A method to estimate irrigation in residential areas: a case study in Orlando, Florida

Consuelo C. Romero, Assistant-In Research Scientist

Agricultural & Biological Engineering, University of Florida. Frazier Rogers Hall, P.O. Box 110570, Gainesville, FL, 32611-0570, ccromero@ufl.edu

Michael D. Dukes, Professor

Agricultural & Biological Engineering, University of Florida. Frazier Rogers Hall, P.O. Box 110570, Gainesville, FL, 32611-0570, mddukes@ufl.edu

Abstract. *A methodology to estimate residential irrigation using monthly metered total water use and irrigation data is presented here. In this work 2,142 homes located in Orlando, Florida, were analyzed. The analysis was based on monthly billing records for the period 2006-2009. Annual total water use and actual irrigation were calculated. This work is based in a previous study where residential irrigation was estimated based on total monthly water use billing records, basic indoor water use using two different methods (minimum month and per capita methods), and estimating the irrigable area using three different percentages of impervious areas covering the green area. The results of this study showed that actual irrigation accounted for 63.8% of the total water use. Average total water use was 18,591 gal month^{-1} and average actual irrigation was 12,087 gal month^{-1}. Also, indoor water use was fairly constant across the year with an average of 6,504 gal month^{-1}. Coefficients of determination (R^2) between actual and estimated irrigation for monthly and annual values ranged between 0.6086 and 0.9991. Monthly and annual equations to estimate irrigation from total water use are presented in this paper, but their applications are recommended for de area of Central Florida.*

Keywords. Actual irrigation, total water use, indoor water use, Florida.

Introduction

There is an increase in the use of irrigation for urban landscapes (Ferguson, 2007). Irrigation water use is the greatest single source of household water consumption (Mayer et al., 1999; Perez et al., 2004), and, as water availability decreases, it is important that landscape managers and homeowners recognize that they are responsible for how water is applied in order to be conserved (Devitt and Morris, 2008). USGS estimated that, during certain times of the year, 25-75% of residential water use is for outdoor purposes (primarily lawn watering) in Florida (DEP, 2010). A study based on 27 cooperating residential homes in Central Florida reported that 64% of the residential water use volume accounted for irrigation in a 30 month period (Haley et al., 2007). A different study conducted in homes encompassed by City of Tampa Water Department (TWD) and Orange County Utilities (OCU) concluded that 25-35% of the homes in Tampa and 53-60% of homes in Orlando over-irrigated during a period from 2003 through 2007. This study was based on an estimation of irrigation in single-family homes using billing records of monthly total water use (Romero and Dukes, 2012).

There is little information about how much water is used for both outdoor and indoor purposes in the U.S. especially quantitative analysis for irrigation purposes (Mayer et al., 2003; Palenchar et al., 2009). Irrigation can be accurately measured by installing dual water meters at residential homes, a main water meter and an irrigation meter. A utility company installs the main water meter within the main water inlet pipe, and is used to determine the total amount of water used by the household for billing purposes. Then the irrigation meter is connected to the utility main pipe that will measure only the irrigation water use (Haley and Dukes, 2010). Otherwise, irrigation is typically estimated by subtracting the indoor water use from the total metered water use consumption (Mayer et al., 1999). One assumption is to consider the winter low water use as a representative indoor use only (Dziegielewski and Kiefer, 2009). This approach works well and gives a baseline for outdoor water use in areas where winter is well defined, but in areas like Florida where there is no clear winter season this approach may over-estimate indoor use (Haley and Dukes, 2007).In warmer areas, like Florida, the minimum month method could adjust better (DeOreo et al., 2008, Mayer et al., 2009). Another approach is the per capita method (Mayer et al., 1999). To apply this method, an estimated value of indoor water use per capita per day is multiplied by the average number of inhabitants in a household, by 30 days.

The objective of this paper is to validate a methodology to estimate irrigation from total water use using observed irrigation data for a selected group of homes in Orlando, Florida.

Materials and Methods

Water use data base and quality control

Monthly total water use billing records of 2,142 households located in Orlando, Florida, were available from Jan 2006 through May 2009. Monthly irrigation records for the same homes were available too. These homes had separate total and irrigation water meters. Additional information available were customer name, address, parcel area, built area, date. A quality control procedure was performed on the database, where missing and/or negative values in the categories of total water use, irrigation water use, parcel area, and built area, were not considered in the analysis. Both, annual total water use and annual irrigation were also calculated by adding the corresponding monthly values (January through December) at each household, since annual data was not available in the water use billing records.

Determining total water use, actual irrigation, and indoor water use

Total water use data for the period 2006 through 2009, and their corresponding actual irrigation were used to calculate indoor water use by simple subtraction (indoor use = total water use – actual irrigation). These data were categorized by months (e.g. January, February, etc.) and the results were analyzed. The annual values were aggregated into one database and their results also were analyzed. The observed monthly indoor use results were compared to those values obtained by using two standard methods to estimate indoor water use: the per capita and the minimum month methods. In the per capita method an estimated value of monthly indoor water use is obtained by multiplying the indoor water use per capita per day, times the average number of inhabitants per single-family home, times 30 days. The number of inhabitants per home was estimated at 2.25 for Orlando (Mayer et al. 1999; U.S. Census Bureau 2009). Mayer et al. (1999) estimated an indoor water use of 66.1 gallons per capita per day for Central Florida, giving as a result 4,462 gal month^{-1}. In the minimum month method (Mayer et al. 1999) the lowest-use month in a year was assumed to represent indoor use and all differences between the other months and the lowest-use month value were considered to be outdoor use. This method is based on the assumption that indoor use remains fairly consistent across season (Mayer et al., 1999). Our previous study (Romero and Dukes, 2012) showed that the lowest use month ranged from 5,221 to 13,115 gal month^{-1}, representing the indoor uses for Orlando area, from 2003 through 2007.

Irrigation estimation

Irrigation was estimated on a monthly basis in order to compare the obtained values with the actual irrigation. Annual estimated irrigation was also determined for the analysis. We used the methodology presented by Romero and Dukes (2012). To estimate irrigation, the basic monthly indoor water use determined by the per capita method was subtracted from the monthly metered water use. The resulting values were divided by an estimated green area, which was obtained by subtracting the building area from the parcel area. An assumed impervious area was subtracted from the green area to finally obtain the irrigable area. Since we considered three impervious areas scenarios (5, 15 and 20% from total green area) we obtained three estimated irrigation values per home. We will show the results using 15% impervious area, but a discussion about differences among the three values is shown.

Comparison of estimated and actual irrigation (Jacknife analysis)

The estimated and actual monthly irrigation values were aggregated by month, which included data from 2006 through 2009. A sample equivalent to 70% of the estimated irrigation data was used and compared against their corresponding actual irrigation to determine the regression equations and regression coefficients for each month. These equations were used to estimate new monthly irrigation values (or ‘corrected irrigation values’) on the remaining 30% of the data for each month. The new corrected estimated irrigation values were compared against actual irrigation and their new regression coefficients were analyzed (Jacknife analysis; Wu, 1986). In Jacknife analysis, new estimates are compared against actual measured values for a set of data different from those used as input data. The same procedure was performed with the annual irrigation data.

Equations to calculate irrigation from total water use

Regression analyses were carried out between actual irrigation and property characteristics (including total water use, parcel area, built area, green area) to understand the relationship between the dependent variable (actual irrigation) and the rest of parameters. R^2 and F-values (significance of the equations) were analyzed. Equations to calculate actual irrigation are presented for each month and for a year.

Results and Discussion

Water use data and quality control

After the data quality control, the initial number of homes (2,142) was reduced depending on the annual or monthly aggregation. The total number of households per year ranged from 539 to 1781. For the monthly analysis, the number of households ranged from 1392 to 1816 (Table 1).

Table 1: Number of households evaluated in the present analysis

		N° of homes
Year	2006	539
	2007	1,182
	2008	1,781
	2009	1,722
Months	Jan	1,722
	Feb	1,729
	Mar	1,786
	Apr	1,818
	May	1,816
	Jun	1,570
	Jul	1,392
	Aug	1,464
	Sep	1,507
	Oct	1,607
	Nov	1,653
	Dec	1,707

Total water use, actual irrigation and indoor water use

Monthly and annual total water use, actual irrigation and indoor water use are shown in Tables 2 and 3. The maximum average monthly total water use was observed in May at 22,887 gal month^{-1}, while the minimum was observed in the month of February, at 16,006 gal month^{-1}. The average actual irrigation ranged from 9,347 to 16,051 gal month^{-1} in July and May, respectively. Maximum total water use and irrigation values were observed in May, when temperature starts increasing but rainfall amount is not as high as in the coming months (Jun-Sep). Minimum values for total water use and irrigation is also observed in a warm month (July) where rainfall amounts is higher than the rest of the months. The average indoor water ranged from 5,812 to 7,154 gal month^{-1}, in February and August, respectively. Clearly, the statement said by Mayer et al. (1999) about indoor use remains fairly consistent across season can be observed in these monthly data. These actual indoor use values were lower than our previous findings using the minimum month method. In our previous study (Romero and Dukes, 2012) we found that the lowest-use months ranged from 5,221 gal month^{-1} in 2005 to13,115 gal month^{-1} in 2006, with an average of 9,479 gal month^{-1} for the period 2003 through 2007 in the same study area (Orlando). The minimum month method estimated 2,975 gal month^{-1} more indoor water use than what was observed. The per capita method gave an indoor value of 4,462 gal month$^{-1,}$ which seems to be under-estimated compared to the actual indoor use.

The average annual total water use was 130,359, the average annual actual irrigation was 83,172, and the average annual indoor use was 47,187. In this study, actual irrigation water use accounted for 63.8% of the total water use. This is supported by Haley et al. (2007) showing that more than 50% of the total household water use is for irrigation purposes. Romero and Dukes (2012) estimated that 68.3% of the total water was used for irrigation purposes when the per capita method was used to calculate indoor water use. When the minimum month method was applied, only 32.6% of the total water was used for irrigation purposes. With our current results we can say that the minimum month method can over-estimate indoor water use and as a consequence under-estimate irrigation water use.

Table 2: Average monthly values of total water use, actual irrigation and indoor water use

Month	Avg. total water use	Avg. actual irrigation gal month^{-1}	Avg. indoor use
Jan	17,088	10,670	6,417
Feb	16,006	10,193	5,812
Mar	19,213	12,586	6,627
Apr	22,560	15,871	6,689
May	22,887	16,051	6,835
Jun	17,949	11,739	6,211
Jul	15,634	9,347	6,287
Aug	18,952	11,798	7,154
Sep	17,257	10,850	6,407
Oct	18,606	12,042	6,564
Nov	18,684	12,250	6,434
Dec	18,258	11,646	6,613
Average	**18,591**	**12,087**	**6,504**

Table 3: Average annual values of total water use, actual irrigation and indoor water use

Month	Avg. total water use	Avg. actual irrigation gal year^{-1}	Avg. indoor use
2006	89,117	57,782	31,335
2007	177,043	116,328	60,715
2008	164,305	100,443	63,861
2009	90,972	58,136	32,835
Average	**130,359**	**83,172**	**47,187**

Comparing estimated against actual irrigation

The monthly estimated irrigation values were compared against the monthly actual irrigation values to analyze the relationship between these two datasets. Table 4 (column on the left) shows the coefficients of determination (R^2) obtained by plotting a sample of 70% of data from the estimated and actual irrigation databases. R^2 ranged from 0.7562 to 0.8419, and these values corresponded to the months of September and June, respectively.

Table 4: R^2 values for monthly curves comparing estimated irrigation versus actual irrigation.

Month	R^2 (Estimated irrigation vs. actual irrigation)	R^2 (Corrected estimated irrigation vs. actual irrigation)
Jan	0.8015	0.8012
Feb	0.7942	0.8487
Mar	0.8095	0.8298
Apr	0.7970	0.9991
May	0.8177	0.9974
Jun	0.8419	0.8437
Jul	0.7858	0.7902
Aug	0.7576	0.6846
Sep	0.7562	0.7683
Oct	0.8005	0.6154
Nov	0.8082	0.7300
Dec	0.8234	0.6086

Figure 1 (column ‘a’) shows the resulting curves, linear regression equations, and R^2 values from comparing actual irrigation and estimated irrigation using 70% of the data for 6 months of the year. There are few irrigation values that are over-estimated. All R^2 values were higher than 0.7500. The remaining 30% of the data were used to correct the estimated irrigation values by using the equations previously obtained. The corrected estimated irrigation values in most of the cases showed higher R^2 values than those obtained during the initial comparison, ranging from 0.6086 to 0.9971. R^2 were lower for the winter months, as these can be observed in Table 4 (column on the right). Some of the new corrected irrigation values are over-estimated.

Figure 2 (a) shows the comparison between actual annual irrigation and estimated annual irrigation using 70% of the total data. The R^2 was 0.7982. The corrected annual estimated irrigation values (calculated with the remaining 30% of the data) were plotted against the actual annual irrigation and R^2 obtained was 0.7984. Both trends were similar.

The effect of the percentage of impervious area on the estimated irrigation was as follows: it increased 6% when 20% impervious area was used compared to 15% impervious area; and it decreased 10% when 5% impervious area was used (also compared to 15% impervious area; Romero and Dukes, 2012). When plotted against actual irrigation, the three coefficient of determination values were the same ($R^2 = 0.7977$), and according to the linear regression equations the actual irrigation is approximately 58 to 69% of the estimated irrigation.

Equations to calculate irrigation from total water use

Equations to estimate monthly and annual irrigation are shown in Figures 3 and 4. These equations show irrigation as a function of total water use only. The units are in gallons $month^{-1}$ and gallons $year^{-1}$. Regression analyses between actual irrigation and property characteristics such as parcel area, built area and green area did not show good coefficients of determination (R^2) and the regression equations were not significant (Table 5). Monthly and annual equations to calculate irrigation from total water use were significant at 99% and then we can accept these equations.

The monthly equations are recommended due to the seasonal variability of temperature and rainfall in the area, so the estimated irrigation values can be more reliable. However, a general annual equation is also recommended. The application of these equations is recommended to the Orlando area only. The results obtained by using these equations with total water use records from locations other than Orlando must be always be used with caution since the conditions for their determination are unique for Central Florida.

Table 5: Regression analysis results between actual irrigation and property characteristics.

	Coef. of determination (R^2)	Significance F
Actual irrigation vs. total water use	0.8701	0
Actual irrigation vs. parcel area	0.0496	3.705E-178
Actual irrigation vs. built area	0.0237	4.7479E-85
Actual irrigation vs. green area	0.0454	1.1149E-162

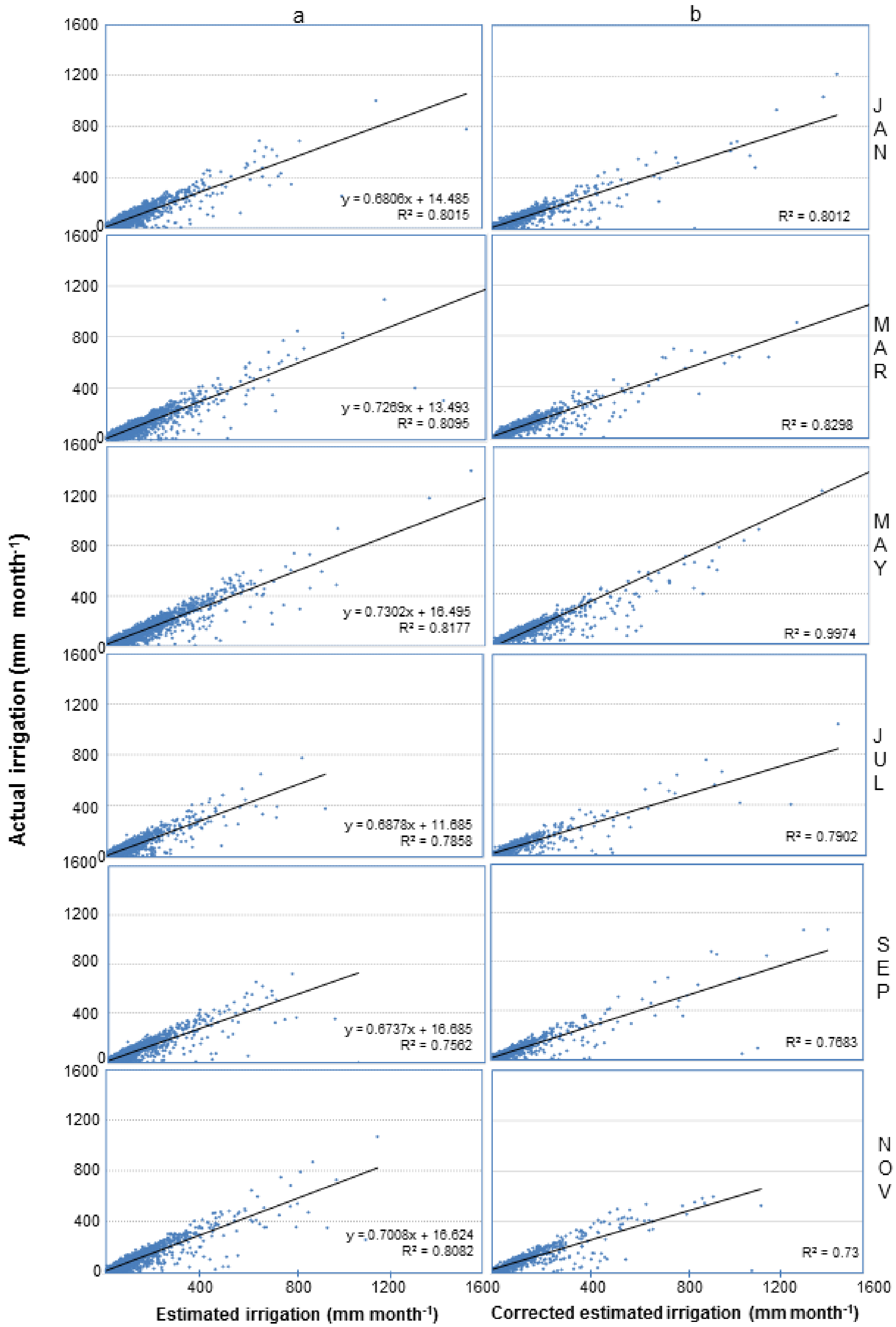

Figure 1. Comparison between actual irrigation and (a) estimated irrigation and (b) corrected estimated irrigation.

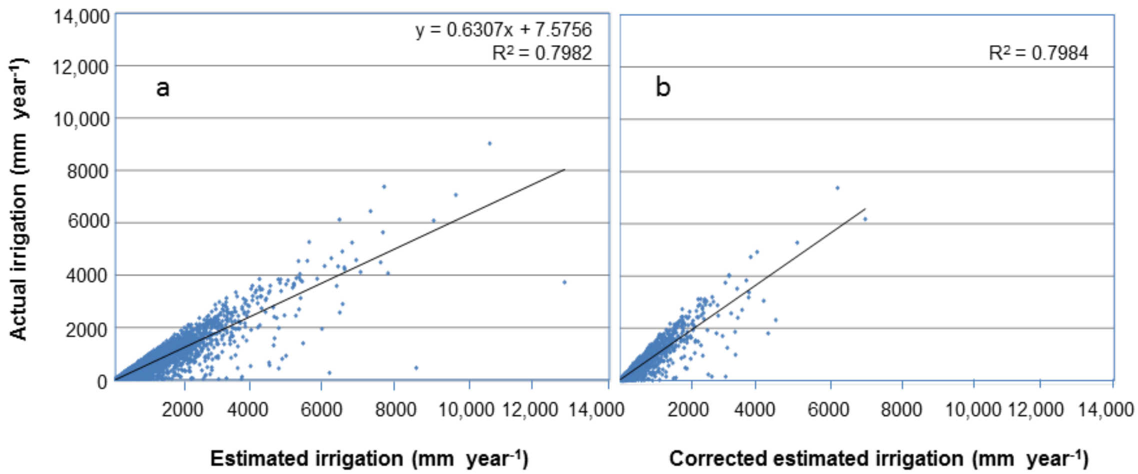

Figure 2. Comparison between actual annual irrigation and (a) estimated annual irrigation and (b) corrected annual irrigation.

Conclusions

Total water use billing records as well as actual irrigation records for 2,142 homes in Orlando, Florida, were available and analyzed to estimate irrigation. Maximum average monthly total water use was 22,887 gal month^{-1} for the month of May, while minimum was observed in the month of February, at 16,006 gal month^{-1}. Average actual irrigation ranged from 9,347 to 16,051 gal month^{-1} in July and May, respectively. Average indoor water ranged from 5,812 to 7,154 gal month^{-1}, in February and August, respectively and values remained fairly consistent across season. Actual irrigation water use accounted for 63.8% of the total water use.

Seventy percent of the data was used to compare and establish the relationship between estimated irrigation values and actual irrigation by getting linear regression equations. The monthly analysis gave R^2 that ranged from 0.7562 to 0.8419. The annual analysis gave a R^2 of 0.7982. The corrected estimated irrigation values plotted against the actual irrigation and their R^2 values ranged from 0.6086 to 0.9971.

Monthly and annual equations to estimate irrigation are shown in this paper as a function of total water use (in gal month^{-1} or gal year^{-1}). The application of these equations is recommended to the Orlando area only.

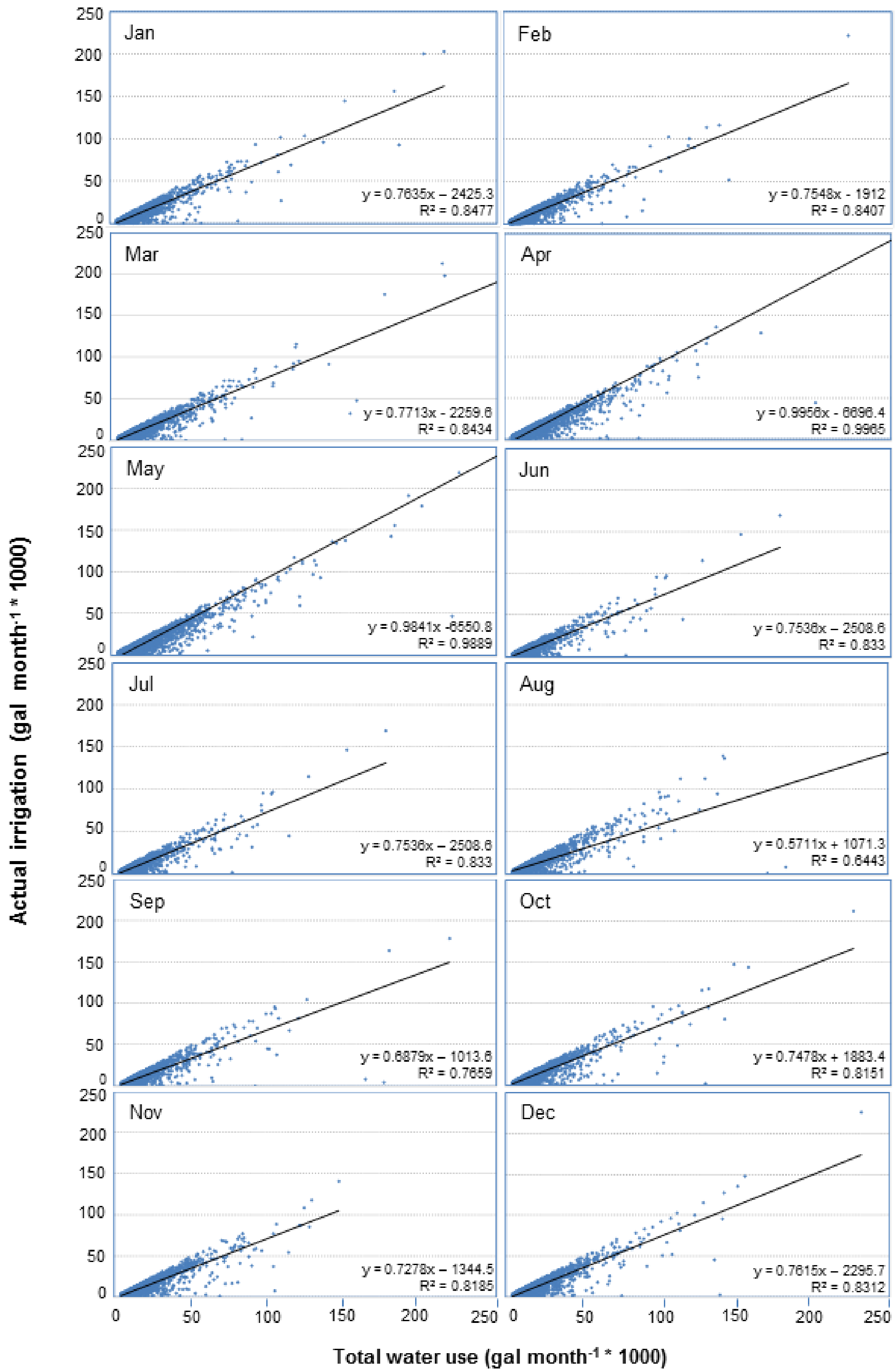

Figure 3. Monthly equations to estimate actual irrigation from total water use.

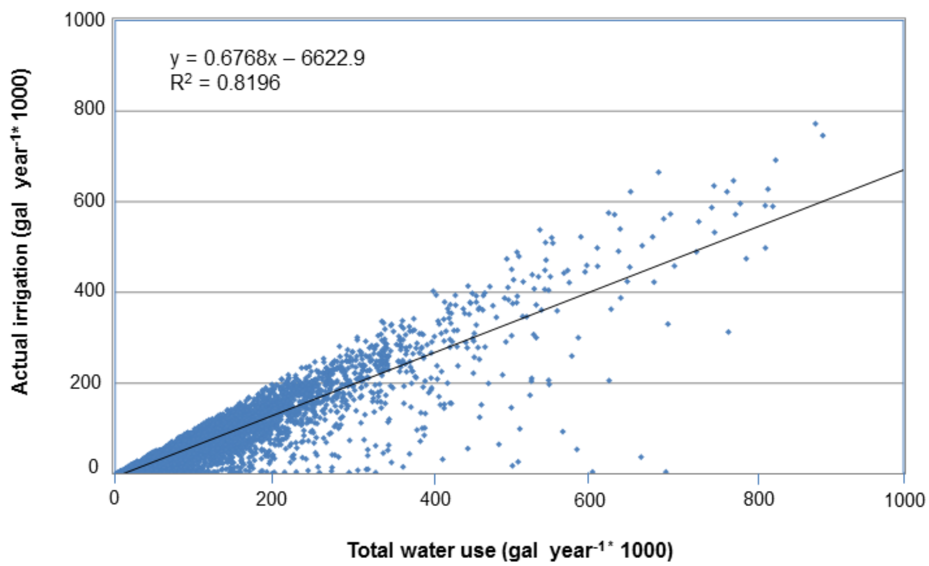

Figure 4. Annual equation to estimate actual irrigation from total water use.

Acknowledgements

The authors wish to thank Orange County Utilities for the availability of water use database as well as the following funding agencies for their support of this research: Florida Department of Agriculture and Consumer Services, Florida Nursery Growers and Landscape Association, Florida Agricultural Experiment Station, South Florida Water Management District, and Water Research Foundation.

References

DeOreo,W., J. Whitcomb, P. Mayer, J. Henderson, P. Gleick, G. Wolfe, J.O. Nelson, and B. Gauley, B. 2008. California Single Family Water Use Efficiency Study: Draft Report. Aquacraft, Inc., Water Engineering and Management, Boulder, CO.

Devitt, D. A. and R.L. Morris. 2008. Urban landscape water conservation and the species effect. In: J.B. Beard and M.P. Kenna. *Water quality and quantity issues for turfgrasses in urban landscapes.* The Council for Agricultural Science and Technology, IO, USA.

Dziegielewski, B. and J.C. Kiefer. 2009. Water conservation measurement metrics guidance report. Denver, CO.: American Water Works Association, Water Conservation Division Subcommittee.

Ferguson, B.F. 1987. Water conservation methods in urban landscape irrigation: an exploratory overview. J. Am. Water Resour. As. 23(1):147-152.

Haley, M.B. and M.D. Dukes. 2007. Evaluation of sensor based residential irrigation water application. ASABE Meeting Presentation. Paper Number: 072251. Minneapolis, MN.

Haley, M.B. and M.D. Dukes. 2010. Irrigation water use separation from overall use: evaluation of methodology and verification of assumptions. 5th National Decennial Irrigation Conference Proceedings, 5-8 December 2010, Phoenix Convention Center, Phoenix, Arizona, USA IRR10-9810.

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

Mayer, P.W., W. B. DeOreo, E. Towler, and D. M. Lewis. 2003. Residential indoor water conservation study: evaluation of high efficiency indoor plumbing fixture retrofits in single-family homes in the east bay municipal utility district service area. Prepared for and submitted to East Bay Municipal Utility District and The United States Environmental Protection Agency. Also at: http://library.conservefloridawater.org/publications/05633808.pdf.

Palenchar, J., K. Friedman, and J.P. Heaney. 2009. Hydrograph separation of indoor and outdoor billed water use in Florida’s single family residential sector. University of Florida, Conserve Florida Water Clearinghouse. Gainesville, Fl. To appear, Proc. Fall 2009 FSAWWA Fall Conference, Orlando. Also at: http://library.conservefloridawater.org/publications.1663684.pdf.

Perez, L., J.A. Rodriguez, E. Camacho, R. Lopez, J. Roldan, M. Alcaide, J.A. Ortiz, and R. Segura. 2004. IGRA: An approach for the application of the benchmarking initiative to irrigation areas. WatSav2004-Award Winning Paper.

Romero, C.C. and Dukes, M.D. 2012. Estimation and analysis of irrigation in single-family homes in Central Florida. Submitted to J. Irrig. Drain. E_ASCE (October 2012).

U.S. Census Bureau. 2009. State and County Quick Facts. Also at: http://quickfacts.census.gov/qfd/states/12/12057.html.

Wu, C.F.J. 1986. Jacknife, bootstrap and other resampling methods in regression analysis. The Annals of Statistics 14(4):1261-1265.