SPECIAL PUBLICATION SJ2006-SP14

RESIDENTIAL IRRIGATION EFFICIENCY ASSESSMENT
FINAL REPORT

Residential Irrigation Efficiency Assessment

SJRWMD Contract Number SE451AA
UF-IFAS Account 7207 494 12
UF Project 000 348 49

Final Report

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Submitted to
St. Johns River Water Management District

September 17, 2004

This special publication is the first of two documents in a series. It contains a comprehensive description of the original project and provides a full description of the project objectives, methodologies, results and conclusions. Special Publication SJ2006-SP15 is its companion document and was undertaken to continue the time series data collection and further substantiate the conclusions outlined in this document.

Executive Summary

This project was performed to assess current 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. Individual homeowners were recruited as cooperators in sand ridge areas of Marion, Lake, and Orange counties. 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 native, drought tolerant 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 one case not irrigated after establishment.

Monitoring included monthly reading of the utility meter and an irrigation meter on 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 ET demands.

Overall, the average household used 62% of total water consumption for irrigation. T1 homes averaged 75% of total water use for irrigation, T2 averaged 66%, and T3 averaged 46%, for average irrigated areas of 1347, 966, and 850 m^2. T1 had the highest average monthly irrigation water use of 142 mm (63-259 mm range). On average, T2 homes consumed 119 mm (31-175 mm range) for irrigation purposes. T3 used the least amount of water for irrigation, 87 mm (36-221 mm 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. Additional water conservation could be achieved by lowering water use on individual homes.

Calculated reference ET (ET_o) for the 29-month monitoring period totaled 3055 mm. Over this time period, T1 and T2 used more irrigation water than ET_o, not considering rainfall. Estimating the annual average crop coefficient as 0.75 and assuming the entire irrigated area was turfgrass resulted in 82%, 52%, and 29% (not including establishment) more water use than necessary on T1, T2, and T3, respectively. When rainfall is considered, all treatments used more water than theoretically necessary. Microclimates in each yard, mixed plant communities, and irrigation inefficiency could account for some of the difference. Nevertheless, T2 and T3 had significantly reduced average monthly water use compared to T1 (16% and 39%, respectively). The increased irrigation water savings on T3 homes compared to the similarly scheduled T2 homes was due to reduction of turfgrass area and irrigation of landscape beds with microirrigation. Microirrigation of the landscape beds resulted in irrigation of part 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.

Even further irrigation water savings could potentially be achieved by improving irrigation system efficiency. Irrigation efficiency defines how effectively an irrigation system supplies water to a given crop or turf area. Efficiency can be computed as the ratio between water used beneficially and water applied, and is expressed as a percentage. Irrigation system distribution uniformity is a measure of how evenly water is applied over a given area and is an indication of system efficiency. The low quarter distribution uniformities (DU_{lq}) of the homes tested in this study ranged from 0.32 to 0.60, averaged 0.45, and would be considered in the "fair" to "fail" range, with the exception of one "good" according the Irrigation Association (IA). The mean DU_{lq} of the rotor zones was 0.49, which was statistically higher than the mean DU_{lq} of the spray zones at 0.41.

Based on equipment testing under manufacturer recommended conditions, rotary sprinklers and spray heads performed at the low end of the IA quality ratings with an average DU of 0.58 and 0.53, respectively at recommended pressure. According to the home and equipment testing results, irrigation system design was a small component of system non-uniformity. Based on this testing, a theoretical gain of 0.09 and 0.12 DU_{lq} points could be achieved by improving irrigation system design on the homes tested. Although low by industry standards, DU_{lq} did not appear to negatively impact turf quality during this study. The rating scales published by IA may be unrealistically high for the equipment tested in this study.

The T3 costs ranged widely due to 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 $10,010, depending on landscape size and plant materials selected by homeowners. The average irrigation water use reduction rate (T3 compared to T1) observed in this study was 1234 mm (not including establishment of T3) over 29 months, or 42.5 mm/month.

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Introduction

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 where on average the precipitation rate is greater than the evapotranspiration rate, the spring and winter seasons are normally dry. The average annual precipitation for the central Florida ridge is approximately 1320 mm, with the majority of this in the summer months. The spring months are typically the hottest and driest (USDA 1981). This region is also characterized by highly permeable 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 low water holding capacity of the soil make irrigation necessary to maintain the high quality turfgrass and common ornamental landscape plants used in residential landscapes.

Residential water use comprises 61% of the public supply category (Marella 1999). The mostly groundwater derived public supply is responsible for the largest portion, 43%, of groundwater withdrawn in Florida. Groundwater withdrawals increased by 135% between 1970 and 1995 (Fernald and Purdum 1998). The current Florida population of 16 million is projected to exceed 20 million people by 2020 (USDC 2001) and with the average residential irrigation cycle consuming several thousand gallons of water, water conservation has become a state concern. Competition between residential, agricultural, and industrial users will continue to grow. Conservation of current supplies may be one approach to satisfy the needs of all users.

Several research projects regarding residential irrigation distribution uniformity and or 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 used for irrigation compared to the theoretical requirement of 726 mm (Qualls et al. 2001). Residential irrigation uniformities (DU_{lq}) have been found to average 0.37 (Aurasteh et al. 1984) to 0.49 (Pitts et al. 1996). Reasons for non-uniform systems have been documented as lack of maintenance, mixed sprinklers within zones, poor nozzle selection, and improper sprinkler spacing (Pitts et al. 1996; Thomas et al. 2002).

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. 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 native, drought tolerant 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 one case not irrigated after establishment.

Instrumentation

Weather stations were installed in late February 2002, in Marion and Lake Counties to enable calculation of reference evapotranspiration (Fig. 1). 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 (200 ft) away from the station (Fig. 2). 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 nonirrigated 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).

Positive displacement flow meters were purchased and installed on each of the 27 cooperating residential homes to determine irrigation water use separate from total water use. 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 meters, which are relatively inexpensive, yet accurate, are used in domestic water systems. A flow meter was installed in the irrigation mainline to determine the volume of irrigation water used. Meters were installed with no obstruction within approximately ten 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). A Time Domain Reflectometry (TDR) soil moisture measuring device (Field Scout TDR 300 Soil Moisture Probe, Spectrum, Inc., Plainfield, Illinois) with 20 cm rods was purchased to measure soil moisture variability during distribution uniformity (DU) testing of the residential home sites.

Cooperator Recruitment and Treatment Establishment

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 T 2 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 these homes 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 (Figs. 3-5). Existing irrigation was rotary sprinklers and spray heads installed to irrigate both landscape and turfgrass during the same irrigation cycle (Fig. 6). 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. Cooperator recruitment began and a sufficient number of homes were recruited for both T1 and T2. Uniformity testing of these homes and several T3 homes, which did have well designed irrigation systems, resulted in no uniformity differences between the two groups. 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 (Figs. 7-9). 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 native drought tolerant plants. Ornamental landscape plants were irrigated by microirrigation as opposed to standard spray and rotor heads to achieve further water savings (Figs. 10-12).

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. The turfgrass portion of the T3 homes averaged 31% (5-66% range). The remaining landscaped area was established with Florida native plant material and irrigated with microirrigation or in one case not irrigated after establishment.

System distribution uniformity via the catch-can method and soil moisture uniformity via TDR measurements were quantified. Obvious problems such as head misalignments and leaks were repaired prior to testing. In addition, pressure differences across each irrigation system were measured.

The catch-can method of uniformity testing was used to test the distribution uniformity of the system. The catch-can method of uniformity testing is described by both the ASAE and the NRCS (ASAE 2000, Micker 1996). The procedure used was modified to test residential sprinkler irrigation systems rather than linear move and center pivot sprinkler systems as in the ASAE Standard, and was more detailed than NRCS Mobile Irrigation Lab (MIL) method.

Catch cans were distributed around the turf area in either a 1.5 or 3 m square grid depending on the irrigated area (3 m grid for lawns with an area greater than 750 m^2 and 1.5 m grid otherwise). The grid was positioned 0.8 m from property boundaries to reduce edge effects.

Thirty-centimeter wire stem flags were used to mark the grid and were bent to level the catch cans and prevent movement. The cans had an opening diameter of 15.5 cm and a depth of 20.0 cm. The irrigated area of each zone was recorded and the system was set to run for 25 minutes on spray zones and 45 minutes on rotor zones. This resulted in an average catch-can depth of at least 1.3 cm of water. A sketch of the house and landscape beds was drawn to scale with the location of each can marked. This allowed calculation of each irrigation zone area. Irrigation volume was determined from the flow meters and coupled with the area calculations was used to calculate monthly irrigation depth for each home. The type and location of each sprinkler head was also recorded. The volume of water collected in each can was measured with either a 500 or 1000 ml graduated cylinder depending on catch-can volume.

The initial system pressure and flow meter reading were recorded before the uniformity test was performed. According to ASAE standards (ASAE 2000) the wind speed was measured every 30 minutes during the test. If the wind speed was above 5 m/s, or if the distribution was affected by the wind at lower speeds, the test was discontinued. When practical, the test was performed at night to minimize evaporative losses. If night time operation was impractical (i.e. due to homeowner concerns or storms), the test was run during early morning hours when ET was lowest and catch volumes were measured immediately following the test. Once the entire system had cycled, the collected water in each can was measured.

The soil water content was measured with the TDR within 0.5 m of each catch-can to ensure similarity in measurement point and grid location. TDR measurements were taken immediately after each irrigation run cycle. Typically irrigation uniformity is determined by the catch-can method, where DU_{lq} (see Appendix II, eqn. 4) is calculated based on the volume collected in the cans. When calculating the uniformity with the TDR, the DU_{lq} was based on the soil moisture readings.

Turfgrass quality was assessed every three months (i.e. seasonally) on each home across the entire turfgrass area to determine if the irrigation system uniformity or scheduling impacted turf quality. The assessment of turfgrass is a subjective process following the National Turfgrass Evaluation Procedures (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 aesthetics (i.e. density, uniformity, texture, smoothness, growth habit, and color) and functional use.

Statistical analyses were performed in SAS (SAS Institute, Inc., Cary, NC, 2003, version 8.02) using the GLM procedure. Means separation was performed with Duncan's Multiple Range Test at the 5% significance level.

Residential Irrigation Uniformity

Measured DU_{lq} values of homes in this project averaged 0.45 with rotor zones averaging 0.49 and spray zones averaging 0.41 (Table 1). These values are in the range of research findings on similar systems in other states (Aurasteh et al. 1984, Pitts et al. 1996). Rotary sprinkler DU_{lq} was statistically higher than spray zone DU_{lq} ($p = 0.044$). The low-quarter distribution uniformities can be classified by the overall system quality ratings in Table 2 (IA 2003) as "fair" to "fail", with the exception of one "good". When looking at the DU_{lq} of the spray and rotor zones individually, it can be noted that the ratings of the spray zones were much lower, with half of the spray zone uniformities receiving a “fail” rating. The ratings of the rotor zones were normally distributed about the mean within the “good” to “fail” range.

The DU_{lq} values for this study were lower than values reported by the MILs (Table 3). The MIL DU_{lq} values in Table 3 were significantly higher, averaging 0.55 ($p = 0.02$) than the overall DU_{lq} values in Table 1 of 0.45. According to the overall system quality ratings in Table 2, two of the regions surveyed by the MIL resulted in an irrigation system quality rating of “good” or “very good”, one other as “fair”, one as “poor” and two others as “fail”. The DU_{lq} differences between measurements in this study and MIL reports were likely based on testing procedure. As stated previously, the catch-can tests performed for this study were a combination of the testing methods of both the ASAE standards and the NRCS MIL guidelines. The MIL catch-can test procedure requires only 16-24 cans to be distributed centrally within one of the largest zones. The procedures performed in this study used a grid with 100-500 cans distributed evenly across the entire irrigated turf area. Consequently, some edge effects and challenging design areas, such as side lawns, are included in the tests of this study. Due to the greater number of catch-cans, a larger percentage of the under-irrigated areas were also included. Despite this difference in methodologies, it is thought that the procedures used in this study provide a more realistic determination of the variation in irrigation water application depth for the entire irrigation system. If the turfgrass edges of an irrigation zone in a residential setting begin to become stressed and turf quality declines, the homeowner will likely increase the irrigation volume applied to that area. As such, it is important to include the edge areas in uniformity testing. Table 1 shows a comparison between the DU_{lq} determined with the catch-cans placed in the grid formation, as specified in the discussed procedure, as well as the DU_{lq} determined by using only

16-24 can samples simulating the MIL procedure on the largest turfgrass area. The uniformity results were significantly higher when following the MIL method (0.58) compared to the methodology used in this study (0.45).

As previously mentioned, the MIL guidelines specify that the can placement should be in the largest area of the yard. Typically the largest irrigation zone in a yard is irrigated with rotary sprinkler heads. Based on equipment alone, rotary sprinklers tend to have greater uniformity compared to spray heads (Table 1); therefore, catch can location will increase the DU_{lq} value. Since the testing in this study was more representative of actual conditions, the IA table may be unrealistic for the conditions of this study. Although the homes tested had relatively poor DU values, the overall turfgrass quality for the homes was consistently acceptable.

Mathematical calculation methods also affected the uniformity values. The coefficient of uniformity (CU) method (Table 1) produced higher values than the DU_{lq} method. This is because CU takes into account both over and under-irrigation, while DU_{lq} only considers the lowest quarter on the under-irrigated area.

Pressure differences across residential irrigation zones did not vary more than 10%, which is considered acceptable (Pair 1983). As a result it was concluded that pressure variations did not negatively impact uniformity. Head spacing likely resulted in non-uniformity; however, well designed systems did not have higher uniformity when compared to typical systems in this study. This is due to the difficult design areas such as small side yards and strips of turfgrass, which are all difficult to irrigate evenly with minimal overspray.

It was also hypothesized that the equipment, in addition to irrigation system design, might also be a source of variation in the uniformity testing. Therefore, five typical spray heads and three rotary sprinkler heads were tested. Tests were conducted under low wind conditions with a square grid formation (1 m X 1 m can spacing) at the Agricultural and Biological Engineering Department facilities in Gainesville, FL. Spacing of the sprinkler heads was performed according to manufacturer recommendations (Table 4). Two pressure levels were used to test rotary sprinklers, while three pressure levels were used to test spray heads as shown in Table 4. Other testing procedures were similar to the homes in the study. Generally, the rotary sprinklers and spray heads overall performed at the low end of the IA quality ratings with rotary sprinklers and spray heads having an average DU at recommended pressure of 0.58 and 0.53, respectively. Figures 13 and 14 show the results of this testing. The high pressure tested here did not impact spray head uniformity while low pressure resulted in slightly degraded performance with both spray heads and rotary sprinklers.

Based on the home and equipment testing results, irrigation system design was a small component of system nonuniformity. The average DU_{lq} of rotary sprinkler zones and spray heads on homes was 0.49 and 0.41, respectively. If sprinkler spacing and irrigation system design accounted for all of the variation in DU_{lq}, then testing equipment under controlled conditions would have resulted in DU_{lq} values in the ranges specified by the IA (Table 2). However, equipment testing resulted in average DU_{lq} over the three rotary sprinklers tested of 0.58 (0.51-0.68 range) and 0.53 (0.35-0.70 range) for spray heads at recommended pressures. These would both be classified as “fair” by the IA (Table 2; 2003). Based on this testing, a gain of 0.09 and 0.12 DU_{lq} points for rotary sprinklers and spray heads, respectively could theoretically be achieved by improving irrigation system design on the homes tested. Practically, the distribution uniformity measured on the homes tested is probably as high as possible. The rating scales published by IA (Table 2; 2003) are unrealistically high for the equipment tested in this study.

This study also compared the distribution uniformity values determined by the catch-can test to those determined by TDR measurements. The TDR device would allow for a quick and easy method for calculating system uniformity, because there is no significant set up time as with the catch-can tests. When collecting the measurements, a large volume of water collected in a catch can was typically correlated to a high TDR volumetric water content (VWC) reading. However, DU_{lq} determined by catch can was not correlated to TDR DU_{lq}. Differences may have resulted from changes in soil properties or errors due to splaying of the probes, which reports false low VWC values. It is also possible that due to localized runoff and redistribution of water within the soil that the soil uniformity is not represented well by catch can uniformity.

Residential Irrigation Water Use

Overall, the average household used 62% of total water consumption for irrigation. This is in the range observed by previous research (Mayer et al. 1999; Aurasteh et al. 1984). T1 homes averaged 75% of total water use for irrigation, T2 averaged 66%, and T3 averaged 46% (Table 5), which were statistically different ($p<0.0001$). Figure 15 shows the monthly fraction of total water use for irrigation. Fraction of water used for irrigation tended to increase in the hot and dry spring months of March through May in all treatments (Table 5).

Many of the homeowners, particularly in Marion and Lake counties, were out of town for extended periods of time in the summer months. During these periods, the percentage of water use consumed for irrigation purposes was higher in proportion to amount of water consumed inside the house. Three of the T3 homes were vacant for part of the data collection period because the irrigation system and landscape 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 controller settings were adjusted as part of the study. The lack of occupancy did, however, affect the percentage of water used for irrigation by the household; therefore, months in which the percentage was 100% were omitted.

T1 homes (user controller setting with typical irrigation system and landscape) had the highest average (averages calculated as weighted averages based on number of homes monitored a particular month) monthly irrigation water use, 141 mm (Fig. 16). On average, T2 (60% historical ET replacement with typical irrigation system and landscape) consumed 119 mm for irrigation purposes. T3 (larger proportion of landscape bedding in irrigated area and 60% historical ET replacement) used the least water for irrigation at 87 mm (not including establishment). Individual home monthly water use averages ranged 63-259 mm, 31-175, and 36-221 mm for T1, T2, and T3, respectively. This indicates that there was a fairly wide range in individual homes due to factors such as homeowner preference, irrigated area, and plant selection. Additionally, this indicates the potential for lowering water use on T2 and T3 homes even further. T2 consumed 16% less water than T1, and T3 consumed 39% less than T1. The average monthly irrigation depth was significantly different ($p<0.0001$) across all treatments.

Figure 16 shows the variability of irrigation over the study period. Generally, all treatments had reduced irrigation in the cooler months (Dec-Feb). T2 and T3 used less water in the cooler months because the time clocks were set very low most of the time. During this time period, the turfgrass went dormant and used very little water, although many cooperators thought the turfgrass required water. Some cooperators desired green grass in the winter months and would attempt to achieve this effect with high inputs of water and fertilizer. Note that T3 homes had water use higher than T1 and T2 in much of 2002. This was a time period when four of the T3 homes were being established (i.e. new landscape and irrigation system). During the establishment period, irrigation is often applied several times a day to turfgrass, every day for 30 days or more. Although the first two months of irrigation data were removed from T3 due to establishment watering, some excess occurred in 2002, due to homeowner and contractor adjustment of the controllers. T1 and T2 homes did not have this establishment period during the study since the landscapes already existed. Table 6 shows monthly water use over the study period with the two-month establishment irrigation volume removed. Removing the establishment water from the 29-month monitoring period resulted in a total of 2945 mm of irrigation water on T3, while including the establishment water increased the total by 261 mm (total of 3206 mm).

Table 5 shows the seasonal average irrigation use for each treatment, the fraction of water used for irrigation, and turfgrass quality for the season. In the winter months, when the turfgrass is typically dormant, T3 used the least water, 55 mm, primarily because irrigation was limited and the microirrigation zones resulted in a smaller wetted irrigation area compared to sprinkler irrigation. In spring months, T1 used the most irrigation water (176 mm) with T2 (135 mm) and T3 (95 mm) using less in that respective order. The impact of microirrigation on irrigation water use of T3 compared to T2 homes is again apparent. However in the summer months, there was not a statistically significant difference in irrigation water use between the treatments. In these months, calculated ET_o was the highest and the adjusted controller run time settings were similar to that of typical user set run times. In addition, with frequent rainfall and rain sensors on the systems, the small differences between T1 compared to T2 and T3 scheduling were minimized. In the fall months, T1 and T2 consumed similar amounts of irrigation water, 155 mm and 148 mm, while T3 consumed significantly less, 102 mm. Turf quality was statistically lower on T3 homes in the winter season. In part, this may have been due to reducing the irrigation amounts such that the turf went partially dormant. However, in all seasons over all treatments, turf quality did not fall below the acceptable limit of “5” (Table 5). In addition, the turfgrass experienced green up in the spring and there was not a significant difference in turf quality across treatments for other seasons of the year.

The homes in Orange County had the highest average water use at 130 mm/month. This water use is directly correlated with the irrigation system design. The yards in Orange County had the smallest turfgrass areas, which were irrigated by a greater percentage of spray heads versus rotary sprinkler heads (a ratio of 5:1). Spray zones have a higher precipitation rate and the water output is more sensitive to the programmed run time. For all treatments, the homes in Lake County used the greatest percentage of water for irrigation because the yards in this area were the largest. The irrigation water use difference between the three counties was marginally significant (p-value of 0.06).

Calculated ET_o for the monitoring period totaled 3055 mm. Over the 29-month monitoring period, all treatments used more irrigation water than ET_o not including rainfall as an input. While the actual crop water use is unknown because turfgrass crop coefficients (Kc) for this region and Kc values for landscape plants in mixed communities such as residential yards are not available, we estimate that annual turfgrass water use is approximately 75% of ET_o for this region. If these values are used to roughly calculate actual water requirements for the irrigated yards in the study assuming the entire irrigated area were turfgrass (landscape plants not included) for the monitoring period, T1, T2, and T3 resulted in 82%, 52%, and 29% (not including establishment) more water use than necessary, respectively. It is unknown how much of the rainfall is effective (i.e. available for plant consumption); however, if it is estimated that 50% of the total rainfall is effective, then over-irrigation was considerable on all treatments (155%, 124%, and 101%, respectively). Microclimates in each yard, mixed plant communities, and irrigation inefficiencies could account for some of the over-irrigation. The increased irrigation water savings on T3 homes was due to irrigation of landscape beds with microirrigation where a fraction of planted area (i.e. in between plants) is not irrigated, as opposed to sprinkler irrigation, which is intended to irrigate all planted area evenly.

Although it appears that precipitation alone would have met crop needs, the sporadic and intense rain events in the study region often resulted in short dry periods even in the summer rainy season (Table 6). Irrigation was generally necessary in the spring months (Mar-May), in the fall (Sep-Nov), and during short dry periods in the summer (Jun-Aug).

Low amounts of irrigation that can be observed in some of the winter months (Table 6), specifically December 2002, through February 2003, are acceptable because of partial or complete turf dormancy during the winter months. During dormancy, the turf does not require water for transpiration; therefore, the vast majority of the ET is from evaporation.

Irrigation and Landscape Cost Analysis

Irrigation system cost information was compiled across treatments for comparison. Costs for the T1 and T2 homes were documented for Marion and Lake counties; however, since Orange County consisted of established homes, cost data were not available. The combined landscape and irrigation cost of T1 and T2 in Marion County was $3,500-$4,500 per home. In Lake County the combined cost was $15,000 for a T1 or T2 home as required by community rules.

The costs for T3 homes ranged due to the variety of landscapes installed (Figs. 10-12). In Marion County, the cost was $6,500, which was $2,000 to $3,000 above the cost for the T1 and T2 homes. In Lake County, the cost ranged from $10,987 for a retrofit installation on an existing home to $20,710 and $25,010 on new homes. This was $5,710 to $10,010 above the typical landscape and irrigation system cost. The T3 homes in Orange County were all retrofit on existing homes with smaller yards where the costs were $6,966, $7,512, and $8,147. These costs should not be considered as totally additional to the existing landscape and irrigation system because it is considerably less expensive to implement proper T3 irrigation design from the beginning of new home construction as opposed to retrofitting an existing system.

The T3 costs ranged widely due to lot sizes, cooperator choices of plant material and design. The average irrigation water use reduction rates (T3 compared to T1) observed in this study was 1234 mm (not including establishment of T3) over 29 months, or 42.5 mm/month.

Tables

Table 1. Residential distribution uniformity catch-can test results.

County	Rep	CU Overall System	DU_{lq} Overall System	DU_{lq} Spray Head	DU_{lq} Rotor Head	DU_{lq} MIL Style (16-24 cans)
Marion	1	0.60	0.44	.*	.	0.54
	2	0.59	0.39	0.12	0.45	0.51
	3	0.72	0.60	0.57	0.63	0.70
	4	0.60	0.46	.	.	0.58
	5	0.65	0.47	0.51	0.49	0.54
	6	0.55	0.35	0.35	.	0.64
	7	0.54	0.50	0.50	0.47	0.60
	8	0.55	0.39	0.39	.	0.45
Lake	1	0.57	0.39	0.15	0.45	0.64
	2	0.68	0.58	0.67	0.55	0.63
	3	0.61	0.50	0.49	0.48	0.50
	4	0.60	0.42	0.16	0.49	0.42
	5	0.55	0.40	.	0.41	0.50
	6	0.64	0.50	0.66	0.47	0.64
	7	0.71	0.54	0.52	0.59	0.65
	8	0.52	0.33	0.41	0.32	0.82
	9	0.60	0.54	0.45	0.64	0.70
Orange	1	0.60	0.48	0.42	0.49	0.64
	2	0.57	0.38	0.33	0.50	0.51
	3	0.50	0.32	0.31	0.34	0.48
	4	0.57	0.44	0.47	0.50	0.49
	5	0.54	0.36	0.32	0.39	0.42
	6	0.50	0.34	0.23	0.44	0.65
	7	0.62	0.56	0.43	0.63	0.68
	8	0.63	0.47	0.47	.	0.67
Average		*0.59*	*0.45*	*0.41*	*0.49*	*0.58*

* "." Indicates that spray and rotor zones could not be separated.

Table 2. Irrigation Association (IA, 2003) overall system quality ratings, related to distribution uniformity.

Quality of Irrigation System	Irrigation System Rating (ISR)	Distribution Uniformity (DUlq)
Exceptional	10	> 0.85
Excellent	9	0.75 – 0.85
Very Good	8	0.70 - 0.74
Good	7	0.60 - 0.69
Fair	5	0.50 - 0.59
Poor	3	0.40 – 0.49
Fail	< 3	< 0.40

Table 3. Florida Mobile Irrigation Lab turf DU_{lq} results.

County	Distribution Uniformity (DU)			
	Average	Minimum	Maximum	Samples
Fort Myers (2002)	0.59	0.40	0.82	173
Hillsborough (1993)	0.48	0.11	0.71	68
Lake (2001)	0.38	0.12	0.74	64
St. Johns (2001)	0.39	0.12	0.74	64
South Dade (1993-94)	0.71	0.34	0.89	25
St. Lucie (2000)	0.64	0.38	0.80	75
St. Lucie (2001)	0.67	0.13	0.85	88
Average	0.55	0.23	0.79	80

Table 4. Pressure and rated throw distance for spray and rotor heads tested under controlled conditions.

Head Type	Brand	Recommended Pressure (kPa)	Low Pressure (kPa)	High Pressure* (kPa)	Distance of Throw (m)
Rotary	A	345	207	.	12.8
	B	379	207	.	11.3
	C	345	207	.	11.3
Spray	A	207	69	414	4.6
	A-adj.	207	69	414	4.6
	B	207	69	414	4.6
	B-adj.	207	69	414	4.6
	C	207	69	414	4.6

*High pressure tests were only performed on the spray heads.

Table 5. Seasonal water use across irrigation/landscape treatments.

		Winter	Spring	Summer	Fall	Average
Treatment 1	Water Use (mm)	103a*	176a	134a	155a	142
	Fraction of Total Water Use (%)	75	77	82	62	75
	Turf Quality Rating#	5.7a	5.9a	5.8a	6.6ab	6.0
Treatment 2	Water Use (mm)	78b	135b	110ab	148a	119
	Fraction of Total Water Use (%)	63	74	66	61	66
	Turf Quality Rating	6.4a	6.6a	5.6a	6.9a	6.3
Treatment 3 (3a$)	Water Use (mm)	61b (55b)	98c (95c)	104ab (96b)	107b (102b)	91 (87)
	Fraction of Total Water Use (%)	37	42	63	55	46
	Turf Quality Rating	5.4b	6.4a	5.1a	5.8b	5.7

*Letters indicate differences across season as indicated by Duncan's Multiple Range Test at the 95% confidence level.
#"1" is lowest, "5" is rated as acceptable, and "9" is highest.
$Treatment 3a refers to the treatment 3 homes with the first two months excluded due to increased water use for landscape establishment period.

Table 6. Average across three sites of monthly irrigation water use, fraction of total water use, number of homes monitored for each treatment, ET_o, ET_c, and rainfall.

Month	Treatment 1			Treatment 2			Treatment 3					
	Water Use (mm)	% of Total Water Use	No. of Homes	Water Use (mm)	% of Total Water Use	No. of Homes	Water Use (mm)		% of Total Water Use	No. of Homes	
Jan-02	259	81	1	77	79	3	120	(0)**	44	2	(0)
Feb-02	64	81	5	139	73	6	59	(0)	50	2	(0)
Mar-02	124	85	5	164	74	6	128	(128)	66	2	(2)
Apr-02	144	87	5	154	90	6	168	(168)	76	2	(2)
May-02	186	89	5	173	31	6	173	(173)	68	2	(2)
Jun-02	124	76	5	85	31	6	173	(173)	58	2	(2)
Jul-02	90	75	5	116	81	7	186	(186)	58	2	(2)
Aug-02	154	69	8	129	57	8	221	(178)	35	3	(2)
Sep-02	148	83	8	168	81	9	177	(148)	36	3	(2)
Oct-02	158	82	8	155	80	9	201	(201)	37	3	(3)
Nov-02	135	83	8	172	61	9	156	(150)	38	4	(3)
Dec-02	106	60	8	97	65	9	134	(110)	39	4	(3)
Jan-03	135	78	8	31	46	9	58	(58)	20	4	(4)
Feb-03	97	80	8	42	47	9	67	(67)	32	4	(4)
Mar-03	142	79	8	66	56	9	111	(119)	48	7	(4)
Apr-03	184	85	8	100	67	9	119	(143)	65	7	(4)
May-03	162	91	8	133	73	9	80	(80)	89	7	(7)
Jun-03	177	90	8	167	64	9	103	(101)	88	10	(7)
Jul-03	117	31	8	72	63	9	87	(75)	59	10	(7)
Aug-03	123	31	8	85	71	9	58	(58)	31	10	(10)
Sep-03	177	81	8	157	76	9	90	(90)	52	10	(10)
Oct-03	158	57	8	162	76	9	89	(89)	55	10	(10)
Nov-03	110	75	8	115	69	9	76	(76)	32	10	(10)
Dec-03	104	67	8	81	61	9	47	(47)	31	10	(10)
Jan-04	83	77	8	74	64	9	37	(37)	34	10	(10)
Feb-04	102	77	8	107	69	9	58	(58)	43	10	(10)
Mar-04	245	80	8	124	69	9	74	(74)	57	10	(10)
Apr-04	157	71	8	154	75	9	61	(61)	47	10	(10)
May-04	214	68	8	175	63	9	97	(97)	48	10	(10)
Average*	142a	75		119b	66		91c	87c	46		
Total	4179			3473			3206	2945			

Table 6 continued.

Month	Evapotranspiration		Rainfall	
	ET_o (mm/month)	ET_c*** (mm/month)	Total Depth (mm/month)	No. of Events (#/month)
Jan-02	.	.	.	.
Feb-02	.	.	.	.
Mar-02	123	92	98	7
Apr-02	134	101	45	6
May-02	156	117	184	10
Jun-02	129	97	354	21
Jul-02	139	104	389	23
Aug-02	134	101	246	19
Sep-02	124	93	111	13
Oct-02	112	84	101	13
Nov-02	91	68	50	15
Dec-02	81	61	175	25
Jan-03	86	65	16	11
Feb-03	88	66	107	12
Mar-03	109	82	129	23
Apr-03	131	98	45	14
May-03	151	113	112	19
Jun-03	131	98	256	20
Jul-03	139	104	84	11
Aug-03	125	94	185	21
Sep-03	107	80	103	14
Oct-03	97	73	51	10
Nov-03	75	56	52	15
Dec-03	61	46	57	10
Jan-04	59	44	64	10
Feb-04	76	57	106	5
Mar-04	112	84	50	6
Apr-04	130	98	59	8
May-04	155	116	78	5
Average*	113	85	122	14
Total	3055	2291	3307	367

* The average is a weighted average by the number of homes included in the treatment.
** Landscape initial establishment irrigation removed.
*** ET_c was calculated with a Kc value of 0.75 for warm season grasses (such as St. Augustine).

Figures

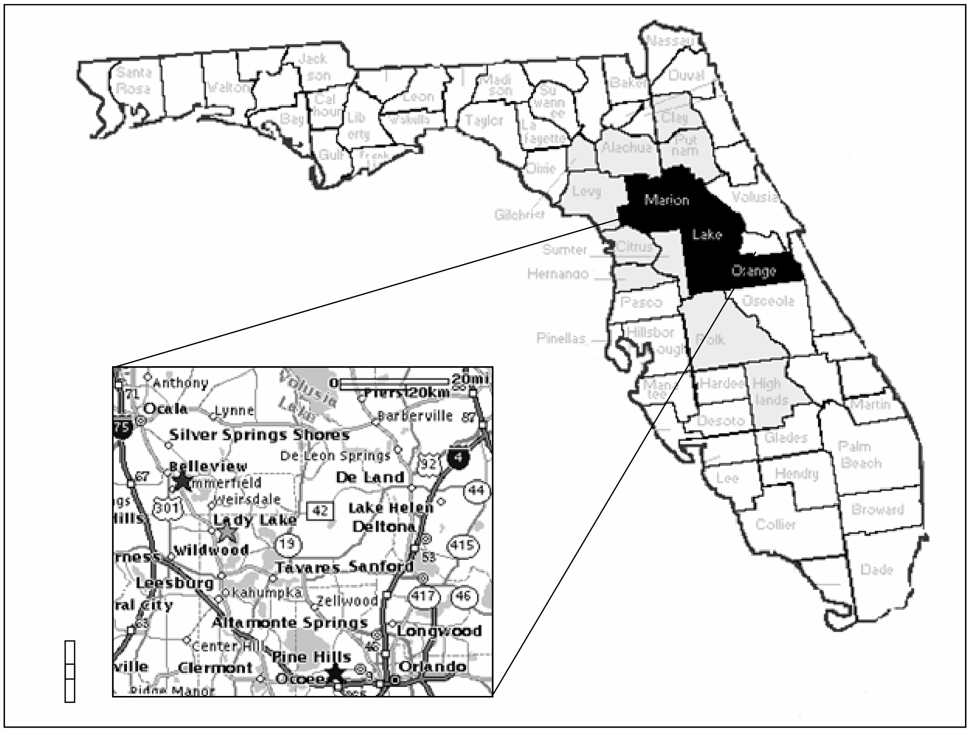

Figure 1. Project site locations in Marion, Lake, and Orange Counties.

Figure 2. Reference ET weather station.

Figure 3. Example cooperator home, Marion County, T1.

Figure 4. Example cooperator home, Lake County, T1.

Figure 5. Example cooperator home, Orange County, T1.

Figure 6. Landscape and turfgrass in the same irrigation zone.

Figure 7. Example cooperator home, Marion County, T2.

Figure 8. Example cooperator home, Lake County, T2.

Figure 9. Example cooperator home, Orange County, T2.

Figure 10. Example cooperator home, Marion County, T3.

Figure 11. Example cooperator home, Lake County, T3.

Figure 12. Example cooperator home, Orange County, T3.

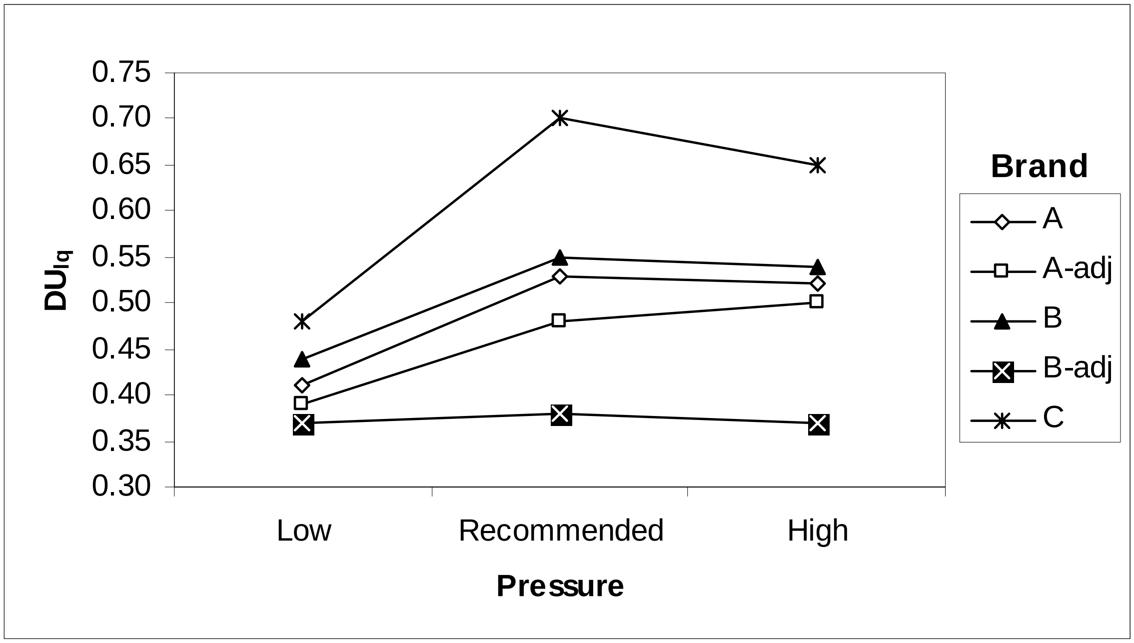

Figure 13. Spray head controlled testing distribution uniformity.

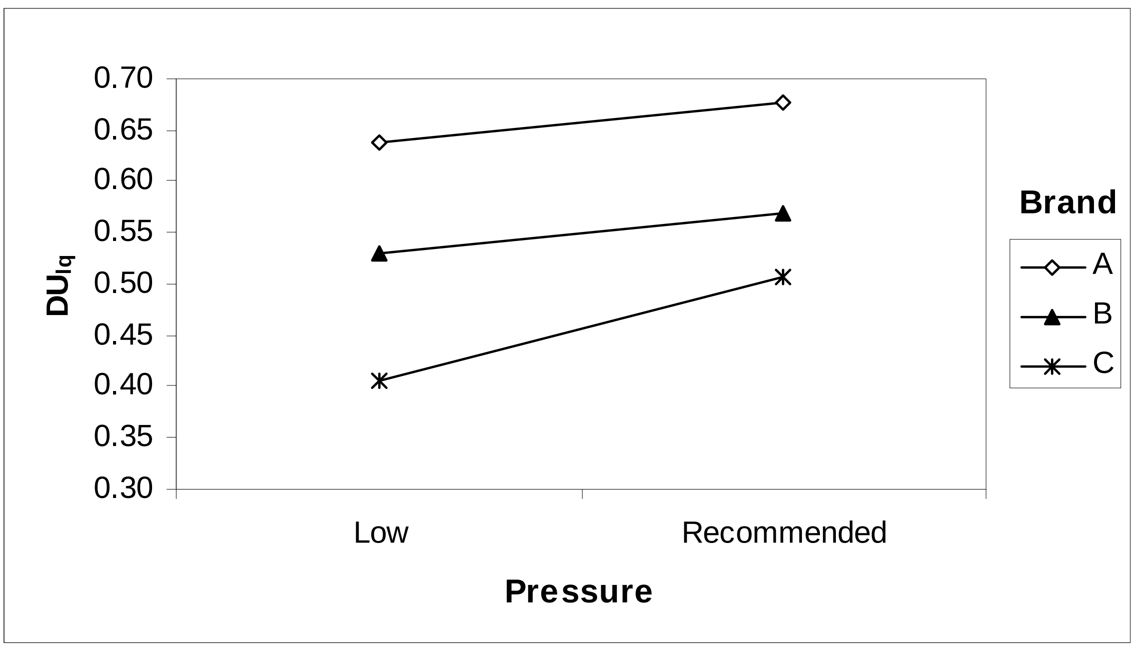

Figure 14. Rotary sprinkler controlled testing distribution uniformity.

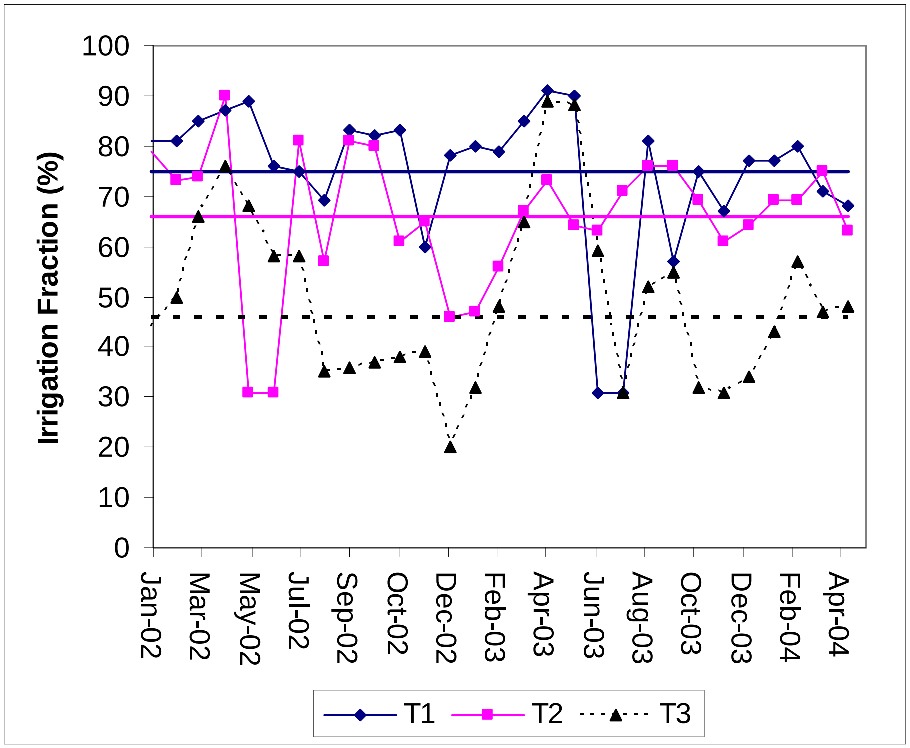

Figure 15. Monthly fraction of water used for irrigation Jan 2002 – May 2004. Averages are shown as horizontal lines.

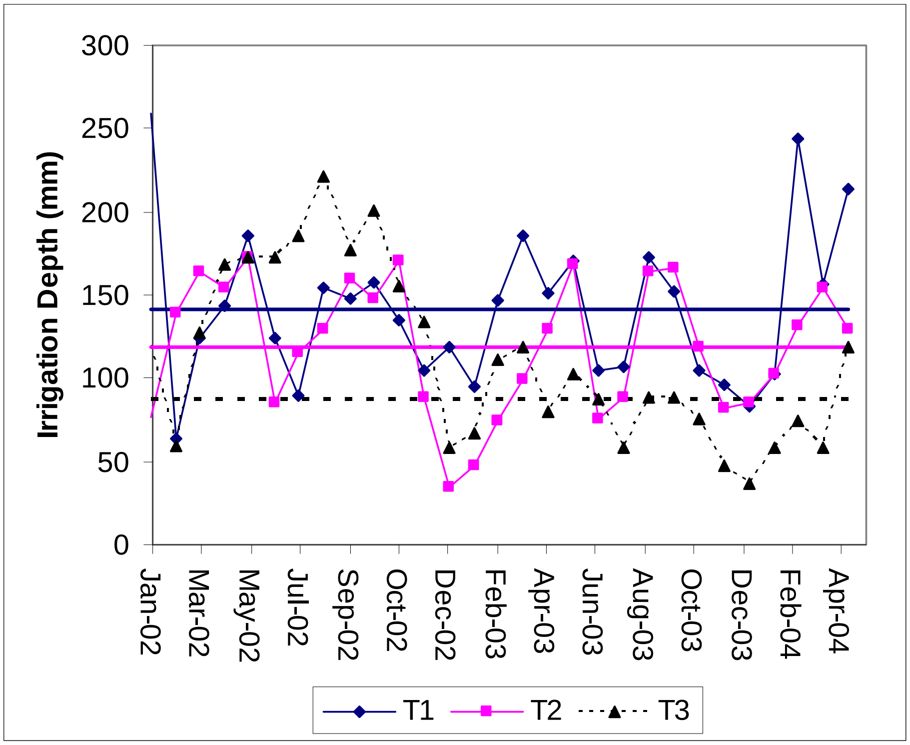

Figure 16. Monthly irrigation water use Jan 2002 – May 2004. Averages are shown as horizontal lines. T3 average not including landscape establishment.

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Appendix I – Contract Tasks

1. Purchase necessary equipment operational capital outlay (OCO) to perform monitoring of irrigation system performance.

1d. Seven landscapes and irrigation systems will be installed to complete setup of the project for data collection. The costs for the systems range between $2,000 and $5,000, but the average is expected to be $3,500.

2. Assist the St. John's River Water Management District in recruiting cooperators (i.e. homeowners, community managers, and irrigation contractors) for the irrigation study.

3. Literature search to assess work to date on evaluation of residential irrigation system efficiencies in the state, including data from various Mobile Irrigation Labs that have audited residential irrigation systems. The literature search may also include other areas in the humid region.

4. Instrument Treatment 1 sites in all subdivisions. Treatment 1 will consist of existing irrigation systems and typical landscape plantings in three subdivisions in Florida's central sand ridge region.

5. Measure landscape irrigation water use volumes on sites established as Treatment 1. Conduct irrigation system uniformity tests and assess system efficiency on Treatment 1 systems. Soil moisture measurements will be taken during uniformity tests. Uniformity testing shall be in accordance with procedures defined by the NRCS Mobile Irrigation Lab manual. In addition, turf and landscape quality will be assessed on a regular basis. Total amount of precipitation and irrigation water will be documented for each landscape.

6. Design and install treatment 2 sites. Treatment 2 will consist of an irrigation system designed according to specifications for optimal efficiency and scheduling will be

conservative where practical and appropriate to accomplish maximum water savings while ensuring landscape health.

7. Conduct measurements on Treatment 2 as outlined in Task 5.
8. Design and install Treatment 3 sites. Treatment 3 will consist of a landscape design that minimizes turf and maximizes the use of water-wise plants. These landscapes should use a minimum amount of irrigation water while adhering to the landscape design standards of the various subdivisions. In addition, an irrigation system will be designed to be as efficient as practically possible. Where components are available and practical, irrigation systems will contain automatic systems (i.e. soil moisture probes) to initiate irrigation events.
9. Conduct measurements on Treatment 3 as outlined in Task 5.
10. Assemble project findings into a final report and submit to the District. Create fact sheets and submit to the District.

Appendix II – Literature Review

This literature review was conducted to determine previous work on residential irrigation water use or distribution uniformity.

Irrigation efficiency defines how effectively an irrigation system supplies water to a given crop or turf area. Efficiency can be computed as the ratio between water used beneficially and water applied and is expressed as a percentage. There are three concepts of irrigation efficiency: water conveyance efficiency (E_c), water-application efficiency (E_a), and reservoir storage efficiency (E_s). These efficiencies can be calculated respectively by the following equations:

$$E_c = 100 \cdot \frac{W_d}{W_i} \qquad [1]$$

$$E_a = 100 \cdot \frac{W_s}{W_d} \qquad [2]$$

$$E_s = 100 \cdot \frac{W_p}{W_{rs}} \qquad [3]$$

where W_d is the water delivered to the area being irrigated, W_i is the water introduced into the distribution system, W_s is the irrigated water stored in the root zone, W_p is the water pumped from the reservoir and W_{rs} is the water stored in the reservoir (Smajstrla et al., 1991). Water conveyance efficiency is calculated from the point of discharge (pump) while water application efficiency is calculated over an entire field (or lawn). Reservoir storage efficiency is the ratio between water pumped from the reservoir to water stored in the reservoir. Factors that may lower efficiency are leaks, evaporation, wind drift, improper equipment adjustment, drainage below the root zone, and runoff. Reservoir storage efficiency is variable depending on site conditions and the lowest values can be attributed to surface reservoirs due to evapotranspiration (ET) and seepage. Since most residential irrigation water in Florida is derived from groundwater, reservoir storage efficiency is thought to be as high as technically possible. Water withdrawn from surface reservoirs would be subject to evaporation and seepage losses. Water conveyance in pressurized sprinkler irrigation systems efficiency is nearly 100% unless there is a leak in the pipeline or distribution equipment. Thus, application efficiency is the component that may vary greatest in residential irrigation systems. It is necessary to maintain even distribution of irrigated water over the target area to achieve relatively high application efficiency.

Uniformity of water distribution measures the relative application depth over a given area. The term uniformity refers to the measure of the spatial differences between applied (or infiltrated) waters over an irrigated area. Two methods have been developed to quantify uniformity: distribution uniformity (DU) and the Christiansen's coefficient of uniformity (CU).

The low quarter irrigation distribution uniformity (DU_{lq}) can be calculated with the following equation (Merriam and Keller, 1978):

$$DU_{lq} = \frac{\overline{D}_{lq}}{\overline{D}_{tot}} \qquad [4]$$

where, $\overline{D}_{lq}$ is the average lower quarter of catch can observations and $\overline{D}_{tot}$ is the average of all catch can observations over a given irrigated area. Distribution uniformity is usually represented as a ratio, rather than a percent (Burt et al., 1997) to signify the difference between uniformity and efficiency. This method emphasizes the areas which receive the least irrigation by focusing on the low quarter.

Burt et al. (1997) defined common irrigation performance measurements, which discussed standardization and clarification of irrigation definitions and quantified irrigation measurements. Distribution uniformity is not considered efficiency. Over-irrigation can result from mismanagement although a system may have even distribution. According to the IA (2003), the distribution of the lower half (DU_{lh}) is recommended for scheduling residential irrigation systems:

$$DU_{lq} = \frac{\overline{D}_{lh}}{\overline{D}_{tot}} \qquad [5]$$

$$DU_{lh} = 0.386 + .614 \times DU_{lq} \qquad [6]$$

where, $\overline{D}_{lh}$ is the lower half of the average depth of the water irrigated and $\overline{D}_{tot}$ is the total average of the depth of water irrigated of a given area. Determining distribution uniformity helps to reduce excess water used for irrigation purposes. DU_{lh} is suggested over DU_{lq} because the lower quarter over-estimates the effect of non-uniformity for landscapes (IA, 2003).

The coefficient of uniformity treats over-irrigation and under-irrigation equally as compared to the mean, and can be calculated by the Christiansen formula:

$$CU = 1 - \frac{\sum_{i=1}^{n} \left| V_i - \overline{V} \right|}{\sum_{i=1}^{n} V_i} \qquad [7]$$

where V_i refers to the volume in a given catch can and $\overline{V}$ refers to the average volume over all catch can observations (Christiansen, 1942).

Linaweaver et al. (1967) found that the amount of water used for residential lawns is 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. In Wyoming, from the summer 1975 through spring 1977, a study was conducted on actual lawn water application rates for residential households and evaporation rates of lawn turfgrass. The application rates found were between 122 and 156% of calculated seasonal evapotranspiration rates (Barnes, 1977).

A model for estimating turf water requirements was created in Utah (Aurasteh, 1984). Urban irrigation was studied with the irrigation use measured weekly by 20 homeowners. The objectives of the study were to measure residential distribution uniformities using catch cans, assess potential application efficiencies, and to compare water use to ET rate. The ET rate was calculated, and an empirical model for determining urban irrigation needs was created. Residential solid set (i.e. in-ground) and movable systems were compared; application efficiency analysis of these systems showed that the average water application was about 30% for hand-move and 37% for solid set systems (Aurasteh et al., 1984). It was also noted that the homeowners used approximately 61% of their total water supply for irrigation.

In a study monitoring 1,188 homes across the U.S., Mayer et al. (1999) found that 58% of total water use was outdoor water use with most of that being irrigation. In addition, they found a positive correlation between lot size, house size, and outdoor use.

In Florida, Mobile Irrigation Labs (MILs) were established as a public service beginning in 1992 as parts of various water conservation programs. Funding for these programs is from the USDA and the individual water management districts. The Florida MILs were modeled after those operating in California and Texas. They evaluate irrigation systems in both agricultural and urban areas by conducting a series of tests, measuring pump flow rates, sprinkler pressures and flow rates, and application uniformities (Micker, 1996).

While uniformity of irrigation systems has been measured in Florida, many of the MILs do not currently measure irrigation system uniformity; therefore, there is a lack of information regarding current residential irrigation system performance and water use. In some MILs distribution uniformity results that were judged to be low were discarded (anonymous MIL source).

In assessments of irrigation system performance in California, Pitts et al. (1996) found a mean DU of all systems tested as 0.64. The average DU for non-agricultural turfgrass sprinklers (residential lawns) was 0.49. Greater than 40% of the tested systems had a DU of less than 0.40. This study concluded that the low DU values were based on the following reasons in order of frequency: maintenance and faulty sprinkler heads, mixed zones (spray and rotor), excessive pressure variations, and inadequate head spacing resulting in poor head-to-head coverage. Many of the cooperators in this study were unaware of importance of scheduling based on potential evapotranspiration and uncertain about the application rates of their systems. It was found that scheduling was usually based on the appearance of the turfgrass (Pitts et al., 1996).

Granular matrix soil moisture sensors were used to control the irrigation for urban landscapes in Colorado. The objective of the study was to evaluate the effectiveness and reliability of soil moisture sensors for irrigation control. The soil moisture systems proved to be very reliable and reduced the irrigation application below theoretical requirements. The calculated theoretical irrigation requirement was 726 mm, while the actual water applied, as allowed by the sensor system, was 533 mm (Qualls et al., 2001).

Operating time was improperly set on many homes tested according to the irrigation audits conducted by the University of Georgia. Spray heads distributed three to five times the water application rate per given area as compared to rotary sprinklers (Thomas et al., 2002).

The effects of surface slope on sprinkler uniformity were studied in Brazil because of the wide use of sprinkler irrigation as an irrigation method on sloping lands. A direct correlation was found between distribution uniformity and both nozzle and riser angle, increasing as the nozzle angle was varied from vertical to perpendicular to the ground surface. However, the DU decreases with an increase in ground slope. The DU was improved with a triangular precipitation pattern for all ground slopes and nozzle angles (Soares et al., 1991).

A number of computer models have been created to aid in uniformity testing of sprinkler systems. A data acquisition system for sprinkler uniformity testing was created in Brazil (Zanon et al., 2000). The system was designed to test a two radii precipitation pattern (head-to-head) for low to medium pressure sprinklers under no wind conditions. A method was developed for evaluating water application rate and the coefficient of uniformity, CU, of sprinklers with head to head coverage in Japan. The tests were under realistic conditions, including monitoring the effect of wind drift (Fukui et al. 1980).

Numerous modeling studies have been conducted with regard to residential irrigation uniformity and efficiency. The SIRIAS software was produced in Spain. This model for sprinkler irrigation uses the ballistic theory to predict the path of drops discharged, obtaining wind-distorted water distribution, and formulation for the air drag coefficient. The program has three options for evaporation and drift losses within the irrigation process to consider actual environmental conditions (Carrion et al., 2000). A widely used model based on numerical solutions was modified for simplicity of use at Oregon State University. Accurate analytical approximations for DU, CU, application efficiency, water requirement efficiency, deficiently irrigated volume, and the average deficit over the deficiently irrigated area were developed. The approximations proved to be more accurate than earlier approximations and introduced negligible error when used for practical applications (Smesrud and Selker, 2001). The use of the normal distribution function in describing sprinkler irrigation uniformity was simplified for evaluation of irrigation system performance in terms of economic and environmental decisions (Walker, 1979). Elliot (1980) reported on the comparison of statistical models to approximate sprinkler patterns with various coefficients of uniformity, calculation of water volume needed, and irrigation efficiency. It was found that for uniformity coefficients the normal distribution was a better fit than the linear model. However, at uniformities below 0.65 the linear model fit best (Elliott et al., 1980).

Evapotranspiration (ET) is the rate at which water may be removed from soil and plant surfaces to the atmosphere by a combination of evaporation and transpiration (Allen et al., 1998). Evaporation (E) is the conversion of water into its vapor phase. The main factors influencing evaporation are the supply of energy by solar radiation and the transport of vapor away from the surface (e.g. by wind). Transpiration (T) refers to the water used by plants and is affected by plant physiology and environmental factors. The evapotranspiration process refers to the availability of energy and evaporated water to be transferred to the air closest to the surface and is climate controlled. White et al. (2004) studied the use of potential evapotranspiration (PET), a landscape coefficient (L_c), and landscape size, to develop water budgets for residential landscapes. It was determined that PET irrigation budgeting with an L_c of 1.0 would account for substantial irrigation water savings, especially in the summer months.

A Time Domain Reflectometry (TDR) device can be used to determine soil water content by relating the time needed for an electrical signal to travel along wave guides. As opposed to the measurement of irrigation application, the soil water volume is measured as a function of the volume of soil. Catch-can tests and soil moisture sensor measurements with TDR in turfgrass irrigation auditing were compared by the Northern Colorado Water Conservancy District. When calculating the DU_{lq}, it was found that the soil moisture uniformity was higher than the catch-can uniformity. From the data collected in the study, the soil moisture DU_{lq} was 0.15-0.20 (maximum value of 1.00) higher than the DU_{lq} determined by the catch-can method (Mecham, 2001). Although the catch-can DU_{lq} could help determine the overall quality, these uniformity values did not properly express the distribution of the water through the thatch or as affected by the soil properties. Estimating irrigation run times based on the catch-can DU_{lq} would lead to over-irrigation, due to the low nature of these DU_{lq} values (Mecham, 2001).

In Florida, a study compared microirrigation (drip) uniformity determined by both time domain reflectometry and the conventional volumetric method. The study concluded that the TDR can be a useful tool for quick determination of uniformity. Inversely in this study, for the drip systems the TDR DU_{lq} was lower than the DU_{lq} calculated by the conventional method. Differences were thought to be a result of soil properties and point measurement locations (Dukes and Williams, 2002).

Appendix III – Fact Sheet

Irrigation and Landscape Combinations for Water Conservation

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Introduction

Due to recent droughts, irrigation has become a necessity 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 where on average the precipitation rate is greater than the evapotranspiration rate, the spring and winter are normally dry. The dry spring weather and sporadic large rain events in the summer coupled with low water holding capacity of the soil make irrigation necessary for the high quality landscapes desired by homeowners.

Residential water use comprises 61% of the public supply category (Marella, 1999). The mostly groundwater derived public supply is responsible for the largest portion, 43%, of groundwater withdrawn in Florida. Between 1970 and 1995 there was a 135% increase in groundwater withdrawals (Fernald and Purdum, 1998). The current population of 16 million is projected to exceed 20 million people by 2020 (USDC, 2001) and with the average residential irrigation cycle consuming several thousand gallons of water, and the average homeowner irrigating two cycles per week, water conservation has become a state concern.

Lawn Type and Irrigation Schedule Interaction

Decreasing the amount of water consumed by a residential irrigation system without causing stress or reduced quality to the turfgrass and landscape is possible. Based on a recent research project where 27 homes were monitored in Central Florida, residential lawns were categorized into one of three treatments based on lawn type and irrigation scheduling. Treatment one (T1) consisted of existing irrigation systems and typical landscape plantings, where the homeowner controlled the irrigation scheduling. Treatment two (T2) homes also consisted of existing irrigation systems and typical landscape plantings, but the irrigation scheduling was based on 60% replacement 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 native drought tolerant plants. On T3 homes, an average of 69% of the irrigated area was landscape bedding and was irrigated with microirrigation as compared to 25% for T1 and T2 homes that were irrigated with sprinkler irrigation.

Examples of Typical Landscapes vs. T3 Landscapes

Figures 1 and 2 show examples of the T1, T2, and T3 homes in the study.

(a) (b) (c) (d)

Figure 1. Examples of typical landscapes, where the turfgrass area is greater than the bedded area, T1 and T2.

(a) (b)

(c)  (d) 

Figure 2. Examples of T3 landscapes, where the turfgrass area was minimized and the bedded area irrigated by microirrigation.

Microirrigation in Landscape Bedding

The T3 irrigation designs included microirrigation in the bedded areas. Microirrigation components utilized included micro-spray heads and drip tubing. The benefit of microirrigation is the low volume water output, which allows for the irrigated area to be concentrated around the root zone.

Figure 3. Sample of drip tubing.

Figure 4. Microspray or microjets in a plant bed.

Treatment 1

Treatment one homes consisted of a typical irrigation systems and landscape where the homeowner controlled the irrigation scheduling. Typical landscape implies a greater percent of turfgrass than bedding. The homeowner interaction involved in treatment one homes could be considered as “set it and forget it”, with minimal alteration of the irrigation schedule based on seasonal changes. The homes in T1 consumed the most water for irrigation purposes.

Treatment 2

Treatment two homes also maintained the existing irrigation systems and had landscapes which are mostly turfgrass. The irrigation scheduling for T2 systems was updated monthly based on historical ET. The EDIS document "Operation of Residential Irrigation Controllers" (Dukes and Haman, 2001) explains how to determine zone run times based on the irrigation zone water application rate. The document goes into detail on the suggested monthly zone run times based on historical ET. However, it is most important to adjust the irrigation run times based on seasonal weather changes. For the Central Florida Ridge area, depending on system performance and uniformity, the T2 run times were set according to Table 1.

Table 1. Seasonal irrigation run times for spray and rotor zones.

Head Type	Summer	Fall	Winter	Spring
Spray	20-30 min	10-20 min	0-10 min	15-25 min
Rotor	30-50 min	20-40 min	0-20 min	25-45 min

The homes in T2 consumed 16% less irrigation water than T1 based on monthly water use data over a 29-month period. Therefore, adjusting the controller setting seasonally can lead to a 640 to 800 gal savings per week based on typical system usage. \

Treatment 3

Treatment three irrigation systems were designed according to specifications for optimal efficiency and include a landscape design that had minimal turfgrass and an increased use of native drought tolerant plants. To further achieve water savings in T3, most landscape plants were irrigated by microirrigation as opposed to standard spray and rotor heads.

Run time settings for T3 were the same as the T2 for the spray and rotor zones. The run time settings for the T3 microirrigation zones can typically follow the rotor zone settings. However, in the winter months the microirrigation zones were turned completely off. Once the ornamental plants have become established, the microirrigation zone run times can often be decreased.

The homes in T3 consumed 39% less irrigation water than T1 (based on monthly water use data over a 29-month period), which would lead to a weekly water savings of 1440 to 1800 gal per week based on irrigating twice weekly for the homes included in this study.

Seasonal Water Use

Based on irrigation water consumption data collected over a 29-month period, the following seasonal water use averages were determined. The data reported for treatment 3 includes in parentheses an adjusted T3 water depth value. The adjusted water depth takes the initial increased water use for landscape establishment into consideration and has the first two months of a water use for the home omitted to account for the initial establishment period.

From Table 2 it can be seen that T1 used the most water for irrigation purposes regardless of season. The T3 systems used the least water for irrigation purposes regardless of season. Irrigation water consumption was lowest in the winter months (December through February), as would be expected due to reduced plant needs.

Turfgrass quality ratings were based on the National Turfgrass Evaluation Procedures, NTEP, rating method (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 aesthetics (i.e. density, uniformity, texture, smoothness, growth habit, and color) and functional use. The minimum rating while still maintaining acceptable quality is 6. Lower ratings will not necessarily imply drought stress. Treatments 1 and 2 maintained minimum or above average quality during the project data collection period. The T2 turfgrass had no significant differences in quality form T1 under a decreased irrigation schedule. The T3 lawns did have lower quality ratings as compared to T1 and T2. The ratings were just below the NTEP acceptable rating of 6. In the fall and winter months there was a decrease in turf quality, 5, because the turfgrass was permitted to go into a small degree of dormancy. During dormancy, which is the normal state of turfgrass in the winter months, irrigation run times can be decreased because the plant has decreased water needs. When the turfgrass goes into dormancy, the turfgrass color changes to tan rather from green. The decreased turf quality was color related and not due to drought stress or winter injury. In the spring months, after “green-up”, when the grass comes out of dormancy, the T3 turf quality was actually better than T1.

Table 2. Seasonal water use and turf quality across treatments.

		Winter	Spring	Summer	Fall	Average
Treatment 1	Water Use (mm)	103	176	134	155	142
	Fraction of Total Water Use (%)	75	77	82	62	75
	Turf Quality Rating	6	6	6	7	6
Treatment 2	Water Use (mm)	78	135	110	148	119
	Fraction of Total Water Use (%)	63	74	66	61	66
	Turf Quality Rating	6	7	6	7	6
Treatment 3 (3a*)	Water Use (mm)	61 (55)	98 (95)	104 (96)	107 (102)	92 (87)
	Fraction of Total Water Use (%)	37	42	63	55	46
	Turf Quality Rating	5	6	5	6	6

*Treatment 3a refers to the landscape establishment period of the T3 homes, where the first two months of irrigation water consumption are excluded.

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