual-metered) was reported as 14 inch/year (Friedman et al. 2013). The method for determining irrigators that was used in Gainesville, Florida is not applicable in southwest Florida where irrigation may occur year-round (Haley and Dukes 2012, Mayer et al. 1999).

Relying solely on direct customer surveys to estimate irrigation use is often insufficient. Survey respondents may provide inaccurate answers or survey results may be misleading (Silva et al. 2010). In a phone survey of customers in thirteen North Carolina utilities, customers who said that they never applied water to their landscape still used more water during the growing season than the dormant season (5,500 gal/month and 4,300 gal/month total water use, respectively). The study hypothesized that customers, who were not aware that the researchers had access to their billing records, did not want to be perceived as wasting water and thus underestimated their irrigation use (Fair & Safley 2013).

Spatially, mapping customer groups can provide insights as to where the highest users tend to cluster or how certain areas respond to outside factors such as water restrictions. Mini et al. (2014) coupled water billing records with land cover data to model irrigation rates by census track in Los Angeles, California, and Ozan & Al Sharif (2013) mapped areas in Tampa, Florida that were most likely to receive citations for water restrictions violations.

Residential irrigation is often reported as an average across all customers, but the irrigation rate and its percentage of total water use can vary considerably between individual customers and throughout the year. Static assumptions of irrigation overlook both intra-customer and seasonal variation of irrigation. For example, in their survey of irrigation habits in North Carolina, Fair & Safley (2013) found that the percentage of regularly irrigating customers and the percentage of customers who never irrigated were approximately equal. Reporting one irrigation rate of the entire study area would understate the use of the 27% of customers who self-identified as regularly irrigating and overstate the use of the 30% of customers who self-identified as never irrigating. Reported utility-wide irrigation rates are often confusing because it is not clear if the rate applies to all customers or only those who irrigate, and the difference can be substantial. A small number of customers tend to have high irrigation use while a large number of customers tend to irrigate little if at all (Friedman et al. 2013, DeOreo &

Mayer 2012, Mayer et al. 1999). As an example of high irrigator behavior, DeOreo et al. (2011) observed that 8% of accounts were responsible for 38% of the total excess irrigation in California. As an example of low irrigator behavior, 47% of customers in Gainesville, Florida were classified as non-irrigators based on an extremely low threshold of less than 1 inch/year estimated irrigation (Friedman et al. 2013).

The strength of correlating factors in predicting irrigation use has varied considerably in previous studies. Customers in Layton, Utah were classified as conserving, acceptable, or wasteful based on their monthly billing records and a water budget (Endter-Wada et al. 2008). A customer's irrigation classification was correlated to the type of irrigation system, with those using manual hose watering most likely to be acceptable irrigators and those using programmable in-ground systems most likely to be wasteful irrigators (i.e., customers with the greatest potential for wasting water wasted the most). Demographic characteristics, motivation to conserve, knowledge of water issues, environmental attitudes, and other conservation efforts were not significantly correlated to irrigation (Endter-Wada et al. 2008). Notably included in the demographics characteristics, the year the house was built, which is often used as a proxy for the presence of an irrigation system, had no significant correlation. This may have been because as the houses were updated over time (mean age= 1968), improvements such as adding an in-ground irrigation systems were made.

Several studies support Endter-Wada et al.'s (2008) conclusion that the type of irrigation system is correlated to irrigation use. Mayer et al. (1999) and Friedman et al. (2013) observed that the presence of in-ground irrigation systems and dedicated irrigation meters influenced irrigation behavior. Customers in North Carolina with an automated in-ground irrigation system used 139% more total water during the growing season than those without (13,600 gal/month and 5,700 gal/month, respectively) (Fair & Safley 2013). In Gainesville, Florida, customers with an irrigation meter used 75% of total water for irrigation whereas customers with a combined meter used an estimated 20% of total water for irrigation (Friedman et al. 2013). In the case of Gainesville, the presence of an irrigation meter may have been linked to the age of the house, with newer homes more likely to have in-ground irrigation and thus irrigation meters. Friedman et al. (2013) reported that in Gainesville, Florida, less than 10% of new homes built before 1983 had in-ground systems whereas almost 90% of the homes built in 2013 had in-ground systems. The majority of these homes (older and newer) did not have dedicated irrigation meters.

The relationship between irrigated area and irrigation rate in previous studies has varied. Loh & Coghlan (2003) did not find a strong relationship between irrigable area and outdoor water use (indicating inefficient irrigation), DeOreo & Mayer (2012) reported a negative correlation (-0.27) in the irrigating customers (meaning homes with smaller irrigable areas tend to have higher irrigation rates). DeOreo & Mayer (2012) and Loh & Coghlan (2003) observed that income effects outdoor water use, but income is not a consistent indicator of irrigation. Silva et al. (2010) correlated high irrigation to affluent customers in Orange County, Florida, but in Phoenix, Arizona, high irrigation was better correlated with customers that identified themselves as “non-environmentally conscious.”

With an estimated 105 million households in the United States receiving water bills (Boyle et al. 2011), billing data can provide a wealth of information. The goal of this project was to provide an improved understanding of customers' irrigation habits, thereby allowing utilities to make more informed decisions regarding irrigation conservation initiatives. The primary objective was to stratify customers into irrigating groups of occasional, low, medium, and high irrigating. The secondary objectives were to: determine the volumetric impact of each irrigating group, investigate whether irrigation could be correlated to factors such as property value, and explore the spatial distribution of irrigation.

Materials and Methods

The initial data pool included over one million single-family potable water customers without access to reuse water for irrigation in the Southwest Florida Water Management District (SWFWMD). Customers were in one of seven member-government service areas of Tampa Bay Water (TBW), the regional water supply authority. The service areas were: Pasco County (PAS), New Port Richey (NPR), Pinellas County (PIN), St. Petersburg (STP), Northwest Hillsborough County (NWH), City of Tampa (COT), and South Central Hillsborough County (SCH) (Figure 3-1). The service areas are located in three Florida counties: Pasco, Pinellas, and Hillsborough. With populations of approximately 479,000, 933,000, and 1,302,000, respectively, the three-county area is home to 14% of Florida's residents (EDR, 2015).

Monthly billing data were provided by TBW for the approximate dates of 1998-2010. Account information for each service area was provided as a separate comma separated values (.csv) file. Water billing data sets had 25 variables for each record, including total (indoor and outdoor combined) water use, customer identification number (customer ID), and parcel identification number (parcel ID). Water meter reading dates varied by customer and were adjusted by TBW so that each record reflected the water use in the calendar month rather than the water use between reading dates. Additionally, TBW provided parcel data for each service area as separate files. The parcel data had 24 variables, including parcel ID, parcel area, and estimated greenspace area (parcel area minus the sum of the building area and any additional taxable impervious features). Water and parcel data sets were imported into SAS 9.4 (SAS Institute, Cary, NC) and the two data sets for each service area were merged by parcel ID.

The water billing records were subject to the several restrictions. The purpose of the restrictions was to minimize error while avoiding additional bias, where the additional bias was avoided by setting well-defined criteria based on defensible assumptions. The Florida Department of Revenue (DOR) code must have indicated that the property was a single family residential property. Depending on service area, approximately 85-96% of the monthly billing records provided were for single family homes. The property must not have had access to reuse water or have a dedicated irrigation meter. The record must have had a unique, non-zero customer ID in order to track the water use of individual customers. Although parcel numbers and location identification numbers were also provided, customer IDs were important because more than one family may have lived at a given location over the course of the study period and different families may have had different water use habits. Records with location IDs and parcel IDs equal to zero were also deleted. Accounts must have had at least six monthly records because a record of less than six months was deemed too short to have any value in observed trends. Duplicate observations were deleted. Customers with estimated greenspace areas less than 1,000 square feet were deleted (Knight et al. 2015).

The total water use was subject to minimum and maximum criteria. The minimum threshold for estimated indoor water use was calculated using a minimum per capita use of 32.4 gpcd and one person per household, where the minimum per capita use was one standard deviation below the calculated mean in Mayer et al.'s (1999) study. If a house did not meet this minimum threshold, it was assumed the house was unoccupied and that month's record was not included in the analysis. The maximum monthly water use for each customer was assumed to be the customer's mean monthly water use plus three standard deviations in order to exclude inaccurate readings or high water use due to a leak.

Because of the extremely large size of the initial water billing data set (approximately 61 million records), stringent criteria could be applied and the resulting data set used in the analysis was still large: approximately 30 million records and 165,000 customers. Initial data and data used in analysis are summarized in Table 3-1.

Irrigation Demand

Irrigation demand was estimated by subtracting the estimated indoor water use from the total monthly water use. All outdoor water use was assumed to be due to irrigation, and all other outdoor uses (i.e., filling swimming pools or washing cars) were treated as irrigation. Pool water use was ignored because there was no data available on the prevalence of pools and, even when present, the impact of pool water use in the study area of southwest Florida was assumed to be minimal. A conservatively high estimate of annual pool water use in the Tampa area is about 9,091 gallons (Lee and Heaney 2008), which is the equivalent of 3 inches of irrigation based on the mean irrigated area of landscapes in this study. In contrast, pool water use can be five times greater in Phoenix, Arizona or over four times greater in southern California (Forrest and Williams 2010).

Irrigation demand was based on per capita indoor water use because the minimum month method to calculate indoor water use is not applicable in southwest Florida, where irrigation can occur year-round (Haley and Dukes 2012, Mayer et al. 1999, Romero and Dukes 2015). Estimated indoor water use was calculated using an average per capita indoor use of 69.3 gpcd (Mayer et al. 1999), block-level household sizes from the 2010 U.S. Census, and the number of days in the month of the billing record. As previously discussed, an updated per capita indoor use of 58.6 gpcd (DeOreo et al. 2016) was published while this paper was under review. Analysis presented in this paper may therefore systematically underestimate irrigation because the larger indoor water use estimate was used. For the mean lot size of landscapes in this study, using 58.6 gpcd would increase mean annual irrigation by 3 inch/year.

The block-level household size was determined using ArcGIS 10 Desktop (Environmental Systems Research Institute, Redlands CA) and SAS. The census shapefile contained block-level data with over 100 variables including household size, income, age of head of household, and race (U.S. Census 2015). Census blocks are areas bound by features such as roads, streams, property lines, and city limits and are the smallest units within census data. Within the study area, there were over 46,000 census blocks. The census blocks used in the analysis had a mean of 21 households and a range of 0 to 1,030 households.

Parcel shapefiles for each of the three counties in the study area were obtained from the Florida Department of Revenue (2011). Water customer parcel lists were generated in SAS and imported into ArcGIS. For each service area, the parcel shapefile and customer parcel list were joined by parcel ID and only matching records were displayed. These matching records yielded a polygon for each identified water customer, which was intersected with the census block layer to obtain the census block for each parcel. The attribute tables were exported from ArcGIS and imported into SAS. If a customer parcel fell in more than one census block, the census block that covered the largest area in the parcel was assigned to the entire parcel. Census variables that included demographic information were retained for use in correlations, and the household size was used in irrigation demand calculations. Household sizes were reported as whole numbers.

The calculated volumetric irrigation demand estimate was converted to a depth by dividing by the estimated irrigated area, which was given in the parcel datasets as the estimated greenspace area. It was assumed that irrigation was applied over the entire landscape at the same rate. No adjustments for additional pervious or impervious areas were made because reductions for impervious areas, such as driveways, and additions for pervious areas, such as the irrigated area in the right-of-way (i.e., the area between the sidewalk and the street that is outside the parcel boundary but maintained by the homeowner), were assumed to offset each other. This assumption was based on delineating a small subset of residential properties into landscaped areas and impervious areas using satellite images (Hillsborough County Property Appraiser 2013, Pasco County Property Appraiser 2013, Pinellas County Property Appraiser 2013).

Delineating the irrigated areas using satellite imagery would have been problematic for the study location because of permanent tree canopy cover and cloud cover. Site visits of each of the 165,356 customers in study area was beyond the scope of the project.

Gross Irrigation Requirement

In contrast to the estimated irrigation demand which estimates actual water used, the GIR is the amount of irrigation that is theoretically required to maintain a landscape consisting of well-watered turfgrass and ornamental plants. It was assumed that each landscape consisted of 79% turfgrass and 21% ornamental plant beds (Haley & Dukes 2012, Haley et al. 2007). The water requirement for the ornamental plant beds areas was assumed to be zero because typical ornamentals in Florida have been shown to maintain acceptable quality without irrigation six to twelve months after planting (Moore et al. 2009, Shober et al. 2009, Scheiber et al. 2008).

The monthly turfgrass GIR for each customer was calculated using site-specific weather and soil conditions and general plant water needs in a daily soil moisture balance. Weather data included daily reference evapotranspiration and rainfall data on a 1.2 mi grid (USGS 2011, USGS 2005), with each grid square referred to as a pixel. Soil data was available by county and included soil types, available water holding capacity, and ArcGIS shapefiles of soil polygons (Soil Survey Staff 2013). The majority of parcels had either sandy or urban-influenced sandy soils. The water holding capacity was typically 0.5 to 1 inch in the assumed 12 inch root zone. The maximum allowable depletion was 50%. Crop coefficients for warm season turfgrass varied monthly (Jia et al. 2009). The procedure for calculating the daily soil moisture balance to determine the monthly GIR is outlined in Boyer et al. (2014). Calculations were performed using ArcGIS 10 Desktop, SAS, and R 2.13.2 (www.r-project.org).

Because weather (i.e., rainfall and evapotranspiration) can vary significantly in Florida even within a small geographic area, the detailed irrigation requirements could more accurately capture the unique conditions for each customer. For example, in July 2000, mean rainfall was 1.9 inch, but varied from 0.2 inch (a tenth of the mean) to 5.9 inches (three times greater than the mean) across the study area, indicating the importance of using fine-resolution weather and soil data.

Irrigation Ratio

The ratio of irrigation demand to GIR was calculated for each monthly water use record for each customer as the calculated estimated irrigation demand from the billing record divided by the calculated theoretical GIR. The ratio, I_{app}/I_{req}, can indicate whether a customer is sufficiently irrigating ($I_{app}/I_{req} = 1$), under-irrigating ($I_{app}/I_{req} < 1$), or over-irrigating ($I_{app}/I_{req} > 1$). Additionally, since weather parameters are used to calculate GIR, the influence of weather on irrigation demands is taken into account by converting irrigation demands to ratios. For example, some time periods may have had higher rainfall, resulting in lower irrigation demand regardless of landscape type.

Stratifying Customers into Occasional, Low, Medium, and High Irrigator Groups

The k-means statistical clustering was previously used by Palenchar (2009) to stratify water customers of Gainesville Regional Utilities into groups of low, moderate, and high water users. The k-means clustering groups data into k number of clusters, with these groups being as separate and distinct as possible (Abonyi & Feil 2007). Generally, the k-means clustering algorithm assigns each data point to a cluster, calculates the centroid of the cluster, re-assigns points to the cluster whose centroid it is closest to, and repeats until the distance between all points and centroids has been minimized. The customer's individual data determines the divisions between groups, meaning that the group divisions are not arbitrary. In addition, by clustering using the irrigation ratio, variations in soil and daily weather observations were incorporated. A benefit of the k-means clustering is that the irrigation behavior over several years can be included in the analysis.

All monthly irrigation ratios for March, April, and May for the years 2006-2008 were used in the k-means clustering analysis to classify customers into irrigating groups. The spring months were selected because these are traditionally the months that have the highest irrigation requirements (Romero and Dukes 2013). If a customer was irrigating at all, there was a high chance that they would be irrigating during the spring months. The spring ratios are expected to be low because the irrigation requirements (the denominators of the ratios) are so high at this time of the year. The years 2006-2008 were selected to increase the chance of capturing current customers who had several years of data to characterize their historical use. The ratios were first clustered into two groups, high irrigators and all others using k=2 clusters. If only a few customers were assigned to the high cluster, these were deemed outliers. They were temporarily removed from the dataset, the clustering procedure was run again, and the high outliers were assigned to the resulting high irrigator group. The “all others” group was then clustered into occasional, low, and medium, irrigators using k=3 clusters. The corresponding irrigation classification (occasional, low, medium, and high) determined by the clustering groups was appended to each customer record. The number of customers and the average irrigation ratio varied for each service area. Two analyses were run: first, all service areas were analyzed separately and, second, all data was combined. After the clustering procedure was first performed on each of the service areas separately, all data was combined and a new variable that included the service area and customer ID was created, and the clustering procedure was repeated. If a customer was deemed a high outlier in the clustering by service area, it was automatically assigned to the high cluster for the combined data.

Correlations

Irrigation demands and irrigation ratios were correlated with potential influencing factors. Influencing factors included: property characteristics from the TBW parcel records (e.g., year built, property value, building value, green space), demographics from the block-level census data (e.g., household size, age of head of household), and weather (e.g., precipitation and GIR). For correlations of irrigation to parcel or census data, one mean irrigation demand and one mean irrigation ratio calculated over the entire period of record was used for each customer. For correlations with monthly variables such irrigation requirements and ratios, the monthly irrigation demand or ratio was used. Correlations were run in SAS.

Geographic Areas of High Irrigation Use

A dataset generated in SAS that included the low, medium, and high irrigators from the seven service areas along with their irrigation, parcel, and demographic data was imported into ArcGIS. The text file was joined to a parcel shapefile of all customers identified in the TBW billing and parcel data, and the parcel shapefile was spatially joined with the 1.2 mi pixel grid used for the weather data. Data in the resulting shapefile included the total number of irrigators, aggregate monthly volumetric irrigation for all irrigators, mean irrigation depth of irrigators, mean property value of all low, medium, and high irrigators in each pixel.

Results and Discussion

All results shown are statistically significant (alpha= 0.05). The majority of customers of the Tampa Bay Water service areas substantially under-irrigated as compared to both GIR and previous studies in other geographic areas. The histogram depicting the distribution of customer's mean irrigation demand (Figure 3-2) was similar in shape to previous studies (Friedmen et al. 2013, DeOreo et al. 2011), but the demand was lower than in the other geographic areas. Figure 3-2 is based on one mean irrigation demand (inch/month) for each of the 165,326 customers that met the previously outlined criteria for analysis. Seven and a half percent of customers used no irrigation over their entire period of record, and 67% of customers used 1 inch/month or less (as compared to 47% of the Gainesville, Florida [single and dual meter] customers in Friedman et al.'s 2013 study). Eighty four percent of customers used less than the average monthly GIR of 2.2 inch/month.

The median irrigation demand (taken as 50% on the cumulative distribution function curve) was 0.5 inch/month. This was lower than what was observed in several previous studies in different geographic areas. Median irrigation demand in Gainesville, Florida (GIR = 1.7 inch/month) was 1.25 inch/month for dual-metered customers using potable water (Knight et al. 2015), but would be expected to be less for customers with combined meters because of the higher cost (water and wastewater charges) of combined meter irrigation (Tiger et al. 2011). Median irrigation has been reported to be higher in the southwestern United States, where high evapotranspiration and low rainfall lead to high irrigation requirements. Median irrigation demand in California was approximately 3.4 inch/month across ten water agencies (DeOreo et al. 2011). Mean irrigation demand in southern Nevada was 2.3 inch/month for Xeriscape-dominated landscapes and 9.8 inch/month for turfgrass-dominated landscapes (Sovocool et al. 2006).

Tables 3-2 and 3-3 summarize the mean monthly irrigation demand as a depth and the mean monthly irrigation ratios of all seven Tampa Bay Water member-government service areas individually and combined. The mean monthly irrigation demands as depths for the seven service areas followed similar trends, but differed in magnitude. For all service areas, mean monthly irrigation demand was highest in the spring (maximum of 2.30 inch for Pasco County in May) and lowest in the winter (minimum of 0.36 inch for St. Petersburg in February). This trend, but not the magnitude, is consistent with turfgrass irrigation requirements in Florida. Annual irrigation demand varied from 4.9 inch/year for St. Petersburg to 20.4 inch/year for Pasco County. The annual irrigation demand for all service areas are consistent with previously published demand for the area. The annual irrigation demand in the City of Tampa was 11.6 inch/year, as compared to previously published values based on smaller sample sizes for Tampa of 22 inch/year (DeOreo 2011) and 6.3 inch/year (Mayer et al. 1999).

The mean monthly irrigation ratios follow similar trends among service areas and opposite trends as the irrigation demand in units of depth. Ratios varied from 0.08 (May mean for St. Petersburg) to 2.48 (January mean for Pasco). For each service area and all areas combined, the lowest ratios were in the spring, when irrigation requirements (the denominator of the ratio) are highest. With the exception of low-water using St. Petersburg, all service areas had mean monthly ratios that exceed one during the winter, indicating excess winter irrigation.

Figure 3-3, Part A further illustrates the results of Table 3-2. The figure shows the mean monthly irrigation demand as a line graph (the same values as the last column of Table 3-2) and the mean monthly GIR as a column graph. The demand was more consistent throughout the year, whereas GIR had higher seasonally variability. Over-irrigation, on average, occurred in January, February, and December when the demand exceeded the required. Under-irrigation was prevalent the remainder of the year when GIR exceeded demand. Results are reported with 95% confidence interval error bars, but because of the high number of observations, the error bars are so small that they are not visible on the line graph and barely visible on the column graph.

Although mean monthly irrigation demand is within the range of previous studies, the magnitude is less than expected for a customer that is truly irrigating regularly. UF-IFAS recommends that irrigation be applied at a rate of 0.5-0.75 inch/cycle (Trenholm 2012). Based on this rate, the results for all areas combined shown in Table 3-2 and Figure 3-3, Part A indicate that a sprinkler system was run approximately two to three times each May. Since irrigation requirements tend to be higher in May and irrigators were assumed to be irrigating twice a week under normal weather conditions (a typical allowance of watering restrictions), the demand results may have under-estimated the water use of those who were actually irrigating. These results demonstrate the need to separate customers into irrigating groups.

The clustering results in Figure 3-3, Part B, which stratify customers into high, low, medium, and occasional irrigator groups, provide an improved depiction of the irrigation habits of customers. The mean demand of the high and medium irrigator groups exceeded the mean GIR every month of the year and the low irrigator group demand exceeds the mean GIR for ten months of the year. The occasional irrigating group had a consistently low demand ranging from 0.85 to 1.35 inch/month. While the original intent of the lowest irrigating group was to isolate customers who did not irrigate at all, the clustering procedure resulted in the occasional irrigating group instead. The irrigation demand of these customers may be due to estimation errors (e.g. size of household, per capita indoor use, or greenspace area) or irrigation limited to periods of prolonged dry weather averaged over each customer's entire period of record. The estimation errors could be minimized with more site-specific data, although collecting the level of data required would most likely be time and cost prohibitive. Better estimates of indoor water use could be achieved through automatic meter reading meters or dual meters (measuring indoor and outdoor water separately), individual household sizes (rather than census block averages), or field-verified greenspace areas.

In the context of water conservation, the irrigation demand of the high, medium, and low groups have the highest potential for water conservation. On average, if a high irrigator reduced their irrigation demand to GIR, 62 inch/year (322 gallons per account per day [gpad] over a mean greenspace area of 3,548 square feet [ft2]) could be conserved. Similarly, a medium irrigator could conserve 35 inch/year (201 gpad over 3,938 ft2) and a low irrigator could conserve 10 inch/year (74 gpad over 4,618 ft2). The potential conservation may be even greater since warm season turfgrass has been shown to maintain acceptable aesthetic quality under deficit irrigation conditions (Cathey et al. 2011). Reductions would occur every month for all three groups except for the low irrigators in April and May. In contrast, there is little room for conservation in the occasional irrigator group, who irrigate little to nothing on a monthly basis.

Although their individual demand is very low, the aggregate volumetric demand of the occasional irrigator group is substantial because of the high percentage of customers in the group. Sixty-four to 91 percent of customers in each service area were classified as occasional irrigators (Table 3-4). When evaluating all the service areas combined, the occasional irrigators were 85% of the customers and responsible for 51% of volumetric irrigation demand. In contrast, the high irrigator group was just less than 2% of the customers and was responsible for 9% of the volumetric irrigation demand (Figure 3-4).

Mean volumetric irrigation demand of all customers was 42 gpcd, and mean irrigation of the low, medium, and high groups was 142 gpcd. As a whole, the high, medium, and low groups contained 15% of customers and were responsible for 49% of irrigation. It is this 49% of volumetric irrigation that has the most potential for reduction under water conservation initiatives, as further appreciable reductions in the irrigation demand of occasional irrigators would be extremely difficult to obtain. Only 4% of all customers have a mean demand that exceeds required (average irrigation ratio > 1), and these customers are responsible for 19% of volumetric irrigation. The result that high irrigators were responsible for a disproportionate amount of irrigation demand is consistent with previous studies (Friedman et al. 2013, DeOreo and Mayer 2012, Mayer et al. 1999). Grouping customers is important in the context of considering a conservation initiative such as evapotranspiration (ET) controllers, which are typically programmed to water based on historic or real-time GIR. With 96% of customers irrigating below GIR on an annual basis, indiscriminate implementation of ET controllers could drastically increase area-wide irrigation. This phenomenon was observed in an ET controller study in California where participants who historically irrigated below the GIR increased their irrigation demand 20% when ET controllers were implemented (Mayer and DeOreo 2010).

In addition to using irrigating groups to isolate customers that could best benefit from a conservation measure, the irrigating groups can help inform decisions on irrigation supply capacity. For example, SWFWMD, the regulating agency responsible for managing the water supply of the study area, has used a planning estimate of a constant 300 gpad when designing new reuse distribution systems for residential customers. Figure 3-5 shows that a constant 300 gpad severely overestimates the daily volumetric demand of the occasional irrigators, while underestimating the demand of the high and medium irrigators. The planning estimate is similar to the low irrigator group’s mean demand of 286 gpad, but does not capture its seasonal variability. The seasonal variability in demand of high, medium, and low irrigators (with a peak of 667 gpad in April for high users) and the consistently low demand of the occasional irrigators (mean of 62 gpad) would impact the design of a reuse distribution system. Static assumptions of irrigation demand may not adequately capture demand.

There were no meaningful variables that correlated with irrigation demand. The statistical significance was simply the result of large sample sizes (ranging from n= 25,144 for high, medium, and low groups to n= 165,326 for all customers in analysis). Irrigation demand as a depth was weakly correlated (0.22) to irrigation demand as a volume, indicating the importance of the customer-specific estimated irrigated area rather than one constant area assumed service area-wide. As expected, GIR was negatively correlated with precipitation (-0.48) and positively correlated with evapotranspiration (0.52). When less precipitation and more evapotranspiration occurred, GIR increased. The irrigation demand as a depth was highly correlated to the irrigation ratio (demand correlation to ratio = 0.99, required correlation to ratio = 0.11), most likely due the prevalence of extremely low monthly irrigation demands and a "set it and forget it" irrigation scheduling mentality of customers who don't sufficiently adjust their irrigation habits to weather conditions. Of all the parcel property variables provided by TBW, the strongest correlation was to property value (land and building combined) at 0.20. Results for correlations with the census data (e.g. age of head of household, household size) were weak (<0.20), possibly because the census data was an average for entire census blocks. For customers in the Tampa Bay area, the irrigation demand cannot be effectively predicted by any readily available weather, site, or demographic variables at their current resolution.

Mapped depictions of irrigation behavior shows spatial trends that can be helpful for geographically tailoring conservation programs. Figures 3-6, 3-7, and 3-8 provide visual estimations of where irrigation occurred. Since the demand of the occasional irrigators is so low and most likely could not be decreased through conservation programs, only the high, medium, and low irrigators are mapped (n= 25,144).

Irrigation volume is typically of primary interest to utilities and policy makers. Figure 3-6 shows the total monthly volumetric irrigation demand of all high, medium, and low irrigators in each pixel. These volumetric amounts are for the irrigators considered in this analysis and are only a fraction of all customers in the Tampa Bay area. However, the trend of volumetric demand is assumed to be representative of all customers. Similarly, Figure 3-7 shows the spatial distribution of irrigation depths and Figure 3-8 shows the distribution of the low, medium, and high irrigators. Figure 3-6 can be used to determine hot spots of high irrigation use that a service area or SWFWMD may want to target for the largest impact on conserving water supply by reducing the largest volumes. Alternative water sources, for example, may be most beneficial in the volumetric hotspots. The results in Figure 3-7 show where application rates are the highest. Here conservation initiatives such as irrigation system audits or smart irrigation controllers could be targeted to the demand depth hotspots. Finally, the customer counts shown in Figure 3-8 could be used be targeting programs that benefit from programs that are best for high-densities, such as a door-to-door educational campaign.

Chapter Conclusions

The majority of customers in the seven member-government service areas of Tampa Bay Water under-irrigated as compared to the estimated GIR. Sixty-seven percent of customers irrigated less than 1 inch/month and 84% used less than GIR. Eighty-five percent of customers were classified as occasional irrigators whereas only 2% of customers were classified as high irrigators. For all service areas and irrigating groups, irrigation demand and required were highest in the spring months. Given the limits of the data, irrigation demand could not be explained by any of the correlated factors tested. Mapping irrigation behavior provided a spatial depiction of irrigation demand and could be used to target particular conservation initiatives to particular areas.

The methodology outlined to stratify customers into irrigating groups is reproducible by utilities that maintain monthly billing records and have access to parcel records. Linking volumetric water use to parcel characteristics is key to developing irrigation demand estimates in units of depth (thereby making demand easier to compare across varying landscape areas) and developing irrigation requirements using site-specific weather and soil data. As utilities increase their understanding of customers' current irrigation behavior through analysis of water billing records, the most effective conservation measures can be selected and water conservation can be maximized.

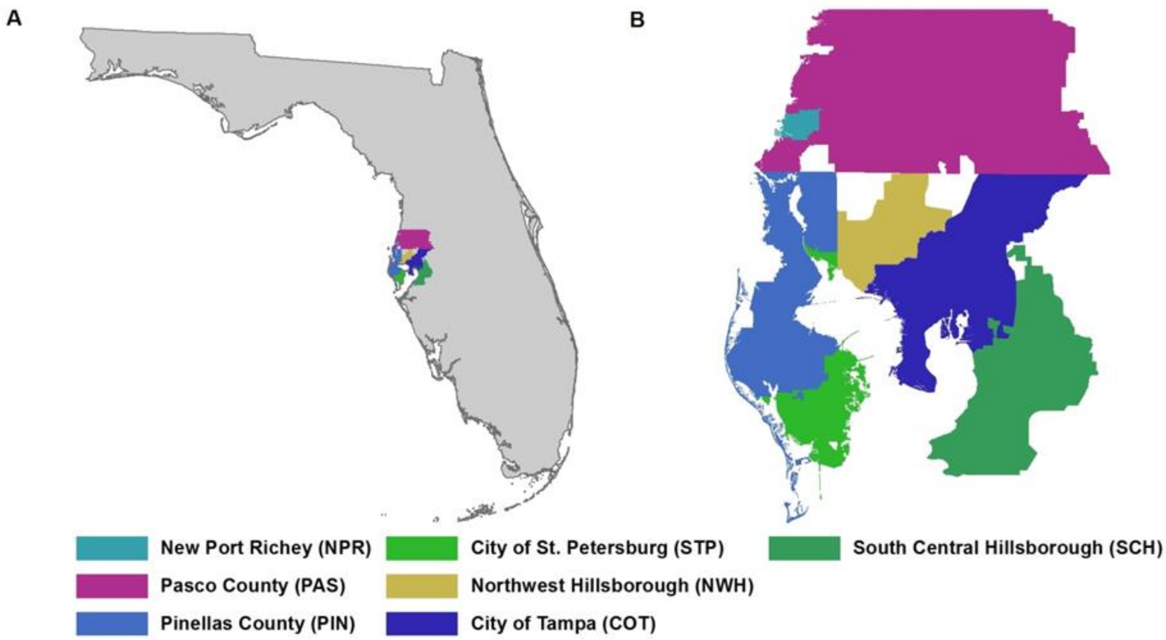

Figure 3-1. Tampa Bay Water member-government service areas in southwest Florida, United States.

Table 3-1. Summary of water billing records used for estimating irrigation demand in data analysis.

Service area	Date of first record*	Monthly billing records	Unique customers	Billing records used in analysis	Customers included in analysis	Percent of records included in analysis	Percent of customers included in analysis	Mean number of records per customer
NPR	Jan 1998	1,170,794	17,272	373,066	1,460	32	8	60
PAS	Jan 1998	7,642,788	194,709	3,987,640	20,823	52	11	38
PIN	Jan 1998	12,538,538	288,128	7,306,396	43,073	58	15	64
STP	Feb 1998	10,758,149	147,253	6,566,835	32,513	61	22	64
NWH	Feb 1998	5,966,043	168,432	2,939,669	16,597	49	10	110
COT	Jan 1998	14,243,544	227,571	4,256,336	21,630	30	10	62
SCH	Jan 1998	9,555,990	315,542	4,892,156	29,260	51	9	50
All Areas	Jan 1998	61,875,846	1,358,907	30,322,098	165,356	49	12	63

*Date of last record for all service areas was January 2010.

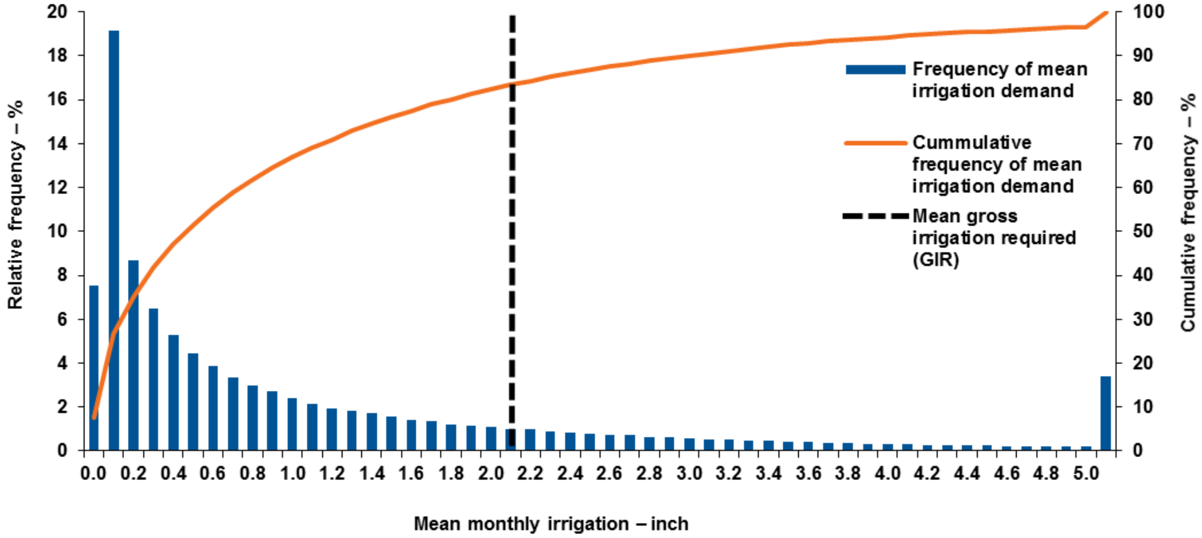

Figure 3-2. Histogram of relative and cumulative frequency of mean monthly irrigation demand (n = 165,326).

Table 3-2. Mean monthly irrigation depth (inch) for all customers used in analysis by service area.

	NPR	PAS	PIN	STP	NWH	COT	SCH	All areas
January	0.86	1.42	1.33	0.37	0.77	0.84	0.70	0.85
February	0.85	1.45	1.21	0.36	0.87	0.89	0.78	0.88
March	1.04	1.86	1.33	0.43	1.08	1.07	1.00	1.05
April	1.17	2.10	1.74	0.47	1.34	1.18	1.21	1.28
May	1.27	2.30	1.71	0.52	1.56	1.23	1.39	1.35
June	1.15	1.73	1.76	0.44	1.07	1.03	0.92	1.15
July	1.03	1.45	1.26	0.38	0.77	0.84	0.68	0.87
August	0.93	1.46	1.31	0.38	0.78	0.80	0.68	0.89
September	0.88	1.56	1.21	0.37	0.83	0.86	0.74	0.89
October	0.96	1.84	1.56	0.39	1.04	0.97	0.93	1.08
November	0.91	1.62	1.47	0.38	1.05	0.97	0.96	1.04
December	0.94	1.55	1.79	0.38	0.89	0.93	0.83	1.00
Mean	1.00	1.70	1.47	0.41	1.00	0.97	0.90	1.03

Table 3-3 Mean monthly irrigation ratio for all customers used in analysis by service area.

	NPR	PAS	PIN	STP	NWH	COT	SCH	All areas
January	1.45	2.48	2.06	0.58	1.19	1.26	1.10	1.36
February	1.05	2.12	1.51	0.42	0.97	1.04	0.94	1.05
March	0.53	1.02	0.74	0.21	0.57	0.60	0.53	0.57
April	0.24	0.46	0.37	0.09	0.29	0.26	0.27	0.28
May	0.19	0.37	0.26	0.08	0.24	0.20	0.22	0.21
June	0.42	0.69	0.75	0.16	0.54	0.50	0.45	0.50
July	0.61	1.01	0.86	0.26	0.67	0.69	0.51	0.64
August	0.49	0.92	0.97	0.27	0.56	0.59	0.55	0.64
September	0.52	0.84	0.79	0.25	0.49	0.57	0.46	0.56
October	0.43	0.98	0.71	0.17	0.58	0.51	0.58	0.55
November	0.74	1.44	1.50	0.34	0.95	0.88	0.91	0.98
December	1.64	2.62	2.82	0.61	1.34	1.40	1.30	1.64
Mean	0.69	1.25	1.11	0.29	0.70	0.71	0.65	0.75

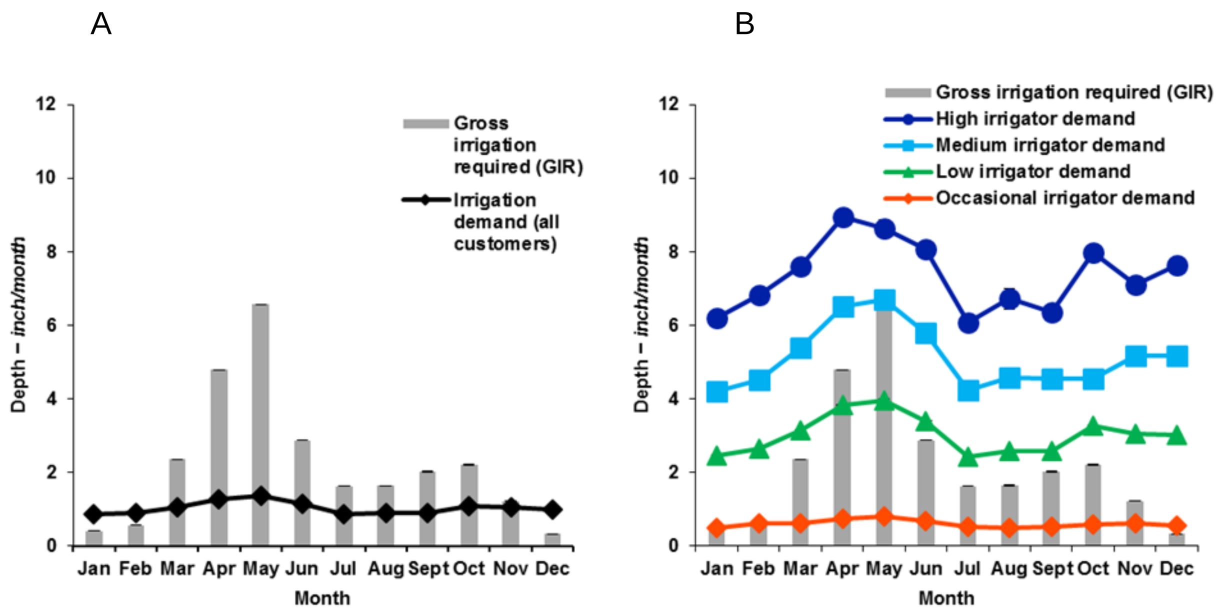

Figure 3-3. Mean monthly irrigation demand and gross irrigation required (GIR) for (A) all customers and (B) customer groups. Error bars indicate 95% confidence interval.

Table 3-4. Percent of customers in each irrigating group.

	Occasional	Low	Medium	High
NPR	71	11	12	6
PAS	64	19	6	12
PIN	91	6	2	<1
STP	80	15	4	1
NWH	69	19	6	6
COT	73	19	6	2
SCH	86	8	5	<1
All Areas	85	11	2	2

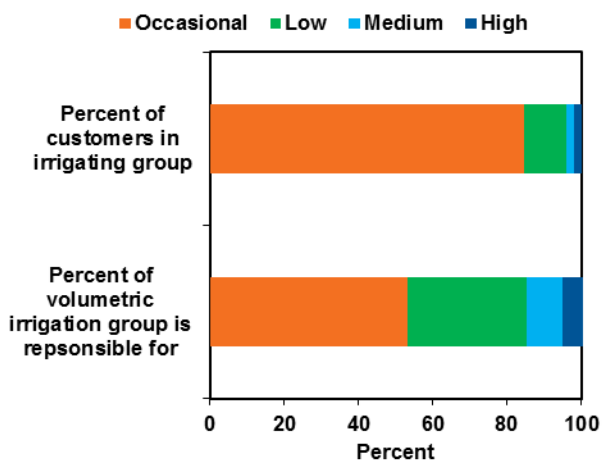

Figure 3-4. Percent of customers in each irrigating group and their total volumetric irrigation.

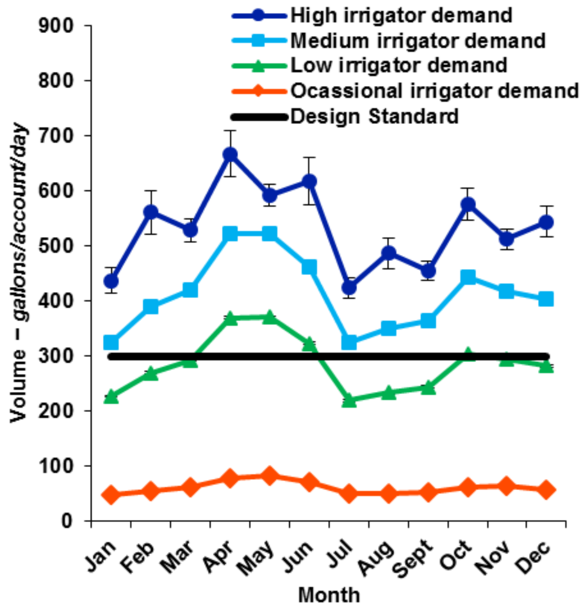

Figure 3-5. Mean volumetric demand of irrigating groups compared to the design standard of 300 gallons per account per day. Error bars indicate 95% confidence interval.

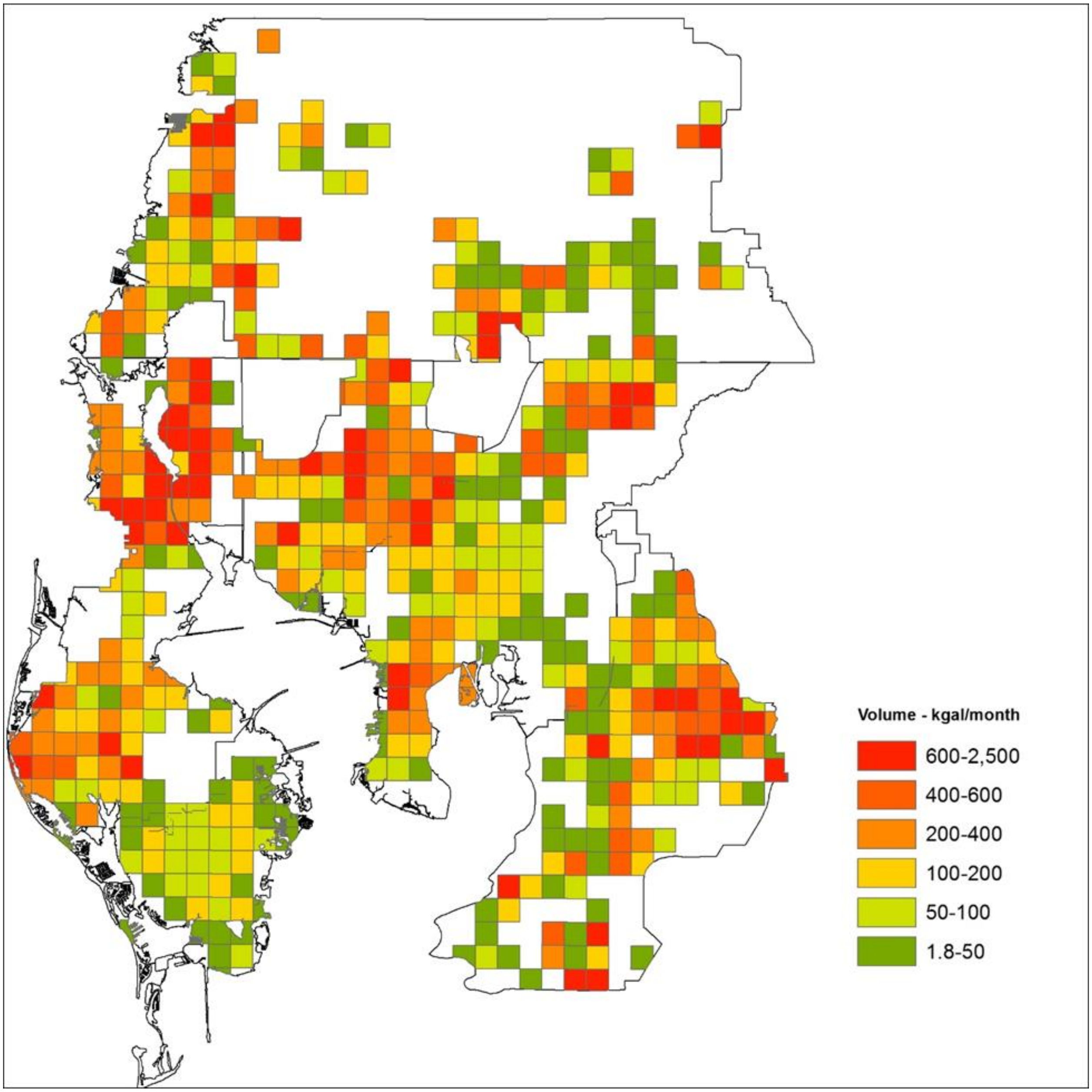

Figure 3-6. Spatial distribution of aggregate irrigation demand as a volume for high, medium, and low irrigating customers. Aggregate irrigation demand is equal to the sum of all estimated mean monthly volumetric irrigation demands for high, medium, and low irrigators within each 1.2 mile pixel grid.

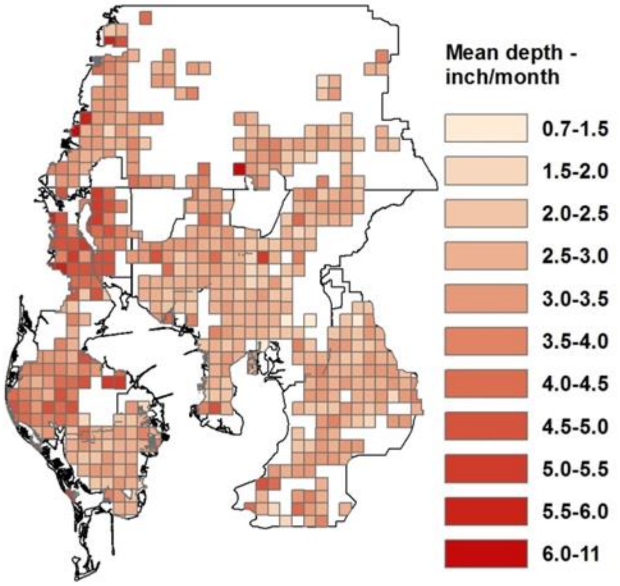

Figure 3-7. Spatial distribution of mean irrigation demand as a depth for high, medium, and low irrigating customers. Mean irrigation demand as a depth is equal to the mean of all estimated irrigation demands as depths for high, medium, and low irrigators within each 1.2 mile pixel grid.

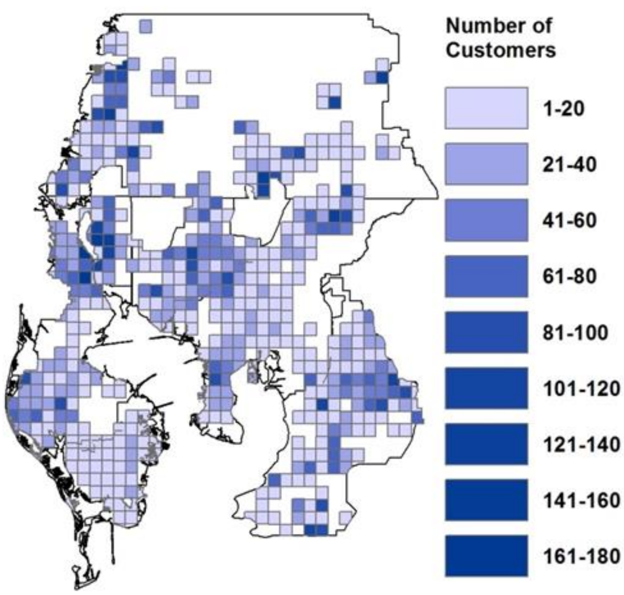

Figure 3-8. Spatial distribution of customer counts for high, medium, and low irrigating customers. Customer counts are the number of high, medium, and low irrigators within each 1.2 mile pixel grid.

CHAPTER 4
WATER CONSERVATION BENEFITS OF LONG-TERM RESIDENTIAL IRRIGATION RESTRICTIONS IN SOUTHWEST FLORIDA

Chapter Abstract

This study determines the effectiveness of long-term watering restrictions to reduce single-family residential irrigation in southwest Florida. Analysis was based on monthly water billing records of approximately 127,250 customers in five utilities from 1998 to 2010. Each customer's mean irrigation demand for each month under two day per week and one day per week allowable irrigation restrictions was calculated. Annual irrigation demand decreased 13% (11.3 to 9.8 inch/year), while the amount of irrigation required increased 3% (25.0 to 25.7 inch/year) under the more stringent restrictions. The majority of customers were deficit irrigators. Occasional and high irrigators had a -20% (-0.3 inch/year) and 20% (10.2 inch/year) change in irrigation demand, respectively, under the more stringent conditions, indicating that those who irrigated most had the most potential for conservation. Additional conservation potential existed for high irrigators, where the irrigation demand was still 56% above irrigation required under one day per week restrictions.

Chapter Introduction

Residential irrigation watering restrictions are often a standard water conservation tool for utilities, especially in the southeast and southwest where water resources are particularly limited and there have been prolonged droughts. Water restrictions take various forms throughout the United States. Most residential ordinances ban irrigating during the hottest daytime hours (when irrigation water can be lost to evaporation before it has a chance to be used by plants) and limit homes to specific watering days. Some restrictions are voluntary while others are mandatory.

Many have exceptions for newly planted landscapes or hand watering. Despite the prevalence of water restrictions, there is little published research on their effectiveness. Research is generally limited to short time durations or utility-wide averages. One of the first documented instances of water restrictions in the United States occurred in 1908 in Tucson, Arizona where the local newspaper reported that although irrigation had been restricted to three days per week, there was no reduction in utility water use (Arizona Daily Star 2014). Limited books, peer-reviewed reports, and peer-reviewed studies on water restrictions have been published since Tucson first struggled with a water shortage over one hundred years ago.

Historical Use of Irrigation Restrictions in the United States

Fort Collins, Colorado, 1977

Fort Collins implemented forty days of water restrictions in the summer of 1977 in response to low river flows (Anderson et al. 1980). Although utility-wide water use decreased 41% compared to the previous year under the restrictions, half of this savings was attributed to cooler and wetter weather conditions. The study's models were based on daily municipal water use, daily weather conditions, daily change in reservoir levels, and presence of water restrictions.

The initial water restrictions were based on geographic area: one quarter of the city was allowed to irrigate on Mondays, a second quarter on Tuesdays, a third quarter on Wednesdays, and the final quarter on Thursdays. Half of customers could water again on Saturdays, and the remaining half could water on Sundays. Although this irrigation schedule may have been easier to enforce, the irrigation demand to each geographic area was so great that water pressure could not be maintained in the distribution system. Twelve days into the restrictions, restrictions were modified to set watering days based on the last digit of the street address.

Austin, Texas, 1984-1985

Water restrictions were implemented in Austin, Texas in the summers of 1984 and 1985 (Shaw & Maidment 1987). City officials implemented restrictions according to predicted reservoir levels using a daily water forecasting model that incorporated current water use and forecasts of daily maximum temperature and precipitation. The initial restriction allowed irrigation once every five days, where property addresses ending in 0 or 1 irrigated on the first day, 2 or 3 on the second day, and so forth. The water demand was highest when the 0 and 1 address group irrigated because the group had the largest number of properties and these properties often were corner lots or businesses with larger irrigated areas. Mandatory restrictions limiting irrigation to once every five days for in-ground irrigation systems were in effect July 16 to August 18, 1984 and July 31 to September 12, 1985 and were structured so that there was a one-week grace period. Water use increased 6% from the baseline the last day of the grace period, then fell to 6% below the baseline the first day restriction were enforced. The authors hypothesized that affluent residents in the northwest service areas were trying to apply as much water as possible before the restrictions took effect. Compared to peak water use of 170 MGD, mandatory restrictions reduced water use 13.5 MGD (8%) in 1984 and 5.5 MGD (3%) in 1985.

Los Angeles, California, 2000-2010

Mini et al. (2014) developed a method for using remotely sensed vegetation to predict monthly irrigation, and this technique was then used to estimate the effectiveness of water restrictions. Monthly water billing records for approximately

480,000 customers in twelve neighborhoods serviced by the Los Angeles Department of Water and Power were aggregated to 855 census tracks. Spatial data included land cover, land use, and vegetation. The vegetation data was used to estimate normalized difference vegetation index (NDVI), a measure of an area's greenness. Irrigated areas were assumed to have constant NDVI values whereas non-irrigated areas were assumed to have NDVI values that followed precipitation patterns. The surplus NDVI, defined as the difference between these two values, was modeled to predict outdoor water use as the census tract level. The model also contained a variable for water restrictions.

Voluntary water restrictions were implemented in June 2007, mandatory water waste restrictions (e.g. prohibiting irrigation during rain, fixing leaks, limiting cycle times) were implemented in August 2008, and mandatory water waste and two day per week irrigation restrictions with price conservation measures were implemented in June 2009. Irrigation accounted for 54% of total single-family water use when there were no irrigation restrictions and decreased to 51% and 35% of total water use under voluntary and mandatory restrictions, respectively (assuming all conservation occurred in the landscape). Voluntary restrictions and mandatory water waste restrictions were more effective for lower income groups than for higher income groups (12% and 4% reductions, respectively). Both income groups responded similarly to mandatory restrictions that limited irrigation to two days per week and reduced irrigation by 35%.

Colorado, May-August 2002

Eight Denver area water providers, Thorton, Aurora, Denver Water, Westminster, Fort Collins, Boulder, Louisville, and Lafayette, each responded to an extreme drought in 2002 with their own water restrictions (Kenney et al. 2002). The restrictions implemented varied because each provider had their own unique water source portfolio and water rights and, consequently, the severity of the drought's impact varied. Depending on the water provider, restrictions specified watering times and durations, planting new sod, car washing, and filling swimming pools. All providers had public education programs. The study period was May 1 to August 31, 2002, the months that historically have the highest irrigation demand. The reduction in net use compared daily utility-wide water use under restrictions to historical water use. The reduction in expected use was calculated using utility-wide demand under restrictions compared to estimated demand without restrictions, where demand without restrictions was estimated from a regression model based on daily maximum temperature, precipitation, and a one-day lag water use. To incorporate the substantial population growth, reduction in expected use per capita was then calculated by dividing the expected use by the population.

Voluntary restrictions had limited benefits but mandatory restrictions were all effective in reducing water use. In general, as restrictions became more stringent, water conservation increased. Thorton, the only utility that used only voluntary restrictions, had a 9% reduction in expected use per capita but an 8% increase in net use. The four utilities that used both voluntary and mandatory restrictions all had greater reductions under the mandatory restrictions. The reduction in expected use per capita under mandatory restrictions was 22% (14% net use) in Aurora, Denver Water, and Westminster, 33% (30% net use) in Fort Collins, Boulder, and Louisville, and 56% (53% net use) in Lafayette for water providers with three day, two day, and one day per week restrictions, respectively. As an outcome of the 2002 drought, the water providers formed a working group to develop uniform restrictions and evaluation methods.

North Carolina, 2006-2008

Boyle et al. (2011) discussed the value of mining monthly water billing data to better understand customer demand and to customize conservation strategies, and used water restrictions as an example. When an unnamed North Carolina utility implemented conservation efforts in the form of mandatory water restrictions and increased rates for high water use, the mean household use utility-wide increased slightly in fiscal year 2008 as compared to fiscal year 2007, initially indicating that the restrictions were unsuccessful. However, 67% of the high users (>20,000 gallons/month baseline) decreased their monthly water use. These reductions were offset by increases of low users (< 5,000 gallons/month) that were deemed too small to be due to irrigation.

Reno, Nevada, 2014

Castledine et al. (2014) found that less stringent restrictions decreased water use for Truckee Meadows Water Authority customers in northern Nevada during the summer months of 2008 and 2010. Irrigation was allowed two days per week in 2008 and three days per week in 2010. Daily water consumption was collected June 22 to August 23, 2008 (n=8,747 customers) and June 20 to August 21, 2010 (n=7,652 customers). Although the data collection was based on similar meter routes, 0 to 60% of customers overlapped in the two data sets depending upon the week. Customers were grouped weekly after analyzing the data based on their daily water use: the schedule group followed the allowable irrigation days, the schedule-plus group irrigated on the allowable days and at least one additional (banned) day, and the off-schedule group had a range of irrigation behavior with the most common behavior being not irrigating on an allowable day. The schedule and schedule-plus groups were combined for the analysis. Weekly water use and peak use were 20-25% and 30-40% higher, respectively, for customers in the schedule/schedule-plus group than those off-schedule customers that irrigated an identical number of days.

Historical Use of Irrigation Restrictions in Florida

Southwest Water Management District, Florida, 1998-2003

As part of a study on water rates, Whitcomb (2005) evaluated the impact of reducing allowable irrigation from two days per week to one day per week using monthly billing records for six utilities in the Southwest Florida Water Management District. The one day per week restrictions generally began March to May 2000 and ended October to December 2003. Total (indoor and outdoor combined) volumetric reductions for all utilities combined ranged from 9 to 20%, with the greater reductions generally associated with the highest property value group (n=1,473 single-family residential customers).

St. Johns River Water Management District, Florida, 1998-2003

Whitcomb (2006) estimated the effectiveness of two day per week allowable irrigation restrictions in eight utilities in the St. Johns River Water Management District. Although daily production data did show a trend of higher water use on days where irrigation was allowed in three utilities, it was not possible to estimate the water use changes attributed to restrictions. Using monthly billing records comparing post-restrictions (2001-2003) to pre-restrictions (1998-2000), an 11.6-12.8% reduction in total water was observed in the City of Ocoee (n=6,332 single-family residential customers) and a 16.9-18.5% reduction in irrigation water was observed in Seminole County (n=2,715 single-family residential customers). Water savings were adjusted for weather conditions.

Collier County, Florida, 2007-2008

Residential customers in Collier County were limited to two days per week allowable irrigation from April 2007 through December 2007 and one day per week allowable irrigation from January 2008 through April 2008. Duke and Burgerhoff (2011) reported that mean total water use was 23% lower in April 2008 (a month that had above average precipitation and more stringent water restrictions) than in April 2007, although 27% of customers increased their water use (n = 874 customers in Home Owners Associations [HOAs]). The study noted that there was no significant difference between the four study groups (control, restrictions information received through HOA, had been cited for violating restrictions, and neighbors of the customers who received citations).

Wellington, Palm Beach County, Florida, 2009

A study of 165 households in Wellington, Palm Beach County using either public-supplied potable water or a private well for irrigation were evaluated for compliance with water restrictions (Survis and Root, 2012). The authors compared the target irrigation based on weekly evaporation and precipitation to the actual use in a conservation effectiveness ratio. All households in the study had in-ground irrigation systems and were subject to two days per week water restrictions. The households were observed daily from July 12, 2009 to October 30, 2009 for signs of irrigation. Irrigation application rates were based on system audits of a subset of houses. Households irrigated an average of 1.3 times and 1 inch per week. Households had less irrigating events per week than the two allowed under water restrictions, but the irrigation applied exceeded the target irrigation in fifteen of the sixteen weeks, meaning customers over-irrigated. The authors concluded that although customers were following the intent of restrictions, they were not conserving as much as they could.

Tampa, Florida, 2004-2008

Ozan and Alsharif (2013) used monthly billing records to measure the effectiveness of water restrictions in the City of Tampa. The study focused on three subdivisions that had a high number of water restriction violations. Of the twenty-seven populated zip codes in Tampa, zip code 33647, where all of the study homes were located, had 52% of all water restriction citations. Thirty percent of the 225 studied homes had received an irrigation citation, as opposed to the city-wide average of 1.5%. The study compared monthly total water use under two day per week restrictions (June 2004-May 2006) and one day per week restrictions (June 2006-May 2008). Although there was a correlation between total water use and precipitation (-0.59), there was no statistical difference between water use under the two types of restrictions. The authors hypothesized that the homeowners irrigated more during drought conditions despite the watering restrictions. The Ozan and Alsharif study established a framework for evaluating the effectiveness of water restrictions using monthly billing records, but their results may have been influenced by their choice of study homes.

As part of their Water Shortage Mitigation Plan (2017), Tampa Bay Water evaluated the effectiveness of water restrictions for all their member-governments, including two (New Port Richey and Pasco County) that were excluded from the study presented in this paper. Using monthly water billing records from 2000-2013 and assuming that all member-governments followed the same restrictions at the same time (i.e., two day per week restrictions January 2000- January 2007 and July 2010-

December 2013, and one day per week restrictions February 2007-June 2010), there was no statistical difference in single family residential total (indoor and outdoor combined) volumetric water demand under the two restrictions.

Goal and Objectives

Irrigation restrictions in the Tampa Bay Water area offer a unique look into both long and short term restrictions, as well as the behavior of individual customers. The goal of this project was to determine the effectiveness of long-term watering restrictions to reduce irrigation of individual single-family residential customers in southwest Florida. The primary objective was to compare each customer's irrigation demand under two day per week and one day per week allowable irrigation restrictions. Next, high, medium, low, and occasional irrigating groups were identified and the high irrigators were mapped to determine if there was a geographic component to irrigation behavior. Finally, the impact of short-term banned in-ground irrigation in Tampa was evaluated.

Materials and Methods

Study Area

Tampa Bay Water (TBW) and its predecessor the West Coast Regional Water Supply Authority have been subject to continuous water restrictions ordinances since 1987. Tampa Bay Water is a regional water wholesaler that provides water to its member-governments (utilities). The utilities included in this analysis are Pinellas County, City of St. Petersburg, Hillsborough County (sub-divided into the Northwest and South Central areas), and City of Tampa (Figure 4-1). These utilities are located in southwest Florida within Pinellas and Hillsborough counties, which contain 11.5% of Florida's population (EDR, 2015). Examples of residential landscapes in the study area are shown in Figure 4-2.

Water, Parcel, Census, Soil, and Weather Data

Tampa Bay Water provided monthly water billing records and parcel records for the five utilities. The records generally span the years 1998-2010, but varied by utility. The data contained almost fifty variables including customer identification number (customer ID), location identification number, parcel identification number (parcel ID), total (indoor and outdoor combined) potable water use, month and year of water use, whether the customer had access to reuse water or had a dedicated irrigation meter, and estimated greenspace area (parcel area minus the building footprint and any other taxable impervious features). The total potable water use was based on meter readings taken approximately monthly for Pinellas County, St. Petersburg, Northwest Hillsborough, and South Central Hillsborough or once every two months for Tampa. Readings were adjusted by Tampa Bay Water to reflect the estimated water use in the calendar month rather than the use between meter readings.

Data were received as separate comma separated values (.csv) files and imported into SAS 9.4 (SAS Institute, Cary, NC). The analysis included only single-family residential customers without access to reuse and without dedicated irrigation meters. Additionally, customers must have had unique non-zero customer and parcel ID numbers and had a greenspace area of at least 1,000 square feet (Knight et al. 2015). A minimum criterion for total water use was used to eliminate homes that were unoccupied and was based on a minimum per capita water use of 23.9 gallons per capita per day (gpcd) and one person per household, where the minimum use was one standard deviation below the mean indoor water use (DeOreo et al. 2016). The maximum criterion was used to eliminate inaccurate readings or readings due to leaks and was based on the customer’s mean plus three standard deviations. While reviewing the water billing records, an error in Pinellas County's total water use (most likely due to how the raw billing data was adjusted to reflect usage during the calendar month) was apparent for October 2002- December 2004. These observations, approximately 4% of all monthly billing records included in this study, were excluded from the analysis.

Block-level household sizes (number of people per house) were obtained from the 2010 U.S. Census (2015) using ArcGIS 10 Desktop (Environmental Systems Research Institute, Redlands CA) and SAS. Lists of customer parcels for each utility were generated in SAS from the water billing records. These lists were imported into ArcGIS and used to isolate parcel shapefiles from the Florida Department of Revenue (FDOR, 2011) that were included in our analysis. The census shapefile was intersected with the parcel shapefiles to determine the block-level household size for each customer in the analysis. Household sizes were given as whole numbers.

Soil and weather parameters for each customer were obtained in a similar manner to the household sizes. ArcGIS shape files that included soil polygons throughout the study area and soil characteristics such as the available water holding capacity were obtained from the Natural Resources Conservation Service (Soil Survey Staff 2013). Daily weather data including reference evapotranspiration and precipitation on a 1.2 mi grid along with a shapefile of the grid were obtained from the U.S. Geological Survey (2011, 2005) and through personal communication with the Southwest Florida Water Management District (SWFWMD). The soil and weather shapefiles were intersected with the customer parcels to yield high-resolution parameters for each customer. Similar data and analysis methods were used in Boyer et al. (2016) and Boyer et al. (2014).

Water Restriction Ordinances

Tampa Bay Water recommends water restrictions for its members to the regulatory agency Southwest Florida Water Management District (SWFWMD), but members may choose to self-impose more stringent restrictions. Restrictions were triggered by past and then-current climate and hydrologic conditions during the study period. Restrictions have varied by year and utility, with baseline restrictions since 1992 that limit irrigation to a maximum of two days per week year-round. The most drastic restrictions were two months of banned irrigation (hand watering was still permitted once per week) in the City of Tampa in 2009. There were approximately fifty water executive orders and ordinances released by SWFWMD and the utilities during our study period of 1998-2010 (Table 4-1). The primary focus of the water restrictions was to limit the number of allowable irrigation days per week, but often also included allowable times of day for irrigation and rules for establishing new landscaping. Allowable irrigation days were assigned based on customers' street addresses, with one schedule for even-numbered addresses and one schedule for odd-numbered addresses. Each utility was responsible for enforcing the water restrictions and issuing citations. No information was available on enforcement of citations during the study period. Water billing rates, which are often used as a separate method for influencing conservation, were also provided by Tampa Bay Water. All utilities had tiered rate structures, meaning that higher water use was charged at a higher rate.

Irrigation Demand

Irrigation demand is the amount of water a customer used on their landscape based on their monthly billing records. Irrigation demand was estimated using the monthly water billing records, parcel records, and census data. The per capita indoor use method was used to estimate irrigation demand from the total (indoor and outdoor combined) volumetric water because the two other most common methods of estimating irrigation from total use, the minimum month method and the winter average method, are not applicable in southwest Florida where irrigation may occur year-round (Romero and Dukes 2015). All outdoor water was assumed to be used for irrigation (i.e., swimming pools and power washing were ignored). Volumetric indoor water use for each customer in each month was estimated using 58.6 gallons per capita per day (gpcd, DeOreo et. al 2016) and the census block-level household size. The indoor water estimate was subtracted from the total water use to yield estimated volumetric irrigation. The volumetric irrigation was divided by the estimated greenspace area given in the parcel data sets to yield irrigation demand as a depth. It was assumed that the greenspace is equal to the irrigated area.

Gross Irrigation Requirement

Irrigation required is the amount of water the landscape theoretically needs based on agricultural principles. Irrigation required was estimated using parcel, soil, and weather data. It was assumed that each landscape consisted of 79% well-watered turfgrass and 21% ornamental plant beds (Haley & Dukes 2012). The irrigation requirement of the ornamental plant beds, which typically don’t need supplemental irrigation after six to twelve months of planting, was assumed to be zero (Shober et al. 2009, Scheiber et al. 2008).

A daily soil moisture balance for turfgrass tracked the water inputs (i.e., precipitation and irrigation), outputs (i.e., evapotranspiration and runoff), and available water storage in the turfgrass root zone. The high-resolution soil and daily weather data were able to capture each customer’s site conditions more accurately. Most customers had sandy or urban-influence sandy soils, with water holding capacities of 0.5 to 1 inch in the assumed 12- inch turfgrass root zone. The maximum allowable water storage depletion was assumed to be 50%, the irrigation efficiency was assumed to be 80%, and crop coefficients for warm season turfgrass used with the reference evapotranspiration varied monthly (Jia et al. 2009). Separate calculations for each combination of high-resolution soil and weather data were performed for each day of the approximately twelve year study period. Daily results were summed monthly to yield the monthly irrigation required for each customer. A more detailed description of the soil moisture calculations is available in Boyer et al. (2014).

Irrigation Expected

Irrigation expected is the amount of irrigation that a customer is expected to use if the customer is following water restrictions. It is based on the number of allowable irrigation days in the month and an estimated amount of irrigation per day. The number of irrigation days allowed in a month varied from 0 to 9 during the study period and was calculated for each customer for each month based on the ordinance in effect, the allowable weekly irrigation days, and the customer's street address. The estimated amount of irrigation per day was assumed to be ¾" based on common recommendations.

Defining Customer Data Set

Customers were sorted by month under two day per week and one day per week restrictions. Only customers with at least one record in each calendar month under both restrictions conditions were included in the analysis. Because the time period and number of observations often varied for each customer, mean monthly irrigation variables were calculated for each customer. For example, each customer had one mean irrigation demand as a depth, irrigation demand as a volume, and irrigation ratio for two day per week allowable irrigation in the month of January, then the same variables for one day per week allowable irrigation in the month of January. Developing this data set allowed each customer to be weighted equally with others. There were approximately 127,250 customers with a total of 11.5 million monthly observations included in the analysis.

Irrigation Ratio and Defining Irrigating Groups

Customers were classified into irrigating groups based on their mean annual ratio of irrigation demand to irrigation required under two day per week restrictions. Occasional irrigators were defined as having a ratio less than 0.25, low irrigators had a ratio of 0.25-0.50, medium irrigators had a ratio of 0.50-1, and high irrigators had a ratio greater than 1. Tampa Bay area customers tend to have low irrigation ratios as opposed to other regions. For example, in Layton, Utah, 63% of customers had an irrigation ratio greater than 1 (where irrigation required was based on reference evapotranspiration, a crop coefficient, rainfall, and a distribution uniformity of 0.7). The boundaries selected for the divisions between irrigating groups for the customers of this study may not be appropriate for customers in other regions.

Geographic Distribution of Restriction Compliance

The mean annual change (calculated as the sum of the monthly means) in irrigation demand for each high irrigating customer when going from two day per week to one day per week allowable irrigation was calculated as both a percentage and as a depth. Using the customer addresses, mean values for each zip code in the study area were calculated. This data set was exported from SAS, imported into ArcGIS, joined to a shapefile of zip codes, and clipped to the boundaries of the utility service areas.

Statistical Modeling

A statistical model was used to test the hypothesis that annual irrigation demand under two days per week and one day per week was significantly different. To achieve approximate normality, the response variable $y_{i,j}$ was defined as the natural logarithm of the sum of the irrigation depth and one (Boyer et al. 2014). Because of the longitudinal character of the data, a one-way ANOVA model with customer-specific random effects was used, written as $y_{i,j} = \alpha_j + \gamma_i + \epsilon_{i,j}$ (McCulloch and Searle, 2003). Here, $y_{i,j}$ is the log-transformed annual mean irrigation depth for customer i under j day water restrictions where j is 1 or 2, α_j is the overall mean for j day water restriction and γ_i are normal household-specific deviations from these annual means. The model were fit using a linear mixed model framework in R 2.13.2 (www.r-project.org, library lme4); because of the size of the data set, the model was run on the University of Florida's High Performance Computing Center. All results presented in this paper, including the modeling results are statistically significant at $p < 0.05$.

Results and Discussion

The mean monthly total (indoor and outdoor) volumetric water demand for customers in the five utilities is shown in Figure 4-3A. All utilities show seasonal patterns, with the highest total water demand in the early spring and lowest demand typically in the winter or occasionally in the summer. This demand behavior follows the general trend of irrigation required in Florida: required irrigation is generally highest in the spring when plant water needs are high but precipitation is low and is generally lowest in the winter when plant water needs are low or in the summer when frequent precipitation is common. In Figure 4-3A, values at the beginning and end of each utility's available data tend to be low, which is most likely due to data collection and adjusting the water meter readings to calendar months. Annual mean total water use per customer decreased from 1999 to 2008, with reductions ranging from 6% (Northwest Hillsborough) to 26% (Pinellas County). DeOreo et al. (2016) noted a similar downward trend in per customer total water use, where the North America-wide per household water use was reported as 12,167 gallons/month in billing data collected 1996-1998 from 12 utilities and as 7,333 gallons/month in billing data collected 2010-2013 from 23 utilities, a 40% decrease in water use. The decrease in indoor water use was attributed to more efficient fixtures and appliances and was not due to changes in occupancy or behavior. Outdoor use was highly variable, but in general the volumetric irrigation applied decreased while the application rate increased (DeOreo et al. 2016).

Water billing rates increased during the study period, leading to increased mean monthly water bills (Figure 4-3B). Mean water bill increases ranged from 3% (Tampa) to 58% (St. Petersburg). Since water bills in all five utilities were based on a tiered rate structure, the water demand directly impacted the rate at which the customer was billed. The Pearson correlation coefficient of total water use and water bill was 0.88 and the Pearson correlation coefficient of irrigation depth and water bill was 0.67.

Irrigation demand and required as depths under two day per week and one day per week maximum allowable irrigation is shown in Figure 4-4. Annual irrigation demand (based on the water billing records) decreased 13% (from 11.3 to 9.8 inch/year), while annual irrigation required (based on weather and plant water needs) increased 3% (from 25.0 to 25.7 inch/year) during the time period of the more stringent restrictions. The monthly conservation impact varied. June was a successful month for conservation:

although the irrigation required was 43% higher under one day per week restrictions, irrigation demand increased just 14%.

Customers' irrigation demand tended to be much lower than the irrigation required, classifying the region as a whole as deficit irrigators. Mean monthly irrigation demand was relatively constant month-to month and ranged from 0.8 to 1.3 inch/month, which is consistent with a previous utility-wide study in southwest Florida (Romero & Dukes 2011). Mean irrigation required was much more variable and ranged from 0.6 to 6.8 inch/month. Because deficit irrigators already have low irrigation demands, additional water conservation becomes more difficult. Water restrictions are aimed at reducing irrigation demand, but only works for those who are truly irrigating. Considering that customers known to have and use in-ground irrigation systems have been shown to have a demand of 1.6 to 2.4 inch/month in southwest Florida, (Davis & Dukes 2014, Haley & Dukes 2012), the mean monthly irrigation of 0.8 to 1.3 inch/month indicates that a substantial portion of customers are irrigating infrequently if at all.

To separate the occasional or non-irrigating customers from those that are consistently irrigating, customers were grouped based on the ratio of their annual irrigation demand to required. The distribution of annual irrigation demand of all customers under two day per week allowable irrigation is shown in Figure 4-5. The histogram's distribution is typical for water utilities. Previous studies (DeOreo et al. 2016, Boyer et al. 2016, Romero & Dukes 2011) have shown that most customers irrigate at lower rates and that a small fraction of customers are disproportionately responsible for the utility-wide irrigation demand. Fifty-nine percent of customers were classified as occasional irrigators, 14% as low irrigators, 15% as medium irrigators, and

12% as high irrigators. Customers whose annual irrigation demand exceeded ten times their irrigation requirement (0.5% of all customers) were assumed to be outliers due to leaks or inaccurate data and were excluded.

Figure 4-6 shows both the benefits and short-comings of day of the week water restrictions to reduce irrigation demand. The figure shows the mean monthly irrigation demand of the four groups and the mean monthly irrigation required. Although there is variability month-to-month, the difference between 2 day/week and 1 day/week in mean annual irrigation required was less than one inch. It is clear from the magnitude of the irrigation demand that the high group irrigated regularly (3.2 to 5.6 inch/month under two day per week restrictions), whereas the occasional group irrigated little if at all (less than 0.3 inch/month). Therefore, the high group had a greater potential for conserving. High irrigators reduced their irrigation by 10.2 inch/year under one day per week allowable irrigation compared to two day per week allowable irrigation, whereas occasional irrigators increased their irrigation by 0.3 inch/year (Table 4-2). The percentage change in irrigation (-20% for high and 20% for occasional) is misleading because the baseline irrigation demands for the two groups are so different. Day of the week restrictions were successful in reducing irrigation demand of the highest users, but may also encourage some customers to irrigate.

Figure 4-6 also illustrates the tendency of high irrigators, and to some extent the medium irrigators, to over-irrigate (where the irrigation demand exceeds the irrigation required). Irrigation demand exceeding irrigation required indicates that customers could have reduced their irrigation demand to the irrigation required without compromising the quality of their landscape. Under two day per week restrictions the irrigation demand of

50.3 inch/year exceeded the irrigation required of 25.0 inch/year by 25.3 inch/year, and under one day per week restrictions the irrigation demand of 40.1 inch/year exceeded the irrigation required of 25.7 inch/year by 14.4 inch/year. Although the more stringent restrictions reduced irrigation demand, there was still over-irrigation and additional conservation potential.

Two predictive factors for irrigation demand were explored. As previously discussed, irrigation required considered plant water needs and weather conditions and was calculated without consideration of allowable watering days. Irrigation expected is the amount of irrigation that a customer is expected to use if the customer is following allowable watering days. If a customer followed either the irrigation required or the irrigation expected, scatter plots would show results along the y = x line (Figure 4-7). Because of the extremely large number of observations (n = 11.5 million), only a subsample of data is shown for graphical clarity. The Pearson correlation coefficient for irrigation demand to required (Figure 4-7A) was 0.07, the Pearson correlation coefficient for irrigation demand to expected was -0.04, indicating no relationship between irrigation demand and the predictive factors. When just customers in the high group were considered, the Pearson correlation coefficients improved slightly to 0.13 for irrigation demand to required and 0.09 irrigation demand to expected.

The lack of correlation between irrigation demand and either required or expected does not necessarily contribute to a lack of water conservation. For the 88% of customers whose annual irrigation demand was less than their irrigation required (those customers in the medium, low, and occasional groups), following the irrigation requirement would have led to increased irrigation demand. Likewise, expected irrigation was based on the number of allowable irrigation days and did not consider whether irrigation was actually needed that day. Irrigating just because it was allowed and not because it was needed would have unnecessarily increased irrigation demand. However, for high irrigators, following the irrigation required would have reduced annual irrigation demand all months except April and May (Figure 4-6). For the customers whose demand fell above the y = x line in Figure 4-7B, following the irrigation expected could have led to reduced irrigation demand.

The change in irrigation demand for the high irrigating group by percent and inch/year when switching from two day per week allowable irrigation to one day per week allowable irrigation is shown in Figure 4-8. Results were aggregated by zip code and indicate how effective water restrictions were geographically. All but one zip code reduced annual irrigation demand under the more stringent restrictions, although substantially variation existed within each zip code. For example, the only zip code with a mean increase in annual irrigation demand (shown in red) had 158 customers with a difference in irrigation demand ranging from 55 inch/year decrease to 107 inch/year increase. The percent change in irrigation demand depth and the absolute difference in demand depth are both provided because they give different measures of the restrictions’ success.

Pinellas County tended to have the largest reduction in irrigation demand, both in terms of percent and depth. However, Pinellas County high irrigators also had the highest annual irrigation demand of all five utilities (61.1 inch/year in Pinellas County as compared to 50.3 inch/year for the entire study area). South Central Hillsborough County tended to have higher percent reductions (Figure 4-7A), but the depth reduction was lower (Figure 4-7B) because the utility had a lower background irrigation demand (39.6 inch/year in South Central Hillsborough County as compared to 50.3 inch/year for the entire study area).

Of particular interest is zip code 33647 shown in Figure 4-8. The zip code contained 714 high irrigators, with irrigation demand of 25 to 220 inch/year under two days per week and 1.3 to 160 inch/year under one day per week restrictions. The mean decrease in irrigation for the 714 high irrigators in zip code 33647 was 19% and 8.6 inch/year (14% and 3.9 inch/year, respectively, if all customer groups were considered). This zip code was the subject of Ozan and Alsharif's (2013) study that showed no significant difference in total volumetric water use when irrigation restrictions changed to one day per week. Differences in results can be attributed to the current study using irrigation depth rather than total water, a larger more inclusive sample size, and a longer period of analysis.

Within each irrigating group, the percentage of customers that increased or decreased irrigation demand as restrictions became more stringent indicates how individual customers responded to the changes in restrictions (Figure 4-9). Decreased was defined as at least 10% less, increased was defined as at least 10% more, and maintained was defined as within 10% of the baseline. Some customers may have chosen to disregarded water restrictions, prioritizing the continued maintenance of their landscape over the risk of receiving a citation for violating restrictions, as may have been the case in Ozan and Alsharif's (2013) selected sample. Other occasional or low irrigating customers may have interpreted the water restrictions as being under drought conditions and concluded that their landscape needed irrigation because precipitation was scarce. (Precipitation actually had a minimal impact, as annual irrigation required increased only 3% under the time period of more stringent restrictions.) Still others may have started to follow the allowed irrigation schedule, irrigating on their allowed day regardless of whether their landscape actually needed it because they did not want to wait a week for their next opportunity to irrigate. The majority of customers in each group decreased their irrigation (Figure 4-9), indicating that most customers respond to the more stringent restrictions. Sixty-five percent of high customers decreased their irrigation demand by at least 10% which is promising because these customers have the most potential for conservation and are therefore the primary targets of water restrictions.

The primary focus of this study was long-term water restrictions. However, there was one period of short-term restrictions in one utility. The City of Tampa experienced a brief ban on irrigation using in-ground systems in April and May 2009. (Although in-ground systems were banned, hand watering was allowed once per week for established lawns and more frequently for establishing new lawns.) Figure 4-10 shows the mean monthly irrigation demand in April and May under two days, one day, and zero days allowable irrigation per week in Tampa. The figure can be used to observe the general trend in irrigation demand, but the demands and reductions must be used with caution because of the data collection method. Tampa was the only utility of the five to record water meter readings every two months rather than every month. Consequently, a reading taken in mid-April could have water use for half of February, March, and half of April. Tampa Bay Water adjusted the readings to reflect the use in the calendar month rather than the time between readings. With short-term restrictions, these adjustments could overlook sudden changes in irrigation demand. Even with the uncertainty of the irrigation demands, it is clear that there was a large decrease in irrigation demand when in-ground irrigation was banned. When irrigation restrictions changed from two days per week to one day per week, the high group reduced irrigation demand, but under the banned in-ground irrigation all groups reduced irrigation demand. Figure 4-10 does indicate that some irrigation was still occurring during the banned in-ground irrigation period, and this could be attributed to several causes: customers were hand watering once per week as allowed, customers were disregarding the watering restrictions, or the adjustment of the bi-monthly meter readings distorted the data. The irrigation required was actually lower during the banned in-ground irrigation months (4.4 inch/month as compared to 5.6 inch/month under two day and 5.7 inch/month under one day per week allowable irrigation), so the observed irrigation demand could not be attributed to the change in irrigation required. Overall, the response of customers to the drastic, short-term restrictions was a substantial reduction in irrigation demand. This behavior is consistent with other short-term restrictions such as Kenney et al. (2004).

Chapter Conclusions

Long-term water restrictions that periodically reduced allowable irrigation from two days to one day per week during the study period of 1998 to 2010 were successful in reducing irrigation demand in southwest Florida. Annual irrigation demand decreased 13% (from 11.3 to 9.8 inch/year), while annual irrigation required increased 3% (from 25.0 to 25.7 inch/year) under the more stringent restrictions. Throughout the region, customers' irrigation demand tended to be much lower than the irrigation required, classifying the region as a whole as deficit irrigators. As a group, high irrigators, defined as having annual irrigation demand that exceeded the irrigation required, reduced their irrigation demand 20% under the more stringent conditions, indicating that those who irrigated most had the most potential for conservation. Additional conservation potential existed for high irrigators, where the irrigation demand was still 56% above irrigation required under one day per week restrictions. The primary focus of this study was long-term water restrictions, but the brief ban on irrigation in the City of Tampa in April and May 2009 resulted in a substantial reduction in irrigation demand as well.

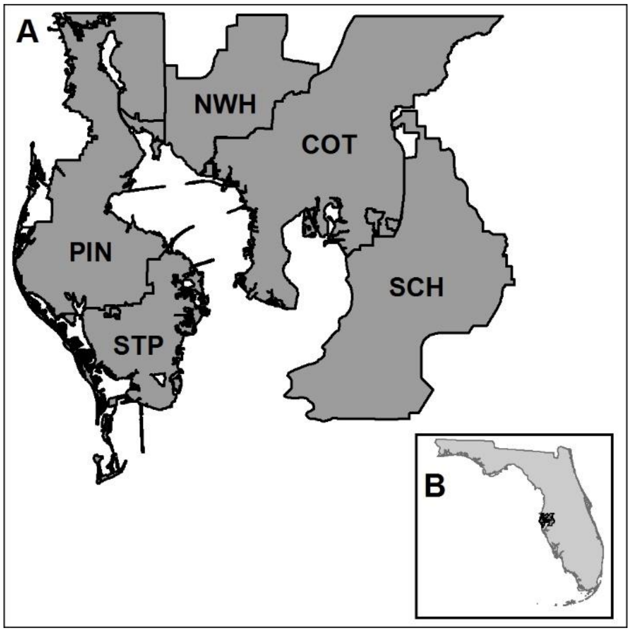

Figure 4-1. Study area. (A) Service areas of Northwest Hillsborough County (NWH), City of Tampa (COT), South Central Hillsborough County (SCH), Pinellas County (PIN), and City of St. Petersburg (STP). (B) Location of service areas within the state of Florida.

Figure 4-2. Examples of residential landscapes in study area. (A) Representative landscape 1, (B) Representative landscape 2, and (C) Representative landscape 3. Photos courtesy of Michael Gutierrez. 2011.

Table 4-1. Time periods for irrigation restrictions by utility.

	2 day/week allowable irrigation	1 day/week allowable irrigation	0 day/week allowable irrigation
NWH	6/10/1992 - 3/15/2000; 9/15/2003 - 6/8/2004; 8/4/2004 - 12/7/2006	3/16/2000 - 9/14/2003; 6/9/2004 - 8/3/2004; 12/8/2006 - 11/15/2010	
SCH	6/10/1992 - 3/15/2000; 9/15/2003 - 6/8/2004	3/16/2000 - 9/14/2003; 6/9/2004 - 11/15/2010	
COT	6/10/1992 - 3/15/2000; 11/1/2003 - 5/3/2006	3/21/2000 - 10/31/2003; 5/4/2006 - 4/2/2009; 5/28/2009 - 11/15/2010	4/3/2009 - 5/27/2009
PIN	6/10/1992 - 4/30/2000	5/1/2000 - 11/15/2010	
STP	6/10/1992 - 3/20/2000; 9/16/2003 - 1/29/2007	3/22/2000 - 9/15/2003; 1/30/2007 - 11/15/2010	

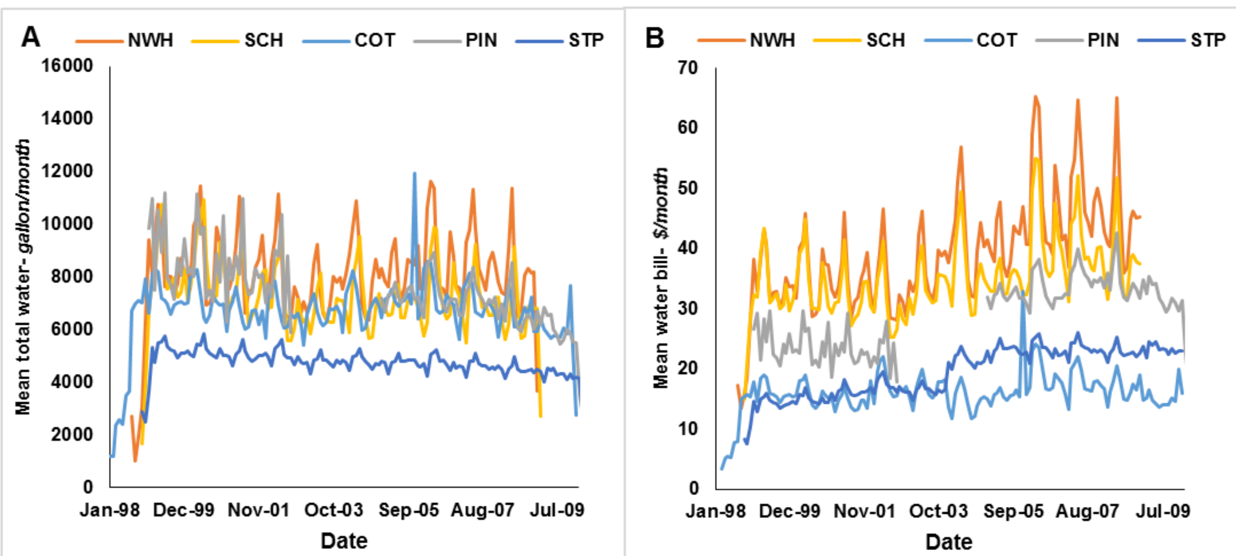

Figure 4-3. Historical water use and water bills. (A) Total (indoor and outdoor combined) volumetric monthly water demand and (B). Monthly water bill by utility throughout the study period.

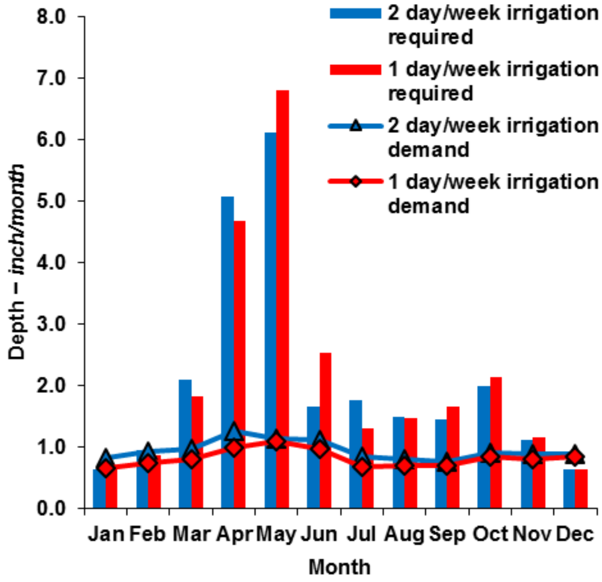

Figure 4-4. Irrigation demand and required under two day per week and one day per week restrictions for all customers. Irrigation demand is the estimated use based on the water billing data and irrigation required is the estimated water needed based on landscape and weather conditions.

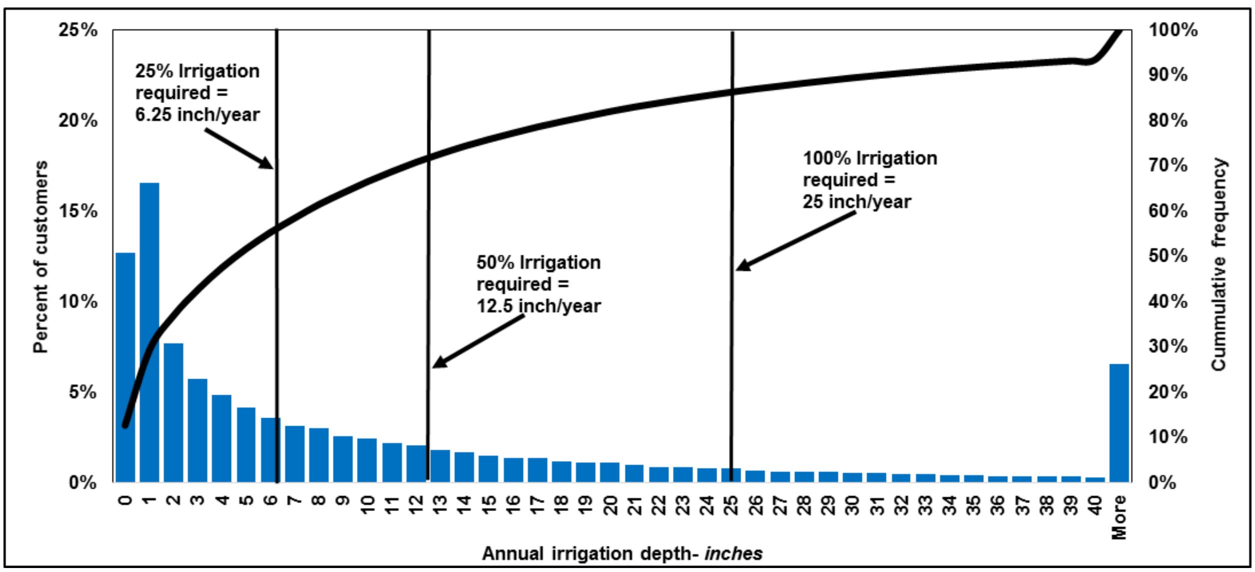

Figure 4-5. Distribution of annual irrigation demand of customers under two day per week allowable irrigation restrictions.

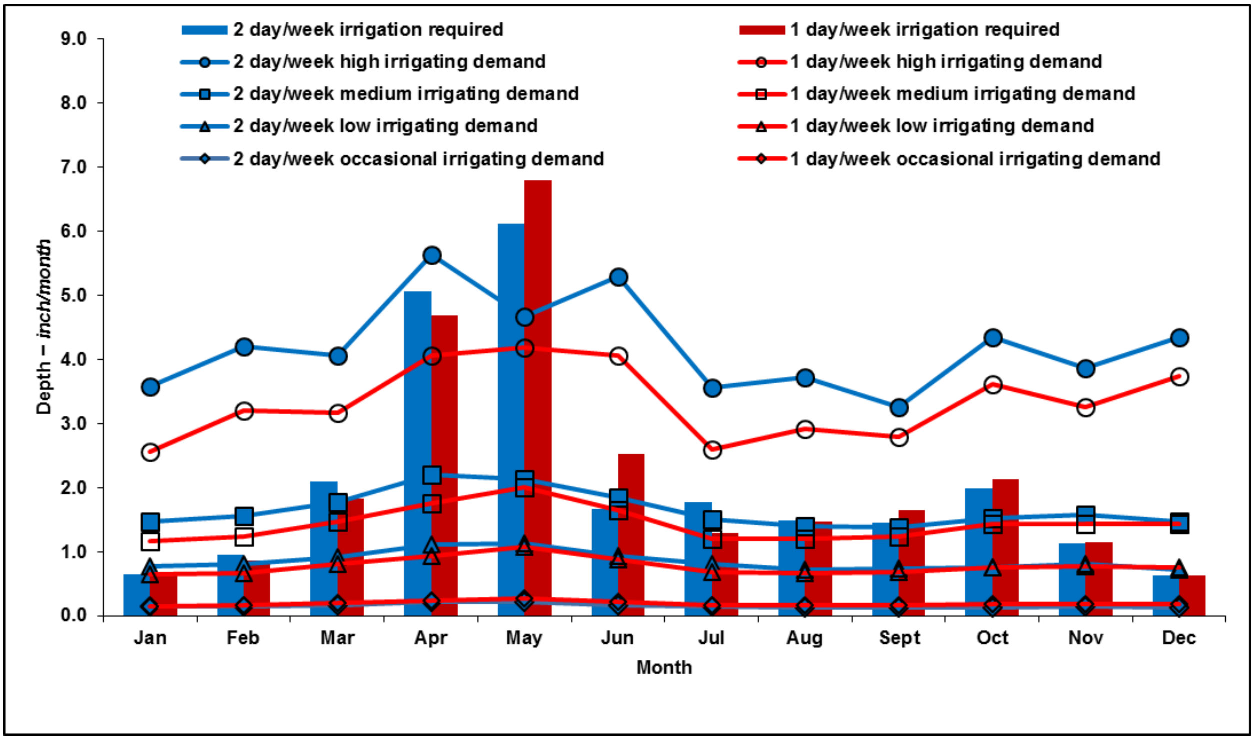

Figure 4-6. Mean monthly irrigation demand and required under two day per week and one day per week allowable irrigation for high, medium, low, and occasional irrigating groups.

Table 4-2. Change in irrigation depth for each utility by irrigating group (high, medium, low and occasional).

	Percent of customers of the utility in each group				2 day/week irrigation, inch/year				1 day/week irrigation, inch/year				Percent change in irrigation			
	High	Med	Low	Occ	High	Med	Low	Occ	High	Med	Low	Occ	High	Med	Low	Occ
NWH	18%	19%	17%	45%	43.6	19.0	9.7	2.1	39.5	18.7	10.2	2.7	-9%	-2%	6%	31%
SCH	13%	19%	16%	52%	39.6	18.0	9.2	1.8	30.4	15.2	8.5	2.1	-23%	-16%	-8%	19%
COT	16%	17%	16%	51%	47.3	18.8	9.5	1.8	37.6	16.9	9.3	2.6	-20%	-10%	-2%	46%
PIN	21%	17%	19%	42%	61.1	22.3	11.6	2.9	46.8	18.0	9.5	3.1	-24%	-20%	-18%	6%
STP	2%	7%	12%	78%	42.1	19.4	10.1	1.6	35.1	16.9	9.0	1.8	-17%	-13%	-11%	16%
Total	12%	14%	15%	59%	50.3	19.7	10.2	1.9	40.1	17.2	9.3	2.2	-20%	-13%	-9%	20%

Note: Decreasing irrigation is shown as negative values, and increasing irrigation is shown as positive values.

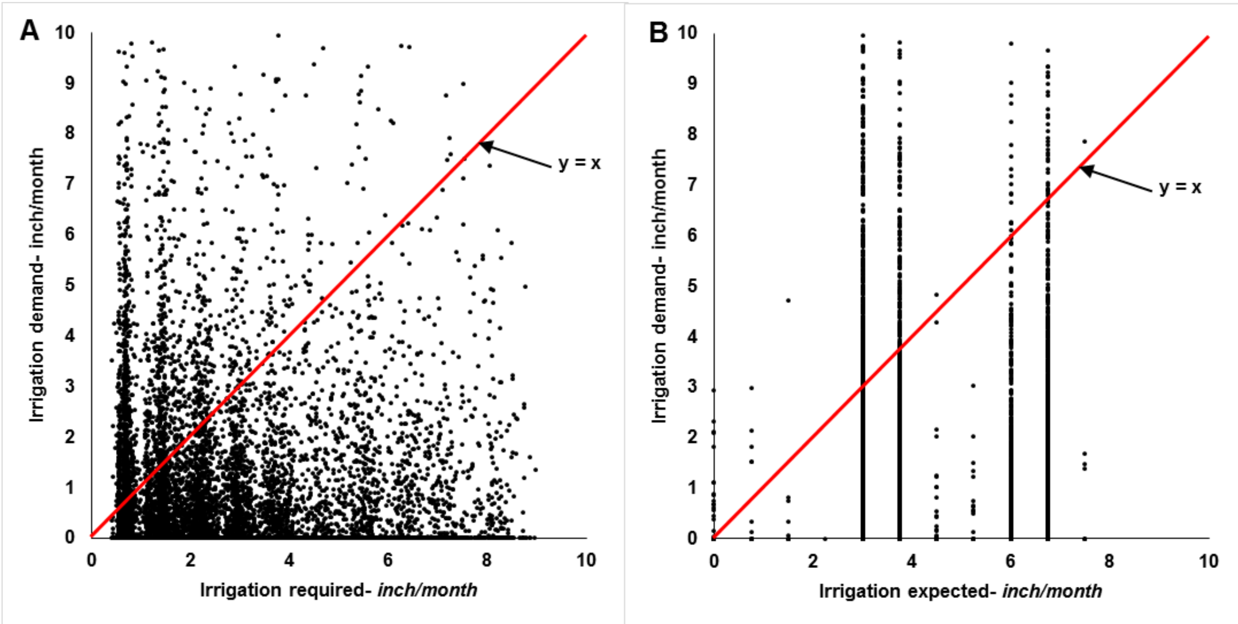

Figure 4-7. Response of irrigation demand to (A) irrigation required and (B) irrigation expected. Irrigation demand is the estimated use based on the water billing data, irrigation required is the estimated water needed based on landscape and weather conditions, and irrigation expected is based on the allowable number of irrigation events per month and an irrigation rate of 0.75 inches per month. Results are shown for a random subsample of 0.1% of all observations.

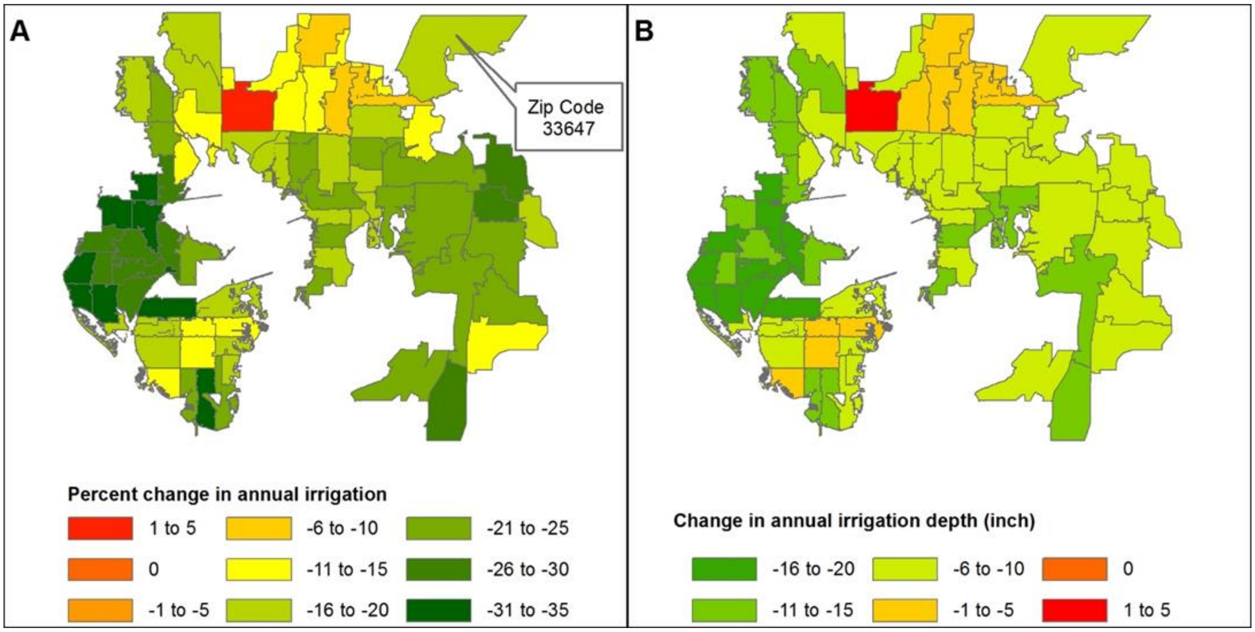

Figure 4-8. Response to more stringent water restrictions by zip code. (A) Percentage change and (B) difference in irrigation depth under 1 day per week restrictions as compared to two day per week restrictions by zip code for high irrigating group. Decreasing irrigation is shown as negative values, and increasing irrigation is shown as positive values.

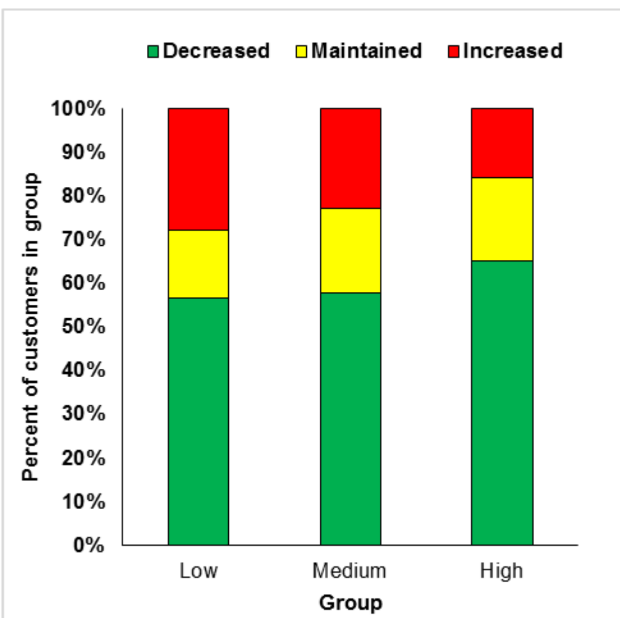

Figure 4-9. Percentage of customers that decreased, maintained, or increased irrigation when going from two day per week to one day per week allowable irrigation by group.

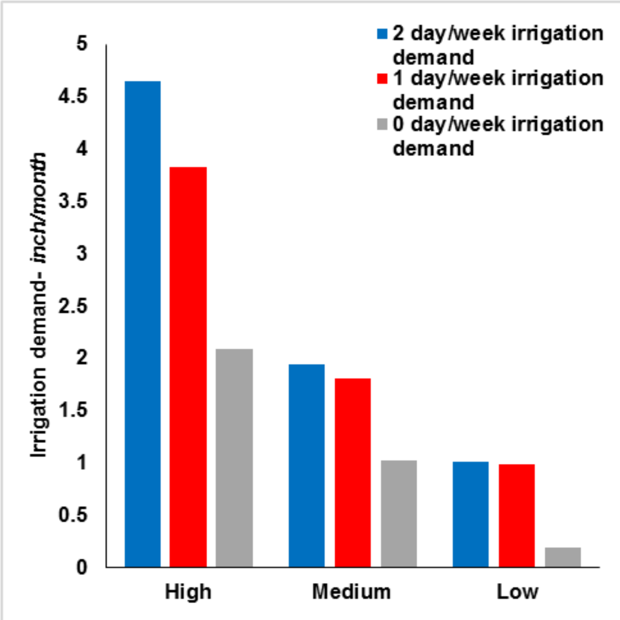

Figure 4-10. Mean monthly irrigation demand under two day per week, one day per week, and zero day per week in Tampa for high, medium, low, and occasional irrigating groups. Results are shown for April and May, the only months in which banned in-ground irrigation occurred.

CHAPTER 5
PREDICTING WATER SAVINGS: BASELINE IRRIGATION INFLUENCES CONSERVATION POTENTIAL IN FLORIDA

Chapter Abstract

Targeted implementation of conservation tools could decrease irrigation demand without impacting those who have historically used minimal irrigation. Historical monthly potable water billing records for single-family residential customers in Hillsborough County Utilities and Orange County Utilities, Florida were coupled with field studies of three conservation tools: soil moisture sensor controllers (SMS controllers), evapotranspiration controllers (ET controllers) and Florida-Friendly Landscaping (FFL). Customers who would benefit from the conservation tools were identified, and the utility-wide impact to irrigation demand was estimated. The majority of customers in both utilities were deficit irrigators, although a larger percentage of customers were classified as occasional irrigators in HCU. High irrigators were responsible for a disproportionate amount of volumetric irrigation: 23% of customers were responsible for 62% of irrigation in HCU and 46% of customers were responsible for 79% of irrigation in OCU.

For SMS controllers, predicated irrigation demand could be reduced to 57% and 82% of historical demand, for HCU and OCU, respectively. The impact of ET controllers would be minimal, with predicted irrigation demand at 97% and 91% of historical irrigation demand for HCU and OCU, respectively. The highest percentage of customers (40% in HCU and 66% in OCU) would benefit from FFL and the predicted irrigation demand would be lowest (48% of historical in HCU and 37% of historical in OCU). Understanding each customer’s historical irrigation demand and the limits of the conservation tools can help maximize potential irrigation conservation.

Chapter Introduction

Florida's rapidly growing population coupled with limited potable water sources has led to an increasing emphasis on water conservation. Florida is the third most populated state and ranks sixth in population growth (U.S. Census Bureau 2016). Approximately 2.3 billion gallons of fresh and saline water are withdrawn daily in order to meet the public supply water demand, accounting for 15% of all water withdrawals (Marella 2014). The state's commitment to water conservation is demonstrated by programs such as Florida Water Star and Florida-Friendly Landscaping. With 50% of single-family potable water use occurring outside the home (DeOreo et al. 2016), residential irrigation is a logical target for water conservation. As the interest and need for water conservation continues to grow, utilities must be able to make informed decisions regarding how to best use their limited conservation funds. Previous research in Florida has focused on two separate topics: the irrigation demand of potable water customers in southwest and central regions of the state and the irrigation conservation of three water saving tools in plot and field tests. This paper combines the previous research in order to predict the change in irrigation demand if all customers were to adopt the conservation tools.

The water conservation tools as defined for this paper are soil moisture sensor controllers (SMS controllers), evapotranspiration controllers (ET controllers) and Florida-Friendly Landscaping (FFL). Both SMS and ET controllers are smart technologies that adjust or override irrigation based on weather or soil conditions. Soil moisture sensor controllers bypass manually scheduled irrigation events when the measured soil moisture is greater than a user-specified threshold. Soil water balance evapotranspiration controllers typically use weather data (either historical or real-time) and user-selected program settings to describe the landscape characteristics (i.e., soil type, soil, sun exposure). The ET controller then determines the irrigation schedule instead of using manually selected days and runtimes. Both SMS and ET controllers are used in conjunction with automatic, in-ground sprinkler systems. The technologies differ in that, without user interference (e.g., a homeowner adjusting their irrigation settings), SMSs can only decrease irrigation whereas ET controllers can increase or decrease irrigation.

Florida-Friendly Landscapes are alternative landscapes that promote several environmental practices including using ornamental plants and turfgrass appropriately, fertilizing appropriately, attracting wildlife, and watering efficiently. Florida-Friendly Landscapes may have automatic, in-ground sprinkler systems or may not require irrigation. Rather than rely on a technology, potential water conservation is based on prescriptive means. The FFL program recommends watering only at signs of wilt, grouping plants with similar water needs, reducing irrigation in the summer and winter, and installing low-volume irrigation in ornamental plant beds. Although FFL is specific to Florida's hot, humid climate, the program has many similarities to Xeriscape, an alternative landscape promoted in arid climates. Additional landscape programs specific to other geographic regions include California Friendly Landscaping (Los Angeles Department of Water and Power, 2017), Louisiana Friendly Landscaping (LSU AgCenter Research and Extension, 2017), and Tennessee Smart Yards (University of Tennessee Institute of Agriculture, 2017).

Plot studies on SMS and ET controllers have been conducted at the University of Florida's main campus in north central Florida, the Gulf Coast Research and Education

Center in southwest Florida, and the tropical Research and Education Center in south Florida. The plot studies were all designed with multiple treatments (often equipment brands or different settings), replicates, and controls. The plots had automatic in-ground sprinkler systems and the irrigation to each plot was recorded using flowmeters. Summaries of plot studies are given in Table 5-1 (SMS controller plot studies) and Table 5-2 (ET controller plot studies). The reduction in irrigation ranged from 11% to 72% for SMS and -20% to 59% for ET controllers.

Three field studies evaluated the conservation potential of SMS and ET controllers. These field studies installed smart technologies in established homeowner landscapes that had well-maintained in-ground automatic sprinkler systems. One SMS study and one ET controller study were located in southwest Florida, and one study of both SMS and ET controllers was located in central Florida.

Soil moisture sensor controllers reduced the monthly irrigation demand and the frequency of irrigation events as compared to the control (monitor only) homes in southwest Florida. The study by Haley and Dukes (2016) collected irrigation data every 15 minutes for 26 months (July 2006-December 2008) for 58 homes under four treatments in Palm Harbor, Pinellas County. All homes had homeowner-programmed automatic in-ground irrigation systems. Study participants tended to have lower historical water demands than in central Florida. The irrigation required for each homeowner was calculated using site conditions and local weather data. The irrigation required estimated the amount of irrigation theoretically needed to maintain a well-watered landscape.

Treatments included: monitor only, rain sensor, SMS controller, and SMS controller with education and a rain sensor. The rain sensors were set to interrupt irrigation after 0.25 inches of rainfall. Treatments with SMS controllers used a sensor set at 10% volumetric water content threshold coupled with an existing irrigation timer. The SMS sensors were installed at a depth of 3 inches in the sunniest part of the yard (where irrigation demand would be highest). If the moisture content of the soil exceeded 10%, the SMS would send a signal to the controller to bypass the scheduled irrigation event. The SMS controller plus education and rain sensor included recommendations for irrigation run times and explained irrigation conservation.

The SMS controller treatment used 65% less irrigation than the monitored only treatment and had 62% less irrigation events per month. The monitored only homes used 49% more than the gross irrigation requirement whereas the SMS controller homes used 44% less than the gross irrigation requirement while still maintaining acceptable turfgrass quality. The rain sensor treatment performed similar to the monitor only treatment and the SMS controller plus education and rain sensor treatment performed similar to, but not as well as, the SMS controller treatment.

The ET controller study conducted in southwest Florida demonstrated the difficulty of evaluating conservation under field conditions where outside factors cannot be controlled. The study by Davis and Dukes (2014) collected sub-hourly irrigation data for 24 months (February 2009-January 2011) for 36 homes (21 with ET controllers and 15 control, or comparison, homes). All homes had automatic in-ground irrigation systems. Participants' mean historical irrigation demand was less than those reported in central Florida (Haley et al. 2007). The irrigation required for each homeowner was calculated using site conditions and local weather data.

There was a fundamental shift in irrigation demand for both the ET controller and comparison groups during the study period. Historical irrigation demand was estimated using water billing records as 28 inch/year (27.0 inch/year for ET controller and 29.3 inch/year for comparison), but mean irrigation measured during the study was 18.5 inch/year (18.3 inch/year for ET controller and 18.7 inch/year for comparison). Several possible explanations for the drastic reduction in irrigation demand were proposed: an economic decline that caused more efficient watering, well-publicized drought conditions in the surrounding area, or interaction of the homeowners with researchers.

There was no statistical difference in irrigation demand between the ET controller group and the comparison group. The ET group did, however, apply irrigation at 32% below the irrigation required and 29% below historical irrigation demand. However, because of the fundamental shift in irrigation demand by both groups, the results are not transferrable.

A field study of high irrigators in central Florida evaluated the effectiveness of SMS and ET controllers (Davis & Dukes 2015, Breder and Dukes 2014). Homes were served by Orange County Utilities and were recruited for participation based on their historical water use. In an attempt to identify irrigators with conservation potential, participants were identified that irrigated at least 50% above their irrigation requirement for at least three months per year for three consecutive years and had in-ground automatic irrigation systems. The study included four treatments and a control (monitor only). The first two treatments were SMS and ET controller groups installed by the irrigation contractor without the researcher’s input, and the last two groups included researchers programing the technologies to site-specific conditions and educating the homeowner. The study had a total of 167 participants (28 with SMS controller, 28 with ET controller, 38 with SMS and researcher input, 38 with ET controller and research input, and 35 monitor only). Site conditions and local weather data were used to calculate each homeowner’s irrigation requirement. Soil type (flatwooods [loamy sand] and sand) and seasonal period (wet or dry) were significant factors that impacted the irrigation demand results.

Smart technologies generally reduced irrigation as compared to the monitor only homes, with additional reductions from the researcher’s education and site-specific programming. The SMS controller homes as a whole were more consistent in their irrigation savings and were effective in both soil types as compared to the ET controller homes. Improving the response of the ET controllers to rainfall during the wet season would have increased irrigation savings. Overall, the two SMS controller treatments used 37% less irrigation than monitor only homes and the two ET controller treatments used 26% less irrigation than the monitor only homes.

The field study of FFLs was designed differently than the smart technology field studies previously discussed. Boyer et al. (2014) identified 125 single-family homes in southwest Florida (Hillsborough, Pasco, and Pinellas counties) with recognized FFLs. The monthly irrigation demand estimated from water billing records of these FFLs was compared to 736 traditionally landscaped neighbors. All sites were evaluated from the public right-of-way without interaction of the homeowner, and irrigation practices (including the presence of an in-ground sprinkler system) were unknown. When considering all FFLs and comparisons, the FFLs used 50% less irrigation. When considering high-quality FFLs and comparisons, the FFLs used 76% less irrigation.

The goal of this paper is to predict the effectiveness of three water conservation tools, soil moisture sensors, evapotranspiration controllers, and Florida-Friendly Landscapes, to reduce irrigation for single-family residential customers serviced by two Florida utilities. Historical irrigation of customers in the two utilities, Hillsborough County Utilities and Orange County Utilities, will be compared, customers classified into irrigating groups, and the effectiveness of the conservation tools for each customer will then be estimated.

Materials and Methods

Study Area and Data Collection

Hillsborough County Utilities (HCU) is located in southwest Florida and Orange County Utilities (OCU) is located in central Florida (Figure 5-1). Within HCU are two sub-areas, Northwest Hillsborough and South Central Hillsborough. Both utilities serve approximately 500,000 customers. Both Hillsborough and Orange counties contain a major city (Tampa and Orlando, respectively), but these are served by separate utilities and therefore not included in this study.

Monthly water billing data for single-family residential customers without access to reuse in HCU and OCU were provided by Tampa Bay Water (the water wholesaler for HCU) and OCU. The HCU records ranged from October 1998 to February 2009, and the OCU records ranged from January 2004 to June 2009. The HCU data was provided as .csv files and contained almost fifty variables including customer identification number, parcel identification number, total (indoor and outdoor combined) potable water use, month and year of water use, and estimated greenspace (landscape) area. The

OCU data was provided in a database with eight tables, each with multiple variables including service identification number, property identification number, total potable water use, month and year of water use, lot size, and living area. Customers in HCU and OCU that had access to reuse were excluded from the analysis.

Irrigation Demand and Required

Irrigation demand was estimated by subtracting estimated indoor water use from the total monthly water use of the billing data. Indoor water use was estimated using 69.3 gallons per capita per day (Mayer et al. 1999) and the estimated household size (number of people per house). For HCU, the block-level household sizes were obtained from the 2010 U.S. Census (2015) and were whole numbers. The household size for OCU was assumed to be a constant 2.25 persons per account (Davis and Dukes 2015). The resulting volumetric irrigation demand was divided by the estimated landscape area (greenspace variable for HCU and lot size variable minus living area variable for OCU).

The gross irrigation required was estimated using parcel, soil, and weather data in a daily soil moisture balance and represents the amount of supplemental irrigation that is theoretically required to maintain well-watered turfgrass. Daily weather data for HCU included rainfall and evapotranspiration on a 1.2 mi grid and was obtained from the Southwest Florida Water Management District and the U.S. Geological Survey (U.S. Geological Survey (2011, 2005). Soil types throughout the HCU service area were obtained from the Natural Resources Conservation Service (Soil Survey Staff 2013). Weather data for OCU was collected from the FAWN station at the Mid-Florida Research and Education Center in Apopka, Florida. All OCU soils were assumed to have a maximum soil water holding capacity of 9% and the permanent wilting point of the turfgrass was assumed to be 4% (Davis and Dukes 2014).

Landscapes were assumed to be 79% turfgrass and 21% ornamental plant beds (Haley & Dukes 2012), and ornamental plant beds were assumed to have an irrigation requirement of zero (Shober et al. 2009, Scheiber et al. 2008). Additional assumptions in the soil moisture balance were: 12- inch turfgrass root zone, maximum allowable water storage depletion of 50%, irrigation efficiency of 80%, and crop coefficients for warm season turfgrass used with the reference evapotranspiration that varied monthly (Jia et al. 2009). Daily soil moisture calculations were made for the overlapping study period (January 2004 to December 2008). Calculations were performed in SAS 9.4 (SAS Institute, Cary, NC), R 2.13.2 (www.r-project.org), ArcGIS 10 Desktop (Environmental Systems Research Institute, Redlands CA), and Excel 2013. All results are statistically significant ($p < 0.05$). Detailed irrigation demand and required calculations for HCU are outlined in Boyer et al. (2016) and Boyer et al. (2014).

Predicting Irrigation Demand of Customers Adopting Conservation Tools

Three of the previously discussed field studies were used to predict irrigation demand if all customers in each utility implemented FFL, SMS, or ET controllers (Figure 5-2). The field study of ET controllers in southwest Florida (Davis & Dukes 2014) was not used because the dramatic decrease in comparison homes' irrigation demand confounded the results of irrigation savings due to the ET controllers. Since only one FFL study and one ET controller study was available, the results were applied to both HCU and OCU. Since one SMS study in southwest Florida and one SMS study in OCU were available, the results of southwest Florida study was applied to HCU and the results of the OCU study was applied to OCU.

It was assumed that only customers whose mean annual irrigation demand exceeded that of the conservation tool (Table 5-3) would be eligible for implementing the tool. It would be impractical and/or unrealistic if, for example an occasional irrigator received an ET controller. The occasional irrigator most likely would not have a well-functioning in-ground irrigation system to use with the ET controller and, even if one existed or were installed, there would be a drastic increase in irrigation demand because of the ET controller. It was also assumed that customers who received a SMS would not make any changes to their existing irrigation setting.

The predicted change in irrigation demand was based on two components. First, irrigation demand with each conservation technology could not fall below a certain threshold given by the mean monthly irrigation demand observed in the previous field studies (shown as the grey lines in Figure 5-2). Second, the percentage change in irrigation demand could not exceed that observed in the field studies (calculated based on the difference between the black and grey lines in Figure 5-2. The minimum thresholds and maximum percent reductions are shown in Table 5-3. For SMS and ET controllers, both technologies work with in-ground automatic irrigation systems and it was therefore assumed that home with these smart controllers would have automatic irrigation systems as well.

Results and Discussion

Historical Water Demand

Total annual water demand was 94 thousand gallons per year (kgal/year) for HCU and 122 kgal/year for OCU. The lower demand in HCU was expected because the Tampa Bay region has historically experienced greater water shortages and therefore had an earlier focus on conservation. Demand for both utilities was higher than the North American average, which was also expected because irrigation can occur year-round in the warmer climate of Florida. In a study of billing data for 23 North American utilities, total annual water demand ranged from 44 to 175 kgal/year, with a mean of 88 kgal/year (DeOreo et al. 2016). The demand in HCU was most similar to Austin Water in Texas, the City of Chicago in Illinois, and the City of Santa Barbara in California. The demand in OCU was most similar to Denver Water in Colorado and Otay Water District in southern California.

For both utilities most customers under-irrigated rather than over irrigated, which is typical behavior within a utility (Mayer et al. 2016). However, HCU customers tended to irrigate less and OCU customers tended to irrigate more. The distribution of the annual irrigation ratio, where the ratio was calculated as the annual irrigation demand divided by the annual gross irrigation required, is shown in Figure 5-3. Customers were classified as high, medium, low, and occasional irrigators based on their mean annual irrigation ratio. High customers had a ratio greater than one, medium customers had a ratio between 0. 5 and 1, low customers had a ratio between 0.25 and 0.5, and occasional irrigators had a ratio less than 0.25. Customers with ratios greater than 10 were deemed outliers (possibly due to leaks or misclassification of building type) and were excluded from analysis. Analysis is based on 94,438 customers in HCU and 116,413 customers in OCU.

Mean monthly irrigation demand by group and utility, along with mean monthly irrigation required are shown in Figure 5-4. Mean annual irrigation required was 27.0 inch/year in HCU and 25.5 inch/year in OCU during the study period. Irrigation conservation while still maintaining well-watered turfgrass is possible where the irrigation demand exceeds the irrigation required. For the occasional and low irrigators, all mean monthly demands fall below the mean requirements, indicating that additional conservation would be minimal. The medium irrigators only exceed the mean irrigation required in the winter (January, February, and December in HCU and December only in OCU; Fig. 5-5). The high irrigating group has the most potential for conservation, with demands that exceeded requirements for all months except for the late spring and early summer (April, May, and June for HCU and April and May for OCU; Fig. 5-5) when plant water needs are high but rainfall is low. Figure 5-4 is of particular interest when considering ET controllers because the technology aims to match irrigation demand to required (although results from Breder & Dukes [2014] indicated that demand consistently exceeded required when ET controllers were used). It is clear that ET controllers would substantially increase irrigation demand for the majority of customers in HCU and OCU.

Predicted Irrigation Demand with Conservation Tools

Table 5-4 shows the potential impact of implementation of the three conservation tools for high, medium, low, and occasional irrigators in HCU and OCU. The table includes the percent of customers within the group that would be eligible for the conservation tool, the predicted irrigation demand with the tool, and the predicated irrigation demand savings. Because customers were grouped based on their mean annual irrigation ratio but deemed eligible for a conservation tool based on their annual irrigation as a depth, it is possible for a customer in a lower group to qualify for a conservation tool even though all customers in higher groups did not qualify. For example, 69% of medium irrigators and 4% of low irrigators would benefit from SMS controllers.

The composition of annual volumetric irrigation demand and the impact of utility-wide implementation of conservation technologies are shown in Figure 5-6. As was shown in Figure 5-4, occasional irrigators represent 49% of customers in HCU and 23% of customers in OCU, and high irrigators represent 23% of customers in HCU and 46% of customers in OCU. Volumetrically, the occasional irrigators are responsible for 8% of the demand in HCU and 3% in OCU, whereas high irrigators are responsible for 62% and 79% of the demand in HCU and OCU (Figure 5-6). With the implementation of the conservation tools by targeted customers, the utility-wide irrigation demand has the potential to decrease. Providing SMS controllers to a targeted 34% of customers in HCU and 26% of customers in OCU would reduce predicated irrigation demand to 57% and 82% of historical demand, respectively. The impact of ET controllers would be minimal, with predicted irrigation demand at 97% and 91% of historical irrigation demand for HCU and OCU, respectively. The highest percentage of customers (40% in HCU and 66% in OCU) would benefit from FFL and the predicted irrigation demand would be lowest (48% of historical in HCU and 37% of historical in OCU). Although this may indicate FFL to be the "best" conservation tool, factors such as the cost and knowledge to implement and maintain the conservation tool that are not discussed in this paper would impact practicality.

There are limitations related to the field studies' participants and the utility-wide monthly billing records for HCU and OCU. There is little research on how a broad range of customers (not just high irrigators) would change their behavior when adopting a conservation tool. The SMS and ET controller field studies used in this analysis both selected participants that regularly used their in-ground irrigation systems, had good quality turfgrass, and passed an irrigation system evaluation. However, the presence or condition of in-ground systems for each customer in HCU and OCU is unknown.

Previous studies have shown that customers' reactions to water conservation measures are not always as expected. Water restrictions are designed to reduce residential irrigation by limiting irrigation to certain days (but not requiring irrigation on those days). Although utility-wide irrigation demand has been shown to decrease under more stringent restrictions in southwest Florida, there can still be considerable variation in individual customers' responses to the restrictions. Generally, customers that were historically high irrigators reduce their irrigation demand, while customers that were historically occasional irrigators increased their irrigation demand (Boyer et al. in preparation). A similar trend in behavior was also observed in North Carolina (Boyle et al. 2011). In the southwest Florida ET controller study (Davis & Dukes 2014), study results were clouded by the unexpected behavior of the comparison homes: without any study intervention, comparison homes reduced their irrigation by 36%. Outside factors such as those observed by Davis & Dukes (2014) could also impact utility-wide implementation of a water conservation tool. The analysis presented in this paper provide a first-step approximation of predicted irrigation demand.

Chapter Conclusions

Although irrigation demand in HCU and OCU is higher than many other parts of North America due a climate that allows for landscapes to grow year-round, the majority of customers irrigate below the theoretical irrigation requirements of their landscapes. Because of this, additional irrigation conservation measures must be considered carefully. Targeted implementation of conservation tools such as FFL, SMS controllers, and ET controllers could decrease irrigation demand for the targeted customers without impacting those who have historically used minimal irrigation. Understanding each customer’s historical irrigation demand and the limits of the conservation tools can help maximize potential irrigation reductions.

Table 5-1. Soil moisture sensor controller (SMS) plot studies.

Publication	Turfgrass type	Location	Water savings (%)	Technology tested	Comments
Cardenas-Lailhacar et al. 2008	Bermuda	North central FL	72	Acclima Digital TDT RS-500; Watermark 200SS-5; Rain Bird MS-100; Water Watcher DPS-100	Normal rainfall conditions
McCready et al. 2009	St. Augustine	North central FL	11 to 53	LawnLogic LL1004; Acclima Digital TDT RS500	Drought conditions with extended dry periods
Cardenas-Lailhacar et al. 2010	Bermuda	North central FL	34	Acclima Digital TDT RS-500; Watermark 200SS-5; Rain Bird MS-100; Water Watcher DPS-100	Drought conditions with extended dry periods
Cardenas-Lailhacar et al. 2010	Bermuda	North central FL	54	Acclima Digital TDT RS-500; Watermark 200SS-5; Rain Bird MS-100; Water Watcher DPS-101	Normal rainfall conditions
Dobbs et al. 2013	Bahia	South Florida	64-73	Baseline WaterTec S100	Wet weather conditions
Cardenas-Lailhacar et al. 2016	St. Augustine	North central FL	63	Acclima Digital TDT RS-500; AquaSpy SMS-100; Baseline BiSensor; Dynamax SM200	Potable water
Cardenas-Lailhacar et al. 2016	St. Augustine	North central FL	55	Acclima Digital TDT RS-500; AquaSpy SMS-100; Baseline BiSensor; Dynamax SM200	Reclaimed water, dryer than potable water study

Table 5-2. Evapotranspiration (ET) controller plot studies.

Publication	Turfgrass type	Location	Water savings (%)	Technology tested	Comments
Davis et al. 2009	St. Augustine	Southwest FL	43	Toro Intelli-Sense; Etwater Smart Controller 100; Weathermatic SL 1600	Dry weather conditions
Rutland and Dukes 2012	St. Augustine	Southwest FL	25 to 41	Toro Intelli-Sense	Larger savings using rain sensor and rain pause
Dobbs et al. 2013	Bahia	South Florida	66 to 79	Rain Bird ESP-SMT	Wet weather conditions
McCready et al. 2009	St. Augustine	North central FL	-20 to 59	Toro Intelli-Sense; Rain Bird ET Manager	Drought conditions with extended dry periods

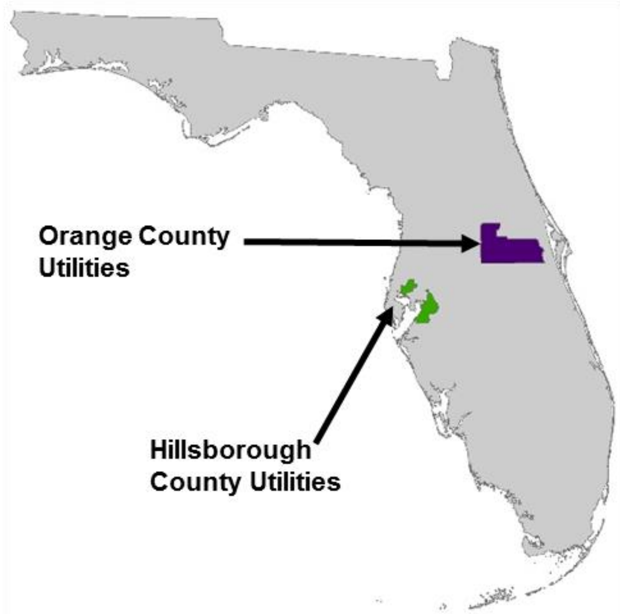

Figure 5-1. Locations of Hillsborough County Utilities and Orange County Utilities.

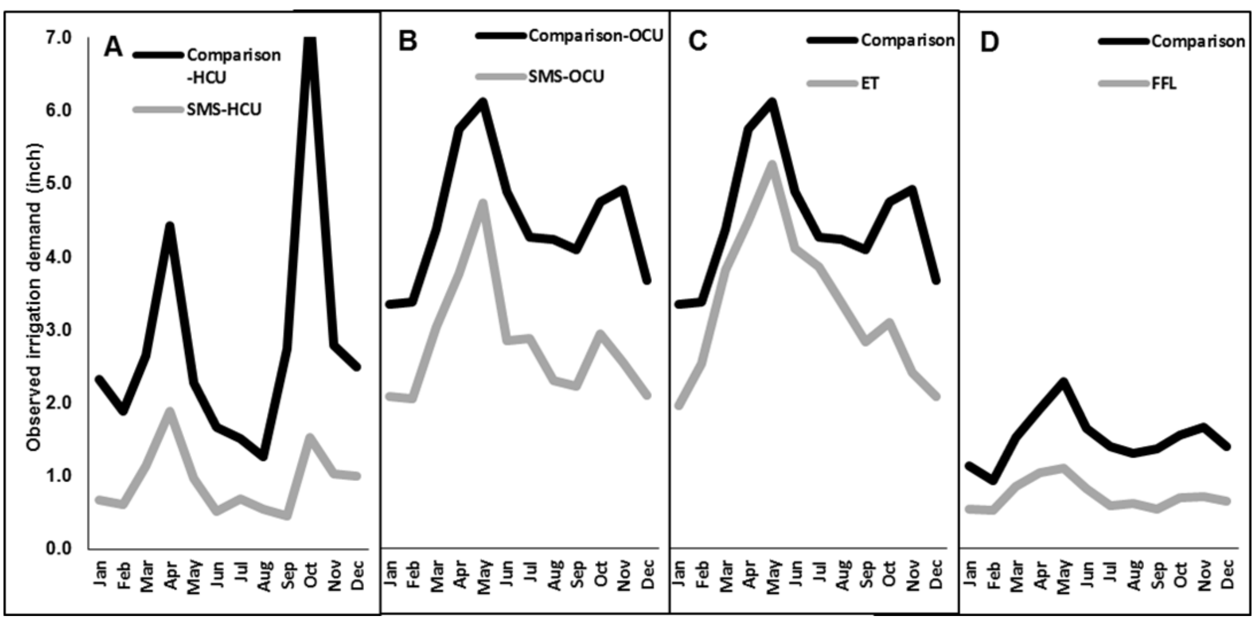

Figure 5-2. Summary of monthly irrigation demand results for comparison homes and homes with conservation tools. Results are shown for (A) Soil Moisture Sensor Controllers in Hillsborough County (Haley & Dukes 2012), (B) Soil Moisture Sensor Controllers in Orange County Utilities (Breder & Dukes 2014), (C) ET Controllers (Breder & Dukes 2014), and (D) Florida-Friendly Landscaping (Boyer et al. 2014),.

Table 5-3. Minimum thresholds and maximum percent reductions of the conservation tools.

	Minimum Threshold (inch)				Maximum Percent Reduction			
Month	SMS-HCU	SMS-OCU	ET	FFL	SMS-HCU	SMS-OCU	ET	FFL
Jan	0.7	2.1	2.0	0.5	71%	38%	41%	41%
Feb	0.6	2.1	2.5	0.5	68%	39%	25%	25%
Mar	1.1	3.0	3.8	0.9	57%	31%	13%	13%
Apr	1.9	3.8	4.5	1.0	57%	34%	22%	22%
May	1.0	4.7	5.3	1.1	58%	23%	14%	14%
Jun	0.5	2.9	4.1	0.8	69%	42%	16%	16%
Jul	0.7	2.9	3.9	0.6	55%	32%	9%	9%
Aug	0.6	2.3	3.4	0.6	56%	46%	21%	21%
Sep	0.5	2.2	2.8	0.5	83%	46%	31%	31%
Oct	1.5	2.9	3.1	0.7	79%	38%	35%	35%
Nov	1.0	2.5	2.4	0.7	63%	48%	51%	51%
Dec	1.0	2.1	2.1	0.6	60%	43%	43%	43%
TOTAL	11.0	33.5	39.8	8.7				
AVERAGE	0.9	2.8	3.3	0.7	65%	38%	27%	76%

Note: (Florida-Friendly Landscaping, Soil Moisture Sensors in Hillsborough County Utilities, Soil Moisture Sensors in Orange County Utilities, and ET Controllers).

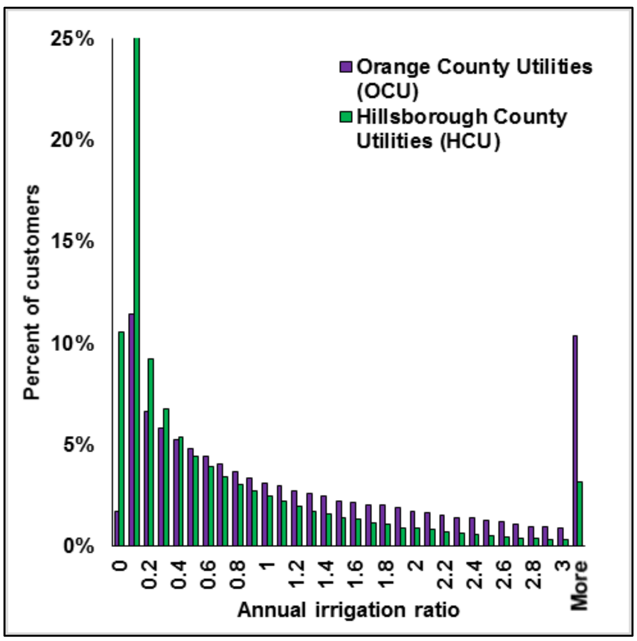

Figure 5-3. Distribution of annual irrigation ratio (irrigation demand/gross irrigation required) of customers.

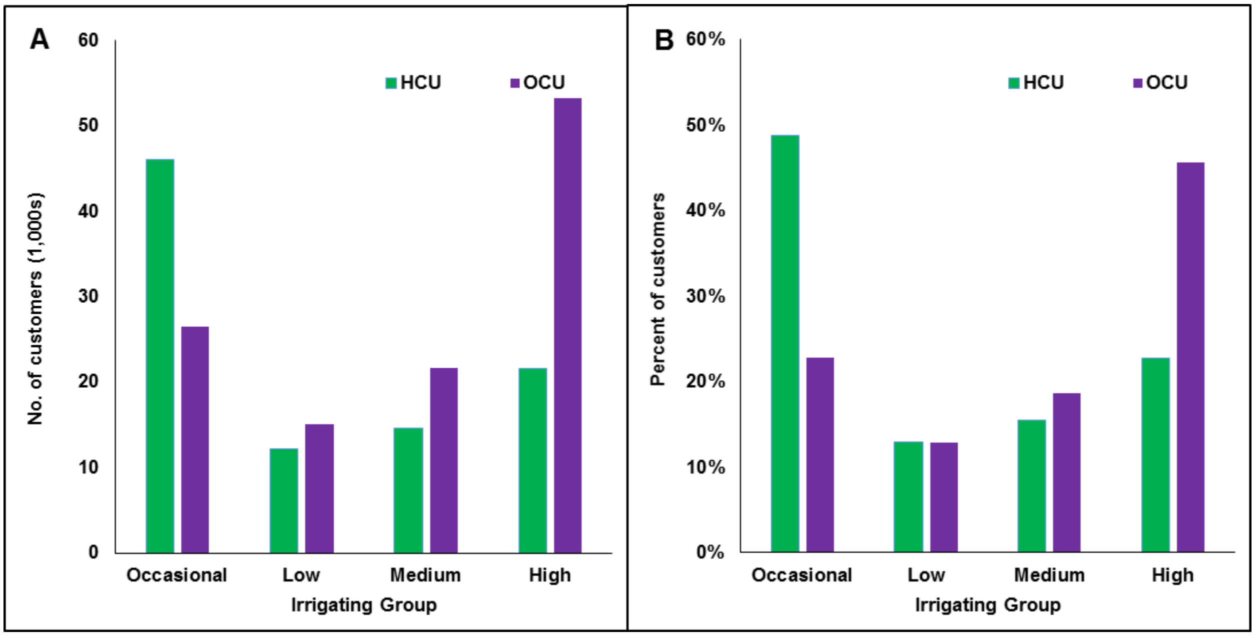

Figure 5-4. Number of customers (A) and percent of customers (B) in each irrigating group for Hillsborough County Utilities and Orange County Utilities.

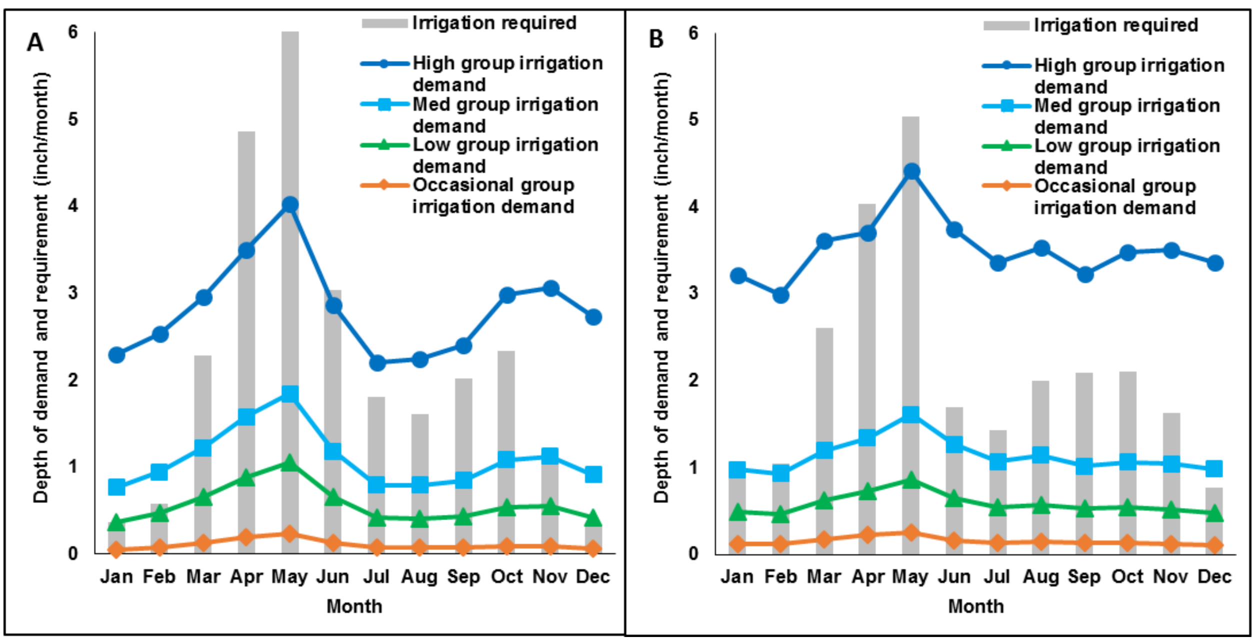

Figure 5-5. Mean monthly irrigation demand and required for high, medium, low, and occasional irrigating groups in (A) Hillsborough County Utilities and (B) Orange County Utilities.

Table 5-4. Predicted irrigation demand and savings of customers who could benefit from conservation tools.

Utility	Conservation Tool	Irrigating Group	% of Group to Adopt Conservation Tool	Predicted Demand (gallon/year/customer)	Predicted Savings (gallon/year/customer)
HCU	SMS	High	100%	45,577	59,295
		Medium	69%	37,660	19,338
		Low	4%	25,864	16,724
		Occasional	0%	12,072	12,812
	ET	High	12%	130,606	23,155
		Medium	0%	-	-
		Low	0%	-	-
		Occasional	0%	-	-
	FFL	High	100%	31,676	73,101
		Medium	91%	30,593	22,226
		Low	17%	26,116	14,136
		Occasional	0%	15,150	18,699
OCU	SMS	High	57%	115,654	51,687
		Medium	0%	-	-
		Low	0%	-	-
		Occasional	0%	-	-
	ET	High	44%	147,570	33,359
		Medium	0%	-	-
		Low	0%	-	-
		Occasional	0%	-	-
	FFL	High	100%	36,036	96,131
		Medium	96%	29,619	21,093
		Low	17%	26,788	10,919
		Occasional	0%	-	-

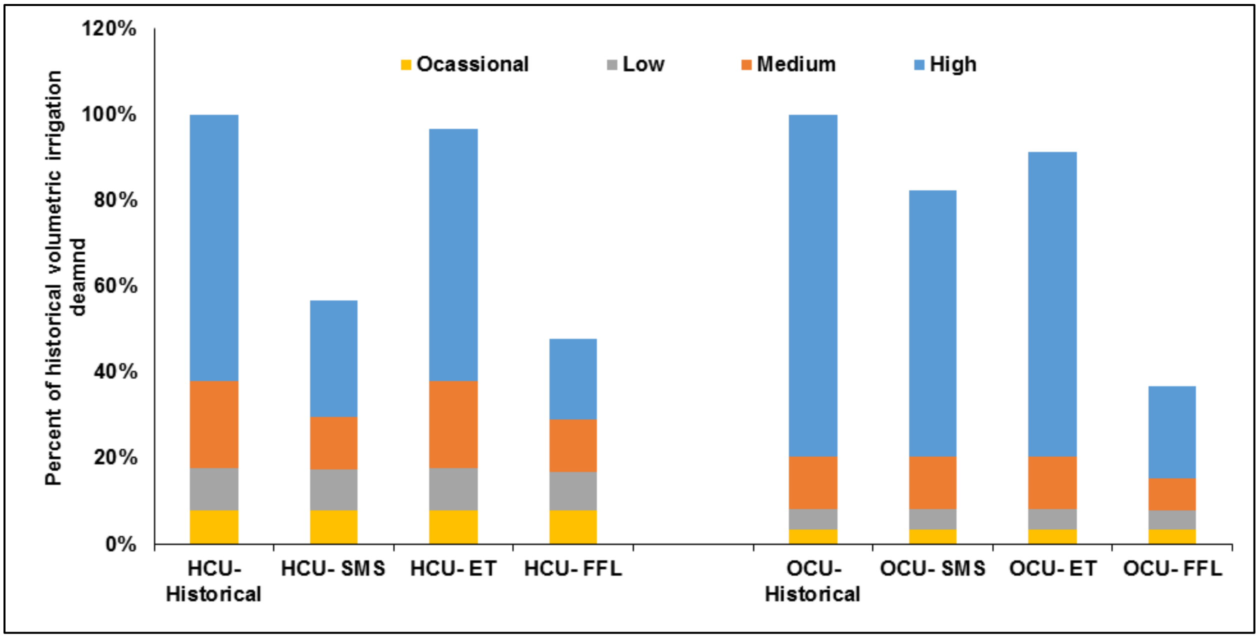

Figure 5-6. Composition of volumetric irrigation demand in Hillsborough County Utilities and Orange County Utilities by irrigating group and the impact of utility-wide implementation of conservation technologies (Soil Moisture Sensor Controllers, ET Controllers, and Florida-Friendly Landscaping).

CHAPTER 6
CONCLUSIONS

The historical irrigation demand of single-family residential potable water customers without access to reuse in southwest and central Florida was estimated using approximately twelve years of monthly water billing records for customers in seven member-government service areas of Tampa Bay Water and in Orange County Utilities. The majority of customers under-irrigated as compared to the estimated gross irrigation required. Sixty-seven percent of customers irrigated less than 1 inch/month and 84% used less than GIR. Mapping irrigation behavior provided a spatial depiction of irrigation demand and could be used to target particular conservation initiatives to particular areas.

The methodology outlined to stratify customers into irrigating groups is reproducible by utilities that maintain monthly billing records and have access to parcel records. Linking volumetric water use to parcel characteristics is key to developing irrigation demand estimates in units of depth (thereby making demand easier to compare across varying landscape areas) and developing irrigation requirements using site-specific weather and soil data. As utilities increase their understanding of customers' current irrigation behavior through analysis of water billing records, the most effective conservation measures can be selected and water conservation can be maximized.

The observed impact of two conservation strategies, Florida-Friendly Landscaping and irrigation water restrictions, were estimated using the monthly billing records coupled with FFL recognition lists and water restriction ordinances. FFL can result in a substantial irrigation savings for single-family residential customers irrigating with potable water as compared to their traditionally landscaped neighbors. Irrigation savings when considering all FFL-recognized homes was 50%, and irrigation savings when considering high quality FFLs and comparison homes was 76%. Prior to recognition, FFL customers were already using less irrigation than their neighbors, indicating that those most concerned with water use were the ones that adopted FFL practices.

Long-term water restrictions that reduced allowable irrigation from two days to one day per week were successful in reducing irrigation demand. Annual irrigation demand decreased 13% (from 11.3 to 9.8 inch/year), while annual irrigation required increased 3% (from 25.0 to 25.7 inch/year) under the more stringent restrictions. High irrigators, defined as having annual irrigation demand that exceeded the irrigation required, reduced their irrigation demand 20% under the more stringent conditions, indicating that those who irrigated most had the most potential for conservation.

Predicted irrigation changes in Hillsborough County Utilities and Orange County Utilities were estimated using the monthly billing records coupled with field studies of three water conservation tools: FFL, soil moisture sensor controllers, and evapotranspiration controllers. The majority of customers in both utilities irrigate below the GIR of their landscapes. Because of this, additional irrigation conservation measures must be considered carefully. Utility-wide implementation of conservation tools such as FFL, SMS, and ET controllers could have the unintended consequence of increasing irrigation demand for those customers who have historically used minimal irrigation. Targeted implementation of conservation tools such as FFL, SMS, and ET controllers could decrease irrigation demand for the targeted customers without impacting those who have historically used minimal irrigation. Understanding each customer’s historical irrigation demand and the limits of the conservation tools can help maximize potential irrigation reductions.

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BIOGRAPHICAL SKETCH

Mackenzie Boyer began her academic career at Carnegie Mellon University, where she received a Bachelor of Science in civil engineering with a minor in environmental engineering in 2002. Her interest in water issues were solidified by internships with the Metropolitan District Commission in Hartford, Connecticut and the Indian Health Services on the Tohono O’odam Nation’s tribal lands in southern Arizona. She continued her studies at the University of North Carolina at Chapel Hill and received a Master of Science in environmental engineering in 2004. Ms. Boyer then worked in water and wastewater treatment design for Black & Veatch in Cary, North Carolina from 2004-2008 and CH2MHill in Gainesville, Florida from 2008-2010. She joined the Department of Agricultural and Biological Engineering as a graduate student in 2010 and is receiving her Doctor of Philosophy degree in 2017. Ms. Boyer is registered Professional Engineer in North Carolina and Florida.