Residential Irrigation Water Use in Central Florida

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Abstract: Automatic inground irrigation is a common option for residential homeowners desiring high-quality landscapes in Florida. However, rapid growth is straining water supplies in some areas of the state. The first objective of this study was to document residential irrigation water use in the Central Florida ridge region on typical residential landscapes (T1). The second objective was to determine if scheduling irrigation by setting controllers based on historical evapotranspiration (ET) (T2) and reducing the percentage of turf area combined with setting the controllers based on historical ET (T3) would lead to reductions in irrigation water use. The time frame of this study was 30 months beginning in January 2003. Irrigation accounted for 64% of the residential water use volume over all homes monitored during this project. The T1 homes had an average monthly water use of 149 mm/month. Compared to the T1 homes, T2 resulted in a 30% reduction (105 mm/month), and T3 had a 50% reduction (74 mm/month) in average monthly water use. Average monthly water use was significantly different ($p < 0.001$) across the three irrigation treatments. Setting the irrigation controllers to apply water according to seasonal demand resulted in significantly less irrigation water applied. In addition, increasing the proportion of landscape area from 23% (T1 and T2) ornamental plants irrigated with sprinklers to 62% and irrigated with micro-irrigation (T3) resulted in the largest reduction in irrigation water applied. Compared to T2 where only the irrigation controllers were adjusted, this additional decrease in irrigation water applied was a result of low volume application on only a portion of the landscaped beds where irrigation is only applied to the root zone of plants.

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Introduction

Irrigation systems are common in many residential communities built in recent years or are currently under construction in Florida due to the high-quality landscapes that are typically installed. Turfgrass is a key landscape component, and normally the most commonly used single type of plant in the residential landscape. Although Florida has a humid climate, the spring and winter are normally dry. The average annual precipitation for the Central Florida ridge is approximately 1,270 mm, with most of this in the summer months (June through August). The spring months (March through May) are typically the driest (USDA 1981). This region is also characterized by sandy soils with a low water-holding capacity; therefore, storage of water is minimal. The dry spring weather and sporadic large rain events in the summer (coupled with the low water-holding capacity of the soil) make irrigation necessary to ensure high quality of landscapes desired by homeowners.

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Residential water use comprises 61% of public-supply water withdrawals (Fernald and Purdum 1998). Public supply is the second largest use (43%) of the groundwater withdrawn in Florida, after agriculture. Between 1970 and 1995, public-supply water withdrawals increased 135% (Fernald and Purdum 1998) and Florida consumes more fresh water than any other state east of the Mississippi River (Solley et al. 1998).

The current population in Florida of over 16 million is projected to exceed 20 million by 2015 (USDC 2001). Due to drought conditions in the past few years, some municipalities within the St. Johns River Water Management District (SJRWMD) have limited residential irrigation to twice a week. Residential irrigation is prohibited between 10 a.m. and 4 p.m., whether the water is from public supply, domestic self-supply (i.e., wells), or surface water (SJRWMD 2005). Irrigation outside of these hours is thought to reduce evaporative and wind losses. The irrigation systems used by the households in this region typically include stationary spray heads and gear driven rotor sprinklers for the turf and landscape. The SJRWMD has implemented rain sensor rebate programs and media programs to encourage outside irrigation water conservation efforts.

Several research projects regarding residential irrigation water use were found in the literature indicating that irrigation water in residential landscapes is often excessively applied. Barnes (1977) found residential irrigation rates ranging from 122 to 156% of seasonal evapotranspiration (ET) rates in two Wyoming cities. A study using soil moisture sensors to control residential or small commercial irrigation systems resulted in 533 mm used for irrigation, compared to the theoretical requirement of 726 mm (Qualls et al. 2001). Aurasteh et al. (1984) compared residential solid set and movable systems in Logan, Utah. Analysis of the application efficiency of these systems showed that the average water application efficiency was about 30% for hand-move and

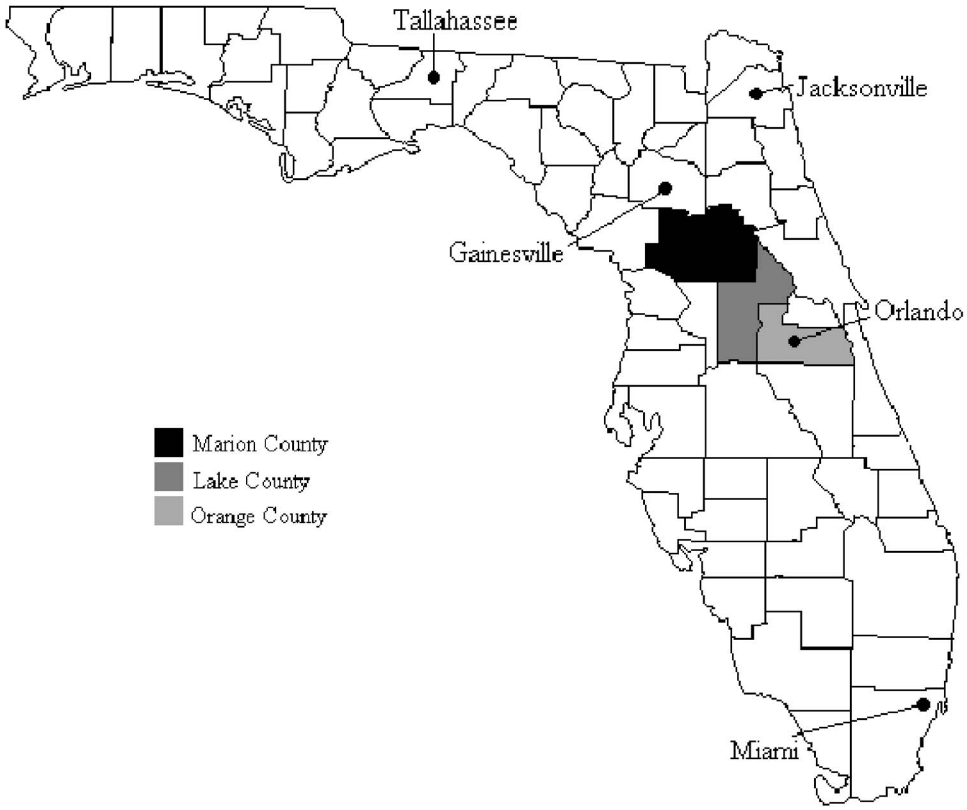

Fig. 1. Map of site locations in Florida where shaded counties denote site locations

37% for solid set systems. It was also noted that these homeowners used approximately 61% of their total water supply for irrigation. Northern Utah receives less average annual precipitation, 449 mm (NRCS 1990), compared to the 1,270 mm received in the Central Florida ridge (Fernald and Purdum 1998). Linaweaver et al. (1967) found that the amount of water used for residential lawns was affected by the total number of consumers, the economic level of the residential area, the area of turfgrass and bedding requiring irrigation, the evapotranspiration rate, and the quantity of effective rainfall.

White et al. (2004) investigated using potential ET, a landscape coefficient (L_c), and the landscape size, to develop water budgets for residential landscapes. It was determined that potential ET irrigation budgeting with a L_c of 1.0 where the irrigation budget was L_c multiplied by potential ET would account for substantial irrigation water savings, especially in the summer months. The authors concluded that a L_c of 0.7 would save additional water without a negative impact on landscape plant quality in a mixed species landscape.

In a survey on residential end uses of water, Mayer et al. (1999) reported that homes with inground irrigation systems used 35% more water than houses with no irrigation. Automatic timer controls incorporated into the system led to a 47% increase in water use. The use of drip irrigation resulted in 16% more water used than homes that did not irrigate the area with inground irrigation. Homes that only hand (hose) watered areas used 33% less water than those with inground systems, and homes that included a consistently maintained garden used 30% more outdoor water than those without. Homes grouped into the low-water-use category through the use of low-water-use landscape plants applied an average of 826 mm per year for the irrigated area. Typical landscapes applied 927 mm per year; however, there was not a statistically significant difference between these two groups.

The objectives of this project were to determine residential irrigation use in the Central Florida ridge and if combinations of irrigation scheduling and landscape/irrigation design could reduce irrigation water application. Specifically, irrigation and landscape treatments were implemented to determine if (1) water consumption in homes with typical irrigation systems and landscapes would be reduced by adjusting the time clock seasonally according to historical ET demands; and (2) if installing a landscape with substantially more ornamental planting beds that are micro-irrigated and adjusting the irrigation schedule according to historical ET demands would reduce irrigation water consumption compared to irrigation practices and landscapes typical in the region.

Materials and Methods

This study was conducted in the Central Florida ridge in Marion, Lake, and Orange Counties (Fig. 1). The soils in the Florida ridge are excessively to moderately well drained sandy quartzipsamments (USDA 1981). The water table in most areas of the ridge is below the root zone of landscape plants. The prevalent soil series in the Marion and Lake County sites is Astatula sand, which allows for rapid permeability, has a very low available water capacity, and little organic matter content (USDA 1975). The dominant soil series in the Orange County site location is Urbanland-Tavares-Pomello, which is a moderately well drained soil that is sandy throughout (USDA 1989). The available water holding capacity for these soil types ranges from 5 to 10% volumetric water content (Carlisle et al. 1989).

Fig. 2. (Color) Representative T1 or T2 landscape design where the entire landscape is irrigated with sprinklers

The irrigation systems used by the households typically include stationary spray heads and gear driven rotor sprinklers for the turf and landscapes. The lawn areas of the yards all consisted of St. Augustinegrass (*Stenotaphrum secundatum*), which is a warm season turfgrass and commonly installed as sod in Florida residential home construction. Positive displacement flow meters were installed on the irrigation main line of each of the 27 cooperating residential homes and monitored monthly to determine irrigation water use independent of total water use. All of the homes included in this study obtained water from local utilities. The utility water meter was also monitored to determine the total amount of water consumption. Meters were installed with no obstruction within approximately 10 pipe diameters of the inlet and outlet of the meter. This was to ensure minimal turbulence in flow through the meter to maintain accuracy (Baum et al. 2003). In addition, all homes had an irrigation system evaluation at the beginning of the project and intensive catch can testing to determine irrigation system uniformity (Baum et al. 2005).

Within each of the three locations, the homes were divided into three treatments. The first landscape and irrigation treatment (T1) consisted of existing irrigation systems and typical landscape plantings, where the homeowner controlled the irrigation schedule (Fig. 2). Existing irrigation systems consisted of rotary sprinklers and spray heads installed to irrigate both landscape and turfgrass during the same irrigation cycle. Initial T1 installation (water meters and irrigation evaluation) began in January 2002, and by August 2002 eight T1 homes were being monitored. Treatment 2 (T2) homes were similar in irrigation and landscape design to T1 homes (Fig. 2); however, the time clocks of T2 homes were adjusted on a seasonal basis to replace 60% of historical ET according to guidelines established by Dukes and Haman (2001). The implementation of all T2 homes began in December 2002 and since implementation consisted of setting the irrigation time clock, all nine T2 homes were established by January 2003. Treatment 3 (T3) consisted of an irrigation system designed according to specifications for optimal efficiency, including a landscape design that minimized turfgrass and maximized the use of landscape plants (Fig. 3). Ornamental landscape plants were irrigated by micro-irrigation on separate irrigation zones from turfgrass as opposed to standard spray and rotor heads. The date range of data collection where all ten T3 homes were being monitored was May 2003 through July 2005. Although the total monitoring period was 42 months (January 2002 through June 2005), there were 30 months (January 2003 through June 2005) where all T1 and T2 homes were being monitored, while most T3 homes were installed. Therefore, data reported here are for the January 2003 through June 2005 time period.

The average T1 or T2 irrigated landscape was comprised of approximately 75% turfgrass (60–88% range) where turfgrass and landscape plants were irrigated on the same irrigation zones (Table 1). The turfgrass portion of the T3 homes averaged 31% (5–66% range). The remaining landscaped area was established with Florida native plant material or low-water-use species in many cases, and irrigated with micro-irrigation, or in one case, not irrigated after establishment.

Weather stations were installed in late February 2002 in Marion and Lake Counties to enable calculation of reference evapotranspiration. The third weather station was installed May 2003 in Orange County. The weather stations were located in flat-grassed areas so that the nearest obstruction was at least 61 m away from the station. Irrigated areas were chosen when possible; however, this resulted in one of the stations (Marion County) collecting irrigation water in the precipitation bucket. Therefore, a separate precipitation bucket and data logger (Davis Instruments Corp., Hayward, CA and Onset Computer Corp., Bourne, MA) were installed in an un-irrigated area to separate precipitation events from irrigation events. The irrigation quantities from the original tipping bucket were not included in the precipitation totals. In most cases, residential home sites were located within 1 km of the weather stations. Date, time, relative humidity, and temperature (model HMP45C, Vaisala, Inc., Woburn, Mass.), solar radiation (model LI200X, Li-Cor, Inc., Lincoln, Neb.), wind speed and direction (model WAS425, Vaisala, Inc., Sunnyvale, Calif.), and precipitation (model TE525WS, Texas Electronics, Inc., Dallas, Texas) were recorded in 15 min intervals via a CR10X data logger (Campbell Scientific, Inc., Logan, UT).

Fig. 3. (Color) Representative T3 landscape design. Note that nonturfgrass area is irrigated with micro-irrigation.

Reference ET (ET_o) was calculated by the methodology described in FAO-56 (Allen et al. 1998).

As a comparison with actual irrigation water applied to the residential landscapes, the theoretical monthly irrigation water requirement was calculated from a soil water balance as follows:

$$I_{\text{calc}} = \text{ET}_c - P_e + D + \text{RO} + \Delta S \tag{1}$$

where I_{calc}=calculated irrigation requirement (mm/month); ET_c=calculated ET from the entire landscape (mm/month); P_e=effective rainfall (mm/month); D=drainage below the root zone from excess irrigation (mm/month); RO=surface runoff (mm/month); and ΔS=change in soil water storage within the root zone (mm/month). Simplifying assumptions applied to this equation were as follows: (1) Ideally, irrigation is applied such that drainage (D) is negligible, (2) surface runoff (RO) is neglected due to the coarse nature of the soils at the study sites where infiltration rates have been shown to be as high as 225 mm/h from field studies (Gregory et al. 2006) and within the same order of magnitude from lab scale studies (Carlisle et al. 1989), and (3) the change in soil water storage (ΔS) over a month is negligible due to the shallow root zone of turfgrass and coarse nature of the soils at the study sites. These assumptions were intended to represent an ideal irrigation scenario and resulted in the following equation:

$$I_{\text{calc}} = \text{ET}_c - P_e \tag{2}$$

The Penman-Monteith equation, as outlined in FAO-56, was used to calculate reference evapotranspiration, ET_o. The

Table 1. Percentage Irrigated Area That Is Turfgrass or Landscaped Bedding as well as the Total Irrigated Area for Each Home

	Treatment 1 landscape			Treatment 2 landscape			Treatment 3 landscape		
House	Turfgrass (%)	Beds (%)	Area (m^2)	Turfgrass (%)	Beds (%)	Area (m^2)	Turfgrass (%)	Beds (%)	Area (m^2)
1	66	34	2,165	60	40	497	5	95	495
2	70	30	1,709	66	34	2,434	10	90	1,636
3	74	26	495	74	26	495	15	85	1,059
4	80	20	351	74	26	743	20	80	775
5	82	18	655	75	25	822	40	60	1,050
6	85	15	3,198	76	24	611	50	50	450
7	85	15	697	78	22	1,059	50	50	400
8	88	12	1,505	85	15	701	59	41	1,737
9	—[a]	—	—	85	15	1,328	60	40	450
10	—	—	—	—	—	—	66	34	448
Average	79	21	1,347	75	25	966	38	63	850
SD[b]	8	8	991	8	8	613	23	23	506
CV[b](%)	10	37	74	11	32	63	61	37	60

[a]Total of eight homes on T1, nine on T2, and ten on T3 monitored throughout the project.

[b]SD=standard deviation; CV=coefficient of variation.

evapotranspiration for a specific crop is denoted as ET_c and is calculated from ET_o and a crop coefficient (K_c) (Allen et al. 1998)

$$ET_c = K_c \times ET_o \tag{3}$$

Crop coefficient values for turfgrasses in Florida have not been documented and many of the values available in the literature are for cool season grasses. Furthermore, irrigation on T1 and T2 homes was applied to both landscape and turfgrass simultaneously, making the use of a K_L representing the entire landscape necessary; similar to the approach taken by White et al. (2004) and advocated by the Irrigation Association (IA 2005). Therefore, $K_L=1$ was selected to represent the entire landscape for all seasons for all treatments. This selection was conservative since seasonal K_c values are typically below 1 for turfgrasses and many ornamental plants (Carrow 1995; Meyer and Gibeault 1987). Using $K_L=1$ would lead to an overestimate in I_{calc}, which would in turn minimize the difference between I_{calc} and the amount of actual irrigation applied.

Effective rainfall is the portion of rainfall that is beneficial to the plants, and does not include that rainfall producing runoff or drainage below the root zone. Effective rainfall was estimated by the NRCS (formerly SCS) TR-21 methodology (USDA 1970). This method has been shown to estimate effective rainfall within 10% of a daily soil water balance under Florida conditions for micro-irrigated citrus (Obreza and Pitts 2002). The following equations present the effective rainfall estimation (Fangmeier et al. 2005):

$$P_e = f(D)[1.25P_m^{0.824} - 2.93][10^{0.000955ET_c}] \tag{4}$$

$$f(D) = 0.53 + 0.0116D - 0.894 \times 10^{-5}D^2 + 2.32 \times 10^{-7}D^3 \tag{5}$$

where P_e=effective rainfall (mm/month); P_m=mean monthly rainfall averaged across three locations (mm/month); ET_c=total monthly landscape evapotranspiration (mm/month); $f(D)$=adjustment factor for a given soil water deficit, and D=representative soil water deficit for the homes in this project. The calculated D value was 12 mm using a root zone of 30 cm, an average available water content of 8% based on literature values (Carlisle et al. 1989), and assuming a maximum depletion of 50%.

Turfgrass quality on each home was rated seasonally (i.e., every three months) by the same person throughout the study. The assessment of turfgrass is a subjective process following the National Turfgrass Evaluation Procedures (NTEP; Shearman and Morris 1998). This evaluation is based on visual estimates such as color, stand density, leaf texture, uniformity, disease, pests, weeds, thatch accumulation, drought stress, traffic, and quality. Turfgrass quality is a measure of functional use and aesthetics (i.e., density, uniformity, texture, smoothness, growth habit, and color). The rating system uses a subjective score ranging from "1" (worst quality) to "9" (best quality), with "5" being acceptable quality.

The statistical analysis of the monthly total irrigation water use and seasonal turfgrass quality was conducted using the general linear model function of the SAS software for the analysis of variance (ANOVA; SAS 2001). Seasons were categorized as winter (December, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November). The means are reported as weighted means based on the number of homes in each treatment for a given month. Interactions, such as year treatment or season treatment were tested, and the three locations were nested for proper data analysis. Means separations were determined with Tukey's procedure.

Results and Discussion

The average fraction of total water used for irrigation was 64% across all the homes during the study period. Treatment 1 averaged 74% of the total water use for irrigation, T2 averaged 66%, and T3 averaged 51%, which were statistically different ($p<0.001$). This decline in the fraction of total water used for irrigation was a result of less irrigation water applied to T2 and T3 due to seasonal controller adjustments and effectively less irrigated area on the T3 homes due to the use of micro-irrigation.

Over the entire monitoring period, treatment, season, and year were significant factors ($p<0.0001$) in the ANOVA, while season year ($p=0.0115$) and treatment year ($p<0.0184$) interactions were also significant. Treatment 1 (user controller setting with typical irrigation system) had the highest average monthly irrigation water application, 149 mm/month. Treatment 2 resulted in 105 mm/month applied, and T3 (adjusted controller setting incorporating micro-irrigation) resulted in the least amount of water for irrigation, 74 mm/month. The T2 homes resulted in 30% less irrigation water applied than T1, and T3 resulted in 50% less irrigation applied than T1.

Because the county was not a significant factor in the ANOVA (Table 2), average values were used across the county for comparison of I_{calc} to actual irrigation water applied. In addition, precipitation was similar at the three locations with total cumulative values of 4.29 m, 4.74 m, and 4.29 m at Marion, Lake, and Orange Counties (Fig. 4). During the study period, the precipitation was near or slightly above average compared to 4.23 m, based on a historical annual average of 1,270 mm/year.

Since there were significant interactions between year and season as well as treatment, the ANOVA was performed year by year. Table 2 shows the means categorized by treatment, season, and county for each year. In the first year of the study, T1 homes applied significantly more irrigation water than either T2 or T3 homes at 141 mm, compared to 93 and 80 mm, respectively. In years 2 and 3, T1, T2, and T3 all had significantly different mean monthly irrigation depths applied. The trend was T1 with the most water applied followed by T2 and T3. In years 2 and 3, T1 homes applied 155 mm/month and 153 mm/month compared to 117 mm/month and 107 mm/month for T2; 67 mm/month and 79 mm/month for T3.

All of the homes in the study reduced irrigation water applied in the winter compared to the other seasons (Table 2). This trend in water use across all treatments indicates that even the T1 homeowners, who scheduled their own irrigation, reduced their water use in the cooler months. However, most homeowners in the T1 group did not cease irrigation altogether; whereas, irrigation on T2 and T3 homes was frequently discontinued in the winter. Any other seasonal trends are not apparent, since irrigation in the fall of year 2 was less than the spring; however, in year 3, spring irrigation was lower than summer irrigation (Table 2).

Fig. 5 shows I_{calc} and actual irrigation applied to each treatment along with precipitation on a monthly basis. T1 had the highest water application (149 mm/month) compared to calculated irrigation needs and these homes on average applied 2.4 times the calculated irrigation water required, based on a conservative calculated irrigation estimate, as described previously. The T2 water applied was reduced compared to T1 due to more appropriate scheduling. However, note that T2 homes still had a

Table 2. Mean Monthly Irrigation by Year to Irrigation Treatments, Season, and in a County

	Year 1			Year 2			Year 3		
	I_{actual}[a] (mm/month)	N[b] (#)	CV[c] (%)	I_{actual} (mm/month)	N (#)	CV (%)	I_{actual} (mm/month)	N (#)	CV (%)
Treatment[d]									
T1	141a[e]	96	49	155a	102	60	153a	48	10
T2	93b	108	59	117b	108	47	107b	48	24
T3	80b	87	71	67c	113	91	79c	54	31
Season[f]									
Spring	124a	66	51	140a	81	78	118b	75	27
Summer	107a	75	67	122a,b	82	52	140a	25	19
Fall	113a	81	50	109b	74	58	—[g]	—	—
Winter	73b[h]	69	81	77c	86	76	87c	50	43
County									
Marion	100a	89	61	118a	98	50	108a	48	34
Lake	107a	94	59	106a	104	61	119a	42	32
Orange	106a	108	67	110a	121	92	110a	60	35

Note: Superscript letters indicates footnotes.

[a]Monthly average irrigation applied.

[b]N=number of months of data in the comparisons.

[c]CV=coefficient of variation that is the standard deviation divided by the mean.

[d]Irrigation treatments are: T1, typical irrigation and landscaping with homeowner scheduled irrigation; T2, landscape and irrigation identical to T1 but irrigation scheduled based on historical ET; T3, increased area of microirrigated landscape beds with scheduling the same as T2.

[e]Numbers followed by different letters are statistically different at the 95% confidence level within a year.

[f]Seasons defined as: spring, March, April, May; summer, June, July, August; fall, September, October, November; winter, December, January, February.

[g]Data collection ended June in year 3.

[h]Winter of year 1 consisted of January and February only.

substantial amount of over irrigation. This excess irrigation is an artifact of the scheduling method, which used historical ET to generate an irrigation schedule. During the time period of this study, the historical ET approach overestimated the theoretical landscape water requirement, because in any given time period, the actual climate conditions may not match the historical average. Irrigation scheduling would be improved by scheduling via real time, ET estimates. The trend of irrigation water applied on

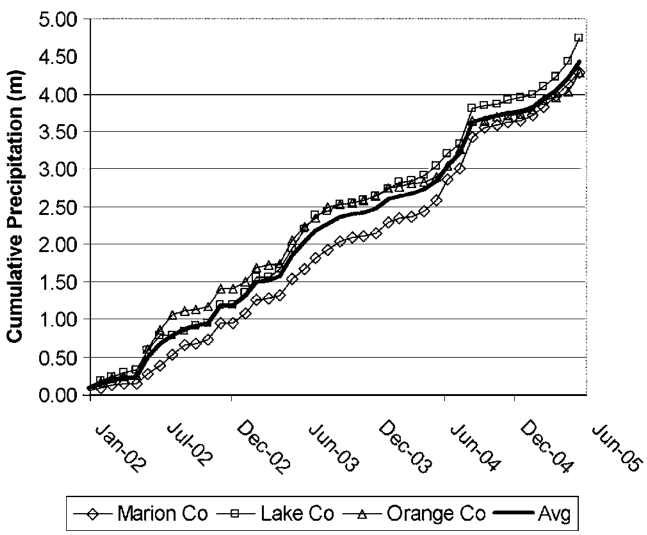

Fig. 4. Cumulative precipitation at the three study locations where precipitation data for all sites are not available in September 2004 due to hurricanes

T2 homes mimicked the calculated irrigation trend over the study period (Fig. 5); however, on average, these homes applied 1.7 times more irrigation (105 mm/month) than theoretically necessary. The T1 irrigation water-use trend was similar to calculated need, but with peaks higher than the T2 homes. T3 irrigation water applied matched the calculated irrigation water requirement reasonably well during this study. From Fig. 5, it can readily be seen why landscape quality did not suffer as a result of irrigation reductions, since the calculated irrigation requirement was similar to the actual irrigation applied, and why T3 homes on average used significantly less water (74 mm/month) than T1 or T2 homes. There was not a statistical difference in turfgrass quality among the treatments for the duration of this study, and all treatments rated acceptable quality or better (>5); with average quality ratings on T1, T2, and T3 of 6.0, 6.2, and 5.8, respectively.

Summary and Conclusions

The average household in this study used 64% of the total household water supply for irrigation. Substantial over irrigation occurred on landscapes with homeowner scheduled irrigation and irrigation scheduled based on deficit historical ET, compared to calculated irrigation requirements. Irrigation water use was greatest on the homes with typical landscapes and irrigation systems where the homeowner set their own controller run times (T1). At the homes where the landscape irrigation system consisted of a typical design, but the controller run times were adjusted based on historical evapotranspiration rates (T2), the irrigation water consumption, 105 mm/month, was reduced by 30% compared to T1 (149 mm/month). The homes with both the adjusted controller

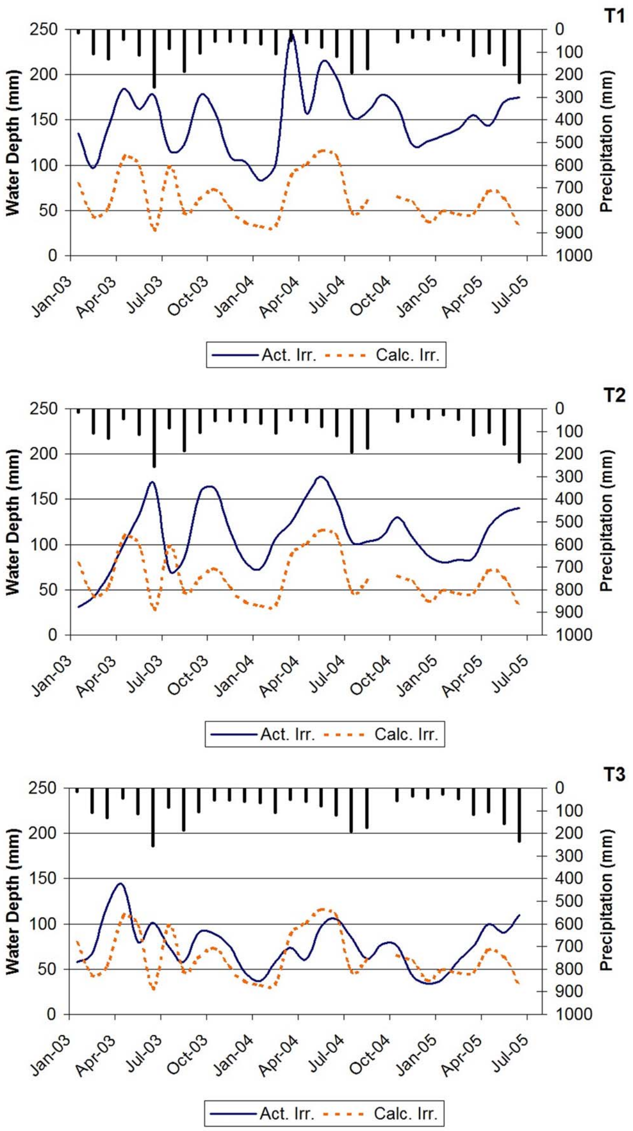

Fig. 5. Actual irrigation compared to calculated irrigation, where calculated irrigation was based on a soil water balance between estimated landscape ET, effective rainfall, and irrigation applied. T1 represents typical irrigation and landscape and homeowner irrigation scheduling, T2 is the same type of landscape and irrigation as T1 but irrigation is scheduled at 60% of estimated seasonal turfgrass demand, and T3 scheduling is similar to T2, but has most of the landscape area irrigated with micro-irrigation and ornamental plants. Precipitation data not available in September 2004 due to hurricanes.

run time settings and the incorporation of micro-irrigation in a substantial portion of the bedded areas (T3) consumed the least amount of irrigation water, 74 mm/month, which was a 50% water savings, compared to T1.

The actual irrigation water use of each treatment was compared to the calculated irrigation need with a simple soil water balance equation and calculated effective rainfall. T3 homes applied irrigation water similar to calculated needs. The main reason for reduced water use on T3 compared to T1 was due to less actual area irrigated, since micro-irrigation was designed to irrigate only the plant root zone, leaving the area in between ornamental plants with no irrigation. Over irrigation may have occurred on the sprinkler irrigation zones. The water input for the T1 homes was always higher than necessary. Adjusting the irrigation time clock with respect to historical ET demands resulted in reduced water application on T2 homes compared to T1; however, irrigation exceeded the calculated irrigation requirements for the entire monitoring period. The scheduling could be improved by using real time or near real time weather data to calculate ET, rather than historical data. The use of soil moisture sensors for irrigation control would also improve irrigation scheduling.

Turfgrass quality was not negatively impacted by the irrigation and landscape treatments. Consequently, irrigation scheduling following historical evapotranspiration demands and incorporating micro-irrigation into the bedded areas are adequate methods to reduce irrigation water application in this region.

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