A METHOD TO ESTIMATE RESIDENTIAL IRRIGATION FROM POTABLE METER DATA

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A Tribute to the Career of Terry Howell, Sr.

ABSTRACT. *A methodology to estimate residential irrigation using monthly metered total water use and metered irrigation data is presented here in a case study in central Florida. The objective of this article was to determine the most accurate method of indoor/outdoor water use separation for single-family homes. In this study, 1781 homes located in Orlando, Florida, were analyzed. The analysis was based on monthly billing records for the January 2006-June 2009 period where total metered water use and separately metered irrigation data were available. Residential irrigation was estimated based on minimum month and per capita methods to derive indoor use, and by assuming three different irrigable areas for each home. Average total water use was 70.4 m^3 $month^{-1}$ and average observed irrigation was 45.8 m^3 $month^{-1}$. This method was calibrated and validated using metered irrigation data. Metered irrigation data indicated that irrigation accounted for 64% of the total water use. Observed indoor water use was fairly constant across the year with an average of 24.6 ± 1.3 m^3 $month^{-1}$, and values were compared to those estimated by the minimum month method and the per capita method. The minimum month method over-estimated indoor water use as 61.3 m^3 $month^{-1}$ whereas the per capita method estimated the value as 16.9 m^3 $month^{-1}$. Observed annual cumulative irrigation was 60% higher than the gross irrigation requirement and this excess irrigation varied from 10% to more than 300% depending on month with most excess in the winter months. The calibration and validation demonstrated that around 60% to 99% of the variability of the observed data can be reproduced by this proposed method. However, this approach maintains a limited area of potential application just for central Florida.*

Keywords. *Estimated irrigation, Florida, Indoor water use, Landscape irrigation requirements, Minimum month method, Observed irrigation, Per capita method.*

There is an increase in the use of irrigation for urban landscapes (Ferguson, 1987). 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 there is a responsibility for how water is applied, in order to be conserved (Devitt and Morris, 2008). The United States Geological Survey estimated in Florida that, during certain times of the year, 25% to 75% of total residential water use is for outdoor purposes (primarily lawn watering) (FDEP, 2010). A study based on 27 cooperating residential homes in central Florida reported that 64% of the residential water use volume accounted for irrigation over a 30 month period (Haley et al., 2007). A different study based on an estimation of irrigation in single-family homes using billing records in the City of Tampa Water Department (TWD) and Orange County Utilities (OCU) concluded that 25% to 35% of the homes in Tampa and 53% to 60% of homes in Orlando over-irrigated during a period from 2003 through 2007 (Romero and Dukes, 2014).

There is little information about how much water is used for both outdoor and indoor purposes in the United States, 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 may be estimated by assuming indoor consumption is consistent with winter low water use (Mayer et al., 1999, Dziegielewski and Kiefer, 2009). This approach works well and gives a baseline for outdoor water use in areas where winter is well defined. In areas like Florida and other parts of the southern United States where there is no clear winter season, this approach may over-estimate indoor use (Haley and Dukes, 2012). Another approach to separation of

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irrigation from total billing data 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 mean daily per capita indoor use found in 12 study sites across the United States and Canada ranged from 216 liters per capita per day (lpcd) in Seattle to 316 lpcd in Eugene, Oregon, with a mean of 262 lpcd, and standard deviations ranged from 89 lpcd in San Diego to 261 in Eugene, Oregon, which shows the great variability in indoor water use (Mayer et al., 1999).

The objective of this study was to determine the most accurate method of indoor/outdoor water use separation for single family homes in central Florida given that most potable water use data combines both indoor and outdoor on one meter.

TOTAL WATER USE DATA BASE, QUALITY CONTROL AND WEATHER DATA

Monthly total water use billing records of a maximum of 1,818 households located in Orlando, Florida, were available from January 2006 through May 2009. Total water use included indoor plus outdoor water use. Monthly irrigation records were also available since these homes had separate irrigation meters. Additional information in the database included customer name, address, parcel area, built area, month, and year. A quality control procedure was performed on the database, where missing and/or negative values were not included in the analysis. Weather data was available from National Climatic Data Center (NCDC, 2009), for a weather station located in Orlando, Florida (Orlando International Airport).

OBSERVED INDOOR WATER USE COMPARED TO INDOOR WATER USE ESTIMATION

Indoor water use was calculated by subtracting the observed monthly irrigation from the observed monthly total water use. Indoor water use was also estimated by two methods: (1) the per capita method, and (2) the minimum month method. 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 for a specific location, times 30 days. Mayer et al. (1999) reported an indoor water use of 250 lpcd for central Florida, and the number of inhabitants per home was estimated at 2.25 for Orlando (Mayer et al., 1999; U.S. Census Bureau, 2009). In the minimum month method (Mayer et al., 1999) the lowest-use month in a year is assumed to represent indoor use. This method is based on the assumption that indoor use remains fairly consistent across seasons (Mayer et al., 1999).

ESTIMATING IRRIGATION AT EACH HOME USING BILLING DATA: CALIBRATION AND VALIDATION OF A METHODOLOGY TO ESTIMATE IRRIGATION

Irrigation was estimated for each home by using a methodology presented by Romero and Dukes (2014). Irrigation was estimated, on a monthly basis, by subtracting the estimated indoor water use from the total water use registered in the billing data. We used only one method to estimate indoor water use according to the results found in the previous section. The method that performed the best was chosen. Because irrigation is expressed as a depth, the estimated irrigation volume was divided by irrigable area. The irrigable area was obtained by subtracting the building area from the parcel area, minus an assumed impervious surface. Two impervious areas values (5% and 15% from total green area) were considered based on estimations in Hillsborough County and Tampa area (Mayer et al., 1999), since paved areas were neither measured nor included in the original database.

The estimated and observed irrigation values for the period 2006-2009 were aggregated by month. In order to calibrate and validate the methodology presented by Romero and Dukes (2014) a random sample equivalent to 70% of the observed irrigation data was used and compared against the estimated irrigation to determine the regression equations and regression coefficients for each month. Then, these equations were used to estimate new monthly irrigation values (or 'corrected irrigation values') on the remaining 30% of the data. The new corrected estimated irrigation values were compared against the 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.

GROSS IRRIGATION REQUIREMENT (GIR) ESTIMATION

The GIR was estimated as a basis for the irrigation required in a given landscape. The net irrigation water requirement was estimated with a daily soil water balance described by Romero and Dukes (2014). Each day the estimated landscape evapotranspiration (ET) was subtracted from the soil water until the water content reached the maximum allowable depletion level which was taken as 50% of the available water content (Allen et al., 1998). When the simulated moisture content reached this point, an irrigation event was simulated to refill the soil water to field capacity. Effective rainfall was calculated automatically in the water balance spreadsheet as the rainfall that was stored within the soil profile. Excess rainfall was simulated as lost to drainage below the root zone or runoff. We used a 20 cm root zone depth for established turfgrass (Peacock and Dudeck 1985; Huang et al., 1997; Shedd et al., 2008). For the homes in this study area, the soil association Tavares/Pomello (hyperthermic Arenic Haplohumods) was selected as the most representative soil type (Doolittle and Schellentrager, 1989) with a sandy texture and average available water content of 6% (by volume) which yielded 12 mm of available water in the root zone. Monthly turfgrass crop coefficient (K_c) values were used from Florida data reported by Jia et al. (2009) as follows: 0.71, 0.79, 0.78, 0.86, 0.99, 0.86, 0.86, 0.90, 0.87, 0.86, 0.84, and 0.71 for January through December, respectively. These K_c values were used to adjust reference ET (ET_o) to crop ET (ET_c) for these turfgrass dominated landscapes. Weather data were available from the National Climatic Data Center (NCDC, 2009) at Orlando

International Airport. Data included daily maximum and minimum temperature, maximum and minimum relative humidity, and average wind speed. Daily solar radiation was estimated by using the daily temperature differential using the Hargreaves and Samani equation presented by Allen (1997). These data were used to estimate daily ET_o according to the ASCE-EWRI standardized reference ET equation (Allen et al., 2005). Daily rainfall data were also available for input into the daily net irrigation requirement estimation.

RESULTS AND DISCUSSION

DATA QUALITY CONTROL AND NUMBER OF HOMES EVALUATED

After the data quality control, the number of records was reduced to 34,881 from an initial number of 46,770. Approximately 25% of the data was not useful due to invalid values within the database, such as zeroes instead of values for total water use, lot size or living area. The total number of households analyzed per year ranged from 539 to 1,781, because every year a number of homes with an irrigation meter installed increased and was considered in the database (table 1). Table 2 shows the monthly averages for maximum and minimum temperature for the Orlando area as well as the monthly totals of rainfall. Average maximum temperature ranged from 24.1°C to 33.7°C observed in January and August, respectively. Average minimum temperatures reached as low as 9.5°C and as high as 23.1°C in August. Average rainfall ranged from 26 mm in November to 181 in June. This area shows maximum temperatures around the months of May to September, exceeding 30°C in all of these months. In additions, these hot months coincide with the highest amounts of rainfall in the area, from 141 to 181 mm month^{-1}.

ANALYSIS OF OBSERVED TOTAL, OBSERVED INDOOR WATER USE, AND OBSERVED IRRIGATION

Table 3 shows the average monthly data of observed total water use, indoor water use, and observed irrigation. The maximum average monthly total water use was observed in May at 86.6 m^3 month^{-1} (just when the rainfall season goes above 100 mm month^{-1}), while the minimum was observed in the month of July, at 59.2 m^3 month^{-1}, which was one of the months with the maximum average rainfall, with 180 mm after June with 181 mm (table 2). The average observed indoor water use ranged from 22.0 to 27.1 m^3 month^{-1}, in February (lowest average rainfall, table 2) and August, respectively, although it remained quite constant through the year, with an average of 24.6 m^3 month^{-1}. The average observed irrigation ranged from 35.4 to 60.8 m^3 month^{-1} in July and May, respectively. The lowest irrigation was observed during one of the wettest months (July) with 180 mm. Average totals per year per home reached 845 m^3 for total water use, 549 m^3 for irrigation and 295 m^3 for indoor water use. Maximum total water use and irrigation values were observed in May, when temperature starts increasing and rainfall amount was not as high as in the coming months (June-September). Minimum values for total water use and irrigation were observed in July, when rainfall amount was higher than the rest of the months (table 2). Based on the monthly data, irrigation accounted for 65% of the total water use at a household level. This value is very similar to Haley et al. (2007) findings in a study case in central Florida. They reported that the average household used 64% of the total household water supply for irrigation. Romero and Dukes (2014) estimated that 68% of the total water was used for irrigation in residential homes in Orlando. The statement

Table 2. Average monthly values (2006- part of 2009) of maximum and minimum temperature, and rainfall for Orlando, Florida.

Month	Tmax. (°C)	T min. (°C)	Rainfall (mm)
Jan	24.1	9.9	51
Feb	24.1	9.5	36
Mar	27.1	12.4	42
Apr	29.4	14.9	48
May	31.8	18.4	141
Jun	33.0	21.4	181
Jul	33.1	22.7	180
Aug	33.7	23.1	174
Sep	32.5	22.3	145
Oct	29.8	18.8	88
Nov	25.4	12.3	26
Dec	25.6	12.8	46
2006 (avg.)	29	17	922
2007 (avg.)	29	17	994
2008 (avg.)	29	16	1384
2009 (Jan-May avg.)	27	12	490

Table 1. Number of households evaluated in the present analysis.

		No. 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

Table 3. Average monthly values of total water use, observed irrigation, and indoor water use.

Month	Avg. Total Water Use (m^3 month^{-1})	Avg. Observed Irrigation (m^3 month^{-1})	Avg. Observed Indoor Use (m^3 month^{-1})
Jan	64.7	40.4	24.3
Feb	60.6	38.6	22.0
Mar	72.7	47.6	25.1
Apr	85.4	60.1	25.3
May	86.6	60.8	25.9
Jun	67.9	44.4	23.5
Jul	59.2	35.4	23.8
Aug	71.7	44.7	27.1
Sep	65.3	41.1	24.3
Oct	70.4	45.6	24.8
Nov	70.7	46.4	24.4
Dec	69.1	44.1	25.0
Month Avg.	70.4	45.8	24.6
Annual total (m^3)	845	549	295

established by Mayer et al. (1999) about indoor use remaining fairly consistent across seasons was confirmed in these observed monthly data. However, when the minimum month method was applied, only 32.6% of the total water was used for irrigation purposes.

TESTING INDOOR WATER USE METHODS AND COMPARISON WITH OBSERVED INDOOR USE DATA

Table 4 shows a summary of indoor water use estimates using the per capita method and the minimum month method. The estimated indoor water use using the per capita method was 16.9 m^3 $month^{-1}$ assuming 0.25 m^3 $month^{-2}$ of basic water use per capita, and 2.25 persons living per home. The minimum month method gave the following results: 69.9, 59.5, 55.5, and 60.4 m^3 $month^{-1}$ for 2006, 2007, 2008, and 2009, respectively, with an average of 61.3 m^3 $month^{-1}$. The months with the lowest water use were December, February, July, and June in 2006, 2007, 2008, and 2009, respectively. Percent error reached 140% between observed indoor use (25.5 m^3 $month^{-1}$) and the minimum month method, and -34% compared to the per capita method. These errors in indoor consumption estimation yield corresponding errors of 17% and -80% when used to estimate irrigation from total meter data. Our previous findings using the minimum month method (Romero and Dukes, 2014) for the same study area showed that the lowest-use months ranged from 19.8 to 49.6 m^3 $month^{-1}$ for the period 2003-2007 with an average of 35.9 m^3 $month^{-1}$ in the same study area. For that study, the minimum month method estimated 11.3 m^3 $month^{-1}$ more indoor water use than what was observed. In this study, the per capita method was estimated as 16.9 m^3 $month^{-1}$ indoor use assuming 0.25 m^3 $month^{-2}$ of basic water use per capita. The difference observed between the current and the previous estimated indoor water use using the minimum month method (61.3 vs. 35.9 m^3 $month^{-1}$) could be due to the number of evaluated months (5 years in the previous study vs. 3 years and 5 months in this study) which indirectly could include variability in weather (rainfall, temperatures) that influenced water consumption at a monthly basis, making the average lower. During the study year maximum and minimum temperatures were almost constant, with 29°C and 17°C on average, respectively, but rainfall varied from 922, 994, 1,384, and 490 mm in 2006, 2007, 2008, and 2009 (January-May), respectively. Also, we do not really know the number of inhabitants of these approximately 1800 homes. The number of people in these homes may be higher and/or their per person water use higher. The minimum month method, on the other hand, is substantially over-estimating the indoor water use in this area. The per capita method would be a better choice when indoor water use is to be estimated in central Florida although it has error as well.

Table 4. Average observed versus estimated indoor water use using two methodologies.

		Estimated Indoor Water Use	
Years	Observed Indoor Water Use (m^3 $month^{-1}$)	Min. Month Method (m^3 $month^{-1}$)	Per Capita Method (m^3 $month^{-1}$)
2006	28.7	69.5	16.9
2007	25.1	59.5	16.9
2008	24.3	55.5	16.9
2009	23.8	60.4	16.9
Avg. 2006-2009	25.5	61.3	16.9
Error		140%	-34%

ESTIMATED IRRIGATION VERSUS OBSERVED IRRIGATION

Irrigation was estimated by subtracting indoor water use (using the per capita method) from total water use on a monthly basis. Table 5 shows the average observed irrigation per month, as well as the average estimated irrigation using 5% and 15% impervious area. The maximum observed monthly irrigation was 129 mm for the month of April, while February had the least irrigation with 82 mm. The mean observed monthly irrigation was 97 mm. The mean monthly estimated irrigation varied from 102 to 115 mm when 5% and 15% impervious area were considered. When comparing the average observed irrigation with the average estimated irrigation the percent error was -19% when 15% impervious surface were considered, and -5% when coincidentally 5% impervious area were tested (table 5). In a previous study using the same methodology, Romero and Dukes (2014) found that the mean monthly estimated irrigation in Hillsborough County, Florida, was 39 and 43 mm when considering 5% and 15% impervious area in the estimations. Figure 1 shows the similarities in trends among observed irrigation and estimated irrigation. When 5% impervious area was used to estimate irrigation, the results were more similar to the observed data. The gross irrigation requirements per month are also shown in table 4 and figure 1. Observed irrigation exceeds the gross irrigation requirement for every month. The ratio of observed irrigation/GIR shows that observed irrigation was 3.2 times the theoretical value in December and 2.8 in January. May was the month that showed very similar required irrigation and observed irrigation with 118 versus 128 mm. Excessive irrigation in winter months (December and January) could be related to low temperature affecting turfgrasses appearance (probably the turfgrass is dormant), requiring homeowners to over-irrigate to get the lush color of their lawns. Over-irrigation in the winter months was also reported by Haley and Dukes (2012) in another area of central Florida.

Table 6 shows the coefficients of determination (R^2) obtained by plotting a sample of 70% of the observed and corresponding estimated irrigation data (using per capita method for indoor estimation and 5% impervious area). R^2 ranged from 0.76 to 0.84, and these values corresponded to the months of September and June, respectively. The remaining 30% of the data were used for the validation process, 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 0.61 to 1.00. R^2 were lower for the winter months, as these can be observed in table 6 (column on the right). The validation demonstrated that around 60 to 99% of the variability of the observed data can be reproduced by the methodology proposed by Romero and Dukes (2014) depending on the chosen month.

Table 5. Average observed irrigation, and estimated irrigation using per capita and impervious area (I.A.) of 5% and 15%. The gross irrigation requirements and ratios (gross/observed irrigation) are also shown.

Month	Avg. Observed Irrigation (mm)	Avg. Est. Irrig (15% I.A.) (mm)	Avg. Est. Irrig. (5% I.A.) (mm)	Error (15% I.A.) (%)	Error (5% I.A.) (%)	GIR (mm)	Ratio of GIR/ Observed Irrig.
Jan	85	102	99	-20	-16	30	2.8
Feb	82	94	84	-15	-2	40	2.1
Mar	100	119	106	-19	-6	72	1.4
Apr	129	148	131	-15	-2	100	1.3
May	128	148	131	-16	-2	118	1.1
Jun	93	108	96	-16	-3	65	1.4
Jul	76	92	82	-21	-8	46	1.7
Aug	96	118	105	-23	-9	78	1.2
Sep	88	105	93	-19	-6	52	1.7
Oct	97	115	103	-19	-6	56	1.7
Nov	99	116	103	-17	-4	42	2.4
Dec	94	112	99	-19	-5	29	3.2
Avg.	97	115	102	-19	-5	61	1.6
Annual	1,167	1,377	1,232			728	

Table 6. R^2 values for monthly curves comparing estimated irrigation versus observed irrigation.

Month	R^2 (estimated irrigation vs. irrigation)	R^2 (corrected estimated irrigation vs. actual irrigation)
Jan	0.80	0.80
Feb	0.79	0.85
Mar	0.81	0.83
Apr	0.80	1.00
May	0.82	1.00
Jun	0.84	0.84
Jul	0.79	0.79
Aug	0.76	0.68
Sep	0.76	0.77
Oct	0.80	0.62
Nov	0.81	0.73
Dec	0.82	0.61

SUMMARY AND CONCLUSIONS

Total water use billing records as well as observed irrigation records for a maximum of 1,781 homes in Orlando, Florida, were available and analyzed to estimate irrigation. The maximum average monthly total water use was 86.6 m^3 $month^{-1}$ for the month of May, while the minimum value was observed in July, at 59.2 m^3 $month^{-1}$. The average observed irrigation ranged from 35.7 to 60.8 m^3 $month^{-1}$ in July and May, respectively. The average observed indoor water use ranged from 22.0 to 27.1 m^3 $month^{-1}$, in February and August, respectively. The observed irrigation accounted for 64% of the total water use.

Additionally, two methods to estimate indoor water use were tested. The minimum month method over-estimated indoor use by 140%, while the per capita method underestimated indoor use by 34% with corresponding

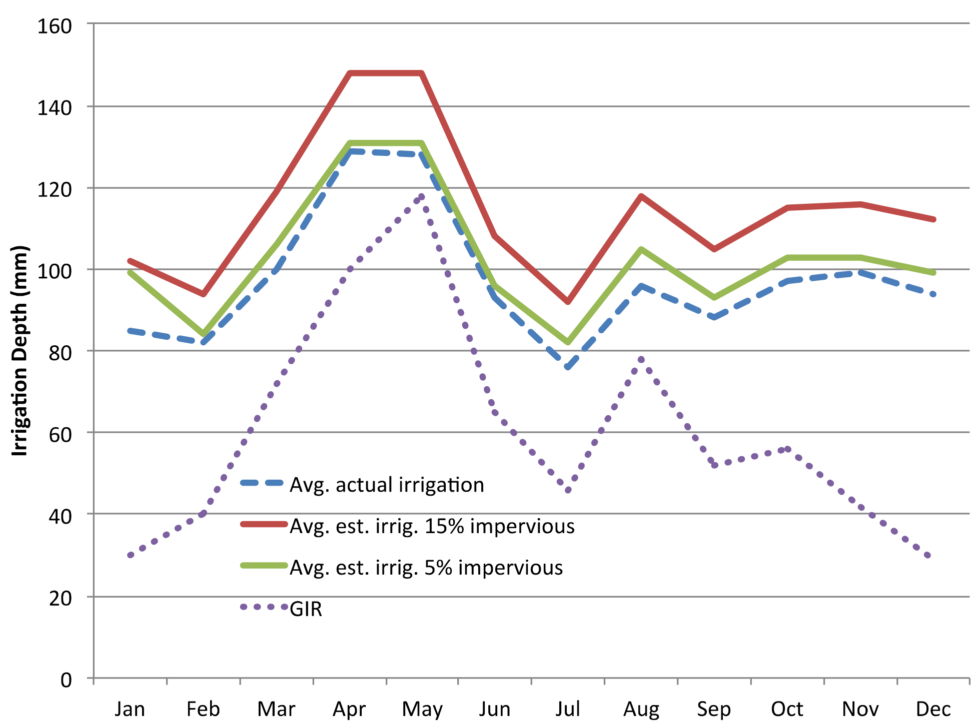

Figure 1. Comparison of observed irrigation (January 2006 through June 2009), gross irrigation requirement (GIR), and estimated irrigation (by using two different impervious area values).

irrigation underestimation of 80% and overestimation of 17% when used to estimate irrigation from total meter data. We concluded that the per capita method is the most reliable method to estimate indoor water use for central Florida conditions. The range of impervious areas tested in this study (5% to 15%) showed percent error ranging from 5% to 19%, respectively; showing that impervious surfaces covering green areas is minimal in this area of central Florida. The monthly theoretical irrigation requirements were much lower than the observed irrigation, demonstrating over-irrigation particularly in the winter months with excess irrigation as much as 300% of requirements. In addition, a methodology to estimate irrigation from billing records (Romero and Dukes, 2014) was calibrated and validated. The validation demonstrated that around 60% to 99% of the variability of the observed data can be reproduced by this proposed method for this specific location.

The approach of this study maintains a very limited area of potential application (central Florida) so, similar studies in other areas outside central Florida should be carried out to provide a greater applicable geographic area for this methodology.

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