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RESIDENTIAL IRRIGATION EFFICIENCY ASSESSMENT MONITORING FINAL REPORT

Residential Irrigation Efficiency Assessment Monitoring

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Final Report

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This special publication is a companion document to Special Publication SJ2006-SP14. It was undertaken to continue the time series data collection and further substantiate the conclusions outlined in Special Publication SJ2006-SP14.

Executive Summary

The purpose of this project was to continue data collection for the project entitled "Residential Irrigation Efficiency Assessment" for one additional year. The original project assessed residential irrigation water use compared to actual needs in central Florida sand ridge conditions by examining irrigation system distribution uniformity, irrigation scheduling, landscape planting, and design choices. The following description will present the original project with updated irrigation and weather data.

Three irrigation and landscape combinations were established and monitored. Treatment one (T1) consisted of existing irrigation systems and typical landscape plantings, where the homeowner controlled the irrigation scheduling. Existing irrigation was rotary sprinklers and spray heads installed to irrigate both landscape and turfgrass during the same irrigation cycle. Treatment two (T2) also consisted of existing irrigation systems and typical landscape plantings, but the irrigation scheduling was based on 60% of historical evapotranspiration (ET). Treatment three (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 Florida water-wise plants. T3 irrigation was scheduled similar to T2 for sprinkler irrigation zones. The average T1 or T2 irrigated landscape was comprised of approximately 75% turfgrass compared to an average of 31% (5-66% range) on T3. The remaining landscaped area was considered bedding and irrigated with microirrigation or in two cases not irrigated after establishment.

Monitoring began in January 2002, and continued through June 2005. The residential monitoring included monthly reading of the household utility meter as well as an irrigation meter installed at each home, measurement of irrigation system distribution uniformity at the beginning

of the project, turfgrass evaluation every three months, and continuous measurement of meteorological parameters in each county to allow estimation of reference ET demands.

The household average total water consumption for irrigation was 64%. T1 homes averaged 74% of total water use for irrigation, T2 averaged 66%, and T3 averaged 51%, for average irrigated areas of 1347 m^2 (14,494 ft^2), 966 m^2 (10,394 ft^2), and 850 m^2 (9,146 ft^2). T1 had the highest average monthly irrigation water use of 149 mm (5.9 inches) (64-259 mm, 3.5-10.2 inch range). T2 homes consumed an average of 117 mm (4.6 inches) (31-175 mm, 1.2-6.9 inch range) for irrigation purposes. T3 used the least amount of water for irrigation, 81 mm (3.2 inches) (34-201 mm, 1.3-7.9 inch range), when the initial landscape establishment period was not included. The wide range in individual home irrigation water use within each treatment was due to factors such as homeowner preference, irrigated area, and plant selection.

Calculated reference evapotranspiration (ET_o) for the 42-month monitoring period totaled 4408 mm (173.5 inches) and averaged 110 mm/month (4.3 inches/month). T1 and T2 used more irrigation water than ET_o over this time period, not considering rainfall. All treatments used more water than theoretically necessary when rainfall is considered. Microclimates in each yard, mixed plant communities, and irrigation inefficiency could account for some of the difference. Nevertheless, T2 and T3 had significantly lower average monthly water use compared to T1 (22% and 54%, respectively). The increased irrigation water savings on T3 homes compared to the similarly scheduled T2 homes was because more of the irrigated area used microirrigation in the landscape beds. Microirrigation of the landscape beds resulted in irrigation of only a portion of the planted area (i.e. only the plant root zone was irrigated), as opposed to sprinkler irrigation, which is intended to irrigate all of the planted area evenly.

The T3 costs ranged widely because of lot sizes, cooperator choices of plant material and design. Irrigation and landscaping cost of T3 homes above that of T1 and T2 ranged from $2,000 to $10,000 depending on landscape size and plant material selections by homeowners. In addition, some landscape designs included considerable hardscape (i.e. paved paths, rock walls, etc.) costs. The average irrigation water use reduction rate (T3 compared to T1) observed in this study was 2296 mm (90.4 inches) (not including establishment of T3) over 42 months, or 54.7 mm (2.3 inches) per month.

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Introduction

Irrigation has become nearly a standard option for residential homeowners desiring high quality landscapes in Florida. 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 average precipitation rate is greater than the evapotranspiration rate), spring and winter are normally dry. The average annual precipitation for the central Florida ridge is approximately 1320 mm (52.0 inches), 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 also is characterized by (USDA/NRCS) Type A soils, which are highly permeable sandy soils with a low water-holding capacity. 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 for the high-quality landscapes desired by homeowners.

This study focused on the central Florida ridge in the St. Johns River Water Management District (SJRWMD). SJRWMD has limited residential irrigation to two times per week in this area for the last four years. 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 2002). Irrigation outside of these hours reduces evaporative and wind losses. The irrigation systems used by the Treatment 1 (T1) and Treatment 2 (T2) households in this study include stationary spray heads and gear driven rotor sprinklers for the turf and landscape. Water conservation oriented designs include microirrigation for the landscape bedding with rotary and spray sprinklers with head-to-head coverage in turf areas.

Irrigation efficiency defines how well an irrigation system supplies water to a given crop or turf area. Efficiency is the ratio between water used beneficially and water applied, and is expressed as a percentage. To determine if the water is used beneficially, it is necessary to determine the overall quality of the lawn. The assessment of turfgrass is a subjective process using 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).

Several research projects regarding residential irrigation water use were found in the literature. Barnes (1977) found residential irrigation rates ranging from 122 to 156% of seasonal ET rates. A study using soil moisture sensors to control residential or small commercial irrigation systems resulted in 533 mm (21.0 inches) used for irrigation compared to the theoretical requirement of 726 mm (28.6 inches) (Qualls et al. 2001).

A study of residential end uses of water, funded by the American Water Works Association (AWWA) Research Foundation (Mayer et al. 1999), concluded that homes with in-ground irrigation systems used 35% more water than houses without these systems, automatic timer controls incorporated into the system led to 47% more water used, drip irrigation systems used 16% more water than homes which did not irrigate the area with in-ground irrigation, homes watered only by hand used 33% less water than those with in-ground systems, and homes which included a consistently maintained garden used 30% more outdoor water. The sample, which were grouped into the low-water-use treatment, applied an average of 828 mm/yr (20.3 gal/ft^2/yr) for the irrigated area. The standard landscape treatment applied 930 mm/yr (22.8 gal/ft^2/yr). However, there was not a significant difference (95% confidence interval) between these two treatments. One reason for the inconclusive finding was that the low-water-use landscaping required an initial establishment period of additional water.

The objectives of this project were as follows: 1) determine residential irrigation distribution uniformity across homes in central Florida, 2) determine residential irrigation water use across homes in the region, and 3) determine if combinations of irrigation scheduling and landscape/irrigation design could reduce water use. All findings of the residential irrigation distribution uniformity analysis were reported in the initial project final report submitted in September of 2004 (Dukes et al. 2004). This follow-up project final report presents further observations and final data analysis on the water use and turf quality of the study homes.

Cooperator Recruitment and Treatment Establishment

The project required cooperation of homeowners who would be willing to allow data to be collected on their property. Each yard used in the study was categorized into one of three treatments based on irrigation system and landscape combinations, identified as T1, T2, and Treatment 3 (T3).

Six formal presentations and numerous individual visits were performed across Marion, Lake, and Orange counties to recruit project cooperators. Nine cooperators from each location were randomly selected from the participants that showed interest. One cooperator withdrew from the program in Marion County and one was added in Orange County, for a total of 27 cooperators. Installation of monitoring equipment on all sites began in December 2001. All T1 homes were being monitored by August 2002. All T2 homes were being monitored by September 2002, and all T3 homes were being monitored by August 2003.

The original project plans called for developers to assist in the identification of new home sites and/or cooperating sites for T3. However, one developer chose not to participate and others proved reluctant to provide homes for the study; therefore, recruitment of cooperators was pursued through additional workshops and dialogue with individual residents. Additional funds were allocated as an incentive to the homeowners to participate in the project as a cost sharing measure because of the lack of developer participation.

T1 consisted of existing irrigation systems and typical landscape plantings, where the homeowner controlled the irrigation scheduling. Existing irrigation was rotary sprinklers and spray heads installed to irrigate both landscape and turfgrass during the same irrigation cycle. T2 homes initially were to consist of an irrigation system designed for as high efficiency as practically possible and a typical landscape on new homes. Investigation of replacing or installing new systems revealed that both installation methods and low quality products would negate any benefits of a well designed system. In light of this information, it was decided in consultation with SJRWMD staff to adjust the time clocks of T2 cooperators on a seasonal basis to replace 60% of historical ET according to guidelines established by Dukes and Haman (2001). Accordingly, T2 homes consisted of existing irrigation systems and typical landscape plantings similar to T1. T3 homes consisted of an irrigation system designed according to specifications for optimal efficiency, including a landscape design that minimized turfgrass and maximized the use of Florida water-wise plants. Ornamental landscape plants were irrigated by microirrigation and in two cases not irrigated after establishment, as opposed to standard spray and rotor heads, to achieve further water savings. All three treatments were irrigated under the two-day per week watering restriction that was in place during the time of the study.

The homes in T1 and T2 were irrigated by either rotary or spray irrigation zones. The homes in T3 incorporated a portion of the irrigated area covered by microirrigation. The landscape designs for T3 homes also included larger bedding and decreased turfgrass areas. The typical T1 or T2 landscape averaged 76% (60-88% range) turfgrass (Table 1). The turfgrass portion of the T3 homes ranged from 66% to 5%, and averaged 35%. The remaining percentage of the landscaped area was considered bedding and irrigated with the microirrigation. Bedded areas included the use of ground covers in some sections of the T3 homes[1].

Instrumentation

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 in May 2003, in Orange County. The weather stations were located in flat-grassed areas so that the nearest obstruction was at least 61 m (200 ft) away from the station. Irrigated areas were chosen when possible; however, this resulted in one of the stations collecting irrigation water in the precipitation bucket. A separate rain bucket and data logger (Davis Instruments Corp., Hayward, CA and Onset Computer Corp., Bourne, MA) was installed in a non-irrigated area to separate precipitation events from irrigation events. The residential home sites were located within 1 km of the weather stations. Date, time, relative humidity and temperature (model HMP45C, Vaisala, Inc., Woburn, MA), soil heat flux (model HFT3, Radiation Energy Balance Systems, Bellevue, WA), solar radiation (model LI200X, Li-Cor, Inc., Lincoln, NE), wind speed and direction (model WAS425, Vaisala, Inc., Sunnyvale, CA) and, precipitation (model TE525WS, Texas Electronics, Inc., Dallas, TX), were recorded in 15 minute intervals via a CR10X data logger (Campbell Scientific, Inc., Logan UT).

All of the homes included in this study obtained water from local public supply utilities. The utility water meter was used to determine the amount of water consumed by the household. Positive displacement flow meters were installed on each of the 27 cooperating residential homes to determine irrigation water use separate from total water use. Positive displacement meters, which are relatively inexpensive, yet accurate, are used in domestic water systems. The flow

[1] Individual landscape pictures can be found in Appendix A

meter was installed in the irrigation mainline to determine the volume of irrigation water used. Meters were installed such that obstructions were at least ten diameters from 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).

Analysis and Calculations

The amount of irrigation water use was compared with the reference evapotranspiration (ET_o) and effective rainfall to determine whether over irrigation has occurred. ET_o accounts for the assumed water need by the plant. Irrigation and effective rainfall are both water inputs; however, rainfall is unpredictable.

The Penman-Monteith equation is a widely used combination method for calculating ET_o. As outlined in the FAO-56 publication (Allen et al. 1998), this equation takes the following form:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad [1]$$

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \qquad [2]$$

$$R_n = R_{ns} - R_{nl} \qquad [3]$$

$$R_{nl} = \sigma\left[\frac{T_{max,K}^4 + T_{min,K}^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \qquad [4]$$

$$R_{ns} = (1-\alpha)R_s \qquad [5]$$

$$R_{so} = (0.75 + z(2 \text{ x } 10^{-5}))R_a \qquad [6]$$

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin(\varphi)\sin(\delta) + \sin(\omega_s)\cos(\varphi)\cos(\delta)\right] \quad [7]$$

$$d_r = 1 + 0.033 \cos\left(\frac{2\pi}{365} J\right) \quad [8]$$

$$\delta = 0.409 \sin\left(\frac{2\pi}{365} J - 1.39\right) \quad [9]$$

$$\omega_s = \arccos\left[-\tan(\varphi)\tan(\delta)\right] \quad [10]$$

$$e_s = \frac{e^o(T_{max}) + e^o(T_{min})}{2} \quad [11]$$

$$e_a = \frac{e^o(T_{min})\frac{RH_{max}}{100} + e^o(T_{max})\frac{RH_{min}}{100}}{2} \quad [12]$$

$$e^o(T) = 0.6108 \exp\left[\frac{17.27T}{T + 237.3}\right] \quad [13]$$

where

ET_o = Potential evapotranspiration, mm/day
Δ = slope of the vapor pressure curve, kPa $^oC^{-1}$
R_n = net radiation of the turf surface, MJ m^{-2} day^{-1}
R_{nl} = net outgoing longwave radiation, MJ m^{-2} day^{-1}
R_{ns} = net solar or shortwave radiation, MJ m^{-2} day^{-1}
R_{so} = clear sky solar radiation, MJ m^{-2} day^{-1}
R_s = measured solar radiation W/m^2 x 0.0864, MJ m^{-2} day^{-1}
R_a = extraterrestrial radiation, MJ m^{-2} day^{-1}
G = measured soil heat flux density, MJ m^{-2} day^{-1}
G_{sc} = solar constant, 0.0820 MJ m^{-2} min^{-1}
T = measured air temperature at a 1.5 m height, ^oC
u_2 = measured wind speed at a 2 m height, m s^{-1}
e_s = saturation vapor pressure, kPa
e_a = actual vapor pressure, kPa
$e^o(T)$ = saturation vapor pressure at air temperature, kPa
RH = relative humidity at 1.5 m height, %
d_r = inverse relative distance Earth-Sun
ω_s = sunset hour angle, rad
δ = solar declination, rad
γ = psychometric constant, 0.067 kPa $^oC^{-1}$

σ = Stefan-Boltzmann constant, 4.903 x 10^{-9} MJ K^{-4} m^{-2}
J = Julian day
φ = latitude, radians

Effective rainfall is the portion of rainfall that is beneficial to the plants, and is essentially the rainfall that contributes water to the plant root zone. Effective rainfall was estimated by the SCS method, presented by the following equation (Schwab et al. 1993):

$$P_e = f(D)[1.25P_m^{0.824} - 2.93][10^{0.000955 ET_o}] \quad [14]$$

$$f(D) = 0.53 + 0.0116D - 0.894 \times 10^{-5} D^2 + 2.32 \times 10^{-7} D^3 \quad [15]$$

where

P_e = estimated effective rainfall for soil water deficit depth, mm

P_m = mean monthly rainfall, mm

ET_o = average monthly evapotranspiration, mm

f(D) = adjustment factor for soil water deficits or net irrigation depths

D = soil water deficit or net irrigation depth, mm (used 25 mm)

The statistical analysis of the collected data utilized the general linear model (GLM) function of the SAS software for the analysis of variance tables (SAS 2001). The means are reported as weighted means. All significance tests were at the 95% confidence interval, unless otherwise noted. Interactions, such as year or season with treatment were observed, and the three locations were nested for proper data analysis.

Water Use Results

The average household used 64% of total water for irrigation[2]. T1 homes averaged 74% of the total water use for irrigation, T2 homes used 66%, and T3 homes used 51% (Table 2), which were statistically different ($p<0.001$).

Many of the homeowners, particularly in Marion and Lake counties, left town for extended periods of time in the summer months (June–August). Irrigation of the landscape continued when the homeowner was not in town. Data collection was conducted for part of the data collection period even when three of the T3 homes were vacant because the irrigation system was installed prior to the sale of the house. This lack of occupancy did not affect the irrigation water use for the homes because the homes were part of T3, where the controller settings were adjusted as part of the study. The lack of occupancy did however have an effect on the fraction of water used for irrigation by the household. Months in which the fraction of water use was 100% were omitted.

T1 (user controller setting with typical irrigation system) had the highest average monthly irrigation water use, 149 mm (5.9 inches). T2 (adjusted controller setting to 60% historical ET replacement with typical irrigation system) consumed 117 mm (4.6 inches) for irrigation purposes. T3 (adjusted controller setting at the 60% replacement and incorporated microirrigation) used the least water for irrigation, 81 mm (3.2 inches). The average monthly irrigation depth was significantly different ($p<0.001$) across all treatments. The T2 homes consumed 22% less water than T1, and T3 consumed 46% less than T1 (Table 2).

Evapotranspiration and rainfall data are reported in Table 3 for the comparison of the effective rainfall plus the applied irrigation contrast to ET_o. T1 had a higher water input than ET_o across all three years. The T2 water use was very similar to T1, especially in the summer

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[2] Individual landscape water use can be found in Appendix B

months (Figure 1). Water input decreased during the first winter; this is when controller adjustments began for the T2 homes. The reason that the T2 water input did not decrease as much during the later part of 2003 and early 2004, was because the homeowners would periodically re-adjust their controllers. The controller settings were based on historical ET and during this time rainfall was higher than the historical average, increasing the probability that rain events occurred after scheduled irrigation. The T3 water input was much lower after the first year due to wetter weather conditions and acceptance of the irrigation controller settings by homeowners.

Years two and three, 2003 and 2004, were full years of data collection where the irrigation run times were seasonally adjusted. Significant differences were observed between treatment and season during this cycle of seasons, however, there was not an interaction between treatment and season. Water use trends during the later portion of 2004 and 2005 consistently showed that irrigation scheduling and the use of microirrigation will decrease water use for residential irrigation (Figure 1).

All three treatments used significantly less water in the winter months across the 42 months of data collection, 78 mm (3.1 inches) (Table 4). The summer months accounted for the second lowest amount, 120 mm (4.7 inches). There was not a significant difference between the fall and spring months (127 and 133 mm; 5.0 and 5.2 inches, respectively) when the most water was used for irrigation. T3 used the least water, 51 mm (2.0 inches) in the winter months (December-February) when the turfgrass is typically dormant, primarily because the microirrigation zones result in a smaller effective irrigated area and turfgrass irrigation could be stopped or greatly reduced. T1 applied the most irrigation water, 176 mm (6.9 inches) in the spring months (March-May). T2 used 130 mm (5.1 inches), and T3 consumed the least, 94 mm (3.7 inches) in the spring. ET_o was the highest during the spring months, and the adjusted controller run time settings were similar to those of typical user set run times. T1 and T2 resulted in similar application amounts of 157 mm (6.2 inches) and 137 mm (5.4 inches), and T3 significantly less at 87 mm (3.4 inches) in the fall months (September-November),

Turf quality was rated seasonally (Table 4). The minimum acceptable turf quality rating is 5, and lower ratings do not necessarily imply drought stress. The lawns maintained minimum or better quality during the project data collection period. The T2 and T3 turfgrass was not significantly different in quality from T1 under a decreased irrigation schedule (Table 4).

Water Use Conclusions

The average household in this study used 64% of the total household water for irrigation purposes. Substantial over-irrigation occurred on all treatments when compared to theoretical requirements. Over-irrigation resulted from poor uniformity and improper scheduling.

Irrigation water use was greatest on the homes with typical irrigation systems where the homeowners set their own controller run times (T1). On the homes where the irrigation system still consisted of a typical design, but the controller run times were adjusted based on historical evapotranspiration rates (T2), the irrigation water consumption was decreased by 22% compared to T1. The homes with both the adjusted controller-run time settings and the incorporation of microirrigation in the bedding areas (T3) consumed the least amount of irrigation water, 54% water savings compared to T1. It was observed that T3 had the lowest water input, which was similar to the evapotranspiration. The water input for the T1 homes was always much higher than ET_o. Irrigation application with respect to ET_o for T2 fluctuated and over-irrigation still occurred. The increased irrigation water savings on T3 homes compared to the similarly scheduled T2 homes occured because more of the T3 irrigated area used microirrigation in the landscape beds. Microirrigation of the landscape beds resulted in irrigation on only a portion of the planted area (i.e. only the plant root zone was irrigated), as opposed to sprinkler irrigation, which is intended to irrigate all of the planted area evenly.

Rainfall supplies a significant portion of the plant water requirements in Florida, but high rainfall values will not supply plant water needs over time where water holding capacity is low because rain events are often intense and excess water will runoff or contribute to deep percolation.

Turfgrass quality did not vary significantly across the treatments. Consequently, irrigation scheduling and incorporating microirrigation into the bedded areas are adequate methods of decreasing irrigation water use.

Tables

Table 1. Percentage irrigated area, which is turfgrass or landscaped bedding, as well as the total irrigated area for each home

	Treatment 1			Treatment 2			Treatment 3		
House	**Turfgrass (%)**	**Bedding (%)**	**Area (m^2)**	**Turfgrass (%)**	**Bedding (%)**	**Area (m^2)**	**Turfgrass (%)**	**Bedding (%)**	**Area (m^2)**
1	66	33	2165	60	40	497	5	95	495
2	70	30	1709	66	33	2434	10	90	1636
3	74	26	495	74	26	495	15	85	1059
4	80	20	351	74	26	743	20	80	775
5	82	18	655	75	25	822	40	60	1050
6	85	15	3198	76	24	611	50	50	450
7	85	15	697	78	22	1059	50	50	400
8	88	12	1505	85	15	701	59	41	1737
9	.	.	.	85	15	1328	60	40	450
10	.	.	.	.	.	.	66	34	448
Average	**78**	**21**	**1347**	**74**	**25**	**966**	**35**	**65**	**850**

Table 2. Average across three sites of monthly irrigation water use, fraction of total water use, and number of homes monitored for each treatment

	Treatment 1			**Treatment 2**			**Treatment 3**		
Month	**Water Use (mm)**	**% of Total Use**	**No. of Homes**	**Water Use (mm)**	**% of Total Use**	**No. of Homes**	**Water Use (mm)**	**% of Total Use**	**No. of Homes**
Jan-02	259	81	1	77	79	3	.	44	2
Feb-02	64	81	5	139	73	6	.	50	2
Mar-02	124	85	5	164	74	6	128	66	2
Apr-02	144	87	5	154	90	6	168	76	2
May-02	186	89	5	173	31	6	173	68	2
Jun-02	124	76	5	85	31	6	173	58	2
Jul-02	90	75	5	116	81	7	186	58	2
Aug-02	154	69	8	129	57	8	178	35	3
Sep-02	148	83	8	168	81	9	148	36	3
Oct-02	158	82	8	155	80	9	201	37	3
Nov-02	135	83	8	172	61	9	150	38	4
Dec-02	106	60	8	97	65	9	110	39	4
Jan-03	135	78	8	31	46	9	58	20	4
Feb-03	97	80	8	42	47	9	67	32	4
Mar-03	142	79	8	66	56	9	119	48	7
Apr-03	184	85	8	100	67	9	143	65	7
May-03	162	91	8	133	73	9	80	89	7
Jun-03	177	90	8	167	64	9	101	88	10
Jul-03	117	31	8	72	63	9	75	59	10
Aug-03	123	31	8	85	71	9	58	31	10
Sep-03	177	81	8	157	76	9	90	52	10
Oct-03	158	57	8	162	76	9	89	55	10
Nov-03	110	75	8	115	69	9	76	32	10
Dec-03	104	67	8	81	61	9	47	31	10
Jan-04	83	77	8	74	64	9	37	34	10
Feb-04	102	77	8	107	69	9	58	43	10
Mar-04	245	80	8	124	69	9	74	57	10
Apr-04	157	71	8	154	75	9	61	47	10
May-04	214	68	8	175	63	9	97	48	10
Jun-04	197	72	8	147	56	9	106	52	9
Jul-04	154	69	8	103	67	9	85	56	9
Aug-04	159	74	8	103	71	9	62	58	9
Sep-04	178	78	8	109	65	9	77	69	9
Oct-04	164	72	8	130	63	9	76	45	9
Nov-04	122	67	8	107	71	9	42	56	9
Dec-04	126	69	8	87	76	9	34	56	9
Jan-05	133	67	8	80	78	9	39	42	9
Feb-05	140	63	8	83	69	9	59	43	9
Mar-05	155	78	8	85	62	9	75	55	9
Apr-05	144	72	8	120	66	9	100	58	9
May-05	170	74	8	135	65	9	90	55	9
Jun-05	175	89	8	140	69	9	110	67	9
Average	**149a**	**74**		**117b**	**66**		**81c**	**51**	
Total	**6196**			**4904**			**3900**		

* Different letters indicate difference across season as indicated by Duncan's Multiple Range Test at a 95% confidence level.

Table 3. Average across three sites of monthly ET_o, ET_c ($ET_c = 0.65*ET_o$), and rainfall for each treatment

	Evapotranspiration		Rainfall	Effective Rainfall		
Month	ET_o (mm/month)	ET_c (mm/month)	Total Depth (mm/month)	T1 Total Depth (mm/month)	T2 Total Depth (mm/month)	T3 Total Depth (mm/month)
Jan-02	.	.	.	.	.	.
Feb-02	.	.	.	.	.	.
Mar-02	123	80	98	70	71	70
Apr-02	134	87	45	36	36	37
May-02	156	101	184	136	133	133
Jun-02	129	84	354	213	208	218
Jul-02	139	90	389	231	235	247
Aug-02	134	87	246	159	158	188
Sep-02	124	81	111	79	80	81
Oct-02	112	73	101	71	71	77
Nov-02	91	59	50	36	37	36
Dec-02	81	53	175	105	104	106
Jan-03	86	56	16	12	9	11
Feb-03	88	57	107	70	59	66
Mar-03	109	71	129	87	81	86
Apr-03	131	85	45	37	35	36
May-03	151	98	112	85	84	81
Jun-03	131	85	256	168	165	162
Jul-03	139	91	84	64	61	62
Aug-03	125	81	185	122	119	111
Sep-03	107	69	103	73	71	70
Oct-03	97	63	51	38	38	37
Nov-03	75	49	52	36	36	35
Dec-03	61	40	57	38	37	33
Jan-04	59	38	64	41	40	34
Feb-04	76	50	106	67	68	62
Mar-04	112	73	50	52	38	36
Apr-04	130	85	59	46	46	42
May-04	155	101	78	71	63	61
Jun-04	166	108	80	70	65	64
Jul-04	127	83	125	88	87	86
Aug-04	135	88	110	81	79	74
Sep-04	107	70	.	.	.	.
Oct-04	91	59	13	9	9	9
Nov-04	74	48	51	35	35	30
Dec-04	56	37	42	29	28	23
Jan-05	61	40	40	27	27	23
Feb-05	66	43	44	30	29	28
Mar-05	96	63	64	46	45	44
Apr-05	119	78	37	29	29	29
May-05	130	85	84	64	62	61
Jun-05	125	82	103	76	74	74
Average	**110**	**72**	**105**	**72**	**71**	**71**
Total	**4408**	**2871**	**4100**	**2825**	**2755**	**2761**

Table 4. Seasonal water use, fraction of total water use, and turf quality rating between treatments for each season.

Season	**Treatment**	**Water Use (mm)**	**Fraction of Total Water Use (%)**	**Turf Quality Rating**[#]
Winter	T1	107a[*]	75	5.9a
	T2	76b	63	6.4a
	T3	51c	37	5.8a
Spring	T1	176a	77	5.9a
	T2	130b	74	6.3a
	T3	94c	42	6.4a
Summer	T1	151a	82	5.8a
	T2	113b	66	5.6a
	T3	91b	63	5.5a
Fall	T1	157a	62	6.6a
	T2	137a	61	6.6a
	T3	87b	55	5.9a
Average	**T1**	**149**	**74**	**6.0**
	T2	**115**	**66**	**6.2**
	T3	**81**	**51**	**5.9**

[#] 1” is lowest, “5” is rated acceptable, and “9” is highest.
[*] Different letters indicate difference across season as indicated by Duncan’s Multiple Range Test at a 95% confidence level.

Figures

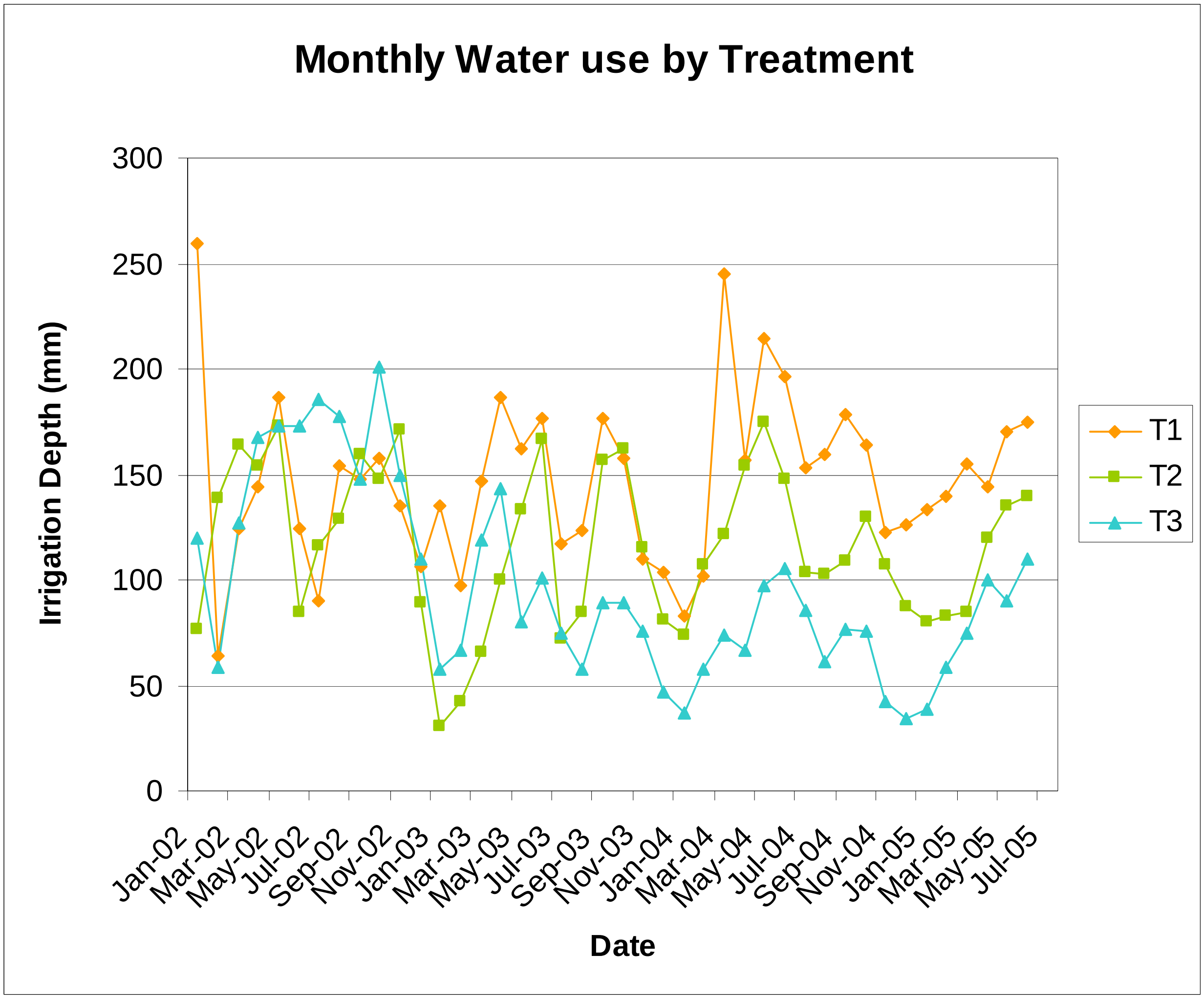

Figure 1. Monthly water use by treatment

References

Allen R.G., Pereira L.S., Raes D. and M. Smith. 1998. Crop evapotranspiration: Guidelines for computing crop requirements. Irrigation and Drainage Paper No. 56, FAO, Rome, Italy.

Barnes, J.R. 1977. Analysis of Residential Lawn Water Use. Masters thesis. Laramie: University of Wyoming, Laramie, WY.

Baum, M.C.; M.D. Dukes, and D. Haman. 2003. Selection and Use of Water Meters for Irrigation Water Measurement. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, ABE 18. University of Florida, Gainesville, FL.

Dukes, M.D. and D.Z. Haman. 2001. Operation of residential irrigation controllers. Circular 1421. Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL.

Dukes, M.D., G.L. Miller, and M.B. Haley. 2004. Residential Irrigation Efficiency Assessment. Final Report submitted to St. Johns River Water Management District. Agricultural and Biological Engineering Dept., University of Florida, Gainesville, FL. pp. 54.

Mayer, P.W., W.B. DeOreo, E.M. Opitz, J.C. Kiefer, W.Y. Davis, B. Dziegielewski and J.O. Nelson. 1999. Residential End Uses of Water. American Water Works Association Research Foundation. Denver, CO.

Qualls, R.J., J.M. Scott, and W.B. DeOreo. 2001. Soil Moisture Sensors for Urban Landscape Irrigation: Effectiveness and Reliability. *Journal of the American Water Resource Association*, 37(3), 547-559.

SAS. 2001. *SAS User's Guide: Statistics*. Ver. 8.02. SAS Institute, Inc., Cary, NC.

Schwab, G.; D. Fangmeier, W. Elliot, and R. Frevert. 1993. *Soil and Water Conservation Engineering, 4th Ed.* John Wiley & Sons, Inc. New York, NY.

Shearman. R. C., and K. N. Morris. 1998. NTEP Turfgrass Evaluation Workbook. NTEP Turfgrass Evaluation Workshop, October 17, 1998, Beltsville, MD.

SJRWMD. 2002. Districtwide Water Restrictions. Water Restrictions Index. St. John’s River Water Management District. Palatka, Florida. http://sjrwmd.com/programs/outreach /conservation/restrictions/districtwide.html, last accessed 05/09/03.

USDA. 1981. Land Resource Regions and Major Land Resource Areas of the United States. Soil Conservation Service Handbook 256. United States Department of Agriculture, Washington, D.C.

APPENDIX A

Individual Home Pictures

13919, Marion County

13615, Marion County

9279, Marion County

12935, Marion County

13601, Marion County

12485, Marion County

13422, Marion County

5712, Lake County

13838, Marion County

39416, Lake County

39640, Lake County

39433, Lake County

5319, Lake County

6129, Lake County

5325, Lake County

2019, Orange County

5512, Lake County

733, Orange County

1683, Orange County

805, Orange County

851, Orange County

505, Orange County

2674, Orange County

1601, Orange County

APPENDIX B

Individual Home Water Use

Treatment 1 - Water Use (mm)								
	Marion County		Lake County			Orange County		
Month	13919	13601	39640	5712	39416	5131	733	2019
Jan-02	-	259	-	-	-	-	-	-
Feb-02	35	111	69	66	38	-	-	-
Mar-02	93	219	131	75	102	-	-	-
Apr-02	97	166	189	116	153	-	-	-
May-02	137	215	208	201	169	-	-	-
Jun-02	158	82	205	43	133	-	-	-
Jul-02	134	0	129	110	78	-	-	-
Aug-02	163	43	165	94	85	210	235	235
Sep-02	206	124	73	96	90	182	206	206
Oct-02	232	80	174	102	104	207	181	181
Nov-02	178	79	78	107	65	159	207	207
Dec-02	131	51	14	77	77	130	182	182
Jan-03	206	89	169	51	54	55	206	247
Feb-03	113	115	76	62	91	116	91	109
Mar-03	235	143	210	89	116	131	107	107
Apr-03	209	135	295	137	173	190	166	166
May-03	64	150	186	92	95	239	233	233
Jun-03	86	289	174	65	153	215	215	215
Jul-03	0	159	80	88	0	206	203	203
Aug-03	0	159	80	88	0	191	234	234
Sep-03	118	206	233	77	167	201	208	208
Oct-03	81	161	201	75	136	211	201	201
Nov-03	50	101	108	51	88	163	178	139
Dec-03	74	102	138	64	76	32	187	161
Jan-04	0	142	163	65	97	18	69	108
Feb-04	61	219	169	73	102	18	69	105
Mar-04	145	168	165	82	108	223	530	535
Apr-04	114	181	112	98	161	74	375	141
May-04	111	226	206	115	163	119	578	196
Jun-04	86	289	174	153	231	211	215	215
Jul-04	132	159	80	191	80	178	203	206
Aug-04	155	159	80	208	93	155	234	191
Sep-04	118	206	233	167	160	132	208	201
Oct-04	81	161	212	136	173	138	201	211
Nov-04	70	201	108	88	137	0	188	183
Dec-04	104	232	81	103	140	1	170	176
Jan-05	94	208	122	91	94	88	175	188
Feb-05	133	192	169	113	101	94	180	126
Mar-05	233	82	99	143	153	159	231	157
Apr-05	200	91	180	161	241	81	23	176
May-05	151	106	141	143	208	159	293	157
Jun-05	171	119	140	157	191	178	259	182
Average	121	152	147	105	119	139	213	191
Total	4959	6379	6018	4314	4876	4860	7440	6688

Treatment 2 - Water Use (mm)

	Marion County			Lake County			Orange County		
Month	9279	13615	12935	39433	5319	5325	1683	2674	857
Jan-02	44	78	109	-	-	-	-	-	-
Feb-02	89	50	271	129	116	176	-	-	-
Mar-02	135	169	256	161	116	146	-	-	-
Apr-02	110	149	135	186	167	177	-	-	-
May-02	172	161	90	76	233	306	-	-	-
Jun-02	50	40	65	89	97	167	-	-	-
Jul-02	20	77	22	127	129	158	-	279	-
Aug-02	74	23	0	137	30	205	134	429	-
Sep-02	52	182	85	229	114	210	132	275	234
Oct-02	110	84	63	43	79	206	108	489	216
Nov-02	102	119	116	138	107	208	139	440	180
Dec-02	10	156	62	112	128	98	91	56	163
Jan-03	0	0	0	91	73	64	28	26	0
Feb-03	24	32	36	79	88	48	0	67	0
Mar-03	66	83	94	117	108	53	38	39	0
Apr-03	40	108	104	158	164	89	58	75	0
May-03	35	118	74	170	226	155	107	147	104
Jun-03	171	193	123	221	126	204	132	166	163
Jul-03	117	98	75	80	83	9	6	110	155
Aug-03	132	100	78	89	76	74	6	121	33
Sep-03	189	196	98	212	195	70	29	270	61
Oct-03	206	164	142	198	175	155	58	198	99
Nov-03	142	65	84	145	122	66	59	239	130
Dec-03	93	91	39	178	76	91	49	33	81
Jan-04	57	40	19	146	92	81	33	131	71
Feb-04	134	112	39	162	86	90	109	126	0
Mar-04	150	117	42	157	92	93	196	131	48
Apr-04	143	152	74	178	174	125	159	229	74
May-04	123	170	69	335	211	127	165	208	137
Jun-04	183	171	123	65	126	204	146	155	130
Jul-04	100	135	78	88	114	135	137	33	56
Aug-04	117	142	89	90	102	92	131	61	117
Sep-04	170	175	98	77	147	70	58	79	29
Oct-04	164	145	142	75	155	155	114	130	58
Nov-04	109	98	66	51	105	176	142	112	29
Dec-04	64	77	30	56	47	169	158	97	0
Jan-05	96	89	60	0	72	88	76	111	132
Feb-05	68	124	55	71	84	41	66	128	107
Mar-05	120	40	76	0	120	31	86	161	129
Apr-05	119	83	93	79	133	65	149	172	183
May-05	130	75	46	86	134	29	246	191	275
Jun-05	163	110	97	153	72	120	145	158	245
Average	105	109	84	123	119	123	100	163	101
Total	4392	4591	3518	5035	4893	5027	3492	5873	3438

Treatment 3 - Water Use (mm)

	Marion County			Lake County		Orange County			
Month	12485	13422	13838	5512	6129	505	805	1601	538
Jan-02	-	-	-	57	-	-	-	-	-
Feb-02	-	-	-	0	-	-	-	-	-
Mar-02	-	-	-	113	-	-	-	-	-
Apr-02	-	-	-	130	-	-	-	-	-
May-02	-	-	-	140	-	-	-	-	-
Jun-02	-	-	-	152	-	-	-	-	-
Jul-02	-	-	-	156	-	-	-	-	-
Aug-02	307	-	-	153	-	-	-	-	-
Sep-02	236	-	-	93	-	-	-	-	-
Oct-02	192	-	-	203	-	-	-	-	-
Nov-02	127	172	-	95	-	-	-	-	-
Dec-02	127	206	-	0	-	-	-	-	-
Jan-03	25	25	-	0	-	-	-	-	-
Feb-03	51	43	-	0	-	-	-	-	-
Mar-03	167	49	-	88	-	115	48	136	-
Apr-03	224	19	-	139	-	109	44	105	-
May-03	99	19	-	87	-	109	35	103	-
Jun-03	143	21	55	137	99	90	54	70	172
Jul-03	9	39	42	68	100	90	71	70	203
Aug-03	13	39	0	138	15	90	71	70	143
Sep-03	60	39	52	119	109	90	71	70	237
Oct-03	46	39	58	149	167	90	71	70	130
Nov-03	133	39	0	157	83	90	71	70	74
Dec-03	46	0	0	49	48	64	91	10	130
Jan-04	61	0	10	99	49	48	6	8	74
Feb-04	66	0	16	100	54	48	6	8	258
Mar-04	66	0	21	100	51	183	26	23	258
Apr-04	66	25	43	91	75	80	0	24	180
May-04	89	43	12	95	184	92	16	207	431
Jun-04	172	143	54	137	55	41	191	90	70
Jul-04	203	9	71	68	42	39	176	90	70
Aug-04	143	13	71	138	0	30	0	90	70
Sep-04	183	60	71	119	52	0	48	90	70
Oct-04	130	46	71	149	58	0	70	90	70
Nov-04	185	88	29	30	12	0	1	13	23
Dec-04	158	62	0	0	0	0	0	47	37
Jan-05	162	86	0	0	0	0	0	51	49
Feb-05	142	101	77	25	4	19	43	68	56
Mar-05	168	86	82	56	19	40	71	51	98
Apr-05	198	129	132	79	32	63	54	66	143
May-05	153	111	110	90	52	77	42	52	122
Jun-05	186	143	89	136	17	105	63	98	157
Average	130	59	47	94	55	64	51	69	133
Total	4537	1893	1167	3933	1377	1805	1439	1940	3325