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HOW MUCH WATER IS 'ENOUGH'? USING PET TO DEVELOP WATER BUDGETS FOR RESIDENTIAL LANDSCAPES

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ABSTRACT

Conserving and reducing the amount of water used for landscape irrigation continues to be a major issue for municipalities throughout Texas and the nation. Landscape irrigation increases dramatically during summer months and contributes substantially to peak demand placed on municipal water supplies. A survey of monthly water use during 2000 through 2002 for 800 residences of similar size and appraised value in College Station, Texas indicated that average peak water consumption increased as much as 3.3 fold during the summer compared to the non-peak months of December, January, and February. Although conservation education programs typically suggest ways to reduce indoor and outdoor water use, information that can provide homeowners with a realistic estimate of the amount of water required to sustain their landscape at an acceptable quality is lacking.

Potential evapotranspiration (PET) modified by the appropriate crop coefficient is commonly used to increase irrigation efficiency for crops and turf. However, very limited information exists about landscape coefficients (Lc) for use in PET based irrigation of landscapes with multiple plant species. Recent studies at Texas A&M University indicated that 0.70 appears to be a good estimate of Lc to use in PET based landscape irrigation during the summer months.

Based on Lc, landscape size, and PET, water budgets were derived for 800 residential landscapes to predict monthly residential water consumption and then compared with actual monthly water used. These comparisons demonstrated seasonal water use patterns as well as the potential for very large reductions in landscape water use. In 2000, 2001, and 2002, an average of 347, 410, and 476 households, repectively, applied irrigation water in excess of PET. Had these households applied landscape irrigation during May through October at 100% of PET, which is equivalent to an Lc of 1.0, total predicted annual water savings for these households would have been 74, 104, and 85 acre feet in 2000, 2001, and 2002, respectively. Had irrigation been applied using an Lc of 0.7, the estimated savings would have totaled 92, 111, and 100 acre-feet during the same period.

These data demonstrate the substantial potential that exists to conserve water used for landscape irrigation by using PET, Lc, and landscape size to derive realistic water budgets. If adopted and applied by homeowners, such budgets could result in very large reductions in landscape water use. Historically, tools available to help water utilities curb outdoor water use in high demand periods have included limitations on customers' watering days and times and general recommendations on how much water a landscape needs. Using PET combined with Lc has the potential to provide realistic water budgets for residential landscapes and greatly reduce landscape water use. Quantitative data showing the amount of water that landscapes need, compared to how much water is typically applied to landscapes, will help utilities target their conservation efforts for maximum results.

KEYWORDS

Landscape irrigation, water conservation, potential evapotranspiration, water use, crop irrigation coefficients, landscape irrigation coefficient

INTRODUCTION

Effective conservation programs are essential for preservation of our greatest natural resource – water. Landscape ordinances and water conservation programs in Texas and throughout the United States promote the use of drought resistant, water conserving trees, shrubs, and groundcovers in urban landscapes. Yet, irrigation management may not be altered substantially with changes in landscape design type and therefore altering landscape design or plant species without concomitant changes in irrigation management may not result in reduced landscape water use. Poor landscape irrigation system design, maintenance, and operation, particularly for in-ground automatic systems, continue to be major impediments to water conservation. Inefficient landscape irrigation system operation is the most formidable cause of excess outdoor water use.

During summer months, outdoor water use may account for 40 to 60% of residential water consumption. Much of this outdoor water use is associated with landscape irrigation. Although one inch a week is an often recommended amount of irrigation water to apply to lawns and landscapes, little science based information is available to allow an estimation of landscape irrigation water requirement. Almost no information exists in the literature on actual evapotranspiration (ETa) from landscapes with multiple plant species. A knowledge of landscape ETa and the relationship of ETa to potential evapotranspiration (PET) would allow an estimate of a crop coefficient (Kc) or in the case of landscapes, a landscape coefficient (Lc) that could be used in conjunction with landscape size and PET to calculate a landscape water budget. Landscape water budgets would be invaluable information for homeowners that desire to irrigate landscapes more efficiently and would assist utilities in the delivery of water conservation programs to achieve maximum results.

The objectives of our research were to determine 1) the relationship between ETa and PET for a multiple plant species landscape, 2) use this relationship to calculate a landscape coefficient (Lc) for use in the development of residential water budgets, and 3) compare actual residential water use to residential water budgets for municipal water consumers for three years.

METHODOLOGY

In November 2002, 192 volumetric soil moisture sensors (ECHO Soil Moisture Probes; Decagon Devices, Logan Utah) were installed in 64 locations at 3 different depths in a 9041 ft^2 landscape comprised of multiple plant species at the Texas A&M University Research and Extension Center in Weslaco, Texas. The installation depths were 0 to 8, 8 to 16, and 16 to 24 inches. The soil type at the site was a Willacy fine sandy loam and the vegetation types evaluated included a mature walnut tree (*Juglans microcarpa*), crape myrtles (*Lagerstroemia indica*), St. Augustinegrass (*Stenotaphrum secundatum*), dwarf yaupon (*Ilex vomitoria nana*), ficus (*Ficus benjamina*), and rose (*Rosa sp.*).

The landscape was maintained by staff members at the site. The fertilization program was based on soil nutrient analyses. The turf was mowed weekly at about 3 inches, and the trees and shrubs were pruned as needed. Supplemental irrigation was applied based on visual assessments of the site. As plants began to wilt, along with leaf-rolling of the turf, irrigation water was applied. The landscape had an in-ground sprinkler irrigation system plus a drip irrigation line for the roses. Both systems were equipped with totalizing water meters.

Data were collected from soil moisture sensors at 30-minute intervals and downloaded daily from the datalogger (CR10; Campbell Scientific Instruments; Logan, Utah). Soil water content (inches) was measured at 0 hr of each day and daily soil moisture loss (inches) was calculated as the difference in volumetric water content at 0 hr of successive days. Actual evapotranspiration (ETa) was determined by adding soil water loss from each of the three depths, while potential evapotranspiration (PET) was estimated by the Penman-Monteith equation and meterological data from a Texas ET Network (http://texaset.tamu.edu) weather station within 150 feet of the site . Landscape coefficients (Lc) were estimated from the daily average ratios of ETa:PET and from using the slope of the linear regression of ETa with PET for all days.

Actual monthly water use, lot size, and heated area for about 979 homes in three different subdivisions were obtained from College Station Water Utilities in College Station, Texas. Data for January through December for each of 2000, 2001, and 2002 were obtained and used in the analysis. Landscape size was estimated by:

Landscape area= lot size - (1.5 x heated area)

The heated area was multiplied by 1.5 as an estimate of hard scape (drive, sidewalks, patios, garages, etc.) plus heated area for each residence. This estimate of landscape area in square feet was used to develop a water budget for each residence. Landscapes less than 1,200 and greater than 9,500 ft^2 were excluded from the data set. Also, residences that used less than 1,000 gallons per month in any month were excluded.

Water budgets for each residence were developed from estimates of landscape area, specific Lc values, and PET and precipitation data from a Texas ET Network weather station located at the Texas A&M University Golf Course in College Station, Texas. Monthly precipitation was subtracted from PET in the development of water budgets. During months with precipitation greater than PET, PET was set to zero. Indoor water use was estimated by averaging the gallons of water consumed during December, January, and February for all homes and years. The average monthly water use during December, January, and February was about 7,000 gallons. The monthly water budget for an Lc of 1.0 for each residence was estimated by:

$$\text{MWB} = 7{,}000\text{ g} + \left(\text{LA ft}^2 \times \left((\text{PET - precipitation}) \times \left(\frac{27{,}154\text{ g}}{43{,}560\text{ ft}^2} \right) \right) \right)$$

where MWB is the monthly water budget (or predicted water use) in gallons, 7,000 is the base indoor use in gallons, LA is landscape area in square feet, PET is potential evapotranspiration in inches, precipitation is in inches, 43,560 is the square feet per acre, and 27,154 g is the gallons of water that covers an acre one inch deep. Monthly water budgets (or predicted water use) so derived were then compared with actual monthly water use for each residence.

RESULTS

Knowledge of actual water lost via evapotranspiration (ETa) from landscapes is required to develop realistic residential water budgets or to predict water consumption from month to month. We measured ETa in a multiple plant species landscape and, by using PET as a reference, determined a landscape coefficient that can be used in PET based irrigation programs. Landscape irrigation coefficients (Lc) were estimated from linear regression analysis and compared to coefficients calculated from mean daily ratios of ETa:PET for the period of February to September 2003. The two methods produced similar Lc values for most individual plant species as well as the whole landscape. Our data indicated that Lc of 0.65 from daily ratios of ETa:PET or 0.69 from the slope of the linear regression of ETa with PET ($r^2=0.62$; ($P < 0.001$) could be used without jeopardizing landscape quality. Two Lc values were used in the computation of residential water budgets: Lc=1.0, which would replace 100% of PET and Lc=0.7, which would replace 100% of ETa based on measurements of actual water loss from a multiple plant species landscape. The water budget estimates were then compared with actual monthly residential water consumption for single-family homes.

Mean water use across all years for all homes ranged from 7,000 gallons per month from December through February to about 25,000 gallons per month in August as shown in Figure 1. Water consumption during the peak use months of May through October increased from about 2 to 3.3 fold that of non-peak use months of December through February. The increased use during May through October is assumed to be due to increases in outdoor water use and that the majority of outdoor water use during this period was for landscape irrigation. These data are consistent with other reports that landscape irrigation accounts for 25 to 60% of municipal water consumed during the summer.

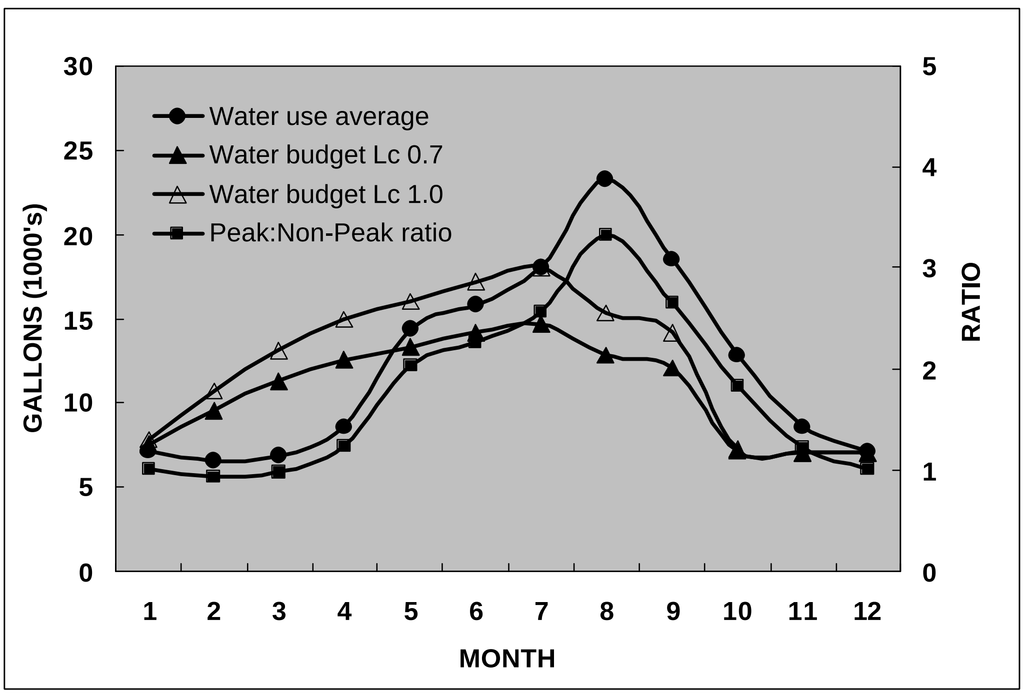

Figure 1. Average monthly water use, peak to non-peak ratio, and water budget amounts estimated using landscape coefficients (Lc) of 1.0 and 0.7 for single family residential homes in College Station, Texas during 2000 through 2002.

One of our major objectives was to compare actual residential water use to residential water budgets or predicted water consumption for municipal water consumers. Although water consumption is known to increase during the summer, no prior information was available to determine whether the increased use was appropriate to meet landscape water requirements. Water budgets and actual consumption were compared for all landscapes by month within years. As shown in Figure 1, average water used during January through February was below budget amounts estimated with an Lc of 1.0 or 0.7. Landscape plant growth and therefore water required during this period would be minimal in College Station, Texas and the landscape water budget could actually be set to near zero gallons for November through April in most years. Average water use was less than or equal to the water budget estimated with an Lc of 1.0 in May, June, and July. Average water use, however, exceeded the Lc 1.0 water budget estimate during August through November. When a more conservative water budget was estimated using an Lc of 0.7, as determined from the relationship of measured multiple species landscape ETa and PET, average actual use exceeded the Lc 0.7 water budget during May through November.

Although average actual water use during several months was in close agreement with average Lc 1.0 and Lc 0.7 water budgets, a substantial range in municipal water consumption was observed for single family homes in this study, as shown in Table 1.

Table 1. Mean, minimum, and maximum actual water use, landscape area, and estimate of mean and maximum depth of irrigation water applied by month across three years.

Month	Actual water use			Mean landscape area	Mean[1] irrigation applied	Maximum[1] irrigation applied
	Mean	Minimum	Maximum			
	gal./home	gal./home	gal./home	ft^2	in./home	in./home.
January	7,117	1,000	62,000	4,887	0	18
February	6,520	1,000	62,000	4,816	0	18
March	6,841	1,000	46,000	4,820	0	13
April	8,631	1,000	65,000	4,898	1	19
May	14,344	1,000	99,000	4,803	2	31
June	15,856	1,000	87,000	4,876	3	26
July	18,037	1,000	134,000	4,880	4	42
August	25,253	1,000	128,000	4,876	6	40
September	18,514	1,000	149,000	4,872	4	47
October	12,875	1,000	103,000	4,881	2	32
November	8,572	1,000	88,000	4,871	1	27
December	7,135	1,000	80,000	4,870	0	24
Total	149,695	-	-	-	22	336

[1]Mean and maximum irrigation applied was estimated from mean and maximum gallons, respectively, mean landscape area, and a value of 27,154 gallons per acre-inch after subtracting 7,000 gallons per month for indoor consumption.

Based on estimates of mean and maximum irrigation applied, these households applied from an average of 22 inches of irrigation water per year up to a potential maximum of 336 inches a year per landscape. These data demonstrated that some households were using well above the average of all households and that outdoor water use, most likely for landscape irrigation, was excessive for these households.

The average water use, as shown in Figure 1 and Table 1, likely included households that had in-ground automatic irrigation systems, used a hose and sprinkler for irrigation, or did not irrigate their landscape at all. Thus, the average water use does not identify the number of households that used an excessive amount of water for landscape irrigation and that need to improve the efficiency of irrigation system operation. A subset of homes representing households that consumed water in excess of a water budget estimated from landscape size, PET, and an Lc of 1.0 for each household is shown in Table 2.

Table 2. Potential water savings for residential municipal water consumers estimated from potential evapotranspiration, landscape irrigation coefficient, and landscape size for homes selected as those using in excess of their water budget calculated using and Lc of 1.0.

Year and month	Number[1] of homes	Average actual use	Average[2] water budget		Average potential savings		Total[3] potential savings	
			Lc 1.0	Lc 0.70	Lc 1.0	Lc 0.70	Lc 1.0	Lc 0.70
2000		gal/home	gal/home	gal/home	gal/home	gal/home	acre-feet	acre-feet
May	483	14,785	7,000	7,000	7,785	7,785	12	12
June	155	25,329	17,352	14,247	7,977	11,083	4	5
July	180	38,006	29,118	22,482	8,888	15,523	5	9
August	305	37,892	25,954	20,268	11,938	17,624	11	16
September	475	30,678	17,799	14,560	12,879	16,118	19	23
October	484	16,703	7,718	7,502	8,985	9,200	13	14
Mean	347	27,232	17,490	14,343	9,742	12,889	11	13
Yearly total							75	92
2001								
May	84	25,393	19,011	15,408	6,382	9,985	2	3
June	141	27,844	21,320	17,024	6,524	10,820	3	5
July	284	29,694	20,339	16,337	9,355	13,356	8	12
August	724	26,272	7,000	7,000	19,272	19,272	43	43
September	668	16,238	7,000	7,000	9,238	9,238	19	19
October	559	15,610	7,000	7,000	8,610	8,610	15	15
Mean	410	23,508	13,612	11,628	9,897	11,880	15	16
Yearly total							105	113
2002								
May	254	26,272	19,256	15,579	7,016	10,693	5	8
June	527	23,450	13,638	11,647	9,812	11,803	16	19
July	625	15,450	7,000	7,000	8,450	8,450	16	16
August	502	23,390	14,463	12,224	8,927	11,166	14	17
September	310	24,555	17,099	14,070	7,456	10,485	7	10
October	636	14,626	7,000	7,000	7,626	7,626	15	15
Mean	476	21,290	13,076	11,253	8,214	10,037	12	14
Yearly total							85	99

[1]Number of homes out of a total of 800 homes for each month that consumed more than their estimated water budget using an Lc of 1.0.
[2]Average water budget estimated from landscape size, PET, and an Lc of 1.0 or 0.7 for each household.
[3]Total potential savings were estimated from the average potential savings per month times the number of homes per month that used in excess of their water budget. Gallons were converted to acre-feet for presentation.

The data, as shown in Table 2, included only the peak water use months of May through October. The number of households using in excess of their water budget varied by month and year as did the average monthly potential savings and total potential savings that could have been realized had landscape irrigation been applied within their water budget using an Lc of either 1.0 or 0.7. Average potential monthly savings ranged from 7,785 to 12,879, 6,382 to 19,272, and 7,016 to 8,927 gallons in 2000, 2001, and 2002, respectively, if these households had based landscape irrigation on PET and used an Lc of 1.0. The total annual potential savings estimated by the number of homes and the average potential monthly water savings for 2000, 2001, and 2002 were 75, 105, and 85 acre-feet, respectively, as estimated by PET, landscape size, and an Lc of 1.0. Even greater potential water savings could have been realized by using a more conservative Lc of 0.7. The potential annual municipal water savings are substantial.

CONCLUSIONS

The data presented here demonstrated the substantial potential that exists to conserve water used for landscape irrigation by using PET, Lc, and landscape size to derive realistic landscape water budgets. If adopted and applied by homeowners and others, such budgets could result in very large reductions in landscape water use. Our comparison of actual water used by residential municipal water customers in College Station, Texas with landscape water budget estimates demonstrated a potential savings of 24 to 34 million gallons of water per year if all 800 customers had irrigated based on PET and an Lc of 1.0. Historically, tools available to help water utilities curb outdoor water use in high demand periods have included limitations on customers' watering days and times and general recommendations on how much water a landscape needs. Using PET combined with Lc has the potential to provide realistic water budgets for individual residential landscapes and greatly reduce landscape water use. Quantitative data showing the amount of water that landscapes need, compared to how much water is actually applied to landscapes, will help utilities target their conservation efforts for maximum results.

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