Benchmarking System Efficiency within Orange County, California

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Abstract. *Excessive outdoor water use results from system inefficiency and poor management. The average water savings potential within Orange County, CA will be benchmarked by examining a sub-sample of water use of approximately 50,000 single family residences, along with six program evaluations. Water budgets (theoretical irrigation need) have been calculated for each meter with respect to weather data. Pre/post implementation comparisons can be made by cross referencing the rebate program database. Examination of "well-maintained" systems will benchmark realistic system efficiency goals. Using predictive ellipses to forecast the water savings of timer rebate program yields a potential for 5% to 11% of total household use at 95% confidence. This analysis suggests that the potential for water savings from management is minimized when the system has greater inefficiencies, and air temperature resulted in the strongest predictive variable of irrigation trends.*

Keywords. *Residential landscape irrigation, Commercial landscape irrigation, Weather-based irrigation controllers, system efficiency*

Introduction

Irrigation is required to maintain outdoor landscapes in Orange County, California. Orange County has a Mediterranean climate: a semi-arid environment with mild winters, warm summers, and moderate rainfall. The climate is semi-arid and consistent with coastal Southern California. The general region lies in the semi-permanent high-pressure zone of the eastern Pacific. As a result, the climate is mild, tempered by cool sea breezes. The usually mild climatological pattern is interrupted infrequently by periods of extremely hot weather, winter storms, or Santa Ana winds.

IN a typical year, Orange County's average daily temperatures range from 58˚F in December and January to 74˚F in August. The average annual precipitation is 14 inches, although the region is subject to significant variations in annual precipitation. The average evapotranspiration (ET_O) is almost 50 inches per year, which is four times the annual average rainfall. This translates to a high demand for landscape irrigation for homes, commercial properties, parks, and golf courses. A region with low rainfall, like Southern California, is also more prone to droughts.

The Municipal Water District of Orange County (MWDOC) is a regional water wholesaler and resource planning agency managing all of Orange County's imported water supply with the exception of water imported to the cities of Anaheim, Fullerton, and Santa Ana. MWDOC serves more than 2.3 million residents in a 600-square-mile service area. MWDOC implements landscape water use efficiency programs that target excessive outdoor water use resulting from system inefficiency and poor management. Landscape water use efficiency is a priority in Orange County as nearly half the water supply is imported and the region is vulnerable to water shortages.

This paper involves two analyses aimed at benchmarking system efficiency and savings potential within Orange County. The first performs a meta-analysis of program evaluations for MWDOC landscape water use efficiency programs to test the hypothesis that the installation of new irrigation technology or better management of equipment would reduce the observed water consumption for participating customers. The second is an examination of the landscape water use of "well-maintained" systems to benchmark realistic system efficiency goals.

Data and Methods

Meta Analysis of Program Evaluations

Since 2001, MWDOC has been providing incentives for the installation of weather-based irrigation controllers (smart timers) at residential and commercial properties, through either standard rebates or direct installs programs, all with 100% post-installation inspections. These programs have been evaluated through six independent studies following a similar water savings analysis approach (Hunt et al. 2001; Bamezai 2001; A&N Technical 2004; A&N Technical 2006; Kennedy Jenks Consultants 2008; A&N Technical 2011).

To complete a meta-analysis of these studies, results from approximately 10,000 consumption records were compiled from the retail agency billing systems for customers in these study areas. Billing histories were obtained from meter reads between 2001 and 2011. Since the number of days contained in a meter read can vary, the analysis converted customer water consumption to average daily values in a meter read period to standardize use across varying lengths of meter read periods. Observed water consumption was statistically controlled for weather and customer/site heterogeneity.

Since installation of smart timers (weather-based irrigation controllers) through a county-wide rebate program requires the voluntary agreement of the customer to participate, these sample of customers can be termed "self-selected." While this analysis does quantitatively estimate the reduction of participant's water consumption, one may not directly extrapolate this finding to non-participants. This is because self-selected participants can differ from customers that decided not to participate.

Daily weather measurements - daily precipitation, maximum air temperature, and evapotranspiration - were collected from the National Oceanographic and Atmospheric Administration Weather Service Office weather stations located in Orange county, the California Irrigation Management Information System (CIMIS) station No. 75, and Irvine Ranch Water District (IRWD) weather stations. Additionally, the previously evaluated CIMIS spatial interpolations of evapotranspiration data were developed for each participating agency. Additional weather zones specified for IRWD - inland, middle, and coastal - with customer accounts were assigned to one of the three Spatial ET_o measures on the basis of zipcode. This "Spatial ET_o" was statistically tested against nonlocal ET_o measurements. The daily weather histories for rainfall and temperature were collected as far back as were available (January 1, 1948 for NOAA stations) to provide the best possible estimates for "normal" weather through the year. Thus we have at least 63 observations upon which to judge what "normal" rainfall and temperature for January 1st of any given year. CIMIS Spatial ET_o measures were available back to 2004. Rolling monthly and bimonthly averages of rainfall, temperature, and evapotranspiration were created to exactly match to meter read dates for all customer water consumption histories.

Robust regression techniques were used to detect which observations are potentially data quality errors. This methodology uses a given model fro to determine the relative level of inconsistency of each observation. A measure is constructed to depict the level of inconsistency between zero and one; this measure is then used as a weight in subsequent regressions. Less consistent observations are down-weighted. Other model-based outlier diagnostics were also employed to screen the data for any egregious data quality issues. Interviews with conservation staff and site visits were conducted to track down and confirm data quality issues.

Benchmark of Water Savings Potential

To benchmark the water savings potential of existing outdoor landscapes, research is being conducted to determine whether single-family household residents adjust landscape irrigation based on climate or income in Orange County, California. Specifically, the goal of this research is to (1) determine the amount of over- or under-irrigation compared to theoretical need and (2) determine the climatic and socio-economic controls on landscape irrigation. A research partnership was established between six water retail agencies in Orange County: City of Huntington Beach, El Toro Water District, Irvine Ranch Water District, East Orange County Water District, City of San Juan Capistrano, and Laguna Beach County Water District. These agencies represented a wide range of climatic and economic conditions of single-family residential water use data on a monthly/bimonthly basis.

Using information from this ongoing research, data from 50,000 accounts on household water use, climate, and socioeconomic factors were mapped using Arcview GIS. A multiple regression of single-family residential water use was conducted with air temperature (California Irrigation Management Information System), precipitation (Orange County ALERT Precipitation Network), and household income (US Census) as possible explanatory variables.

The theoretical irrigation demand is calculated by subtracting the amount of effective precipitation from the landscape water need. The landscape water need is calculated with the following equation:

$$\text{Landscape Water Need} = \frac{ET_o \times k_{c-turf} \times A_{turf}}{IE_{turf}} + \frac{ET_o \times k_{c-shrub} \times A_{shrub}}{IE_{shrub}} + ET_o \times k_{c-pool} \times A_{pool}$$

Where,

ET_O = evapotranspiration (inches/month)
k_c = crop/pool coefficient
A = fraction of area (%)
IE = irrigation efficiency (%)

The average landscape coefficients used were: 0.8 for turfgrass (varied by month), 0.5 for ornamental/shrub areas, and 1.0 for pools.

Three million rows of household level water use data were analyzed. Outdoor water use was estimated using the "minimum month method". The volume of outdoor water use was then divided by area to obtain depth of irrigation. Area measurements were obtained from National Agriculture Imagery Program 2009 land areas, where the total average error on these areas is 7.5% (Mende and Norris 2010). Sixty seven percent of the IRWD service area sample (n = 34,116 of the 50,950 single-family residences) were matched and presented here. Additionally, monthly outliers greater than five standard deviations above the annual mean for a single-family residences were removed. Inclusion of this data would have skewed the results. Low-end outliers were not removed, as they may be representative.

Results

Meta Analysis of Program Evaluation

Table 1 summarizes the findings of six independent evaluations of programs conducted by MWDOC on residential and commercial weather-based irrigation controller programs. Table 1 lists the study title, evaluation consultant, and water savings for each study. Figures 1 and 2 illustrate the water savings from these study areas as percentages of overall water use, and net water savings from each of the studies listed in Table 1.

The standard ellipse used in Figures 1 and 2 is a descriptive tool; it is used to visualize the variability of individual samples. The standard ellipse serves the same purpose as the standard interval mean, +/- standard deviation in univariate statistics. The prediction interval ellipse describes the area in which a single new observation can be expected to fall with a certain probability (i.e. 95% confidence), given that the new observation becomes a distribution with the parameters (means, standard deviations, covariance) as estimated from the observed points shown in the plot. For residential sites, the predictive ellipses allude to a potential water savings of 5% to 11%, with 95% confidence, and between 29 and 54 gallons per day per household. For commercial sites, the predictive ellipses depict that a potential water savings has a much broader range, -6% up to 40%, with 95% confidence, and between approximately 400 and 800 gallons per day per site.

Table 1. Compilation of MWDOC's weather-based irrigation controller program evaluations.

<table>
<tr><th>Study Title</th><th>Year</th><th>Author</th><th>Sector</th><th>Water Savings per WBIC[Z] (gal/day)</th><th>Retrofit Accounts in Study (#)</th><th>Total Water Use (%)</th><th>Landscape Water Use (%)</th></tr>
<tr><td>Residential Weather-Based Irrigation Scheduling: Evidence from the Irvine "ET Controller" Study</td><td>2001</td><td>Hunt et al.</td><td>Residential</td><td>37</td><td>40</td><td>7%</td><td>16%</td></tr>
<tr><td>ET Controller Savings Through the Second Post-Retrofit Year: A Brief Update</td><td>2001</td><td>Western Policy Research</td><td>Residential</td><td>41</td><td>40</td><td>8%</td><td>18%</td></tr>
<tr><td rowspan="2">Residential Runoff Reduction Study</td><td rowspan="2">2004</td><td rowspan="2">A&N Technical Services, Inc.</td><td>Residential</td><td>41</td><td>112</td><td>10%</td><td>-</td></tr>
<tr><td>Commercial</td><td>545</td><td>26</td><td colspan="2">21%[Y]</td></tr>
<tr><td>Commercial ET-Based Irrigation Controller Water Savings Study</td><td>2006</td><td>A&N Technical Services, Inc.</td><td>Commercial</td><td>601</td><td>-</td><td colspan="2">22%</td></tr>
<tr><td rowspan="2">Pilot Implementation of Smart Controllers: Water Conservation, Urban Runoff Reduction, and Water Quality</td><td rowspan="2">2010</td><td rowspan="2">Kennedy Jenks Consultants</td><td>Residential</td><td>37</td><td>899</td><td>7%</td><td>-</td></tr>
<tr><td>Commercial</td><td>556</td><td>209</td><td colspan="2">3%</td></tr>
<tr><td rowspan="2">MWDOC SmarTimer Rebate Program Evaluation</td><td rowspan="2">2011</td><td rowspan="2">A&N Technical Services, Inc.</td><td>Residential</td><td>49</td><td>70</td><td>9%</td><td>-</td></tr>
<tr><td>Commercial</td><td>727</td><td>132</td><td colspan="2">28%</td></tr>
</table>

[Z] WBIC = Weather-based irrigation controller

[Y] Commercial sites had dedicated irrigation meters

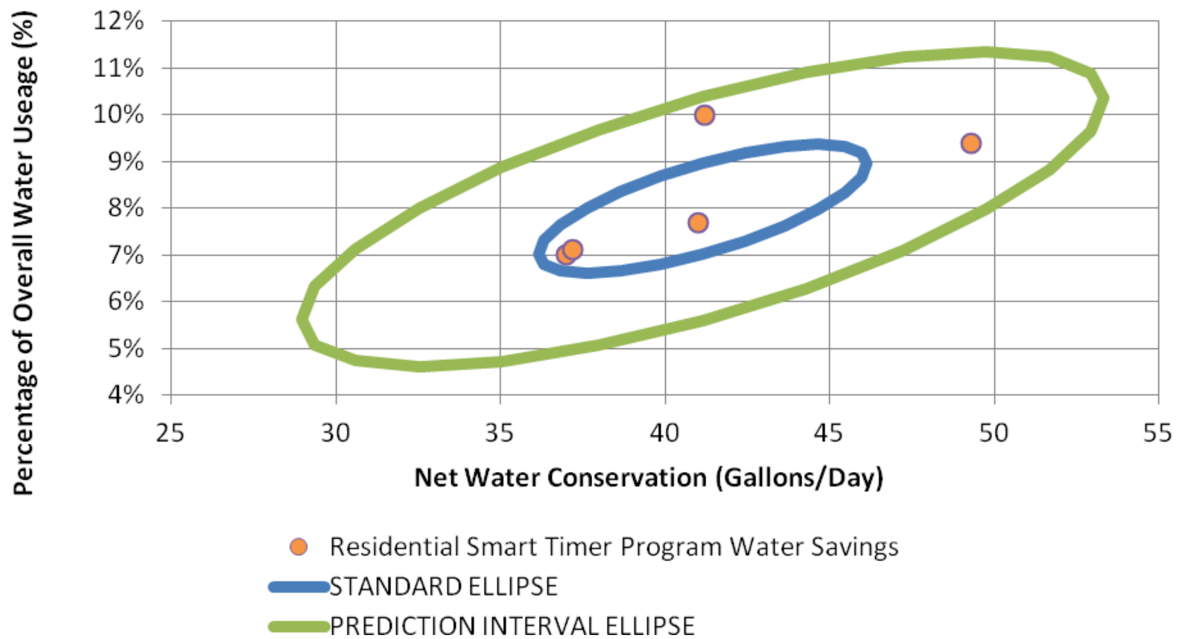

Figure 1. Residential program evaluation water savings with standard and prediction interval ellipses at the 95% confidence level.

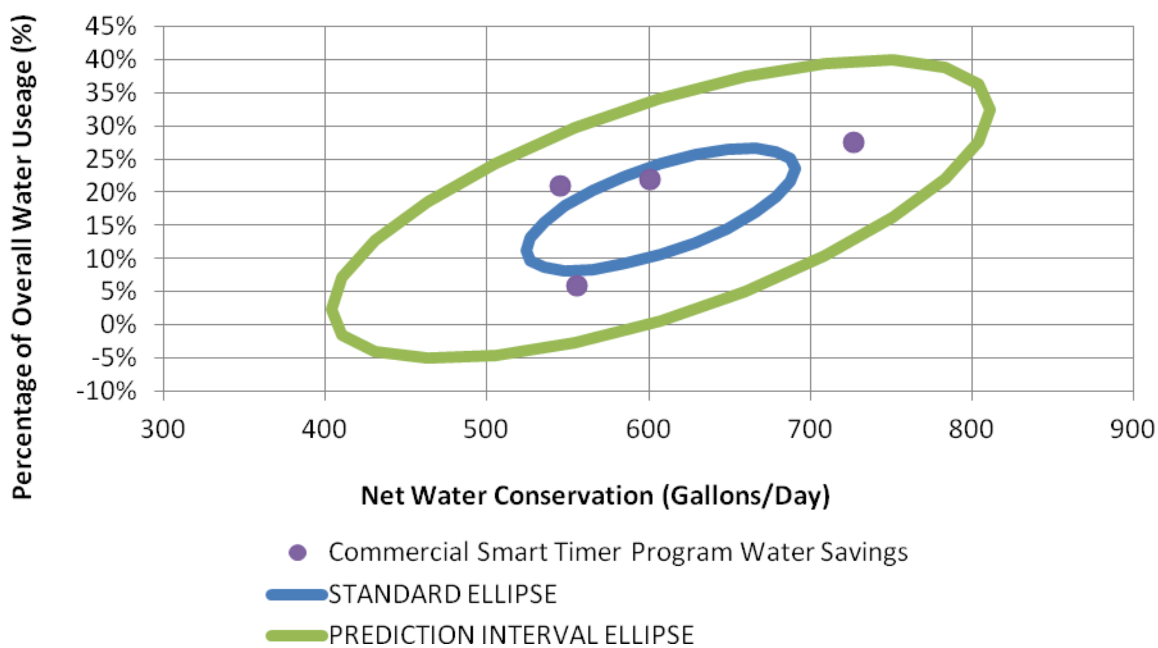

Figure 2. Commercial program evaluation water savings with standard and prediction interval ellipses at the 95% confidence level.

Benchmark of Water Savings Potential

As the actual system efficiency was unknown, the system efficiency was considered at two scenarios to determine the water savings potential: a common industry assumption of 80% and a lower assumption of 55%. Note, this potential for water savings resulting from over-irrigation, that which is excessively applied, is a proxy for management and greater in Scenario 1 (Table 2), particularly in fall and winter months. In Scenario 2, with an equivalent plant-water need to Scenario 1, more water is used to compensate for system inefficiencies and, therefore, there is a lesser amount of water savings potential (Figures 3 and 4).

Using a multiple regression model of the outdoor water use (inches) at the census tract level with air temperature, precipitation, and income showed an R^2 of 0.67 ($p < 0.0001$). The increasing air temperature had the greatest influence on water use patterns, explaining 65% of the increase in use. Additionally, increasing precipitation explained 2.6% of the decrease in total outdoor water use, while income only influenced 0.8% of the trend irrigation water use.

Analysis of over-irrigation using the multiple regression model of outdoor water use at the census tract level resulted in an R^2 of 0.26 ($p < 0.0001$). An increase in air temperature explains 22% of the increase in over-irrigation. In this analysis, increased income explains 3% of the decrease in over-irrigation, which is contrary to other research (Hanke and Mare 1982). Variation in precipitation explains 2% of the trends in over-irrigation. However, precipitation events also correlate with lower air temperature in this region, with a Pearson's correlation coefficient of 0.51 (Greco 2013).

Previous studies have found that ET_O and weather events significantly affect outdoor water use practices (Danielson et al. 1980; Duble 1997; DeOreo et al. 1997; Haley, 2012). A five-year study conducted across 221 communities in Texas found correlation (R^2=0.39) between per capita water use in relation to climate, average water price, and annual income (Griffin and Chang 1989). A more recent two year study conducted in Austin, Texas with 803 participating homes found residential outdoor water use to correlate (R^2=0.204) with temperature, rainfall, ET, household size, appraised value, lot size, and presence of a pool (Tinkler et al. 2005). Similar results were also reported in a study conducted in Malmo, Sweden, where rainfall, household income, household size, age of home, and water prices were modeled (R^2=0.259) (Hanke and Mare 1982).

Table 2. Irrigation applied in excess of that needed to compensate for system inefficiencies, shown by percent of homes and water use that is applying irrigation.

System Efficiency	Percent of Homes Resulting in Over-irrigation				Percent of Total Use Resulting from Over-irrigation			
	Spring[Z]	Summer[Y]	Fall[X]	Winter[W]	Spring	Summer	Fall	Winter
Scenario 1: 80%	29%	35%	44%	36%	9%	8%	10%	14%
Scenario 2: 55%	16%	21%	34%	24%	10%	5%	4%	6%

[Z] Spring: months of March, April, and May
[Y] Summer: months of June, July, and August
[X] Fall: months of September, October, and November
[W] Winter: months of December, January, and February

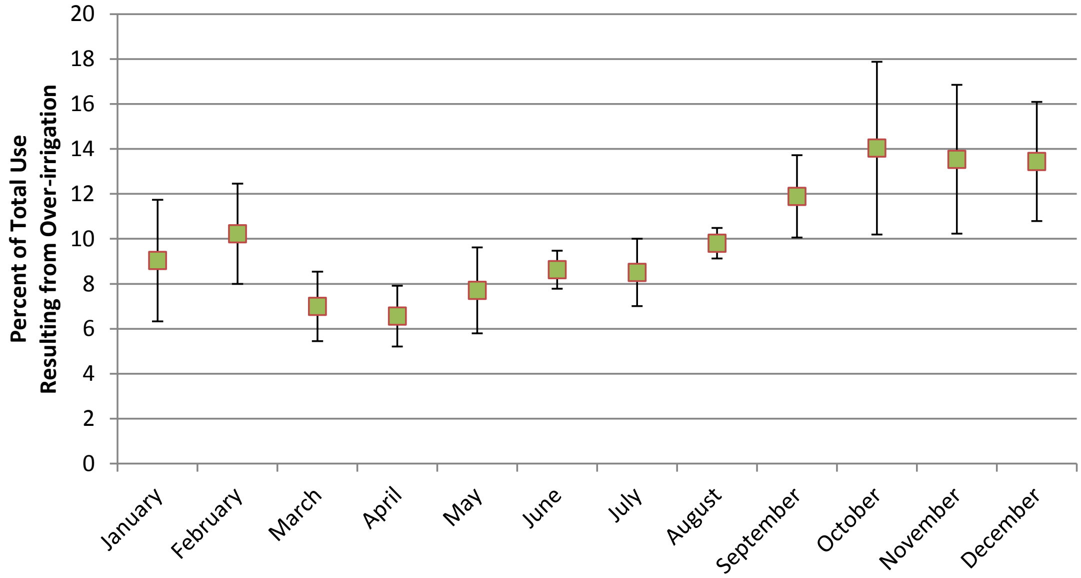

Figure 3. Percent of total single-family residential water use that is over-irrigation at 80% system efficiency.

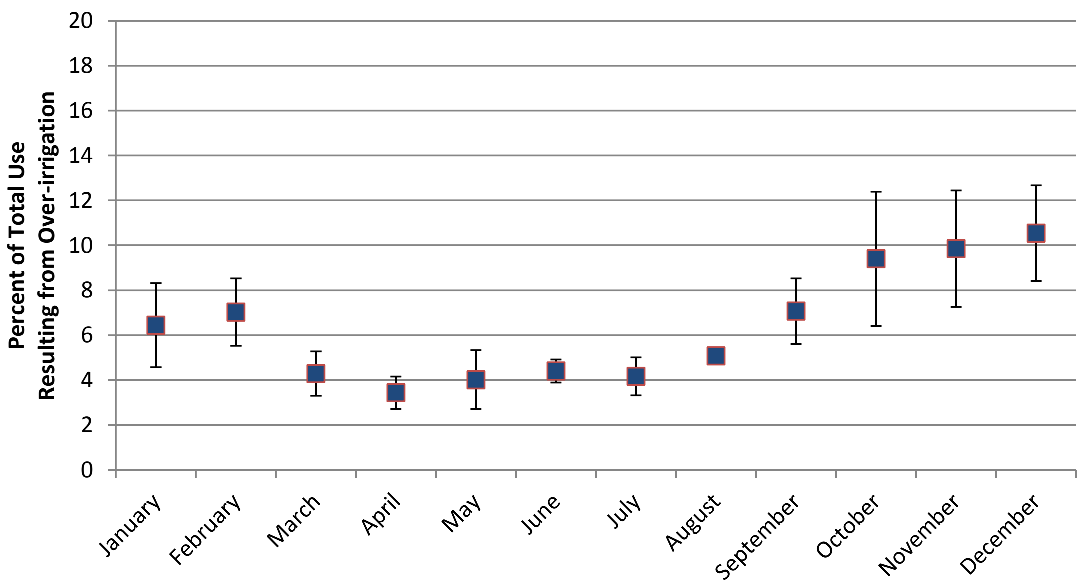

Figure 4. Percent of total single-family residential water use that is over-irrigation at 55% system efficiency.

Conclusions

Meta Analysis of Program Evaluation

The predictive ellipses developed from the evaluations conducted within the MWDOC service area since 2001 allude to a potential total household water savings of approximately 5% to 11% from the inclusion of a weather based irrigation controller. Actual evaluation results ranged from 7% to 10% of total household water savings. These devices can be considered a proxy for better management at the site and more closely aligns with the system efficiency from Scenario 2 in benchmarking the water savings potential.

Benchmark of Water Savings Potential

When, benchmarking the water savings potential within a sample set of more than 34,000 usable accounts of the 50,000, the potential for water savings primarily from management is assumed from Scenario 1 where the system efficiency is 80%. This Scenario suggests between 8% and 14% improvement by reducing over-irrigation resulting from mismanagement.

Further, this analysis suggests that the potential for water savings from management is minimized when the system has greater inefficiencies. The additional water applied is needed to compensate for the system inadequacy, leaving a smaller potential for water savings from scheduling. This analysis suggests that the management potential for savings at the sites where system efficiency is 55% ranges from 4% to 10%.

Air temperature resulted in the strongest predictive variable of irrigation trends. Even though some customers are decreasing irrigation in response to rain, these rain events are infrequent in the local climate. Precipitation events also correlated with lower air temperature, reducing the predictive power of that variable.

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