UTILITY REVENUE AND WATER DEMAND CHANGES RESULTING FROM RATE MODIFICATION

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2015
To my family and friends for their patience and support.
ACKNOWLEDGMENTS

Making the decision to return to graduate school after years of working to pursue a doctorate was a difficult decision. I am grateful to Dr. James Heaney for providing direction in that process and for accepting me as a doctoral student. During my graduate experience he has provided guidance and mentoring that were critical to my success and I am grateful for his time and energy. I also thank Dr. Michael Annable, Dr. Michael Dukes, and Dr. John Sansalone for their time and advice as part of my committee. Completing my research would have been nearly impossible without the help, assistance, and expertise of my peers and friends: Kenneth Friedman, Miguel Morales, Kristen Riley, and Randall Switt. I am also very grateful to the United States Geological Survey and the University of Florida – Environmental Engineering Sciences Department for providing funding for my research.

The data used in my research was a critical part of pursuing my degree and would not have been possible without the assistance of Gainesville Regional Utilities (special thanks to Richard Hutton, Diana Powers, and Julian Weschler).

Finally, I would like to thank my family and friends who have provided immensely valuable advice and support during this long process and it has helped me reach this point.

Words cannot begin to express the gratitude, respect, and love I feel for my wife, Erica. Without her I certainly would not have been able to pursue this degree. Maddy, Henry, and George, I love you and look forward to spending more time with all of you. Thank you for your patience while Daddy was in school.
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With increasing frequency utilities are being required to reduce water withdrawals while maintaining fiscal health. This research focuses on using water rates for residential irrigation to manage water demand. Three specific areas of residential irrigation were evaluated: maximum water use with “free” reclaimed water, the impact of a small commodity charge, and customer responses to increasing water rates.

Data sets for two groups of customers in Gainesville, Florida, reclaimed water customers and potable dual meter customers, were evaluated. Maximum water use was calculated for a group of 510 reclaimed customers that received flat-rate water (no charge based on the amount used) for one year, but had their use metered. These customers applied 328% of the estimated landscape requirement on average, and nearly 500% of the amount of water applied by potable water customers who paid typical rates. Additionally, 95% of these customers applied in excess of the landscape requirements. A method was presented to allow utilities to estimate water demand for customers who receive flat-rate reclaimed water.

Extending the analysis from the single year of flat-rate water demand to a seven year period for the same reclaimed water customers, the change in use resulting from a modest commodity charge ($0.60-$0.65/kgal) was evaluated. This analysis found that customers reduced
use by 47% and improved irrigation efficiency by 12% and that extreme use was largely
 discontinued. This analysis also showed that customers with smaller irrigable areas tended to
over-apply to a greater extent. Customers were not observed to rebound to higher use, but
between 14% and 27% of users increased their use in each of the post-rate years.

By incorporating potable dual meter customers with higher water rates, a model was
developed to estimate the irrigation behavior of customers based on their average water rate.
This showed that where reclaimed customers applied 200-300% of the landscape requirement,
customers with higher water rates applied only 82%. By fitting a function to the irrigation
behavior of the customer and the average water price an elasticity of -0.495 was calculated. This
would indicate that utilities could predictably manage customer irrigation demand by altering
rate structures.
CHAPTER 1
INTRODUCTION

Water supplies in many areas of the country are stressed due to human uses, changes in the climate, and modifications to the natural environment. In the face of increasing water scarcity and uncertainty, methods of managing water demands are being evaluated to alleviate stresses on municipal water supplies. Management strategies have been put in place around the country, but are especially prevalent in the southwestern United States. Some of the most aggressive outdoor water use incentives have occurred in the arid west and include increasing block rates, irrigation audits, rain sensors, smart irrigation controllers, coupons for smart car washes, xeriscaping, and turf buyback programs (Aurora Water 2014, Southern Nevada Water Authority 2014). One of the primary water demands in many urban and suburban areas is for irrigating single-family residential landscapes (Mayer et al. 1998, Richards et al. 2008, Mayer and DeOreo 2010, Tiger et al. 2011, Friedman et al. 2013). Recently, Mayer et al. (2015) completed an extensive synthesis of published research on outdoor water demand. This review found that work is needed to standardize methods used in the conservation field to assess demand and savings. Additionally, most of the outdoor demand management field is under-studied including savings from landscaping, water rates, drought restrictions, training programs, audits, and regional variability. There was also a need identified to better understand the human interaction of outdoor water demand and the effect of climate.

It is anticipated in many of the global circulation models that climate change may exacerbate water stress in areas of the United States. Roy et al. (2012) and Brown et al. (2013) separately estimated changes in water availability and water demand resulting from changes in population and climate and found that water availability with a changing climate is expected to worsen as shown in Figure 1-1.
Florida is viewed by many as a water rich state surrounded on three sides by the ocean and receiving plentiful rainfall. However, burgeoning populations, agricultural water use, and historic water management decisions have caused high quality aquifer water supplies to shrink, damaging ecosystems and threatening water supplies throughout the state. This vulnerability and stress was identified in both the work of Roy et al. (2012) and Brown et al. (2013) who predicted increased vulnerability of water supplies resulting from climate change. In this context, the state’s five Water Management Districts (WMDs) have begun to evaluate methods of ensuring future water supplies for people and the environment. These efforts have included consumptive use permitting, irrigation restrictions, studies of minimum flows and levels (MFLs) for water bodies, best management practices (BMPs), and funding of water conservation studies. As a result of the increased prevalence of automated irrigation systems (Friedman et al. 2013) per capita water use could increase, despite efforts to conserve water. To counteract the potential for increasing outdoor water demands, many recent studies have focused on water-saving measures for irrigation. These studies have included evaluations of rainfall sensors (Cardenas-Lailhacar and Dukes 2008, Meeks et al. 2012a, Meeks et al. 2012b), determination of theoretical water needs (Romero and Dukes 2011, 2013), installation of reclaimed systems for irrigation (Okun 1997), outdoor water conservation models (Friedman et al. 2013), and other topics including water-efficient landscaping (Dukes et al. 2008).

One method of reducing the need for new potable water use for irrigation has been to treat wastewater to a high-level for reclaimed water irrigation. Florida led the United States in reclaimed quantities for 2006 with 663 million gallons per day (mgd) representing 50.9% of the total for the eight leading states as shown in Table 1-1. California accounts for 44.5% of the total reclaimed use for these eight states and the other six states account for the remaining 4.6%.
The purpose of this research is to develop a water demand management methodology to better manage municipal irrigation demand through pricing. Specifically, this research focuses on how metering and commodity charges affect outdoor water demand. The use of flat-rate reclaimed water is the initial focus of this research using high-quality parcel-level data. This bottom-up approach has been used successfully to evaluate indoor water conservation potential (Morales et al. 2013), outdoor water conservation potential (Friedman et al. 2013, 2014) and commercial, industrial, and institutional (CII) water use (Morales et al. 2011, 2013) and provides insight into the nature of the demand and how it varies among customers. A key benefit of parcel-level data is the ability to analyze the variability of inputs (e.g. irrigable area) and responses to more accurately predict the outcome of pricing strategies across the range of reactions. This can in turn provide better guidance to the utility when making decisions about conservation or rate-making options. The next chapter discusses literature relevant to this research including: outdoor water demand, benchmark irrigation, irrigable area, price elasticity, and reclaimed water demand. The subsequent chapter discusses the data sets, data cleaning, and methods applied. The next three chapters cover the three primary research foci: maximum average water demand for residential irrigation in the absence of a commodity charge, the impact of a small commodity charge on demand, and finally a water demand price relationship to predict water demand based on typical potable water rates. The summary, conclusions, and recommendations for future work are presented in the final chapter.
Figure 1-1. Water supply sustainability risk index (left) and water stress with climate change in the United States (right) (Roy et al. 2012, Brown et al. 2013)

Table 1-1. Reclaimed water use in 2006 for the top eight states (adapted from Florida Department of Environmental Protection 2014)

<table>
<thead>
<tr>
<th>State</th>
<th>2006 Pop. (Million)</th>
<th>Recl. Use (MGD)</th>
<th>Recl. Use (GPCD)</th>
<th>Rank</th>
<th>% of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Florida</td>
<td>18.0</td>
<td>663</td>
<td>36.8</td>
<td>1</td>
<td>50.9%</td>
</tr>
<tr>
<td>California</td>
<td>36.1</td>
<td>580</td>
<td>16.1</td>
<td>2</td>
<td>44.5%</td>
</tr>
<tr>
<td>Virginia</td>
<td>7.6</td>
<td>11.2</td>
<td>1.5</td>
<td>3</td>
<td>0.9%</td>
</tr>
<tr>
<td>Texas</td>
<td>23.4</td>
<td>31.4</td>
<td>1.3</td>
<td>4</td>
<td>2.4%</td>
</tr>
<tr>
<td>Arizona</td>
<td>6.2</td>
<td>8.2</td>
<td>1.3</td>
<td>5</td>
<td>0.6%</td>
</tr>
<tr>
<td>Colorado</td>
<td>4.8</td>
<td>5.2</td>
<td>1.1</td>
<td>6</td>
<td>0.4%</td>
</tr>
<tr>
<td>Nevada</td>
<td>2.5</td>
<td>2.6</td>
<td>1.0</td>
<td>7</td>
<td>0.2%</td>
</tr>
<tr>
<td>Idaho</td>
<td>1.5</td>
<td>0.7</td>
<td>0.5</td>
<td>8</td>
<td>0.1%</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>1,302</td>
<td></td>
<td></td>
<td>100%</td>
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CHAPTER 2
LITERATURE REVIEW

Urban residential water demand has been studied extensively since at least the 1960s. More recently, Mayer et al. (1999) conducted a nationwide study of residential water use using a database of 1,200 single family residences in 12 cities across North America. Each home was monitored using 10 second data that allowed the investigators to separate individual water use events (DeOreo, Heaney, and Mayer 1996). This was the largest national study since the 1961-66 national study by Linaweaver et al. (1966) who collected 15-minute data from master meters for 41 residential areas across the United States. Research on the residential uses of water by Mayer et al. (1999) found that the indoor portion of this water use was relatively consistent nationwide (average of 69.3 gallon per capita per day [gpcd] with a range of 26.4 gpcd). However, outdoor water use, which can and often does exceed indoor water use (11-302% of indoor use), tends to be far more variable (Mayer et al. 1999, Haley et al. 2007, Tiger et al. 2011, Friedman et al. 2013). For some utilities, a portion of this demand is being met by treating wastewater to a high level and delivering reclaimed water to a portion of their customers through a separate pipe network for non-potable irrigation. Volo et al. (2015) found that municipal irrigation guidelines may overestimate plant requirements. Benchmark irrigation models as presented by Dukes (2007), Romero and Dukes (2013), and Volo et al. (2015) provide methods to determine appropriate irrigation requirements. Each of these topics is presented below with relevant literature.

**Metering and Single Family Residential Outdoor Water Use**

Single family residential (SFR) water use has been individually metered for decades, with about 80% of SFRs having individual meters as early as the 1960s (Seidel and Cleasby 1966). These single meters measure total water use as the sum of indoor and outdoor use. A classic
work in the metering field is the 1961-66 study of residential water use by The Johns Hopkins University (Linaweaver et al. 1966). They measured residential water use in 28 metered areas, 8 flat-rate areas, and 5 apartment areas in 11 metropolitan areas in six major climatic zones across the United States. Participating cities purchased master meters with recorders to install in areas of varying socio-economic status. The master meters were installed for residential areas varying from 34 to 2,373 dwelling units with an average of 267 dwelling units per master meter. These areas provided water to 6,997 total dwelling units. Water use was measured at 15-minute intervals at each master meter for up to 30 months. Using this high frequency data, the total water use was separated into its indoor and outdoor components. Outdoor water use was estimated as a function of irrigable area, climatic factors, and the price of water.

Comparative results for the metered and unmetered areas are shown in Table 2-1 that is adapted from Linaweaver et al. (1966). The average indoor water use of 247 gallons per account per day (gpad) for the ten metered areas is very close to the average of 236 gpad for the eight flat-rate areas. However, average outdoor water use of 420 gpad for the flat-rate areas was 2.26 times larger than for the ten metered areas. Metering and commodity charges appear to have had a major impact on landscape sprinkling (LS) rates on an annual as well as a summer basis. On an annual basis, the actual LS was only 62% of the potential LS requirement (PLSR) for the ten metered areas while it was 266% of the PLSR for the eight flat-rate areas as shown in Table 2-1.

Subsequently, Howe and Linaweaver (1967) collaborated on a more in-depth evaluation of the economics of water pricing and its effect on water use using the same data set. They define commodity charges as those that vary based on the quantity of water used. Flat-rate charges are defined as any combination of charges that are independent of actual use. Their research focused on factors that impact water demand including billing type, economic and climatic factors. They
assume that summer sprinkling demand \( Q_s, \text{ gpad} \) can be estimated as shown in Equation 2-1; based on irrigable area \( b, \text{ acres} \), Thornthwaite summer potential evapotranspiration \( w_s, \text{ in.} \), summer precipitation \( r_s, \text{ in.} \), summer marginal commodity charge \( p_s, \$/k\text{gal} \), value of the home \( v, \$1,000 \), and respective elasticity coefficients \( \beta^{1-4} \).

\[
Q_s = \beta_0 b^{\beta_1}(w_s - 0.6r_s)^{\beta_2}p_s^{\beta_3}v^{\beta_4}
\]  

(2-1)

The physical components of this equation are \( b, w_s, \) and \( r_s \) where daily outdoor water use per account is the product of irrigated area, \( b, \) in acres, multiplied by the average daily irrigation demand in inches during the summer. The house value, \( v, \) is used as the measure of affluence, and the price, \( p, \) reflects the impact of the commodity charge. This multiplicative functional form is very convenient to interpret with elasticities corresponding to the exponents of each variable (e.g. \( \beta^4 \) for \( v \) corresponding to income elasticity). Interestingly, Howe and Linaweaver’s best fit for summer outdoor water use in their western study areas did not include the irrigated area, but their best fit in the eastern areas did include the irrigated area.

In a study of water demand changes with the addition of individual metering and commodity charges in Boulder, Colorado, Hanke and Boland (1971) examined water use before and after individual water meters were installed. Before individual metering, only use at the master meter route level was known so master meter routes were used for the analysis. They found that water use per account during the flat rate period was 302 gallons per day and after the commodity charge began was 193 gallons per day. Additionally, outdoor water use as a percent of ideal decreased from 165% to 81% (Hanke 1970). Ideal irrigation was defined based on both weather and home characteristics to represent the amount of water to maintain a lawn’s appearance. These findings indicate that water users significantly reduced their use following a change from flat-rate to a commodity charge billing system with metering.
Residential Irrigation Benchmarks

Extensive studies have examined urban irrigation and the associated soil, plant, water relationships in Florida. For comparing and defining the efficiency of irrigation it is necessary to define a benchmark irrigation requirement. Irrigation efficiency can be defined based on two components: water application adequacy (the plant needs) and water application effectiveness (the delivery system efficiency) (Grabow et al. 2013). A third consideration, acceptable landscape quality, can also be part of the irrigation benchmark. For the purposes of this research, the water application adequacy is being evaluated at the annual and monthly time intervals, assuming the delivery is completely effective and satisfies the desired landscape quality. In Florida, extensive studies of irrigation requirements across much of the state have been completed to determine the application adequacy. Similarly, in some arid portions of the country (e.g. Arizona) researchers including Volo et al. (2015) have examined the water needs for acceptable landscape quality. In their research, Volo et al. (2015) found that municipalities tended to grossly overestimate the required water input to maintain healthy landscaping and that substantial savings could be achieved by increasing allowable plant stress to reduce irrigation event frequency.

A primary source of information on urban application adequacy in Florida is the work of Romero and Dukes (2011, 2013) who evaluated irrigation requirements for ten cities in Florida and one city in Alabama. Their study used 30-years of climatic data for each city and a daily soil water balance to estimate the quantity of supplemental irrigation required to maintain the soil profile moisture content between the field capacity (FC) and maximum allowable depletion (MAD). The MAD used by Romero and Dukes (2013) is similar to the allowable water stress term (θ_A) used by Volo et al. (2015). The model used by Romero and Dukes (2013) initiated irrigation when the soil profile reached the MAD (set at 50% of the available water holding...
capacity) and filled the profile to the FC. A similar value of 50% for the MAD was applied by Levin and Zarriello (2013) for their work on agricultural crop demand forecasting. Two depths in the soil profile were evaluated (8 and 12 inches) with the results averaged to provide the long-term average monthly net irrigation demand (NID). For the primary study area of this research, Gainesville, Florida, the long-term average annual NID was 19.9 inches of supplemental irrigation per year. The use of this daily soil-water balance approach is an improvement over the difference between seasonal potential evapotranspiration and precipitation (Howe and Linaweaver 1967), or the theoretical application rate used by Hanke (1970).

**Irrigable Area**

When evaluating irrigation at the single family residential (SFR) scale, it is imperative to estimate how much of the parcel is irrigated. Using geographic information systems (GIS), Friedman *et al.* (2013) used parcel-level attributes to determine the irrigable area for each SFR parcel individually in an automated fashion. This effort built on the work of Palenchar (2009) who developed a methodology using Florida parcel-level data to determine the portion of the parcel that was irrigable. The parcel data used in this calculation is available for the state of Florida from the Florida Department of Revenue (FDOR) and County Property Appraisers (CPA) and includes total parcel area (calculated from GIS), structure footprint (FDOR), associated impervious area (some CPAs or calculated), and non-applicable areas. The calculation of irrigated area (IA) based on these data sets was formalized by Friedman *et al.* (2013) to yield Equation 2-2; based on the total parcel area (TA), structure footprint (FS), associated impervious area (AIA), and the non-applicable areas (NA). Friedman *et al.* (2013) found that non-applicable areas were only significant for very large parcels and not pertinent because of a 100,000 ft² maximum allowable irrigable area limit implemented in their analysis. For the purposes of the
Friedman et al. (2013) study and this study, the irrigable area and the irrigated area are considered equivalent.

\[ IA = TA - FS - AIA - NA \]  

(2-2)

**Irrigation Application Rates and Ratios**

The application rate (AR, in/yr) at the parcel-level is defined as the depth of water applied over the irrigable area (IA, ft\(^2\)) based on the annual water demand (Q, gallons per year) as shown in Equation 2-3 (adapted from Palenchar 2009). The application rate can be used to define the application adequacy or irrigation application ratio (IAR) as proposed by Mayer and DeOreo (2010) in their study of smart irrigation controllers. This approach is similar to methods applied in the work of Howe and Linaweaver (1967) and Hanke (1970) who developed ratios for the application adequacy. In each case the IAR was defined as the application rate divided by the NID with an IAR of one meaning that the user applied exactly the depth of water required by the landscape although it may not have been applied with the exact timing. However, Mayer and DeOreo (2010) noted that 80% application efficiency would occur in a well-designed and operated system in a residential setting and this efficiency would require an IAR of 125% to meet the needs of the landscaping. This is important because even if an irrigator is applying adequate water it is possible that landscape water needs are not being met because of poor timing of the deliveries.

\[ AR_i = 1.60 * \frac{Q_i}{IA_i} \]  

(2-3)

The prevalence of automatic in-ground irrigation systems has also increased in newly constructed SFRs (Friedman et al. 2013) allowing residents to easily program and apply water across their parcel. In Gainesville, this increasing prevalence began in 1982, with approximately 10% of new homes having an irrigation system and the number of installed systems has
increased nearly linearly through 2007, to 85% of newly constructed homes (Figure 2-1). This trend has important implications when considering the expectation of decreasing indoor per-capita water use (Balling and Gober 2006), and the higher application rates shown by irrigators with in-ground systems (Friedman et al. 2013). These competing factors could make prediction of future water use more challenging. Further complicating estimates of irrigation in Gainesville have been the changes in parcel size and the corresponding irrigable area (Figure 2-2). Friedman et al. (2013) found that irrigable areas increased until about 1984 before steadily decreasing since that time.

**Outdoor Water Savings**

The study by Mayer and DeOreo (2010) highlights the problem with trying to improve efficiency of irrigators by providing smart controllers to a random cross section of SFR homes with sprinkling systems. Despite some users having large savings, smart irrigation controllers increased the application rates of under-irrigators largely offsetting the savings from reductions for higher application rate users. In their study, the net result was a 6.1% decrease in water use for all sites evaluated because 47% of accounts initially under-irrigated. In a study of residential irrigation for Central Florida, Romero and Dukes (2014) found that between 22 and 64% of customers over-irrigated in the evaluated utilities. Friedman et al. (2013) found similar results in Gainesville, Florida where only 37% of potable irrigators with irrigation systems applied in excess of the NID of 19.9 in/yr. In this case, Friedman et al. (2013) found if all irrigators irrigating in excess of 25 in/yr were targeted for retrofit, a maximum of about 0.5 MGD could be saved if targeting was perfect, but total water use could increase by about 5.0 MGD if all irrigators were increased to 25 in/yr.
The irrigation ratio (IAR), shown in Equation 2-4 provides a metric to estimate the adequacy of irrigation at either the SFR level or aggregate level based on the application rate (AR) and the net irrigation demand (NID). The IAR can provide an indication of the suitability of an irrigator or utility for retrofit to conserve water. The IAR was evaluated by Friedman et al. (2013) based on results from Romero and Dukes (2013) for 11 cities and found that the IR varied between 46% and 102% with results from GRU showing an IAR of 72% (or 66% when weighted by irrigable area). The weighted IAR indicates that smaller irrigators tend to over-apply water more than irrigators with larger irrigable areas. This indicates an economy of scale for irrigation that might be explained by the increase in cost of irrigating, additional management of larger systems, improved efficiency for larger areas, or other mitigating factors. However, many variables can influence irrigation needs at the parcel-level including plant types, soils, light availability, and customer’s operating policies. Economies-of-scale have been documented for water use in indoor applications (USEPA 2005) and in CII applications (Morales et al. 2014).

**Water Pricing**

Water utility charges can be divided into those that are based on the quantity of water used (commodity charges) and those that are independent of usage (flat-rate) as defined by Linaweaver et al. (1966). Pricing or rate-setting has been an important consideration for as long as utilities have existed as regulated monopolies (Brown 2010). The multiple objective goals for effective rate-setting have been discussed by many authors, but a nice synthesis is proposed by Griffin (2006) who identifies the following primary objectives:

- **Revenue Sufficiency** – Revenues cover all costs.
- **Economic Efficiency** – Rates maximize the customers’ net benefits or net present value.
• Equity – Customers with the same characteristics pay the same amount.
• Fairness – Rates are perceived as fair.
• Simplicity – Rates are easy to comprehend.
• Legality – Rates are legal.

These components of effective rate-setting include some of the commonly held tenets, but are acknowledged to not be exhaustive. Griffin (2006) goes on to discuss each component in additional detail including challenges and the inherent tension in balancing the needs of sometimes competing interests. Many of these guidelines are incorporated in the American Water Works Association (AWWA) Manual M1, currently in its sixth edition and used extensively by utilities for rate-setting (AWWA 2012). Brookshire et al. (2002) also discussed the inclusion of a “scarcity value” to account for the value of water that is often being supplied below cost due to former government projects that did not have the full costs passed on to consumers and that does not account for any intrinsic value of the resource. However, this could be perceived based on the above conditions of causing rates that are illegal because they exceed the actual costs of supplying the resource.

To achieve the goals discussed above, many utilities use a combined approach to rate-making with the utility bill including a fixed fee for supplying water independent of use and a commodity charge based on the quantity used. Within the commodity charge portion of the bill, rates can be increasing, constant, or decreasing functions of usage. Raftelis Financial Consultants survey water utilities every two years regarding their pricing practices.
Table 2-2 shows the percentage of utilities using declining block, uniform, and increasing block charges from 1988 to 2012. The decreasing block has dropped from 51% in 1988 to 18% in 2012. The uniform block was used by 30% of the utilities in 2012, and the increasing block option is being used by 52% of the utilities (Raftelis 1988, 2012). Furthermore, in a decreasing block structure, the price signal sent to the customer encourages higher water use because the price signal per unit decreases with increasing use.

Customers have been observed to have a poor understanding of the source and costs of their water. In 2011, a Nature Conservancy survey found that 77% of Americans surveyed did not know the natural source of the water in their home (AWE 2014). Surveys of water utility customers in Florida and elsewhere indicate limited awareness of pricing by customers (Whitcomb 2005), but more than half expressed concerns with their bills. Whitcomb (2005) found users to be non-responsive to the fixed fee portion of their water bill. Whitcomb (2005) also evaluated source substitution in his Florida study areas and found that more than one third of the surveyed users reported tapping into another source for irrigation (e.g. irrigation wells).

Customers respond to the commodity charge component of their water and wastewater bills (Whitcomb 2005). However, significant debate has occurred over whether the customer responds to average or marginal costs. Recent work by Ito (2012) found that electric utility customers responded to the average price rather than to the marginal price. One modification of the average and marginal price was introduced by Shin (1985) who recommended the addition of a “perception” variable (k) to describe the customer’s level of awareness to the marginal price (MP) versus average price (AP), termed the perceived price (P*) as shown in Equation 2-5.

$$P^*_t = MP_t \left( \frac{AP_t}{MP_t} \right)^k$$  \hspace{1cm} (2-5)
Shin (1985) found that electricity customers appeared to respond preferentially to the average price. A significant limitation of Shin’s proposal is that local survey data are needed to estimate $k$ in Equation 2-5. Griffin (2006) also discusses the average versus marginal price question and concludes that both offer benefits from a rate-making standpoint, but customers generally lack an understanding of their bill beyond the total cost. The work by Ito (2012) also expressed that the complexity of marginal and average rates is challenging for customers to understand. Both Shin (1985) and Ito (2012) discuss the high cost of information about consumption and the real-time marginal cost that encourages customers to favor the average price that can be easily calculated from the utility bill. More recently, AWE (2014) addressed the challenge of average versus marginal costing by recommending that utilities blend marginal and average cost pricing and better define the true cost of service including environmental and long range water supply requirements.

A specific analysis of the use of water pricing to promote water conservation was completed by Chiogioji and Chiogioji (1973) for the residential, industrial, and agricultural sectors. Relative to domestic demand, the authors evaluated existing literature and spoke with utility managers. They concluded that outdoor demand has greater potential to be managed through pricing as a result of higher elasticity. The recommendations of the study were to use increasing block rate price structures, have different rate structures in summer (irrigation season), and increase reclaimed water use. A more recent analysis by Olmstead and Stavins (2009) compared price and non-price approaches to water conservation in an urban setting. The authors conclude that price approaches to water conservation are preferable because they are lower cost and allow the customer the choice of how to modify their behavior. The authors also conclude
that politically, pricing can be costly and assigning value can be challenging between varying uses of water.

There is uncertainty in the literature as to the permanence of changes in water demand resulting from changes in price. This variable has been discussed in multiple studies with different conclusions reached. Chiogioji and Chiogioji (1973) discussed several studies that found that water use changes are temporary in nature, returning to past levels after varying lengths of time. In several other utilities they reviewed, water use changes appeared to be more permanent. Included in the recommendations of the Chiogioji and Chiogioji (1973) study was the use of public information campaigns to maintain a level of awareness among the customers that may enhance the long-term performance of a pricing conservation tool. In a separate study, Hanke (1970) found that changes in water use resulting from switching from flat-rate to commodity charges appeared to be permanent in Boulder, Colorado.

**Price Elasticity**

Elasticity is used to describe the change in demand/output caused by a change in input and price elasticity of water can then be defined as the percent change in water use (Q) per percent change in water price (P). Equation 2-6 shows the water price elasticity (WPE) definition.

\[
WPE = \frac{dQ/Q}{dP/P}
\]  
(2-6)

Elastic demand results when users percent change in demand exceeds the percent change in price (elasticity>1 or elasticity<-1). Inelastic demand therefore results when users percent change in demand is lower than the percent change in price (1>elasticity>-1). Consistently, but not exclusively, studies have found overall urban water demand to be inelastic (Baumann *et al.* 1998, Espey *et al.* 1997, Dalhuisen *et al.* 2003). Baumann *et al.* (1998) reported on 52 studies of
price elasticity using linear, log-log, and semi-log estimates based on temporal or cross-sectional data of price elasticity. Other meta-analyses of price elasticity studies have been completed by Espey et al. (1997) and Dalhuisen et al. (2003) who evaluated existing studies of price elasticity. Additionally some price elasticity studies have evaluated specific classes of price elasticity including seasonal, indoor, outdoor, single-family, multi-family, etc. In a study of price elasticity in Florida for single-family homes, Whitcomb (2005) found that use decreased across income levels with increasing prices. Additionally, higher valued homes (a surrogate for income) tended to reduce water use to a lesser extent indicating positive income elasticity. In a study by Harlan et al. (2009), researchers found that affluent users in Arizona used much more water than lower income individuals which was suggested to be the result of landscaping features, water using devices, larger homes, and generally less concern over the cost of water. Recommended remedies for these users were additional education combined with more stringent building codes for water conservation, higher taxes on bigger homes, and introducing “very progressive” water rate structures to penalize large consumers.

Baumann et al. (1998) examined elastic studies for different types of use, and found the ranges shown in

Table 2-3. Certain classes of water use are observed to be more elastic, such as outdoor water use and water use during summer (Howe and Linaweaver 1967, Danielson 1979, Baumann et al. 1998). Similarly, income elasticity has generally been found to be positive and inelastic meaning that users with higher incomes use more water (Baumann et al. 1998, Whitcomb 2005). Indoor use and winter use have been found to be lower (Baumann et al. 1998). This result is anticipated based on the results of Mayer et al. (1999) who found indoor use to be consistent spatially in North America with larger differences in outdoor water use. This result was found
explicitly by Pope et al. (1975, from Baumann et al. 1998) who found irrigators to have price
elasticities of -0.31 to -0.67 compared to non-irrigators elasticities of -0.06 to -0.36. Outdoor
demand being more price elastic indicates the potential value of a water demand management
measure that is dependent on pricing.

An addition to the existing price elasticity concept was presented by Characklis et al.
(1999) in their evaluation of the optimal mix of water allocation among two urban users and
three agricultural users. They used power functions to estimate the demand curves for water, but
added a “choke price” for field crops to place an upper bound on the price of irrigation water that
these users would pay. If the market price for water exceeded the choke price, these irrigators
would switch to dryland farming. This addition of the choke price compensates for the change in
use that can be expected at elevated water prices when certain uses become economically
unreasonable.

**Reclaimed Water Use**

Reclaimed irrigation systems in Florida have expanded widely over the past 20 years
(Figure 2-3) with 719.5 MGD of reclaimed water provided in Florida in 2013 (FDEP 2014).
When applicable, water utility charges (typically monthly) for reclaimed water, like potable
water, are the sum of a fixed charge and a variable commodity charge per unit of water provided.
Nearly a third of the reuse utilities provide this water for a zero commodity charge as shown in
Table 2-4. This is in contrast to most potable water systems that have been metered and
billed for decades (Seidel and Cleasby 1966). Even when a commodity charge is levied, it is
typically at a much lower rate than is charged for potable water. In some areas, this has resulted
in reclaimed water being applied at a much higher application rate than irrigation using potable
CDM (2012) did an extensive study of reclaimed water systems and developed the Guidelines for Water Reuse for the USEPA. This document included an evaluation of prices and pricing policy. For 94 sample utilities in Florida, the reclaimed water rate was compared to the potable water rate. This work found that 41% of reclaimed water was provided with no commodity charge, but also that 45% of the remaining reclaimed water utilities provided water at less than half the cost of potable water. Only 5% of the sampled utilities provided reclaimed water at the full potable cost. The report goes on to recommend that pricing be considered based on the objectives and primary purpose of the reclaimed system. If the primary purpose is to dispose of wastewater, then prices may be very low to subsidize high levels of use. However, if reclaimed supplies are limited, the price may match that of potable water to encourage lower use.

Reclaimed water in Florida is applied on an estimated 317,000 acres of land. A large portion of this land is residential areas (45.5%), although the quality of these areas is unknown. In addition to being the largest area, the single largest use (25.6%) in 2013 was for residential irrigation (Table 2-5). Application rates were calculated for each reclaimed water use and varied between 12.7 and 987.2 in/yr. The average application rate for residential areas was 17.1 in/yr.

Reclaimed water use for residential irrigation in Florida began in the 1970s when the St. Petersburg utility in Southwest Florida began supplying reclaimed water to residential customers for irrigation to avoid higher levels of treatment for wastewater discharge to natural ecosystems (Okun 1997). This water was delivered through a dual piping system to avoid contamination of potable water supplies. One of the primary benefits that emerged from this project was decreases in withdrawals that were damaging lakes and wetlands near the City’s well fields (Okun 1997). Water on this system was provided for a flat-rate to customers and use has exceeded expectations spurring the city to look at metering and instituting commodity charges (Okun 1997).
The large use of reclaimed water has again brought metering to the forefront. Where potable water systems have generally been metered with a commodity charge for decades, about 32% of Florida reclaimed water users pay no commodity charge (FDEP 2014). As was observed by Okun (1997) water use on reclaimed systems with flat-rates was much higher than for potable water. As discussed previously, Howe and Linaweaver (1967) and Hanke (1970) observed similar results for flat-rate water use on potable water systems. Initially reclaimed water was delivered for low flat rates for three reasons according to the Reuse Coordinating Committee (RCC) (2003): to minimize costs (i.e. metering), improve customer acceptance, and maximize wastewater disposal. Over time the needs of the utilities have shifted as discussed by Okun (1997) to include the offset of potable water demand. This concept was discussed in detail by the RCC (2003), who recommended that a potable water quality offset credit (OC) be used to evaluate efficiency. This concept is shown in Equation 2-7 and is based on the potable application rate (AR_{potable}) and the reclaimed application rate (AR_{reclaimed}). When AR_{potable} is unknown or unavailable, the NID could be used directly, or with the IAR to estimate an appropriate value for AR_{potable}.

\[
OC = \frac{AR_{potable}}{AR_{reclaimed}} \times 100\% \tag{2-7}
\]

Offset credits were evaluated for the Tampa Bay Region of Florida by Andrade and Scott (2002) who examined pre-reclaimed and post-reclaimed irrigation use for both flat-rate and commodity charge areas. Areas without metering were observed to have smaller OCs of 25-35% and metered areas were observed to have higher OCs of 45-55%.
Table 2-1. Comparison of metered and flat-rate water use (adapted from Linaweaver et al. 1966)

<table>
<thead>
<tr>
<th></th>
<th>Metered</th>
<th>Flat-Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Areas</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Leakage</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>Indoor</td>
<td>247</td>
<td>236</td>
</tr>
<tr>
<td>Outdoor</td>
<td>186</td>
<td>420</td>
</tr>
<tr>
<td>Total</td>
<td>457</td>
<td>692</td>
</tr>
</tbody>
</table>

Water Use — gpad

<table>
<thead>
<tr>
<th></th>
<th>Outdoor Application Rate (OAR)</th>
<th>Potential OAR Requirement</th>
<th>OAR/OARR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>14.0</td>
<td>22.5</td>
<td>62%</td>
</tr>
<tr>
<td></td>
<td>39.4</td>
<td>14.8</td>
<td>266%</td>
</tr>
</tbody>
</table>

Outdoor Application Rate — in/yr

Figure 2-1. Prevalence of automatic in-ground irrigation systems in Gainesville, Florida (Friedman et al. 2013)
Figure 2-2. Average irrigable area and impervious area for homes in Gainesville, Florida (Friedman et al. 2013)
Table 2-2. Trends in the popularity of water rate structures (adapted from Raftelis 1988, 2012 and AWWA and RFC 2014)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Decreasing Block</td>
<td>51%</td>
<td>35%</td>
<td>31%</td>
<td>25%</td>
<td>24%</td>
<td>28%</td>
<td>19%</td>
<td>18%</td>
<td>16%</td>
</tr>
<tr>
<td>Uniform</td>
<td>32%</td>
<td>36%</td>
<td>37%</td>
<td>39%</td>
<td>40%</td>
<td>32%</td>
<td>31%</td>
<td>30%</td>
<td>30%</td>
</tr>
<tr>
<td>Increasing Block</td>
<td>17%</td>
<td>29%</td>
<td>32%</td>
<td>36%</td>
<td>36%</td>
<td>40%</td>
<td>50%</td>
<td>52%</td>
<td>54%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 2-3. Water price elasticity values by type of use (adapted from Baumann et al. 1998)

<table>
<thead>
<tr>
<th>Type</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Types</td>
<td>-0.01</td>
<td>-1.57</td>
</tr>
<tr>
<td>Single-Family</td>
<td>-0.01</td>
<td>-1.57</td>
</tr>
<tr>
<td>Single-Family, Winter</td>
<td>-0.01</td>
<td>-0.49</td>
</tr>
<tr>
<td>Single-Family, Summer</td>
<td>-0.13</td>
<td>-1.57</td>
</tr>
<tr>
<td>Mixed Residential</td>
<td>-0.02</td>
<td>-1.02</td>
</tr>
</tbody>
</table>

Figure 2-3. Reclaimed water use in Florida (adapted from FDEP 2014)

Table 2-4. Water delivery by fee structure for reclaimed water systems in Florida (adapted from FDEP 2014)

<table>
<thead>
<tr>
<th>Type</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Commodity Charge</td>
<td>43</td>
<td>32.3%</td>
</tr>
<tr>
<td>No Fixed Fee</td>
<td>16</td>
<td>12.0%</td>
</tr>
<tr>
<td>Flat-Rate</td>
<td>27</td>
<td>20.3%</td>
</tr>
<tr>
<td>Commodity Charge</td>
<td>90</td>
<td>67.7%</td>
</tr>
<tr>
<td>No Fixed Fee</td>
<td>43</td>
<td>32.3%</td>
</tr>
<tr>
<td>Combination</td>
<td>47</td>
<td>35.3%</td>
</tr>
<tr>
<td>All</td>
<td>133</td>
<td>100.0%</td>
</tr>
<tr>
<td>Public Access</td>
<td>Flow (MGD)</td>
<td>% of Use</td>
</tr>
<tr>
<td>---------------</td>
<td>------------</td>
<td>----------</td>
</tr>
<tr>
<td>Resid. Irrig.</td>
<td>184.1</td>
<td>25.6%</td>
</tr>
<tr>
<td>Golf Irrig.</td>
<td>123.0</td>
<td>17.1%</td>
</tr>
<tr>
<td>Other Public Acc.</td>
<td>78.8</td>
<td>10.9%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Agriculture</th>
<th>Flow (MGD)</th>
<th>% of Use</th>
<th>Area (ac)</th>
<th>% of Area</th>
<th>AR (in/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edible Crops</td>
<td>13.0</td>
<td>1.8%</td>
<td>13,763</td>
<td>4.3%</td>
<td>12.7</td>
</tr>
<tr>
<td>Other Crops</td>
<td>58.1</td>
<td>8.1%</td>
<td>22,670</td>
<td>7.1%</td>
<td>34.4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Recharge</th>
<th>Flow (MGD)</th>
<th>% of Use</th>
<th>Area (ac)</th>
<th>% of Area</th>
<th>AR (in/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RIBs</td>
<td>98.8</td>
<td>13.7%</td>
<td>14,799</td>
<td>4.7%</td>
<td>89.8</td>
</tr>
<tr>
<td>Absorp. Fields</td>
<td>2.1</td>
<td>0.3%</td>
<td>491</td>
<td>0.2%</td>
<td>58.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Industrial</th>
<th>Flow (MGD)</th>
<th>% of Use</th>
<th>Area (ac)</th>
<th>% of Area</th>
<th>AR (in/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment Plant</td>
<td>59.0</td>
<td>8.2%</td>
<td>803</td>
<td>0.3%</td>
<td>987.2</td>
</tr>
<tr>
<td>Other Facilities</td>
<td>66.4</td>
<td>9.2%</td>
<td>4,854</td>
<td>1.5%</td>
<td>183.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other</th>
<th>Flow (MGD)</th>
<th>% of Use</th>
<th>Area (ac)</th>
<th>% of Area</th>
<th>AR (in/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wetlands</td>
<td>33.8</td>
<td>4.7%</td>
<td>5,440</td>
<td>1.7%</td>
<td>83.5</td>
</tr>
<tr>
<td>Other</td>
<td>2.5</td>
<td>0.3%</td>
<td>254</td>
<td>0.1%</td>
<td>131.6</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Total</th>
<th>Flow (MGD)</th>
<th>% of Use</th>
<th>Area (ac)</th>
<th>% of Area</th>
<th>AR (in/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>719.5</td>
<td>100%</td>
<td>317,493</td>
<td>100%</td>
<td>30.5</td>
<td></td>
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CHAPTER 3
DATA, DATA CLEANING, AND METHODS

Water Use Data

The data sets used for this research included monthly water use for reclaimed and dual metered customers in Gainesville, Florida. The data sets included 783 reclaimed customer accounts with water demand data from April 2007 through October 2014 and 1,764 dual meter accounts with data from October 2003 through October 2014. Before these data could be analyzed it was necessary to extensively clean the data to address errors including:

- Unrealistically high or low values;
- Large numbers of missing months or zero months;
- Accounts with uniform usage;
- Parcels without attributes or incorrect attributes;
- Parcels with multiple meters;
- Non-SFR accounts; and
- Accounts without associated parcels.

To eliminate high and low outliers, a requirement was placed on all values in the database that compared each water demand (Q) to an allowable maximum and minimum for that account. These maxima and minima were based on the 25th and 75th percentiles for the specific account with the limits shown in Equation 3-1. All data points that fell outside of the specified range were deleted yielding a blank in the account data.

\[
25th\% - 3 \times (75th\% - 25th\%) < Q < 75th\% + 3 \times (75th\% - 25th\%) \quad (3-1)
\]

Because the focus of this research was on irrigation, the accounts were limited based on the consistency of irrigation. Accounts were required to have at least nine months per year with positive water demand. This helped eliminate accounts that came online later in the analysis period that would have impacted aggregate statistics and accounts with inconsistent irrigation. Based on the work of Romero and Dukes (2013), years with no need for supplemental irrigation in greater than two months are rare with none occurring during the seven study years. In addition
to removing users with insufficient irrigation records, some accounts were removed for some of
the other above reasons. This resulted in final datasets of 510 reclaimed customers and 610 dual
meter customers in Gainesville. This represents a significant decrease when compared to the
entire datasets and illustrates one of the primary challenges of working with larger longitudinal
datasets, such as the occurrence of zero values in large numbers of records that can bias statistics
when viewed in the aggregate.

Water use data are collected by meter readers on intervals that may vary in frequency.
Meters were generally read monthly, but not on a fixed schedule. Because read dates vary on
which day of the month they occur, the number of days in the read period may vary. This is
particularly important when evaluating monthly water use. For example, if in a two month period
one read occurs after 15 days and the other after 46 days, one of the months will have a reported
quantity that includes half of the other month. To improve the accuracy, data were rectified by
using read dates to assign the appropriate water use to the appropriate month following the
method described by Dziegielewski and Opitz (2002).

Weather Data

To better simulate daily irrigation demands, detailed weather data were collected from
the Florida Automated Weather Network (FAWN) operated by the University of Florida through
the Institute of Food and Agricultural Sciences (IFAS). The FAWN collects data from 42
stations around the state and provides up to the minute weather data. These data are available
through downloads from the FAWN archive for historical periods dating from 1997 to the
present. For this research, daily weather data were collected for three stations in the vicinity of
each study area for parameters of interest including:

- Precipitation
- Solar radiation
- Temperature (max, mean, and min)
- Wind speed
- Pressure
- Relative humidity

The Gainesville estimate was prepared using an inverse distance square weighting algorithm to assign weights to each of the three nearby FAWN stations (Alachua 57%, Bronson 26%, Citra 17%). In addition to these values, FAWN provides a reference evapotranspiration (ET) value. However, calculating ET directly from the data was the preferred approach as the methods used by FAWN are not fully documented or reviewed. Using the methods of Zotarelli et al. (2009), the Penman-Montieth (FAO-56) ET was calculated for the study area based on the three nearby weather stations and assigned weights. This produced a daily ET estimate for the study period in the study area.

**Irrigation Demand Model**

Estimating the landscape irrigation demand was a critical part of this research. A daily irrigation demand model has two primary components: 1) a soil water balance approach for each time step; and 2) an assumed operating policy. The model can be calibrated by matching its estimates with historical data. Both Dukes (2007) and Romero and Dukes (2013) discuss a daily soil water balance approach to simulate the demand for irrigation to maintain the soil water in the root zone between the available water holding capacity (field capacity minus the permanent wilting point water content) and the maximum allowable depletion (MAD). The general soil water balance formulation from Romero and Dukes (2013) is shown in Equation 3-2 with each term described in additional detail. The equation includes the soil water content (SW), irrigation (I), rainfall (R), crop adjusted evapotranspiration (ETc), drainage (D), and runoff (Roff) for either the current or previous time step (t or t-1, respectively).

\[
\Delta SW = SW_t - SW_{t-1} = I_{t-1} + R_{t-1} - ETc_{t-1} - D_{t-1} - Roff_{t-1}
\]  
(3-2)
The soil water content is the amount of water available within the root zone of the modeled vegetation and represents the change in storage in a water balance sense. Irrigation is calculated by determining the difference between the SW and the water available to the plant. The water available to the plant is based on the field capacity (FC – in$^3$/in$^3$), permanent wilting point (PWP – in$^3$/in$^3$), available water holding capacity (AWHC – in$^3$/in$^3$), root zone depth (RZ – in.), available water in the root zone (AW – in.), the maximum allowable depletion (MAD %), and the plant available water (PAW – in.). These equations, from Dukes (2007), are shown in Equations 3-3 through 3-5. Finally, irrigation is calculated based on the AW of 0.56 inches for the study area, and the SW at the current time step, Equation 3-6.

\[
\begin{align*}
AWHC &= FC - PWP \hspace{1cm} (3-3) \\
AW &= AWHC \times RZ \hspace{1cm} (3-4) \\
PAW &= AW \times MAD \hspace{1cm} (3-5) \\
I_t &= AW - SW_t \hspace{1cm} (3-6)
\end{align*}
\]

The precipitation for the study area was taken from the FAWN data for the study area. The reference evapotranspiration (ET) for the study area was calculated, as previously discussed from the FAWN data and the work of Zotarelli et al. (2009) who present a method for calculating the Penman-Montieth ET for the parameters available from FAWN. The ET was then corrected for the crop of interest, turf grass, by applying monthly coefficients from Dukes (2007; adapted from Jia et al. 2007) to yield ETc. The deep percolation was calculated based on the SW, R, ETc, and I to maintain no more than the AW within the root zone of the plant as calculated using equation 3-7. For this study and the generally coarse-grained sandy soils in Gainesville, Florida, the runoff is treated as negligible.

\[
D_t = SW_t + I_t + R_t - ETc_t - AW \hspace{1cm} (3-7)
\]
The MAD, which can be adjusted and represents more of an operator dependent variable, was set at 50% based on Dukes (2007). This yields a PAW of 0.28 inches in the root zone. The MAD can be adjusted to simulate irrigator tolerance to stressed lawn conditions. Dukes (2007) stated that 50% wilt conditions were observed in St. Augustine grass with a 50% MAD.
CHAPTER 4
FLAT-RATE RECLAIMED USE AND SAVINGS IN SINGLE-FAMILY HOMES

Scope and Overview

In the face of increasing water scarcity, methods of managing demands for water use are being evaluated to alleviate stresses on municipal water systems. One of the primary water demands in many urban and suburban areas is residential irrigation (Mayer et al. 1998, Mayer and DeOreo 2010, Tiger et al. 2011), which has increased significantly in recent years due partially to the increased popularity of automatic in-ground irrigation systems (Friedman et al. 2013). Methods of managing these demands have included best management practices (e.g. soil moisture sensors) whose savings can be quantified and measures (e.g. audits) that are more difficult to quantify. One method of meeting irrigation demands without using potable water has been providing reclaimed (treated) wastewater through a separate pipe network for irrigation. This alternative was initially used to avoid additional required treatment before wastewater disposal to receiving waters (Okun 1997). More recently it has been considered a way to offset potable water use (Central Florida Water Initiative [CFWI] 2014). Based on studies of some of the earliest reclaimed water projects in southwest Florida, it was found that unmetered customers used two to four times more water than those on metered systems (Okun 1997, Andrade and Scott 2002), who generally pay a commodity charge of $2 to $7 per 1,000 gallons. The practice of providing low-cost or free reclaimed water in Florida is common with 74% of reclaimed providers supplying water for less than $1 per 1,000 gallons (kgal) (Florida Department of Environmental Protection [FDEP] 2014). This much higher irrigation demand can have consequences when sizing the reclaimed treatment, storage, and distribution system and could result in reclaimed water itself becoming a limited resource. This paper addresses the demand for reclaimed water at a flat-rate and evaluates the potential savings associated with the reduction of
irrigation application rates on reclaimed systems. This analysis is possible due to a rare, if not unique, data set of 510 reclaimed single family residential (SFR) customers in Gainesville, Florida who were charged a flat-rate for more than a year, but had their water use individually metered and recorded at monthly intervals. This is in contrast to typical flat-rate water systems which are un-metered or master-metered because of the expense associated with installing and reading meters and the lack of an incentive in the form of additional revenue for this expenditure by the utility. The water use for the reclaimed customers is compared to 6,305 potable SFR irrigators also in Gainesville who were individually metered and charged potable water rates for their water use. Finally, a benchmark irrigation rate is recommended to develop a predictive estimate of irrigation in flat-rate areas without individual metering, and an estimate of potential water savings if water use is reduced to the benchmark application rate.

**Related Research**

Existing research has focused on multiple facets of irrigation including irrigation demands for landscape, flat-rate water use, and more recently parcel-level analysis of outdoor water use. The work on irrigation demands has improved the understanding of water availability and irrigation adequacy in residential settings. This research is used in this paper to define irrigation benchmarks for assessing application adequacy of residential irrigation. Flat-rate water use has been studied historically, but no recent studies have examined the application of flat-rate water use at the parcel level. Leveraging parcel-level statewide databases, several recent studies in Florida have evaluated water use at the parcel level. Several of the methods offered by these studies are incorporated in this research. The relevant literature is described in the following four sections that discuss reclaimed water use in Florida, flat-rate water use, parcel-level irrigation use, and irrigation adequacy.
Reclaimed Water Use in Florida

Single family residential outdoor water use has become a more significant and growing proportion of total residential water use in Florida for at least two reasons: 1) SFR indoor water use per capita is decreasing due to more efficient end use devices, and 2) the rapid growth in the popularity of in-ground irrigation systems, e.g., from about 10% of new homes in 1980 to about 90% of new homes in 2008 in Gainesville, Florida (Friedman et al. 2013). In order to mitigate the effects of this trend on potable water demand, the State of Florida has encouraged the reuse of reclaimed water for irrigation. Florida has emerged as the national leader in reclaimed water use with 719 million gallons per day (MGD) in 2013 (Florida Department of Environmental Protection 2014). Reclaimed water providers are required to submit an annual report to FDEP with the quantity of water treated and other distribution statistics. Based on these reports, reclaimed water capacity and use can be seen to have increased dramatically since the 1980s (Figure 4-1), where capacity is the design flow for the reclaimed production facility and use is the quantity of water supplied to the users. A total of 184 MGD or 25.6% of reclaimed water use in 2013 was for residential irrigation, the largest of any single use of reclaimed water in Florida. Fee structures and rates vary widely for reclaimed water with water often provided at little or no cost to customers (FDEP 2014). For a total of 133 residential reclaimed systems in Florida in 2013, 43 (32.3%) provided water without a commodity charge (Table 4-1). Of these, 16 had no fees associated with reclaimed water use and the other 27 charged only a flat-rate. For the remaining 90 utilities a commodity charge was levied, but 43 of these utilities had no fixed fee. The average commodity charge for the 90 utilities who charged one was $0.96/kgal. The fixed monthly charge for the 27 utilities with no commodity charge was $10.48/month and for the utilities with commodity charges was $8.08/month.
Flat-Rate Outdoor Water Use

Recent research focusing on the magnitude of urban water use for systems that do not assess a water use commodity charge is limited. This is the result of a vast majority (~80%) of all residential water provided on public water supply systems in urban areas of the United States being accompanied by individual metering as early as 1960 (Seidel and Cleasby 1966). These single meters measure total water use as the sum of indoor and outdoor use. A classic work in this field is the 1961-66 national study of residential water use by Johns Hopkins University (Linaweaver et al. 1966). They measured residential water use in 28 metered areas, 8 flat-rate areas, and 5 apartment areas in 11 metropolises in 6 major climatic zones across the United States. Participating cities purchased master meters with recorders to install in areas of varying economic levels. The master meters were installed for residential areas (single family homes and apartments) varying from 34 to 2,373 dwelling units with an average of 267 dwelling units per master meter. These areas provided water to 10,947 dwelling units. Water use was measured at 15-minute intervals at each master meter for up to 30 months. Using this high frequency data, the total water use was separated into its indoor and outdoor components. Outdoor water use was estimated as a function of irrigable area, climatic factors, and the price of water for each master metered area.

Comparative results for the metered and unmetered areas in the western United States are shown in Table 4-2. The average indoor water use of 247 gallons per account per day (gpad) for the ten metered areas is very close to the average of 236 gpad for the eight flat-rate areas. However, average outdoor water use of 420 gpad for the eight flat-rate areas was 2.26 times larger than for the 10 metered areas. Metering and commodity charges appear to have had a major impact on outdoor application rates (OAR) on an annual as well as a summer basis. On an
annual basis, the actual OAR was only 62% of the potential OAR requirement for the ten metered areas while it was 266% for the eight flat-rate areas as shown in Table 4-2.

In a study of water demand changes with the addition of individual metering and commodity charges in Boulder, Colorado, Hanke and Boland (1971) examined water use before and after the installation of individual water meters. Before individual metering, only use at the meter-reading route level was measured. They found that water use per account during the fixed charge period was 302 gallons per day and after the commodity charge it decreased to 193 gallons per day. Additionally, outdoor water use as a percent of ideal decreased from 165% before individual metering to 81% after metering (Hanke 1970). Ideal irrigation was defined based on both weather and home characteristics to represent the amount of water to maintain a lawn’s appearance. These findings indicate that water users significantly reduced their use following a change from a fixed charge to a commodity charge billing system. The limited studies available and lack of account-level metered data and accurate determinations of irrigated areas demonstrate the challenge of developing an accurate analysis of irrigation water demand absent a commodity charge. A major limitation of these early studies is that it was difficult to estimate irrigated area and the potential outdoor application requirement due to lack of geographical information systems (GIS) and high quality climate and water use data.

**Parcel-Level Irrigation Water Use**

Thanks to major advances in GIS during the past 40 years, high quality estimates of irrigable area are available at the parcel level (Friedman et al. 2013). Annual application rate for an entity (individual customer, sub-system, etc.) is defined as the depth of application (AR, in/yr), which is derived from total annual irrigation water use (Q, gallons per year) divided by irrigated area (IA, ft²) (Equation 4-1).
\[ \overline{AR}_{\text{ann}} = 1.60 \times \frac{Q_{\text{ann}}}{IA} \] (4-1)

For the purposes of this study, and the work of Friedman et al. (2013), irrigable area and irrigated area are considered to be equivalent, although this may not be the case for all parcels. The vast majority of SFR meters measure total flow into the parcel. In this case it is necessary to separate indoor and irrigation water use using hydrograph separation and assuming that the water use in the minimum-month is indoor use. The minimum-month method (MMM) is straightforward to use in colder climates with a distinct non-irrigated period during the colder months. However, the MMM may not work as well in areas with the potential for year-round irrigation, as shown by Romero and Dukes (2014) who found that the MMM produced higher minimum water use during dry years in Florida. This difficulty is negated for utilities that allow the installation of dual water meters to measure indoor and irrigation water use separately. Dual meter installation can benefit the customer by providing more accurate wastewater charges. For analyzing irrigation water use, dual meters can directly provide irrigation demand through the outdoor meter. A similar setup is used by all utilities that provide reclaimed water since water is delivered through a separate pipe network, although use may or may not be metered.

**Irrigation Application Adequacy Benchmark**

An irrigation benchmark can be defined in a variety of ways. Grabow et al. (2013) define irrigation efficiency as composed of: water application adequacy and water application efficiency. A third component of this efficiency or benchmark can be acceptable landscape quality. For this study, application efficiency is assumed to be 100% with application adequacy the primary focus. To compare the water use amongst irrigators it is necessary to have a benchmark irrigation. For this paper, the benchmark applied is the net irrigation demand (NID), equivalent to Romero and Dukes’ (2012) net irrigation requirement (NIR), defined as an amount
of water that provides an adequate landscape based on bio-physical and weather considerations, without explicitly considering the impact of other irrigator preferences. Demand was used to replace the term requirement to acknowledge the role of the customer in choosing how to apply water, separate from the plant’s biophysical requirements.

In Florida, and specifically Gainesville, Romero and Dukes (2013) have studied the NID, corresponding to the water application adequacy described by Grabow et al. (2013). Romero and Dukes (2013) used a 30-year modeling period to evaluate plant water needs on a daily basis by maintaining the soil moisture content between the maximum allowable depletion and field capacity. The daily volume of irrigation required to maintain this soil moisture content was calculated based on local weather data. This daily irrigation demand estimation is a major improvement over previous estimates based on monthly data that do not capture the dynamics of irrigation that responds to daily moisture deficits. Romero and Dukes (2013) found that the average NID was 19.9 inches per year for Gainesville, Florida varying by month based on rainfall and evapotranspiration. This average annual NID value was used as a benchmark in this study for “efficient” irrigation. To evaluate use relative to the NID, an irrigation application ratio (IAR) was developed for each user to compare the average annual application rate (AR) to the NID as shown in Equation 4-2. This equation is similar to that applied by Mayer and DeOreo (2010), and defines the percentage of the NID applied. For example, a user who applies an amount of water at exactly the NID would have a value of 100%. Users who apply less than the NID would have an IAR less than 100% and users who apply more than the NID would have an IAR greater than 100%. Irrigation demand is influenced by many parameters including rainfall depth, rainfall timing, evapotranspiration, soil type, vegetative type, and system application efficiency. By narrowing this analysis to a single year of data for a single geographic area the
meteorological conditions can be considered to be consistent across the study area. This study focuses only on the actual application for each account that used reclaimed or potable water and not other factors that may influence water use.

\[
\overline{IAR_{\text{ann}}} = \frac{\overline{AR_{\text{ann}}}}{NID_{\text{ann}}} \times 100\% \tag{4-2}
\]

Irrigation application ratios have been evaluated in multiple areas around Florida by Romero and Dukes (2011) and added to by Friedman et al. (2013). Their results show that, on average, 78% of estimated irrigation needs were being met for the 11 areas evaluated by Romero and Dukes (2011) and 66% of estimated irrigation needs, based on a weighted average, were met for the households in Gainesville, Florida evaluated by Friedman et al. (2013). All of these locations had commodity charges for water use. These values are comparable to the results of forty years prior of Howe and Linaweaver (1967) who found that users in the western United States who paid a commodity charge applied 62% of ideal and those of Hanke (1970) who found that users with billed water applied 81% of ideal.

The idea of irrigation adequacy is embodied in the concept of the potable water offset credit (OC) discussed by the Reuse Coordinating Committee (RCC) (2003) of Florida. The OC (0% ≤ OC ≤ 100%) defines the percentage of the reclaimed water (AR\text{reclaimed}) applied that “efficiently” replaces the potable water (AR\text{potable}) that would have been used, as shown in Equation 4-3. The quantity of potable water applied could be adequate, excessive, or insufficient to maintain landscape quality and the OC can vary widely for this reason. By replacing the historical potable use, AR\text{potable}, with the benchmark irrigation (NID) the uncertainty of an appropriate potable application rate can be eliminated and OC = 1/IAR from Equation 4-2.

\[
OC = \frac{AR_{\text{potable}}}{AR_{\text{reclaimed}}} \times 100\% \tag{4-3}
\]
It was obvious from early studies of irrigation with flat-rate or low-cost reclaimed water that users applied more water than would have been used on the potable water system (Okun 1997, Andrade and Scott 2002). To ensure that the utilities with residential reclaimed irrigation projects were not given more credit than their initial or projected potable irrigation use, the OC was applied as far back as the 1980s in Southwest Florida (Andrade and Scott 2002). The concept of the OC allows regulators to provide credit to utilities for reducing their potable water use. The recommended OCs for SFRs presented by RCC (2003) and Andrade and Scott (2002) are shown in Table 4-3. Based on the above analysis, the offset credit (OC) should be a function of the benchmark potable application rate, not the historical potable application rate that can vary widely based on numerous bio-physical and irrigator preference factors.

**Gainesville Residential Reclaimed System with Individual Meters**

This study was made possible by the availability of monthly metered water use data for 510 SFRs in Southwest Gainesville, Florida in planned neighborhoods. During the initial 18 months of operation of the meters, these SFRs received water with no commodity charge. Accounts on this portion of the reclaimed system were charged a flat-rate of $10.00 per month regardless of use. The homes in these neighborhoods have homeowners associations that monitor the quality of the landscapes. Water use for these SFRs was individually metered on a monthly basis, thereby providing an unusual opportunity to analyze metered irrigation water use in the absence of a commodity charge.

Using similar techniques to those applied in this study, Friedman *et al.* (2013) evaluated 6,305 SFRs that were classified as irrigators with in-ground irrigation systems in Gainesville, Florida. They classified irrigators as those users who had an application rate between 1 and 100 inches per year and irrigable areas between 1,000 and 100,000 ft$^2$. All of these residences irrigated on the potable water system in 2008 and paid a flat-rate of $5.35 per month and
commodity charges of $1.56 to $4.93 per 1,000 gallons (2008$) depending on their usage tier. These SFRs were compared to the reclaimed SFRs of this study with summary data shown in Table 4-4. The average year built for the potable irrigation homes is 1995, nine years older than the average year built of 2004 for the homes on reclaimed irrigation. Because watering new landscaping during establishment is allowed for up to 60 days and can increase water demand, the reclaimed data set was evaluated for age built. More than 86% of the potable water accounts were built before 2007 indicating that the initial irrigation of the landscape should not be a significant contributor to above average water use. The 2008 average values of these homes were $304,515 for the potable homes and $408,267 for the reclaimed homes. The potable irrigation homes have an average irrigable area of 14,000 square feet as compared to 10,600 square feet for the reuse homes.

Probability density functions (PDFs) and cumulative density functions (CDFs) provide a more detailed picture of the mix of SFRs in the data sets. The histograms of the irrigable area data sets, shown in Figure 4-2, indicate that both the potable and reuse histograms have a positive skew with a longer tail to the high side of the histograms. The distributions of irrigable areas are similar between the data sets with the SFRs with potable irrigation systems having slightly larger IAs overall.

Application Rates and Irrigation Efficiency of Flat-Rate Irrigation

As mentioned earlier, the benchmark application rate for Gainesville is 19.9 inches per year. The potable water homes with commodity charges in the $1.56 to $4.93 per kgal range used 13.2 inches per year, about 67% of the benchmark level. In sharp contrast, the reuse homes with free water applied 65.2 inches per year, 328% of the benchmark value. Thus, price can have a dramatic impact on outdoor water use. For this study, reclaimed data were filtered to remove accounts that had fewer than 1,000 ft² of irrigable area or that were classified as non-
irrigators (>4 months of zero water use in WY2008), but since all use is through a separate meter no accounts were eliminated because of large irrigable areas or application rates.

A wide variety of probability distributions were tested to see which distributions fit the data best. Distribution fitting software from Palisade Corporation (@Risk Version 6) was used to find the best fits according to three criteria: Chi-squared, Kolmogorov-Smirnoff, and Anderson-Darling. Detailed descriptions of these three criteria are contained in Ang and Tang (2007). Based on this fitting exercise, the lognormal model was in the top three best fits for both the reclaimed irrigable area and application rate. Because of the prevalence of the lognormal model and the quality of the data fits the lognormal model was selected as the preferred model. The lognormal distribution is defined based on the mean and standard deviation of the log transformed data. Equation 4-4 presents the CDF equation for the lognormal model, where the parameter value (X) is calculated based on the mean (µ=E(ln(x))), and the standard deviation (σ=[Var(ln(x)])^{0.5} [Ang and Tang 2007]). The lognormal fits for the irrigable area and application rate are shown with the probability plots in Figure 4-3, part A-D. In both cases, the lognormal model is observed to be a good fit for the data. The probability of the irrigable area or the application rate taking on a value between a lower bound, a, and an upper bound, b, can be found using Equation 4-4 or taken directly from the CDFs in Figure 4-3.

\[
P(a < X \leq b) = \Phi \left( \frac{\ln(b) - \mu}{\sigma} \right) - \Phi \left( \frac{\ln(a) - \mu}{\sigma} \right) \quad (4-4)
\]

The lognormal model can be defined simply based on the mean and standard deviation of the data. The fits for both irrigable area and application rate are observed to be well represented by the lognormal distribution based on the shape and probability plots. For the irrigable area, the lognormal fit with an untransformed mean of 8,452 square feet and an untransformed standard deviation of 1,938 square feet provides a good approximation that can be used to calculate the
CDF of the IA at any value. Similarly, for the application rate, an untransformed mean of 62.9 in/yr and an untransformed standard deviation of 1.98 in/yr provide a good approximation of the data.

The ARs are compared using PDFs and CDFs in Figure 4-4 and show striking differences between the data sets. The reclaimed accounts display an entirely different water use pattern covering a much broader range of application rates than the SFRs with irrigation systems. As part of their analysis, Friedman et al. (2013) removed users with more than 100 inches per year of application which were considered outliers for their data sets. However, the reclaimed accounts have approximately 25% of users applying in excess of 100 inches per year. The application rates on the flat-rate reclaimed system range from 5.1 to 738 inches per year. Referring to Figure 4-4, 486 (95.3%) of the 510 irrigators applied water above the average NID of 19.9 inches (IR>100%). Additionally 126 irrigators (24.7%) applied more than 100 inches per year. This is the result of irrigation with automated irrigation systems that are ubiquitous in this study area and the lack of a commodity charge. The impact of the commodity charge can be evaluated by comparing with irrigators on the potable water system evaluated by Friedman et al. (2013) and Romero and Dukes (2013). IARs are shown for the reclaimed accounts and other Florida utilities in Table 4-5. This comparison shows that the IAR for the reclaimed accounts without commodity charges is much higher than for water use in other areas around the state.

Variability in use is one of the primary focuses of this study. Howe and Linaweaver (1967), Hanke and Boland (1971), and Andrade and Scott (2002) determined that higher use occurred in the absence of commodity charges (flat-rate charges only), but each study was limited by the lack of account-level water use data. This lack of data limited the analysis for these studies to aggregate estimates of water use with no variability or understanding of how
individual accounts use water. In this study, significant differences were found to exist in the use behaviors across accounts receiving flat-rate water. A majority of all reclaimed customers apply water at an IAR of 150% to 400%, with 4.7% of users applying less than the NID and 34.1% applying water at an IAR greater than 400% as shown in Figure 4-5. This result is drastically different than irrigators on the potable water system where more than 63% have an IAR of less than 100%. Given the relatively consistent climatic conditions spatially across Gainesville, the primary difference for users with in-ground irrigations systems receiving potable or reclaimed water is the price of the water. In 2008, the potable irrigators were charged between $1.56 and $4.93 per 1,000 gallons (kgal) (dependent on their use tier) while the reclaimed water users were charged a flat-rate of $10 per month. For the average irrigable area of in-ground irrigators found by Friedman et al. (2013) of 14,023 square feet and the area-weighted application rate of 13.2 inches per year, water would cost an estimated $20.33 per month for potable users (assuming no indoor use), 203% of the reclaimed cost. The average use of 65.2 inches per year for reclaimed users would cost an estimated $120.36 per month if billed at the potable water rates and assuming no indoor use.

The reclaimed users applied water at an average application rate of 65.2 inches per year, nearly five times greater than the average rate found by Friedman et al. (2013) of 13.2 inches per year for SFRs with potable irrigation systems. Applying Equation 4-3 yields an OC of 20.2% for reclaimed users billed at a flat-rate for their use, or an OC of 30.5% when compared to the NID of 19.9 inches per year. When this OC is compared to offset rates proposed by Andrade and Scott (2002) of 25 to 35% for flat-rate users, the 20% offset rate found in this study is similar. However, the range of offsets across customers is highly variable from as much as 100% to as
little as 3%. It is anticipated that the inclusion of a commodity charge would narrow the variation in use because it would provide a clear price signal based on use.

**Water Savings Potential for Flat-Rate Reclaimed Customers**

Based on the findings of this research, significant water use reduction potential exists for reclaimed customers who do not pay a commodity charge for their irrigation use. Based on findings by Friedman *et al.* (2013), 2,327 of the 6,305 SFRs with irrigation systems, or 37%, irrigated in excess of their NID while 95%, or 486 reuse customers, irrigated in excess of the NID. Interestingly, despite the many more potable SFRs available to reduce water use, nearly an equal amount of water could be saved in the reclaimed group as shown in Table 4-6. In addition to the overall savings, reducing all of the potable water irrigators to no more than the NID of 19.9 inches per year would save an average of 195 gallons per day (gpd) for each of the modified SFRs, whereas 882 gpd per modified SFR could be saved by making the same reduction for the reclaimed customers.

Finally, the implications to the utility were considered. By reducing customers to the NID, the water demand savings can be shifted to provide water for new customers, for aquifer recharge projects, or other uses. By using the average irrigable area, the number of new customers who could be provided reclaimed water if existing customers were reduced to the NID can be estimated. For the potable customers, nearly 937 new customers (15% increase) could be provided with water at a rate of 19.9 inches per year, and for the reclaimed customers 1,174 new customers (230% increase) could be provided 19.9 inches of reclaimed water per year without increasing the total quantity of water delivered by the utility.

**Extrapolation to Other Flat-Rate Areas**

To apply the findings of this study in areas without water use data, the lognormal CDF can be used to estimate how SFRs might apply water in the absence of a commodity charge. The
lognormal CDF, Equation 4-4, is developed based on two parameters: the untransformed mean, 316.1%, and untransformed standard deviation, 197.5%. In areas without data, it might be reasonable to assume the average and standard deviation of this study yielding the same CDF. However, actual total water savings will be based on the IA, number of customers, and the local NID. In areas of Florida where the NID is not directly available, Figure 4-6 can be used to estimate NID. Using the values from Romero and Dukes (2013), ArcGIS was used to interpolate contours that were then smoothed to yield the shown contours. This generalization should be used with caution, especially in areas that are relatively distant from one or more of the 18 data points.

The lognormal-fit CDF and corresponding histogram and CDF for this data set are shown in Figure 4-7. Policies could be developed that would allow the utility to manage these demands to what might be considered a desirable application rate through metering and commodity charges or alternative delivery schedules (e.g. water is delivered to customers twice per week). Total water savings can be estimated for conservation efforts in flat-rate areas that reduce the maximum demand to the NID or any specified IAR by applying Equation 4-5. This equation is based on the NID, IAR, average irrigable area ($IA_{avg}$), number of customers (n), ratio of customers exceeding the NID ($R_{NID}$), and the IAR for the pre period ($IAR_{pre}$). This allows a utility to estimate the water savings in kgal per day, from reducing the application rate. These savings can then be used to bring new customers onto the reclaimed irrigation system, to recharge the aquifer, or for other uses. For this study area, application of Equation 4-5 produces an estimated savings of 377 kgal/day. This is approximately 12% less than the actual potential savings for the users of 428 kgal/day shown in Table 4-6. The discrepancy is due to presence of three extreme cases in this data set and the properties of the lognormal model that have very low
probabilities for extreme cases. In the case of this data, set three accounts have extreme use more than 50% greater than the fourth highest value. If these three accounts are eliminated from the savings calculation the potential water savings decrease to 384 kgal/day and in-line with the prediction of 377 kgal/day from the lognormal model.

$$Water\ Savings = 0.00171 \times IA_{avg} \times (n \times R_{NID}) \times NID \times (IAR_{pre} - IAR)$$ \hspace{1cm} (4-5)

Synopsis

Potable and reclaimed water users can be expected to use more water for irrigation when the water is provided free of a commodity charge. This study focused on a data set of 510 irrigators in Gainesville, Florida who received flat-rate reclaimed water for irrigation via secondary water meters. These customers were observed to apply more than three times the average NID of 19.9 inches per year in Gainesville, Florida. A majority of the users applied 100% to 400% of the NID, with more than one third of customers applying in excess of 400% of the NID, and only 4.7% applying less than the NID. If a utility designs its reuse system to meet the average and peak demands associated with providing free water, then the system will be much larger than needed if it was designed to meet demands that reflect the NID. This study provides an account-level analysis of water use that provides a clear understanding of not only the average water use characteristics, but also the range and variability of use. Furthermore, a lognormal function was developed to predict how users in other areas might be expected to use water in the absence of a commodity charge. This relationship allows a utility to apply their local NID to estimate the range of water use for their customers. By applying the savings calculations presented in this study a utility can estimate, based on the specific attributes of their utility and an estimate of the benchmark application rate for their area, the total potential savings if over-irrigators were to reduce their application rate to the NID.
These results can be applied in different ways for utilities with different needs, as discussed in two examples below. A utility that desires to decrease demand on a water resource might want to convert users to reclaimed water to reduce irrigation demand for potable water. The method for this utility might be to provide reclaimed water to customers with a commodity charge to incentivize use at a rate similar to the NID so that the largest number of potable users can be offset. This has been the case in Central Florida where water supply planning is expecting an offset rate of 64% (CFWI 2014). Conversely, a utility may want to decrease disposal of treated wastewater to minimize environmental or social concerns. In this case the utility might want to provide water for a flat-rate to customers so that irrigation will consume a large portion or all of the treated wastewater, minimizing the need for other disposal options. However, this approach can have long-term ramifications for the utility in sizing infrastructure during initial installation for this high use. When evaluating the water use associated with providing reclaimed water to customers for non-potable irrigation, the utility should consider how the water will be provided (flat-rate or commodity charges) and how much is to be used to determine the likely potable water offset. The results of this study provide a basis for utilities to make these estimates for customers receiving flat-rate water. Because of the limited nature of data availability, caution should be exercised when applying these techniques in areas with substantially different climatic or socio-economic conditions. If system-wide changes are to be made it may be necessary to collect additional location specific information that can be used to better define the relationships regionally.

Future work should include adding additional data sets to enhance the spatial extent of these findings and to ensure consistency in other areas. Evaluating irrigation use with commodity charges could indicate the ability to manage demand for reclaimed water. Also important in
reclaimed systems are the impacts of peak monthly demands on system sizing, the effect of irrigable area and home value on water use, and the fiscal impacts of current reclaimed water policy on utilities.

Figure 4-1. Reclaimed water use and reclaimed capacity in Florida (adapted from FDEP 2014)

Table 4-1. Reclaimed water delivery by price structure for reclaimed water systems in Florida (adapted from FDEP 2014)

<table>
<thead>
<tr>
<th>Type</th>
<th>Count</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Commodity Charge</td>
<td>43</td>
<td>32.3%</td>
</tr>
<tr>
<td>No Fixed Fee</td>
<td>16</td>
<td>12.0%</td>
</tr>
<tr>
<td>Flat-Rate</td>
<td>27</td>
<td>20.3%</td>
</tr>
<tr>
<td>Commodity Charge</td>
<td>90</td>
<td>67.7%</td>
</tr>
<tr>
<td>No Fixed Fee</td>
<td>43</td>
<td>32.3%</td>
</tr>
<tr>
<td>Combination</td>
<td>47</td>
<td>35.3%</td>
</tr>
<tr>
<td>All</td>
<td>133</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 4-2. Comparison of ten metered and eight flat-rate water use study areas (adapted from Linaweaver et al. 1966)

<table>
<thead>
<tr>
<th>Water Use — gpad</th>
<th>Metered</th>
<th>Flat-Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leakage</td>
<td>24</td>
<td>36</td>
</tr>
<tr>
<td>Indoor</td>
<td>247</td>
<td>236</td>
</tr>
<tr>
<td>Outdoor</td>
<td>186</td>
<td>420</td>
</tr>
<tr>
<td>Total</td>
<td>457</td>
<td>692</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outdoor Application Rate — in/yr</th>
<th>Metered</th>
<th>Flat-Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor Application Rate (OAR)</td>
<td>14.0</td>
<td>39.4</td>
</tr>
<tr>
<td>Potential OAR Requirement</td>
<td>22.5</td>
<td>14.8</td>
</tr>
<tr>
<td>OAR/OARR</td>
<td>62%</td>
<td>266%</td>
</tr>
</tbody>
</table>
Table 4-3. Reclaimed water offset credits (adapted from RCC [2003] and Andrade and Scott [2002])

<table>
<thead>
<tr>
<th>Reclaimed Activity</th>
<th>Offset Credit</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aesthetic features</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Agricultural irrigation - efficient</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Agricultural irrigation - inefficient</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Commercial laundries</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Cooling towers</td>
<td>100%</td>
<td>Reuse Coordinating Committee (2003)</td>
</tr>
<tr>
<td>Fire protection</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Landscape irrigation - efficient</td>
<td>75%</td>
<td></td>
</tr>
<tr>
<td>Landscape irrigation - inefficient</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Vehicle washing</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Toilet flushing</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Residential irrigation - metered</td>
<td>45-55%</td>
<td>Andrade &amp; Scott (2002)</td>
</tr>
<tr>
<td>Residential irrigation - flat-rate</td>
<td>25-35%</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-4. Average characteristics of Gainesville, Florida homes with irrigation systems

<table>
<thead>
<tr>
<th>Account Type</th>
<th>Count</th>
<th>Year Built</th>
<th>2008 Value ($)</th>
<th>Irrigable Area (1,000-sq.ft.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SFRs w/Potable Irrigation</td>
<td>6,305</td>
<td>1995</td>
<td>304,515</td>
<td>14.0</td>
</tr>
<tr>
<td>SFRs w/Reclaimed Irrigation</td>
<td>510</td>
<td>2004</td>
<td>408,267</td>
<td>10.6</td>
</tr>
</tbody>
</table>

Figure 4-2. Comparative PDFs and CDFs of irrigable areas for the potable and reclaimed accounts
Figure 4-3. Lognormal fit of irrigable area and application rate with CDF (Part A & C) and probability plot (Part B & D)

Figure 4-4. Comparative PDFs and CDFs for application rate for reclaimed and potable accounts
Table 4-5. Irrigation application ratio for GRU reclaimed accounts (no commodity charge) and other Florida utilities

<table>
<thead>
<tr>
<th>Utility</th>
<th># of Accounts</th>
<th>Irrigation Application Ratio</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>GRU – Potable</td>
<td>6,305</td>
<td>66%</td>
<td>Friedman et al. (2013)</td>
</tr>
<tr>
<td>Apollo Beach</td>
<td>1,020</td>
<td>93%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Brandon</td>
<td>3,514</td>
<td>73%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Dover</td>
<td>103</td>
<td>58%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Gibsonton</td>
<td>369</td>
<td>46%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Lutz</td>
<td>1,599</td>
<td>92%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Riverview</td>
<td>3,315</td>
<td>75%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Ruskin</td>
<td>1,443</td>
<td>68%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Seffner</td>
<td>1,364</td>
<td>58%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Sun City</td>
<td>122</td>
<td>102%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Tampa</td>
<td>12,209</td>
<td>78%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>Valrico</td>
<td>3,704</td>
<td>93%</td>
<td>Romero &amp; Dukes (2011)</td>
</tr>
<tr>
<td>GRU – Reclaimed</td>
<td>510</td>
<td>328%</td>
<td>This Study</td>
</tr>
</tbody>
</table>

Figure 4-5. Comparative PDFs and CDFs for irrigation application ratio of reclaimed and potable accounts
Table 4-6. Savings potential for SFRs with potable irrigation and reclaimed systems

<table>
<thead>
<tr>
<th>SFR Account Type</th>
<th>Potable w/Irrigation</th>
<th>Reclaimed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Customers</td>
<td>6,305</td>
<td>510</td>
</tr>
<tr>
<td>Customers &gt;NID</td>
<td>2,327</td>
<td>486</td>
</tr>
<tr>
<td>Total Daily Savings (gpd)</td>
<td>453,158</td>
<td>428,609</td>
</tr>
<tr>
<td>Daily Savings per SFR (gpd)</td>
<td>195</td>
<td>882</td>
</tr>
<tr>
<td>New Customers Supplied</td>
<td>937</td>
<td>1,174</td>
</tr>
</tbody>
</table>

Figure 4-6. Estimated net irrigation demand contours for Florida (based on Romero and Dukes 2013 data)
Figure 4-7. Histogram and CDF for reclaimed customers receiving flat-rate water and fit to estimate range of consumption
CHAPTER 5
EFFECT OF COMMODITY CHARGES ON THE DEMAND FOR RECLAIMED WATER

Scope and Overview

Understanding and managing outdoor water demand for residential irrigation is imperative to address water scarcity throughout the United States. In many areas, water use for residential irrigation has the potential to increase with the growing popularity of automatic irrigation systems in new homes (Friedman et al. 2013). The increased ability to automatically irrigate outdoors could offset the savings being realized through improved indoor efficiency. One method of meeting increased outdoor demand has been to supply reclaimed water for landscape irrigation. Florida led the nation in 2006 with 663 million gallons per day (mgd) of reuse or an overall statewide average of 36.8 gallons per capita per day. The Florida Department of Environmental Protection inventories reuse annually to satisfy a state law (Bryck et al. 2008). Reuse in Florida has grown from 663 mgd in 2006 to 719 mgd in 2013. A total of 184 mgd of the 719 mgd, or 25.6%, was for residential irrigation in 2013.

Charges for reclaimed water in Florida vary widely, but generally fall into one of four categories (Florida values in parentheses): no charge (12.0%), a fixed-fee (20.3%), a commodity charge only (32.3%), or a combination of methods (35.4%) (FDEP 2014). Based on FDEP survey data from 2013, 32.3% of the 133 utilities sampled did not levy a commodity charge for reuse water (FDEP 2014). For utilities without a commodity charge, water use is expected to exceed potable irrigation demand needs (Howe and Linaweaver 1967, Hanke 1970, Knight et al. 2015a). Specifically for Gainesville, Florida, Knight et al. (2015a) found that water use without a commodity charge was 328% of average annual irrigation requirements, and one-quarter of users applied more than 500% of the average annual requirements.
The first public reclaimed systems were installed in Southwest Florida to avoid increased regulations for surface water discharge to natural features (Okun 1997). However, as the extraction of high quality aquifer water has increased, ecological impacts have been observed, and reclaimed water is being considered as an offset to meet demands for outdoor use. Balancing both short- and long-term utility goals is an important component of widespread reclaimed irrigation development. These goals can vary from maximizing reclaimed water use to minimize wastewater disposal, to maximizing the number of customers on the reclaimed system to minimize potable withdrawals. The relative emphasis on these two goals can change over time as the reclaimed water demand-supply relationship changes. This study builds on the results of Knight et al. (2015a) and presents an analysis of the impact on residential irrigation average and peak monthly demand resulting from a 2008 change in the commodity charge from $0.00 per 1,000 gallons (kgal) to $0.60-0.65/kgal for reclaimed water. The data set for this study is comprised of 510 newer single family residences in Gainesville Florida that were metered at the parcel-level both before and after the implementation of the commodity charge. Using observed changes in monthly water use and a daily benchmark irrigation demand estimation model, the customers’ reactions are characterized. By defining the irrigation need, the customer reaction can be defined in terms of their monthly irrigation application. To compare customers and generalize the customer response, a normalization method is presented to classify irrigators based on their water demand. Finally, the results, and their implications, including changes in utility revenue and water supply as a result of changes in customer behavior, are discussed.

**Related Research**

Standard water budgeting calculates the agronomic irrigation demand (AID) as a function of monthly precipitation and evapotranspiration with adjustments for irrigation efficiency and influent water quality (Asano et al. 2007). This approach assumes that demand for irrigation
water is independent of price and that irrigators adjust their application rates to coincide with the monthly values of evapotranspiration and precipitation and thereby follow the AID. With regard to the effect of pricing, extensive research has addressed this question. The first Manual of Practice from the American Water Works Association, M1, released in 1954, and now in its 6th edition, is focused entirely on rate-setting for water providers (AWWA 2012). Dozens of studies have analyzed the impacts of increasing prices on water demand, e.g. Dalhuisen et al. 2003. In virtually all cases, urban indoor and outdoor demands decreased as price increased.

Studies that have analyzed the change in demand resulting from modifying rate structures from flat-rate to commodity-charges are limited. This is partially due to the lack of good water demand data for flat-rate areas where little incentive exists to meter use, and due to the prevalence of metering for potable water as early as the 1960s (Seidel and Cleasby 1966). Two early studies of changing water users from flat-rate to metering and commodity charges were completed by Linaweaver et al. (1966) and Hanke (1970). These studies found that users who were metered and billed for their use had significantly lower water use than users who were provided water at a flat-rate. Additionally, Howe and Linaweaver (1967) found that the primary difference in use for these two classes of customers was in outdoor water use rather than indoor water use, which was nearly identical for the two classes of customers. In a recent study on the impacts of metering residential water use, Tanverakul and Lee (2015) found that customers who were previously unmetered applied 15% to 31% more water on average than similar customers who were metered and charged for their use. With the implementation of metering, these customers were observed to reduce water use until average consumption was similar (-13% to +9%) to that of previously metered customers.
Reclaimed Water Supply in Florida

The earliest reclaimed water systems in Florida provided unlimited water for a flat-rate to their customers. These early adopter utilities avoided comparatively expensive wastewater disposal options by switching to reclaimed water. However, for other utilities, the need to reduce potable water demand has been an important consideration for undertaking reclaimed water projects. In Florida, providing reclaimed water to residential customers requires supplemental treatment including high-level disinfection and filtration before distribution which can increase the cost of treatment.

The difference in purpose for reclaimed water development has led to inconsistencies in charging mechanisms for reclaimed water. The Florida Department of Environmental Protection (FDEP) compiles reclaimed water information on an annual basis for reclaimed water providers. In 2013, of the 133 surveyed reclaimed providers, 43 (32.3%) had no commodity charge based on use and 90 (67.7%) used a commodity charge (FDEP 2014). For the utilities charging a commodity charge, the average rate was $0.96 per 1,000 gallons (kgal). Of the 133 utilities, 59 (44.4%) charged no fixed fee, but the remainder charged an average of $10.48/month for utilities without commodity charges and $8.08/month for utilities with commodity charges.

In some cases, utilities have more than one billing mechanism with a portion of their system billed at flat-rates and the remainder metered with commodity charges. In these cases, early reclaimed users were often provided flat-rate water to minimize the cost to the customers and utility for installing and reading meters, encourage the use of a non-potable water supply, and to maximize demand to reduce disposal needs (Reuse Coordinating Committee [RCC] 2003).
Potable Water Offset Credit

The extensive development of reclaimed water systems in Florida as an inexpensive water source proved to be attractive for irrigators and has resulted in high water use, with only 25-35% of the reclaimed use offsetting the original potable water demand (Andrade and Scott 2002). To describe this phenomenon and give utilities proper credit for projects, the RCC (2003) proposed the concept of the potable water offset credit (OC). This concept compares the average application rate (AR), the depth of water applied over the irrigable area (IA) for a specified time period, using potable water (AR\textsubscript{potable}) or reclaimed (AR\textsubscript{reclaimed}) water as shown in Equation 5-1.

\[
OC = \left( \frac{AR_{\text{potable}}}{AR_{\text{reclaimed}}} \right) \times 100\%
\] (5-1)

Estimated values of the OC have been developed for multiple uses and range widely from 100% for toilet flushing (RCC 2003) to 25-35% for flat-rate irrigation (Andrade and Scott 2002). Andrade and Scott (2002) examined reclaimed irrigation with commodity charges and found OC values of 45-55%. These results indicate that the presence of a commodity charge reduces irrigation application, but that ARs still exceeded typical potable ARs although no detailed information on commodity charges was provided for this study.

The Florida definition of potable water OC is different but complementary to that of the Alliance for Water Efficiency (Christiansen 2015b) who defines water offsets as the projected demand for new development being offset by reductions in existing demand, and water credits as savings from converting existing demand to a lower demand through conservation measures. Christiansen (2015a) summarizes recent efforts to apply water offset credits for new developments that are constrained to not increase the total water demand for the utility even though the number of customers is growing. He includes case studies of 10 utilities in California, two in Massachusetts, and one in New Mexico. Maddaus et al. (2008) describe how this
approach was applied to new residential developments in California and one in Massachusetts. Olmos and Loge (2013) do a similar analysis of a new mixed use development in Davis, California. The objective is to offset the added demand for each new customer by implementing onsite and offsite measures that result in no net increase in water use for the utility. A popular way to meet this condition is for the developer to pay the utility to finance conservation programs elsewhere in their system and/or compensate other users in the watershed for reducing their water use. Maddaus et al. (2008) were able to reduce onsite water use by 20-30% in their case studies. The Florida concept of OC complements this approach by providing a clear approach to valuing the credit that reclaimed water projects will receive.

**Parcel-Level Analysis**

The development of high-quality geographic information system databases allows for an enhanced level of analysis and understanding of residential irrigation. Using county property tax assessor databases in Florida that include, at a minimum, basic structure area, total parcel area, home value, and year built, accurate estimates of irrigable area (IA) can be developed at the parcel-level (Friedman et al. 2013). Furthermore, the combination of monthly water billing data with parcel data provides an estimate of the quantity of water applied for irrigation. This method is especially applicable for parcels that meet irrigation water demands through a secondary reclaimed meter devoted to irrigation, thereby avoiding the complexities of removing the indoor component of the total demand.

**Benchmark Irrigation Application**

Irrigation adequacy can be defined as the combination of water application adequacy and water application efficiency (Grabow et al. 2013) and acceptable landscape quality. Application adequacy describes how well the theoretical needs were met. Application efficiency describes
how much of the applied water met the theoretical needs. The acceptable landscape quality describes the acceptable physical condition that is being maintained through irrigation.

Outdoor residential water demand models typically use monthly or annual precipitation and evapotranspiration data to estimate irrigation (Asano et al. 2007). However, irrigation takes place in response to soil moisture deficits that occur within a few days of the previous irrigation or precipitation event. This paper focuses on the water application adequacy by applying a monthly benchmark irrigation demand derived from a daily soil water balance model developed as part of this study. Monthly values of irrigation demand are developed by summing up the calculated daily demands. The daily irrigation demand model developed for this study follows Dukes’ (2007) daily soil water balance methodology that determines the water availability within the root zone of the chosen plant type, with irrigation provided to maintain the moisture level between the field capacity and the maximum allowable depletion. By maintaining this quantity of water in the root zone with supplemental irrigation the water needs of the vegetation are satisfied. The soil water balance equation used for this calculation was presented by Romero and Dukes (2013) and is shown in Equation 5-2, with all components expressed as depths of water. This benchmark is referred to as the net irrigation demand (NID) in contrast to Dukes’ net irrigation requirement (NIR) because the customer ultimately has the choice whether to meet the NIR or over- or under-apply irrigation. The key parameters in this model are the irrigation (I), soil water (SW), crop adjusted evapotranspiration (ETc), rainfall (R), drainage (D), and runoff (Roff) for the current time step (t) or previous time step (t-1).

\[ I_{t-1} = SW_t - SW_{t-1} + ETc_{t-1} - R_{t-1} + D_{t-1} + Roff_{t-1} \] (5-2)

**Gainesville Study Area Description and Methods**

This study evaluated 510 residential reclaimed water customers in Gainesville, Florida who were metered monthly during the past seven years. Utility services including electric, gas,
water, and wastewater are provided by Gainesville Regional Utilities (GRU). GRU supplies water to approximately 190,000 people and currently provides about 2.4 MGD of public access reuse (PAR) for golf courses, residential irrigation, and recharge wetlands (GRU 2013). The long range plans of GRU include additional PAR and recharge projects. Expansion of the PAR is planned based on reclaimed water service area boundaries that define the future service area in the vicinity of the wastewater facility.

This study examines reclaimed customers for the period from October 2007 through September 2014. During the initial year of metering (fiscal year [FY] 2008 that began in October 2007) the reclaimed customers were charged a flat-rate of $10.00 per month for irrigation water use. During the remaining six years these customers paid relatively low commodity charges ($0.60-0.65/kgal) for their water use with a fixed monthly account charge of $6.00 to $7.85. A summary of rates by year is shown in Table 5-1. This data set provides metered water use both before and after the conversion to commodity charges that can be used to evaluate the reaction of customers to this change in billing. Metered water use data before commodity charges are rarely available because utilities are not incentivized to install meters and collect data if the customer is not being billed based on their use.

The homes in this study are located within planned neighborhoods with homeowner associations (HOAs). The existence of HOAs has the potential to influence customer behavior, but cannot be separated for the customers in this study. However, homeowner’s desires and HOA desires typically align as the HOA is formed to represent homeowners, and furthermore homeowners in Florida may install alternative “Florida-Friendly Landscapes” without HOA approval if they choose (Florida Statutes 373.185). Homes that receive reclaimed water in this area are also exempt from watering restrictions that are in place for potable water users. The
average home in this data set was built in 2004 and had a 2008 value of $408,000 and an average irrigable area of 10,600 square-feet. All of the homes that received reclaimed water have automated irrigation systems. However no data was available for this study about whether parcels used smart irrigation controllers or time-based controllers. These customers are all located in southwest Gainesville within a few miles of the water reclamation facility.

Monthly billing data for the 510 customers were rectified based on read dates to account for the change in read period that could impact the actual water use in a given month. This process produced a monthly data set with the appropriate days of water use in each month. This process is less necessary when evaluating data annually because of the longer averaging period, but at the monthly scale can be significant if read dates vary month to month. For this data set, the rectification caused the annual application rate for the flat-rate period to be 66.0 inches instead of 65.2 inches, a change of 1.2%.

To put the commodity charge for reclaimed water in context, it can be compared to the 30,903 GRU residential accounts who receive potable water. These accounts fall into three classes: 1,402 with separate irrigation meters, 6,902 with single meters and irrigation systems, and 22,599 with single meters and no irrigation systems. In each of these three cases, customers receive water at tiered potable rates. Customers with single meters have three price tiers while customers with dual meters have only two tiers that match the second and third tiers of those with single meters. The water rates for the dual meter customers are about five to ten times higher than equivalent rates for the reclaimed users during the same period and are shown in Table 5-1.

**Benchmark Irrigation Calculation**

A major source of error in irrigation models is the assumed operating policy for the analysis. The typical assumption is that the irrigator is able to operate the system to accurately
apply each day the appropriate amount of water to meet the needs of the plant. However, the actual behavior of the irrigator can vary widely from this assumed ideal irrigation application rate with some irrigators doing little or no temporal management of their irrigation system (e.g. “set it and forget it”). To develop this model, it was necessary to collect weather data and crop and soil parameters. Values for soil and crop parameters were taken from Romero and Dukes (2013) and show a turfgrass growing season typically between April and October. As proposed by Romero and Dukes (2013), runoff was assumed to be negligible for the generally sandy soils in the study area that allow nearly all excess rainfall to drain through the root zone. Irrigation was modeled to occur when the available water content in the soil profile dropped below the maximum allowable depletion (MAD), when half of the soil’s available water holding capacity was empty. Weather data were gathered for the study area from the Florida Automated Weather Network (FAWN), which maintains weather stations throughout the state that report precipitation, solar radiation, wind speed, as well as other parameters of interest to agriculture (University of Florida – Institute of Food and Agricultural Sciences [UF-IFAS] 2014). FAWN offers the benefit of consistent data collection and analytical methods for more than 40 locations across the state. Weather data from the FAWN stations were used to calculate the daily ET based on the Zotarelli et al. (2009) adaptation of the Penman-Montieth Method. This method was developed to facilitate accurate ET calculation using the data collected at FAWN stations and includes appropriate conversions where necessary.

To more accurately represent the precipitation and evapotranspiration for the study area in Gainesville, Florida, three FAWN stations (Alachua, Bronson, and Citra) were weighted based on their distance to the study area. Using the calculated ETc and rainfall, the supplemental irrigation was calculated daily and aggregated to monthly values. This study made use of the
utility fiscal year (FY) designation, corresponding to the water year of October through September, e.g. FY2008 is October 2007 through September 2008. Monthly precipitation and ET patterns from FY2008 to FY2014 for the study area are shown in Figure 5-1. The seven year average annual precipitation is 48.1 inches with a range from 36.8 inches in 2011 to 65.6 inches in 2012. The seven year average ET was 30.5 inches per year with a range from a low of 27.5 inches in 2013 to a high of 32.0 inches in 2008. The monthly precipitation, ETc, and NID are shown in Figure 5-1, Part A for the period of record. Additionally the annual values are shown in tabular format in Figure 5-1, Part B and graphically in Figure 5-1, Part C. As shown in Figure 5-1, Part C, precipitation is more volatile than the ET with a coefficient of variation (COV) of 0.23, over three times the COV of ET. Finally, the average monthly values for the seven years are shown in Figure 5-1, Part D showing the seasonality of the precipitation, ETc, and the NID.

The benefit of calculating the NID is that it provides a mechanistic estimate of the irrigation needed to provide a defined quantity of water to the plant. This is an improvement over methods that rely on monthly data that miss the potential need for irrigation on a nearly daily basis. It also provides a normalized approach that can be applied over a wide geographical area. The concept of the OC and the absolute differences between the quantity demanded and the NID can be used to develop metrics to assess adequacy of irrigation and changes in behavior temporally resulting from changes in price. It is important to clarify that the NID is the actual quantity of water needed in the root zone and does not account for application inefficiencies in irrigation system design that cause water to not reach the root zone (e.g. over-spray on impervious or non-vegetated areas). Lack of application efficiency could cause significant differences in the amount of supplemental irrigation required; a value of 80% was discussed by Mayer and DeOreo (2010) as a representative level of efficiency for residential irrigation. This
equates to customers having to apply 25% excess to achieve the NID, however for this study the application efficiency was assumed to be 100% for all analyzed accounts.

**Irrigation Efficiency Calculation**

In previous research, Knight *et al.* (2015a) calculated the annual OC using the annual AR and a long-term average annual NID of 19.9 in/yr for Gainesville from Romero and Dukes (2013). The reciprocal of this value was termed the annual irrigation application ratio (IAR) and was used to express how much of the average annual NID was supplied as irrigation. During the FY2008 flat-rate period, the 510 users in this study had IARs of 328% on average indicating that they applied an average of 65.2 in/yr of supplemental irrigation. A limitation of using annual averages is that annual irrigation values do not account for how the water is applied during the year, and may not accurately reflect how well the NID was met. As an example, a customer who sets their irrigation meter on January 1st and makes no changes during the year applying 20 in/yr has an identical IAR to a customer who follows the seasonal pattern of the NID and applies 20 in/yr. Using the minimum of the monthly AR and monthly NID with the annual NID, the IAR can be transformed into the irrigation demand satisfied (IDS<sub>y</sub>). The IDS<sub>y</sub> specifically defines the portion of the monthly NID that was satisfied for the analysis year. The annual IDS<sub>y</sub> can be calculated by applying Equation 5-3 and ranges from 0% (none of the NID<sub>y</sub> was satisfied) to 100% (all of the NID was satisfied).

\[
IDS_y = \left( \frac{\sum_{m=1}^{12}(\min(NID_m, AR_m))}{\sum_{m=1}^{12} NID_m} \right) \times 100\%
\]  

(5-3)

The second term defined and used in this study is the annual effective irrigation application (EIA<sub>y</sub>) which defines the portion of the applied irrigation that contributes to meeting the annual NID. As with the IDS, the EIA was defined as the lesser of the monthly AR or monthly NID compared to the annual AR. This ratio defines the percentage of the water applied
that effectively met the NID. The EIA ranges from 0\% (none of the applied water met the NID) to 100\% (all applied water met the NID) and is calculated as shown in Equation 5-4.

\[
EIA_y = \frac{\sum_i^2 \left( \min(NID_m, AR_m) \right)}{\sum_i^2 AR_m} \times 100\%
\]  

(5-4)

The EIA does not penalize under-application by irrigators. By evaluating the minimum of the AR and NID, the user is not penalized if they apply less than the NID, and could achieve 100\% efficiency by applying much less than the NID, except 0 kgal which would indicate that the customer is a non-irrigator. The combination of both the IDS and the EIA accounts for both under- and over-irrigators by evaluating not only the portion of the NID met, but also how efficiently it was met. This allows for classification of users based both on their monthly application and the magnitude of application. The IDS and EIA are related as shown in Equation 5-5.

\[
\frac{IDS_y}{EIA_y} = \frac{\sum_i^2 (AR_m)}{\sum_i^2 (NID_m)} = IAR_y
\]

(5-5)

An example that shows the tradeoffs between IDS and EIA is shown in Figure 5-2 with the same monthly NID pattern for three scenarios. The first year shown is an example of an over-irrigator who applies water to meet the peak month demands and over-applies during all other months. The second year shows an irrigator attempting to follow the seasonal demands with slight deviations above and below the NID. The final year shows an irrigator who consistently under-applies water, maximizing the efficiency of their application, but not meeting all the needs of their landscape.

**Change in Customer Demand with a Commodity Charge**

As shown by Knight et al. (2015a) reclaimed customers charged only a flat-rate can be expected to apply water in excess of the plant’s agronomic irrigation demands. This study expands on this annual analysis by focusing on how well the customer met the monthly values of
the NID and whether they improved their irrigation practices after charges began for their water use. During the seven year analysis period (1-year flat-rate, 6-years commodity charges) values of the NID ranged between 14.0 and 22.8 inches per year. Application rates during the flat-rate year (fiscal year [FY] 2008) averaged 66.0 inches per year. Following the commodity charge starting in FY2009, application rates decreased to an average of 45.1 inches per year. Between FY2010 and FY2014 application rates varied between 28.5 and 42.3 inches per year. Average AR and the NID as well as statistics for the AR, NID, and IAR are shown in Figure 5-3.

Despite consistent irrigation beyond the NID, not all users met all of the theoretical plant demands every month. The irrigation demand satisfied (IDS), shown in Equation 5-3, provides an estimate of how much of the plant’s needs were met on a monthly basis. Customers during the flat-rate period applied 333% of the average NID, but only met 87% of the monthly NID. If data are evaluated in the aggregate on an annual basis using an area-weighted average it appears that sufficient water was provided to meet all needs, but when each account is individually considered with credit given only for the water on each parcel that satisfied the NID it can be seen that some portion of the users applied less than the NID in specific months. By evaluating monthly water use at the parcel-level the number of times under-application occurred can be counted for each year. In FY2008, there were 751 user-months that did not meet the NID for 2008, or 12.3% of the total 6,120 user-months.

After commodity charges began in October of 2008, the portion of the IDS decreased to an average of 78% of the NID, with a range from 68% to 85% for the six years with commodity charges. Additionally the number of user-months when the NID was not satisfied increased to between 1,399 (22.9%) and 1,835 (30.0%) per year between FY2010 and FY2014.
These results show a major decrease in the average application rate after the commodity charge began in October 2008, Figure 5-3, Part A. In order to eliminate the effect of the transition, the post-period begins in FY2010. Additionally users maintained this lower AR over the six years with commodity charges. From the pattern of average AR, irrigators appear to not follow the pattern of the NID with a peak in May or June followed by reduced need in late summer and virtually no need in winter. This leads to irrigators operating in a relatively seasonal fashion with high and consistent values during the summer and slightly lower but consistent values in the winter. Especially in the three winter months with the lowest average NID (December, January, and February), this results in higher ratios of AR to NID than during the three spring months with the highest NID (April, May, and June) as shown in Figure 5-3, Part B. The higher winter ratio of AR to NID of 10.7 would indicate that customers could be encouraged to reduce water use during the period of minimal irrigation needs. This figure also shows a primary challenge for reclaimed water systems that have highly variable monthly use despite a relatively consistent supply and the potential need for large capacity storage to optimize and increase the efficiency of these systems.

To visualize the water savings from the flat-rate to commodity charge period, each year with a commodity charge was individually compared to the flat-rate year. This provides a difference in use for each customer, which can be sorted to develop a cumulative density function (CDF) of savings. This data is presented both normalized and in absolute water savings in Figure 5-4, Part A and B, respectively. The normalized CDF shows that all years had similar shapes with approximately 60 to 70% of the savings occurring from 20% of the customers. Additionally each year shows that some customers increased their use. Economic theory postulates that users will decrease demand when faced with increasing prices (Espey et al. 1997,
Dalhuisen *et al.* 2003, Whitcomb 2005, Griffin 2005). In each year, between 14 and 27% of users increased their water use compared to the flat-rate year and caused increases of between 5 and 14% in use, Figure 5-4, Part A. The absolute savings between each of the commodity charge years and the flat-rate years were also produced and show that between 196,000 and 352,000 gallons could be saved per day with commodity charges in place if all users are included. If only users that decreased water use are included, then savings would be between 227,000 and 371,000 gallons per day. To examine the differences in savings for the different years, the 2008 NID of 19.8 inches was compared to the NID for each of the commodity charge years and the difference is shown in Figure 5-4, Part B. With the exception of FY2010 and FY2012 that had similar NIDs, the smallest savings are observed to occur in years with higher NID values. This indicates that the customers are aware of the needs of their landscaping and are adapting their use to approximate those needs.

**Change in Effective Irrigation Application with a Modest Commodity Charge**

Of interest to this study is not only the availability of water in the soil profile, but how much water the users applied to maintain this soil moisture. This metric termed the effective irrigation application (EIA – Equation 5-4) relates the amount of water provided that met the NID to the total water applied. Overall, water use decreases as price increases. However, this group of customers could be expected to reduce use less because of the offsetting influence of the higher value of their properties. The average home value can be used as a surrogate for income as proposed by Whitcomb (2005) and averaged $408,000 for the 510 customers in this study. GRU provides not only water, but also gas, electric, and wastewater services that are all included on the monthly bill. Assuming average utility bills of about $250 for single family homes, reclaimed water use at a flat-rate of $10 month comprises only 4% of the monthly bill. Even if users had continued to apply the same average volume of water (36 kgal/month) after
rates were changed to commodity charges in 2009, their total bill would have only increased by $18/month with reclaimed water making up 10% of the $268 bill. This change in monthly costs is minimal when compared to the average home value, and these users still would have paid less than a similar potable dual meter customer applying only 7 kgal/month in 2009.

Despite the relatively low cost of reclaimed water, EIA increased from 39% in FY2008 to between 48% and 55% during FY2010 to FY2014. This increase in EIA means that users applied water more efficiently after commodity charges began. These increased EIA values indicate that a larger portion of the water supplied met the NID. When this result is examined in the context of the decreasing value of the IDS, it is observed that users met less of the overall NID, but this portion was met more efficiently.

**Customer Classification Based on Irrigation Behavior**

By combining the two metrics, IDS and the EIA, a better picture of the type of irrigator can be developed. To convey these results, clustering techniques were applied to characterize different types of users. The Two-Step Clustering technique implemented in SPSS v21 was used to do a pre-clustering and a final assignment of sub-clusters based on the desired number of clusters (IBM 2012). The users were assigned to three clusters based on their IDS and EIA for the 2008 flat-rate period. These clusters illustrate three groups of customers with different behaviors with regard to IDS and EIA (Figure 5-5, Part A). The 135 Cluster 1 users had lower IDS and generally higher EIA values. These users have lower overall application rates that average 28.6 in/yr. The 156 Cluster 3 users have IDS values of close to 100%, but have generally low EIA values indicating that they applied enough water to meet the NID, but did so by applying excess irrigation, an average of 155.3 in/yr. The other 219 users in Cluster 2 fall between Clusters 1 and 3 and include customers who had relatively high IDS, but also had a generally higher EIA applying an average of 59.9 in/yr.
By keeping the customers in the same clusters, but plotting the IDS and EIA for the post flat-rate period (Figure 5-5, Part B) it is observed that fewer customers had high IDS values and there was a shift toward higher EIA with the customers in Clusters 2 and 3 migrating towards Cluster 1. These figures show that the customers overall had reduced IDS and improved EIA. During the flat-rate period, 231 customers had IDS values of 100%. Following the commodity charge, this value decreased to an average of 136 customers per year. Average application rates for Clusters 1, 2, and 3 also decreased by 20%, 40%, and 62% (Figure 5-5, Part C), respectively and the overall application rate decreased by 47%. These results indicate that extremely high application rates were largely discontinued in the presence of a modest commodity charge. Also, the magnitudes and gradients of the change in centroid positions of the clusters indicate that the customers with the greater responses are the highest water users.

By examining the time series for the three clusters in Figure 5-6 it is observed that Clusters 2 and 3 both lowered use and maintained this lower use without a rebound to higher application rates. Cluster 1 reduced their application rates to a lesser extent and increased both their IDS and EIA values. This indicates that these users better matched the seasonality of irrigation demands. Clusters 2 and 3 both increased their EIA, but maintained their IDS near 100% with Cluster 2 missing some of the peak demand months after commodity charges began.

**Irrigable Area Impacts on Effective Irrigation Application**

Customers are expected to apply water based on their irrigable area. This would have the effect in an ideal setting of irrigators across parcel sizes supplying different quantities of water dependent on how much area they are irrigating but with similar application rates and it might be hypothesized with similar values for IDS and EIA. However, when the data were evaluated for the flat-rate period, accounts with smaller irrigable areas generally had lower values of EIA than larger lots. Furthermore, even after the commodity charge began, smaller lots continued to have
lower values of EIA. Clustering was used to divide the accounts into two groups based on irrigable area and the value of the EIA. For the flat-rate period Cluster A (n=125) had an average irrigable area of 22,700 square-feet and an EIA value of 53% and Cluster B (n=385) had an average irrigable area of 7,300 square-feet and an EIA value of 25% as shown in Figure 5-7, Part A. The period after the commodity charge was also plotted based on the same clusters, Figure 5-7, Part B. This showed that the value of EIA increased significantly for Cluster B to 39% and to a lesser extent for Cluster A to 61%.

The results of clustering on irrigable area and the value of EIA indicate that irrigators with smaller irrigable areas generally apply water less efficiently than irrigators with large lots. Additionally smaller lots improved their efficiency following implementation of a commodity charge to a greater extent, but still over-applied to a greater extent. When the IDS is included it shows the opposite trend to the EIA with Cluster B having an IDS of 95% and Cluster A having an IDS of 77%. After the commodity charge began the Cluster B IDS decreased to 86% and Cluster A IDS decreased to 71%. These results show that both groups had decreases in how well they met the landscaping NID because less total water was applied.

In evaluating this phenomenon it is important to understand that irrigable area in this study was calculated based on parcel attributes. For this data set, high-valued homes in relatively new neighborhoods, this approach should work well. However, as lot size increases, irrigable areas may not increase as more of the property may be in an alternative un-managed and/or un-irrigated condition. This phenomenon was discussed by Friedman et al. (2013) who included a cutoff of 100,000 square-feet of irrigable area for outdoor irrigation.

**Application of Findings to Reclaimed Water Systems**

Utilities treat and distribute reclaimed water for varying purposes. With limits on the development of new water supplies in Florida, reclaimed water is now being viewed by some
utilities as an alternative water supply. These utilities may have an incentive to decrease use and maximize efficiency to increase the offset of new potable withdrawals. The findings of this study indicate that a utility attempting to minimize wastewater discharges might encourage additional use by customers if reclaimed water is provided for a flat-rate. Similarly a utility currently providing reclaimed water for a flat-rate might be able to expand their customer base by adding a commodity charge. Installation and operation of a flat-rate reclaimed system may have implications in system sizing that could require larger infrastructure. This could have additional upfront costs for larger pipes and pumps and higher long-term operation and maintenance costs. For these reasons long-term planning for reclaimed water systems is important to determine not only the near term goals, but also the way the system might be used in the more distant future.

**Synopsis**

This study found that irrigators decreased irrigation with reclaimed water by 47% when their billing changed from flat-rate to a commodity charge of $0.60-0.65 per kgal. Furthermore, customer water use was not observed to rebound after the initial decreases occurred. By applying two metrics, the IDS and EIA, customers decreased the portion of the landscape NID they supplied (87 to 77%), but increased the effectiveness with which they applied water (39 to 51%). This increase in efficiency did not occur simultaneously with an increase in satisfying the NID, but rather occurred concurrently with a decrease in the IDS. This outcome indicates that there is an opportunity to gain additional irrigation savings by increasing irrigator knowledge of vegetative requirements.

Clustering of similar customers showed that the 156 irrigators in Cluster 3 who initially applied an average of 155 in/yr of water during the flat-rate period decreased use by 62% to 58 in/yr after the commodity charges began. This was illustrated by the increases in EIA for all clusters of customers. A second series of clustering showed that irrigators with smaller irrigable
areas generally applied water less efficiently than irrigators with larger irrigable areas. This was true during the flat-rate year and continued during the commodity charge period. This result is not surprising as irrigators on smaller lots can provide a larger application rate at a lower total cost than an irrigator with a large lot. Even after improvements in efficiency, the irrigators in this data set continued to apply an average of 205% of the NID for the years with commodity charges. This shows that the potential exists to gain additional savings by improving irrigator efficiency. By evaluating the NID for the maximum and minimum three month periods it was observed that the highest ratio of AR to NID occurs during the winter period with the lowest need. By targeting this period and helping users understand landscaping needs, outdoor water use in these periods could be reduced.

Future work should include development of irrigation relationships for accounts that experience higher commodity charges. Evaluating water use in other regions could improve the findings of this study and increase the applicability in other regions. Home value should be included as an explanatory variable for water use as more diverse groups of homes are evaluated. Findings for reclaimed water use should be compared to irrigators on potable systems to determine whether the type of water supplied has an impact on application practices or whether irrigators are oblivious to water source.
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<td>20</td>
</tr>
</tbody>
</table>
Figure 5-1. Precipitation (Precip.), evapotranspiration (ETc), and net irrigation demand (NID); monthly for Gainesville, Florida for FY2008 to FY2014 (Part A), annual statistics (Part B), annual graph (Part C), and average monthly statistics (Part D).

Figure 5-2. Example application rates and calculations of irrigation demand satisfied and effective irrigation application.
Figure 5-3. Monthly net irrigation demand and application rate for 510 reuse customers during 2008-14 (Part A) and statistics (Part B)

<table>
<thead>
<tr>
<th></th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>NID (in)</td>
<td>19.8</td>
<td>19.0</td>
<td>17.5</td>
<td>22.8</td>
<td>16.5</td>
<td>14.9</td>
<td>14.0</td>
</tr>
<tr>
<td>AR (in)</td>
<td>66.0</td>
<td>45.1</td>
<td>35.7</td>
<td>42.3</td>
<td>38.3</td>
<td>30.7</td>
<td>28.5</td>
</tr>
<tr>
<td>IAR</td>
<td>333%</td>
<td>238%</td>
<td>204%</td>
<td>186%</td>
<td>232%</td>
<td>206%</td>
<td>204%</td>
</tr>
<tr>
<td>Spring (Apr-Jun) Ratio</td>
<td>1.8</td>
<td>1.3</td>
<td>1.1</td>
<td>1.1</td>
<td>1.2</td>
<td>1.2</td>
<td>0.9</td>
</tr>
<tr>
<td>Winter (Dec-Feb) Ratio</td>
<td>15.6</td>
<td>8.1</td>
<td>20.8</td>
<td>5.9</td>
<td>6.9</td>
<td>7.8</td>
<td>9.5</td>
</tr>
</tbody>
</table>

Figure 5-4. Cumulative water savings for the flat-rate period compared to the subsequent water years, normalized (Part A) and absolute savings (Part B)
Figure 5-5. Flat-rate clustering based on EIA and IDS for the pre-commodity (Part A) and post-commodity (Part B) periods with cluster statistics (Part C)

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Count</th>
<th>IA (sqft)</th>
<th>AR Pre (in/yr)</th>
<th>AR Post (in/yr)</th>
<th>AR Change</th>
<th>EIA Pre</th>
<th>IDS Pre</th>
<th>EIA Post</th>
<th>IDS Post</th>
<th>EIA Change</th>
<th>IDS Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>135</td>
<td>16,482</td>
<td>28.6</td>
<td>22.9</td>
<td>-20%</td>
<td>53%</td>
<td>72%</td>
<td>57%</td>
<td>71%</td>
<td>4%</td>
<td>-1%</td>
</tr>
<tr>
<td>2</td>
<td>219</td>
<td>9,615</td>
<td>59.9</td>
<td>36.1</td>
<td>-40%</td>
<td>32%</td>
<td>96%</td>
<td>45%</td>
<td>82%</td>
<td>13%</td>
<td>-14%</td>
</tr>
<tr>
<td>3</td>
<td>156</td>
<td>6,907</td>
<td>155.3</td>
<td>58.3</td>
<td>-62%</td>
<td>15%</td>
<td>99%</td>
<td>33%</td>
<td>87%</td>
<td>18%</td>
<td>-12%</td>
</tr>
<tr>
<td>Average</td>
<td>510</td>
<td>10,604</td>
<td>66.0</td>
<td>35.1</td>
<td>-47%</td>
<td>39%</td>
<td>87%</td>
<td>51%</td>
<td>77%</td>
<td>12%</td>
<td>-10%</td>
</tr>
</tbody>
</table>

Figure 5-6. Temporal application rates for Clusters 1, 2, and 3 (Part A) with annual IDS and EIA statistics (Part B)
Figure 5-7. Clustering based on IA and EIA for the pre-commodity (Part A) and post-commodity (Part B) charge periods and the cluster statistics (Part C)
CHAPTER 6
RESIDENTIAL IRRIGATION DEMAND AND UTILITY REVENUE UNDER INCREASING RATES

Scope and Overview

Outdoor water use can and often does exceed indoor water use in single family residential (SFR) areas. Additionally, outdoor SFR water use tends to be seasonal with a higher demand irrigation season and a lower off-season demand. This seasonality, combined with high peak demands, requires utilities to provide infrastructure sized to treat and deliver peak irrigation flows. Utility revenue is the sum of fixed and variable charges. Variable charges rely on the installation and reading of meters with rates assessed in a variety of ways ranging from higher unit charges for the initial usage and lower unit charges for higher usage (declining block charges) to the opposite (increasing block charges). A simple intermediate option is to assess a uniform rate for all usage. To satisfy regulators, the utility needs to demonstrate that their charging system is based on cost recovery. A recent example of this requirement is the California Opinion in Capistrano Taxpayers Association v. City of San Juan Capistrano that a proposed increasing block rate did not satisfy the requirement that the charges were based on cost of service (California Courts 2015). Complicating revenue recovery is the more responsive nature of outdoor demand, when compared to indoor demand, to changes in rates (Mayer et al. 1999).

To promote water conservation, increasing block rates have been proposed to incentivize customers to curtail use of high demand, higher cost water. However, increasing blocks can have the unintended consequence of making utility revenue increasingly volatile as customers change their demand.

This uncertainty in revenue recovery has encouraged many utilities to collect more of their costs through the fixed account charge (Noyes Carter et al. 2015). Nationally, as the prevalence of increasing block rates has expanded, the percentage of costs recovered through the
fixed charges has also increased slightly. In the western United States, a majority of utilities use an increasing block rate structure (70%), but more than 40% of the revenue is collected from the fixed charge (Noyes Carter et al. 2015). As monopolies, utilities are scrutinized by regulators to ensure fair business practices including rate setting. In Florida, the Public Service Commission regulates utilities to maintain safe, reliable, and reasonable service. This regulation is important to maintain competitive service and pricing, but is a further challenge to the utility meeting revenue requirements with uncertain demand.

This study examines the outdoor water demand for two classes of SFR customers who were dual metered (separate indoor and outdoor meters) over a period of seven years. A total of 510 customers received reclaimed water and 610 customers received potable water for irrigation with variable price signals during the study period from fiscal years (FY) 2008 through 2014. An important element in this database is that the first year of reuse water was provided to customers for no commodity charge and monthly water use was measured during this period. Outdoor water use is a function of climate and would therefore differ from year to year for the same irrigated area independent of price. This study accounts for this factor by applying a daily irrigation estimation model developed for the study area, based on measured climatic data and an assumed operating policy. Irrigators exhibit a myriad of operating policies ranging from closely following the agronomic irrigation needs with smart controllers to a simple one time setting of irrigation application, e.g., apply one half inch of irrigation twice per week year round. This daily irrigation estimation model can be calibrated to match measured and predicted water use patterns. The high quality customer data set, detailed water rate data, and irrigation water balance model are used as inputs to a water demand model. This water demand model provides a method for utilities to plan for changes in revenue based on changes in weather, irrigable area, and water
rates. The following section discusses the relevant literature, followed by a discussion of the data sets and soil water balance model. The remainder of the paper discusses the analysis of customer data, the proposed water demand model, and the impacts of water demand on utility revenue.

**Related Research**

**Effect of Water Price on Demand**

Maximum annual average water demand for residential irrigation has been evaluated in several studies when users have received water in the absence of a commodity charge, i.e., for a flat rate independent of actual usage. Howe and Linaweaver (1967) found that customers charged a flat-rate applied approximately 266% of the theoretical irrigation requirement, whereas users with a commodity charge applied only 62% of the theoretical requirements. Hanke (1970) found that flat rate customers in Boulder, Colorado applied 165% of theoretical needs and only 81% after metering with commodity charges began. In a recent study of flat rate reclaimed water use in Gainesville, Florida, Knight *et al.* (2015a) found that customers applied 328% of the net irrigation demand. This recent study provides an upper limit on customer demand in the absence of a commodity charge with automated irrigation systems that are ubiquitous in both reclaimed and potable dual meter systems.

Water price elasticity (WPE), is used to describe the change in water demand (Q) caused by a change in price (P) as shown in Equation 6-1.

\[
WPE = \frac{\frac{dQ}{Q}}{\frac{dP}{P}}
\]  

(6-1)

Elastic demand results when users’ percent change in water demand exceeds the percent change in price (WPE<-1). Inelastic demand therefore results when users’ percent change in demand is lower than a one percent change in price (0>WPE>-1). Consistently, but not exclusively, studies have found aggregate WPE of residential water demand to be inelastic and
negative (Baumann et al. 1998, Espey et al. 1997, Dalhuisen et al. 2003). Baumann et al. (1998) reported on 52 studies of price elasticity using linear, log-log, and semi-log estimates based on temporal or cross-sectional data found that overall price elasticity varied between -0.06 and -0.93 for SFR annual demand that is the sum of indoor and outdoor water use. Other meta-analyses of price elasticity include studies by Espey et al. (1997) who found a mean price elasticity of -0.51 for 124 estimates of WPE from 24 studies, and Dalhuisen et al. (2003) who found a mean price elasticity of -0.41 for 314 estimates from 64 studies.

**Outdoor Price Elasticity**

Water demand studies by Howe and Linaweaver (1967), Danielson (1979), Baumann et al. (1998), Whitcomb (2005), and others have reported WPE estimates for specific categories of water demand, e.g. SFR and multi-family residential, seasons of the year, and indoor and outdoor use. Indoor use and winter use WPEs have been found to be closer to zero than outdoor or summer WPEs (Baumann et al. 1998). Mayer et al. (1999) found SFR indoor use to be less variable than SFR outdoor water use in 1,200 SFRs in 12 utilities in North America. In their study of residential uses of water using high frequency metered data, Mayer et al. (1999) found an outdoor price elasticity of -0.83, exceeding all classes of indoor price elasticity. Pope et al. (1975, from Baumann et al. 1998) found a similar result with SFR irrigators having price elasticities of -0.31 to -0.67 compared to non-irrigator elasticities of -0.06 to -0.36. Danielson (1979) specifically divided total residential use between sprinkling demand and winter demand and found more negative values of WPE during sprinkling periods than winter periods, -1.38 versus -0.31.

The finding of greater price elasticities in outdoor water demand is reasonable since, unlike indoor water, outdoor water use is not generally considered necessary for health and well-being. In a study of SFR water demand in Florida for 7,200 single-family homes in 16 utilities,
Whitcomb (2005) found that outdoor use decreased across income levels with increasing prices. The study also found that higher valued homes (a surrogate for income) tended to have higher water demand indicating positive income elasticity. Outdoor water demand can experience choke prices as presented by Characklis et al. (1999) in their evaluation of the optimal mix of water allocation among urban and agricultural users. Using power functions to estimate the demand curves for water, they added a “choke price” for agricultural users to estimate a maximum price for irrigation water that users would pay. If the market price for water exceeded the choke price, these irrigators would switch to dryland farming or only irrigate crops with high enough values to make a profit. This addition of the choke price compensates for the change in use that can be expected at elevated water prices when certain uses become economically inefficient. As an example, a homeowner may prioritize watering trees or ornamentals over turf grass or re-landscape (e.g. xeriscape) if prices for water rise to a high-enough level. In the study area, this could also be illustrated by water customers choosing to discontinue receiving water from the utility and rather installing a private well for irrigation.

**Parcel-Level Analysis**

The development of high-quality geographic information system databases and the ability to access individual customer billing data allow separate outdoor water demand analyses at the parcel scale. This bottom-up approach provides much more insight into customer response than relying on aggregate data for all customers or estimating the proportion of total use that is outdoor use. Using county property tax assessor databases in Florida that include basic structure area, total parcel area, home value, and year built, accurate estimates of irrigable area (IA) can be developed (Friedman et al. 2013). By combining monthly water billing data with IA characteristics, the monthly depth of water applied for irrigation can be determined for each parcel in the data set. This depth of water is termed the application rate (AR) and is calculated...
monthly for each parcel in the data set. This method is more accurate for parcels that have irrigation water demands measured through a secondary meter because there is no need to separate indoor and outdoor demands. It is important to rectify the monthly data to account for meter readings that occur inconsistently through the months. The data for this study were rectified following procedures described by Dziegelewski and Opitz (2002).

**Benchmark Irrigation Application**

This study evaluates water application for residential irrigation by applying a monthly benchmark irrigation, the net irrigation demand (NID). The NID is derived from a daily soil water balance methodology developed by Dukes (2007). By leveraging daily weather data from the Florida Automated Water Network (FAWN) and calculations of Penman-Montieth evapotranspiration (ET) from Zotarelli *et al.* (2009), daily ET estimates were developed for the study area. By combining the daily local ET, precipitation, and the soil characteristics of the study area, a daily estimate of the irrigation demand is developed by maintaining the soil water between the field capacity and the maximum allowable depletion (MAD). The MAD simulates the portion of the water in the root zone that is available to the vegetation. A value of 50% was applied for this study based on the recommendation of Dukes (2007) for Florida turf grass. Using the daily soil water balance model presented by Knight *et al.* (2015b) provides several benefits over monthly or annual data by capturing the need for irrigation over short time periods on the order of one day to one week. This is in contrast to a monthly or annual approach that may show enough rainfall occurred to meet all irrigation demands, but could have resulted from short high-intensity storms (*e.g.* hurricanes) that caused runoff rather than meeting the irrigation demand. The daily crop evapotranspiration (ETc) was calculated by using the calculated ET for the study area and crop parameters for turfgrass from Dukes (2007).
Figure 6-1 shows daily data for June 2012 in Gainesville, Florida when 18.1 inches of rainfall fell, more than enough to satisfy the monthly landscape irrigation needs, but because of the short duration and intense storms, supplemental irrigation of 2.0 inches was still required in that month. Furthermore, irrigation and rainfall both occur on June 7, 2012 because the need for supplemental irrigation is calculated based on the prior day demand and if scheduled early in the day may occur before any rainfall event. Daily irrigation needs were summed to monthly NIDs for comparison to the monthly water use data, or to annual NIDs for calculating the customer’s irrigation application ratio (IAR) as described in Knight et al. (2015a). This study did not provide for specific watering days because of the lack of daily water demand data and the varying requirements based on parcel house number.

**Rate Structures**

The type of rate structure impacts the price signal received by the customer. Three primary rate structures are used in water rate-making: decreasing block, uniform, and increasing block (AWWA 2012). These rate structures are typically in addition to a flat monthly rate for service regardless of quantity demanded. The total water bill is the sum of the flat rate plus the usage in each block. Based on the 2014 Water and Wastewater Rate Survey (Noyes Carter et al. 2015), the median percentage of fixed to total revenue per typical residential customer ranges from 22% (Northeast) to 44% (West) with a national median of 32%. The relative sizes of the various terms in the total water bill are important indicators of their impact. As an example, 70% of the utilities in the West have conservation-oriented residential rates. However, these same utilities assess about 44% of their bills as fixed charges. Water rate data have been collected and summarized by Raftelis (1988, 2012) and AWWA and RFC (2015) for more than two decades by type of rate structure as shown in Figure 6-2. These data show that decreasing block and
increasing block rate structures have switched in dominance with uniform structures having similar prevalence throughout the analysis period.

The prevalence of increasing block rates, also known as conservation rates, is important because these rate structures have increasing marginal charges for water customers as usage increases. These increasing block rates have been promoted as a way to discourage higher use (Griffin 2006). However, the efficacy of an increasing block structure is largely dependent on the size of the blocks, the rate differences between each block, and the number of customers whose water bill is impacted by each block.

The customer response to a rate structure can be calculated based on the average or marginal rate experienced. Billings and Agthe (1980) used a combination of the marginal price and the difference between the actual payment and the theoretical amount if all water was at the marginal price. This question is further discussed by Dalhuisen et al. (2001, 2003) who present a kinked demand curve when increasing or decreasing block rates occur. This has led to various studies using only the marginal cost or average cost. However, disagreement has occurred over which option is best. Shin (1985) presented a separate approach and postulated that being a well-informed customer cognizant of the marginal rates and various blocks is difficult and costly because it would require a thorough understanding of the rate structure and the amount of product demanded in near real-time. Therefore, the customer might react to the monthly bill and average rate. Based on these observations, Shin (1985) proposed the perceived price, $P$, constructed as a function of the marginal price ($MP$), average price ($AP$), and a price perception parameter ($k$) as shown in Equation 6-2. This formulation can yield either the marginal price ($k=0$), average price ($k=1$), or a combination of the marginal and average prices ($0<k<1$). A challenge in applying this equation is the selection of a proper value of $k$. In a more recent study,
Ito (2012) reported on customer responses to the average versus marginal rate for electric power in California. This study found that customers in the vicinity of each other, but within separate electric utilities with different rate structures, responded more closely to the average cost than to the marginal cost. This was believed to be the result of the cost of information being high for these consumers to understand both the rate structure and their current consumption.

\[ P = MP \left( \frac{AP}{MP} \right)^k \]  

(6-2)

**Gainesville, Florida Data Sets**

**Water Customers**

This study examines two groups of customers located in Gainesville, Florida. One group is comprised of 610 customers who received potable water through two meters (referred to as potable dual meter): one for indoor use and one for outdoor use. These potable dual metered water customers are located throughout Gainesville in both planned and unplanned neighborhoods. The other group is 510 reclaimed water customers (referred to as reclaimed) who obtained their irrigation water with no commodity charge for one year, though monthly water use was still metered during this period. Then, they began paying a uniform commodity charge for the next six years. The reclaimed water customers live relatively near the wastewater reclamation facility in southwest Gainesville. Characteristics of the potable dual meter and reclaimed water customers are compared to the general potable water customers in Gainesville (which include the potable dual meter customers) in Table 6-1. Both the potable dual meter and reclaimed customers have higher valued homes than the general Gainesville population. Additionally, the potable dual meter customers have larger irrigable areas (IAs) than the Gainesville customers with sprinklers and the reclaimed customers have smaller IAs on average than both of the other
groups as shown in Figure 6-3. This figure also shows that more than 75% of irrigators in each group of customers have IAs less than 20,000 square-feet.

**Water Rates and Revenue**

The potable dual meter and reclaimed customers experience different price signals for their water use. The water rates experienced by the potable dual meter customers have changed each year over the seven year study period from 2008 to 2014. These changes have been made in the fixed fee, individual block prices, and/or the size of Tier 1 as shown in Table 6-2.

For the purposes of this study, the fixed fee was excluded from calculations of the average water rate since it is experienced by each customer independent of use. However, for calculating utility revenue, the fixed charge is an important and consistent source of revenue. For the potable dual metered customers, the Tier 1 rate has risen annually. Tier 2 water use increased in price for two years and has been maintained since 2010. During the study period, the cutoff for Tier 1 use has changed resulting in varying quantities of water charged at the Tier 1 price. Reclaimed users paid only a flat rate (fixed charge) in 2008, but paid a single tier commodity charge (uniform rate) for the remainder of the study period.

Examining a rate structure for a period of seven years has the potential to produce skewed results unless inflation is accounted for. For the purposes of this study, the Florida Public Service Commission (PSC) Price Index for water and wastewater utilities (Florida PSC 2014) was used to adjust the prices based on the value of the dollar and typical utility related expenses and inflation. All rates were converted to 2008 dollars based on the PSC Approved Index for Water and Wastewater Utilities, to have all rates correspond to the beginning of the data sets. The value of a 2008 dollar in this study varied from 97.5 to 90.6 cents between 2009 and 2014 as shown in Table 6-3. The PSC values are similar to the Consumer Price Index values, but lower than the increases in water and wastewater utility rates reported by Noyes Carter et al. (2015) and the
Federal Reserve Bank of St. Louis (FRED 2015) who showed annual increases of about 5.4% and 5.5%, respectively. However, these rate increases also include, among other things, expenses associated with expanding and renovating infrastructure, paying outstanding bonds, and acquiring new water sources.

This study chose to use the average water price, calculated by determining the total commodity charge for water through the meter divided by the total metered use. It is the case for these customers that information about the marginal price of water is “expensive” as described by Shin (1985) and Ito (2012). Marginal cost pricing has been debated in the water utility field for many years, most recently in the 6th edition of AWWA Manual M1, Principles of Water Rates, Fees and Charges (AWWA 2012). A fundamental issue is that water utilities are regulated monopolies that must justify their rates based on cost recovery. Marginal cost advocates promote its value in terms of improved economic efficiency and ability to promote water conservation by discouraging higher usage. However, it is difficult to estimate marginal costs especially in complex multi-tiered rate structures (Ito 2012). There is no guarantee that the resultant revenue generated using marginal cost pricing will equal the utility’s cost as required by regulations. Also, the potential impact of marginal cost pricing depends upon its relative importance in the water bill. The impact of pricing depends upon the percentage of water sales that are affected. Thus, if the marginal price is relatively high but only affects a few larger users, it may only impact a small percentage of the water sales. The customers in this study receive only monthly information on use from the utility. To increase the available information, it would be necessary to regularly check their water meter, independent of the utility, and make the necessary calculations to determine the water use to that date and comparing to the block thresholds. Furthermore, by applying the average price the kink in the demand curve described by Dalhuisen
et al. (2001) is avoided and the customer reaction is not expressed based on small excursions into Block 2.

**Net Irrigation Demand**

The net irrigation demand (NID) was calculated based on the work of Dukes (2007) as described previously. The data used for this calculation was taken from the Florida Automated Weather Network (FAWN) with the reference ET calculated based on Zotarelli *et al.* (2009). Annual totals for precipitation (P), crop-adjusted evapotranspiration (ETc), and net irrigation demand (NID) are shown for the study period in Figure 6-4. Annual rainfall varied significantly with the highest total of 65.6 inches in 2012 and the lowest total of 36.8 inches in 2011. The lowest rainfall of 36.8 inches is also observed to correspond with the highest ETc and NID. This is logical given that rainfall is generally associated with overcast conditions that would reduce ET. Therefore periods with less rainfall would typically be sunnier and increase ET which reduces soil moisture and increases the NID.

As formulated, the irrigation model used for this study can be used to simulate operational decisions by irrigators. These can include higher or lower aesthetic thresholds for landscape appearance, daily watering restrictions, or rain sensor shutoffs. To model the acceptable landscape appearance, the maximum allowable depletion (MAD) can be adjusted. The MAD was set at 50% when calculating the NID for this study, based on the recommendation of Dukes (2007). Dukes (2007) reported that a 50% wilt condition was observed at a MAD of 50%. However, it can be varied based on irrigator preference, e.g. a customer is willing to experience more wilt in their landscape. A sensitivity analysis for the MAD was developed by varying the value between 10 and 90% for each of the seven years and calculating the NID as shown in Figure 6-5. Using a MAD of 50% for the seven years resulted in an average NID of 17.8 inches per year. The corresponding NIDs for MADS of 10% or 90% were 21.9 or 15.4
inches, respectively. One unexpected outcome of this analysis is that in some cases lower MAD values produced lower NID values. This shows that the timing is crucial and that less irrigation may occur when those events are more synergistically applied with landscape demand.

The direct outcome of decreasing the MAD is that less water holding capacity is available in the soil. This necessitates more frequent irrigation and smaller applications to maintain landscape quality. This was evaluated in the MAD analysis and showed that the frequency of irrigation could be fit well with a power function as shown in Figure 6-6. The frequency of irrigation events at a 10% MAD was nearly 200 times per year, but at a MAD of 90% was only 27 times per year as shown in Figure 6-6. At the MAD of 50% selected for this study, irrigation is observed to be needed about weekly, but the required frequency varies throughout the year with the most demand in April and May.

**Customer Water Demand Patterns**

The 610 potable dual meter water customers irrigated at an average application rate (AR) of 14.7 in/yr of supplemental irrigation with an average minimum of 10.7 in/yr and an average maximum of 18.0 in/yr during the seven years as reported in Table 6-4. The associated monthly water use can be converted to application rate by applying a multiplier of 0.89 for the potable dual meter customers. The customer irrigation application rate decreased between 2008 and 2014 at an overall rate of 0.9 in/yr. The years of 2011 and 2012 were exceptions to this decrease with ARs in 2011 exceeding application rates in all other years. The customer demand and the NID were observed to closely track each other.

The 510 reclaimed customers were observed to have an average application rate of 66.0 in/yr in 2008 (flat rate) with values between 28.5 and 45.1 in/yr during the remainder of the period as shown in Table 6-4. The associated monthly water use can be converted to application rate by applying a multiplier of 0.55 for the reclaimed customers. The extent of rebounding of
water use to earlier levels was evaluated using linear trend analysis and showed that during the post-intervention period (2010-14) for reclaimed water use, water use continued to decline at a rate of 1.4 kgal/mo. Thus, no rebounding is evident. Both the potable dual meter and reclaimed customer demand are regressed against the NID in Figure 6-7. The relationship between NID and the application rate was evaluated independently using linear regression for the potable dual meter and reclaimed meter customers (Figure 6-7) with $R^2$ of 0.91 and 0.69, respectively. For the reclaimed water customers, 2008 and 2009 were excluded because the rate was flat in 2008 and customers were still adjusting irrigation behaviors in 2009 in response to the metering and commodity charge. Overall, the IAR ratio for the seven years is 82% for the potable dual meter customers. This ratio is similar to the value of 72% for Gainesville, Florida potable irrigators reported by Friedman et al. (2013) in their study of residential irrigation. However, as described by Knight et al. (2015b), the reclaimed customers had an IAR of between 186% and 238% for the commodity charge period and 333% during the flat-rate year (FY2008).

**Utility Revenue**

Utility revenue is calculated by summing the account charge and the commodity charges for each tier of use. This was simple in the case of the reclaimed customers who experienced only an account charge in 2008 and an account charge and single tier commodity charge for years 2009 through 2014. In 2008, the total revenue for these customers was $61,200 and increased to between $108,899 and $127,870 for the remainder of the period as shown in Figure 6-8. The potable dual meter customers had a more complex rate structure comprised of an account charge and two tiers. Further complicating calculations was a changing cutoff between the Tier 1 and Tier 2 use as shown in Table 6-2. The total revenue for the potable dual meter customers varied between $357,272 and $572,351 for the study period as shown in Figure 6-8. Also examined for the potable dual meter customers was the portion of the revenue generated
from the different bill components. In all years, the bulk of the revenue was collected from the Tier 1 charges (50-58%), followed by the Tier 2 charges (24-41%), and finally the account charge (9-18%). The percentage of the revenue by year from each source is shown in Figure 6-9. The portion of the reclaimed bill from the account charge was also calculated and varied between 29 and 44% for 2009-14 and was 100% in 2008. These results indicate that GRU collects a smaller portion of potable dual meter customer revenue from the fixed charge than any of the regional areas evaluated by Noyes Carter et al. (2015). However, the reclaimed customers who receive water for a lower commodity charge and with a single tier were more similar to utilities in the western United States that recover about 40% of their total revenue from the fixed charge. The total annual demand for these groups of customers was also evaluated and showed that in all years the total demand for the dual meter customers (n=610) was lower than for the reclaimed customers (n=510).

**Irrigation Demand Estimation**

The irrigation demand curve was used to evaluate the annual data for the aggregated potable dual meter and reclaimed meter customers with a total of 14 demand points at 14 different inflation adjusted prices. The power function is often used because it provides a constant value for price elasticity across the range of prices. However, the power fit is undefined for values of zero; this was the situation with the reclaimed customers during the flat rate year in 2008. Two separate approaches were taken with the 2008 reclaimed flat rate data with a water price of $0.00 per kgal. The first chose to eliminate the 2008 reclaimed flat-rate demand and the second included the water demand at a “small positive value”. When the flat rate data point was excluded, the model produced lower $R^2$ values. By selecting a small value for the flat-rate data, it was observed that this data point had a large impact on the quality of the power fit. However, the small value could be optimized to produce a higher $R^2$ for the power fit. Using the normalization
methods discussed by Knight et al. (2015a) the irrigation application ratio (IAR) was chosen as the preferred metric for calculation of the change in demand for increasing prices (P) in a given year (y) because of the incorporation of the irrigable area and the NID. The power fit for these data is shown in Figure 6-10 and in Equation 6-3.

\[ IAR_y = 1.6051P_y^{-0.495} \]  

(6-3)

The price elasticity coefficient for this fit was -0.495, similar to values in the literature. The optimal value for the flat-rate period was determined and had a value of $0.2265 per kgal. This method makes calculation of total utility revenue more challenging because the demand must be back calculated. To calculate the total utility revenue, it is necessary to first remove the influence of the NID to calculate the application rate (AR) as shown in Equation 6-4.

\[ AR_y = NID_y \times IAR_y \]  

(6-4)

Next the water demand (Q) is calculated by using the weighted average irrigable area (IA) for the utility as presented in Equation 6-5 with the utility revenue calculated based on the prevailing rate structure.

\[ Q_y = (5.19 \times 10^{-5}) \times AR_y \times IA \]  

(6-5)

**Utility Revenue Sensitivity Analysis**

Utilities have limited methods to modify customer outdoor water use behavior. This study specifically focuses on managing demand through price modification, but other methods can include conservation incentives or mandatory watering days. To evaluate the impact of changes on utility revenue, the percentage change in revenue was calculated for the customers in this study by changing the weighted average water price for both groups of customers. By applying Equations 6-3 to 6-5 using the average values for IA and NID while altering the average price by percentages, the revenue was calculated and then normalized based on the revenue for the base condition. The price was varied between -50% to +100%. The results, shown in Table 6-5,
illustrate the impact of changing the price for these customers. To allow for better interpretation, the water demand (in/yr) was also evaluated for the same change in price (Table 6-5). The negative inelastic value of price elasticity indicates that revenue will increase as rates increase, but that generating much higher revenue is increasingly challenging. Furthermore, generating appropriate revenue can be further complicated by changing NID that can impact the total volume of water sold.

Synopsis

Irrigation application in this study was observed to decrease as the average price of water increased. This finding is similar to the results of others but this study expands and improves on these results in several areas. By examining customers who received free water, but had their use measured, an accurate estimation of the maximum annual demand was developed. This maximum demand limits the upper range of the power function. By combining this demand with the daily irrigation model, it was observed that this group of customers reduced their demand with a small commodity charge of about $0.60/kgal from 333% of the net irrigation demand (NID) to 211% of the NID. Furthermore, their use did not rebound during the seven year study period. The second group of potable customers with dual meters expanded the range of prices evaluated and showed that these customers on average applied 82% of the NID. Thus, price can be seen to have a major impact on water use, especially to avoid needing to provide 200 to 300% of the NID by requiring meters and only modest commodity charges.

Utility revenue was calculated for both groups of customers and showed that a high proportion of the reclaimed customer revenue was derived from the flat fee (29-44%), but that only a small portion of the potable customer revenue was generated from the flat fee (9-18%). Also, an average of 34% of the potable customer revenue was generated from Tier 2 indicating the effectiveness of the utility rate structure in this study. The selection of the soil storage for the
daily water balance was observed to be a key parameter that had a major impact on the number of watering days that were recommended by the model.

The application of water for irrigation at the parcel scale was modeled as a function of price and as a function of the normalized irrigation application ratio (IAR). This study applied an improved estimation of water demand that accounted for the parcel irrigable area, which varied between the groups of customers, and the NID that varied annually. These values are both included in the IAR, which was modeled as a function of price. This model produced a negative price elasticity value of -0.495. Utility revenue was then calculated in the context of the model with a range of average prices and showed that increases in price will increase utility revenue except if the NID is reduced. However, a unit percentage change in rates will result in a less than unit percentage change in demand.

The results of this study indicate that it is important for utilities to consider long-range planning when developing water systems so that efficient systems can be constructed that are not oversized to meet the demand for irrigation. The rate structure used by the utility has a direct impact on the customer demand and if set very low can encourage excessive water demand as was the case for the reclaimed customers. It is also important to develop a water rate structure that is legal, logical, and that is based on cost recovery.

Future work should include the addition of other data sets within Florida and other areas. The inclusion of data sets with varying characteristics of home value and irrigable area could improve the treatment of these variables in assessing the impact on irrigation demand. Particularly interesting would be the inclusion of data sets with higher average water prices to examine the applicability of the choke price in the single-family home setting. With the inclusion of more diverse irrigators, the proposed model could be further improved and validated.
Figure 6-1. Daily weather and irrigation demand for June 2012 in Gainesville, FL (Part A) and monthly totals (Part B)

Figure 6-2. Trends in water rate structure in the United States from 1988 to 2014 (adapted from Raftelis 1988, 2012 and AWWA and RFC 2015)
Table 6-1. Average characteristics of reclaimed, potable dual meter, and potable water customers (including potable dual meter) in Gainesville, Florida (Friedman et al. 2013)

<table>
<thead>
<tr>
<th></th>
<th>Reclaimed</th>
<th>Dual Meter</th>
<th>Potable - No Sprinkler</th>
<th>Potable - Sprinkler</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year Built</td>
<td>2004</td>
<td>1993</td>
<td>1980</td>
<td>1995</td>
</tr>
<tr>
<td>2008 Home Value</td>
<td>$408,413</td>
<td>$356,005</td>
<td>$151,061</td>
<td>$304,515</td>
</tr>
<tr>
<td>Irrigable Area (ft²)</td>
<td>10,604</td>
<td>17,058</td>
<td>11,229</td>
<td>14,023</td>
</tr>
<tr>
<td>Count</td>
<td>510</td>
<td>610</td>
<td>9,998</td>
<td>6,305</td>
</tr>
</tbody>
</table>

Figure 6-3. Relative and cumulative distributions of irrigable areas for reclaimed, potable, and potable dual metered customers in Gainesville, Florida
Table 6-2. Water pricing for potable dual meter water customers served by Gainesville Regional Utilities

<table>
<thead>
<tr>
<th>Year</th>
<th>Type</th>
<th>Account Charge ($/month)</th>
<th>Commodity Charge ($/kgal)</th>
<th>Tier 1 Cutoff (kgal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Reclaimed</td>
<td>$10.00</td>
<td>--</td>
<td>15</td>
</tr>
<tr>
<td>2009</td>
<td>Reclaimed</td>
<td>$6.00</td>
<td>$0.60 $0.58</td>
<td>15</td>
</tr>
<tr>
<td>2010</td>
<td>Reclaimed</td>
<td>$6.00</td>
<td>$0.60 $0.58</td>
<td>15</td>
</tr>
<tr>
<td>2011</td>
<td>Reclaimed</td>
<td>$6.50</td>
<td>$0.60 $0.57</td>
<td>15</td>
</tr>
<tr>
<td>2012</td>
<td>Reclaimed</td>
<td>$7.40</td>
<td>$0.60 $0.56</td>
<td>15</td>
</tr>
<tr>
<td>2013</td>
<td>Reclaimed</td>
<td>$7.40</td>
<td>$0.63 $0.58</td>
<td>15</td>
</tr>
<tr>
<td>2014</td>
<td>Reclaimed</td>
<td>$7.85</td>
<td>$0.65 $0.59</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Dual Potable</td>
<td>$5.35</td>
<td>$2.82 $4.93</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$7.00</td>
<td>$3.11 $5.50</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$7.30</td>
<td>$3.30 $6.00 $3.03 $5.36</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$7.75</td>
<td>$3.65 $6.00 $3.50 $5.75</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$8.65</td>
<td>$3.65 $6.00 $3.41 $5.61</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$8.70</td>
<td>$3.75 $6.00 $3.45 $5.52</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$9.00</td>
<td>$3.75 $6.00 $3.40 $5.44</td>
<td>13</td>
</tr>
</tbody>
</table>

Table 6-3. Annual approved index for the Florida Public Service Commission, compared to the Consumer Price Index, and other estimates of utility rate inflation

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>100.0%</td>
<td>2.6%</td>
<td>-0.3%</td>
<td>6.1%</td>
<td>1.6%</td>
</tr>
<tr>
<td>2009</td>
<td>2.6%</td>
<td>97.5%</td>
<td>1.7%</td>
<td>6.3%</td>
<td>1.6%</td>
</tr>
<tr>
<td>2010</td>
<td>0.6%</td>
<td>96.9%</td>
<td>2.7%</td>
<td>5.2%</td>
<td>1.6%</td>
</tr>
<tr>
<td>2011</td>
<td>1.2%</td>
<td>95.8%</td>
<td>2.4%</td>
<td>5.5%</td>
<td>1.6%</td>
</tr>
<tr>
<td>2012</td>
<td>2.4%</td>
<td>93.5%</td>
<td>1.6%</td>
<td>4.5%</td>
<td>1.6%</td>
</tr>
<tr>
<td>2013</td>
<td>1.6%</td>
<td>91.9%</td>
<td>1.6%</td>
<td>4.5%</td>
<td>1.6%</td>
</tr>
<tr>
<td>2014</td>
<td>1.4%</td>
<td>90.6%</td>
<td>1.6%</td>
<td>5.5%</td>
<td>1.6%</td>
</tr>
<tr>
<td>Avg.</td>
<td>1.6%</td>
<td>1.6%</td>
<td>5.5%</td>
<td>5.4%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Figure 6-4. Annual precipitation, evapotranspiration, and net irrigation demand in Gainesville, Florida for fiscal years 2008 to 2014
Figure 6-5. Sensitivity analysis for the maximum allowable depletion for the study period from 2008 to 2014

Figure 6-6. Frequency of irrigation based on the maximum allowable depletion

Table 6-4. Application rate and monthly demand for the potable dual meter and reclaimed customers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Type</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>Avg</th>
</tr>
</thead>
<tbody>
<tr>
<td>AR (in/yr)</td>
<td>Dual</td>
<td>17.4</td>
<td>15.3</td>
<td>14.0</td>
<td>18.0</td>
<td>14.5</td>
<td>12.6</td>
<td>10.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recl.</td>
<td>66.0</td>
<td>45.1</td>
<td>35.7</td>
<td>42.3</td>
<td>38.3</td>
<td>30.7</td>
<td>28.5</td>
<td></td>
</tr>
<tr>
<td>Avg. Q (kgal/mo.)</td>
<td>Dual</td>
<td>15.5</td>
<td>13.6</td>
<td>12.4</td>
<td>16.0</td>
<td>12.9</td>
<td>11.2</td>
<td>9.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Recl.</td>
<td>36.4</td>
<td>24.8</td>
<td>19.7</td>
<td>23.3</td>
<td>21.1</td>
<td>16.9</td>
<td>15.7</td>
<td></td>
</tr>
</tbody>
</table>
Figure 6-7. Regression for potable dual meter and reclaimed customers between application rate and net irrigation demand

Figure 6-8. Total revenue and water demand for the potable dual and reclaimed customers
Table 6-5. Impact of price and net irrigation demand on utility revenue for potable dual or reclaimed customers

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Percentage Change in Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Revenue</td>
<td>-30% -16% -11% -5% -3% 0% 2% 5% 10% 14% 23% 33% 42%</td>
</tr>
<tr>
<td>Demand</td>
<td>41% 19% 12% 5% 3% 0% -2% -5% -9% -12% -18% -24% -29%</td>
</tr>
</tbody>
</table>
Residential landscape irrigation is a large user of water in many cities. With recent severe
droughts in areas of the United States, increasing attention is being paid to managing outdoor
residential demand through many forms including rebates, restrictions, and public education.
This dissertation specifically makes a contribution to water pricing for managing residential
irrigation. Using high quality, large, datasets this research addresses three primary questions, and
produces additional findings while answering these questions. The three primary questions were:
1. How much water is used for residential irrigation when water is provided for a flat-rate?
2. How do customers who received flat rate water for residential irrigation respond when
   they experience commodity charges?
3. What is the customer response to varying water rates for residential irrigation?

In some portions of the country, water for residential irrigation is being supplemented by
treated effluent through “purple pipe” reclaimed systems. These reclaimed systems provide
several benefits by reducing new withdrawals of water for residential irrigation and reducing
disposal to natural or engineered systems. These reclaimed systems are often unmetered with
water charged only at a flat rate without a commodity charge based on use. A utility’s priorities
may vary from maximizing disposal by encouraging use with low cost water, to minimizing new
withdrawals by offsetting the maximum number of users. In addition, both the goals of the utility
and the behavior of the customer may change with time making a necessary management
strategy less obvious.

By examining water demand data for 510 customers in Gainesville, Florida who received
reclaimed water for residential irrigation, but paid only a flat rate, it was possible to examine
how water was applied in comparison to a benchmark irrigation need. This research benefits
from monthly demand data for each customer despite the lack of a billed commodity charge.
These data were evaluated along with parcel data and an estimate of the local lawn net irrigation demand (NID) to examine how customers applied this “free” water. This analysis shows that the reclaimed users displayed a wide range of behaviors, but overall applied 328% of the NID. Additionally, a lognormal model was used to simulate customer water demand and produced fits that could be applied to estimate water savings in other areas. Of the 510 reclaimed customers in this study, 95% applied in excess of the NID indicating significant potential for improving efficiency and producing water savings.

In addition to the single year with no commodity charge, six more years of water use were examined for the same 510 customers. During the six years, the rate for reclaimed water varied from $0.60 to $0.65 per kgal. The customer response to this rate change was examined and shows a decrease of 47% on average. To improve this analysis, the annual NID was calculated for the study year based on a daily soil water balance and showed that the NID varied from 14.0 to 22.8 inches per year during the study period. Despite the implementation of a commodity charge, between 14 and 27% of customers in each year increased water demand when compared to the flat-rate period. With the commodity charge, customers continued to apply in excess of the NID, between 186 and 238% on average. Monthly efficiency calculations show that after commodity charges began, the efficiency of application improved although the customers met less of the lawn irrigation demand. Additionally, examining the monthly data shows that customers generally over-applied water in the three months with the lowest NID and more accurately applied in the three months with the highest NID. The data also show that the customers did not experience a rebound to previous higher use as postulated by some studies, but rather maintained lower irrigation application. Finally, clustering was used to evaluate the
customer behavior with respect to the parcel irrigable area and shows that smaller irrigable areas were irrigated less efficiently than larger irrigable areas.

By including 610 customers who received potable water through dual meters, the range of rates experienced was increased from a high of $0.65 to more than $4.00. These customers, also in Gainesville, were evaluated over the same seven year period. This group of customers applies approximately 82% of the NID over the study period as compared to the reclaimed water customers that applied between 186% and 333% of the NID. Utility revenue from each group of customers was calculated and shows that reclaimed customers use more total water than the potable dual meter customers in all years, but generate less revenue. The reclaimed customers on average had between 29% and 44% of their bill based on the flat account charge, but the potable dual meter customers only had 9 to 18% of their bill from the account charge. Between 24 and 41% of the bill for the potable dual meter customers was generated from the Tier 2 rates. An elasticity model was developed to predict the irrigation application ratio based on changes in the average price for water with an elasticity coefficient of -0.495. Based on local conditions this can then be used to calculate the estimated water demand for customers with increasing or decreasing average rates. Based on this model, utility revenue changes were estimated and showed that meeting utility revenue projections could be difficult in years with lower than normal NID.

Balancing demand for limited water supplies is a major challenge for utilities. Specifically in areas with over-allocated or stressed supplies being able to allocate a human necessity in a fair and equitable manner is paramount. Irrigation for maintaining landscapes is a less vital use of the water and results in a large increase in consumptive use. However, these same irrigated landscapes provide a variety of benefits including shading, cooling, and aesthetics. As water supplies become increasingly stressed, managing demand for water by
increasing water rates can provide a method to incentivize conservation, encourage efficiency, and provide water in a more equitable manner. Water is a unique resource and should be managed in a way that highlights its importance to all life on this planet. Pricing water efficiently is one way to accomplish this objective. If higher rates are charged for water it will allow customers to make choices about how important their landscape is to their well-being. Revenue generated from these increased rates can be used to enhance conservation in other areas (e.g. indoor fixtures and outdoor retrofits) and to subsidize a small water allotment for all served residents. Since most utilities have a monopoly on water supply it can be challenging to change rate structures in meaningful ways because of the necessity of showing that revenues and costs balance and due to political realities. However, treating water conservation as capital projects would allow utilities to more directly allocate resources to water conservation. Similarly, residents need to make their will known to elected officials, who often control water rates, that efficient and equitable water pricing are major priorities.

**Future Work**

This research was based on data from Gainesville, Florida. While the data sets used were high quality and thoroughly processed, adding areas with different regional weather conditions, home values, water rates, and irrigation characteristics would be valuable. Price elasticity is often simulated using a power function for simplicity, including in this research, but there is no particular rationale for demand to have a constant elasticity across a wide range of prices. Additional research should examine different model formulations and data interpretation to develop functions that more accurately describe the demand for water under increasing prices as well as how the demand varies across customers and seasonally.
LIST OF REFERENCES


Florida Public Services Commission, 2014. Annual Reestablishment of Price Increase or Decrease Index of Major Categories of Operating Costs Incurred by Water and Wastewater Utilities. Memorandum, Docket No. 140005-WS.


BIOGRAPHICAL SKETCH

Scott Knight was born in Gainesville, Florida in 1982. He attended Alachua Elementary, Mebane Middle, and Eastside High Schools. He started at the University of Florida in the Department of Environmental Engineering Sciences (EES) in August of 2000. During his undergraduate studies he participated in the University Scholars Program and worked with a graduate student and mentor looking at the efficacy of radar prediction of actual rainfall depths. In his junior year he made the decision to pursue a Master of Engineering Degree through the 4/1 program. He graduated summa cum laude with his Bachelor of Science in Environmental Engineering in December of 2004. During his master’s research he worked with his advisor, Dr. James Heaney and Dan Reisinger on a project related to the Everglades Restoration for the United States Army Corps of Engineers. The project focused on the optimal sizing of above ground storage reservoirs south of Lake Okeechobee in the Everglades Agricultural Area. The water quality treatment potential of these reservoirs was evaluated in conjunction with improved operations of water deliveries. Scott completed his Master of Engineering in December of 2005.

After completion of his bachelor and master’s degree Scott was hired by Jones Edmunds and Associates in Gainesville, Florida as an engineer intern working on water resources projects. This work included stormwater management projects and watershed management plans. In June of 2006, Scott married a former co-worker from Brasingtons Adventure Outfitters. In January of 2008, Scott and Erica moved from Gainesville, Florida to Aurora, Colorado where Scott began working for the City of Aurora – Aurora Water in the water resources group. While in Colorado, Scott became familiar with the complex system of western water rights, water storage projects, and complex water management for potable water systems. In 2009, Scott applied for, sat for, and passed the professional engineering exam in civil engineering.
In September 2009, Madeleine Claire Knight was born. To be closer to family the expanding Knight family moved back to Gainesville in May of 2010 and Scott began working as a water resources engineer for Wetland Solutions, Inc. In this position he worked on ecological monitoring for springs and wetlands, treatment wetland design, and other various projects. In May 2011, Scott received a notice about several Ph.D. degree programs being offered at the University of Florida. During the application process Scott spoke with Dr. James Heaney about a recommendation letter for his application and after some discussion Scott made the decision to pursue a Ph.D. with Dr. Heaney. Beginning part-time in May of 2011, Scott began his research and began taking classes in August of 2011. Scott studied water conservation and the effects of rates on demand for irrigation. During his time as a graduate student Henry William Knight (October 2012) and George Allen Knight (August 2014) joined the Knight family. Scott completed his Ph.D. in December of 2015.