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Evaluating the effectiveness of water restrictions: A case study from Southeast Florida

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ABSTRACT

One of the most commonly employed water conservation strategies is to restrict lawn watering to limited times on specified days. Water managers typically assume that limiting the frequency and duration of lawn watering will reduce water use. Consequently, the effectiveness of water restrictions is often evaluated based on observed compliance to the specified schedule, whether or not actual reductions in water use are achieved. This assessment approach is more practical than quantifying the reduction in water use brought about by restrictions because quantification of lawn water use is hampered by difficulties in disaggregating the various components of residential water use. Dual meters to separately meter the portion of public supply devoted to lawn water use are rare, and for households that withdraw water from private wells, canals, or ponds for lawn watering, there is no record of such water use at all. As a consequence of this gap in water use data, compliance to a prescribed frequency of watering is often equated with effectiveness. In this paper we develop an alternative metric for evaluating the effectiveness of water restrictions and present a case study in a suburban area in Southeast Florida that illustrates some of the challenges of quantifying lawn water use and explores some of the limitations of day of the week water restrictions as a conservation strategy.

1. Introduction

Many utilities and water management agencies have implemented programs to combat water shortages caused by rising demand and/or drought (Jorgensen et al., 2009; Willis et al., 2011). While water restrictions are one of the most common conservation strategies, they are also the least studied. Extensive research exists on the effectiveness of strategies that employ price incentives to curb residential water demand (Dalhuisen et al., 2003; Tsai et al., 2011). Less, but some, research has been conducted to investigate the effectiveness of non-price conservation strategies, such as the use of irrigation control systems, soil moisture sensors, rainwater harvesting programs, and irrigation audit programs (Haley et al., 2007; McCue et al., 2007; Tsai et al., 2011). Public perceptions of and response to water restrictions have also been investigated (Buth, 2008; Jorgensen et al., 2009; Pumphrey et al., 2008; Randolph and Troy, 2008).

Relatively few studies have quantitatively evaluated the effectiveness of water restriction programs, and the approach typically used in such studies is to compare water utility records prior to and during periods of water restrictions to estimate reductions in water use (Kenney et al., 2004; SJWMD, 2011). This approach is sound in areas where the majority of households use the public supply (PS) for lawn watering. However, in parts of the U.S., it is common for homeowners to install a private irrigation well or draw water from a nearby canal or pond to supply lawn water. In such circumstances there is almost never a record of metered use from these self-supply (SS) sources. Furthermore, because permits are seldom required to install private residential irrigation wells or connect sprinkler systems to surface water sources, there is often no record of how many households water their lawns with SS water.

In this paper we present a conservation effectiveness ratio (CER). This metric allows for a quantitative evaluation of the effectiveness of water restrictions based on a water use target rather than on compliance to a prescribed watering schedule. We demonstrate the use of the CER to evaluate the effectiveness of water restrictions in an area of Southeast Florida where a significant number of homeowners use SS for lawn watering. To the authors' knowledge, this paper is the first to evaluate the effectiveness of water restrictions in the context of quantifiable water use targets rather than reductions in use and the first presentation of a lawn water use case study in Southeast Florida.

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2. A metric for evaluating the effectiveness of water restrictions

2.1. Conservation Effectiveness Ratio (CER)

Ratios that compare a measured or estimated parameter to a target value are used ubiquitously as evaluation metrics because they are simple to calculate and easy to understand. Therefore, to quantitatively evaluate the effectiveness of water restrictions we developed a Conservation Effectiveness Ratio (CER) (Equation (1)).

$$\text{CER} = \frac{T}{U} \tag{1}$$

Where,

T = target use
U = actual use

Equation (1) is the most general form of the CER. The mathematical definitions of T and U can be scaled according to the scope of the water conservation program. For example, the CER is suitable for monitoring progress toward target use in regional conservation initiatives, municipal water supply plans, and community lawn water restriction programs (Dziegielewski and Kiefer, 2010).

The closer the CER is to 1, the closer actual use is to target use. In circumstances where water restrictions have not effectively brought about the desired water use target, the CER will be less than 1 and will become progressively smaller as the gap between actual and target use widens. A CER greater than 1 indicates that actual water use was less than the target use.

2.2. Tailoring the CER to compare lawn water use to lawn water demand

2.2.1. Defining the target use

A reasonable goal of water restrictions would be to limit weekly lawn water use to that needed to supplement rainfall to meet the water demand of the lawn. In which case, target use would simply be the difference between rainfall and lawn water demand. Turf grass water demand is approximately equal to potential evapotranspiration (ET_p). Therefore, lawn water demand can readily be estimated from published ET_p rates (Haman et al., 2005). Because a single intense rainfall can obscure dry periods when soil moisture storage is not adequate to maintain a healthy lawn, we calculate the CER on a weekly basis rather than using long-term cumulative data and define both a weekly (T_w) and cumulative weekly target use (T_{cw}) as shown in Equations (2) and (3). Note that in circumstances where weekly rainfall (R_w) exceeds weekly evapotranspiration (ET_{pw}), the target use is zero.

$$T_w = \text{weekly target use} = ET_{pw} - R_w \tag{2}$$

If $ET_{pw} - R_w < 0,\ T_w = 0$.

$$T_{cw} = \text{cumulative weekly target use} = \sum_{\text{week 1}}^{\text{week } n} T_w \tag{3}$$

Where,

ET_{pw} = weekly potential evapotranspiration (cm)
R_w = weekly rainfall (cm)

The above definition of weekly target use (T_w) assumes that 100% of irrigation water reaches the lawn and thus ignores sprinkler evaporation loss and wind drift loss. In circumstances where evaporation and wind drift loss are expected to be significant, a correction factor could easily be incorporated into Equation (3). Because rainfall and ET_p data are typically reported as depths of water, we define all the components of the CER in terms of depth. However, the equations could easily be converted to volumes.

2.2.2. Estimating use

Because lawn water use is rarely metered, it must be estimated using techniques appropriate for the specific circumstance. In areas where lawns are watered using PS, it is often estimated as a “rule of thumb” percentage of total metered water use. In regions where lawn watering is seasonal, it is commonly estimated as the difference between total metered use during the growing season and total metered use during the dormant season. In areas where SS sources, such as private irrigation wells, are used for lawn watering and/or in climates where year-round lawn watering is typical, irrigation system output can be determined with meters or timed capture measurements from a random sampling of residences and total lawn water use estimated from statistics derived from the random sampling (NAP, 2002). As described below, we used a modified version of this approach for estimating weekly use (U_w) and cumulative weekly use (U_{cw}) in our case study. Table 1 summarizes the significance of different CER values when calculated as T_{cw}/U_{cw}.

3. Case study – applying the CER in suburban Southeast Florida

3.1. Study area

The study area for this project was comprised of two neighborhoods totaling 165 households in the Village of Wellington in

Table 1
Explanation of the values of the CER when calculated as T_{cw}/U_{cw}.

CER	Description	Rating
>0–0.34	Actual lawn irrigation was at least 3 times more than required to meet the net lawn water demand considering ET_p and rainfall	Highly ineffective
0.35–0.67	Actual lawn irrigation was 1.5–3 times more than required to meet the net lawn water demand considering ET_p and rainfall	Ineffective
0.68–1.00	Actual lawn irrigation was close to the amount required to meet the net lawn water demand considering ET_p and rainfall	Effective

Other circumstances

CER	Description
≤0	Precipitation alone met lawn water demand. All lawn irrigation was unnecessary. CER does not indicate how much excess water was applied to lawns.
>1.00	Actual lawn irrigation was less than the amount required to meet the net lawn water demand. While this might be desirable from a water conservation perspective, some lawn damage is likely to occur due to under watering.

suburban Southeast Florida (Fig. 1). Through interviews and inspections we determined that 100 households sourced water from SS and 65 households purchased water from PS for lawn irrigation. All lawn cover was St. Augustinegrass (*Stenotaphrum secundatum*), a warm season turf grass species common in Florida, and all lawns were watered using automatic in-ground irrigation systems. Recent droughts have prompted Florida's water management agencies to impose mandatory restrictions on lawn irrigation. During this 2009 study, odd numbered addresses were restricted to lawn watering on Wednesdays and Saturdays before 10 am or after 4 pm, and even numbered addresses were restricted to lawn watering during the same time periods on Thursdays and Sundays. Water restrictions were enforced by code enforcement officers who would make periodic drives through random neighborhoods. Residents found to be irrigating outside of the prescribed times were issued warnings and or fines that ranged from $83 to $258.

3.2. Methods

3.2.1. Determining target use

We estimated weekly lawn water demand using published ET_p rates for South Florida (Haman et al., 2005). To estimate weekly rainfall, two manual rain gauges were installed in the study area. The amount of rain in each gauge was recorded daily at 7:00 am. The average of the two measurements was taken to be the rainfall from the preceding day. The weekly target use (T_w) and cumulative weekly target use (T_{cw}) were calculated as shown in Equations (2) and (3) above.

3.2.2. Estimating lawn water use

Direct observations of lawn irrigation enabled us to consider variations in watering frequency and thus estimate lawn water use for each of the 165 households for every week of the study (U_w) (Equation (4)).

$$U_w = N_w \times Q_e / A_L \times 100\,\mathrm{cm}/\mathrm{m} \tag{4}$$

Where,

U_w = weekly lawn irrigation for each household (cm)
N_w = weighted number of irrigation events per week from Equation (5) below
Q_e = weighted mean output per irrigation event (m^3) from Equation (7) below
A_L = area of lawn (m^2) from digital analysis of aerial photos

The weighted number of lawn irrigation events per week (N_w) was determined through observation rounds to look for signs of watering on each of the 165 study area parcels. These observation rounds were conducted daily during the sixteen week study period from July 12, 2009 through October 30th, 2009. Through a series of test inspections, it was determined that at 7:30 am there was enough sunlight to perform a visual inspection and impervious surfaces were still wet from overnight watering. The following criteria were considered positive indicators of recent lawn watering: 1) distinctive wet areas on surfaces, such as sidewalks, driveways, and streets, and 2) sprinklers currently on. Although there were undoubtedly instances of both over and under accounting, we felt that this method was the best way to directly estimate lawn watering frequency over an extended period of time. In this manner the number of observed weekly watering events (N_o) for each household was determined for every week of the study. To account for days when inspections were not possible because signs of sprinkler activity were obscured by rainfall, N_w, the number of weekly watering events weighted by the number of days during the week when observations were possible (N_p), was calculated (Equation (5)).

$$N_w = N_o \times \frac{7\ \mathrm{days}}{N_p} \tag{5}$$

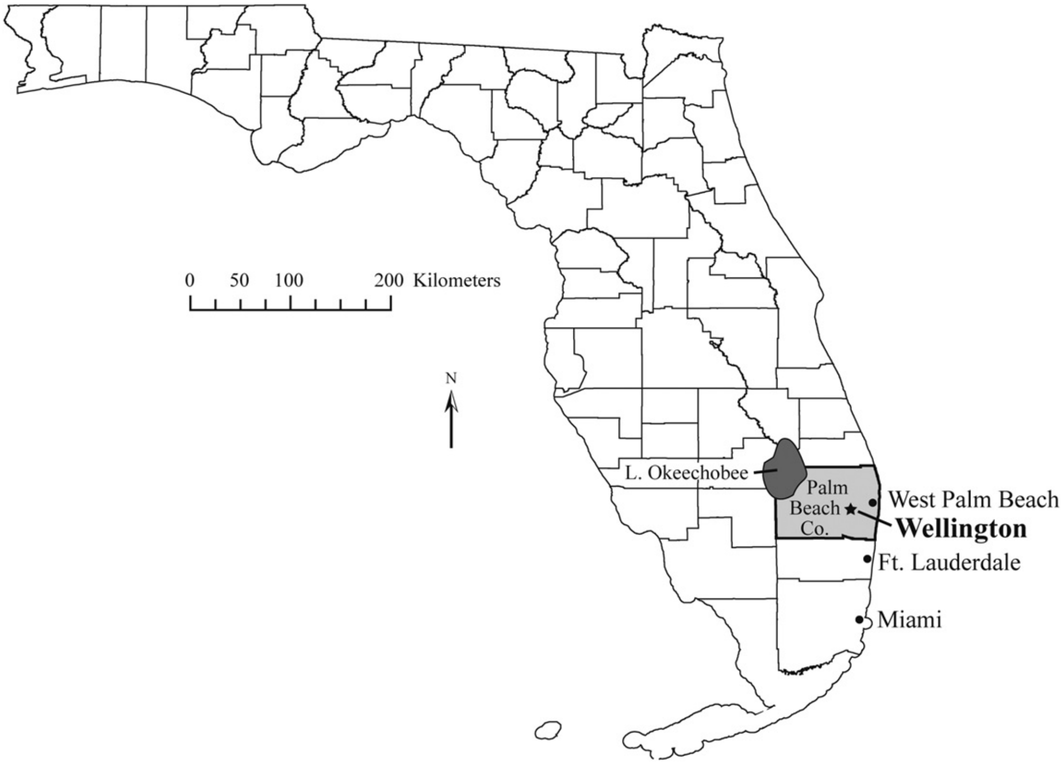

Fig. 1. Map of Florida showing the study area in the Village of Wellington and nearby cities.

Where,

N_w = number of watering events per week weighted by the number of observation days
N_o = number of observed watering events per week
N_p = number of days during the week when observations were possible

The weighted mean output per watering event (Q_e) was determined through timed capture irrigation audits. Because of the price elasticity of water demand, it cannot be assumed that the water use per watering event is similar for PS and SS households, who are not billed for their lawn water use. Therefore, to reduce the error in our water use estimates we treated PS and SS households as separate groups. Thirty six potential irrigation audit subjects were selected by means of random stratified sampling that identified an equal number from the PS and SS groups. Ultimately twelve PS and sixteen SS households participated in the audits during which the output of every sprinkler head (Q_h) was determined by a timed capture measurements. The total output per watering event (Q_{te}) was then calculated for each irrigation audit household by summing the Q_h's for each zone and multiplying by the run time (Equation (6)), which was determined by inspecting the automatic timer systems. Finally, we determined the weighted mean output per household per watering event (Q_e) (Equation (7)) and its standard error (Equation (8)). In estimating weekly lawn water use as shown in Equation (4) above, we assumed that the weighted mean output per lawn watering event was constant throughout the study period.

$$Q_{te} = \sum_{1}^{n} Q_h(\text{zone }1) \times t(\text{zone }1) + \sum_{1}^{n} Q_h(\text{zone }2) \times t(\text{zone }2) + \ldots + \sum_{1}^{n} Q_h(\text{zone }x) \times \text{t}(\text{zone }x) \qquad (6)$$

Where,

Q_{te} = total output per lawn watering event for each irrigation audit household (m^3)
Q_h = output rate of sprinkler head (m^3/min)
t = run time on automatic timer for each zone (min)
n = number of sprinkler heads in each zone

$$Q_e = \frac{\text{Mean PS } Q_{te} \times 65 \text{ households} + \text{Mean SS } Q_{te} \times 100 \text{ households}}{165 \text{ households}} \qquad (7)$$

Where,

Q_e = weighted mean output per household per watering event

$$\sigma = \frac{\sqrt{\left(\frac{N_{ss}^2\sigma_{ss}^2}{n_{ss}} + \frac{N_{ps}^2\sigma_{ps}^2}{n_{ps}}\right) - \left(N_{ss}\sigma_{ss}^2 + N_{ps}\sigma_{ps}^2\right)}}{165 \text{ households}} \qquad (8)$$

Where,

σ = standard error of the weighted mean output per watering event
N_{ps} and N_{ss} = number of PS and SS households in study area
n_{ps} and n_{ss} = number of PS and SS households included in stratified random sample
σ_{ps} and σ_{ss} = standard deviation of water use per watering event; taken as the standard deviation of the Q_{te}'s from the irrigation audits.

3.3. Results

3.3.1. Target use

The average weekly water demand for turf grass during the study period was 2.9 cm, whereas the average weekly rainfall was 4.9 cm (Tables 2 and 3). Rainfall was more than enough to meet lawn water demand in 8 of the 16 weeks and met at least 90% of lawn water demand in 11 of the weeks (Table 2 and Fig. 2). Thus, half of the weeks of the study period had a weekly target use (T_w) of zero. Not surprisingly the average weekly target use, 0.7 cm, was relatively small, and the cumulative weekly target use (T_{cw}) was only 10.5 cm.

3.3.2. Weekly lawn water use

While the observed watering frequency varied greatly across the 165 households during the study period, the weekly average was 1.3 events per household. Over the sixteen week study period, the estimated total number of watering events was 3510 (Table 3). The weighted mean output per watering event per household, was 18.41 m^3/event with a standard error of 0.66 m^3 or 3.6%. Thus, the average per household weekly lawn water use ranged from a low of about 8 m^3 to a high of about 37 m^3. When taken over the total lawn area within the study area and expressed as an application depth, the weekly lawn water use ranged from 0.8 cm to 3.6 cm with an overall 16 week average of 2.4 cm.

3.4. The effectiveness of the water restrictions

3.4.1. CER

In our case study, the cumulative weekly use (U_{cw}) was 38.2 cm, while the cumulative weekly target use (T_{cw}) was 10.5 cm (Table 2). Thus, the CER (T_{cw}/U_{cw}) for the 16-week study period was 0.27. This CER indicates that water restrictions were highly ineffective (Table 1) at limiting lawn water use to our assumed target use (the amount of water required to supplement rainfall in meeting the water demand of the lawn). In fact, the CER indicates that actual lawn watering was nearly four times more than that needed to meet lawn water demand.

In terms of volume, the cumulative weekly rainfall deficit over the 16-weeks (the target use) was 17,770 m^3. Our water use estimates indicate that lawn water use during our study amounted to about 64,650 m^3. Thus, even during water restrictions, 46,880 m^3 of overwatering occurred.

Table 2
Summary of lawn water need, rainfall, and lawn water use for case study.

Week	Dates	Weekly water need ([a]ET_{pw}) (cm)	Rainfall (R_w) (cm)	Water use target ($ET_{pw} - R_w$; 0 if $ET_{pw} < R_w$) (cm)	Lawn water use (cm)
1	7/11/09–7/17/09	3.4	8.8	0.0	1.8
2	7/18/09–7/24/09	3.4	8.4	0.0	2.5
3	7/25/09–7/31/09	3.4	2.4	1.0	3.0
4	8/1/09–8/7/09	3.0	2.8	0.2	2.4
5	8/8/09–8/14/09	3.0	0.0	3.0	3.2
6	8/15/09–8/21/09	3.0	5.1	0.0	3.6
7	8/22/09–8/28/09	3.0	7.6	0.0	2.5
8	8/29/09–9/4/09	3.0	9.6	0.0	2.9
9	9/5/09–9/11/09	2.8	16.3	0.0	0.8
10	9/12/09–9/18/09	2.8	4.8	0.0	2.3
11	9/19/09–9/25/09	2.8	2.5	0.4	1.7
12	9/26/09–10/2/09	2.8	5.7	0.0	2.1
13	10/3/09–10/9/09	2.5	0.5	2.0	1.6
14	10/10/09–10/16/09	2.5	0.0	2.5	2.6
15	10/17/09–10/23/09	2.5	2.3	0.2	2.4
16	10/24/09–10/30/09	2.5	1.2	1.3	2.8
		Avg: 2.9	**Avg: 4.9**	**Avg: 0.7**	**Avg: 2.4**
		Cum: 46.6	**Cum: 78.1**	**Cum (T_{cw}): 10.5**	**Cum (U_{cw}): 38.2**

[a] Monthly ET_p rates for South Florida (Haman et al., 2005) were converted to weekly rates. For weeks 8 and 12, the monthly ET_p rate for September was used.

4. Discussion

4.1. Advantages and limitations of the CER

As a dimensionless ratio, the CER provides a conceptually simple means of evaluating water conservation programs and comparing the success of different conservation programs, which might have varying magnitudes of water use and report water use data in different units. Because target use can be defined on a case-to-case basis, the CER is a flexible tool for evaluating a wide variety of outdoor water conservation programs, not only water restrictions. In fact, the CER could be applied to assess individual conservation strategies or to programs that combine a variety of strategies – for example, price incentives and water restrictions. Additionally, the CER can be used to evaluate the success of water conservation programs over any time period ranging from weeks to years. Whereas traditional studies that compare water utility records from prior to and during periods of water restrictions to estimate reductions in water use, the CER does not require any water use data from a time prior to implementation of the conservation program.

Obtaining accurate estimates of water use is perhaps one of the biggest obstacles in implementing use-based water conservation programs. In circumstances where lawn water use is directly metered or where it can be estimated from water utility records, it should be relatively straightforward to incorporate evaluation tools such as the CER into water conservation programs. However, such water use estimates often are of limited accuracy which will in turn affect the accuracy of the CER. As an example, the case study presented here illustrates the difficulties of estimating lawn water use in an area where private irrigation wells are common.

4.2. Limitations of programs that target lawn water frequency

Although it is relatively easy to observe compliance to a specified day of the week watering schedule, compliance data alone provide no information about how much lawn water is used. In this case study the de facto target established by the two day per week water restrictions was 5280 watering events (2 days per week × 16 weeks × 165 households), and we estimated from daily observations that the actual number of watering events was 3510. Thus, the actual number of watering events was about 44% less than the sanctioned frequency target. In other words, households averaged only 1.3 lawn watering events per week. This compliance-based evaluation alone would indicate that the restrictions were quite successful by limiting lawn watering frequency, yet it obscures the

Table 3
Summary of case study results.

Households	Number	Average lawn area (m^2)	Weighted mean output per watering event per household (m^3)
PS:	65	975	18.41 ($\sigma = 0.66$)
SS:	100		

Watering frequency	Average # of watering events per household per week	Estimated total # of watering events over 16 weeks:
	1.3	3510

Water need and water use	Average weekly depth (cm)	Cumulative weekly depth (cm)
Rainfall (R):	4.9	78.1
Lawn water demand (ET_p):	2.9	46.6
Target use (T):	0.7	10.5
Irrigation water used (U):	2.4	38.2
16-week Conservation Effectiveness Ratio (CER) = 0.27		
Rating: Very ineffective		

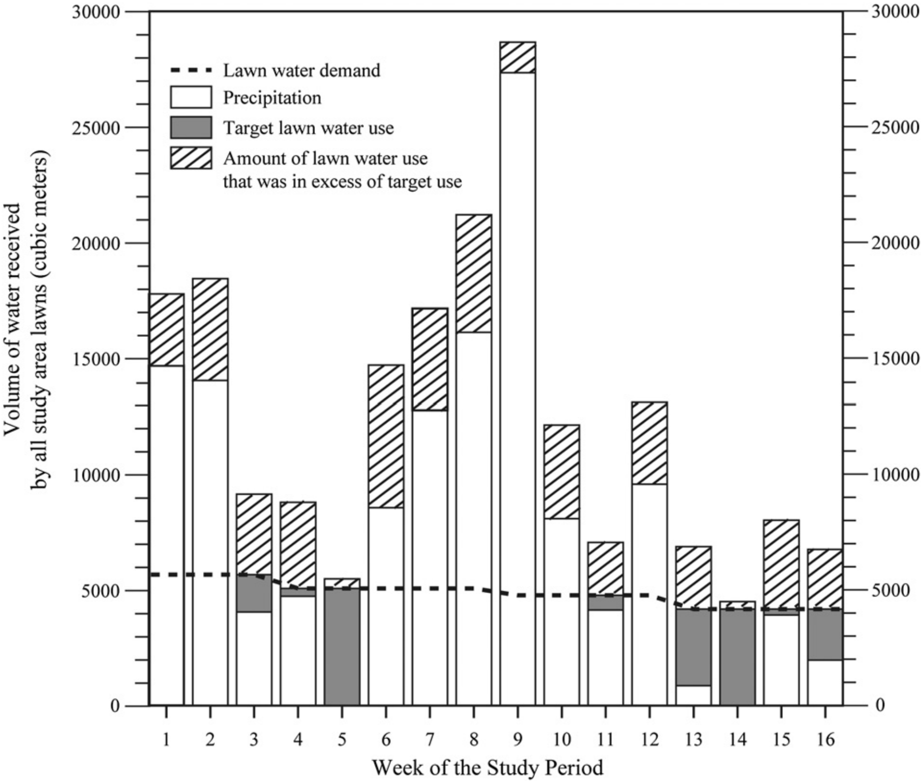

Fig. 2. Weekly volume of water received by all study area lawns.

substantial overwatering that took place even while people were being more conservative than water restrictions allowed. Furthermore, without any frequency data from a time period before the restrictions were in place, it is not possible to determine if this "success" is directly related to the restrictions.

Another limitation of water restriction schedules is that they do not take temporal changes in weather or lawn water demand into account and are not effective at limiting watering during periods when rainfall meets or exceeds the lawn water demand. Indeed, the majority the lawn irrigation observed in this study resulted in overwatering during wet periods (Fig. 2). Although most water restriction programs encourage or require homeowners to refrain from watering when it is raining, this aspect of conservation often gets lost in the logistical details of communicating the watering schedule.

5. Conclusions

Traditional day of the week water restrictions are an appealing strategy because they substitute compliance data, which are readily observable, for scarce water use data. However, such programs provide no direct indication of the amount of water use that actually occurs, whether water savings is achieved, or whether overwatering is occurring. We developed the CER as an alternative metric to evaluate the effectiveness of a water restriction program in a Southeast Florida suburban case study. The CER, which is based on water use rather than on watering frequency, showed that substantial overwatering occurred during a period of water restrictions. This result emphasizes that, for frequency based water conservation programs, compliance cannot necessarily be equated with effectiveness. This study underscores the pressing need for research and pilot programs to develop policies and water conservation strategies that are tied to quantifiable water use targets and facilitate more comprehensive accounting of lawn water use, especially from SS sources such as private irrigation wells.

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References

Buth, R., 2008. Criminological approaches to residential water-restrictions: a 'sensitising perspective'. Social Alternatives 27 (3), 40–43.

Dalhuisen, J.M., Florax, R.J.G.M., de Grott, H.L.F., Nijkamp, P., 2003. Price and income elasticities of residential water demand: a meta-analysis. Land Economics 79 (2), 292–308.

Dziegielewski, B., Kiefer, J.C., 2010. Appropriate design and evaluation of water use and conservation metrics and benchmarks. American Water Works Association Journal 102 (6), 66–80.

Haley, M.B., Dukes, M.D., Miller, G.L., 2007. Residential irrigation water use in central Florida. Journal of Irrigation and Drainage Engineering 133 (5), 427–435.

Haman, D.Z., Clark, G.A., Smajstrla, A.G., 2005. Irrigation of Lawns and Gardens. University of Florida Institute of Food and Agricultural Sciences Circular 825.

Jorgensen, B., Graymore, M., O'Toole, K., 2009. Housewater water use behavior: an integrated model. Journal of Environmental Management 91 (1), 227–236.

Kenney, D.S., Klein, R.A., Clark, M.P., 2004. Use and effectiveness of municipal water restrictions during drought in Colorado. Journal of the American Water Resources Association 40 (1), 77–87.

McCue, T., Murin, J., Meinert, D., 2007. Quantifying potable water savings derived from a residential irrigation audit program in Seminole County. Florida Water Resources Journal, 52–54. 08/2007.

NAP, 2002. Estimating Water Use in the United States: a New Paradigm for the National Water-Use Information Program. National Academies Press.

Pumphrey, G.P., Edwards, J.A., Becker, K.G., 2008. Urban and rural attitudes toward municipal water controls: a study of a semi-arid region with limited water supplies. Ecological Economics 65 (1), 1–12.

Randolph, B., Troy, P., 2008. Attitudes to conservation and water consumption. Environmental Science and Policy 11 (5), 441–455.

SJWMD, 2011. Water Conservation Potential for the District Water Supply Plan 2010. St. Johns Water Management District.

Tsai, Y., Cohen, S., Vogel, R.M., 2011. The impacts of water conservation strategies on water use: four case studies. Journal of the American Water Resources Association 47 (4), 687–701.

Willis, R.M., Stewart, R.A., Panuwatwanich, K., Williams, P.R., Hollingsworth, A.L., 2011. Quantifying the influence of environmental and water conservation attitudes on household end use water consumption. Journal of Environmental Management 92 (8), 1996–2009.