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EFFECT OF COMMODITY CHARGES ON THE DEMAND FOR RECLAIMED WATER

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ABSTRACT

Residential irrigation with reclaimed water is one method to reduce potable water withdrawals in the United States. However, little research has examined how customers use this often low cost or free water. This study evaluates the change in water use for 510 reclaimed customers that were converted from a flat-rate to a commodity charge. Using actual water use data and an irrigation model, two metrics of efficiency were developed: portion of landscape needs satisfied and efficiency of application. After the commodity charge began, the reclaimed customers decreased their use by 47% and improved the efficiency of their application by 12%. However, annually between 14 and 27% of the users increased use compared to the flat-rate period. The impact of irrigable area was also evaluated and showed that customers with smaller irrigable areas were less efficient (26%) than irrigators with larger irrigable areas (52%).

INTRODUCTION

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.* 2015). Specifically for Gainesville, Florida, Knight *et al*. (2015) 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. (2015) 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.

LITERATURE REVIEW

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. 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 application rate (AR), the depth of water applied over the irrigable area (IA) for a specified time period, using potable water and reclaimed water as shown in Equation 1.

$$OC = \frac{\overline{AR}_{potable}}{\overline{AR}_{reclaimed}} \times 100\% \qquad (1)$$

Where: $\overline{\mathrm{AR}}_{\mathrm{potable}}$ is average irrigation application rate with potable water, $\overline{\mathrm{AR}}_{\mathrm{reclaimed}}$ is the average irrigation application rate with reclaimed water.

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. Christansen (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 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.

$$I_{t-1} = SW_t - SW_{t-1} + ETc_{t-1} - R_{t-1} + D_{t-1} + Roff_{t-1} \qquad (2)$$

Where: t denotes the current time step, t-1 denotes the previous time step, SW is the soil water, ETc is the crop evapotranspiration, R is the rainfall, I is the irrigation, D is the drainage, and Roff is the runoff.

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 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 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 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 1, Part A for the period of record. Additionally the annual values are shown in tabular format in Figure 1, Part B and graphically in Figure 1, Part C. As shown in Figure 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 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.* (2015) 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 ($\mathrm{IDS_y}$). The $\mathrm{IDS_y}$ specifically defines the portion of the monthly NID that was satisfied for the analysis year. The annual $\mathrm{IDS_y}$ can be calculated by applying Equation 3 and ranges from 0% (none of the $\mathrm{NID_y}$ was satisfied) to 100% (all of the NID was satisfied).

$$IDS_y = \frac{\sum_1^{12}(\min(NID_m, AR_m))}{\sum_1^{12} NID_m} \times 100\% \qquad (3)$$

The second term defined and used in this study is the annual effective irrigation application ($\mathrm{EIA_y}$) 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 4.

$$EIA_y = \frac{\sum_1^{12}(\min(NID_m, AR_m))}{\sum_1^{12} AR_m} \times 100\% \qquad (4)$$

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.

$$\frac{IDS_y}{EIA_y} = \frac{\sum_1^{12}(AR_m)}{\sum_1^{12}(NID_m)} = IAR_y \qquad (5)$$

An example that shows the tradeoffs between IDS and EIA is shown in Figure 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*. (2015) 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 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 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 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 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 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 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 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 4) relates the amount of water provided that met the NID to the total water applied. Overall, water use deceases 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, 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, 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%, 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 Clusters 1, 2, and 3 (Figure 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 7, Part A. The period after the commodity charge was also plotted based on the same clusters, Figure 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.

SUMMARY AND CONCLUSIONS

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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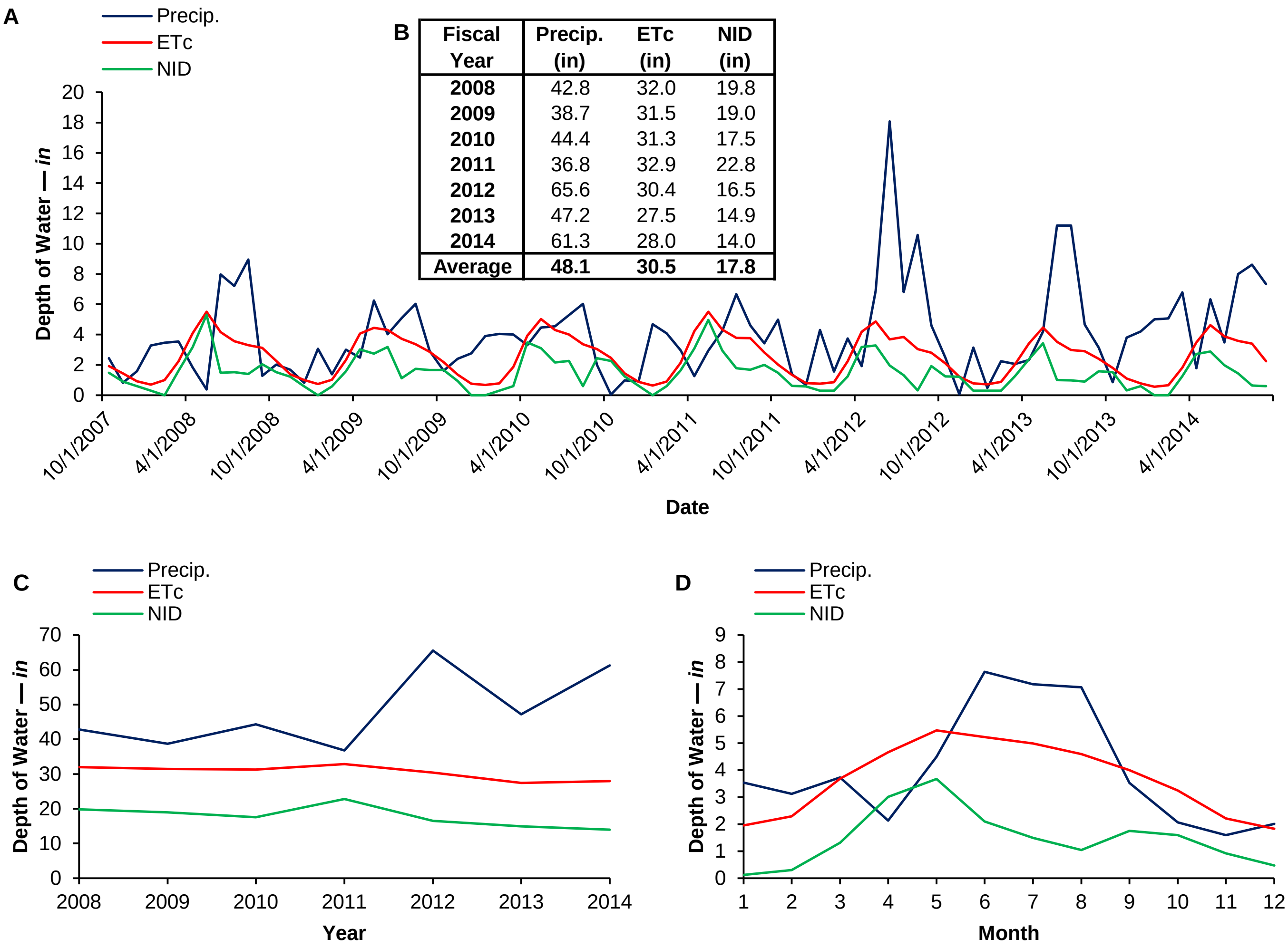
Figure 1 – Precipitation (Precip.), evapotranspiration (ETc), and net irrigation demand (NID); annual and monthly statistics for Gainesville, Florida for FY2008 to FY2014



Fiscal Year	Precip. (in)	ETc (in)	NID (in)
2008	42.8	32.0	19.8
2009	38.7	31.5	19.0
2010	44.4	31.3	17.5
2011	36.8	32.9	22.8
2012	65.6	30.4	16.5
2013	47.2	27.5	14.9
2014	61.3	28.0	14.0
Average	**48.1**	**30.5**	**17.8**

Figure 2 – Example Application Rates and Calculations of Irrigation Demand Satisfied and Effective Irrigation Application

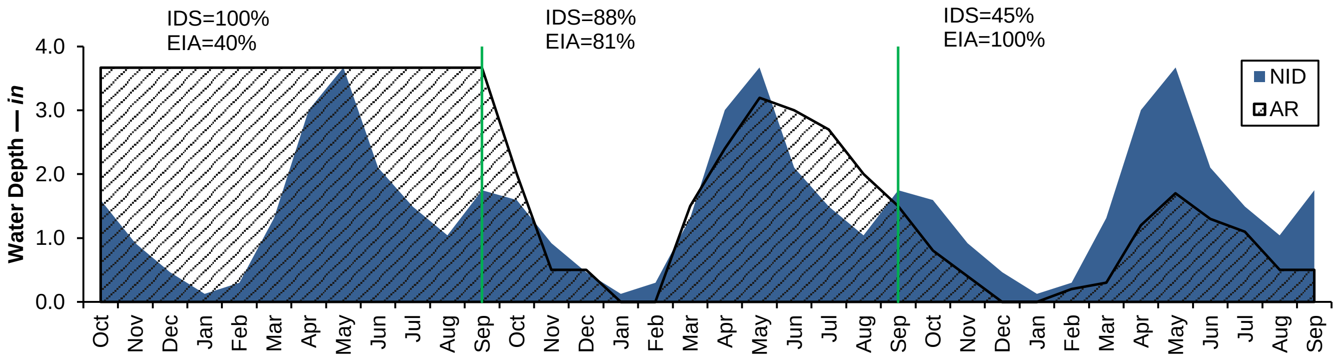
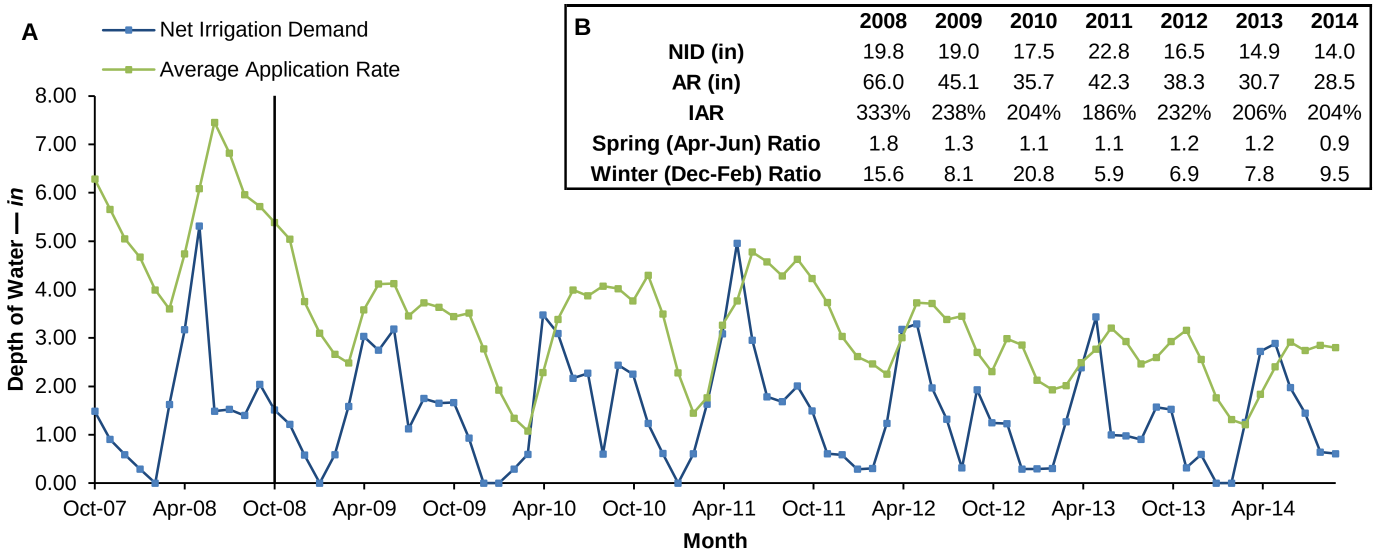


Figure 3 – Monthly net irrigation demand and application rate for 2008-14



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

Figure 4 – Cumulative water savings for the flat-rate period compared to the subsequent water years, normalized (Part A) and absolute savings (Part B)

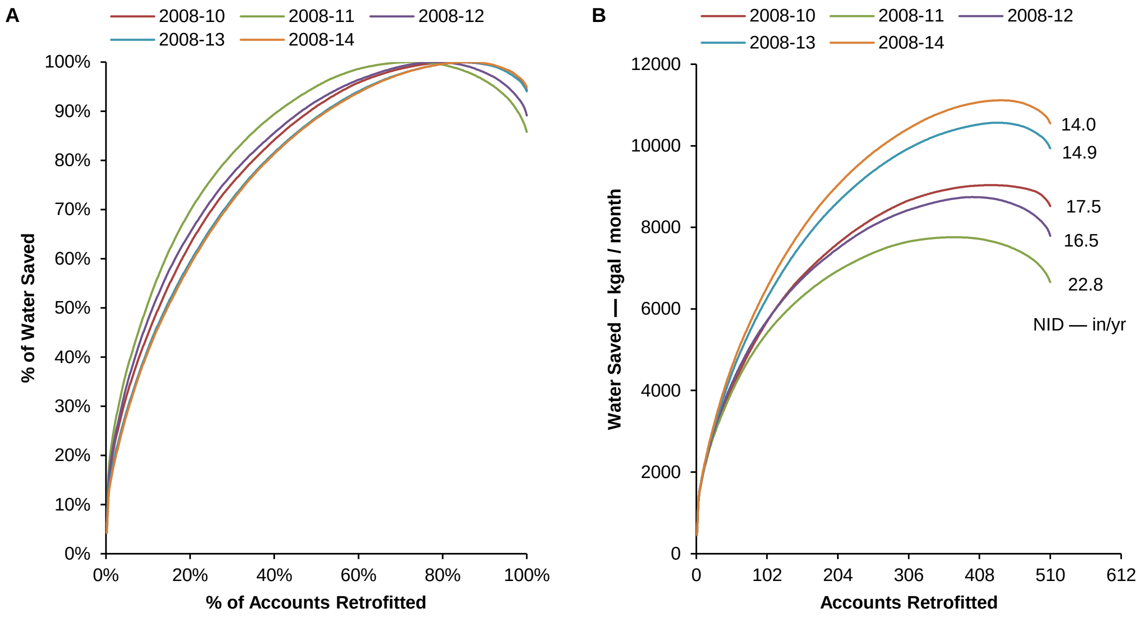
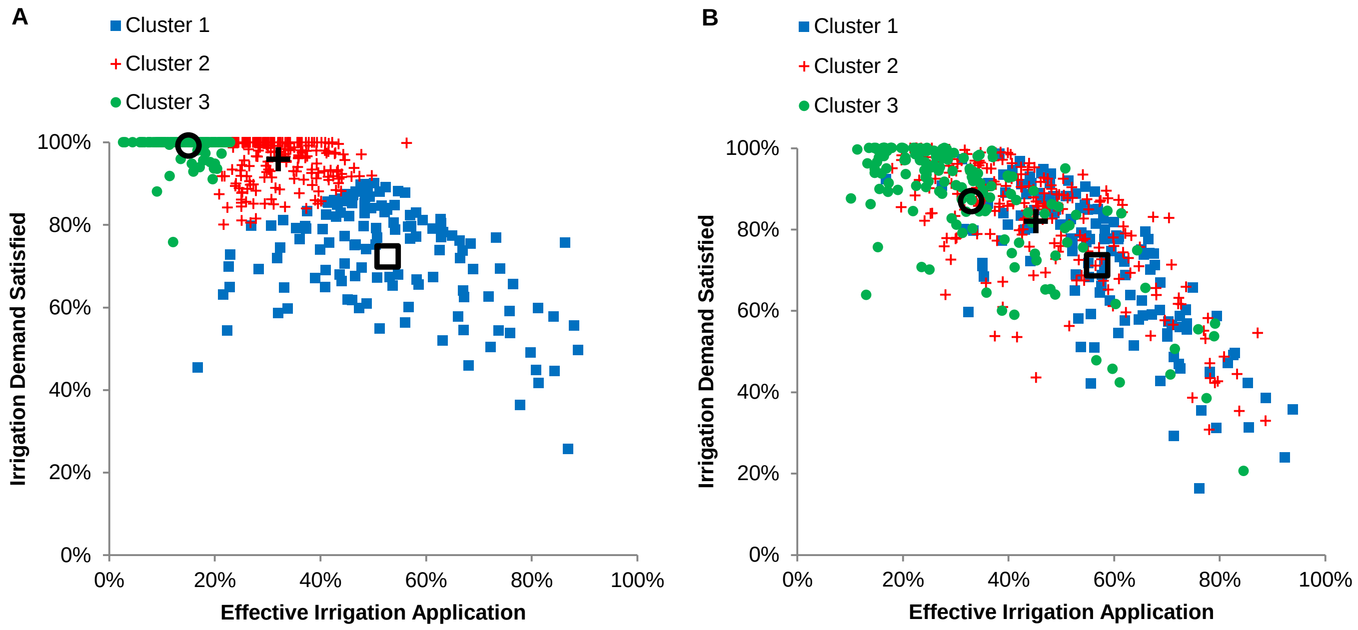


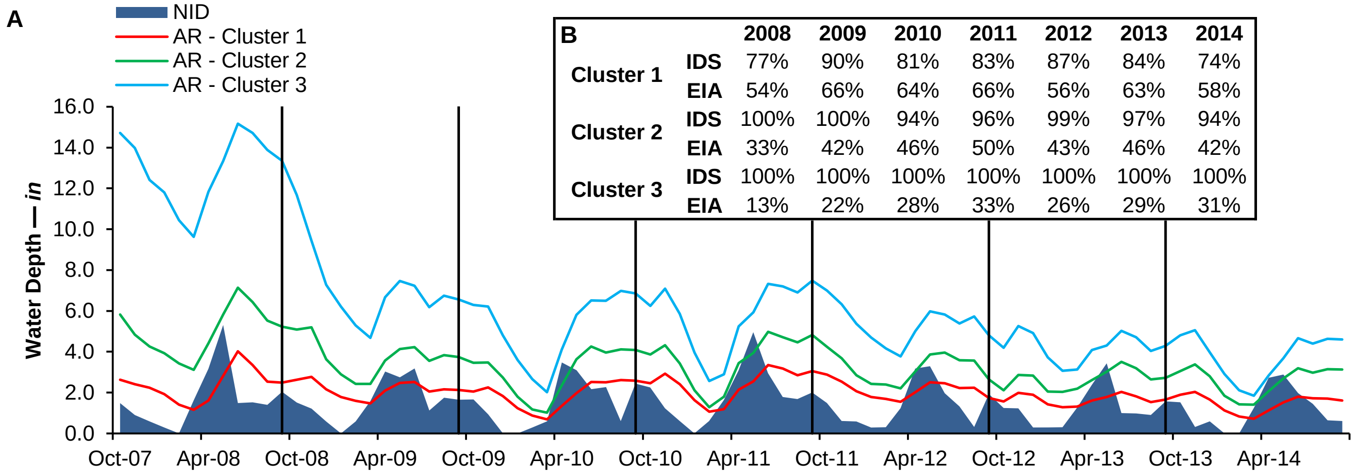
Figure 5 – Flat-rate clustering based on EIA and IDS for the pre-commodity (Part A) and post-commodity (Part B) periods with cluster statistics (Part C)



C

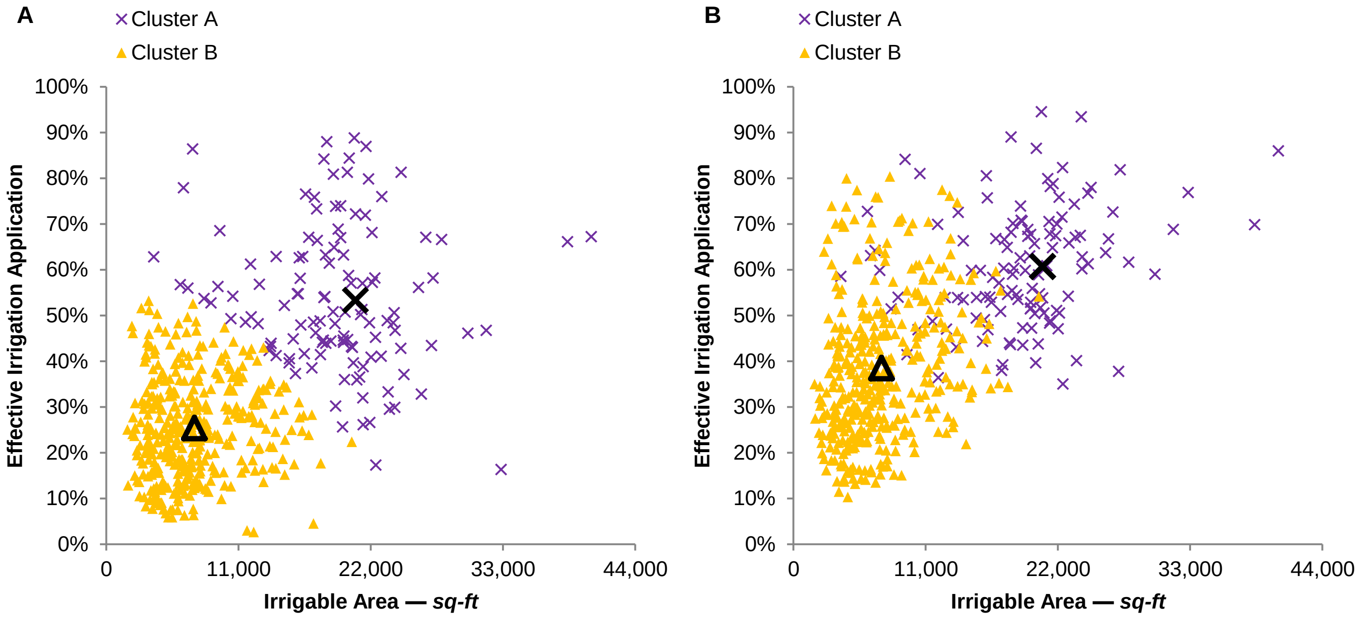
Cluster	Count	IA (sqft)	AR Pre (in/yr)	AR Post (in/yr)	AR Change	EIA Pre	IDS Pre	EIA Post	IDS Post	EIA Change	IDS Change
1	135	16,482	28.6	22.9	-20%	53%	72%	57%	71%	4%	-1%
2	219	9,615	59.9	36.1	-40%	32%	96%	45%	82%	13%	-14%
3	156	6,907	155.3	58.3	-62%	15%	99%	33%	87%	18%	-12%
Average	510	10,604	66.0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

Figure 6 – Temporal application rates for Clusters 1, 2, and 3 with annual IDS and EIA statistics



		2008	2009	2010	2011	2012	2013	2014
Cluster 1	**IDS**	77%	90%	81%	83%	87%	84%	74%
	EIA	54%	66%	64%	66%	56%	63%	58%
Cluster 2	**IDS**	100%	100%	94%	96%	99%	97%	94%
	EIA	33%	42%	46%	50%	43%	46%	42%
Cluster 3	**IDS**	100%	100%	100%	100%	100%	100%	100%
	EIA	13%	22%	28%	33%	26%	29%	31%

Figure 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)



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Cluster	Count	2008 Value	IA (sqft)	AR Pre (in/yr)	AR Post (in/yr)	Change	Avg. Post Charge	EIA Pre	IDS Pre	EIA Post	IDS Post	EIA Shift	IDS Shift
A	125	$567,046	20,727	34.2	22.4	-34%	$14.82	52%	77%	61%	69%	9%	-8%
B	385	$356,909	7,318	95.3	46.7	-51%	$10.89	26%	95%	41%	83%	15%	-12%
Average	510	$408,413	10,604	66.0	35.1	-47%	$11.85	39%	87%	51%	77%	12%	-10%

Table 1 – Monthly rates for Gainesville, Florida

reclaimed and potable water customers

			Commodity Charge ($/kgal)				
Type	**Year**	**Account Charge ($/month)**	**Tier 1**	**Tier 2**	**Tier 3**	**Tier 1 Cutoff (kgal)**	**Tier 2 Cutoff (kgal)**
Reclaimed	2008	$10.00				N/A	
	2009	$6.00	$0.60			N/A	
	2010	$6.00	$0.60			N/A	
	2011	$6.50	$0.60			N/A	
	2012	$7.40	$0.60			N/A	
	2013	$7.40	$0.63			N/A	
	2014	$7.85	$0.65			N/A	
Potable	2008	$5.35	$1.56	$2.82	$4.93	9	24
	2009	$7.00	$1.59	$3.11	$5.50	9	24
	2010	$7.30	$1.65	$3.30	$6.00	9	24
	2011	$7.75	$1.99	$3.65	$6.00	9	24
	2012	$8.65	$2.05	$3.65	$6.00	7	20
	2013	$8.70	$2.20	$3.75	$6.00	7	20
	2014	$9.00	$2.30	$3.75	$6.00	6	20