Advanced Controller Features Show Unexpected Results

[1]David W. Smith, Extension Program Specialist
Texas A&M AgriLife Extension Service, Biological & Agricultural Engineering, College Station, Texas
[2]Charles Swanson, Extension Program Specialist
Texas A&M AgriLife Extension Service, Biological & Agricultural Engineering, College Station, Texas
[3]Jennifer Nations, Water Resource Coordinator
City of College Station, Texas

Abstract. Modern residential irrigation controllers include several features that enable fine-tuning of irrigation schedules to accommodate different plant water needs and improve overall irrigation efficiency. These include the water budget or seasonal adjust option, rain sensor connection ports, and multiple programs and start times capability. What portion of residents actually use these features, and among those who do, are they applying less water compared to those who do not? Since 2010 College Station, Texas Water Utilities performed more than 500 residential landscape irrigation 'checkups'. Using data collected from the 'checkups' and monthly water records, irrigation was compared for customers who do and do not use these controller options. Surprisingly, irrigation applied from residents with rain sensors consistently exceeded those without rain sensors. Residents who used multiple cycles per irrigation day applied slightly more water than those who used only one cycle, and residents who used multiple programs irrigated slightly more compared to those who used a single program. Although the difference in irrigation applied between groups was not statistically significant ($p<0.05$), results suggests that, whether because of lack of knowledge or because programming is too complex, the water savings benefit of these controller features was not realized for these residential customers.

Keywords. Turf/Landscape (Residential), sprinkler, conservation, scheduling, controllers

INTRODUCTION

Landscape irrigation for residential and commercial properties, golf courses, athletic fields, and other types of recreation areas is estimated to be the third-largest user of water in Texas, behind only agriculture and municipal uses (Cabrera et al., 2013). With a growing population and competing interests for limited water supply, local communities employ various strategies to reduce potable water consumption including tiered water rates, prescriptive irrigation days, citations for water waste, and education campaigns. The greatest potential for municipal water conservation is in landscape irrigation. A study of monthly water use of 800 residences from 2000 through 2002 in College Station, Texas indicated that the average peak water consumption during the summer increased as much as 3.3 times the winter water use (White et al., 2004) as plant water requirements typically exceed precipitation. With in-ground, automated irrigation systems much of this water is wasted due to poorly-designed systems, improper scheduling (over-irrigation), and failure of system integrity. Furthermore, residential water customers find programming and operation of their controller difficult and confusing. This presents a real challenge for municipal and water utility driven water conservation efforts that encourage strategies such as potential evapotranspiration-based (ETo) scheduling, multi-cycling irrigation events to prevent runoff, and prescriptive, address-based weekly operation schedules. These strategies assume that customers are proficient in programming their controllers. In fact, failure to properly implement these recommendations can be counter-productive and actually increase overall irrigation use.

In 2010, College Station Water Utilities began providing free landscape irrigation ‘checkups’ to residential customers. To date, the City has performed more than 500 irrigation checkups, primarily for customers identified as having above average seasonal water use (Coleman, 2014). The checkup includes a general inspection of system components to identify damaged or broken hardware, documentation and evaluation of existing controller programming, and education on how to reduce runoff and install rain shut off sensors. Following the checkup a written report is delivered to the customer detailing significant findings along with recommendations for reducing irrigation use. Beginning in May 2012, College Station Water Utilities, in collaboration with the Texas A&M Department of Recreation, Parks, and Tourism provided additional resources to perform irrigation system checkups to meet increasing demand for this service. A licensed irrigator was hired to conduct irrigation inspections during the peak irrigation season.

The objective of this study was to evaluate water consumption records for residential customers who do and do not utilize advanced residential controller features to determine any differences, patterns, or trends in the amount of irrigation applied (when normalized by unit landscape area). Results of this study can inform future educational efforts by the City and others to encourage irrigation efficiency and water conservation. These results may also be helpful to determine whether residential customers properly employ such advanced features or whether, because of lack of understanding or training, application of these features actually increases irrigation use.

METHODOLOGY

Landscape Irrigation Checkup

College Station Water Utilities publicizes the free irrigation checkup service by distributing a letter to approximately 5,000 residential customers whose historical water consumption substantially exceeded their estimated water budget. The City also hosts a series of summer ‘sprinkler system workshops’ in the summer season for approximately 200 residents per year. Interested residents contact City staff either by email or telephone to schedule an appointment with the irrigation inspector. In 2012, 2013, 2014, and 2015 irrigation checkups were conducted for 211 residential customers (205 unique customers). Irrigation checkups were performed in 44 subdivisions within the city of College Station. Fifty-eight percent of all inspections were conducted in four subdivisions: Pebble Creek (58), Castlegate (34), Emerald Forest (20), and Edelweiss Estates (11).

Data collected during the checkup included the number and type of application devices, brand and model of controllers, irrigation start times, run times, presence of rain shut-off sensors, and inventory of hardware deficiencies and operational problems.

Data Collected

- Controller brand
- Current controller time/date
- Irrigation start times
- Irrigation programs being utilized (‘A’, ‘B’, ‘C’, etc.)

- Individual station run times
- Seasonal adjust or water budget setting
- Presence of controller backup battery
- Presence and functionality of rain shut-off sensor
- Type(s) of sprinkler heads (per station)
- Dominant plant type (turfgrass, shrubs, flowers, etc. per station)
- Description of area being irrigated per station
- Extent of sun exposure per station (full sun, part sun, shade)
- Integrity of system devices (backflow prevention device, solenoid valves, sprinkle heads)

Though not included in this report, data was also analyzed to determine any difference and/or trends in irrigation applied when comparing landscape size and age of property. This information too can be instrumental in prioritizing specific topics for future water conservation education, outreach, and training for residential customers.

Irrigation Use Analysis

All residences in this study were served by a single water meter that registered combined indoor and outdoor water consumption. College Station Water Utilities provided monthly water consumption data for the seven year period from 2008 through 2015. Irrigation use was calculated by subtracting average indoor water use from total metered water consumption on a monthly basis. For the purpose of this study irrigation use was investigated and compared for the typical growing season in College Station – April through September. Indoor water use was estimated to be the average monthly consumption for December, January, and February over the period from 2008 to 2015 or over the period of reliable record during this seven year period.

Landscape water use (irrigation) in 'gallons' was normalized for landscape size and converted to inches of water applied using the following equation.

Irrigation (inches) = irrigation (gallons) / [area of landscape (sqft) x 0.6234]

Estimate of residential landscape area was calculated as the total property size (in square feet) minus the residential footprint, space occupied by garages, out-buildings, patios, sidewalks, and driveways. Total property, garage, and patio area was acquired from the Brazos County Appraisal District, http://www.brazoscad.org/. Further deductions for sidewalks, driveways, and other non-pervious area were estimated using Google Earth satellite maps and area/distance calculator tools.

Area of landscape (sqft) = total property area (sqft) – non-pervious area (sqft) (including house, garage, patio, sidewalk, and driveway footprint)

Net Plant Water Requirement (Net-PWR) Estimation

Net plant water requirement was computed using a daily water balance approach utilizing measured evapotranspiration (ETo) and precipitation data, crop coefficients for warm season turfgrass, and soil water storage constraints assuming a 6-inch root zone depth and clay soil type. ETo data was acquired from two automated weather station locations – the Texas A&M University Golf Course and Texas A&M Turf Lab. Net plant water requirement (Net PWR) was calculated using the following relationship:

Net PWR (inches) = (ETo (inches) x Kc x Af) – Reff (inches)

Where:

Kc = monthly crop coefficient (dimensionless)
Af = allowable stress factor (dimensionless)
Reff = effective rainfall (inches)

Long term average monthly crop coefficients for College Station are referenced in the Texas Landscape Irrigation Auditing and Management Short Course Manual – Version 3 (Fipps et. al., 2009). For this analysis, a stress adjustment factor of 1 (no stress) was used.

Methodology for estimating effective rainfall followed that used for similar analyses performed by the Texas A&M School of Irrigation (Swanson, 2015).

IF R < 0.1, THEN Reff = '0'
IF 0.1 < R ≤ 1, THEN Reff = 'R'
IF 1 < R ≤ 2, THEN Reff = 'R x 0.67'
IF R > 2, THEN Reff = '2'

Where:

R = actual daily rainfall (inches)

Daily Net-PWR was further constrained by assuming that plant-available water could be stored within a 6-inch root zone and a clay soil. Total Net-PWR for irrigation season each year was calculated by summing daily Net-PWR from April through September.

Landscape Irrigation Ratio (LIR)

The LIR is one approach to quantifying landscape water use (or irrigation) efficiency (Glenn et. al., 2015). The LIR metric provides a means to evaluate and compare landscape water conservation potential for properties regardless of property size. It is calculated by dividing the volume or normalized equivalent depth of outdoor water use divided by the landscape water requirement over a certain time interval.

LIR = irrigation (inches) / Net-PWR (inches)

This study examined the LIR over the typical landscape irrigation season (April through September).

Glenn et al. (2015) used the LIR approach to assess landscape water use efficiency in single-family residences in Logan, Utah in 2004 and 2005. Category benchmarks, defined by LIR ranges, were specified as 'justifiable' and 'unjustifiable' water use and further classified as 'efficient', 'acceptable', 'inefficient', and 'excessive'. This classification system was used in this study to compare water use efficiency for residences over the typical irrigation season from 2008 to 2015.

Justifiable water use
    Efficient LIR ≤ 1
    Acceptable 1 < LIR ≤ 2

Unjustifiable water use

Inefficient 2 < LIR ≤ 3

Excessive 3 < LIR

RESULTS

Characterization of Irrigation System Hardware and Controller Programming

Controllers and rain shut-off sensors – Of the 211 residential customers Toro®, Hunter®, and RainBird® model controllers were used by 78% (165) of residents. These controllers are similar in basic operation and feature multiple program options ('A', 'B', 'C', etc. programs) and multiple start times per program. Almost all controllers provided for a 9-volt backup battery intended to retain program settings in case of power loss. If a functional backup battery were not present, these controllers reverted to a default irrigation schedule of watering every day, 10 minutes per station, at 5:00 AM start time once power was restored after an outage. Only 18% (38) of irrigation systems inspected were equipped with a rain shut-off sensor. Of those, 63% (24) were wireless and 37% (14) were hard-wired.

Irrigation Stations – A total of 1,204 stations were inspected. The average number of stations per residence is 5.8. Seventy-three percent (154) of residents had 6 or fewer stations. Of these, pop-up fixed spray heads and rotor-type sprinkler heads were the most common representing 52% and 37% of all sprinkler head types. Other sprinkler devices noted include 'mixed' (a combination of multiple sprinkler head types), drip irrigation, and multi-stream application devices designed for slow-application rate.

Irrigation Schedules – A critical part of the irrigation checkup was to educate the resident on the capability and use of their irrigation controller in facilitating efficient irrigation practices such as adjusting individual station runtimes, utilizing multiple programs to compensate for different irrigation frequency needs, and setting multiple start times (multi-cycling) to prevent water runoff. Existing controller settings were documented and immediately brought to the attention of the resident. In most cases, residents were not familiar with their current controller settings and did not realize the implications for inefficient water use.

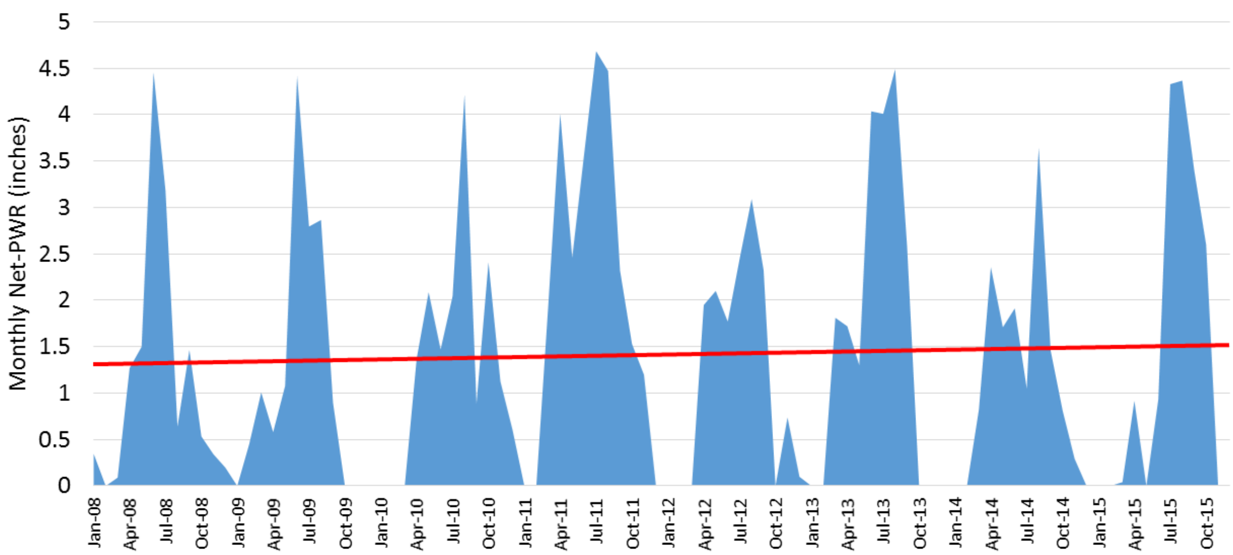
> <u>Station run times:</u> An analysis of all residents suggests that, in general, stations with relatively high application rates were set with lower run times. For example, the average run time for pop-up spray sprinkler heads was 12 minutes while the average run time for rotor sprinkler heads was 17 minutes. Drip irrigation (characterized by relatively low water application rate) was usually set to run much longer. At a minimum, this illustrates that an attempt was being made to adjust individual station run times for different sprinkler types.
>
> <u>Irrigation days:</u> Irrigation days were fairly well dispersed throughout the week with Mondays, Wednesdays, and Fridays being the most common. The calendar day option was obviously the most common selection for setting irrigation day, with less than 4% (23) of residents using the 'odd/ even day', or 'interval day' feature.
>
> <u>Program start times:</u> Eighty-eight percent (347) of all program start times documented occurred between midnight and 8:00 AM. The most common start time was 5:00 AM. This was not surprising given that the default start time for most major controller brands was also 5:00 AM. Though irrigating in the early morning is strongly encouraged and essential for reducing

evaporative losses, there may be a need in some locations or subdivisions to minimize peak morning demand to limit pressure drop.

Net-PWR (2008 – 2015)

Net plant water requirement was calculated using a daily water balance approach using measured evapotranspiration and precipitation, and constrained by an assumed root depth and soil type using the methodology previous defined. This approach was selected to limit the water contribution from heavy or intense rainfall events. During intense rainfall water is more likely to run off the landscape and/or water moves beyond the typical plant root zone thereby becoming unavailable to the plant. Figure 1 shows the normal pattern and overall trend of Net-PWR over the eight-year period. Residential water customers typically begin irrigating in April and continue through September or longer depending on weather trends and early fall tropical storm development in the Gulf of Mexico. Peak Net-PWR usually ranges between 4.0 and 4.5 inches per month in June, July, or August. Overall, Net-PWR trended upward over the study period, most likely a result of the extreme drought conditions in 2011 and 2013.

Figure 1 – Monthly Net-PWR from 2008 to 2015



Water Use Analysis for Various Recommended Conservation Practices

There are several common *best management practices* used to encourage landscape water conservation and irrigation efficiency. Among these are: 1) installing rain shut-off devices that prohibit irrigation during and directly after rainfall events; 2) utilizing multiple programs ('A', 'B', 'C', etc.) that allow for adjusting irrigation frequency to account for different rooting depths and soil types; and 3) utilizing multiple start times or multi-cycling to reduce water runoff and promote infiltration. Water consumption data was analyzed to determine any differences between residents who <u>did</u> and <u>did not</u> adopt these practices.

Rain Sensors

Except for 13 arid counties located in the western part of the State, the Texas Commission on Environmental Quality requires rain or moisture sensor devices be installed on all new irrigation controllers. Many cities and municipalities also enforce ordinances that require rain sensors on irrigation systems as a condition of permitting and inspection. However, in this study many new and old properties lacked rain sensors, and of those who did have these devices, few were found on irrigation systems older than a few years. Of the residences included in this study, only 18% (38) of irrigation systems inspected were equipped with a rain shut-off sensor. Of those, 63% (24) were wireless and 37% (14) were hard-wired.

Table 1 lists the annual mean and range of irrigation applied for residents with and without rain shut off sensors. Surprisingly, irrigation applied from residents with rain sensors consistently exceeded those without rain sensors. However, statistical tests revealed no significant difference. This may be due to the large discrepancy between the number of residents in each group and the high variability within groups. In conversations with residents without rain sensors, many preferred to turn off their systems manually rather than rely upon a device which had to be maintained and periodically replaced. Some also commented that their landscape maintenance company or irrigation professionals had recommended against installing rain sensors due to their "limited life expectancy" and "unreliability".

Table 1. Comparison of irrigation applied for residents with and without rain sensors.

Year	[1]Net-PWR (in.)	Rain Sensor Installed			NO Rain Sensor		
		[2]Mean (in.)	[3]Range (in.)	[4]N	Mean (in.)	Range (in.)	N
2008	12.5	**30.7**	2.5 – 122.4	16	**21.0**	3.0 – 64.1	150
2009	12.6	**21.8**	1.9 – 60.1	18	**21.0**	3.5 – 80.4	153
2010	12.1	**22.2**	1.8 – 98.2	20	**17.7**	1.5 – 55.7	154
2011	21.5	**33.5**	2.1 – 187.1	25	**26.7**	4.2 – 75.6	153
2012	13.7	**19.5**	1.6 – 53.8	27	**18.7**	0.9 – 55.5	157
2013	18.1	**21.2**	2.5 – 49.4	27	**19.0**	1.9 – 73.5	154
2014	12.1	**16.6**	12.4 – 20.4	12	**15.1**	0.2 – 40.2	107
2015	14.0	**17.7**	0 – 37.6	35	**15.4**	0.7 – 45.8	157

[1]Net-PWR is the cumulative net plant water requirement (in inches) from April through September (typical irrigation season).
[2]Average irrigation applied (in inches) from April through September.
[3]Lowest to highest irrigation applied (in inches).
[4]Number of residents.

Multiple Programs

When properly used, multiple controller programs ('A', 'B', 'C', etc.) will allow a residential customer to fine tune their irrigation schedule to accommodate different irrigation frequency needs for various microclimate conditions and plant water requirements. A survey of residents in this study showed that only 16% (34) used more than one program (Figure 2), and 32% (67) practiced multi-cycling.

Figure 2. Number of residents using multiple programs and cycles per irrigation day

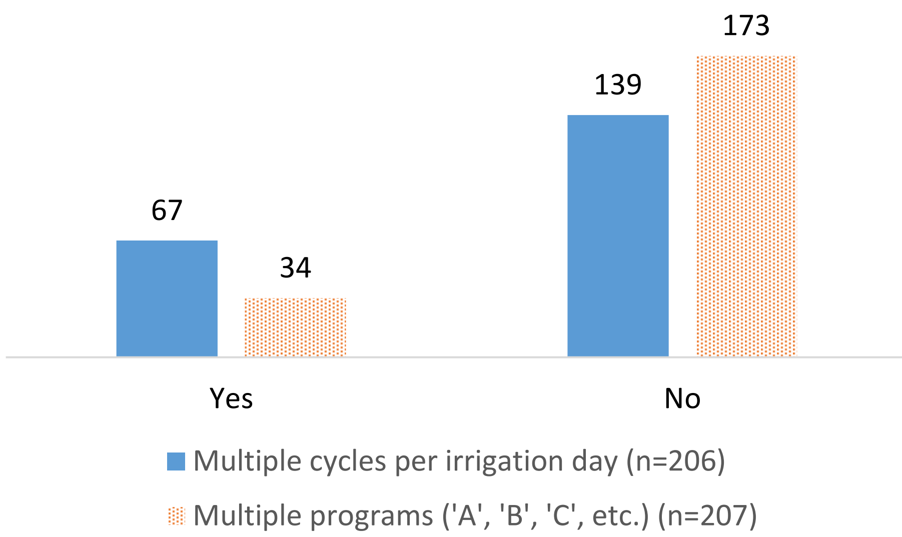


Table 2 compares average irrigation applied from residents who used multiple programs to those who used only one program. Residents who used multiple programs applied slightly more water during the growing season for each growing season, although the difference was not significant.

These results were unexpected, although there are a couple of possible explanations. First, multiple programs were often accidentally set by the resident. As electronic controllers age, their display can get difficult to read and function keys used to set the controller become less responsive. This often leads to unintentional programming errors. Second, despite the best intentions on part of some residents, programming the controller was confusing and absence programming instructions was not helpful.

Table 2. Comparison of irrigation applied for residents employing only one and multiple controller programs ('A', 'B', 'C', etc.).

Year	[1]Net-PWR (in.)	Use 1 Program Only			Use Multiple Programs		
		[2]Mean (in.)	[3]Range (in.)	[4]N	Mean (in.)	Range (in.)	N
2008	12.5	**21.4**	2.6 – 64.1	134	**25.4**	3.8 – 122.4	28
2009	12.6	**20.8**	1.9 – 80.4	138	**23.8**	7.3 – 60.1	28
2010	12.1	**17.6**	1.5 – 55.7	140	**22.6**	3.9 – 98.2	29
2011	21.5	**26.6**	2.1 – 75.6	146	**33.6**	10.0 – 187.1	29
2012	13.7	**18.2**	0.9 – 55.5	149	**22.3**	6.5 – 54.3	30
2013	18.1	**18.7**	3.0 – 73.5	145	**22.5**	1.9 – 47.3	31
2014	12.1	**14.8**	0.2 – 40.2	102	**17.0**	3.5 – 28.8	14
2015	14.0	**15.1**	0 – 36.8	156	**18.6**	1.8 – 37.6	32

[1]Net-PWR is the cumulative net plant water requirement (in inches) from April through September (typical irrigation season).
[2]Average irrigation applied (in inches) from April through September.
[3]Lowest to highest irrigation applied (in inches).
[4]Number of residents.

Multiple Cycles

Most residential controllers provide for multiple start times on a given irrigation day as a means to avoid excessive water runoff that may occur due to steep slopes or in soils with low infiltration rates. For example, instead of irrigating for 20 minutes for one cycle, this feature allows that 20 minutes to be distributed among two or more cycles (e.g., 10 minutes per cycle for two cycles). This allows water applied by sprinkler devices with high application rates a better chance to infiltrate into the soil between cycles. Table 3 compares average irrigation applied from residents who used multiple cycles per irrigation day to those who used only one cycle per irrigation day. Residents who used multiple cycles per irrigation day applied slightly more water than those irrigating only one cycle per irrigation day. Again, the difference between groups was not statistically significant.

Table 3. Comparison of irrigation applied by residents who use only one versus multiple cycles per irrigation day.

Year	[1]Net-PWR (in.)	Use 1 Cycle Only			Multi-cycle		
		[2]Mean (in.)	[3]Range (in.)	[4]N	Mean (in.)	Range (in.)	N
2008	12.5	**21.7**	2.6 – 64.1	113	**22.8**	3.3 – 122.5	53
2009	12.6	**20.2**	1.9 – 80.4	116	**23.3**	5.6 – 60.1	54
2010	12.1	**17.5**	1.5 – 55.7	118	**20.1**	2.9 – 98.2	55
2011	21.5	**27.1**	2.1 – 75.6	122	**29.1**	4.2 – 187.1	56
2012	13.7	**18.8**	0.9 – 55.4	125	**19.1**	5.4 – 54.3	58
2013	18.1	**19.8**	3.0 – 73.5	122	**19.0**	1.9 – 43.4	57
2014	12.1	**15.3**	0.2 – 32.9	88	**14.9**	0.2 – 40.2	31
2015	14.0	**15.4**	0 – 45.8	132	**16.8**	0 – 37.4	60

[1]Net-PWR is the cumulative net plant water requirement (in inches) from April through September (typical irrigation season).
[2]Average irrigation applied (in inches) from April through September.
[3]Lowest to highest irrigation applied (in inches).
[4]Number of residents.

Landscape Irrigation Ratio (LIR)

Water use efficiency describes how closely irrigation applied matches plant water requirement. The LIR metric (used by Glenn et. al, 2015) (defined as the ratio of landscape water use divided by landscape water requirement) is one measure of water use efficiency. Although the choice of LIR classification is somewhat subjective, this methodology does provide a means to gauge the effectiveness of water conservation outreach, education, and awareness efforts among a large population.

LIR was computed for all properties and a comparison of LIRs for residences with and without rain sensors, and residences who do and do not use multiple programs and cycles per irrigation day when scheduling automated irrigation controllers (Figures 3, 4 and 5). Figure 3 illustrates that in all years. On average, water use efficiency was lowest (LIR highest) for properties equipped with rain sensors. Figure 4 demonstrates that water use efficiency was lower in all years for properties utilizing multiple controller programs as part of their controller irrigation schedule. Also, contrary to expectations, those residences utilizing multiple irrigation cycles per irrigation day used slightly more water than those using only one cycle (Figure 5). For all scenarios, there was overall increase in water use efficiency (lower LIR) over the 8-year study period.

Figure 3. LIR comparison and trend for residences with and without rain sensors.

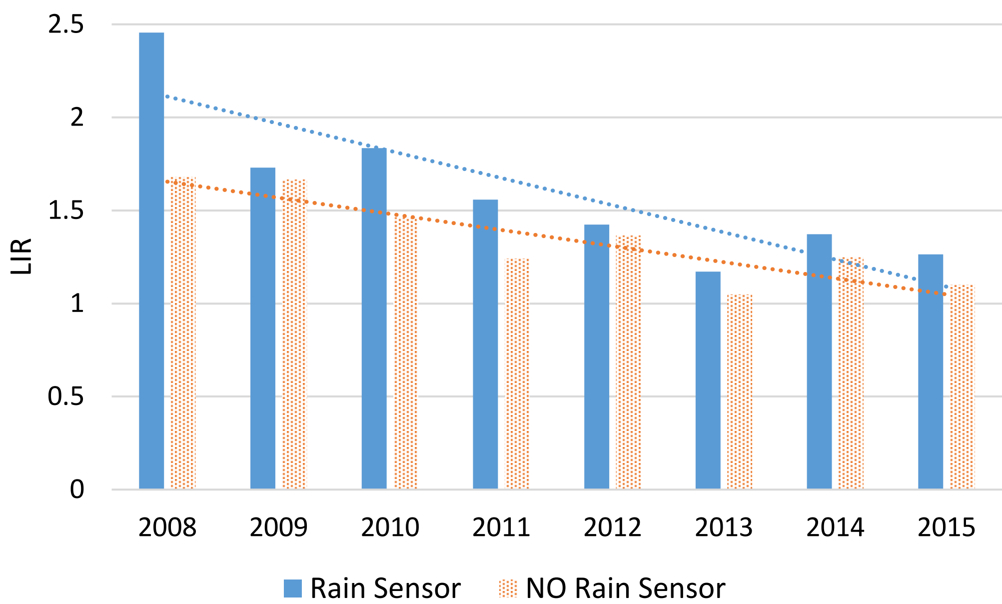


Figure 4. LIR comparison and trend for residences who do and do not utilize multiple programs.

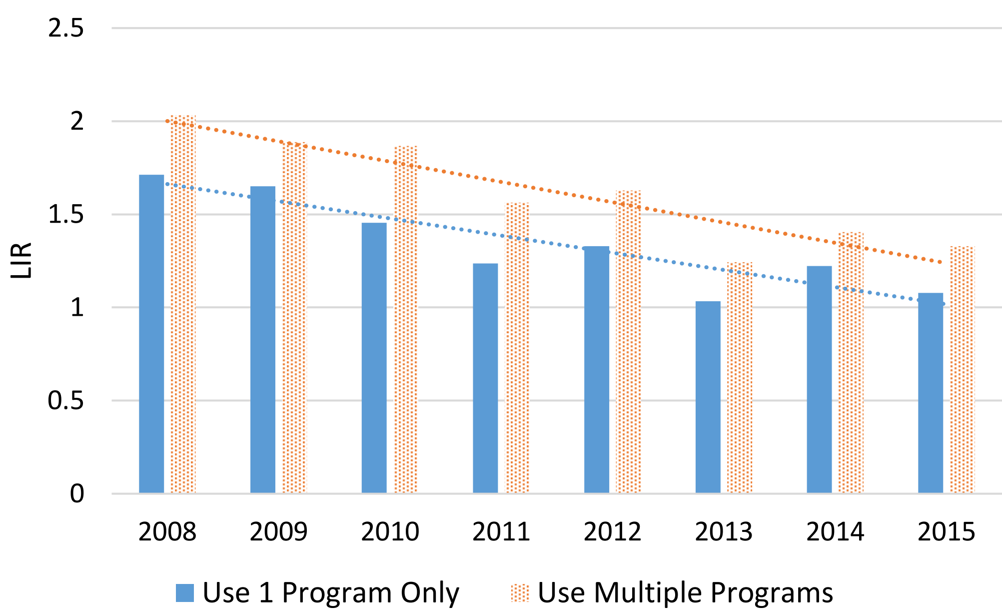
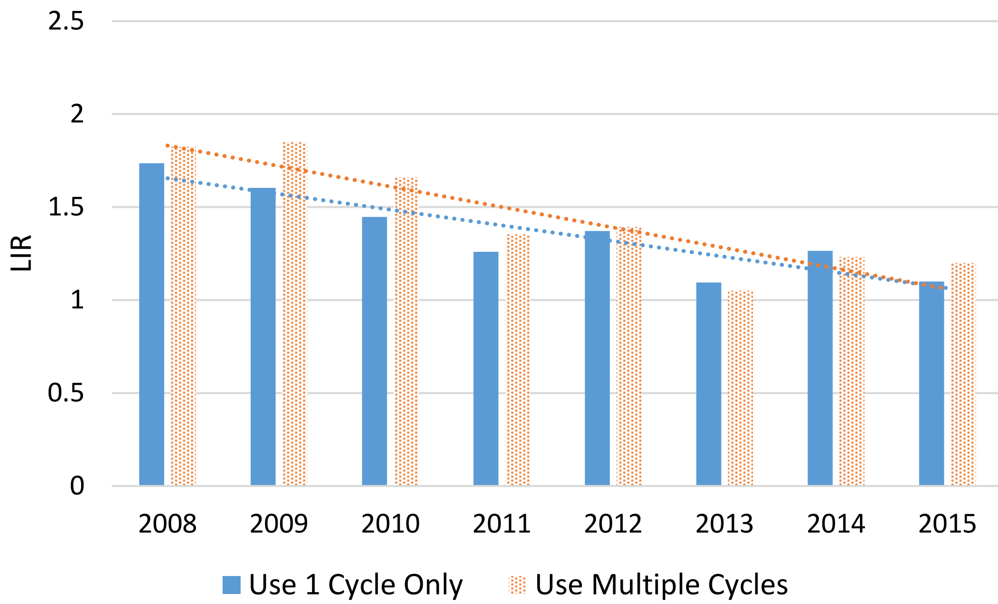


Figure 5. LIR comparison and trend for residences who do and do not utilize multiple cycles per irrigation day.



LIR for all residents included in this study were calculated and categorized in Table 4 using the classification system defined by Glenn et al. (2015). Overall, the percentage of residents classified as either 'efficient' or 'acceptable' increased from 70 percent to 91 percent from 2008 to 2015, with the highest percentages in these two categories occurring in 2011 (93 percent) and 2013 (95 percent), both extremely dry growing seasons. Furthermore, the number of properties classified as either 'inefficient' or 'excessive' dropped dramatically over the study period with less than 10 percent of residents falling into these categories.

Table 4. Distribution of residents by LIR category.

[1]LIR Category	Percentage of residents by LIR category							
	2008	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Justifiable water use								
Efficient LIR ≤ 1	19	19	26	31	26	51	35	41
Acceptable 1 < LIR ≤ 2	51	50	51	62	63	44	50	50
Unjustifiable water use								
Inefficient 2 < LIR ≤ 3	22	25	21	6	9	4	14	8
Excessive 3 < LIR	8	5	2	1	2	1	1	1
Total (%)	100	100	100	100	100	100	100	100
[2]N	167	170	173	178	183	179	119	193

[1]LIR is defined as the ratio of landscape water used divided by landscape water required (Net-PWR). Category designations defined by Glenn et al. (2015).
[2]Number of residents.

DISCUSSION

In 2012, 2013, 2014, and 2015 211 irrigation inspections for 205 unique customers were conducted as part of the College Station Water Utility's free residential irrigation checkup program. The objective of this study was to evaluate water consumption records for residential customers who do and do not utilize advanced residential controller features to identify any differences, patterns, or trends in the amount of irrigation applied (when normalized by unit landscape area). Unexpectedly, Irrigation applied (per unit landscape area) by residents with rain sensors consistently exceeded those without rain sensors. However, statistical tests revealed no significant difference. Irrigation applied by residents who used multiple programs and cycles per irrigation day was consistently higher than those who did not. Again, there was no significant difference among the groups. This data implies a lack of understanding or point of confusion among residents on how to properly utilize these advanced features intended to accommodate different irrigation scheduling needs and microclimates found in many residential properties. Water use efficiency, as measured by the Landscape Irrigation Ratio metric, showed an overall increase over the study period. Trends also show a decrease in the portion of residents classified as 'inefficient' or 'excessive' suggesting that the irrigation checkup service may have long term impact in reducing over-irrigation.

CONCLUSIONS

Results of this study profile existing irrigation system hardware and scheduling practices among residential customers in College Station, Texas. This study has shown that in order for 'best management practices' to be successful in reducing water use, customer education is imperative. Absent basic understanding of controller programming, attempts at implementing these practices may actually increase water use. Finally, although current education and landscape irrigation checkup service appear to be effective in increasing water use efficiency, there is an opportunity to further promote water conservation by delivering training focused on proper use of advanced controller features. There is also a need for education and training focused on proper installation, siting, maintenance, and operation of rain shut off sensors.

ACKNOWLEDGEMENTS

- College Station Water Utilities
- Texas A&M Department of Recreation, Park and Tourism Sciences
- Irrigation Technology Program, Texas ET Network

REFERENCES

Brazos County Appraisal District (2015). http://www.brazoscad.org/

Cabrera R.I., Wagner K.L., Wherley B. (2013): An evaluation of urban landscape water use in Texas. *Texas Water Journal*, 4, pp. 14-27.

Coleman, D. (2014). City of College Station Water Conservation Plan. May 2014. http://www.cstx.gov/Modules/ShowDocument.aspx?documentid=19343

Fipps, G., Welsh, D., Smith, D., and Swanson, C. (2009). Texas landscape irrigation auditing and management short course manual – version 3. Texas A&M AgriLife Extension Service.

Glenn, D.T., Endter-Wada, J., Kjelgren, R., Neale, C.M.U. (2015): Tools for evaluating and monitoring effectiveness of urban landscape water conservation interventions and programs, *Landscape and Urban Planning*, 139, pp. 82-93.

Texas ET Network (2015). http://texaset.tamu.edu/

White, R., Havlak, R., Nations, J., Pannkuk, T., Thomas, J., Chalmers, D., and Dewey, D. 2004. "How much water is enough? Using pet to develop water budgets for residential landscapes." Proc., Texas Water 2004, Texas Section American Water Works Association, Arlington, Tex., *Texas AWWA Paper No. TR-271*.