Flat-Rate Reclaimed Use and Savings in Single-Family Homes

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The widespread use of reclaimed water for irrigation of residential landscapes has the potential to encourage much higher use if water is provided in the absence of a commodity charge. Unlike indoor water needs that are relatively consistent regionally, irrigation demand varies extensively. This research examines the demand for irrigation in the absence of a commodity charge using parcel-level water use data for 510 single-family residences. When compared with a data set of potable accounts, the application rate was observed to be 65.2 in./year for the reclaimed water customers and 13.2 in./year for the potable water customers—an increase of 493%. Additionally, 95% of the reclaimed water customers applied more water than the net irrigation demand (theoretical plant requirements). By leveraging estimates of irrigation demands from other studies, a method is developed to apply the findings of this study to irrigator customers without a commodity charge throughout Florida.

Keywords: *water rates, water demand, reclaimed, reuse, conservation*

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 (Tiger et al. 2011, Mayer & DeOreo 2010, AWWA Research Foundation 1999), which has risen significantly in recent years in part because of 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), savings from which 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 to provide 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 (CFWI 2014).

On the basis of 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 (Andrade & Scott 2002, Okun 1997) and who generally pay a commodity charge of $2–$7/1,000 gal. The practice of providing low-cost or free reclaimed water in Florida is common, with 74% of reclaimed water providers supplying water for less than $1/1,000 gal (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 article addresses the demand for reclaimed water at a flat rate and evaluates the potential savings associated with reduced irrigation application rates on reclaimed systems. This analysis is possible because of a rare, if not unique, data set of 510 single-family residential (SFR) reclaimed water customers in Gainesville, Fla., 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 that are unmetered 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 water customers is compared with 6,305 potable SFR irrigator customers, 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.

LITERATURE REVIEW

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 research on irrigation demands has improved the understanding of water availability and irrigation adequacy in residential settings and is used in this article 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.

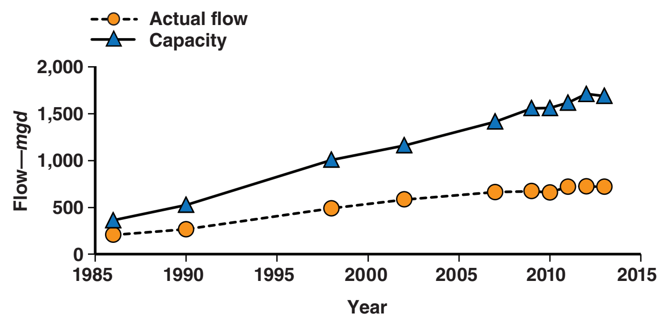
Some of the methods offered by these studies are incorporated in this research. The relevant literature is described in the following sections that discuss reclaimed water use in Florida, flat-rate water use, parcel-level irrigation use, and irrigation adequacy.

Reclaimed water use in Florida. SFR 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 because of more efficient end-use devices and (2) there has been 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) (Friedman et al. 2013). To mitigate the effects of this trend on potable water demand, the state of Florida has encouraged use of reclaimed water for irrigation. Florida has emerged as the national leader in reclaimed water use with 719 mgd in 2013 (FDEP 2014). Reclaimed water providers are required to submit an annual report to the Florida Department of Environmental Protection with the quantity of water treated and other distribution statistics. According to these reports, reclaimed water capacity and use have increased dramatically since the 1980s (Figure 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 being provided at little or no cost to customers (FDEP 2014). For 133 residential reclaimed systems in Florida in 2013, 43 (32.3%) provided water without a commodity charge (Table 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 had no fixed fee. The average commodity charge for the 90 utilities that charged one was $0.96/1,000 gal. The fixed monthly charge for the 27 utilities with no commodity charge was $10.48/month; for the utilities with commodity charges, the fee 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 the 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 & 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 The Johns Hopkins University (Linaweaver et al. 1966). That study measured residential water use in 28 metered areas, eight flat-rate areas, and five apartment areas in 11 metropolises in six major climatic zones across the United States. Participating cities purchased master meters with recorders to install in areas with various 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-min 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 the 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 2. The average indoor water use of 247 gal per account per day (gpad) for the 10 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

FIGURE 1 Reclaimed water use and reclaimed water capacity in Florida



Adapted from FDEP 2014

TABLE 1 Reclaimed water delivery by price structure for reclaimed water systems in Florida

Type	Count	%
No commodity fee	43	32.3
No fixed fee	16	12.0
Flat rate	27	20.3
Commodity charge	90	67.7
No fixed fee	43	32.3
Combination	47	35.3
All	133	100.0

Source: FDEP 2014

TABLE 2 Comparison of 10 metered and eight flat-rate water use study areas

		Metered	Flat Rate
Measures	Study Areas	10 Areas	8 Areas
Water use—*gpad*	Leakage	24	36
	Indoor	247	236
	Outdoor	186	420
	Total	457	692
Outdoor application rate—*in./yr*	OAR	14.0	39.4
	Potential OARR	22.5	14.8
	OAR/OARR	62%	266%

Source: Linaweaver et al. 1966

gpad—gallons per account per day, OAR—outdoor application rate, OARR—OAR requirement to have had a major impact on outdoor application rates on an annual as well as a summer basis. On an annual basis, the actual outdoor application rate was only 62% of the potential outdoor application rate requirement for the 10 metered areas, whereas it was 266% for the eight flat-rate areas as shown in Table 2.

In a study of water-demand changes occurring with the addition of individual metering and commodity charges in Boulder, Colo., Hanke and Boland (1971) examined water use before and after individual water meters were installed. Before individual metering, use at only the meter-reading route level was measured. They found that water use per account during the fixed-charge period was 302 gpd; after the commodity charge, it decreased to 193 gpd. Additionally, outdoor water use as a percent of ideal use decreased from 165% before individual metering to 81% after (Hanke 1970). Ideal irrigation was defined on the basis of 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 after the 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 because of a lack of geographical information systems and high-quality climate and water use data.

Parcel-level irrigation water use. Thanks to major advances in geographical information systems during the past 40 years, high-quality estimates of irrigable area are available at the parcel level (Friedman et al. 2013). The annual application rate for an entity (e.g., individual customer, subsystem) is defined as the depth of application (in./yr), which is derived from total irrigation water use (gal) divided by irrigated area (ft^2) (Eq 1).

$$\overline{\mathrm{AR}}_{\mathrm{ann}} = 1.6 \times \frac{Q_{\mathrm{ann}}}{\mathrm{IA}} \tag{1}$$

in which $\overline{\mathrm{AR}}_{\mathrm{ann}}$ is the average annual application rate (in./yr), Q_{ann} is annual irrigation water use (gal), and IA is irrigable area (ft^2).

For the purposes of this study, and the work of Friedman et al. (2013), irrigable area and irrigated area are considered equivalent, although this may not be the case for all parcels. The majority of SFR meters measure total flow into the parcel. In this case, it was necessary to separate indoor and irrigation water use using hydrograph separation and to assume that the water use in the minimum month is indoor use. The minimum-month method is straightforward in colder climates that have a distinct nonirrigated period during the colder months. However, this method 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 minimum-month method 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 because 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 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 being the primary focus. To compare the water use among irrigators, it is necessary to have a benchmark irrigation definition. For this article, the benchmark applied is the net irrigation demand (NID), which is equivalent to the net irrigation requirement of Romero and Dukes (2013). These are defined as an amount of water that provides an adequate landscape based on biophysical and weather considerations, without explicitly considering the impact of other irrigator preferences. Demand was used to replace the term requirement and acknowledge the role of the customer in choosing how to apply water separately from the plant's biophysical requirements.

In Florida, and specifically Gainesville, Romero and Dukes (2013) have studied the NID, which corresponds 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 the 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 estimate is a major improvement over previous estimates based on monthly data that did not capture the dynamics of irrigation that responds to daily moisture deficits. Romero and Dukes (2013) found that the average NID was 19.9 in./yr for Gainesville, with variances 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 to the NID application rate, as shown in Eq 2. This equation is similar to that applied by Mayer and DeOreo (2010) and defines the percentage of the NID applied. For example, users who apply 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, vegetation type, and system application efficiency. As this analysis was narrowed to a single year of data for a single geographic area, the meteorological conditions can be considered 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 have influenced water use.

$$\overline{\mathrm{IAR}}_{\mathrm{ann}} = \frac{\overline{AR}_{\mathrm{ann}}}{\mathrm{NID}_{\mathrm{ann}}} \times 100\% \tag{2}$$

in which $\overline{\text{IAR}}_{\text{ann}}$ is the average annual irrigation application ratio $\overline{AR}_{\text{ann}}$, is the average annual irrigation application rate, and NID_{ann} is the benchmark annual application rate.

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 evaluated by Friedman et al. (2013). All of these locations had commodity charges for water use. These values are comparable to the results of 40 years before 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 (2003) of Florida. The OC (0% ≤ OC ≤ 100%) defines the percentage of the reclaimed water applied that "efficiently" replaces the potable water that would have been used, as shown in Eq 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_{potable}, with the benchmark irrigation (NID), the uncertainty of an appropriate potable application rate can be eliminated, with OC = 1/IAR from Eq 2.

$$\text{OC} = \frac{\overline{AR}_{\text{potable}}}{\overline{AR}_{\text{reclaimed}}} \times 100\% \tag{3}$$

in which $\overline{AR}_{\text{potable}}$ is the average irrigation application rate with potable water and $\overline{AR}_{\text{reclaimed}}$ is the average irrigation application rate with reclaimed water.

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 a potable water system (Andrade & Scott 2002, Okun 1997). To ensure that the utilities with residential reclaimed irrigation projects were not given more credit than their initial or projected potable irrigation use, an OC was applied as far back as the 1980s in southwest Florida (Andrade & Scott 2002). The concept of an OC allows regulators to provide credit to utilities for reducing their potable water use. The recommended OCs for SFRs presented by the Reuse Coordinating Committee (2003) and Andrade and Scott (2002) are shown in Table 3. Based on the previous analysis, the OC should be a function of the benchmark potable application rate, not the historical potable application rate, which can vary widely based on numerous biophysical 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 SFR customers in southwest Gainesville in planned neighborhoods. During the initial 18 months of operation of the meters, these SFR customers received water with no commodity charge. Accounts on this portion of the reclaimed system were charged a flat rate of $10/month regardless of use. The homes in these neighborhoods have homeowners associations that monitor the quality of the landscapes. Water use for these SFR customers 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 SFR customers who were classified as irrigators with in-ground irrigation systems in Gainesville. They classified irrigators as those users who had an application rate between 1 and 100 in./yr 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/month and commodity charges of $1.56–$4.93/1,000 gal (in 2008 dollars), depending on their usage tier. These SFR customers were compared with the SFR reclaimed water customers of this study, with summary data shown in Table 4. The average year built for the potable irrigation homes is 1995, nine years older than the average year built for the reclaimed irrigation homes, which is 2004. 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

TABLE 3 Reclaimed water offset credits

Reclaimed Activity	Offset Credit—%	Source
Aesthetic features	75	RCC 2003
Agricultural irrigation—efficient	75	RCC 2003
Agricultural irrigation—inefficient	50	RCC 2003
Commercial laundries	100	RCC 2003
Cooling towers	100	RCC 2003
Fire protection	100	RCC 2003
Landscape irrigation—efficient	75	RCC 2003
Landscape irrigation—inefficient	50	RCC 2003
Vehicle washing	100	RCC 2003
Toilet flushing	100	RCC 2003
Residential irrigation—metered	45–55	Andrade & Scott 2002
Residential irrigation—flat rate	25–35	Andrade & Scott 2002

RCC—Reuse Coordinating Committee (Fla.)

TABLE 4 Average characteristics of Gainesville, Fla., homes with irrigation systems

	Count	Year Built	2008 Value $	Irrigable Area *1,000 ft^2*
SFR customers with potable irrigation	6,305	1995	304,515	14.0
SFR customers with reclaimed irrigation	510	2004	408,267	10.6

SFR—single-family residential

water use. The 2008 average values of these homes were $304,515 for the homes with potable irrigation and $408,267 for the homes with reclaimed water. The homes with potable irrigation have an average irrigable area of 14,000 ft^2, compared with 10,600 ft^2 for the reuse homes.

Histograms and probability density functions and cumulative density functions (CDFs) provide a more detailed picture of the mix of SFR customers in the data sets. The histograms of the irrigable area data sets, shown in Figure 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 irrigable areas overall.

APPLICATION RATES AND IRRIGATION EFFICIENCY OF FLAT-RATE IRRIGATION

As mentioned previously, the benchmark application rate for Gainesville is 19.9 in./yr. The homes with potable water having commodity charges in the range of $1.56 to $4.93 per 1,000 gal used 13.2 in./yr, about 67% of the benchmark level. In sharp contrast, the reuse homes with free water applied 65.2 in./yr, 328% of the benchmark value. Thus, price can be seen to have a dramatic impact on outdoor water use. For this study, reclaimed water data were filtered to remove accounts that had fewer than 1,000 ft^2 of irrigable area or that were classified as nonirrigators (>4 months of zero water use in water year 2008), but because all use is through a separate meter, no accounts were eliminated because of large irrigable areas or application rates.

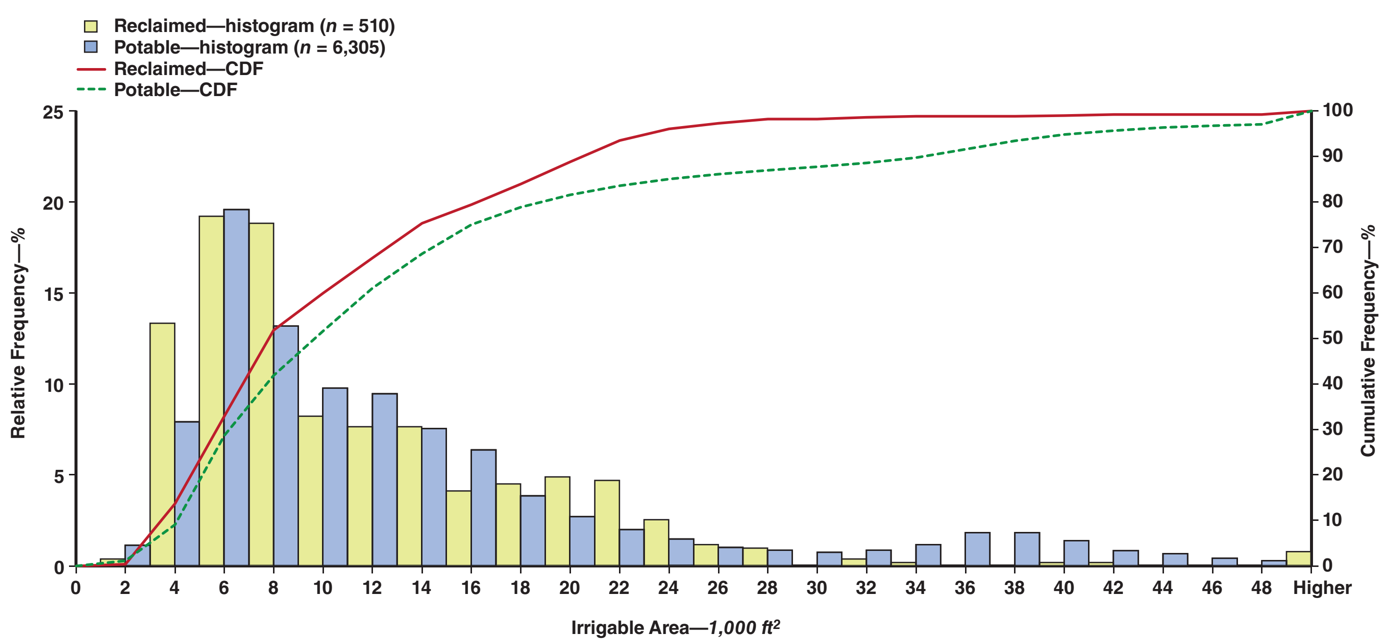
A variety of probability distributions were tested to see which distributions fit the data best. Distribution fitting software[1] was used to find the best fits according to three tests: chi-square, Kolmogorov–Smirnoff, and Anderson–Darling. Detailed descriptions of these three criteria are contained 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 the 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 (SD) of the log-transformed data. Eq 4 presents the CDF equation for the lognormal model. The lognormal fits for the irrigable area and application rate are shown with the probability plots in Figure 3, parts A–D. In both cases, the lognormal model is 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*—is shown using Eq 4 or taken directly from the CDFs in Figure 3.

$$P\,(a < X \leq b) = \varphi\left(\frac{\ln(b) - \mu}{\sigma}\right) - \varphi\left(\frac{\ln(a) - \mu}{\sigma}\right) \quad (4)$$

in which X is the parameter value, μ is the mean and $\mu = E(\ln(x))$, and σ is the SD and $\sigma = [Var(\ln(x))]^{0.5}$ (Ang & Tang 2007).

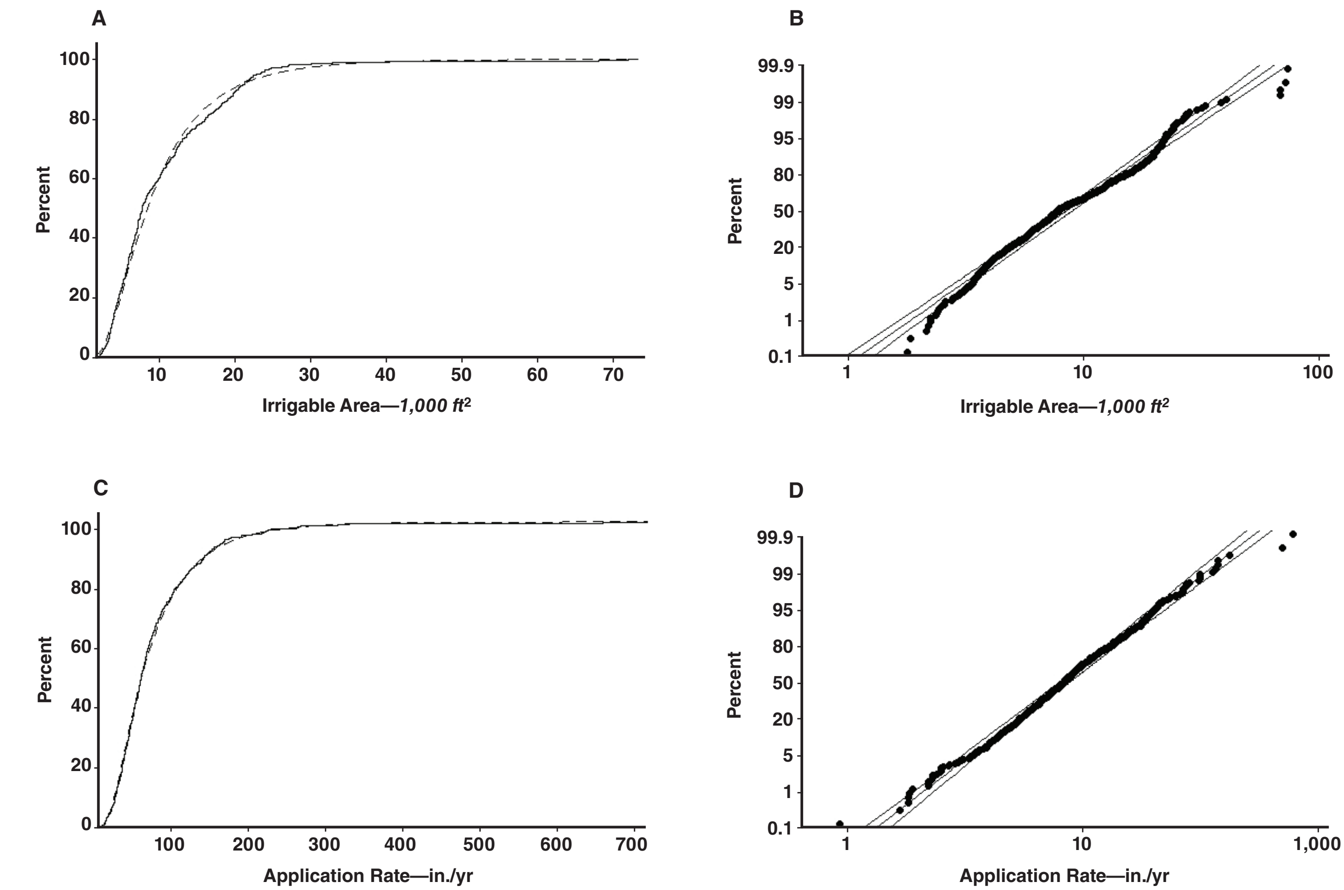
The lognormal model can be defined simply based on the mean and SD of the data. The fits for both the irrigable area and the application rate are well represented by the lognormal distribution based on the shape and probability plots. For the irrigable

FIGURE 2 Comparative histograms and CDFs of irrigable areas for potable and reclaimed water accounts



CDFs—cumulative density functions

FIGURE 3 Lognormal fit of irrigable area and application rate with CDF and probability plot



CDF—cumulative density function

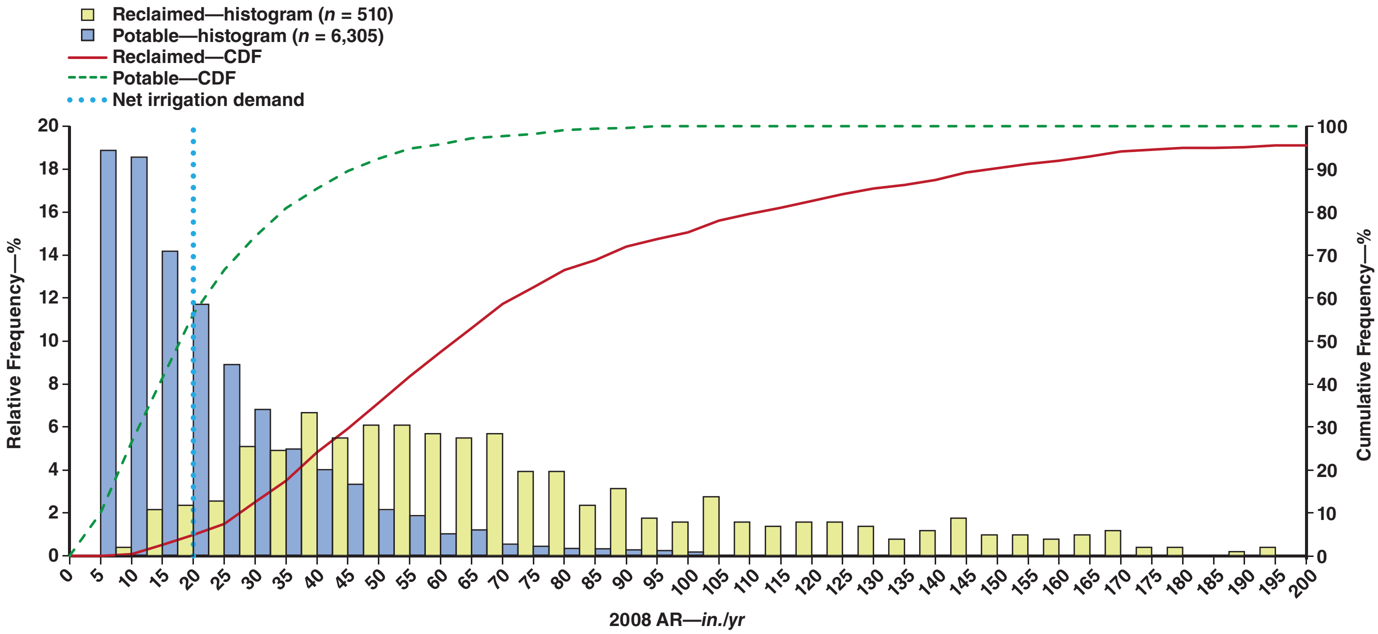
area, the lognormal fit with an untransformed mean of 8,452 ft^2 and an untransformed SD of 1,938 ft^2 provides a good approximation that can be used to calculate the CDF of the irrigable area at any value. Similarly, for the application rate, an untransformed mean of 62.9 in./yr and an untransformed SD of 1.98 in./yr provide a good approximation of the data.

The application rates are compared in Figure 4 using probability density functions and CDFs and show striking differences between the data sets. The reclaimed accounts display an entirely different water use pattern that covers a much broader range of application rates than the SFR customers with irrigation systems. As part of their analysis, Friedman et al. (2013) removed users with more than 100 in./yr of application, which were considered outliers for their data sets. However, the reclaimed accounts have approximately 25% of users applying in excess of 100 in./yr.

The application rates on the flat-rate reclaimed system range from 5.1 to 738 in./yr. As shown in Figure 4, 486 (95.3%) of the 510 irrigators applied water above the average NID of 19.9 in./yr (irrigation ratio > 100%). Additionally, 126 irrigators (24.7%) applied more than 100 in./yr. This is the result of irrigation with automated irrigation systems that are ubiquitous in the study area and the lack of a commodity charge. The impact of the commodity charge can be evaluated by comparing it 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 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. Andrade and Scott (2002), Hanke and Boland (1971), and Howe and Linaweaver (1967) 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 of aggregate estimates of water use with no variability or understanding of how individual accounts use water. In this study, significant differences were found in the use behaviors across accounts receiving flat-rate water. A majority of all reclaimed customers apply water at an IAR of 150–400%, 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 5. This result is drastically different than

FIGURE 4 Comparative histograms and CDFs for application rate for reclaimed and potable water accounts



AR—application rate, CDFs—cumulative density functions

irrigators on the potable water system, in which more than 63% have an IAR lower 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 gal (dependent on their use tier), whereas 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 ft^2 and the area-weighted application rate of 13.2 in./yr, water would cost an estimated $20.33 per month for potable water users (assuming no indoor use), which is 203% of the reclaimed cost. The average use of 65.2 in./yr for reclaimed water 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 in./yr, nearly five times greater than the average rate found by Friedman et al. (2013) of 13.2 in./yr for SFR customers with potable irrigation systems. Applying Eq 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 with the NID of 19.9 in./yr. When this OC is compared with offset rates proposed by Andrade and Scott (2002) of 25–35% 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.

TABLE 5 Irrigation application ratio for GRU reclaimed water accounts (no commodity charge) and other Florida utilities

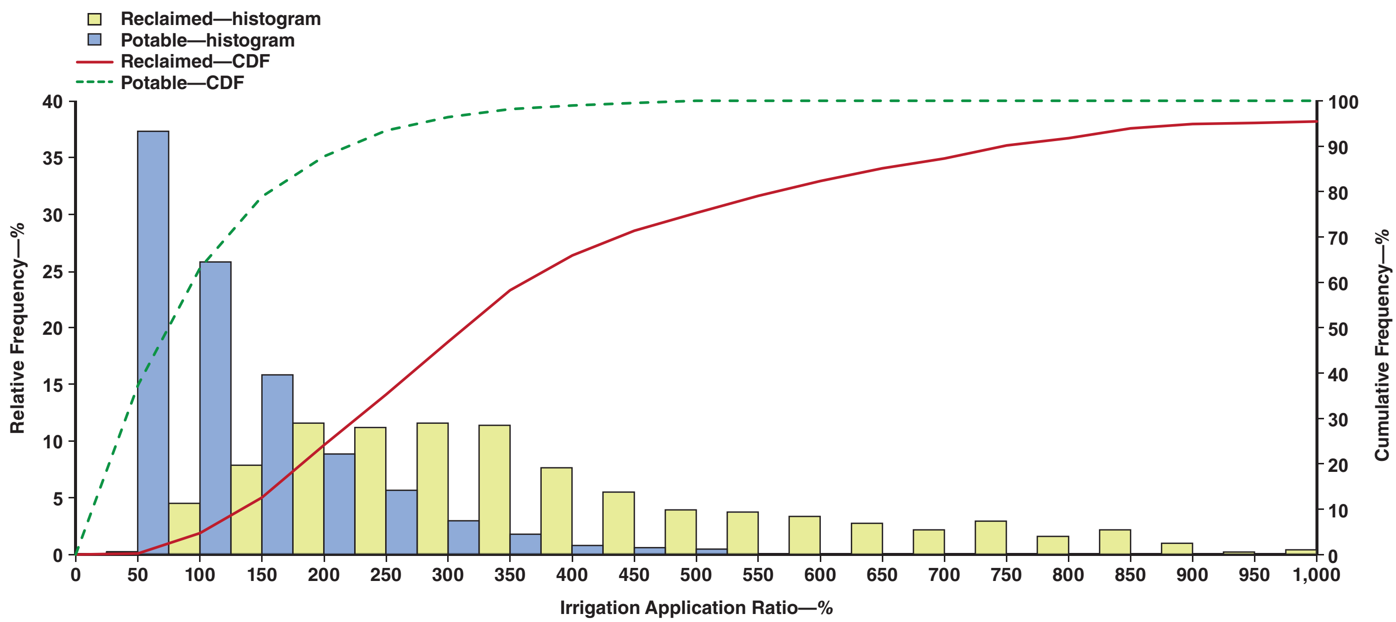
Utility	Number of Accounts	Irrigation Application Ratio %	Source
GRU—potable	6,305	66	Friedman et al. 2013
Apollo Beach	1,020	93	Romero & Dukes 2011
Brandon	3,514	73	Romero & Dukes 2011
Dover	103	58	Romero & Dukes 2011
Gibsonton	369	46	Romero & Dukes 2011
Lutz	1,599	92	Romero & Dukes 2011
Riverview	3,315	75	Romero & Dukes 2011
Ruskin	1,443	68	Romero & Dukes 2011
Seffner	1,364	58	Romero & Dukes 2011
Sun City	122	102	Romero & Dukes 2011
Tampa	12,209	78	Romero & Dukes 2011
Valrico	3,704	93	Romero & Dukes 2011
GRU—reclaimed	510	328	This study

GRU—Gainesville Regional Utilities

WATER SAVINGS POTENTIAL FOR FLAT-RATE RECLAIMED WATER CUSTOMERS

Based on the findings of this research, significant water use reduction potential exists for reclaimed water customers who do

FIGURE 5 Comparative histograms and CDFs for irrigation application ratio of reclaimed and potable water accounts



CDFs—cumulative density functions

not pay a commodity charge for their irrigation use. Based on findings by Friedman et al. (2013), it was observed that 2,327 of the 6,305 SFR customers with irrigation systems, or 37%, irrigated in excess of their NID, whereas 486 reuse water customers, or 95%, irrigated in excess of the NID. Interestingly, despite the many more potable water SFR customers available to reduce water use, nearly an equal amount of water could be saved in the reclaimed group, as shown in Table 6. In addition to the overall savings, reducing all of the potable water irrigators to no more than the NID of 19.9 in./yr would save an average of 195 gpd for each of the modified SFR customers, whereas 882 gpd per modified SFR customer could be saved by making the same reduction for the reclaimed water 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 for other uses. By using the average irrigable area, the

TABLE 6 Savings potential for SFRs with potable irrigation and reclaimed water systems

SFR Account Type	Potable With Irrigation	Reclaimed
Total customers	6,305	510
Customers >NID	2,327	486
Total daily savings—*gpd*	453,158	428,609
Daily savings per SFR—*gpd*	195	882
New customers supplied	937	1,174

NID—net irrigation demand, SFR—single-family residential

number of new customers who could be provided reclaimed water if existing customers were reduced to the NID can be estimated. For the potable water customers, nearly 937 new customers (15% increase) could be provided with water at a rate of 19.9 in./yr; for the reclaimed water customers, 1,174 new customers (230% increase) could be provided 19.9 in./yr of reclaimed water without increasing the total quantity of water delivered by the utility.

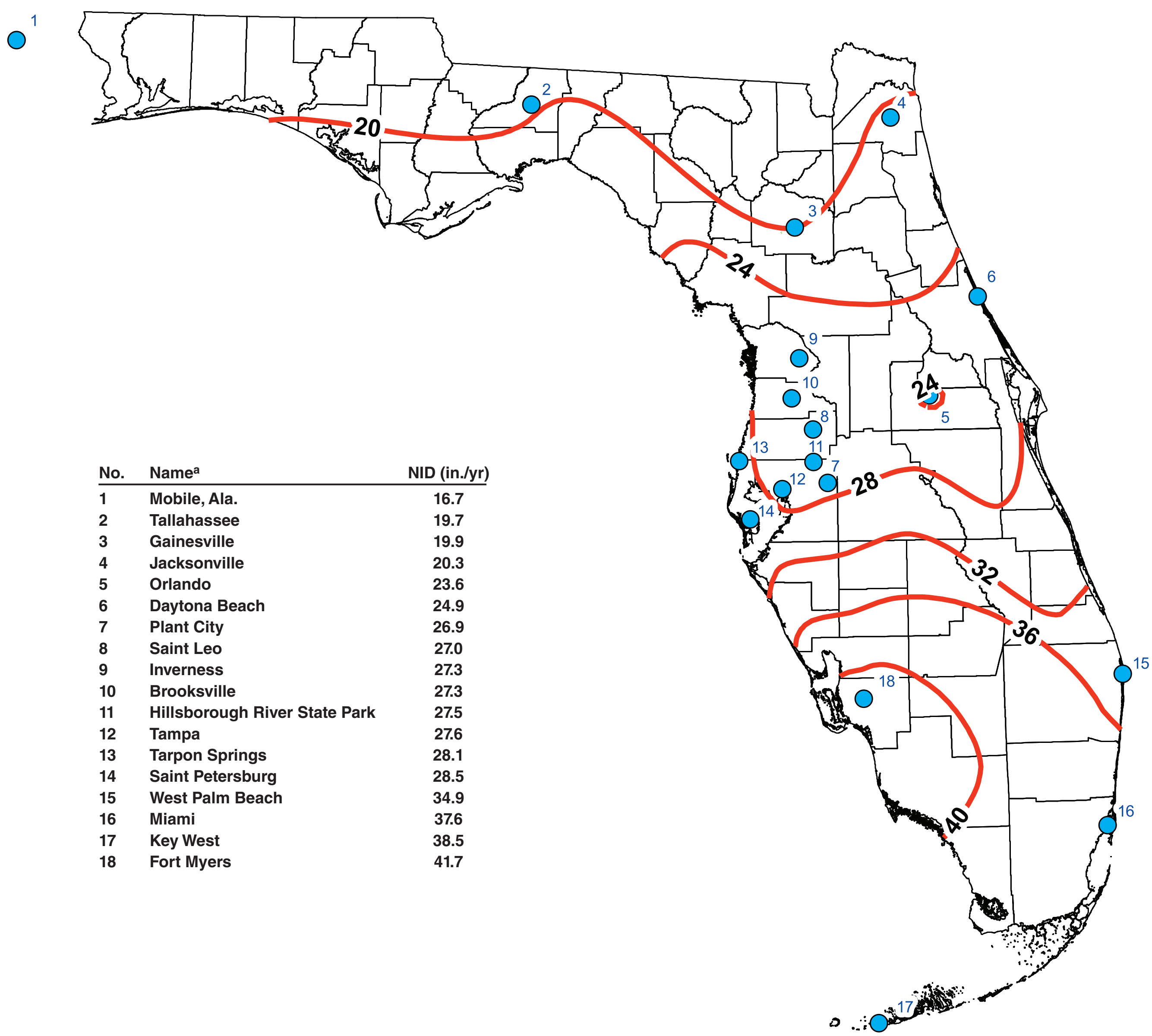
EXTRAPOLATION TO OTHER FLAT-RATE AREAS

To apply the findings of this study in areas without water use data, the lognormal CDF can be used to estimate how SFR customers might apply water in the absence of a commodity charge. The lognormal CDF (Eq 4) is developed based on two parameters: the untransformed mean—316.1%—and untransformed SD—197.5%. In areas without data, it might be reasonable to assume the average and SD of this study yielding the same CDF. However, actual total water savings will be based on the irrigable area, number of customers, and the local NID. In areas of Florida where the NID is not directly available, Figure 6 can be used to estimate NID. Using the values from Romero and Dukes (2013), a geographic information system[2] 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 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 Eq 5. This allows a utility to estimate the water savings 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 Eq 5 produces an estimated savings of 377,000 gpd. This is approximately 12% less than the actual potential savings for the users of 428,000 gpd shown in Table 6. The discrepancy is due to three extreme cases in the 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 an extreme use of more than 50% greater than the fourth highest value. If these three accounts are eliminated from the savings calculation, the potential water savings

FIGURE 6 Estimated NID contours for Florida



No.	Name[a]	NID (in./yr)
1	Mobile, Ala.	16.7
2	Tallahassee	19.7
3	Gainesville	19.9
4	Jacksonville	20.3
5	Orlando	23.6
6	Daytona Beach	24.9
7	Plant City	26.9
8	Saint Leo	27.0
9	Inverness	27.3
10	Brooksville	27.3
11	Hillsborough River State Park	27.5
12	Tampa	27.6
13	Tarpon Springs	28.1
14	Saint Petersburg	28.5
15	West Palm Beach	34.9
16	Miami	37.6
17	Key West	38.5
18	Fort Myers	41.7

Based on data from Romero & Dukes 2013

NID—net irrigation demand

[a]All locations in Florida unless otherwise indicated.

decrease to 384,000 gpd and are in line with the prediction of 377,000 gpd from the lognormal model.

$$\text{Water savings} = 0.00171 \times IA_{avg} \times (n \times R_{NID}) \times NID \times (IAR_{pre} - IAR) \quad (5)$$

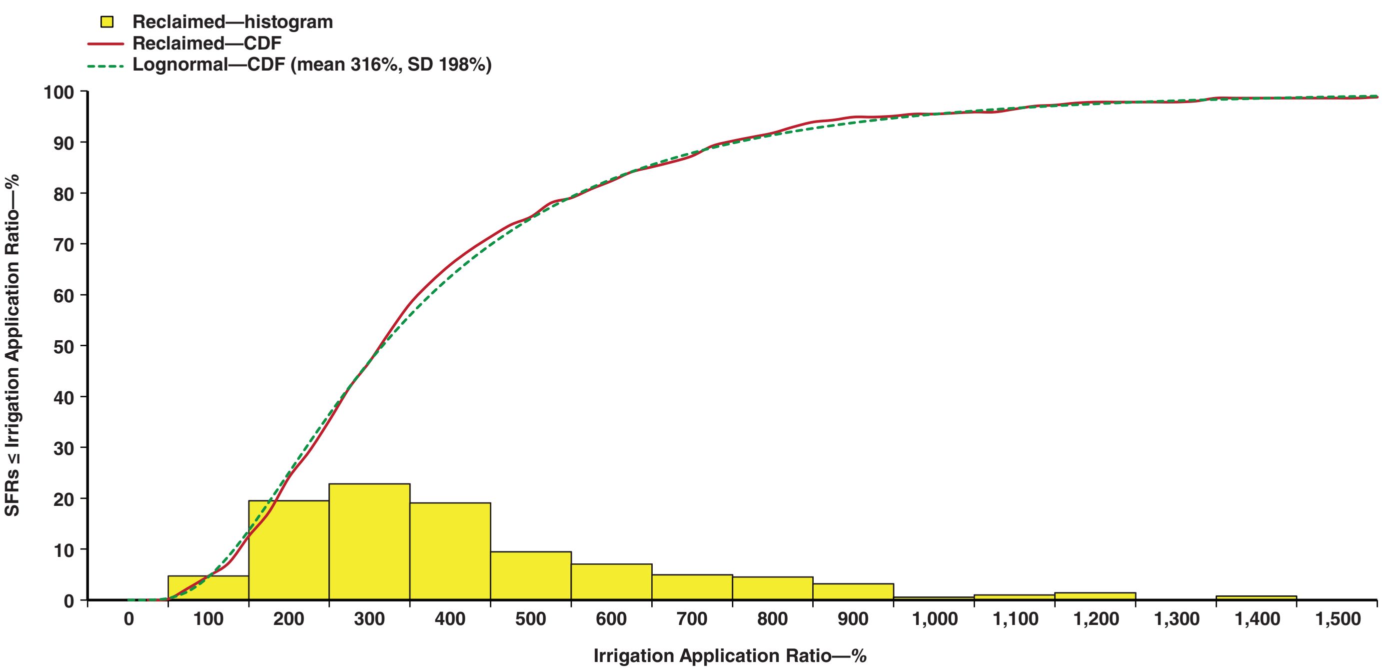
in which water savings is the total savings (1,000 gal/day), IA_{avg} is the average irrigable area (1,000 ft^2), n is the total number of customers, R_{NID} is the ratio of customers in excess of the NID (local value or 95%, as found in this study), NID is the local net irrigation demand (in./yr), IAR_{pre} is the irrigation application ratio (local value or 316%, as found in this study) before modification, and IAR is the modified irrigation application ratio (local target value or the NID, 100%).

SUMMARY AND CONCLUSIONS

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 who received flat-rate reclaimed water for irrigation via secondary water meters. These customers applied more than three times the average NID of 19.9 in./yr. A majority of the users applied 100–400% 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 an 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 use its local NID to estimate the range of water use for its customers. By applying the savings calculations presented in this study, a utility can estimate, based on the specific attributes of the utility and an estimate of the benchmark application rate for its 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 the two examples to follow. A utility that wishes to decrease demand on a water resource might want to convert users to reclaimed water to reduce irrigation demand for potable water. The utility might achieve this by providing 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 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 high-use approach

FIGURE 7 Histogram and CDFs for reclaimed water accounts in Gainesville, Fla., receiving flat-rate water and lognormal fit to estimate consumption



CDFs—cumulative density functions, SFRs—single-family residential customers can have long-term ramifications for the utility in sizing infrastructure during initial installation. When evaluating the water use associated with providing reclaimed water to customers for nonpotable irrigation, the utility should consider how the water will be provided (flat-rate or commodity charges) and how much is to be used as a means of determining 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 limited data availability, caution should be exercised when applying these techniques in areas with substantially different climatic or socioeconomic conditions. If systemwide changes are to be made, it may be necessary to collect additional location-specific information that can be used to better define the regional relationships.

Future work should include adding further 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.

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FOOTNOTES

[1]@Risk, version 6, software, Palisade Corp, Ithaca, N.Y.
[2]ArcGIS geographic information system, Esri, Redlands, Calif.

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PEER REVIEW

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REFERENCES

Andrade, A.J. & Scott, K.F., 2002. Effective Use of Reclaimed Water Demonstrated to Offset Water Demand. Southwest Florida Water Management District, Brooksville, Fla.

Ang, A.H-S. & Tang, W.H., 2007. *Probability Concepts in Engineering: Emphasis on Applications in Civil & Environmental Engineering.* John Wiley & Sons, Hoboken, N.J.

AWWA Research Foundation, 1999. *Residential End Uses of Water.* Prepared by Mayer, P.W.; DeOreo, W.B.; Opitz, E.M.; Kiefer, J.C.; Davis, W.Y.; Dziegielewski, B.; & Nelson, J.O. Denver, Colo. www.waterrf.org/PublicReportLibrary/RFR90781_1999_241A.pdf (accessed Feb. 25, 2015).

CFWI (Central Florida Water Initiative), 2014. Regional Water Supply Plan—Final Draft. Central Florida Water Initiative, Orlando, Fla.

FDEP (Florida Department of Environmental Protection), 2014. Water Reuse Program. Water Reuse. www.dep.state.fl.us/water/reuse/ (accessed June 1, 2014).

Friedman, K.; Heaney, J.P.; Morales, M.; & Palenchar, J., 2013. Predicting and Managing Residential Potable Irrigation Using Parcel Level Databases. *Journal AWWA,* 105:7:372. http://dx.doi.org/10.5942/jawwa.2013.105.0087.

Grabow, G.; Ghali, I.; Huffman, R.; Miller, G.; Bowman, D.; & Vasanth, A., 2013. Water Application Efficiency and Adequacy of ET-Based and Soil Moisture-Based Irrigation Controllers for Turfgrass Irrigation. *Journal of Irrigation and Drainage Engineering,* 139:2:113.

Hanke, S.H., 1970. Demand for Water under Dynamic Conditions. *Water Resources Research,* 6:5:1253.

Hanke, S.H. & Boland, J.J., 1971. Water Requirements or Water Demands? *Journal AWWA,* 63:11:677.

Howe, C. & Linaweaver, F., 1967. The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure. *Water Resources Research,* 3:1:13.

Linaweaver, F.P.; Beebe, J.C.; & Skrivan, F.A., 1966. Data Report of the Residential Water Use Research Project, Baltimore. Department of Civil Engineering, Johns Hopkins University, Baltimore, Md.

Mayer, P.W. & DeOreo, W.B., 2010. Improving Urban Irrigation Efficiency by Using Weather-Based Smart Controllers. *Journal AWWA,* 102:2:86.

Okun, D.A., 1997. Distributing Reclaimed Water Through Dual Systems. *Journal AWWA,* 89:11:52.

Reuse Coordinating Committee, 2003. Water Reuse for Florida: Strategies for Effective Use of Reclaimed Water. Water Reuse Work Group, Tallahassee, Fla.

Romero, C.C. & Dukes, M.D., 2014. Estimation and Analysis of Irrigation in Single-Family Homes in Central Florida. *Journal of Irrigation and Drainage Engineering,* 140:2:04013011.

Romero, C.C. & Dukes, M.D., 2013. Net Irrigation Requirements for Florida Turfgrasses. *Irrigation Science,* 31:5:1213.

Romero, C.C. & Dukes, M.D., 2011. Are Landscapes Over-Irrigated in Southwest Florida? A Spatial-Temporal Analysis of Observed Data. *Irrigation Science,* 29:5:391.

Seidel, H.F. & Cleasby, J.L., 1966. A Statistical Analysis of Water Works Data for 1960. *Journal AWWA,* 58:12:1507.

Tiger, M.W.; Eskaf, S.; & Hughes, J.A., 2011. Implications of Residential Irrigation Metering for Customers' Expenditures and Demand. *Journal AWWA,* 103:12:30.